Individual and Combined Use of Sawdust and Weed Mat Mulch in a New Planting of Northern Highbush Blueberry. III. Yield, Fruit Quality, and Costs

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Abstract. A 4-year trial was established in Oct. 2016 in western Oregon to evaluate the effects of various in-row mulch treatments on yield, fruit quality, and costs of installation and maintenance during establishment of northern highbush blueberry (*Vaccinium corymbosum* L. ‘Duke’). The treatments included douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco] sawdust, black weed mat (woven polypropylene groundcover), green weed mat, and sawdust covered with black or green weed mat. Fruit were harvested during 2018–20 (second through fourth growing seasons). Weed mat color had no effect on yield or fruit quality. In 2018, yield was higher with black weed mat over sawdust mulch than with black weed mat alone, whereas mulch had no effects during 2019 and 2020, or on cumulative yield. Percent total soluble solids in the berries was highest with sawdust and weed mat alone compared with weed mat over sawdust mulches, whereas berry weight, diameter, and firmness were unaffected by mulch. Sawdust was the most expensive mulch over the lifespan of the planting because it required replenishment after 2 years. Black weed mat over sawdust resulted in the highest net profit when fruit sales and cost of materials and labor were considered.

The northwestern United States is an important production region for highbush blueberry (*Vaccinium corymbosum* L.), with 14,170 ha in Oregon and Washington combined and 55% of the total U.S. production of highbush blueberries in 2020 (North American Blueberry Council, unpublished). In the past, common practice was to mulch with douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco] sawdust, which is readily available in the region but has become more expensive (Julian et al., 2011). The majority of new plantings are now established using black woven polypropylene landscape groundcover (“weed mat”) in organic and conventional systems (Strik, 2016) because it is the most economical method of weed control (Strik and Vance, 2017) and can have a positive effect on yield in some cases (Neilsen et al., 2003; Strik et al., 2017a).

However, black weed mat absorbs heat, resulting in increased soil temperatures compared with soil mulched with sawdust or wood chips (Cox, 2009; Larco, 2010; Strik et al., 2017a). For highbush blueberry, the optimum soil temperature for root growth is between 14 and 18 °C (Abbott and Gough, 1987; Spiers, 1995); therefore, mulches that maintain a moderate soil temperature and reduce fluctuations in temperature are likely beneficial to root growth and plant vigor.

Black weed mat mulch placed over bare soil increased irrigation requirements by up to 50% compared with sawdust mulch (Strik et al., 2017a) and reduced soil organic matter (SOM) during long-term studies (Atucha et al., 2011; Choi et al., 2011; Strik et al., 2019). The reduction in SOM and potentially other factors have resulted in reduced plant growth and lower yield for weed mat mulch compared with other mulches in some studies (Krewer et al., 2009; Neilsen et al., 2003), but weed mat increased growth and yield in others (Larco et al., 2013; Strik et al., 2017a).

The use of sawdust mulch insulates the soil from temperature fluctuations and adds organic matter as it breaks down (Strik et al., 2017a, 2019, 2020a; White, 2006). Other organic mulches such as pine bark and hardwood woodchips have similar insulating properties (Cox, 2009; Patten et al., 1988; R. Machado, unpublished data). However, weed management is more time-consuming

and expensive with plant-based mulches than with plastic groundcovers such as weed mat, especially in certified organic production systems, where herbicides have limited efficacy (Julian et al., 2012; Strik and Vance, 2017; Tertuliano et al., 2012). Sawdust also requires replenishment every 2 to 3 years because of displacement from wind, foot traffic during harvest and pruning, animal activity, and hand-weeding, as well as natural breakdown, thereby creating additional costs (Julian et al., 2011; Strik and Vance, 2017). Relative to sawdust mulch, using weed mat over bare soil as a mulch increased the presence of voles (*Microtus* spp.) (Granatstein and Mullinix, 2008; Strik et al., 2017a), which can damage plants by girdling the crown or canes, disrupting the root system, and damaging irrigation lines by chewing them (Gunn et al., 2011; A. Davis, personal observation). Both sawdust and weed mat mulches have positive and negative implications for plant establishment and fruit production, and previous research has suggested that the combination of weed mat placed over sawdust mulch may be a way to mitigate the negative aspects of each in blueberry production systems (Strik et al., 2017b).

Little information is available regarding the impact of the color of weed mat on blueberry growth and yield, although reduced soil temperatures may be achieved by using colors other than black (Johnson and Fennimore, 2005; Makus, 2007). In ‘Ozarkblue’ blueberry, the use of either green or white weed mat reduced soil temperatures compared with black weed mat or bare soil; however, excessive weed growth occurred under white due to light infiltration, and plant survival was highest with green weed mat or pine bark mulch (R. Machado, unpublished data). Johnson and Fennimore (2005) found that the color of plastic mulch did not generally affect the yield of strawberry (*Fragaria xananassa* Duchesne) except when compared with clear plastic; however, it did affect weed growth beneath the mulch. They found that green and brown plastic provided the best combination of weed control and soil warming. In blackberry (*Rubus* L. subgenus *Rubus*, Watson), white plastic mulch resulted in higher yield and percent total soluble solids (TSS) compared with bare soil and black mulches (Makus, 2007) and in apple [*Malus x sylvestris* (L.) Mill. var. *domestica* (Borkh.) Mansf.], it increased fruit coloration (Funke and Blanke, 2005). Green weed mat has not yet been tested for its effects on yield or fruit quality in blueberry in the northwestern United States.

The objective of this study was to evaluate the impact of different mulches, including sawdust, black or green weed mat, and sawdust covered with black or green weed mat, on plant yield and fruit quality from the second through fourth growing seasons. Additionally, a cost-benefit comparison of the mulch treatments was conducted to

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determine if the additional cost of layering weed mat over sawdust is an economically viable practice.

Materials and Methods

The 0.14-ha trial was established in Oct. 2016 at Oregon State University's North Willamette Research and Extension Center (NWREC; Aurora, OR; lat. 45°16'47"N, long. 122°45'23"W). Weather data for this site are available from an AgriMet weather station (U.S. Department of the Interior, 2014). The soil is mapped as a Willamette silt loam (a fine-silty, mixed, superactive mesic Pachic Ultic Argixeroll). Before forming raised beds, a 5- to 8-cm-deep layer of sawdust (target application rate of 282 m³·ha⁻¹) was applied to a 1.5-m-strip that would become the in-row area of all treatments and incorporated by tilling the soil to a depth of ≈20 cm. A bed shaper was used to create raised beds that were ≈1.2 m and 0.6 m wide at the base and top, respectively, and ≈0.3 m high. Standard 18-month-old 'Duke' blueberry plants in 2-L pots were transplanted on 4 Oct. 2016. The plants were irrigated using a line of drip tubing on each side of the row ≈10 cm from the base of the plants. For each treatment, the drip lines were in contact with the soil and covered by the mulch. Plants were pruned each winter according to commercial grower practices. Further details regarding site preparation, planting establishment, and cultural management are provided in our companion work regarding mulch effects on soil and canopy temperature and plant biomass (Strik et al., 2020a) and on nutrient uptake (Strik et al., 2020b).

Treatments. Mulch treatments were applied on top of the raised beds and included an 8-cm-deep layer (378 m³·ha⁻¹) of douglas fir sawdust, black weed mat (Baycor; Ten Cate Nicolon, Pendergrass, GA), green weed mat (Guerner & Irmãos, Perosinho, Portugal), and black or green weed mat over a 5-cm-deep layer (252 m³·ha⁻¹) of sawdust. In each case, weed mat was installed in a "zippered" system with two 1-m-wide panels overlapping at the middle of the beds. Holes were cut in the weed mat around the crown of the plants. The black weed mat and green weed mat had densities of 108 and 130 g·m⁻², respectively, and water infiltration rates of 407 and 554 L·m⁻²·min⁻¹, respectively. Plots of each treatment were arranged in a completely randomized block design with five replicates. At planting, each plot included a row of nine plants spaced 0.9 m apart that was separated from adjacent plots in the row by 3 m. Plants were removed to analyze the nutrient content and biomass as described by Strik et al. (2020a, 2020b), leaving eight plants per plot in 2018 and six plants per plot in 2019 and 2020. Rows were spaced 3 m apart. Guard rows and three-plant border plots were planted on both sides of the main experiment and on the north and south ends of the treatment rows, respectively, and mulched with black weed mat over sawdust.

Data collection. Fruit were harvested by hand as they reached commercially acceptable ripeness, which required two to three harvests, depending on the year (22 and 29 June and 13 July 2018; 26 June and 5 July 2019; 24 June and 1 and 9 July 2020). Fruit were weighed from each plot and divided by the number of plants per plot to calculate yield per plant. The percentage of total yield at each harvest was calculated. A random subsample of 25 berries was taken from each plot on every harvest date to determine average berry weight (a weighted seasonal average mass was then calculated) and assess berry firmness and diameter using a Firm-Tech II (BioWorks, Inc., Wamego, KS). Then, the subsamples were homogenized by hand in a zippered plastic bag and measured for TSS using a temperature-compensating digital refractometer (Atago, Bellevue, WA). Berry diameter, firmness, and TSS are reported as seasonal averages.

The presence of voles in each treatment plot was rated once in Winter 2017–18 and Winter 2018–19 by examining vole runs in the sawdust and under the weed mat at a time when the weed mat was opened (0 = no visible runs; 1–3 = increasing severity of runs).

Treatment cost comparison. The costs of materials were calculated from actual prices paid in Fall 2016, and they may have been lower if purchased in larger quantities for a commercial field of increased size. Labor for installation of mulches was valued at US\$15 per hour for the duration of the study, including worker's compensation, unemployment insurance, and other labor overhead expenses. Sawdust mulch at costs of \$13/m³ and \$15/m³ in 2016 and 2019, respectively, was custom-applied at an estimated labor and equipment cost of \$1050/ha for installing sawdust alone and for the weed mat over sawdust mulches. Net returns were based on actual fruit yield harvested per plot, extrapolated to a per hectare basis, and an estimated price per pound paid to a grower for hand-picked, fresh market 'Duke' in the midseason of production for that cultivar (provided by a commercial packing company) in 2019. Other management costs such as those for pruning and hand harvesting were not considered, but they were expected to be similar among mulch treatments. Although weed management costs would be higher for sawdust mulch alone compared with treatments with weed mat (B. Strik, personal observation), because of the increased presence of weeds in the row requiring hand pulling or hoeing and the greater use of pre- and postemergent herbicides, these differences were not measured; therefore, they are not included.

Data analysis. Statistical analyses were performed with SAS version 9.4 (SAS Institute, Cary, NC) using PROC MIXED, and means were separated at the 5% level using Tukey's honestly significant difference test. The effect of year on fruit quality was analyzed as a split-plot design. Yield was not analyzed by year because the plants were

young and yield was expected to increase during the first few years of establishment. Ratings of vole presence were analyzed by mulch treatment after the 2017 and 2018 growing seasons. Orthogonal contrasts were used to compare the treatment effects, including the average effect of the weed mat color and the addition of sawdust underneath weed mat mulch as compared with sawdust or weed mat alone.

Results and Discussion

Yield. Yield increased from the second through fourth growing seasons, as expected for establishing blueberry plants. In 2018, plants grown with black weed mat over sawdust mulch had a significantly higher yield than those with black weed mat alone, whereas the green, green weed mat over sawdust, and sawdust mulch treatments had intermediate yields (Table 1). Strik et al. (2017b) also found that weed mat over sawdust resulted in a higher yield for several cultivars compared with a compost and sawdust mulch, but they hypothesized that higher soil pH caused by the use of compost was detrimental to yield. In this study, the soil pH was unaffected by mulch from 2017 to 2018 (Strik et al., 2020b) or in subsequent years (average, 4.8; data not shown), and it remained within the recommended range of 4.5 to 5.5 for highbush blueberry (Hart et al., 2006). Contrasts showed that mulch color (black vs. green) had no impact on yield in 2018, whereas the addition of sawdust underneath weed mat increased the yield compared with weed mat alone or sawdust alone. Mulch treatment had no significant effect on yield in 2019 or 2020, or on cumulative yield during the 3-year period. Black weed mat over sawdust did increase plant biomass and nutrient accumulation in 2018 compared with black alone (Strik et al., 2020a, 2020b), likely resulting in the higher yield reported for that year. However, mulch had few consistent effects on soil and leaf nutrients or soil organic matter during the first 2 years of the study (Strik et al., 2020a, 2020b) or in 2019 and 2020 (data not shown), which may be related to the lack of significant differences in yield.

The timing of the fruit harvest was only affected by mulch in 2018, when contrasts showed that a higher percentage of fruit was picked during the first harvest with sawdust (37%) than with either color of weed mat over sawdust (28% on average). Weed mat alone had the highest percentage of fruit picked during the second harvest (39%); during the third harvest, sawdust and weed mat alone resulted in a lower percentage picked (29.5% on average) than weed mat over sawdust (37% on average). These differences may be explained by the higher yield in the weed mat over sawdust mulches slightly delaying ripening compared with weed mat alone or sawdust. In 2019, 71% of total yield was picked during the first harvest and 29% was picked during the second harvest; in 2020, 48%, 39%, and 13% of

Table 1. Effect of mulch on yield in 'Duke' blueberry during the second through fourth growing seasons (2018–20) in Oregon.

Mulch	Yield (kg/plant)			
	2018	2019	2020	Cumulative
Sawdust	0.69 ab ^z	1.9	2.6	5.2
Black weed mat	0.65 b	1.8	2.2	4.7
Green weed mat	0.77 ab	2.1	2.8	5.7
Black weed mat over sawdust	0.84 a	2.1	2.8	5.8
Green weed mat over sawdust	0.79 ab	2.2	2.9	5.9
Significance ^y	0.0170	NS	NS	NS
Contrasts				
Sawdust vs. weed mat	NS	NS	NS	NS
Sawdust vs. weed mat over sawdust	0.0129	NS	NS	NS
Black vs. green weed mat	NS	NS	NS	NS
Weed mat vs. weed mat over sawdust	0.0124	NS	NS	NS

^zMeans followed by the same letter within a column are not significantly different ($P > 0.05$).^yValues provided when $P \leq 0.05$. NS indicates not significant.

Table 2. Fruit quality of 'Duke' blueberry as affected by year and mulch from the second through fourth growing seasons (2018–20) in Oregon.

	Berry wt ^z (g)	TSS ^y (%)	Firmness (g·mm ⁻¹ deflection)	Berry diam (mm)
Year				
2018	2.4 a ^x	14.3 a	214 a	18.8 a
2019	2.2 b	13.0 b	191 b	17.8 b
2020	2.4 a	13.2 b	192 b	18.5 a
Mulch				
Sawdust	2.4	14.0 a	201	18.4
Black weed mat	2.3	13.8 a	203	18.1
Green weed mat	2.4	13.5 ab	198	18.4
Black weed mat over sawdust	2.4	13.1 b	194	18.5
Green weed mat over sawdust	2.3	13.2 b	198	18.4
Significance ^w				
Year	0.0023	<0.0001	<0.0001	0.0005
Mulch	NS	0.0003	NS	NS
Year × mulch	NS	NS	NS	NS
Sawdust vs. weed mat	NS	NS	NS	NS
Sawdust vs. weed mat over sawdust	NS	<0.0001	NS	NS
Black vs. green weed mat	NS	NS	NS	NS
Weed mat vs. weed mat over sawdust	NS	0.0020	NS	NS

^zBerry weight was the seasonal weighted average for the year.^yTSS = average percent total soluble solids for the year.^xMeans followed by the same letter within a column and treatment are not significantly different ($P > 0.05$).^wValues provided when $P \leq 0.05$. NS indicates not significant.

total yield were picked during the first through third harvests, respectively, with no effect of mulch in either year. Previously, we found that weed mat resulted in higher canopy temperatures than sawdust in 2018 (Strik et al., 2020a), which clearly did not advance fruit ripening. In addition, the higher soil temperatures with weed mat alone compared with sawdust or weed mat over sawdust (Strik et al., 2020a) did not have a clear effect on ripening.

Fruit quality. Fruit firmness and TSS were higher in 2018 than in subsequent years, whereas berry weight and diameter were higher in 2018 and 2020 compared with 2019 (Table 2). The difference in berry size was likely due to the heavy bird pressure in 2019, which forced us to harvest fruit at an earlier stage of ripeness and pick the total yield during two harvests rather than three. Consequently, some of the larger ripe fruit may have been eaten by birds before our first harvest. In previous studies, smaller berries tended to be firmer than larger berries (Strik, 2019; Strik and Buller, 2014), but the larger berries in 2018 and 2020 were as firm or firmer than the smaller fruit in 2019. Mulch had no effect on fruit firmness in our study. Strik et al. (2017a) found inconsistent effects

of weed mat compared with sawdust mulch on berry firmness during their 9-year study on organic blueberry.

Berry TSS was the only quality trait impacted by mulch, with the use of sawdust or black weed mat mulches alone leading to higher TSS than black or green weed mat over sawdust (Table 2). In contrast, Strik et al. (2017a) found that black weed mat and sawdust mulches alone had no effect on TSS. Because weed mat color had no impact on soil or canopy temperature, plant growth, or nutrient allocation (Strik et al., 2020a, 2020b), it is not surprising that contrasts consistently showed no effect of weed mat color on fruit quality. Previous studies of blueberry (Strik et al., 2017a, 2017b; Tertuliano et al., 2012) and apple (Choi et al., 2011) also found little impact of mulch on these same fruit quality traits.

Presence of voles. Ratings of the number of vole runs (scale of 0 to 3) in sawdust alone and weed mat over sawdust mulched plots were significantly lower (averages of 0.1 in 2017 and 0.4 in 2018) than those under either green or black weed mat alone (averages of 1.7 in 2017 and 2.6 in 2018; $P = 0.0003$ in 2017 and $P < 0.0001$ in 2018). Voles are of concern to commercial growers who use

weed mat mulch because the voles can protect themselves under weed mat but not under sawdust mulch. When voles had a choice, as in our study, they preferred weed mat mulch over bare soil compared with weed mat over sawdust; similar observations were made during a long-term study of organic blueberry (B. Strik, personal observation). Voles can do significant damage, especially to young plants (Gunn et al., 2011; B. Strik, personal observation), and this is another benefit to adding a layer of sawdust under weed mat.

Treatment cost comparison. The green weed mat used during this study was less expensive per square meter than the black weed mat (US\$0.49 compared with US\$0.62), but the high cost of shipping due to the lack of local availability of green weed mat made this product significantly more expensive overall. Because green weed mat (alone or over sawdust) did not provide any benefit for yield or fruit quality compared to black weed mat during this study, or for plant growth during previous studies (Strik et al., 2020a, 2020b), only sawdust, black weed mat, and black weed mat over sawdust mulches were included in the cost comparison. Considering the costs of raw materials and labor to install each mulch, sawdust was

Table 3. Cost–benefit comparison of three mulch treatments during the first 4 years of establishment of ‘Duke’ blueberry in Oregon (2016–20). Mulch costs were incurred in the planting year and for sawdust when replenishment was necessary (2019).

Mulch	Cost (\$/ha)						
	2016		2019		2016–20		
	Materials ^z	Labor ^y	Materials	Labor	Total cost ^x	Gross returns ^w	Net return ^v
Sawdust	4,983	1,050	5,648	1,050	12,731	55,705	42,974
Black weed mat	5,390	1,853	0	0	7,243	50,679	43,436
Black weed mat over sawdust	8,712	2,903	0	0	11,615	62,803	51,188

^zSawdust alone was mulched to a depth of 8 cm; sawdust was mulched to a depth of 5 cm under black weed mat; weed mat was installed in a zippered system using two strips of 1-m-wide groundcover in both weed mat mulch treatments.

^yLabor for sawdust and black weed mat over sawdust reflects custom application, including equipment rental. Labor cost of \$15/hr is assumed.

^xTotal cost includes cost of materials and labor over the course of the study. It does not include other management costs, such as pruning, harvesting, pest and weed management, or product costs other than for the mulch.

^wGross returns are based on cumulative yield, assuming a return of \$3.03/kg for fresh market ‘Duke’.

^vNet return = gross returns minus total cost.

the most expensive over the course of this 4-year study because it needed to be replenished in 2019 (Table 3). Sawdust covered by weed mat degraded much slower than exposed sawdust, as observed by Strik et al. (2017b), and it did not require renewal during the study. The weed mat used had an expected life span of 5–7 years and was still in good condition at the conclusion of this study. Although cumulative yield was unaffected by these mulches, the net returns were 19% and 18% greater with black weed mat over sawdust compared with sawdust and black weed mat alone, respectively. Our results are similar to those reported by Strik and Vance (2017), who reported that economic returns were better with weed mat than with sawdust or sawdust over compost because of the longevity of the weed mat, increased yield, and lower weed management costs. Although the values presented here do not take into consideration labor costs for pruning, harvesting, or other management tasks, we expect these would be similar among the mulches. In addition, herbicide costs for sawdust mulch would be higher than those for the weed mat mulches due to the larger in-row surface area requiring treatment. Weeds are generally controlled only along the edge of the weed mat using herbicides or mechanical means.

Summary

There was no significant advantage to using green weed mat at our site, which was more difficult to source and therefore more expensive compared with black weed mat, which is the most used weed mat color for blueberry production worldwide. However, green weed mat with similar characteristics (density and water infiltration rates) could be a suitable alternative to black when available. Adding a layer of sawdust under black weed mat improved the yield during the first fruiting season of ‘Duke’ compared with black weed mat alone, but mulch did not affect the yield during the second and third harvest years. Although berry TSS was improved with sawdust or weed mat alone compared with weed mat over sawdust, all treatments were within commercially acceptable levels throughout the study. The combination of weed mat over sawdust mulch is more ex-

pensive initially, but during the 4-year study, the sawdust under the weed mat did not degrade to the point that it needed to be replenished, whereas sawdust alone needed replacement after 2 years. This difference in management increased the overall cost of sawdust mulch alone even before considering the additional weed management costs determined during our previous work involving organic (Strik and Vance, 2017) and conventional (B. Strik, personal observation) systems. We have shown that black weed mat over sawdust has several advantages compared with sawdust and black weed mat alone, including moderated soil temperatures leading to increased plant growth and nutrient uptake and allocation (Strik et al., 2020a, 2020b), reduced presence of voles, greater or equivalent yield, and comparable fruit quality while increasing the potential net profit.

Growers with established fields mulched with sawdust could add weed mat over the existing mulch and drip irrigation lines, if present. We have found that even mature blueberry plants have a positive response to modification of the mulch in this way (Davis and Strik, unpublished data). Sawdust or other wood-based finely chopped products could be added to fields with existing weed mat when growers open the weed mat to apply granular fertilizers, check the irrigation lines, or replace the weed mat. We do caution against using plant-based or animal-based composts regularly under weed mat because of the possible negative effects of increasing the soil pH and soil potassium levels (Strik et al., 2017b, 2019).

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