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Individual and Combined Use of Sawdust and Weed Mat Mulch in a New Planting of Northern Highbush Blueberry. II. Nutrient Uptake and Allocation

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***Abstract*. A 2-year trial was established in Oct. 2016 in western Oregon to evaluate the effects of various in-row mulch treatments on 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. For the most part, plant nutrient concentration and content were unaffected by the color of the weed mat. In both years, mulching with weed mat over sawdust reduced soil NO_3-N compared with weed mat alone. The only other soil nutrient affected by mulch was K, which was highest with sawdust mulch and intermediate with black weed mat alone in year 2. There were inconsistent effects of mulch on leaf nutrient concentration during the study. In 2018, leaf N concentration was lowest with black weed mat over sawdust. There were few mulch effects on nutrient concentrations in senescent leaves in both years and in harvested fruit in year 2. Mulch had greater effect on nutrient concentration in dormant plant parts after the second growing season than after the first, with the addition of sawdust under weed mat leading to significant differences for many nutrients in various plant parts compared with weed mat alone. Total uptake of N ranged from 12 kg·ha^{-1} (black weed mat) to 17 kg·ha^{-1} (black weed mat over sawdust) in year 1 and averaged 33 kg·ha^{-1} in year 2, with no effect of mulch. Fertilizer use efficiency for N was 8% to 12% in year 1 and 42% in year 2. Uptake of other nutrients was unaffected by mulch and, depending on the year, ranged from 1.3 to 4.3 kg·ha^{-1} P, 4.0 to 8.0 kg·ha^{-1} K, 2.1 to 4.9 kg·ha^{-1} Ca, and 1.0 to 1.5 kg·ha^{-1} Mg. Each of these other nutrients was derived from the soil or decomposing roots.**

Fertilizer practices for establishing northern highbush blueberry (*Vaccinium corymbosum* L.) are routinely based on assessment of soil nutrient levels, with fertilizer nutrients amended before planting based on published critical levels, followed by leaf nutrient analysis in summer and comparing the results to published standards (Hart et al., 2006; Horneck et al., 2011). There is evidence that the concentration of many nutrients in the leaves of young or nonfruiting blueberry plants may not align with current standards (e.g., Almutairi et al., 2017; Vargas et al., 2015). Thus, improving understanding of plant nutritional demands and the impact of common cultural practices on these requirements would be beneficial to growers planning fertilization programs.

Determination of plant biomass [or dry weight (DW)] through sequential plant excavation coupled with nutrient analysis of each tissue type is currently the most reliable way to obtain the amounts and seasonal patterns of plant nutrient uptake (Weinbaum et al., 2001). Several studies have reported timing and amount of N in young and mature highbush blueberry plants (Bañados, 2006, 2012; Hanson and Retamales, 1992; Retamales and Hanson, 1989; Throop and Hanson, 1997). Typical rates of N fertilizer application in Oregon average 50 to 100 kg·ha^{-1} per year during planting establishment and 100 to 165 kg·ha^{-1} per year once the field matures (Hart et al., 2006). The application of other nutrients is largely based on soil and leaf tissue analysis tests and general recommendations from testing laboratories. Nutrient requirements in blueberry depend on the amount of new vegetative and reproductive growth and the associated nutrients required, either from reallocation in existing tissues or nutrient uptake (Bryla and Strik, 2015). Nutrients are also lost when fruit are harvested, leaves senesce, and plants are pruned. Gains and losses in nutrients have tended to follow the same pattern of DW in blueberry and blackberry (*Rubus* L. subgenus *Rubus*, Watson) (Bañados et al., 2012; Bryla et al., 2012; Dixon et al., 2016; Harkins et al., 2014). Fertilizer nutrient requirements are also affected by the reallocation of nutrients within the plant and from decomposition of dying or pruned plant tissues. In berry crops, stored reserves of N have been reallocated internally from roots, crown, and woody stems in the spring and from leaves before senescence (Mohadjer et al., 2001; Rempel et al., 2004; Strik et al., 2004) and externally from decomposition of plant tissues such as senesced leaves and roots and pruned wood (Strik et al., 2006).

Bryla et al. (2012) documented the impact of N fertilizer rate on the timing and amount of macro- and micronutrients taken up by northern highbush blueberry plants during the first 1.5 years of establishment. The N rate treatment with the highest uptake of N and other nutrients was moderate (50 kg·ha^{-1} N per year) but promoted more growth and yield than no fertilizer N, while rates $\geq$100 kg·ha^{-1} N were excessive and resulted in salt stress and plant mortality in the young planting (Bañados et al., 2012). The plants had a net gain of 13.7, 1.0, and 4.8 kg·ha^{-1} of N, P, and K, accounting for a fertilizer use efficiency of 27%, 3%, and 7%, respectively, after the first year of establishment (Bryla et al., 2012).

Blueberry fields in the northwestern United States are most commonly mulched with douglas fir sawdust [*Pseudotsuga menziesii* (Mirb.) Franco] or with black, woven polypropylene landscape groundcover, which is often referred to as "weed mat" (Strik, 2016). Weed mat is becoming more common because it is more economical for weed control than sawdust, and it can have a positive effect on yield in blueberry (Strik et al., 2017a; Strik and Vance, 2017). Weed mat captures more longwave radiation and results in warmer soil temperatures than organic mulches, such as sawdust or wood chips (Cox, 2009; Larco, 2010; Strik et al., 2017a, 2020). Weed mat may also change soil nutrient levels and soil properties, such as organic matter and pH, thus affecting nutrient availability in blueberry (Strik et al., 2019). Using a combination of sawdust mulch topped with weed mat showed promise in a long-term study in blueberry (Strik et al., 2017b).

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We reported earlier that weed mat color (black and green) had little effect on plant growth, but blueberry plants established with weed mat over sawdust mulch had a higher net gain in total plant DW over 2 years of establishment than those grown with black weed mat alone (Strik et al., 2020).

The objectives of the present study were to determine the requirements of macro- and micronutrients during the first 2 years of establishment and to examine how the requirements were affected by the type of surface mulch applied to the in-row area. Plants were excavated, separated into relevant plant parts, and analyzed for nutrients at the end of each year with the added objective of determining treatment effects on nutrient losses in leaves and pruning wood in both years and fruit in the second year.

Materials and Methods

The 0.14-ha trial was established at the Oregon State University North Willamette Research and Extension Center (NWREC) in Aurora, OR (lat. 45°16′47″N, long. 122°45′23″W). Weather data for this site are available from an AgriMet weather station at NWREC (U.S. Dept. Interior, 2014). The soil is a Willamette silt loam (a fine-silty, mixed, superactive mesic Pachic Ultic Argixeroll). Before planting, a 5- to 8-cm deep layer of douglas fir sawdust (target application rate of 282 $m^3 \cdot ha^{-1}$) was applied to the in-row area and incorporated by tilling the soil to a depth of ≈20 cm. No fertilizers were applied to the field before establishing the treatments. 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 were removed from 2-L pots and planted on 4 Oct. 2016 at an in-row spacing of 0.3 m with 3 m between rows (industry standard). Pruning was done each winter per standard commercial practice. Plants that were destructively harvested were pruned similarly to the rest of the treatment plants, but pruning wood was kept separate (as discussed later in the article). Further details on site preparation and cultural management are provided by Strik et al. (2020).

Treatments. Mulch treatments were applied on top of the raised beds and included an 8-cm-deep layer 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 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 and green weed mat had a density of 108 and 130 $g \cdot m^{-2}$ and a water infiltration rate of 407 and 554 $L \cdot m^{-2} \cdot min^{-1}$, respectively. Plots of each treatment were arranged in a completely randomized block design with five replicates. Each plot included a row of nine plants and was separated from adjacent plots in the row by 3 m. 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.

Irrigation and fertilization. The plants were irrigated using a line of drip tubing on each side of the row. The tubing had 3.8 $L \cdot h^{-1}$ in-line emitters every 45 cm and was placed ≈10 cm from the base of the plants. In each treatment, the drip lines were in contact with the soil and covered by the mulch. Boron was applied as a foliar spray using disodium octaborate tetrahydrate in the spring (0.45 $kg \cdot ha^{-1}$) and fall (1.5 $kg \cdot ha^{-1}$) of 2018. Liquid urea (20N–0P–0K) was injected through the drip system twice per week from mid-April to late July in 2017 and from mid-April to early July in 2018. A total of 174 $kg \cdot ha^{-1}$ N was applied the first year and 108 $kg \cdot ha^{-1}$ N was applied the second year. Less fertilizer was applied during the second year because the root systems were larger and the plants were able to access more of the N fertilizer than they could in the previous year (Bryla and Strik, 2015).

Nutrient sampling. Leaf tissue samples (most recent fully expanded leaves) were collected each year in late July and were not washed before submission (Hart et al., 2006). Soil samples were collected in late October each year using a 2.4-cm-diameter chrome-plated steel soil probe (Soil Sampler Model Hoffer, JBK Manufacturing, Dayton, OH) to a depth of 0.2 m. Two soil samples were taken per plot (one per side, centered between two plants, directly outside each irrigation line on the east and west side of the row) and pooled. Mulch was removed from the soil surface before taking the samples and replaced afterward. Leaf and soil samples were sent to a commercial laboratory (Brookside Laboratories, New Bremen, OH) for analysis of macro- and micronutrient concentrations. Leaf N was determined using a combustion analyzer with an induction furnace and thermal conductivity detector (Gavlak et al., 1994). Other leaf nutrients, including P, K, Ca, Mg, Al, B, Cu, Mn, Fe, and Zn, were determined using an inductively coupled plasma (ICP) spectrophotometer after wet ashing the samples in nitric/perchloric acid (Gavlak et al., 1994). Extractable soil K, Ca, Mg, Na, B, Cu, Mn, Zn, and Al were determined by ICP after extraction of the nutrients using the Mehlich 3 method (Mehlich, 1984). Soil P was extracted with the Bray-1 method and then determined by ICP. Soil NO_3-N and NH_4-N were determined using automated colorimetric methods after extraction with 1 M KCl (Dahnke, 1990). Soil organic matter and pH were measured using loss-on-ignition at 360 °C (Nelson and Sommers, 1996) and the 1:1 soil:water method (McLean, 1982), respectively. A composite preplant soil sample taken in April 2016 determined that no additional soil amendments were required and provided a baseline soil level [pH: 5.7, macronutrients ($mg \cdot kg^{-1}$): P = 234, K = 290, Ca = 1290, Mg = 121, S = 12, B = 0.5, Fe = 340, Mn = 22, Cu = 3.4, Zn = 3.1, Al = 1389]. Although soil pH was above that recommended for blueberry (4.5–5.5; Hart et al., 2006), elemental sulfur was not added because fertilization with N in the first year was expected to lower soil pH into the proper range (B. Strik, personal experience).

Plant sampling. Three dormant nursery plants were separated into roots, crown, and 1-year-old wood. In addition to leaf sampling at the standard time, senesced leaves were collected from one plant per plot that was netted before leaf fall. In Feb. 2017 and 2018, the northern most plant in each treatment plot was pruned per standard commercial practice. Pruning wood was divided into 1-year-old wood, 2-year-old and older wood, and whips. After pruning, the same plant was carefully dug from the soil to recover as much of the root system as possible and then roots were washed thoroughly. Each plant was separated into 1-year-old wood ("new"), 2-year and older wood ("old"), 1-year-old whips (new shoots arising from the basal portion of the plant), crown, and roots. Ripe fruit were harvested by hand on 22 and 29 June and 13 July 2018. Subsamples of all plant tissues, including fruit from the first harvest, were sent to the commercial laboratory for analysis.

Nutrient content, allocation, and uptake. The nutrient content of each plant part was calculated from nutrient concentration (analysis results) and the biomass of the corresponding plant part (results presented by Strik et al., 2020). Total nutrient gains (plant content in new wood, old wood, whips, crown, and roots relative to the prior season) and losses (through senesced leaves and pruning wood in 2017 and 2018 and fruit in 2018) were calculated each year and used to determine nutrient uptake from planting to the end of the second growing season. Fertilizer use efficiency was calculated for N (the only nutrient applied for the duration of the study except for small amounts of foliar B) by dividing nutrient uptake per year by the amount of N applied per plant.

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 honest significant difference test. Data were analyzed by year except to assess the effect of year on nutrient concentration and content for each plant part using a split-plot design. Orthogonal contrasts were used to compare the various effects of weed mat color and addition of sawdust underneath the weed mat. Trends are discussed when $P > 0.05$ and ≤ 0.1 and may have biological significance.

Results and Discussion

Soil

Soil organic matter (SOM) increased in all treatments from preplant (2.8%) to postplanting levels (4.2% on average) with no year or mulch treatment effect. The increase in SOM was a response to amending the soil with sawdust before forming the raised beds per standard commercial practice (Julian et al., 2011). Soil pH was within the ideal range for blueberry during the study (4.5–5.5; Hart et al., 2006) but, in 2017, was lower under green weed mat and black weed mat over sawdust compared with the other mulches (Table 1). In 2018, soil pH tended to be higher under sawdust alone than under the other mulches. Larco et al. (2013) reported higher soil pH under sawdust mulch than under black weed mat alone after 2 years of establishment in an organic study on northern highbush blueberry. Similar to our study, they reported no effect of mulch type on SOM after 2 years. However, over a longer period of time, use of black weed mat alone reduced SOM and increased soil pH compared with sawdust (Strik et al., 2019).

Most soil nutrients fell within the desired range for blueberry production for all mulches in both years (Hart et al., 2006; Horneck et al., 2011), with an average across all mulches (mg·kg^{-1}) of P = 203, 230; B = 0.3, 0.4; Fe = 375, 283; Mn = 27, 20; Cu = 3.1, 2.9; and Zn = 4.9, 5.1 for 2017 and 2018, respectively. Only soil B was considered below the sufficiency level (i.e., <0.5 mg·kg^{-1}). Soil NO_3-N was significantly lower when weed mat of either color was placed over sawdust as compared with weed mat or sawdust alone in year 2 (Table 1). Weed mat mulch alone, particularly black, had the highest levels of soil NO_3-N. In 2018, there was a trend for sawdust and black weed mat alone to have higher soil NH_4-N than the other mulches (Table 1). Higher soil NO_3-N and NH_4-N were found in blueberry and blackberry under a black weed mat mulch compared with sawdust or bare soil, respectively (Dixon et al., 2016; Larco et al., 2013; Strik et al., 2019), likely a result of higher soil temperatures under the weed mat increasing mineralization of organic matter or nitrification (Larco, 2010). Adding a layer of sawdust under the weed mat reduced soil temperature compared with weed mat alone (Strik et al., 2020), perhaps reducing nitrification as reflected by lower levels of soil NO_3-N. However, soil NO_3-N was higher under sawdust mulch than weed mat over sawdust (Table 1), despite the former having the lowest soil temperature (Strik et al., 2020). Soil levels of NO_3-N and NH_4-N in the autumn are likely related to fertilizer remaining after plant uptake and the impact of soil temperature on nitrification.

In 2018, soil K was highest with sawdust mulch, intermediate with black weed mat alone, and lowest under the other mulches (Table 1). In contrast, there was either no difference in soil K between black weed mat and sawdust mulch in other studies (Larco et al., 2013; Strik et al., 2019) or weed mat increased soil K relative to bare soil (Dixon et al., 2016). In addition, there was a trend for sawdust and black weed mat alone to have higher levels of soil Ca and for sawdust to have higher levels of Mg than other mulches in 2018, whereas soil S that year tended to be higher with weed mat or weed mat over sawdust than with sawdust alone (Table 1). During establishment, Larco et al. (2013) reported higher soil Ca with sawdust than with weed mat but found no effect on other cations. In contrast, in a longer term study, Strik et al. (2019) found higher soil Ca and Mg under weed mat than under sawdust. They also found, however, that soil levels were variable from year to year likely due to differences in sampling methodology, location within the row, and weather preceding sampling collection.

Nutrient concentration

Recent fully expanded leaves. When leaves were sampled at the recommended time of late July to early August (Hart et al., 2006; Strik and Vance, 2015), nutrient concentrations were very similar between the first and second growing seasons. In both years, leaf Ca, S, Mn, and Zn (0.7%, 0.1%, 222 ppm, and 12 ppm in 2017, respectively, and 0.7%, 0.1%, 239 ppm, and 12 ppm in 2018, respectively) were within the sufficiency standards (0.4% to 0.8% Ca, 0.11% to 0.16% S, 30 to 350 ppm Mn, 8 to 30 ppm Zn; Hart et al., 2006). In contrast, leaf K (0.80% and 0.71%) and Fe (244 and 223 ppm) for 2017 and 2018, respectively, were above the standards (0.41% to 0.70% K and 60–200 ppm Fe), and leaf P (0.09% and 0.10%), B (20 and 29 ppm), and Cu (2.3 and 2.0 ppm) were below the recommended levels (0.11% to 0.4% P, 30 to 80 ppm B, 5 to 15 ppm Cu). Leaf N (averaged 2.0% in both years, mulch effects in 2018 are discussed subsequently) was at the top of the sufficiency range (1.76% to 2.0%), and leaf Mg (0.15% in both years) was near the bottom end of the range (0.13% to 0.25%). Larco et al. (2013) similarly found that young plants had leaf %N within normal or above sufficiency levels, whereas others have reported lower levels in the first or second growing season (e.g., Almutairi et al., 2017; Vargas et al., 2015).

In 2017, most leaf nutrient concentrations were unaffected by mulch. Leaf B was higher (P = 0.0061) with green weed mat over sawdust (26 ppm) than with either sawdust or green weed mat alone (averaged 17 ppm), and leaf Cu was lower (P = 0.012) with sawdust and green weed mat over sawdust (averaged 2.1 ppm) than with all other mulches (averaged 2.4 ppm).

In 2018, leaf N was lower (P = 0.0026) with black weed mat over sawdust (1.8%) compared with all other mulches (averaged 2.0%). Leaf S was higher (P = 0.045) with green weed mat alone (0.12%) compared with black weed mat over sawdust (0.11%), whereas all other mulches were intermediate. The impact of mulch on leaf B was different from in 2017, with black weed mat over sawdust having the highest (P = 0.016) concentration (34 ppm) compared with sawdust and black weed mat alone (averaged 26 ppm); green weed mat and green weed mat over sawdust were intermediate (averaged 30 ppm). Leaf Cu was higher (P = 0.030) with black weed mat (2.2 ppm) than black weed mat over sawdust (1.8 ppm) with the other treatments averaging 2.0 ppm. Contrast analysis indicated that mulching with weed mat over sawdust increased leaf P and B (P = 0.041 and 0.0019, respectively) and reduced leaf Fe, Mn, and Cu (P = 0.038, 0.030, and 0.024, respectively) in 2017 and increased leaf B (P = 0.011) and reduced leaf N, K, S, and Cu (P = 0.0056, 0.007, 0.0096, and 0.0021, respectively) in 2018 compared with weed mat alone (data not shown), corresponding perhaps to increased canopy growth (Strik et al., 2020).

Table 1. Effects of sawdust and polypropylene weed mat mulch on soil pH and nutrient levels in 'Duke' blueberry during the first 2 years after planting (2017–18) in Oregon.

Yr	Mulch	Soil pH	Extractable soil nutrients (mg·kg^{-1})					
			NO_3-N	NH_4-N	K	Ca	Mg	S
2017	Sawdust	5.3 a[z]	2.4	1.8	252	867	118	14
	Black weed mat	5.3 a	2.1	1.9	259	974	122	13
	Green weed mat	5.1 b	3.8	2.4	242	842	102	15
	Black weed mat over sawdust	5.0 b	0.5	1.8	204	729	104	17
	Green weed mat over sawdust	5.3 a	0.8	1.9	243	943	106	14
	Significance[y]	0.044	NS	NS	NS	NS	NS	NS
2018	Sawdust	5.3	18 b	5.6	285 a	1069	151	15
	Black weed mat	4.9	29 a	6.3	259 b	962	116	17
	Green weed mat	4.8	21 ab	4.0	218 c	926	111	19
	Black weed mat over sawdust	4.9	7 c	4.0	195 c	777	111	18
	Green weed mat over sawdust	4.9	8 c	4.0	199 c	802	106	18
	Significance	0.067	0.020	0.095	0.039	0.091	0.088	0.067

[z]Means followed by the same letter within a column are not significantly different (P > 0.05) by Tukey's honestly significant difference test.
[y]Values provided when $P \leq 0.10$. NS indicates not significant.

Senescent leaves. Nutrient concentration of senesced leaves in 2017 was influenced by mulch for several nutrients. Leaf P and S were both higher (P = 0.036 and 0.016, respectively) with green weed mat (0.04% and 0.11%) than black weed mat (0.02% and 0.08%), whereas all other mulches averaged 0.03% and 0.10% for P and S, respectively. Leaf Cu was highest (P = 0.034) with black weed mat over sawdust (1.7 ppm) compared with green weed mat over sawdust (1.2 ppm). Leaf Zn was also highest (P = 0.045) with black weed mat over sawdust (14 ppm), but sawdust (13 ppm), and black weed mat alone and green weed mat over sawdust (which averaged 11 ppm) were all significantly lower. Nutrients not affected by mulch in the senesced leaves included N (0.6% on average), Mg (0.1%), K (0.9%), Ca (1.1%), B (63 ppm), Fe (122 ppm), and Mn (796 ppm).

In 2018, mulch had no significant effect on the nutrient concentration of senesced leaves. Average nutrient concentrations were 0.7% N, 0.04% P, 0.12% Mg, 0.9% K, 0.9% Ca, 0.1% S, 73 ppm B, 227 ppm Fe, 549 ppm Mn, 3 ppm Cu, and 12 ppm Zn. The changes in leaf nutrient concentration from the recommended leaf nutrient sampling time in summer to senesced leaves in autumn followed an expected pattern based on the mobility of each nutrient and were similar to the patterns we have reported previously in blueberry (Strik and Vance, 2015). Leaf N, P, and Fe concentrations declined significantly during this time, although the reduction in Fe may also have been due to dust on the leaves during summer that was washed off by rain by the time senesced leaves were collected. Nutrients that remained at similar concentrations at both sampling times included Mg, K, S, Cu, and Zn, whereas Ca, B, and Mn concentrations increased from summer to senescence.

Fruit. In 2018 (the first harvest season), plants grown with black weed mat had a higher fruit Zn concentration (P = 0.045; 7.1 ppm) than those grown with sawdust and green weed mat over sawdust (averaged 6.6 ppm) and green weed mat and black weed mat over sawdust (averaged 5.8 ppm). There was no mulch effect on other nutrients in the fruit, which averaged 0.85% N, 0.07% P, 0.03% Mg, 0.57% K, 0.03% Ca, 0.05% S, 5 ppm B, 18 ppm Fe, 21 ppm Mn, and 1 ppm Cu. Mean fruit concentrations were similar to those reported for mature, conventionally managed 'Duke' blueberry in Oregon (Strik and Vance, 2015).

Dormant plant tissue. After the first growing season in 2017, mulch had no impact on macronutrient concentration in the roots (averaged 1.66%, 0.17%, 0.41%, 0.22%, 0.15%, and 0.13%), old wood (0.76%, 0.09%, 0.25%, 0.12%, 0.04%, and 0.06%), new wood (0.92%, 0.11%, 0.34%, 0.32%, 0.04%, and 0.07%) or the crown (1.32%, 0.18%, 0.34%, 0.10%, 0.06%, and 0.08%) for N, P, K, Ca, Mg, and S, respectively. Nor was there a mulch effect on micronutrient concentration in any plant part (data not shown). In the whips, there was a trend for N (P = 0.087) and K (P = 0.064) concentrations to be higher with black weed mat alone (0.98% and 0.47%, respectively) than with black weed mat over sawdust (0.87% and 0.39%, respectively). Contrasts were significant for plants grown with sawdust, either alone or under weed mat, having lower concentrations of N and K in roots (1.53%; P = 0.037 and 0.37%; P = 0.010, respectively) and N and Ca in whips (0.87%; P = 0.038 and 0.21%; P = 0.043, respectively) than plants grown with weed mat alone (averaged 1.73% and 0.43% for roots and 0.95% and 0.27% for whips, respectively). Contrast analysis indicated that adding sawdust under weed mat decreased Fe and Cu concentration in the crown (P = 0.013 and 0.040, respectively) and Cu (P = 0.031) in old wood, compared with weed mat alone (data not shown). Bañados (2006) found that N fertilization rate affected %N in roots, crown, and 1- and 2-year-old wood in dormant plants of 'Bluecrop' after the first growing season. Similarly, she reported highest concentrations of N in the roots and crown and higher levels in newer wood than older wood.

At the end of the second growing season (2018), mulch treatment had more effect on tissue nutrient concentrations in partitioned plants than was found after the first growing season. Plants mulched with sawdust had a higher K concentration in the crown (0.30%) and tended to have higher root K (0.41%; P = 0.062) than those with black weed mat alone (0.26% and 0.34%, respectively). Sawdust also increased P in old wood (0.094%) compared with all the other treatments (averaged 0.085%). In addition, the crown had higher Cu with sawdust (5 ppm) compared with either color of weed mat over sawdust (averaged 4.5 ppm). In contrast, the crown had lower Zn with sawdust (57 ppm) than with weed mat alone (averaged 69 ppm).

The contrast for weed mat color was only significant for roots with green weed mat increasing the concentration, compared with black, for K (0.39% vs. 0.35%; P = 0.023) and S (0.13% vs. 0.12%; P = 0.021), respectively. Mulching with weed mat over sawdust increased crown K and S (P = 0.0005 and 0.018, respectively), Cu in roots (P = 0.033), N and Fe in whips (P = 0.032 and 0.048, respectively), and N, P, and S in old wood (P = 0.035, 0.0001, and 0.0012, respectively), but decreased Cu in the crown (P = 0.039) as compared with sawdust alone (data not shown). Mulching with weed mat over sawdust compared with weed mat alone decreased N (1.19% vs. 1.29%, respectively; P = 0.025), Ca (0.12% vs. 0.15%; P = 0.0031), B (5.2 vs. 5.6 ppm; P = 0.038), Cu (4.5 vs. 5.3 ppm; P = 0.0006), and Zn (59 vs. 69 ppm; P = 0.0042) in the crown, decreased root Fe (1358 vs. 3338 ppm; P = 0.012) and Cu (8.7 vs. 10.2 ppm; P = 0.039), but tended to increase root P (0.20% vs. 0.19%; P = 0.055) (data not shown).

Nutrient content

End of first growing season. Nutrient content in roots and whips was unaffected by mulch after the first growing season, whereas differences were found for crowns and old and new wood (Table 2). In the crown, black weed mat over sawdust resulted in a higher content of N, Mg, S, B, and Zn than green weed mat and higher content of P and K than black weed mat or green weed mat, driven by a higher biomass (Strik et al., 2020), because there was no treatment effect on concentration. In new wood, only B content was significant with higher amounts in plants mulched with black weed mat over sawdust compared with black weed mat alone. Whole plant nutrient content, before pruning, differed by mulch for P, K, Ca, B, and Zn, with content for P and B higher in black weed mat over sawdust compared with black weed mat alone, following the significant difference between the two mulches found in whole plant biomass (Strik et al., 2020). Mulch had no significant impact on the aboveground to belowground ratio of any nutrient after the 2017 growing season (data not shown).

Contrast analysis showed no significant effect of weed mat color or differences between sawdust and weed mat alone on nutrient content of any plant part at the end of the first growing season (data not shown). However, adding sawdust under weed mat increased nutrient content compared with weed mat alone, including in the roots (Zn; P = 0.021), crown (N, P, K, Mg, S, B, Mn, and Zn; P = 0.0037, 0.0011, 0.0021, 0.0076, 0.044, 0.0076, 0.045, and 0.038, respectively), new wood (N, P, K, Ca, Mg, S, B, Fe, Mn, and Zn; P = 0.0049, 0.014, 0.0054, 0.0095, 0.023, 0.0056, 0.0036, 0.043, 0.046, and 0.040, respectively), old wood (N, P, K, Ca, S, and B; P = 0.036, 0.016, 0.012, 0.036, 0.021, and 0.034, respectively), and total plant before pruning (N, P, K, Mg, Ca, S, B, Mn, and Zn; P = 0.016, 0.0021, 0.0039, 0.019, 0.0021, 0.012, 0.0012, 0.016, and 0.0046, respectively). Earlier, we reported that plants had better growth when mulched with sawdust topped with weed mat compared with weed mat alone (Strik et al., 2020).

End of the second growing season. Following the second growing season, there was no significant effect of mulch on nutrient content of the belowground portion of the plant (Table 3). Phosphorus tended to be highest in the roots (P = 0.052) with black weed mat over sawdust (0.27 g/plant) and lowest with black weed mat (0.18 g/plant), again due to differences in biomass (Strik et al., 2020) because %P was unaffected in either tissue. Plants mulched with black weed mat over sawdust had significantly higher P, Mg, K, S, and Cu content in old wood than with black weed mat (Table 3). Similar trends were found for content of N, B, and Zn. Both black weed mat over sawdust and green weed mat over sawdust had higher Fe than black weed mat alone, whereas both green weed mat alone and black weed mat over sawdust had higher Mn content in old wood than all the other mulches. In new wood, N and Mg content was lower in both black weed mat

Table 2. Effects of sawdust and polypropylene weed mat mulch on nutrient content of 'Duke' blueberry plants dug and segregated by tissue type after the first growing season (Feb. 2018) in Oregon.

		N	P	K	Ca	Mg	S	B	Fe	Mn	Cu	Zn
Tissue type[z]	Mulch[y]	(g/plant)						(mg/plant)				
Roots	Mean	2.2	0.23	0.54	0.28	0.20	0.17	0.93	339	74	1.2	5.1
Crown	Sawdust	0.78 ab[x]	0.10 ab	0.21 ab	0.06	0.03 ab	0.048 ab	0.26 ab	12	18	0.10	1.2 ab
	Black weed mat	0.65 ab	0.09 b	0.16 b	0.05	0.03 ab	0.044 ab	0.20 ab	12	16	0.10	1.3 ab
	Green weed mat	0.55 b	0.08 b	0.14 b	0.04	0.02 b	0.036 b	0.17 b	10	15	0.09	1.1 b
	Black weed mat over sawdust	0.90 a	0.13 a	0.24 a	0.07	0.04 a	0.058 a	0.30 a	11	24	0.13	2.0 a
	Green weed mat over sawdust	0.73 ab	0.10 ab	0.19 ab	0.05	0.03 ab	0.042 ab	0.23 ab	6	18	0.08	1.2 ab
	Significance[w]	0.016	0.0032	0.0077	NS	0.030	0.041	0.020	NS	NS	NS	0.024
Old wood	Mean	0.45	0.05	0.15	0.07	0.02	0.03	0.25	4.98	27	0.04	0.86
New wood	Sawdust	0.42	0.05	0.16	0.15	0.02	0.03	0.37 ab	1.25	20	0.02	0.73
	Black weed mat	0.32	0.04	0.11	0.11	0.02	0.03	0.26 b	0.97	17	0.02	0.63
	Green weed mat	0.37	0.05	0.14	0.13	0.02	0.03	0.33 ab	1.21	25	0.02	0.72
	Black weed mat over sawdust	0.50	0.07	0.20	0.19	0.03	0.04	0.49 a	1.65	31	0.03	0.87
	Green weed mat over sawdust	0.51	0.06	0.19	0.16	0.02	0.04	0.43 ab	1.46	27	0.03	0.84
	Significance	0.059	NS	0.061	0.083	NS	0.063	0.035	NS	NS	NS	NS
Whips	Mean	0.33	0.04	0.15	0.09	0.02	0.03	0.24	0.99	15	0.02	0.52
Whole plant before pruning	Sawdust	4.1	0.48 ab	1.2b	0.69 ab	0.28	0.31	2.1 ab	407	151	1.4	8.4 b
	Black weed mat	3.7	0.42 b	1.1b	0.64 ab	0.26	0.28	1.9 b	265	137	1.3	7.6 b
	Green weed mat	4.0	0.44 ab	1.1b	0.61 b	0.26	0.30	1.9 ab	158	172	1.1	7.7 b
	Black weed mat over sawdust	5.5	0.64 a	1.6 a	0.87 a	0.35	0.39	2.8 a	328	204	1.6	11.5 a
	Green weed mat over sawdust	4.9	0.59 ab	1.5 a	0.80 ab	0.38	0.38	2.6 ab	628	207	1.9	10.5 a
	Significance	NS	0.026	0.044	0.025	NS	NS	0.020	NS	0.069	NS	0.050

[z]"Old" = 2-year-old and older wood; "New" = 1-year-old wood; "Whips" = new shoots arising from the basal portion of the plant.
[y]Means provided when no or few significant differences or trends between mulches were found at the $P \leq 0.1$ level.
[x]Means followed by the same letter within a column are not significantly different ($P > 0.05$) by Tukey's honestly significant difference test.
[w]Values provided when $P \leq 0.1$. NS indicates not significant.

Table 3. Effects of sawdust and polypropylene weed mat mulch on nutrient content of 'Duke' blueberry plants dug and segregated by tissue type after the second growing season (Feb. 2019) in Oregon.

		N	P	K	Ca	Mg	S	B	Fe	Mn	Cu	Zn
Tissue type[z]	Mulch[y]	(g/plant)						(mg/plant)				
Roots	Mean	5.7	0.57	1.16	0.42	0.38	0.39	1.9	622	156	2.90	10.4
Crown	Mean	2.2	0.27	0.49	0.23	0.10	0.15	0.9	128	62	0.87	10.9
Old wood	Sawdust	3.1	0.34 ab[x]	0.90 ab	0.54	0.14 ab	0.22 ab	1.9	57 ab	174 b	0.9 ab	8.7
	Black weed mat	2.4	0.23 b	0.66 b	0.46	0.09 b	0.15 b	1.6	36 b	151 c	0.6 b	6.4
	Green weed mat	2.7	0.29 ab	0.81 ab	0.58	0.12 ab	0.20 ab	2.0	49 ab	211 a	0.8 ab	8.8
	Black weed mat over sawdust	3.3	0.36 a	1.04 a	0.67	0.15 a	0.24 a	2.4	69 a	223 a	0.9 a	9.9
	Green weed mat over sawdust	2.6	0.27 ab	0.73 ab	0.50	0.11 ab	0.18 ab	1.7	65 a	170 bc	0.7 ab	7.7
	Significance	0.088	0.041	0.028	NS	0.023	0.023	0.057	0.0092	0.045	0.037	0.073
New wood	Sawdust	1.4 b	0.16	0.48 ab	0.47	0.05 b	0.10	1.3	3.9	47	0.35 ab	2.6
	Black weed mat	1.5 b	0.15	0.46 b	0.55	0.06 b	0.10	1.5	3.3	54	0.33 b	3.1
	Green weed mat	1.9 ab	0.19	0.59 ab	0.61	0.07 ab	0.13	1.8	4.9	67	0.44 ab	3.7
	Black weed mat over sawdust	2.3 a	0.23	0.78 a	0.76	0.09 a	0.16	2.2	5.3	81	0.50 a	4.4
	Green weed mat over sawdust	1.6 ab	0.18	0.58 ab	0.52	0.06 ab	0.11	1.5	3.8	55	0.36 ab	3.0
	Significance	0.027	NS	0.037	0.052	0.023	0.051	0.077	NS	0.079	0.030	0.069
Whips	Sawdust	1.31	0.14	0.45	0.32	0.05	0.09	1.01 a	3.3 a	36 a	0.22	2.3 a
	Black weed mat	0.27	0.03	0.11	0.06	0.01	0.02	0.21 b	0.6 b	8 b	0.05	0.4 b
	Green weed mat	0.76	0.08	0.29	0.17	0.03	0.05	0.59 ab	1.9 ab	23 ab	0.15	1.4 ab
	Black weed mat over sawdust	0.64	0.07	0.27	0.15	0.02	0.05	0.48 ab	1.4 ab	17 ab	0.13	1.1 ab
	Green weed mat over sawdust	0.84	0.10	0.31	0.19	0.04	0.06	0.64 ab	1.8 ab	27 ab	0.18	1.4 ab
	Significance	0.064	0.087	NS	0.052	0.052	NS	0.046	0.032	0.035	NS	0.045
Whole plant before pruning	Sawdust	14.7 ab	2.3 a	4.8 a	4.3	1.3 a	1.8 a	9.0 ab	1105	493	5.9	36
	Black weed mat	11.0 b	1.8 b	3.7 b	3.9	1.0 b	1.4 b	7.2 b	839	399	4.4	29
	Green weed mat	14.3 ab	2.1 ab	4.6 ab	4.4	1.2 ab	1.7 ab	9.2 ab	930	547	5.8	37
	Black weed mat over sawdust	17.3 a	2.5 a	5.4 a	4.8	1.4 a	1.9 a	10.4 a	613	586	5.9	39
	Green weed mat over sawdust	13.8 ab	2.2 ab	4.6 ab	4.2	1.2 ab	1.7 ab	8.5 ab	573	491	5.4	35
	Significance	0.019	0.0032	0.0015	0.067	0.0024	0.004	0.0068	NS	0.078	0.075	0.098

[z]"Old" = 2-year-old and older wood; "New" = 1-year-old wood; "Whips" = new shoots arising from the basal portion of the plant.
[y]Means provided when no or few significant differences or trends between mulches were found at the $P \leq 0.1$ level.
[x]Means followed by the same letter within a column are not significantly different ($P > 0.05$) by Tukey's honestly significant difference test.
[w]Values provided when $P \leq 0.1$. NS indicates not significant.

and sawdust mulches compared with black weed mat over sawdust due to significantly lower biomass of this tissue in both of those mulches (Strik et al., 2020); however, only black weed mat was significantly lower than black weed mat over sawdust for K and Cu. Several other nutrients in new wood, including Ca, S, B, Mn, and Zn, showed similar trends of having the lowest content in either black weed mat or sawdust and the most in black weed mat over sawdust. In plants grown with sawdust mulch, whips tended to have the highest biomass (Strik et al., 2020), especially compared with black weed mat, resulting in higher content of micronutrients, including B, Fe, Mn, and Zn. Whip content of N, P, Ca, and Mg tended to follow this same response to mulch. When whole plant nutrient content was calculated before pruning, all nutrients except Fe had either significant differences or trends due to mulch, with the greatest differences between black weed mat over sawdust (greatest content) and black weed mat (lowest content), with the green weed mat (with or without sawdust) and sawdust mulches being intermediate (Table 3). Just as in 2017, there were no differences in the aboveground to below-ground nutrient content ratios due to mulch (data not shown).

Despite finding no difference in nutrient concentration or DW (Strik et al., 2020) at the end of the second growing season, green weed mat (averaged with and without sawdust underneath) had higher content of P, Ca, B, Fe, Mn, Cu, and Zn in the whips compared with the black weed mat mulch treatments (P = 0.044, 0.43, 0.035, 0.036, 0.18, 0.04, and 0.028, respectively). Although weed mat color affected root concentration of K and S, this was not reflected by differences in content. Plants grown with sawdust had a lower total content of P, K, Mg, and S (P = 0.019, 0.024, 0.013, and 0.02, respectively) than those with weed mat, on average, despite few differences in plant DW for these mulches (Strik et al., 2020). Adding sawdust mulch under weed mat increased nutrient content of the roots and crown (P; P = 0.035 and 0.031, respectively), old wood (Fe; P = 0.0014), new wood (K; P = 0.043), and the total plant (N, P, K, Mg, S, and B; P = 0.019, 0.002, 0.0016, 0.0053, 0.0058, and 0.026, respectively) compared with weed mat alone.

In establishing 'Bluecrop' blueberry, total plant nutrient content was affected by rate of N fertilization, but most of the treatment effects were related to differences in DW compared with nutrient concentration (Bañados et al., 2012; Bryla et al., 2012).

Nutrient uptake and losses

First growing season. Plant uptake of P and Zn was higher with black weed mat over sawdust compared with black weed mat in 2017, with similar trends seen for N, S, and B uptake (Table 4). Uptake per hectare ranged from 11.7 to 17.2 kg N, 1.3 to 2.0 kg P, 0.9 to 1.2 kg S, 5.7 to 8.4 g B, and 22 to 35 g Zn (black weed mat over sawdust always had the greatest uptake and black weed mat alone had the lowest), whereas uptake of Mg, K, and Ca across all treatments averaged 1.0, 4.0, and 2.1 kg·ha^{-1}, respectively, and Fe, Mn, and Cu averaged 822, 535, and 4 g·ha^{-1}, respectively. In flat beds with no mulch in Oregon, 'Bluecrop' blueberry took up an estimated 14, 1, 5, 5, and 2 kg·ha^{-1} for N, P, K, Ca, and Mg, respectively, by October of the first growing season (Bryla et al., 2012). The plants in that case were fertilized with 50 kg·ha^{-1} N, 35 kg·ha^{-1} P, and 66 kg·ha^{-1} K, and fertilizer uptake efficiency (FUE) was estimated at 29%, 3%, and 7% for each of these nutrients, respectively.

Nutrient losses in senesced leaves and pruning wood were not affected by mulch (Table 4), although there was a significant contrast for plants grown with weed mat over sawdust having greater losses of N, P, K, Ca, S, and B (P = 0.031, 0.025, 0.0052, 0.037, 0.026, and 0.015, respectively) in pruning wood than those with weed mat alone (data not shown). Plants with more growth, as was found with weed mat over sawdust (Strik et al., 2020), require more pruning going into the second growing season to avoid excessive fruit production (Strik and Buller, 2005; Strik et al., 2017b). Additional nutrients may have been lost to root turnover (Valenzuela-Estrada et al., 2008) and may have been affected by mulch treatment, but these could not be estimated.

Net nutrient gain after pruning following the first growing season was higher with black weed mat over sawdust and green weed mat over sawdust compared with the other mulches for P, K, and B, with similar trends found in Mn and Zn (Table 4). Net gain for Ca in 2017 was only significantly higher in

Table 4. Effects of sawdust and polypropylene weed mat mulch on total nutrient gain, nutrient losses, and net nutrient gain in 'Duke' blueberry plants over the first two growing seasons (2017 and 2018) and cumulative net gain from planting through the end of the second growing season in Oregon.

Season gains/losses[z]	Mulch[y]	N	P	K	Ca	Mg	S	B	Fe	Mn	Cu	Zn
		(g/plant)						(mg/plant)				
		First growing season										
Total gain	Sawdust	4.4	0.5 ab[x]	2.0	1.7	0.4	0.4	7.9	276	222	1.3	8.5 ab
	Black weed mat	3.9	0.4 b	1.7	1.4	0.3	0.3	5.9	271	182	1.2	7.2 b
	Green weed mat	4.5	0.5 ab	1.8	1.5	0.3	0.4	6.8	166	244	1.1	7.8 ab
	Black weed mat over sawdust	5.9	0.6 a	2.4	2.0	0.4	0.5	10.2	210	283	1.5	11.7 a
	Green weed mat over sawdust	5.2	0.6 ab	2.2	1.6	0.4	0.4	7.8	283	260	1.8	10.2 ab
	Significance[w]	0.091	0.026	NS	NS	NS	0.080	0.052	NS	NS	NS	0.041
Loss: senesced leaves	Mean[y]	0.6	0.03	0.8	1.0	0.10	0.09	5.5	11.0	74	0.14	1.1
Loss: pruning wood	Mean	0.3	0.04	0.1	0.1	0.01	0.02	0.2	1.0	15	0.02	0.5
Net gain	Sawdust	3.5	0.4 b	1.0 b	0.6 ab	0.2	0.3	1.8 b	260	126	1.2	6.7
	Black weed mat	3.3	0.4 b	0.9 b	0.5 ab	0.2	0.3	1.6 b	262	117	1.1	6.0
	Green weed mat	3.5	0.4 b	1.0 b	0.5 b	0.2	0.3	1.6 b	155	146	0.9	6.1
	Black weed mat over sawdust	4.8	0.6 a	1.4 a	0.7 a	0.3	0.3	2.3 a	196	173	1.3	9.6
	Green weed mat over sawdust	4.4	0.5 a	1.3 a	0.7 ab	0.3	0.3	2.3 a	272	183	1.7	8.8
	Significance	NS	0.024	0.039	0.023	NS	NS	0.015	NS	0.064	NS	0.051
		Second growing season										
Total gain	Mean	12.8	1.2	5.9	4.3	0.8	1.0	52	728	706	5.6	36
Loss: fruit	Sawdust	0.82	0.08 ab	0.59 ab	0.03	0.03	0.05	0.50 ab	1.81	1.80 b	0.10	0.70
	Black weed mat	0.93	0.07 b	0.56 b	0.03	0.03	0.05	0.47 b	1.83	2.26 ab	0.12	0.70
	Green weed mat	1.03	0.08 ab	0.63 ab	0.03	0.03	0.06	0.53 ab	1.82	2.62 ab	0.10	0.63
	Black weed mat over sawdust	0.89	0.09 a	0.69 a	0.04	0.04	0.06	0.60 ab	2.30	2.50 ab	0.11	0.72
	Green weed mat over sawdust	1.06	0.09 a	0.67 ab	0.04	0.04	0.06	0.63 a	2.08	2.63 a	0.13	0.78
	Significance	NS	0.0089	0.037	0.053	0.061	NS	0.011	0.054	0.036	NS	NS
Loss: senesced leaves	Mean	2.26	0.12	2.89	2.78	0.37	0.31	46	144	351	1.59	7.72
Loss: pruning wood	Mean	0.30	0.04	0.12	0.09	0.01	0.02	0.24	1.03	15	0.02	0.51
Net gain	Mean	9.3	1.0	2.2	1.4	0.4	0.6	5.1	582	338	3.9	27
		Planting through second season										
Cumulative net gain	Sawdust	13.6 ab	1.4 ab	3.6 a	2.0	0.8 ab	1.0 ab	7.2 ab	1104	477	5.6	35
	Black weed mat	10.0 b	1.0 b	2.4 b	1.6	0.5 b	0.7 b	5.5 b	838	387	4.0	28
	Green weed mat	13.3 ab	1.4 ab	3.4 ab	2.0	0.7 ab	0.9 ab	7.4 ab	929	530	5.4	36
	Black weed mat over sawdust	16.1 a	1.8 a	4.1 a	2.3	0.8 a	1.1 a	8.4 a	611	564	5.5	38
	Green weed mat over sawdust	12.8 ab	1.4 ab	3.3 ab	1.9	0.7 ab	0.9 ab	6.7 ab	572	475	5.0	34
	Significance	0.027	0.0069	0.0052	0.063	0.046	0.013	0.011	NS	NS	0.061	NS

[z]Total nutrient gains include content in new wood, old wood, whips, crown, and roots relative to the prior season. Losses include senesced leaves and pruning wood in 2017 and 2018 and fruit in 2018. Net gain was calculated by subtracting losses from total gains each year and cumulatively at the end of the second growing season.

[y]Means provided when no or few significant differences or trends between mulches were found at the $P \leq 0.1$ level.

[x]Means followed by the same letter within a column are not significantly different ($P > 0.05$) by Tukey's honestly significant difference test.

[w]Values provided when $P \leq 0.1$. NS indicates not significant.

black weed mat over sawdust compared with green weed mat. The contrast for weed mat over sawdust compared with weed mat alone showed significantly higher net gain of N, P, K, Ca, Mg, S, B, Mn, and Zn for the former (P = 0.016, 0.0019, 0.0036, 0.0017, 0.021, 0.015, 0.0009, 0.016, and 0.0046, respectively; data not shown). There was no significant effect of weed mat color, on average, for nutrient uptake, losses, or net gain in the first growing season.

Second growing season. Nutrient uptake in the second growing season was largely unaffected by mulch, although there was a trend (P = 0.051) for uptake of P to be higher in black weed mat over sawdust (1.5 g/plant) compared with black weed mat (0.9 g/plant) just as in 2017 (means shown in Table 4). Nutrient uptake per hectare averaged 33.3 kg N, 1.5 kg Mg, 8.0 kg K, 4.9 kg Ca, 2.2 kg S, 18 g B, 2087 g Fe, 1211 g Mn, 14 g Cu, and 96 g Zn, and P uptake ranged from 2.4 to 4.3 $kg \cdot ha^{-1}$ with the lowest level for black weed mat and the highest for black weed mat over sawdust.

Nutrient losses in fruit were especially affected by the higher yield harvested with black weed mat over sawdust compared with black weed mat alone (Strik et al., 2020), particularly for P and K, although P was also higher in green weed mat over sawdust compared with black weed mat (this trend was also seen for Ca and Fe) (Table 4). Green weed mat over sawdust was also higher relative to black weed mat for B and compared with sawdust for Mn. Contrast analysis showed higher fruit content of P, K, Ca, Mg, S, B, and Fe for weed mat over sawdust compared with weed mat alone (P = 0.0014, 0.011, 0.0068, 0.014, 0.039, 0.0019, and 0.011, respectively; data not shown). There was no mulch effect on losses in senesced leaves and pruning wood (Table 4). However, the contrast comparing weed mat over sawdust to weed mat alone was significant with higher N, P, K, Ca, S, and B (P = 0.031, 0.025, 0.0052, 0.037, 0.026, and 0.015, respectively) in pruning wood when sawdust was added under weed mat.

Given that few differences were seen in either nutrient uptake or losses in the second growing season due to mulch, it is not surprising that no differences were found in net nutrient gain (Table 4). There was no significant effect of weed mat color, on average, for nutrient uptake, losses, and net gain in the second growing season.

From planting through the second growing season. After two growing seasons when cumulative net nutrient gain was calculated, all nutrients except Fe and Zn showed either significant differences or trends resulting from mulch (Table 4). The cumulative gain of N, P, K, Mg, S, and B was higher for black weed mat over sawdust than black weed mat alone, whereas all other mulches were intermediate. There was a similar trend for Ca and Mn, while Cu tended to be highest with sawdust mulch, especially compared with black weed mat. Contrast analysis showed that sawdust mulch resulted in higher cumulative net gain of K than weed mat alone (P = 0.048) and plants grown with weed mat over sawdust had a higher net gain of N, P, K, Mg, S, and B than those with weed mat alone (P = 0.028, 0.0049, 0.0079, 0.039, 0.03, and 0.037, respectively; data not shown).

Fertilizer use efficiency. In the first growing season, considering total plant uptake of N from planting to before pruning and including what was lost in senesced leaves, plants on average took up 10% of the 48 g of N fertilizer applied. There was trend for plant N uptake to be lowest in black weed mat and highest in black weed mat over sawdust (Table 4) leading to fertilizer use efficiencies ranging from 8% to 12%, respectively. Using N^{15}-depleted fertilizer, Bañados et al. (2012) reported 17% FUE in 'Bluecrop' at the end of the first growing season (October), but >50% of this fertilizer N was lost over winter, after leaf senescence and pruning.

In the second growing season, FUE averaged 42% considering N uptake from a pruned plant at the start of the season to an unpruned plant at the end of the season, including losses in fruit and senesced leaves, and the 30 g/plant of N applied. Because plants were fertigated, the smaller root systems of newly establishing plants in 2017 (Strik et al., 2020) were unable to access much of the fertilizer applied while a higher percentage was accessible during the second year of growth.

Conclusion

There were few effects of weed mat color on nutrient concentration and content, confirming our previous report of mulch effects on plant growth (Strik et al., 2020). Impacts of mulch on soil properties and nutrient levels were found, but greater differences would be expected as the planting continues to age (Strik et al., 2019). Mulching with weed mat over sawdust increased leaf P and B concentrations and reduced leaf Fe, Mn, and Cu in the first year and increased leaf B and reduced leaf N, K, S, and Cu in the second year as compared with weed mat alone. There was little effect of mulch on fruit nutrient concentrations. Mulch had no effect on nutrient concentrations in dormant plant parts after the first growing season. However, significant differences were found in nutrient content between sawdust topped with weed mat compared with weed mat alone. In the second year, we found differences in nutrient concentrations among various dormant plant parts as affected by mulch. The treatment differences in nutrient content and uptake that we found were mainly related to plant biomass (Strik et al., 2020).

Plants were only fertilized with N during the study because soil and leaf test analyses indicated sufficient levels of other nutrients and plant growth was good. In the first year, FUE for N ranged from 8% to 12% with the lowest in black weed mat and the highest in black weed mat over sawdust. In the second year, FUE averaged 42%. The gain in other nutrients per hectare was relatively small (1.3 to 4.3 kg of P, 4.0 to 8.0 kg of K, 2.1 to 4.9 kg of Ca, and 1.0 to 1.5 kg of Mg, depending on year) and would have been derived from the soil or decomposing roots (Valenzuela-Estrada et al., 2008). It is clear from our study that blueberry plants have a low requirement for other nutrients regardless of mulch type.

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