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Optimal soil conditions for organic highbush blueberry growth: Assessment of early results

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Abstract

To ascertain optimal soil conditions for creating an organic and sustainable blueberry operation, 160 highbush blueberry plants representing five different cultivars (Duke, Bluecrop, Jersey, Chandler, and Bluegold) were planted at Knoll Acres Farm, Harrisonburg, Virginia in 2009 within four soil treatment plots (horse manure, sheep manure, pine straw, and Planters Choice mulches). To define optimal growth conditions, selected soil characteristics and plant vigor assessments including photosynthesis and respiration activities as well as plant growth measurements were recorded. Statistical analyses indicated that soil treatments of pine straw and Planters Choice mulches produced significantly higher plant growth values than horse and sheep manure mulches. Among the five cultivars, Chandler bushes thrived the best, based on growth parameters except for bush height. Including cost/benefit considerations, pine straw mulch was the most economical and effective treatment among four mulches tested.

Key words: Soil, organic, sustainable, mulch, Duke, Bluecrop, Jersey, Chandler, Bluegold, *Vaccinium corymbosum*, *Ericaceae*

Introduction

Knoll Acres, a small blueberry farm located in the Shenandoah Valley near Harrisonburg, Virginia, aims to establish a small, sustainable, commercial organic blueberry operation and thereby discern and model best organic horticultural practices in this area of Virginia. Blueberries are members of the *Ericaceae* family. Commercial blueberry types in the United States include southern lowbush, rabbiteye, and northern highbush blueberry. Highbush blueberries (*Vaccinium corymbosum*) are the most widely cultivated species in North America and best fit the growth zone of this area of Virginia (Retamales and Hancock, 2012).

Besides cranberries, blueberries are the only commercially grown endemic fruit crop in the United States (Pritts and Hancock, 1992). In 2009, about 40,500 hectares (100,000 acres) of blueberries were planted in North America which represents a 50% increase over the prior 5 years. World-wide, outside of North America, about 27,000 hectares is under blueberries production (Retamales and Hancock, 2012). The market and demand for fresh blueberries is high; US blueberry consumption in 2004 doubled the consumption rate twenty years earlier. Americans consume 200 million pounds of blueberries each year and the highbush industry in North America is currently worth more than 100 million dollars (Pritts and Hancock, 1992). The area of Virginia is currently not a major source of blueberry production. However, based on a few small successful commercial growers in this area, and a specialty crop profile paper from Virginia Cooperative Extension (Bratsch and Pattison, 2009) blueberry production in this part of the Shenandoah Valley is a viable option.

Many consumers are aware of the health benefits that the fresh blueberries provide (Lewis and Ruud, 2005). These include basic nutrient properties, antioxidant activity (Kratchanova *et al.*, 2008; Philpott *et al.*, 2009), anti-ageing properties (Wilson *et al.*, 2006), cancer prevention (Bagchi *et al.*, 2004; Matchett *et al.*, 2005), protection against age-related neurological defects (Joseph *et al.*, 2007), urinary tract health, protection against diabetes (McDougall and Stewart, 2005), and cardiovascular health (Kalt *et al.*, 2008). The polyphenolics and anthocyanins, found in ripened blueberries, are the primary health promoters and protective agents (Nichenametla *et al.*, 2006) and in comparison to many other fruits tend to contain relatively higher levels of protective anthocyanins (Suojalainen and Keranen, 1961). Berry content of anthocyanins varies among blueberry genotypes (Scalzo *et al.*, 2008). Between the picking of a ripe blueberry and its consumption, the storage and processing of this fruit may affectively lessen the anthocyanin content and antioxidant capacity (Brownmiller *et al.*, 2008; Scibisz and Mitek, 2009; Trost *et al.*, 2008; Nikkah *et al.*, 2007).

Several studies have demonstrated the superiority of organic versus conventionally raised blueberries, but this research needs confirmation and development to convince a potential blueberry grower that organic production techniques are superior to conventional ones (McCullum-Gomez *et al.*, 2009). Wang *et al.* (2008) compared harvested blueberry chemical characteristics from multiple sites and found that organically grown blueberries (Bluecrop) have elevated levels of sugars, total phenolics, total anthocyanins, and antioxidant activity, when compared to conventionally grown blueberries. Missing data from this study elicit questions for the potential organic grower: What is the difference in productivity (yield) between the organic and the conventional blueberry plants? What mechanism accounts for the increased antioxidant activity in the organic versus conventionally grown blueberries? Is it possible that organic (versus conventional) practices can produce blueberries that are healthier, higher in quality and quantity, and more cost effective for the grower? The superior antioxidant quantities (elevated anthocyanins and phenolics) of organic blueberries have not been linked to specific growing practices or to the effect of specific soil profiles or foliar nutrient levels.

Nationwide attention has been given to growing blueberries in an organic system through several important publications (Drummond *et al.*, 2009; Kuepper and Diver, 2004). As interest and grower involvement in organic production have increased, the organic arsenal of effective insecticides and fungicides continue to be researched and expanded (Kamminga *et al.*, 2009). Most of the published papers, providing economic guidance on growing blueberries, are regionally focused for the large conventional acreage growth, rather than the smaller organic producer. Examples include northern highbush blueberries in Oregon (Eleveld *et al.*, 2005), California (Takele, 2005; Takele *et al.*, 2007), and Pennsylvania (Demchak *et al.*, 2001) as well as southern highbush blueberries in Georgia (Fonsah *et al.*, 2006) and Kentucky (Woods, 2008).

A commercial operation is sustainable only to the degree that it is profitable. Costs and steps to initiate a small commercial organic blueberry production facility and its potential profitability have not been fully explored or documented. While economic studies of large commercial (non-organic) blueberry production have been published detailing costs of machine harvesting, it is difficult to extrapolate these findings to smaller *organic* production efforts. A study on highbush blueberry production in New Jersey, investigating best organic practices in cultivar selection, weed and insect management, and usage of selected organic fungicides and insecticides, has been very helpful to the organic grower (Sciarappa, 2008). However, this study did not connect economics and plant productivity to their organic practices. More recently, however, Julian *et al.* (2012) connected establishment costs of organic northern highbush blueberries involving different mulches and fertilization approaches with the productivity of two cultivars, Duke and Liberty.

Blueberries tolerate a wide range of soils. A natural blueberry soil has low fertility, high polyphenol content, and more than 4% organic matter. However, any good loam soil with some amendments will be suitable for blueberries. Loams with an organic matter content of 3-15% are excellent (Gough, 1994). Increased organic matter in the lower levels of the soil enhances downward growth of blueberry roots (Shoemaker, 1978). Given high organic matter content, blueberry optimal growth and production occur in acidic soils with a low pH range of 3.8 to 5.5 (Pritts and Hancock,1992). Blueberry plants thrive on organic fertilizers (Kuepper and Diver, 2004), which tend to slowly release nutrients creating a stable ecosystem.

The purpose of this investigation was to identify optimal soil treatments and cultivar selections for the Shenandoah Valley, based on soil quality measures and indicators of plant vigor. Since substantial berry production does not occur in the first two years after planting, this paper reports on planting methodology, soil characteristics, and plant vigor measures during the early years. These data provide the basis to predict optimal horticultural practices that enhance a sustainable blueberry operation.

Materials and methods

Experimental design and plantings: To assess the effects of varying soil mulch treatments on the growth of five different highbush blueberry cultivars, a block design (Fig. 1) was created with four soil treatment plots: horse manure and sawdust mulch (HM), sheep manure and hay mulch (SM), pine needles and shredded pine bark mulch (PS), and a commercial Planters Choice (PC) mulch based on bovine manure, sawdust, and fodder.

At Knoll Acres in November and December of 2009, planting holes (approximately 50 x 25 cm), at 1.5 meter intervals in the middle of the row, were hand dug (Fig. 2). One hundred and sixty bare-rooted 3 year old dormant blueberry plants representing five cultivars: Duke (40 plants), Bluecrop (39), Jersey (40), Chandler (25) and Bluegold (16) were planted in the moistened holes, using a mix of soil, shredded pine bark, and peat moss as covering material (Fig. 3). The Duke, Bluecrop, and Jersey plants were obtained from Miller Nurseries, New York. The Chandler and Bluegold bushes were obtained from Finch's Blueberry Nursery, NC. After planting, the blueberry plants were top-mulched with 7-9 cm of shredded pine bark and left to over-winter. Although most of the plants thrived in the following spring and summer (Figs. 4 and 5), the initial planting was enhanced by replacing a few plants that were not thriving.

Soil sampling and assays: Soil quality measures were based on soil respiration and rate of water infiltration. Soil respiration, based on a prescribed USDA method (USDA, 2001), is one measure of biological activity and organic decomposition. Specifically, this is a measurement of carbon dioxide (CO_2) released from the soil surface due to aerobic microbial respiration, plant root and faunal respiration, and eventually from the dissolution of carbonates in soil solution. Using an enclosed ring chamber (15.54 cm in diameter and 7.6 cm high), positioned over a sample area, trapped air was drawn through a Draeger tube apparatus to estimate the amount of CO_2 produced and released from the soil surface within a given time frame. The rate of CO_2 release was expressed as CO_2-C kg/ha/day (1 pound / acre = 1.12085116 kg/ha). Soil water infiltration, based also on a prescribed USDA method (USDA, 2001), involved applying 444 mL of water (2.54 cm layer) into a 15.24 cm diameter metal ring driven into the soil and allowing the water to drain freely into the enclosed ring of soil. After an initial infiltration was done to wet the soil, the infiltration time (in seconds) for the second water sample was recorded.

To assay the effectiveness of different fertilizing techniques, soil samples were obtained from the four soil treatment plots: HM, SM, PS, and PC. A soil sample was obtained by mixing five cores taken from a single area 30 cm in diameter. Samples were obtained near plants in each bed with six different samples taken from each soil treatment plot. Soil samples were dried overnight and filtered through a screen to remove the large particles. The screened and dried soil samples were tested using commercial semiquantitative soil test assays (LaMotte, 2001) to determine micronutrient and macronutrient concentrations as well as the pH values.

The four experimental mulches (horse manure, sheep manure, pine straw, and Planters Choice) were also sampled and analyzed for macro- and micronutrient content, pH, and percentage of organic matter at a commercial soil laboratory (Virginia Tech Soil Laboratory, Blacksburg, Virginia).

Cultivar sampling: Measurement data were collected at Knoll Acres in the fall of 2010 about ten months after the bushes were planted (see Fig. 5) in November and December of 2009 as three year old bare-rooted stock from commercial nurseries.To determine plant growth data, all 160 plants representing the five highbush blueberry cultivars were assayed. For the photosynthesis measures, selected Jersey and Bluecrop plants from the different treatment plots were sampled.

Growth parameters: Overall bush height and diameter, length of the primary stalk, primary stalk diameter at 10 and 25 cm, and the number of primary stalks and primary branches were measured. Four growth parameters, considered as measurements of plant vigor, included: average primary stalk diameter (in mm), bush height (in mm), volume of a plant cylinder (in which the volume of a single plant was measured by placing the plant in a virtual cylinder and calculating the formula $V=\Pi r^2 h$), and a relative bushiness value (B), based on the formula B = (PS) (PB) (PSH) where PS, PB, and PSH denote the numbers of primary stalks, average number of primary branches per stalk, and average primary stalk length in cm.

Photosynthesis and transpiration measurements: Rates of photosynthesis and transpiration were measured for two cultivars, Jersey and Bluecrop, with a LiCOR 6400, which simultaneously measures photosynthesis (via net CO_2 uptake) and transpiration (Long *et al.*, 1996). This instrument allows for non-invasive field measurements by isolating individual leaves inside a 2 x 3 cm clamped chamber that measures the difference in incoming and outgoing CO_2 and H_2O. Mature highbush blueberry leaves average 5 cm long and 3 cm wide and completely fill the LiCOR

Fig. 1. Plot design and layout for organic blueberry cultivars. Four different mulch treatment plots: Horse Manure (horse manure and sawdust mulch); Sheep manure (sheep manure and hay mulch); Pine Straw (pine needle and shredded pine bark mulch); Planters Choice (commercial cow manure & fodder mulch). Five highbush blueberry cultivars [number of plants] comprise 160 plants: Duke [40], Bluecrop [39], Jersey [40], Chandler [25], and Bluegold [16].

Row Letter	# Plants /row	Compost Type	Organic Plots													
A	14	Horse Manure	Duke #01 A	Duke #02, A	Duke #03, A	Duke #04, A	Duke #05, A	Duke #06, A	Duke #07, A	Duke #08, A	Duke #09, A	Duke #10, A	Duke #11, A	Duke #12, A	Duke #13, A	Duke #14, A
B	14		Bluecrop #01, B	Bluecrop #02, B	Bluecrop #03, B	Bluecrop #04, B	Bluecrop #05, B	Bluecrop #06, B	Bluecrop #07, B	Bluecrop #08, B	Bluecrop #09, B	Bluecrop #10, B	Bluecrop #11, B	Bluecrop #12, B	Bluecrop #13, B	Bluecrop #14, B
C	13		Jersey #01, C	Jersey #02, C	Jersey #03, C	Jersey #04, C	Jersey #05, C	Jersey #06, C	Jersey #07, C	Jersey #08, C	Jersey #09, C	Jersey #10, C	Jersey #11, C	Jersey #12, C	Jersey #13, C	
D	13		Chandler #01, D	Chandler #02, D	Chandler #03, D	Chandler #04, D	Chandler #05, D	Bluegold #01, D	Bluegold #02, D	Bluegold #03, D	Bluegold #04, D	Bluegold #05, D	Bluegold #06, D	Chandler #06, D	Chandler #07, D	
E	13	Sheep Manure	Duke #15 E	Duke #16 E	Duke #17 E	Duke #18 E	Duke #19 E	Duke #20 E	Duke #21, E	Duke #22, E	Duke #23, E	Duke #24, E	Duke #25, E	Duke #26, E	Duke #27, E	
F	12		Bluecrop #15, F	Bluecrop #16, F	Bluecrop #17, F	Bluecrop #18, F	Bluecrop #19, F	Bluecrop #20, F	Bluecrop #21, F	Bluecrop #22, F	Bluecrop #23, F	Bluecrop #24, F	Bluecrop #25, F	Bluecrop #26, F		
G	11		Jersey #14, G	Jersey #15, G	Jersey #16, G	Jersey #17, G	Jersey #18, G	Jersey #19, G	Jersey #20, G	Jersey #21, G	Jersey #22, G	Jersey #23, G	Jersey #24, G			
H	11		Chandler #08, H	Chandler #09, H	Chandler #10, H	Bluegold #07, H	Bluegold #08, H	Bluegold #09, H	Bluegold #10, D	Bluegold #11, D	Chandler #11, H	Chandler #12, H	Chandler #13, H			
I	12	Pine Straw	Duke #28, I	Duke #29, I	Duke #30, I	Duke #31, I	Duke #32, I	Duke #33, I	Bluecrop #27, I	Bluecrop #28, I	Bluecrop #29, I	Bluecrop #30, I	Bluecrop #31, I	Bluecrop #42, I		
J	11		Jersey #25, J	Jersey #27, J	Jersey #285, J	Jersey #29, J	Jersey #30, J	Jersey #31, J	Chandler #14, J	Chandler #15, J	Chandler #16, J	Chandler #17, J	Chandler #18, J			
K	11	Planters Choice	Duke #34, K	Duke #35, K	Duke #36, K	Duke #37, K	Duke #38, K	Duke #39, K	Bluecrop #32, K	Bluecrop #33, K	Bluecrop #34, K	Bluecrop #35, K	Bluecrop #36, K			
L	11		Jersey #32, L	Jersey #33, L	Jersey #34, L	Jersey #35, L	Jersey #36, L	Jersey #37, L	Jersey #38, L	Jersey #39, L	Jersey #40, L	Jersey #41, L	Duke #43, L*			
M	9		Chandler #19, M	Chandler #20, M	Chandler #21, M	Chandler #22, M	Chandler #23, M	Chandler #24, M	Chandler #25, M	Bluecrop #43, M	Bluecrop #44, M					
N	5		Bluegold #12, N	Bluegold #13, N	Bluegold #14, N	Bluegold #15, N	Bluegold #16, N									
	160															

*Small plant, few roots

Fig. 2. Planting hole for planting bare-rooted 3 year old blueberry plants. Planting holes about 50 cm in diameter and 25 cm deep were initially dug in the center of the row at 1.5 meter intervals. A mixture of soil, peat moss, and shredded pine bark were used as planting media. See the pile of planting media to the left side of the planting hole.

Fig. 3. Newly planted bare-rooted 3 year old blueberry plant. Plants were planted in November/December 2009 while they were dormant. Planting media (soil:peatmoss:shredded pine bark at a ratio of 1:1:1) was firmed around the bare rooted plant and then thoroughly soaked with water.

Fig. 4. Young organic Bluegold blueberry bush at Knoll Acres loaded with blossoms about 5 months after planting. Most of the blossoms were stripped from the plant during this first summer to enhance vegetative and root growth by restricting the flow of plant energies into fruit production.

Fig. 5. Young organic blueberry plants about 10 months (September 2010) after planting.

chamber. LiCOR 6400 infra-red gas analyzer measurements of photosynthesis and transpiration are widely reported in the literature for various plant species (Hunt, 2003; Flexas *et al.*, 2002). Photosynthetic values were expressed as µmol/CO_2/m^2/s; transpiration values were expressed as mmol H_2O/m^2/s. Bluecrop and Jersey bushes were assayed by measuring a minimum of two leaves per plant and two plants per soil treatment.

Statistical analysis: Data were assessed using SPSS Version 4 software. Group descriptive statistics means and standard error of the means (SEM) were determined with the SPSS program. Potential group statistical differences for growth parameters ($P < 0.05$) were determined with One Way ANOVA and Student-Neuman-Keuls post hoc testing to determine differences between soil treatments and/or cultivars.

Results and discussion

Soil treatments and assays: The blueberry planting plots at Knoll Acres consist of a cherty silt loam on what was originally an eroded slope of about 35%. The surface layer is brown cherty silt loam about 15 cm thick. The subsoil extends about 150 cm or more. Between the depths of 15 to 32 cm it is a brown clay loam; at depths greater than 32 cm, it is yellowish red and red clay. Naturally, this soil is slightly acidic with low organic matter content and low natural fertility. The subsoil has moderate permeability and moderate available water. Surface runoff of water is rapid. About a decade ago, these plot areas were wooded. They were then cleared and used as native pasture prior to their usage as blueberry planting plots.

The organic plots at Knoll Acres are located on a south-east hillside with a 35% drop in elevation. To maximize consistent sun exposure to the blueberry plants, rows were designed to run from north to south, which formed an oblique angle with the primary fall of the hill. Consequently, the potentiality of soil erosion and water runoff following rainstorms were concerns. However, due to the incorporation of large amounts of organic materials from the added mulches, the resultant high porosity of the soil effectively absorbs storm water with little or no runoff in the blueberry rows. Water infiltration rates in all of the organic plots were very high with all values less than one minute (Table 1). Between the blueberry rows (the middles, covered with native grasses) storm water runoff was rapid with little resultant erosion due to the vegetative covering.

Soil respiration measurements (CO_2-C kg/ha/day) varied with time and in comparing the mulch treatments (Table 1). Initial respiration measures (November 2009) in the four organic plots varied from a low of 16.3 in the PS to a high of 24.3 in the SM plot. The average reading across all of the organic plots was 19.7. Typically values ranging from 18-36 are considered to reflect medium soil activity. However, a year later (October, 2010) the values increased three-fold with a low of 34.6 in the PS and a high of 84.8 in the PC plot. The average value (in 2010) across all plots was 59.6, which corresponded to what is considered to be ideal soil activity with adequate organic matter and populations of active microorganisms. Differences in soil mulch mixes result in variations in soil organic matter (SOM) and populations of organisms, which are keys to soil respiration. Mulches with a low carbon to nitrogen (C:N) ratio produce higher CO_2 rates than residues with a high C:N ratio. Increases in SOM improve soil aggregation and porosity and therefore aeration and soil moisture content, factors that enhance CO_2 production rates.

The macro- and micronutrient values determined directly from

Table 1. Soil quality parameters: respiration and water infiltration. Values represent averages of three-four samples per plot

Organic Plot	Test Date	Respiration (CO2-C kg/ha/day)	Water Infiltration (seconds)
Horse Manure	November, 2009	18.5	3.4
	October, 2010	46.7	nd
Sheep Manure	November, 2009	24.3	7.5
	October, 2010	72.4	nd
Pine Straw	November, 2009	16.3	6.0
	October, 2010	34.6	nd
Planters Choice	November, 2009	19.8	13.6
	October, 2010	84.8	nd

Respiration values in 2010 reflect higher metabolic activity than in 2009, although soil temperatures were similar. Rapid water infiltration reflects high porosity of the soil plots. Water infiltration records time for 2.54 cm (1 inch) layer of water to be absorbed by prior wetted soil (nd = not determined) mulch samples (Table 2) reflected very high nutrient values. Using these organic mulches as soil amendments thus positively influenced the available nutrients in the soil plots for the blueberry plants. A negative factor, especially in the sheep manure and Planters choice mulches, was their high pH value (8.6 and 8.7, respectively) which consequently elevated the pH of the mulch amended soil plot far above the desired pH of 5. In contrast, the acidity of the added pine straw mulch (5.5) helped to stabilize the soil pH near the desired level in the PS plot. The high percentage of organic matter in the mulches (Table 2) also positively influenced the organic percentage in the various soil plot raising their organic percentages from an average of 2-3% organic matter to an average greater than 12% organic matter across all the four plots with PS plot showing the lowest percentage and SM plot the highest (data not shown). The percentage of organic material in the soil plots is reflected in parallel relative humus values (Table 3).

Soil assays from the four soil treatment plots contained adequate levels of macronutrients (nitrogen, phosphorus, and potassium) with no significant differences between them (Table 3). The levels of micro and macronutrients in PS plot displayed the most variance in comparison to the other treatments. Except for sulfate levels, PS plot contained consistently lower levels of soil nutrients than other plots. PS plot had a significantly lower amount of calcium (542 ± 127 ppm) while SM plot contained a significantly higher level of calcium (3500 ppm) in comparison to the other plots. PS had a significantly lower amount of magnesium (8 ± 1 ppm) than the other soil plots. SM and PC plots contained statistically higher levels of humus than HM and PS plots. Each treatment contained statistically different pH levels. SM plot had the highest pH level of 5.92 ± 0.23 and PS plot, the lowest (3.87 ±.04). The plot pH trends reflected the contrasting pH values of the incorporated mulches. Sheep manure mulch had a pH of 8.6 and pine straw mulch with a pH of 5.5 (Table 2).

Growth parameters- Comparing soil mulch treatments: PC and PS plot bushes had statistically greater heights (73.4±2.6 cm and 73.4±2.6 cm, respectively) than HM and SM (Table 5). Blueberry bushes in PS plot had the largest average stalk diameters (8.20±1.60 mm) compared to all the other plots.

Table 2. Nutrient composition of mulches

Parameter	Horse manure	Sheep manure	Pine straw	Planters Choice
P (ppm)	528	1101	338	544
K (ppm)	2066	1642	428	1999
Ca (ppm)	1363	2940	1744	1916
Mg (ppm)	418	1077	379	616
Zn (ppm)	5.9	8.3	10.9	11.2
Mn (ppm)	28.6	33.2	67	33.2
Cu (ppm)	0.2	0.1	0.2	0.2
Fe (ppm)	7.7	4.5	8.3	5.5
B (ppm)	1	1.7	0.7	1.6
pH	7.2	8.6	5.5	8.7
Organic Matter (%)	45.2	33.1	34.3	55.1
Est/ CEC (meq/100g)	15.5	27.7	15.3	19.7
Base Sat. (%)	100	100	84.5	100
Ca Sat. (%)	43.8	52.9	56.9	48.4
Mg Sat. (%)	22.1	32	20.4	25.7
K Sat. (%)	34.1	15.1	7.2	25.9

Table 3. Soil nutrients and parameters present in multiple soil samples from each mulch treatment plot

Soil nutrient	Mulch Treatment Plots			
	Horse Manure	Sheep Manure	Pine Straw	Planters Choice
Nitrate N (ppm)	65±7[a]	75±0[a]	48±13[a]	71±4[a]
Phosphorus (ppm)	96±4[a]	100±0[a]	92±8[a]	100±0[a]
Potassium (ppm)	78±10[a]	108±16[a]	-	78±9[a]
Calcium (ppm)	1700±300[b]	3500±0[c]	542±127[a]	1400±0[b]
Magnesium (ppm)	64±10[b]	80±0[b]	8±1[a]	62±12[b]
Sulfate (ppm)	458±173[a]	750±250[a]	1167±167[a]	620±233[a]
Humus	2.1±0.3[a]	4.6±0.2[c]	1.7±0.2[a]	3.3±0.8[b]
pH	4.86±0.14[b]	5.92±0.23[d]	3.87±0.04[a]	5.43±0.23[c]

Values are shown as averages ± SEM. N values range from 3 to 6 and represent different composite soil samples taken during the fall of 2010; each individual soil sample consists of a mix of several soil cores taken from the top 6-7 inches. Differing superscript letters, along the rows, indicate statistically significant mulch group differences when $P < 0.05$ based on One-Way ANOVA with Student-Neuman-Keuls post hoc testing

Table 4. Rates of photosynthesis and transpiration compared between Jersey and Bluecrop cultivars across four treatment plots, horse manure, sheep manure, pine straw, and Planters Choice mulches

Parameter	Cultivar	Horse Manure	Sheep Manure	Pine Straw	Planters Choice	Average
Photosynthesis	Jersey	9.8 ± 1.4	5.6 ± 0.8	13.0 ± 1.9	13.0 ± 5.3	10.3 ± 1.6[a]
μmol $CO_2/m^2/s$	Bluecrop	4.1 ± 0.6	2.5 ± 1.2	5.1 ± 0	4.9 ± 0.4	4.3 ± 0.4[b]
Transpiration	Jersey	2.5 ± 0.1	1.4 ± 0.1	2.4 ± 0.5	3.3 ± 1.3	2.4 ± 0.4[a]
mmol $H_2O/m^2/s$	Bluecrop	1.7 ± 0.6	1.0 ± 0.5	1.7 ± 0.2	1.6 ± 0.1	1.5 ± 0.1[b]

Values shown are group averages ± SEM. Jersey photosynthesizes at higher rates than Bluecrop in all treatments. Jersey bushes, planted in Planters Choice plot, have an overall higher rate of photosynthesis than others.

Table 5. Plant growth parameters for all cultivars compared across soil mulch treatments, 2010

Plant parameter	Soil mulch treatments							
	Horse Manure		Sheep Manure		Pine Straw		Planters Choice	
	N	Mean ± SEM	N	Mean ± SEM	N	Mean ± SEM	N	Mean ± SEM
Plant height (cm)	54	62.5 ± 2.2 (a)	47	56.2 ± 2.8 (a)	23	73.4 ± 2.6 (b)	36	62.5 ± 2.2 (a)
Volume cylinder (cm^3) x1000	54	182 ± 15 (a)	47	125 ± 16 (a)	23	381 ± 37 (c)	36	283 ± 20 (b)
Bushiness	54	385 ± 35 (a)	47	322 ± 33 (a)	23	627 ± 131 (b)	36	1171 ± 140 (c)
Primary stalk diameter (mm)	54	6.73 ± 0.19 (a)	47	6.56 ± 0.23 (a)	23	8.20 ± 1.60 (c)	36	7.50 ± 1.51 (b)

N = number of bushes measured in each soil treatment plot. Expressed values represent averages and standard error of the mean for that group. Differing lower case letters across the columns for a given plan parameter indicate statistically different subsets (P <0.05) based on one-way ANOVA with Student Neuman-Keuls post hoc testing.

Similarly, PS plants had the largest plant cylinder volume (381±37 mm^{3}x 1000) in comparison to all other cultivars. Regarding plant bushiness, PC bushes were significantly higher (1171± 140) than all other cultivars. PS and PC plants were each significantly higher in all parameters in comparison to both HM and SM plants. PS bushes had significantly larger average stalk diameters and plant cylinder volumes, and PC plants were greatest in height and bushiness (Table 5).

Growth parameters- Comparing cultivars: Bush height comparison resulted in Bluecrop having a significantly greater height (77.85±2.6 cm) than other cultivars (Fig. 6). Analyses of primary stalk diameter comparisons indicated that Chandler bushes were significantly thicker (8±0.36 mm) than the other cultivars (Fig. 7). Additionally Bluecrop had significantly larger primary stem diameters than either Duke or Bluegold. Plant vigor in terms of an overall plant bushiness assessment resulted in Chandler (976.38 ± 172.8) being significantly greater than Duke (241.44 ± 26.16) and Bluecrop (459.64 ± 40.16), but comparatively similar to Jersey (690.9±119.4) and Bluegold (799.34 ± 116.64) (Fig. 8). Comparative assay of the mean volume of plant cylinders resulted in Duke (114683 ± 14639 cm^3) being smaller than any of the other cultivars (Fig. 9). These statistical analyses of plant growth parameters resulted in the following ranking from superior to inferior cultivar per organic plot: Chandler, Bluecrop, Jersey, Bluegold, and Duke, respectively. The optimal cultivar was Chandler, which was superior in all, but one parameter. Bluecrop had a significantly larger height.

Photosynthesis and transpiration measurements: Results from a Student Independent T-test indicated that Jersey bushes have overall higher rates of photosynthesis than Bluecrop bushes

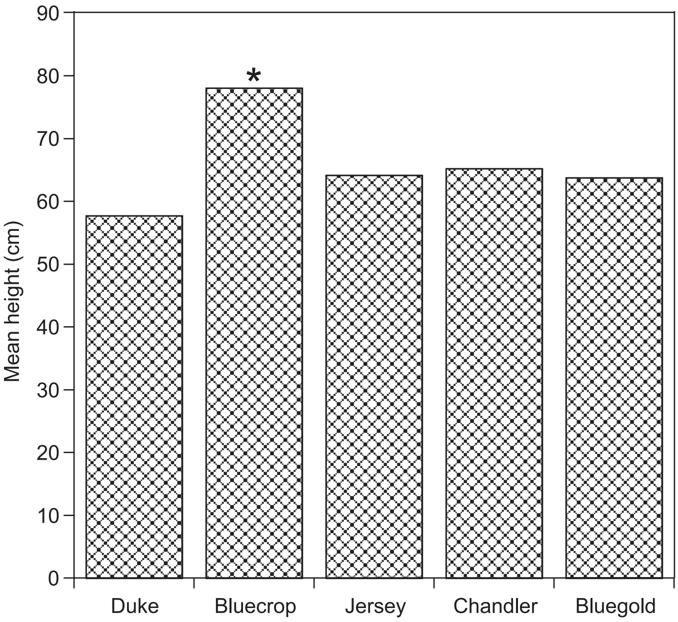

Fig. 6. Bush height comparison across five cultivars. Measurements were taken in the fall of 2010. Asterisk indicates statistically significantly different group ($P < 0.05$). Height is a significant indicator of plant health, suggesting Bluecrop bushes fair the best.

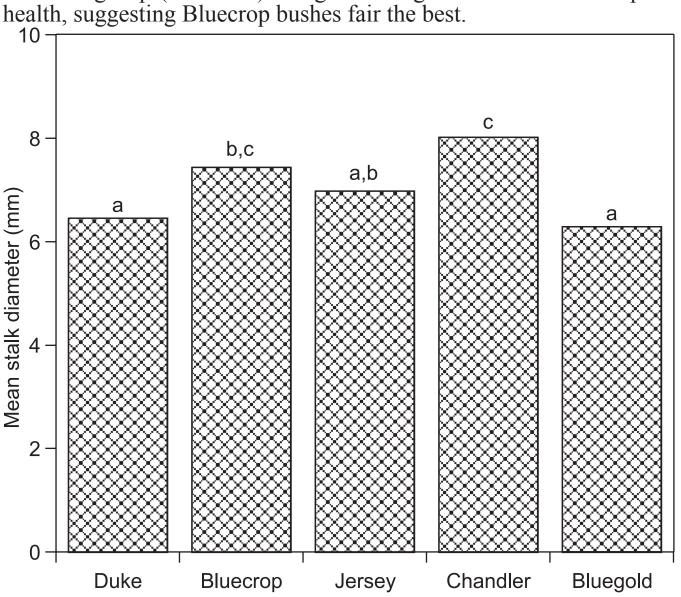

Fig. 7. Mean primary stalk comparison across five cultivars, fall of 2010. Differing lower case letters indicate statistically different subsets ($P < 0.05$). Stalk diameter is a significant indicator of plant hardiness, suggesting Chandler bushes are the hardiest.

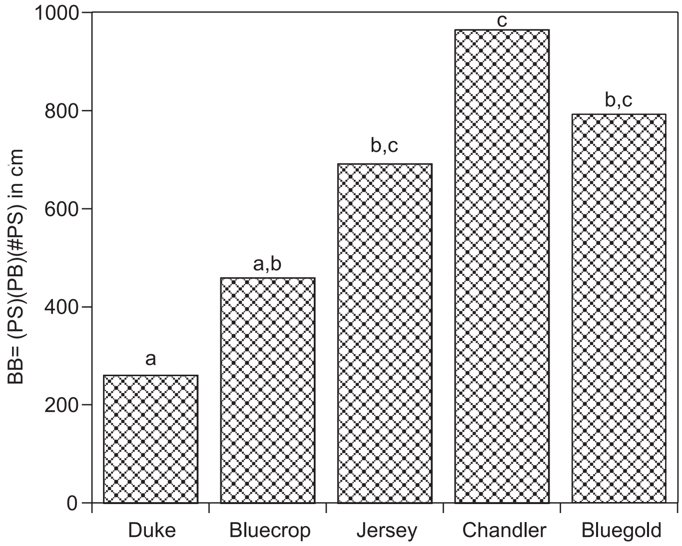

Fig. 8. "Bushiness" comparison across five cultivars, fall of 2010. Measurements were taken in the fall of 2010. Differing lower case letters indicate statistically different subsets ($P < 0.05$). "Bushiness" is a significant indicator of plant health, suggesting Chandler bushes are thriving the best in terms of plant stalk height, number of primary branches, and number of primary stalks.

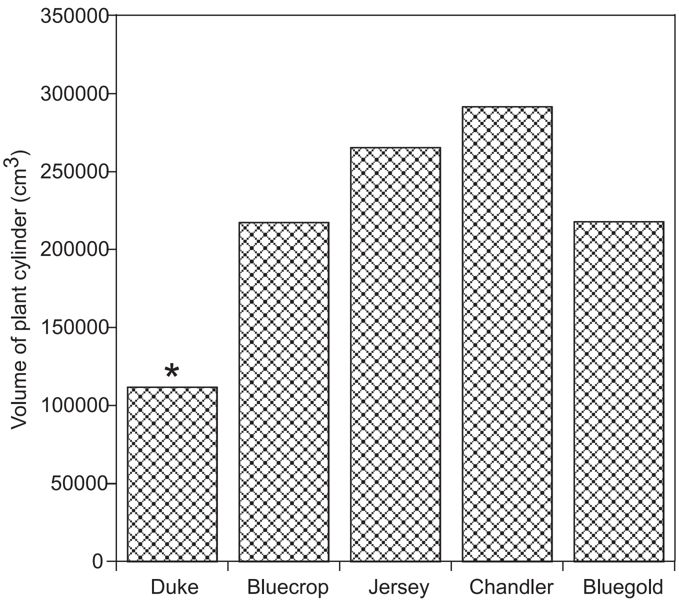

Fig. 9. Average volume of plant cylinder comparison across five cultivars, fall of 2010. Asterisk indicates statistically significantly different group ($P < 0.05$). Since bush volume is a significant indicator of plant vigor, data suggest Chandler bushes thrive better overall.

(See last column in Table 4). There was no significant difference between the soil treatments of each cultivar. Though PS and PC trended toward higher photosynthesis and respiration values than the average (Table 4), these trends were not found to be statistically significant. Thus we cannot definitely say that any one mulch enhances or decreases the photosynthetic or respiration characteristics of a given cultivar. In retrospect, due to reading variations for a given plant, the number of sample readings should have been increased at least 10 fold to be able realistically to determine potential differences due to different soil treatments.

Pine straw and Planters Choice are optimal mulches for highbush blueberries grown in the Shenandoah Valley. Reason, why other mulch treatments were not as beneficial, could be the conditions of the raw components of the horse and sheep manure, causing the bushes planted in the HM and SM plots to respond poorly in all growth parameters as indicated by Table 5. The manure based mulches may have been too raw at time of deposition and therefore promoted the higher levels of nitrate and calcium present in the soil. An excess of nitrate or calcium could have detrimental effects, including growth retardation of blueberry plants. While, the high pH levels in Planters Choice and sheep manure mulches potentially mitigated against optimal growing conditions in the soils of their respective treatment plots, the PC plot contained other elements that apparently enhanced plant growth. Thus while an acidic pH 4.5-5.0 may be more optimal in promoting blueberry growth, other nutritional factors such as increased percentage of organic content or elevated humus levels may alleviate the negative effects of a higher pH (>5.5) and still provide and promote quality growth. Although the soil nutrients for the PS plot were lower than the others, the more acidic pH of that plot (3.87) may have compensated in promoting plant growth with minimal soil nutrient content.

Though PC bushes were determined to be optimal in height and bushiness, cost/benefit consideration should be taken before planting. Planters Choice mulch was locally purchased. Applications of Planters Choice mulch were applied to the PC rows in June 2009 and again in September 2009 at overall purchase cost of $126. In contrast, pine straw was acquired from neighborhood pine trees without charge; the only expense was the hauling and time spent loading the pine needles. Analysis of bushes grown in the PS plot showed that this mulch promotes optimal growing conditions based on both stalk diameter and volume of plant cylinder parameters. Thus pine straw mulch provided the most economic and effective soil treatment to enhance highbush blueberry growth at Knoll Acres.

Results indicate Chandler to be the superior cultivar in all growth parameters except for height. This could be due to the intrinsic characteristics of Chandler highbush blueberries. Chandler bushes have the longest ripening period, largest berries, and harden quickly. Resource allocations to these could explain the growth parameter patterns present, including the shorter overall height in Chandler bushes when compared with Bluecrop.

The measurement of in-field photosynthesis rates indicate that Jersey bushes are photosynthesizing at higher capacities than Bluecrop bushes. This suggests that there could be an intrinsic difference in photosynthetic function across each cultivar. However, Table 4 values indicate that soil treatments play no role in enhancing or decreasing the rate of photosynthesis in each cultivar. A more inclusive study across each cultivar is needed to determine this more fully.

At the time of the initial writing of this report, the planted blueberry bushes had experienced two growing seasons during which flower buds were removed to enable optimal plant growth. No berries were harvested. Our plant growth measures and foliar values (photosynthesis and respiration readings) demonstrated that treatment with horse manure or sheep manure was suboptimal in enhancing plant vigor. In contrast plots treated with pine straw or Planters Choice optimized plant vigor. Based on the first berry harvest which occurred the following summer (data not shown in this paper), harvested berry yields paralleled these reported growth and foliar measures. Per bushberry productivity in the pine straw and Planters Choice plots averaged more than two-fold greater than bushes in the horse manure and sheep manure plots. Thus early growth measures and foliar readings in blueberry bushes can accurately predict future productivity.

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