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Grow Tubes Reduce Root and Crown Growth but Not Early Production during Establishment of Highbush Blueberry

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***Abstract*. Grow tubes are sometimes used in blueberry (*Vaccinium corymbosum* L.) to establish plantings or replace dead plants in older fields. Two experiments were conducted at a commercial farm to evaluate the effect of various grow tubes used during planting establishment of highbush blueberry cultivars. The treatments in the first experiment were cultivar ('Aurora', 'Elliott', 'Liberty') and grow tube treatment (no tube, control; opaque cardboard tube in the first growing season; and opaque plastic tube in the first season or first through the second season). The treatments in the second experiment were cultivar ('Aurora', 'Elliott', 'Liberty', 'Ozarkblue') and grow tube treatment (control; translucent plastic; opaque plastic; and wire mesh tube over plants in the first growing season). The presence of a grow tube from spring to fall of the first growing season decreased crown dry weight (DW) by an average of 37% to 50% and root DW by 30% (all except translucent plastic in Expt. 2) and increased the aboveground:belowground DW ratio relative to the control by an average of 34% to 67%, depending on the experiment. Plants grown in tubes were taller, had a narrower canopy, and had fewer whips, likely a response to low light levels inside the tubes; the fewest whips were found in the opaque plastic or cardboard tubes and the most in the translucent plastic tube with an intermediate response in the wire mesh tube. Removal of grow tubes during the summer led to plant damage from sudden sun exposure. The opaque grow tubes (present in Year 1) reduced yield/plant in Year 2 for 'Elliott' and 'Liberty' (cardboard tube only) but not 'Aurora'. Pruning plants to allow for limited early fruit production (≈0.6 kg/plant) in Year 2 did not reduce yield in Year 3 (≈2.7 kg/plant). Whereas grow tubes reduced root and crown growth in the first season, there appeared to be no longer-term adverse effect on aboveground plant growth or yield.**

Highbush blueberry (*Vaccinium* sp.) area in the United States increased from 22,932 ha in 2005 to 37,816 ha in 2012 (U.S. Highbush Blueberry Council, unpublished data), an average planting rate of 2125 ha/year. Northern highbush blueberries are long-lived perennial plants, requiring 7 years or more to reach full production. The cash costs to establish new plantings, through Year 6, can surpass $30,165/ha for conventional blueberry in Oregon (Julian et al., 2011).

Blueberry plantings are often established on raised beds (Strik, 2007) to help prevent saturated soils, reduce compaction, improve internal drainage (Magdoff and Van Es, 2000), and reduce disease problems such as *Phytophthora* root rot (Bryla and Linderman, 2007). Organic mulches are commonly used in blueberry to help control weeds (Burkhard et al., 2009; Krewer et al., 2009; Larco et al., 2013; Sciarappa et al., 2008), improve blueberry plant growth and yield (Clark and Moore, 1991; Karp et al., 2006; Kozinski, 2006; Krewer et al., 2009), root distribution through the soil profile (Spiers, 2000), and whip and shoot production (Kozinski, 2006; White, 2006).

Weed management is critical for economic production in blueberry (Pritts and Hancock, 1992; Strik et al., 1993). Pre-emergent and contact herbicides are commonly used in conventional production systems, but growers must use extreme caution when using contact herbicides during the blueberry plant-growing season to avoid crop damage.

Blueberry growers, historically, were encouraged to prune off all fruit buds to prevent fruit production in the first and second growing seasons to improve plant growth in the establishment years (Strik et al., 1993). Early cropping or allowing plants to produce fruit in the first 2 years was shown to reduce crown and root growth and fruit production in Year 3 relative to uncropped plants (Strik and Buller, 2005). However, growers experience an increased rate of return when vigorous plants are pruned to produce a limited commercial crop in Year 2 (Julian et al., 2011). Cultural practices that improve plant growth during the establishment year may lead to greater early fruit production and economic returns in blueberry.

Grow tubes (commonly called "tree shelters" in forestry) have been used successfully to improve the establishment of grape (*Vitis* sp.), walnut (*Juglans regia* L.), olive (*Olea europaea* L.), and landscape or forest trees (Burger et al., 1996; Famiani et al., 2007; Hall and Mahaffee, 2001; Kjelgren et al., 1997; Laliberté et al., 2008; Potter, 1988; Tuley, 1983). Grow tubes were originally developed and used in Great Britain to protect young trees from animal browsing; the use of grow tubes in commercial crop plants also offers this advantage in addition to protecting young plants from drift when contact herbicides are used to control weeds. Grow tubes have been shown to improve tree height (Bergez and Dupraz, 2000; Hammatt, 1998; Kjelgren et al., 1997; Oliet and Jacobs, 2007; Sharpe et al., 1999) and reduce suckering or branch growth (Burger et al., 1992; Hammatt, 1998), which may offer advantages in faster tree or vine establishment and a reduction in pruning costs in the establishment years. Whereas suckering is a disadvantage when establishing grapevines or many trees, an important part of establishing good blueberry bush architecture is new whip growth from the base of the plant. Root growth has been reduced in some plants when they are established with tubes, often at the expense of aboveground growth (Burger et al., 1992; Coutand et al., 2008; Famiani et al., 2007; Mayhead and Boothman, 1997; Sharpe et al., 1999; Svihra et al., 1996). Trees established with grow tubes required staking to prevent wind damage after the tubes were removed (Burger et al., 1992; Kjelgren et al., 1997).

Blueberry growers in some production regions in the western United States began using grow tubes to protect plants from mechanical or herbicide damage and from wind in the establishment year. Translucent and opaque grow tubes, commonly used by growers, differ in their effect on microclimate and temperature at the soil–mulch interface within the tube (Tarara et al., 2013). The low shortwave transmissivity of grow tubes reduced blueberry growth within the

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tube, but growth increased once plants grew above the tube height (Tarara et al., 2014).

The objective of the present study was to evaluate the effects of using various types of grow tubes in the establishment year(s) on plant (top and root) growth and early production of northern highbush blueberry cultivars.

Materials and Methods

Study site. The experiments were conducted in new plantings at a large commercial blueberry farm located near Salem, OR (lat. 45°00′ N, long. 122°56’ W). The soil at the site is mapped as a Woodburn silt loam (fine-silty mixed superactive mesic Aquultic Argixeroll). The plantings for each experiment were managed similarly, per standard commercial practice (Strik et al., 1993), unless otherwise indicated below. Douglas fir (*Pseudotsuga menziesii* M.) sawdust (91% of particles less than 4 mm) amendment was incorporated (approximate depth of 9 cm and 1.2 m wide, centered on the row) into the top 0.15 to 0.25 m of soil before forming raised beds (≈0.3 m high) using a bed shaper. Rows were spaced 3.0 m apart. Standard, 18-month-old container stock (3.8 L), with two to four whips per plant, was purchased from a commercial nursery and transplanted into the field at an in-row spacing of 0.76 m (4300 plants/ha) in either Oct. 2004 (Expt. 1) or Oct. 2005 (Expt. 2). After planting, the grower applied douglas fir sawdust mulch at a depth of ≈5 to 8 cm. A permanent grass cover crop (fine fescue, cultivar unknown) was grown between rows and mowed during the growing season as required. Plants were irrigated using two lines of polyethylene drip tubing (Netafim, Fresno, CA) with 1.9 $L \cdot h^{-1}$ in-line pressure-compensating emitters spaced at 0.45-m intervals. The tubing was located along the row near the base of the plants, one per side, under the mulch. Plants were irrigated daily in three 10-min sets from approximately June to September, unless scheduling required adjustment based on grower sampling of soil water content (using a soil probe).

To maximize vegetative growth during the establishment year, plants were pruned by the grower to remove all fruit buds at planting (Strik and Buller, 2005). There was thus no fruit production in the first growing season (2005 in Expt. 1 and 2006 in Expt. 2). The effect of early cropping (fruit production in the second growing season) on plant yield in the third year was evaluated in Expt. 1. Pest management and fertilization were per standard commercial practice (DeFrancesco et al., 2013; Hart et al., 2006) with all treatment plots managed identically.

Expt. 1. The study was conducted in a commercial field planted during early Oct. 2004. Treatments were arranged as a split-split plot design with four replicates and included rows of three cultivars (‘Aurora’, ‘Elliott’, ‘Liberty’) as main plots, five grow tube treatments [no tube (control); cardboard tube on for one growing season; and opaque, plastic tube on for varying times from the first through the second growing seasons; Table 1] as subplots and early cropping (with or without fruit production in the second growing season) as sub-subplots. Each sub-subplot consisted of 12 plants. The white, waxed, cardboard tubes (Vine Protector; Pacific Western Container, Santa Ana, CA) were 61 cm high and 11 cm in diameter. The beige opaque, plastic tubes (Wilson Orchard and Vineyard Supply, Yakima, WA) were 51 cm high and 20 cm in diameter. Tubes were placed over the newly established plants on 9 Mar. 2005 with the bottom edge of each tube pushed into the bed to form a lower boundary seal per standard commercial practice. Tubes were held in place by two vertical bamboo stakes. Tubes present for the first growing season only were removed on 3 Oct. 2005. Tubes that remained on through the next winter or the second growing season were removed on 21 Mar. and 7 Oct. 2006, respectively (Table 1).

Three tube treatments (control, CB1GS, PL1GS; Table 1) were evaluated for their impact on plant growth on 22 June 2005. Tubes were removed and data collected on plant height, total shoot number and length, and total whip number and length. Removing the tubes during the summer led to significant plant damage (predominantly leaf burning from sudden sun exposure on tube plants) and thus the grower requested we only evaluate the growth on two of the four replicates. On 13 Feb. 2006, two plants per plot were randomly selected in each of three treatments (control, CB1GS, PL1GS; Table 1) and excavated from the soil with a shovel to obtain as much of the root system as possible. Soil was removed from the root system using a high-pressure hose and tap water. Plants were separated into roots, crown, 1-year-old shoot growth (originating from 2-year-old wood), and 1-year-old whip growth (arising from older wood). The number of whips/plant and fruit buds/plant were counted. Plant parts were placed in labeled paper bags and dried to a constant weight (≈3 d) at 60 °C using a dryer oven (Fisher Scientific Isotemp oven Model 655F, Montreal, Quebec, Canada). Total plant DW and the aboveground:belowground DW ratio [(aboveground DW)/(root DW + crown DW)] were calculated.

During Winter 2005–06, plants in the early cropped treatment were pruned by the commercial grower to balance plant vigor with potential yield. Plants in the “no early cropping” treatment were pruned to remove all fruit buds (no fruit production in 2006, the second growing season). During 2006, fruit in the early cropped treatments (three cultivars and all five tube treatments; Table 1) were hand-harvested weekly from July through August, depending on the cultivar, and total yield/plot recorded.

During Winter 2006–07, all plants were pruned by the commercial grower. On 22 Jan. 2007, after pruning, one plant/plot in each of three tube (control, PL1GS, PL2GS) and two early cropping treatments for each cultivar was cut to ground height and top growth separated into whips, 1-year-old growth, and older wood. The number of fruit buds/plant was counted. Plant parts were placed in labeled paper bags and dried to a constant weight as described previously. Total aboveground plant DW was calculated. During Summer 2007, total yield per plot was determined for all cultivar, tube, and early cropping treatments.

Analysis of all treatment effects on plant growth and allocation of DW was done as a complete factorial for a split-plot design (for DW and growth data collected on 22 June 2005 and 13 Feb. 2006 and yield in 2006) and for a split-split plot design (analysis of treatment effects including early cropping on 22 Jan. 2007 and yield in 2007) using the PROC MIXED procedure in SAS software package Version 9.3 (SAS Institute, Cary, NC). Data were tested for homogeneity of variance with no transformation required. Means were separated at the 0.05 level using Tukey’s honestly significant difference (HSD) test.

Table 1. Grow tube treatments in northern highbush blueberry cultivars during establishment for Expt. 1 from 2005 to 2006 and Expt. 2, 2006.

		Dates tube present		
Tube type	Treatment name [abbreviation]	9 Mar. to 3 Oct. 2005	4 Oct. 2005 to 21 Mar. 2006	22 Mar. to 7 Oct. 2006
Expt. 1 (plants established Oct. 2004)				
No tube	Control	—	—	—
Cardboard	Cardboard (1 growing season) [CB1GS]	Present	—	—
Opaque plastic	Plastic (1 growing season) [PL1GS]	Present	—	—
Opaque plastic	Plastic (1 growing season + winter) [PL1GSW]	Present	Present	—
Opaque plastic	Plastic (2 growing seasons) [PL2GS]	Present	Present	Present
Expt. 2 (plants established Oct. 2005)		10 Apr. To 20 Oct. 2006	—	—
No tube	Control	—	—	—
Opaque plastic	Opaque	Present	—	—
Translucent plastic	Translucent	Present	—	—
Wire tube	Wire	Present	—	—

Expt. 2. The study was conducted at the same commercial farm as Expt. 1 in an adjacent field planted during early Oct. 2005. Treatments were arranged as a split plot design with four replicates and included rows of three cultivars (‘Aurora’, ‘Liberty’, ‘Ozarkblue’) as main plots and four grow tube treatments [no tube (control); translucent, white, plastic tube; beige, opaque, plastic tube; and a wire mesh tube; Table 1] as subplots. Each subplot consisted of 10 plants and treatment plots were separated by an 11-plant buffer. The white, translucent plastic (Blehyl Farm Service, Grandview, WA) and the beige opaque, plastic (Wilson Orchard and Vineyard Supply, Yakima, WA) tubes were 51 cm high and 20 cm in diameter and were the same tube types as those described by Tarara et al. (2013). Wire “mesh” tubes were constructed using heavy gauge wire with “mesh” dimensions of ≈3 cm × 6 cm; mesh tubes were constructed to the same height and diameter of plastic tubes with an objective of constricting plants to the same tube area but offering less restriction to light or modification of temperature relative to plastic tubes (Fig. 1). The number of wire mesh tubes was limited in supply allowing for destructive analysis only on the 20 Oct. 2006 sample date. Tubes were placed over the newly established plants on 10 Apr. 2006 with the bottom edge of each tube pushed into the bed to form a lower boundary seal per standard commercial practice. Tubes were held in place by two vertical bamboo stakes and were present for the first growing season and removed on 20 Oct. 2006.

The apparent transmissivity (400- to 700-nm waveband) of the tubes at 25 cm aboveground was 65% (translucent) and 35% (opaque) of ambient in midsummer; transmissivity of the tubes was reduced later in the season to the nominal transmissivity of the materials as a result of a lower sun angle and the plant canopy obscuring the top of the tube (Tarara et al., 2013).

Three tube treatments (control, opaque, and translucent) were evaluated for their impact on plant growth on 25 July 2006. Two plants per plot were randomly selected and excavated from the soil with a shovel to obtain as much of the root system as possible. Soil was removed from the root system using a high-pressure hose and tap water. Plants were separated into roots, crown, 1-year-old shoots, whips, and leaves. Leaves were stored at 2 °C for less than 7 d before measurement of total leaf area per plant (LI-3100 leaf area meter; LI-COR, Lincoln, NE). Plant parts were placed in labeled paper bags and dried to a constant weight (≈3 d) at 60 °C using a dryer oven (Fisher Scientific Isotemp oven Model 655F). Total plant DW, proportion of total plant DW allocated to each plant part, and the aboveground:belowground DW ratio were calculated [(aboveground DW, not including leaves)/(root DW + crown DW)].

On 20 Oct. 2006, two plants per plot were randomly selected in all treatments and the grow tubes (if present) removed. Plant height, plant canopy area (calculated from the diameter measured parallel and perpendicular to the row), the number of fruit buds/plant, number of whips/plant, and average whip diameter were measured. Whips were counted if they were 10 cm long or greater and if they were located from the crown base to 10 cm high on the bush (originating from older wood). The plants were then excavated from the soil with a shovel and separated into plant parts and data collected as described previously.

Analysis of all treatment effects on plant growth and allocation of dry weight was done as a complete factorial for a split-plot design using the PROC MIXED procedure in SAS software package Version 9.3. Data were tested for homogeneity of variance with no transformation required. Means were separated at 0.05 level using Tukey’s HSD test.

Results

Expt 1. In Spring 2005, the first growing season, cultivars differed in aboveground growth. ‘Elliott’ produced more shoot growth than ‘Aurora’ or ‘Liberty’, whereas ‘Aurora’ produced more whips/plant than ‘Liberty’ or ‘Elliott’ (Table 2). Plants grown with cardboard or opaque tubes for 105 d (9 Mar. to 22 June) were taller for ‘Aurora’ and ‘Liberty’, but only those grown with cardboard tubes were taller for ‘Elliott’. Although plants grown with plastic tubes produced longer shoots and whips, there was no effect of cardboard tubes on these variables compared with control plants. Both tubes reduced the number of whips/plant (Table 2).

The presence of grow tubes in the first growing season (9 Mar. to 3 Oct. 2005) affected root and crown DW and aboveground:belowground DW ratio, but not the DW of 1-year-old wood on 13 Feb. 2006 (Table 3). Cultivars differed in the DW of 1-year-old wood and tended to differ (P = 0.0584) in the aboveground:belowground DW ratio. There was an interaction of grow tube × cultivar on root and crown DW (Table 3) and total plant DW (data not shown).

The presence of grow tubes in Year 1 reduced the root and crown DW of plants by an average of 30% and 50%, respectively, compared with control plants (Table 3). Tube type did not affect root or crown DW in ‘Aurora’ or ‘Elliott’, whereas ‘Liberty’ plants grown with plastic tubes produced a greater root and crown DW than those with cardboard tubes in the first growing season (Table 3; Fig. 2). ‘Liberty’ plants produced more shoot growth (1-year-wood DW) in the first growing season than ‘Elliott’ or ‘Aurora’ plants, but there was no effect of grow tubes on aboveground growth. Total plant DW was greatest for control plants (244 g) than tubed plants (197 g) in all cultivars (data not shown). Plants grown with plastic grow tubes had a greater plant DW than with cardboard tubes in ‘Aurora’ and ‘Liberty’, but there was no effect of tube type in ‘Elliott’ (data not shown). ‘Aurora’ tended (P = 0.0584) to have a lower aboveground:belowground DW ratio (0.8) than ‘Elliott’ or ‘Liberty’ (0.9). Establishing plants with tubes in Year 1 increased the aboveground:belowground DW ratio by 67% compared with control plants (Table 3). There was no treatment effect on the number of fruit buds, which averaged 63 per plant (data not shown).

All tube treatments were compared for their effect on yield of early cropped plants in the second growing season (2006). There was no difference in yield between plants that had the opaque plastic grow tube on in the first through second growing seasons (PL1GS,

Fig. 1. ‘Liberty’ plants on 20 Oct. 2006 just before plant removal. Translucent, plastic grow tube on left; wire mesh tube on right.

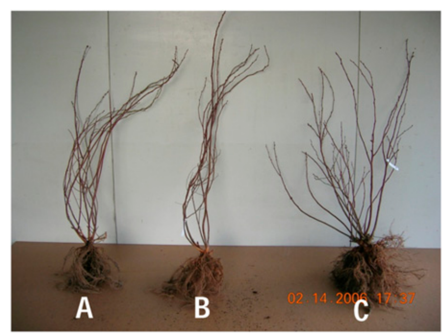

Fig. 2. ‘Liberty’ plants dug on 13 Feb. 2006. Plants had an opaque plastic (**A**), cardboard (**B**), or no grow tube (**C**; control) during the first growing season (9 Mar. to 3 Oct. 2005).

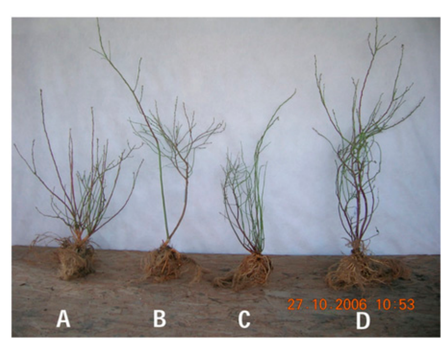

Fig. 3. ‘Aurora’ plants dug on 20 Oct. 2006. Plants had no grow tube (**A**; control), an opaque plastic tube (**B**), a translucent, plastic tube (**C**), or a wire mesh tube (**D**) during the first growing season (10 Apr. to 20 Oct. 2006).

PL1GSW, and PL2GS) and thus only the results for PL1GS are shown in Table 3, the most common treatment used by growers. There was a lot of variability among plants for yield as is typical in commercial fields pruned by large commercial crews. There was no significant effect of cultivar on yield/plant although the mean yield of 'Aurora', 'Elliott', and 'Liberty' averaged 0.29, 0.66, and 0.92 kg/plant, respectively (Table 3). The presence of a cardboard grow tube in the first growing season decreased yield by 42% and 58% the next year in 'Elliott' and 'Liberty', respectively, compared with control plants. In 'Liberty', plants with plastic grow tubes had a yield similar to control plants and greater than those with cardboard tubes, whereas there was no difference among tube types in 'Elliott'. In 'Aurora', there was no effect of grow tube treatment on yield.

On 22 Jan. 2007, cultivars differed in the DW of whips, 1-year-old laterals, older wood, and total aboveground biomass (Table 4). There was no significant difference between the types of grow tubes present during the first growing season (Table 1) on plant biomass, fruit buds/plant, or yield; only data for PL1GS, PL2GS, and the control are thus shown in Table 4 for simplicity.

By the end of Year 2, plants grown with plastic tubes in the first growing season (PL1GS) produced a similar above-ground growth to control plants except for a lower DW of 1-year-old laterals and older wood in 'Elliott' and greater older wood DW on PL1GS tubed plants in 'Liberty' (Table 4). Leaving plastic grow tubes on for two growing seasons (PL2GS) increased the DW of 1-year-old laterals in 'Aurora' and 'Liberty' and older wood DW in all cultivars but reduced whip DW and fruit bud number in all cultivars compared with the control (Table 4). Allowing plants to produce an early crop in 2006 did reduce fruit bud number/plant the next winter (22 Jan. 2007; Table 4) but this had no measurable effect on yield in Year 3, which averaged 2.7 kg/plant and was similar among cultivars and grow tube treatments (data not shown).

Expt 2. In summer of the first growing season (July 2006) when grow tubes had been in place for 106 d, plants growing in opaque tubes had greater shoot but less whip DW than those in translucent tubes or without a grow tube (Table 5); however, there was no measurable effect of grow tube on root, crown, leaf, or total plant DW. 'Ozarkblue' plants had produced less whip and leaf DW than 'Liberty' and 'Aurora' and less leaf area than 'Aurora' (Table 5).

The presence of a plastic or wire mesh grow tube in the first growing season (Table 1) increased plant height in October relative to the control plants (Table 6). Tubes also decreased bush area, particularly in 'Liberty' (Fig. 1), which produced a larger canopy than 'Ozarkblue' or 'Aurora'. 'Ozarkblue' produced the fewest whips/plant, and all cultivars responded similarly to the presence of tubes during the growing season with the most whips/plant produced in control plants or those growing in a translucent tube and the fewest with an opaque tube. Plants growing in a wire mesh tube produced an intermediate number of whips/plant relative to control plants and those growing in an opaque tube. There was no treatment effect on whip diameter (data not shown). The number of fruit buds/plant was unaffected by cultivar, but there was a cultivar × tube interaction because plants grown with a plastic grow tube produced fewer fruit buds than control plants for 'Liberty' and 'Aurora', but there was no effect of tube treatment on flower bud number in 'Ozarkblue'. 'Liberty' and 'Aurora' plants growing in a wire mesh tube produced a similar number of fruit buds as control plants (Table 6).

There was a significant main effect of tube treatment and cultivar on the DW of all plant parts in Oct. 2006, except for 2-year-old wood (Table 7). The presence of a tube during the first growing season decreased root and crown DW by an average of 30% and 37%, respectively, relative to control plants. Translucent tubes reduced crown DW but not root DW relative to the control (Table 7; Fig. 3). Plants grown with an opaque tube produced less 1-year-old wood, whip, leaf, and total plant DW than control plants or those grown with a translucent tube. Plants growing in the wire mesh tube tended to have an intermediate DW of the crown and aboveground plant parts to those grown with a translucent or opaque tube. Tubed plants averaged 34% greater aboveground: belowground DW ratio than the control plants (Table 7).

Table 2. The effect of grow tube treatment on plant growth on 22 June 2005 for three highbush blueberry cultivars planted in Oct. 2004 (n = 2).

	Plant ht (cm)					
Treatment	Aurora	Elliott	Liberty	Total shoot length (cm)	Whips (no./plant)	Avg. whip length (cm)
Cultivar						
Aurora	—	—	—	284.3 b	2.9 a	—
Elliott	—	—	—	541.9 a	2.0 b	—
Liberty	—	—	—	258.1 b	0.5 c	—
Grow tube						
Control (no tube)	38.5 b	64.5 b	53.5 b	319.8 b	3.1 a	20.8 b
Cardboard (CB1GS)	69.0 a	96.0 a	83.5 a	314.5 b	1.8 b	29.0 b
Opaque (PL1GS)	67.5 a	79.0 b	77.5 a	392.8 a	1.5 b	50.4 a
Significance						
Cultivar		<0.0001		<0.0001	<0.0001	NS
Tube		<0.0001		0.0189	0.0194	0.0315
Cultivar × tube		0.02		NS	NS	NS

[z]Means followed by the same letter within a column were not significantly different at the 0.05 level.
NS = nonsignificant.

Table 3. The effect of grow tube treatment on plant dry weight (DW; 13 Feb. 2006) and yield (Summer 2006) for three highbush blueberry cultivars planted in Oct. 2004 (n = 4).

	Root DW (g)			Crown DW (g)			One-yr-wood DW (g)			Aboveground:	Yield (kg/plant)		
Treatment	Aurora	Elliott	Liberty	Aurora	Elliott	Liberty	Aurora	Elliott	Liberty	belowground[z]	Aurora	Elliott	Liberty
Grow tube							84.0 c	102.1 b	119.3 a				
Control (no tube)	102.8 a[y]	105.0 a	126.3 a	45.8 a	35.5 a	61.3 a	—	—	—	0.6 b	0.29 a	0.89 a	1.28 a
Cardboard (CB1GS)	70.0 b	79.3 b	74.3 c	19.0 b	20.0 b	20.5 c	—	—	—	1.0 a	0.21 a	0.52 b	0.54 b
Opaque (PL1GS)	75.3 b	84.3 b	84.5 b	24.5 b	23.3 b	35.3 b	—	—	—	1.0 a	0.30 a	0.58 b	1.03 a
Significance													
Cultivar		NS			0.0128			0.0049		NS		NS	
Tube		<0.0001			<0.0001			NS		<0.0001		0.0002	
Cultivar × tube		0.0285			0.0438			NS		NS		0.0464	

[z]Aboveground:belowground DW ratio = [(aboveground DW]/(root + crown) DW].
[y]Means followed by the same letter within a column were not significantly different at the 0.05 level.
NS = nonsignificant.

‘Liberty’ plants had the greatest root and crown DW and ‘Ozarkblue’ the least (Table 7). ‘Aurora’ and ‘Ozarkblue’ produced a similar 1-year-old wood, leaf, and total plant DW, significantly less than that measured for ‘Liberty’ plants. ‘Ozarkblue’ plants had the greatest aboveground:belowground DW ratio and ‘Aurora’ the least.

Discussion

The presence of an opaque plastic (Expts. 1 and 2) or cardboard (Expt. 1) grow tube from spring to fall of the first growing season decreased aboveground (shoot and leaf DW) and belowground (root and crown DW) growth of blueberry plants in all the cultivars studied. All of the grow tubes studied (including the wire mesh) increased the aboveground to belowground DW ratio, in contrast to what was observed by Tarara et al. (2014) in blueberry but confirming what has been noted in many tree species (Coutand et al., 2008; Famiani et al., 2007; Mayhead and Boothman, 1997; Sharpe et al., 1999).

Plants grown in tubes were taller and had a narrower canopy (cross-sectional area) by the end of the first growing season. As a result, the plants probably would not have been self-supporting had there not been a trellis present as has been noted in other crops (Burger et al., 1992; Kjelgren et al., 1997). A reduction in wind-induced plant movement is thought to be at least partly responsible for decreased trunk diameter in trees that are established in grow tubes (Kjelgren et al., 1997). Cherry trees (*Prunus avium* L.) grown in grow tubes had reduced root biomass, and intentionally bending plants increased dry weight allocation to roots (Coutand et al., 2008). Although the reduction in root dry weight in our study may have been a result of the added sink (or reduced source) of shoots growing inside the low light tubes in the early season, wind movement of plants, reduced when grow tubes are used, has been found to increase root growth (Coutand et al., 2008). In our study, wire mesh tubes, which likely had less impact on canopy temperature and light exposure than the plastic tubes, also reduced root dry weight compared with control plants.

Light saturation levels for blueberry are reported to range from 600 to 900 $\mu mol\cdot m^{-2}\cdot s^{-1}$, depending on cultivar (Kim et al., 2011; Moon et al., 1987; Rho et al., 2012). Plants, when growing within the plastic and cardboard tubes, would be expected to have reduced photosynthesis as a result of low light levels and high temperatures relative to ambient (Munnell, 2003; Tarara et al., 2013). The opaque and translucent tubes greatly reduced light with an average transmissivity (400 to 700 nm) of less than 1% and 21%, respectively (Tarara et al., 2013). The effect of the waxed cardboard grow tube on microclimate was not measured at this site; however, the diameter of this tube was ≈50% that of the opaque plastic tube and light would thus have been further reduced from ambient from the expected low transmissivity of the tube wall (Munnell, 2003) and constriction of the canopy inside the tube.

The average daily maximum temperature recorded in translucent and opaque plastic

Table 4. The effect of grow tube treatment on plant growth (22 Jan. 2007) and yield (Summer 2007) for three highbush blueberry cultivars planted in Oct. 2004 (n = 4).

Treatment	Fruit buds (no./plant)	Dry wt (g)									
		Whips	1-year-old laterals			Older wood			Total aboveground		
Cultivar											
Aurora	—	146.6 b[y]		—			—			—	
Elliott	—	137.8 b		—			—			—	
Liberty	—	346.9 a		—			—			—	
Grow tube			Aurora	Elliott	Liberty	Aurora	Elliott	Liberty	Aurora	Elliott	Liberty
Control (no tube)	1052 a	249.8 a	75.1 b	196.4 a	143.6 b	58.3 b	146.9 b	164.0 b	312.9 b	511.6 a	709.3 a
Opaque (PL1GS)	936 b	210.8 ab	64.5 b	118.6 b	167.8 b	111.3 ab	116.0 c	247.4 a	303.3 b	392.5 b	762.0 a
Opaque (PL2GS)	830 b	170.8 b	126.5 a	175.5 a	207.1 a	158.5 a	211.5 a	235.9 a	417.8 a	474.3 ab	735.3 a
Early cropping[z]											
No	985	—		—			—				
Yes	894	—		—			—				
Significance											
Cultivar	NS	0.0001		0.015			0.0038			0.0014	
Tube	0.0006	0.0057		0.001			<0.0001			NS	
Early cropping (EC)	0.039	NS		NS			NS			NS	
Cultivar × EC; tube × EC	NS	NS		NS			NS			NS	
Cultivar × EC × tube	NS	NS		NS			NS			NS	
Cultivar × tube	NS	NS		0.0234			0.0212			0.0294	

[z]Early cropping; “no” = plant pruned to remove all fruit buds and prevent fruit production in Year 2 (2006); “yes” plants pruned to allow for limited fruit production in Year 2.
[y]Means followed by the same letter within a column were not significantly different at the 0.05 level.
NS = nonsignificant.

Table 5. The effect of grow tube treatment on plant growth on 25 July 2006 for three highbush blueberry cultivars planted in Oct. 2005 (n = 2).

Treatment	Dry wt (g)						
	Root	Crown	Current shoots	Whips	Leaves	Total plant	Leaf area (cm^2)
Cultivar							
Liberty	22.9	10.0	5.6	5.3 a[z]	22.2 b	80.5	1814 ab
Ozarkblue	20.1	7.2	6.2	1.2 b	16.6 c	65.8	1369 b
Aurora	16.4	10.0	6.8	5.0 a	30.1 a	83.2	2259 a
Grow tube							
Control (no tube)	18.9	10.5	5.3 b	4.9 a	26.1	80.1	1922
Translucent	22.6	9.1	4.8 b	5.1 a	21.5	76.4	1919
Opaque	17.9	7.6	8.5 a	1.5 b	21.3	73.0	1603
Significance							
Cultivar	NS	NS	NS	0.0210	0.0047	NS	0.0188
Tube	NS	NS	0.0403	0.0192	NS	NS	NS
Cultivar × tube	NS	NS	NS	NS	NS	NS	NS

[z]Means followed by the same letter within a column were not significantly different at the 0.05 level.
NS = nonsignificant.

Table 6. The effect of grow tube treatment on plant growth on 20 Oct. 2006 for three highbush blueberry cultivars planted in Oct. 2005 (n = 4).

Treatment	Plant ht (m)	Plant area (m^2)			Fruit buds (no./plant)			Whips (no./plant)[z]
Cultivar								
Liberty	1.23 a[y]		0.37 a			—		10.3 a
Ozarkblue	0.95 b		0.21 b			—		5.1 b
Aurora	0.92 b		0.25 b			—		8.6 a
Grow tube:		Liberty	Ozarkblue	Aurora	Liberty	Ozarkblue	Aurora	
Control (no tube)	0.86 c	0.64 a	0.36 a	0.34 a	133 a	152 a	169 ab	11.8 a
Translucent	1.16 a	0.34 b	0.19 b	0.23 c	87 b	124 a	110 c	10.5 ab
Opaque	1.11 ab	0.31 c	0.20 b	0.27 b	97 bc	140 a	129 c	2.5 c
Wire mesh	1.02 b	0.20 d	0.08 c	0.15 d	127 ac	127 a	136 bc	7.2 b
Significance								
Cultivar	0.0001		0.0023			NS		0.0049
Tube	0.0001		0.0001			0.0001		0.0002
Cultivar × tube	NS		0.0109			0.0581		NS

[z]Whips were included if they were greater than 10 cm long and originated from the base of the crown to a height of 10 cm.
[y]Means followed by the same letter within a column were not significantly different at the 0.05 level.
NS = nonsignificant.

Table 7. The effect of grow tube treatment on plant biomass (dry weight) allocation on 20 Oct. 2006 for three highbush blueberry cultivars planted in Oct. 2005 (n = 4).

Treatment	Dry wt (g) Roots	Crown	1-year-old[z]	Leaf	Total plant[y]	Aboveground:belowground[x]
Cultivar						
Liberty	38.3 a[w]	50.2 a	98.2 a	103.8 a	214.1 a	1.45 b
Ozarkblue	19.4 c	22.5 c	49.8 b	80.8 b	120.9 b	2.03 a
Aurora	29.3 b	38.2 b	49.8 b	89.8 b	140.8 b	1.14 c
Grow tube						
Control (no tube)	37.4 a	50.9 a	76.8 ab	106.8 a	191.3 a	1.23 b
Translucent	29.8 ab	39.0 b	85.8 a	96.3 ab	175.8 ab	1.68 a
Opaque	24.3 b	27.4 c	43.6 c	75.2 c	129.5 c	1.61 a
Wire mesh	24.5 b	30.5 bc	57.4 bc	87.7 bc	137.9 bc	1.64 a
Significance						
Cultivar	0.0156	0.0029	0.0002	0.0029	0.0012	0.0083
Tube	0.0059	0.0003	0.0007	0.0018	0.0108	0.0195
Cultivar × tube	NS	NS	NS	NS	NS	NS

[z]One-year-old shoot and whips (growth in 2005).
[y]Total plant dry weight (DW), not including leaves.
[x]Aboveground:belowground DW ratio = [(aboveground DW, not including leaves)/(root + crown) DW].
[w]Means followed by the same letter within a column were not significantly different at the 0.05 level.
NS = nonsignificant.

tubes was 44 and 40 °C, respectively, compared with 34 °C for ambient at the same site (Tarara et al., 2013). In 'Bluecrop' and 'Elliott', photosynthesis was reduced by 24% to 27% when air temperature increased from 20 to 30 °C (Hancock et al., 1992). In our study, available light was likely thus too low and air temperature too high for maximum photosynthesis for a significant portion of the time plants were within the tubes. Photosynthesis may also have been reduced if CO_2 levels were high in the tubes as has been reported by others (Dupraz and Bergez, 1999). Reduced light or shade has also been shown to decrease shoot number and increase shoot length in blueberry (Kim et al., 2011; Lobos et al., 2013; Yáñez et al., 2009). Shade has also reduced shoot number or budbreak in other crops (e.g., Bell et al., 1995; Perez and Kliewer, 1990).

Once shoots grew out of the tubes, they were exposed to ambient conditions. However, the narrow tube constricted growth sufficiently such that the shoots were trained to grow more upright than in control plants. Tree saplings have been reported to grow more strongly toward vertical once growing above a dark tube (Collet et al., 2011). In our study, the shoots remaining inside the dark or low light grow tube would likely have been a sink, depleting reserves in the crown and roots. Later in the season, blueberry plants export carbohydrates, from photosynthesis, to the crown and roots and carbohydrate and nitrogen reserves in the roots, crown, and older canes are important for early-season growth (Bañados et al., 2012; Maust et al., 2000).

The presence of tubes decreased whip production in all cultivars. This may predominantly be a light response because the fewest whips were found in the opaque plastic or cardboard tubes. However, temperature of the crown may also affect whip production. Black landscape fabric mulch reduced whips/plant relative to sawdust mulch, likely as a result of increased soil temperature and possibly canopy temperature in the former (Larco et al., 2013). Although the relationship between crown temperature and whip production is not known in blueberry, light exposure to the crown has been found to increase primocane number in blackberry (Strik et al., 2012; Swartz et al., 1984). In our study, light exposure to the crown likely had the most effect on whip number because there was relatively little effect of the grow tube on temperature of the soil or at the soil–mulch interface (Tarara et al., 2013). Still, it is difficult to separate radiation from temperature effects because these microclimatic variables are coupled (Tarara et al., 2014).

The effect of grow tube on flower buds/plant was inconsistent with no effect in 'Aurora', 'Liberty', or 'Elliott' in Expt. 1 but a reduction of flower buds/plant observed in 'Aurora' and 'Liberty' grown with plastic tubes in Expt. 2. The more prostrate growth of the control plants may have increased flower bud development because vigorously growing upright shoots produce fewer flower buds than slower growing, more horizontal shoots (Strik, personal observation). However, flower bud development was reduced inside the plastic grow tubes because of low light conditions (Tarara et al., 2014). Canopy shading caused by constriction inside the wire mesh tube produced flower bud numbers that were intermediate to those found in the control and plastic grow tubes.

The opaque plastic and cardboard grow tubes, when present during the establishment year, reduced yield/plant of 'Elliott' and 'Liberty' (cardboard tube only) the second growing season, but there was no such effect in 'Aurora'. Considering the grower pruned these plants after the tubes had been removed, treatment results may have been confounded because plants grown with a tube had a different canopy architecture than control plants and may have been pruned differently as a result. Plants that had a plastic grow tube on for two growing seasons (PL2GS; Table 1) still had reduced whip growth, likely as a result of shading of the plant base but had greater 1-year-old shoot dry weight in 'Aurora' and 'Liberty'. These cultivars benefit greatly from trellising in commercial fields and the presence of the grow tube may have promoted more upright, vigorous top growth in these cultivars. Although the greater shoot growth may have increased flower bud number, especially in the PL2GS treatment, this did not correspond to higher yield. There was thus no economic advantage to retaining grow tubes for more than one growing season.

Pruning plants to allow for early fruit production in the second growing season ("early cropping") did reduce flower bud number the next winter, as expected (Strik and Buller, 2005). However, early cropping did not reduce yield in the third growing season. Yield in the second growing season averaged 0.6 kg/plant (2.7 $t \cdot ha^{-1}$), less than the yield/plant reported by Strik and Buller (2005) on unpruned plants. The grower pruned all treatment plants well to limit yield to the recommended level for plants in their second growing season (Julian et al., 2011). However, yield in the third growing season averaged 2.8 kg/plant or 12.0 $t \cdot ha^{-1}$, considered high for a planting of that age (Julian et al., 2011). The relatively "light" pruning by the grower would likely have masked any treatment effects expected from early cropping or grow tubes. In this region, whereas the 18-month old nursery plants used in our study are an industry standard and are commonly pruned at the end of the first year in the field to allow for limited fruit production in Year 2, results may differ with nursery plant age or when grown in other production regions.

When plastic or cardboard grow tubes were removed during the growing season (June 2005 in Expt. 1; July 2006 in Expt. 2), plants within the tubes were observed to have thin, light green (non-woody) growth, some etiolated leaves at the plant base, and already had fewer whips and longer shoots than control plants. The shoots and leaves, when suddenly exposed to the sun, burned and plant growth was subsequently impaired. Clearly, if grow tubes are used, they should remain on the plants for the entire growing season to prevent plant damage as has been noted in cherry (Bergez and Dupraz, 1997). Later growth, into the fall, may be promoted by the presence of grow tubes increasing the risk of subsequent winter cold injury (Bratsch et al., 2003; Kjelgren et al., 1997); tubes should thus be removed in the fall in colder production regions. In our study, there was no growth or yield advantage or disadvantage to retaining tubes through the first winter. Cardboard tubes were not sufficiently sturdy to withstand fall rains and thus only lasted the one growing season.

Conclusions

Use of grow tubes during the establishment year reduced root DW by 30%, crown DW by 37% to 50%, and increased the aboveground to belowground ratio by 34% to 67% relative to control plants. Although plants were only dug up to assess root and crown growth after the first growing season, there appeared to be no adverse effect of grow tube use on aboveground plant growth and yield. After using 18-month-old transplants in the spring of Year 1, early fruit production in Year 2, when limited to ≈0.6 kg/plant at the planting density used in this study, had no negative impact on production in Year 3. Although grow tubes did not offer a yield advantage, the management benefits may outweigh the costs of using tubes, particularly on windy sites. Grow tubes have been documented to facilitate planting management during establishment through reduction of browsing from vertebrate pests, facilitating spot application of contact herbicides through minimizing risk of blueberry plant damage from herbicide drift and reducing damage from wind. Translucent, plastic grow tubes are recommended when choosing a shelter, because this type of tube had the least negative impact on root, crown, and whip growth.

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