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Root Distribution of 'Brightwell' and 'Premier' Rabbiteye Blueberries as Influenced by Pecan Shell Mulch

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Abstract

Pecan (*Carya illinoinensis* [Wangenh.] K. Koch) shell waste lacks effectual, economic disposal. If shells could be repurposed as mulch, then growers may be able to treat shell byproduct as a resource. In 2016, root distribution and growth of 'Brightwell' and 'Premier' rabbiteye blueberries (*Vaccinium virgatum* Aiton syn. *V. ashei* Reade) was examined using the Horhizotron™. Each Horhizotron™ had four wedge-shaped quadrants filled with 10 cm of an amended 80% pine bark and 20% sand (by volume) substrate, then 7.6 cm of "fresh" pecan shells (FPS), "aged" pecan shells (APS), pine bark nuggets (PB), or an unamended 80% pine bark and 20% sand substrate (PBS). Growth was determined weekly by measuring the horizontal root length (HRL) and root depth (RD) of the five longest roots on either side of a quadrant. Roots that grew into the substrate and mulch treatment layers were not measured separately. 'Premier' HRL showed roots in FPS grew a shorter distance across the quadrant profile than roots in PBS, but had similar HRL with APS and PB. In 'Brightwell', both shell treatments had shorter HRL across the quadrant than the roots in PB and PBS. RD measurements for 'Premier' showed roots generally initiated at the same depth for FPS, APS and PB, though the roots in PBS had shallower growth than the roots in PB and FPS. 'Brightwell' RD showed roots initiated more into the upper portions of the quadrant profile in APS and PBS than in FPS or PB. Root system architecture was reflected in root dry weight (RDW). For both cultivars, substrate layer RDW was similar across all treatments, but mulch layer RDW varied. Though APS had a higher mulch layer RDW than the PB treatment in 'Premier', differences in RDW within the mulch layer did not impact total root dry weight (mulch layer RDW + substrate layer RDW). In 'Brightwell', APS had a higher RDW than FPS and PB, though PBS was similar to both APS and FPS. Unlike 'Premier', total RDW in 'Brightwell' was impacted by differences in mulch layer RDW, as the quadrants that contained FPS and PB had a lower total root dry weight than the quadrants containing APS and PBS. These results indicated that root growth in pecan shells, as compared with root growth within and below pine bark, was not hindered.

The success of a blueberry planting is linked to site physical, chemical, and meteorological conditions. Though rabbiteye blueberries sometimes prosper in nutrient-poor mineral soils throughout the southeastern United States, they are best grown in sands and loams high in organic matter (Braswell et al., 2015). Compared with taproot systems, plant species with fibrous roots are often considered less problematic to transplant; however, this generalization has exceptions. For example, while the native ericaceous species mountain laurel (*Kalmia latifolia* L.) produces a fibrous root system, it periodically does not survive transplanting into the landscape (Wright et al., 2004a). Similarly, transplant survival of ericaceous members of the *Vaccinium* genus, such as the blueberry, can also be challenging.

Generally, transplant growth is most commonly limited by water stress (Price et al., 2011). By nature, blueberries possess a fibrous, shallow root system devoid of root hairs (Eck, 1988), which may predispose

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them to water stress (Lyrene, 1997). Thus, the establishment of a healthy root system in mineral soils with depleted organic matter is critical for the survival of newly set blueberry transplants. The root system of the highbush blueberry was described as predominantly composed of fine roots that were concentrated at a 12–25 cm depth within the drip line (Gough, 1980). While the rabbiteye blueberry's root system penetrated more easily and deeply into the soil profile than the highbush blueberry (Himelrick et al., 2002), the rabbiteye blueberry root distribution is nonetheless shallow with roots rarely growing deeper than 40 cm into the soil profile (Patten et al., 1988; Spiers, 1998). Most roots develop within the top 20–30 cm in the soil, of which approximately 90% were located within the blueberry canopy's dripline (Gough, 1980; Sánchez and Demchak, 2003).

Results of several studies support the use of organic materials in blueberry production. Pine bark, peat, and sawdust were commonly used as soil amendments in conventional highbush blueberry culture (Burkhard et al., 2009). Such amendments promoted uniform root development (Spiers, 1986), and enhanced soil aeration and water-holding capacity (Haynes and Swift, 1986). In addition to organic soil amendments, thickly applied organic surface mulches (7–12 cm) after planting are commonly used, as they are ideal for regulating soil temperature (Burkhard et al., 2009; Spiers, 1995) and moisture extremes (Spiers, 1986). Mulches also improved blueberry transplant root development (Hicklenton et al., 2000), a key factor in transplant success.

Rapid initiation of new roots (Wright et al., 2004a) and resistance to water stress (Hicklenton et al., 2000) were critical factors in transplanting success. Yet, despite the influence of root growth on plant survival, data on root growth and root system architecture are often not collected because most methods are time consuming, destructive, or expensive (Wright and Wright, 2004b). Temperature, shoot growth, and seasonality influenced root growth in raspberry plants (*Rubrus idaeus* L.) (Atkinson, 1973) and plum (*Prunus salicina* Lindl.) (Bhar et al., 1970); however, studies focused on the nature of bush fruit root systems were scarce. This is particularly true for the cultivated blueberry. While it is known that the blueberry root system is shallow and fibrous (Austin, 1982; Braswell et al., 2015; Himelrick et al., 2002; Spiers, 1995), and many studies showed that blueberries benefit from surface mulch (Burkhard et al., 2009; Clark and Moore, 1991; Fonsah et al., 2008; Julian et al., 2012; NeSmith, 2003); few studies have investigated blueberry root system architecture within and below alternatives to the industry mulching standards, such as bark and sawdust.

When plants are transplanted into the landscape, uninterrupted plant growth depends on the formation of new roots outside of the original root ball (Wright et al., 2004a). Observation and measurement of roots as they grow is useful in determining root growth preferences, as is studying the location and depth of root formation (Jackson et al., 2005). Thus, understanding root system growth and architecture are important factors that influence transplant survival and production success (Wright and Wright, 2004a). Several instruments were used in the past to study root growth, including the rhizotron (Bohm, 1979; Huck and Taylor, 1982), portable rhizotron (Pan et al., 1998), and the rhizobox (Wenzel et al., 2001); however, these instruments are relatively expensive and limited in their ability to provide information. Other methods of measuring root growth were generally restricted to observation via subjective visual rating scales or by dry weight analysis, with both methods being destructive (Jackson et al., 2005).

The Horhizotron^{TM}, a horizontal root growth measurement instrument developed cooperatively between Auburn University and Virginia Tech, is newer and relatively inexpensive. Wright and Wright (2004b) reported that all materials used in the design were available at building supply stores, and the cost was less than $50.00 per unit. A key factor that makes the Horhizotron™ desirable is that it provides a simple, non-destructive means of measuring root growth under a variety of rhizosphere conditions. Unlike other container-type rhizotrons where roots are not visible until they reach the edge of the container, the Horhizotron™ is constructed of glass, which allows observation of the rate and direction of root growth into the surrounding landscape (Wright and Wright, 2004b). The design also allows the effect of multiple substrates to be evaluated on an individual plant simultaneously.

Pine bark is one of the most commonly used mulches and substrate amendments in the horticulture industry; however, concern regarding cost, supply, and consistency has motivated the search for suitable alternatives in crop production (Jackson et al., 2005; Lu et al., 2006). Amongst the potential organic mulch alternatives to pine bark is pecan shell waste. In 2015, the United States produced approximately 115 million kg of pecans (National Agricultural Statistics Service, 2016). Of that total production, 17% (19 million kg) was sold in-shell, while the remaining 83% (96 million kg) was sold shelled (National Agricultural Statistics Service, 2016). Of the 83% of production that was shelled prior to retail, 41% (39 million kg) was nutmeat and 59% (57 million kg) was shell waste. Most pecan production is located in the southern United States. Georgia has been the leading pecan producing state for the past 3 years, and was also a leading producer of blueberries (National Agricultural Statistics Service, 2016).

Ideal mulches are sourced from materials that are abundant, self-sustaining, and efficient in weed suppression. This category includes commercial standards like pine bark, but it may also encompass new, innovative materials. Because shell waste is a natural byproduct of the commercial pecan industry, the supply is annually renewed. Shell waste may be used in the horticulture industry either as a mulch or container substrate component. While phytotoxic substances and inadequate available water in shell-based substrates were suspected of stunting the growth of tomato plants (*Lycopersicon esultentum* Mill. ‘Rutgers’) (Wang and Pokorny, 1989), pecan shells as a mulch under peach trees (*Prunus persica* L. ‘Loring’) provided acceptable weed suppression (Stafne et al., 2009). The objective of this research was to investigate the effects of pecan shell mulch on rabbiteye blueberry root system architecture compared to pine bark using the Horhizotron™.

Materials and Methods

The Horhizotron™ is a non-destructive root measurement instrument that allows a container-grown plant to be fitted within four quadrants around a container plant’s original root ball (Wright and Wright, 2004b). The Horhizotrons™ used in this research had four quadrants constructed from two 3.2 mm thick glass panes (20.3 × 26.7 cm) that were held together on the top and bottom with vinyl j-channels, and sealed with waterproof caulk (Wright and Wright, 2004b).

Figure 1. Horhizotron™ has four wedge-shaped quadrants that extend out from the root ball. Quadrants are constructed of glass panes connected by vinyl j-channels. The aluminum base onto which the glass panes are attached is fastened to a treated wood frame.

Figure 2. To exclude light and protect the root system from temperature extremes, exterior walls were constructed from foam insulation board and placed around each Horhizotron™.

Each Horhizotron™ had an aluminum base (0.6 m × 0.6 m × 0.3 cm) that was attached to a wooden frame (5.1 × 5.1 cm) constructed from treated lumber. An overhead view of the Horhizotron™ (Fig. 1) depicts the four quadrants extending outward from the original root ball in a star-like configuration. Drainage holes were made where the root ball sat, and within each quadrant to ensure proper drainage.

To exclude light and protect the root system from temperature extremes, exterior walls were placed around each Horhizotron™ (Fig. 2). The walls were made of foam insulation board 1.9 cm with an aluminum foil exterior and plastic interior (Wright and Wright, 2004b). Walls were assembled into one unit by connecting them with top and bottom j-channels, and then fastened into place by fitting them into a 2.5 cm rim around the perimeter of the aluminum base. Upper lids for each Horhizotron™ were made from two sections of foam insulation board (Fig. 3) with a portion cut out to expose the substrate surface immediately around the plant stem, which allowed for easy removal of the lids.

The experiment was arranged in a randomized complete block design. Each Horhizotron™ represented an individual block, and there were six blocks per cultivar. The rabbiteye blueberry cultivars 'Brightwell' and 'Premier' were evaluated because they are two widely grown cultivars in Alabama and the southeastern United States. Two different ages of pecan shells were evaluated: fresh pecan shells that were less than one-year-old (2015 harvest season) and aged pecan shells that were over one-year-old (2014 harvest season) (Whaley Pecan Company Inc., Troy, AL). The shells were milled, finely textured, and mostly free of residual nut meat. The shells were stored outdoors in uncovered piles. Pine bark mini-nuggets (West Fraser Mills, Opelika, AL) were also selected for a standard cultural practice. There were four treatments randomly distributed among each Horhizotron™ unit's four quadrants. The

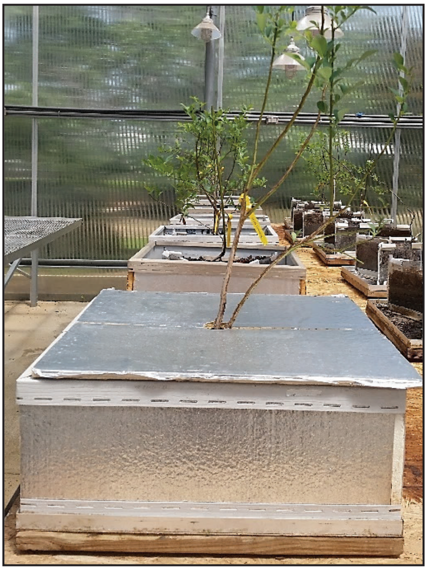

Figure 3. Upper lids for each Horhizotron™ were made from foam insulation board with a portion cut out around the plant stem.

treatments consisted of the three mulches: "fresh" pecan shells (FPS), "aged" pecan shells (APS), and pine bark mini-nuggets (PB). An unamended 80% pine bark and 20% sand (by volume) (PBS) substrate treatment was included with the purpose of adding a "no mulch" treatment.

On 26 Apr. 2016, six mature 11.4 L container plants each of 'Brightwell' and 'Premier' rabbiteye blueberry were removed from their containers and placed into the center of separate Horhizotrons™ (volume of each Horhizotron was 3.7 L) on a greenhouse bench at the Paterson Greenhouse Complex at Auburn University, Auburn, AL. Roots had established throughout the plant's original container profile and touched the edge of the substrate-container interface, but were not circling. When placed into Horhizotrons™, root balls of all plants were undisturbed and positioned snugly against the inner point of each wedge-shaped quadrant composed of two glass panes (20.3 × 26.67 cm) (Wright and Wright, 2004b).

Each of the four quadrants surrounding the root ball were then filled with 10 cm of an 80% pine bark and 20% sand substrate (by volume) amended per 0.76 cubic meter with 2.3 kg of Peafowl® 25N-1.76P-6.64K (Piedmont Fertilizer Company, Inc., Opelika, AL) and 0.7 kg Micromax® (Scotts Co., Marysville, Ohio). No lime was added to the substrate to maintain the acidic soil conditions required by *V. virgatum*. Once each of the four quadrants was filled with the appropriate amount of substrate, each quadrant was gently hand-watered to allow for substrate settling. The remaining space in the Horhizotron™ quadrants was then filled with 7.6 cm of one of the randomly assigned four treatments.

Though the technique used to apply the mulch treatments left the plants at-grade in the Horhizotrons™, layering the treatments on top of the substrate was intended to simulate the modified above-soil grade mulching practice used in conventional commercial blueberry operations, wherein the root ball is fully in the soil profile, and the organic mulch layer is applied above-grade. The unamended PBS substrate (no mulch) treatment was intended to represent traditional at-grade planting without an organic mulch layer. After planting, each plant's root ball and quadrants were hand-watered as needed with tap water to keep roots moist.

Measuring shoot growth was unnecessary due to the design of the Horhizotron™ (each individual plant grew in all four mulch treatments simultaneously); however, initial size indices of plant canopies ([height + widest width + width perpendicular to widest width]/3) were measured to document a baseline for plant size (Price et al., 2009). To measure total length, rather than new length, as roots grew out of the original root ball and along the glass panes of each quadrant profile, the horizontal root lengths (parallel to the base of the Horhizotron™) of the five longest roots visible along each glass pane of a quadrant were measured weekly. A transparent 1 cm × 1 cm grid was placed on the surface of the glass panes to assist with observation and measurement of the five longest roots on either side of a quadrant. Horizontal root length (HRL) measurements represented lateral root penetration into the substrate and mulch treatments after transplanting (Price et al., 2009). The same five roots used for the HRL measurements were used for root depth (RD) measurements, which represented root penetration vertical to the base of the Horhizotron™ and was also documented using the transparent grid. Roots growing into the substrate layer and the mulch treatment layer were not measured separately.

HRL measurements of 'Brightwell' and 'Premier' began 45 days after transplanting (DAP), and were repeated weekly thereafter until roots in one substrate reached the end of the Horhizotron™ quadrant (26 cm). When HRL measurements ceased for 'Brightwell' on 5 Aug. 2016 (101 DAP) and 'Premier' on 12 Aug. 2016 (108 DAP), final size indices of the canopies were measured, which was determined by measuring plant height from the crown to the top of the main shoot, and by taking cross sectional diameters parallel and perpendicular to the row ([height + widest width + width perpendicular to widest width]/3). Plants of 'Brightwell' were removed from Horhizotrons™ for root harvest on 7 Sept. 2016 (132 DAP) and 'Premier' on 12 Sept. 2016 (137 DAP).

Roots in each quadrant were cut from the original root ball where the substrate and treatment met the root ball. To observe the difference in root growth within the mulch treatments versus the substrate portions of the quadrants, roots that grew in the mulch layers were separated from the roots that grew in the substrate layers. Roots from the substrate and mulch layers were then separately washed and dried for 48 h at 66 °C, and weighed to determine root dry weight (RDW) in substrate and mulch treatment portions separately.

An analysis of variance was performed on all response variables using PROC GLIMMIX in SAS version 9.4 (SAS Institute, Cary, NC). Blueberry cultivars were analyzed as separate experiments. Root length and depth were analyzed as a randomized complete blocks design with repeated measures on dates, and root number as sub-samples. Blocks and the Horhizotron™ face were random variables in the model. Least squares means comparisons among mulches were determined using the simulate adjustment in the LSMEANS STATEMENT. Linear, quadratic, or cubic trends over dates were determined using qualitative-quantitative model regressions. All significances were at $\alpha = 0.05$ unless otherwise indicated.

Results and Discussion

As observed in a previous study using the

Table 1. Effect of mulch type on horizontal root length (HRL[z]) of *Vaccinium virgatum* 'Premier' and 'Brightwell' growing in Horhizotron™ in a greenhouse in Auburn AL.

	Premier HRL[z] (mm)										
Treatment[y]	45[x]	52	59	66	73	80	87	94	101	108	Sign.[v]
FPS	19.9 ns[w]	40.1 b	65.6 b	88.3 b	109.7 ab	120.2 b	141.0 b	154.5 b	170.2 b	185.2 b	Q***
APS	36.7	62.9 ab	84.7 ab	104.8 ab	127.9 ab	146.1 a	155.2 ab	175.4 ab	193.8 ab	209.0 ab	Q***
PB	26.2	57.6 ab	69.1 b	91.9 ab	108.2 b	124.5 ab	143.4 b	158.5 b	177.7 b	192.7 ab	Q**
PBS	43.7	65.1 a	97.3 a	114.6 a	132.2 a	156.3 a	176.1 a	190.3 a	207.7 a	213.8 a	Q***
	Brightwell HRL[z] (mm)										
Treatment[y]	45[x]	52	59	66	73	80	87	94	101		Sign.[v]
FPS	35.1 b[w]	73.4 ns	98.1 ns	119.4 ns	136.2 ns	151.8 b	163.0 c	172.1 c	181.5 b		Q***
APS	50.3 ab	75.4	99.1	118.1	138.9	158.7 b	175.2 abc	181.7 bc	194.4 b		Q***
PB	40.9 b	64.7	97.0	121.5	150.7	167.0 ab	182.6 ab	196.6 ab	212.9 a		Q***
PBS	63.1 a	78.3	97.4	122.1	151.6	177.1 a	190.0 a	208.7 a	218.6 a		C***

[z] HRL = root length measured parallel to the ground.

[y] Treatments were 7.6 cm of fresh pecan shells (FPS), aged pecan shells (APS), pine bark (PB), or unamended 80% pine bark and 20% sand (by volume) substrate applied on top of 10 cm of amended 80% pine bark and 20% sand (by volume) substrate in Horhizotron™ quadrants.

[x] Days after planting (DAP) in Horhizotron™ (Wright and Wright, 2004).

[w] LSmeans within columns and cultivars followed by common letters do not differ at the 5% level of significance, by the simulate adjustment.

[v] The mulch treatment by DAP interaction was significant. HRL was analyzed with repeated measures on 7 day intervals that began 45 DAP for both cultivars and concluded at 108 DAP for Premier and 101 DAP for Brightwell. Significant quadratic (Q) or cubic (C) trends using regression models at $\alpha = 0.01$ (**), and 0.001 (***).

Table 2. Effect of mulch type on root depth (RD[z]) measured from the surface of the soil profile of *Vaccinium virgatum* 'Premier' and 'Brightwell' growing in Horhizotrons™ in a greenhouse in Auburn AL.

	Premier RD[z] (mm)										
Treatment[y]	45[x]	52	59	66	73	80	87	94	101	108	Sign.[v]
FPS	59.3 ns[w]	90.7 ns	103.8 ab	114.0 ab	122.2 a	111.5 ab	113.3 ab	113.8 ab	122.0 ab	127.0 ab	C***
APS	69.2	93.8	110.3 a	116.0 ab	103.5 bc	102.3 abc	110.7 ab	106.8 b	105.8 b	110.2 abc	C***
PB	62.5	88.0	106.2 ab	117.5 a	119.8 ab	119.0 a	126.5 a	129.5 a	130.7 a	127.7 a	C**
PBS	65.0	81.7	85.3 c	84.0 c	87.0 c	93.0 c	99.0 b	104.7 b	105.0 b	100.2 c	Q*

	Brightwell RD[z] (mm)									
Treatment[y]	45[x]	52	59	66	73	80	87	94	101	Sign.[v]
FPS	87.6 ns[w]	115.2 a	116.0 a	118.8 ab	122.8 a	123.4 a	125.2 ab	123.4 c	122.6 b	C*
APS	94.0	104.4 ab	110.8 a	104.2 bc	99.4 b	104.2 b	110.8 b	116.0 ab	116.8 ab	C*
PB	90.4	99.8 bc	119.0 a	122.8 a	130.0 a	125.0 a	126.2 a	131.0 a	138.4 a	C***
PBS	83.4	92.4 c	93.2 b	100.4 c	95.2 b	92.6 c	96.2 c	106.4 bc	115.0 b	C***

[z] RD = root length measured perpendicular to the ground.
[y] Treatments were 7.6 cm of fresh pecan shells (FPS), aged pecan shells (APS), pine bark (PB), or unamended 80% pine bark and 20% sand (by volume) substrate applied on top of 10 cm of amended 80% pine bark and 20% sand (by volume) substrate in Horhizotron™ quadrants.
[x] Days after planting (DAP) in Horhizotron™ (Wright and Wright, 2004).
[w] LSmeans within columns and cultivars followed by common letters do not differ at the 5% level of significance, by the simulate adjustment.
[v] The mulch treatment by DAP interaction was significant. RD was analyzed with repeated measures on 7 day intervals that began 45 DAP for both cultivars and concluded at 108 DAP for Premier and 101 DAP for Brightwell. Significant quadratic (Q) or cubic

Horhizotron™, small spaces between the substrate and glass panes at the end of each quadrant air-pruned roots as they grew into them, ceasing growth at that point (Wright et al., 2007). For both cultivars, roots generally initiated further away from the original root ball towards the quadrant profile's end (26 cm) in the PBS and pine bark treatments (Table 1). This trend supported previous observations where roots may have proliferated into a smaller portion of the quadrant profile in those treatments (Wright et al., 2007). RDW was also greatest in the mulch layer for pine bark and aged shells. When compared with aged pecan shells, pine bark had a lower mulch layer RDW for both cultivars (Fig. 4, Fig. 5).

Roots of 'Brightwell' grew more deeply in quadrants with pine bark and fresh pecan shells, whereas the quadrants that contained aged pecan shell mulch and PBS had a shallower RD (Table 2). RD in 'Premier' began to separate between treatments at 66 DAP. By 73 DAP, trends in RD between each treatment were distinctive, and root growth was maintained at those respective depths for the remainder of the study. For 'Brightwell', RD differentiated between treatments by 52 DAP. Treatments remained at those respective depths throughout the remainder of the experiment; however, the RD trend observed with 'Premier' was more pronounced in 'Brightwell.'

RDW in the substrate layer was similar across all treatments, regardless of cultivar. This pattern of root distribution supports previous findings (Haynes and Swift, 1986; Hicklenton et al., 2000) where well-drained substrates composed of organic (bark) and inorganic (sand) materials effectively promoted blueberry root growth. Conversely, root growth within the mulch layer varied. In general, the differences observed between mulch layer RDW for 'Premier' were not pronounced. Pine bark mulch had a lower RDW than the other treatments (Fig. 4). While differences in root distribution amongst the mulch layers based on RDW for 'Premier' was quantifiable, those differences did not impact total RDW, which, like the substrate root layer, was similar across all treatments (Fig. 4). 'Premier' plants were uniform in size throughout the experiment, with an average initial growth index of 48 cm, and final growth index of 110 cm (data not shown).

Consequently, the main difference between cultivars was the variances in root distribution within the mulch layer. Treatment differences between mulch layer RDW were more pronounced for 'Brightwell' than for 'Premier'. Mulch layer RDW for 'Brightwell' was distinctively higher in aged pecan shells than in the fresh pecan shells and pine bark (Fig. 5). While mulch layer RDW did not influence total RDW for 'Premier' those differences did impact total RDW for 'Brightwell.' The same trends for RD and mulch layer RDW for 'Brightwell' were reflected in total RDW. Quadrants containing aged pecan shell mulch and PBS had a higher total RDW than quadrants with fresh pecan shell and pine bark mulches (Fig. 5). 'Bright-

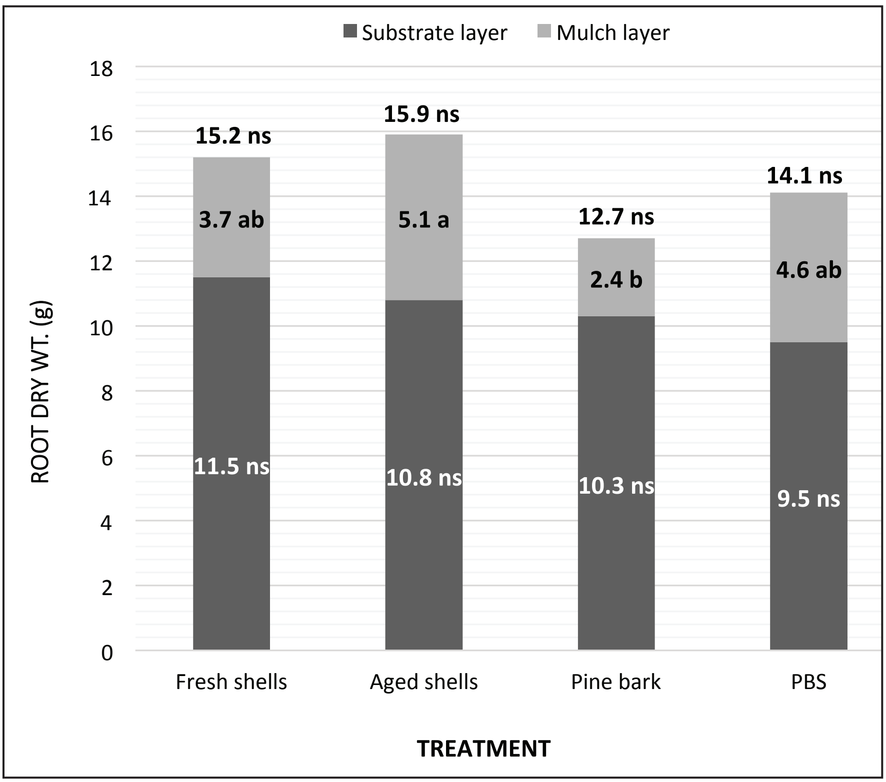

Figure 4. Root dry weight (RDW) of *Vaccinium virgatum* 'Premier'. Roots were divided into mulch (fresh shells, aged shells, pine bark, and unamended 80% pine bark and 20% sand substrate [PBS]) and substrate layers, then washed separately to determine mulch layer RDW and substrate layer RDW. Total RDW = mulch layer RDW + substrate layer RDW. Least squares means comparisons among mulch treatments and substrate layers using the Shaffer-simulated method at $\alpha = 0.05$. ns = not significant. All plants were grown in Horhizotrons™ in a greenhouse in Auburn, AL.

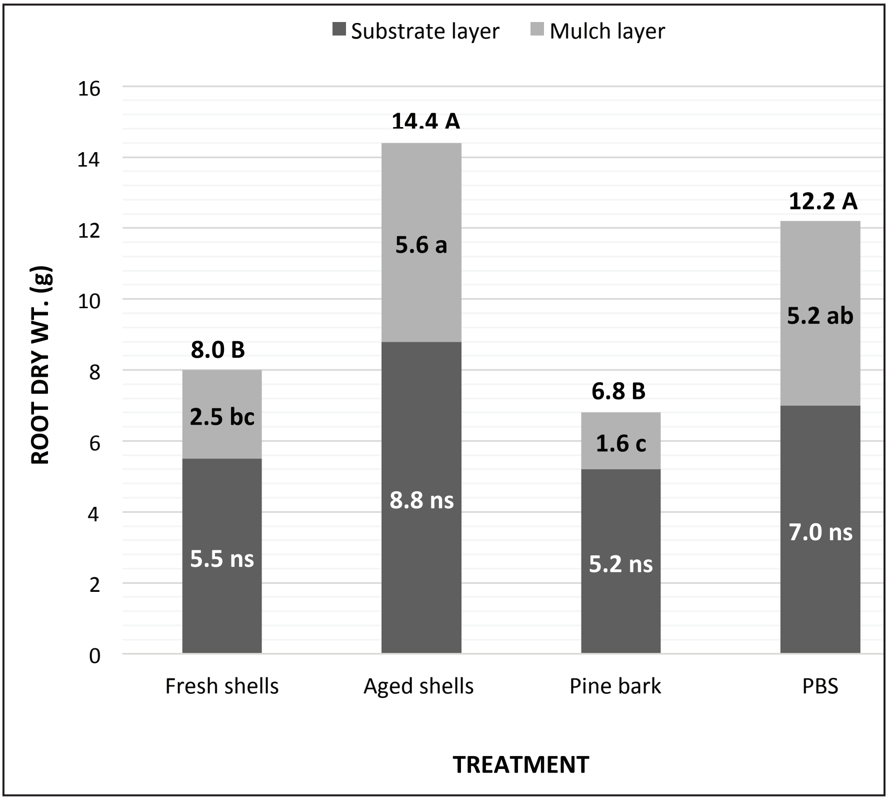

Figure 5. Root dry weight (RDW) of *Vaccinium virgatum* 'Brightwell'. Roots were divided into mulch (fresh shells, aged shells, pine bark, and unamended 80% pine bark and 20% sand substrate [PBS]) and substrate layers, then washed separately to determine mulch layer RDW and substrate layer RDW. Total RDW = mulch layer RDW + substrate layer RDW. Least squares means comparisons among mulch treatments and substrate layers using the Shaffer-simulated method at $\alpha = 0.05$. ns = not significant. All plants were grown in Horhizotrons™ in a greenhouse in Auburn, AL.

well' plants were uniform in size throughout the experiment, with average initial growth index of 47 cm, and final growth index of 113 cm (data not shown).

When organic mulches were tested as a cultural practice with blueberry transplants, they had a higher water stress tolerance (Hicklenton et al., 2000), and a more even root distribution extending from the plant crown (Spiers, 1986). Another blueberry root distribution study estimated that soil moisture and temperature were major limiting factors in blueberry root growth, and when mulches were used, most roots were concentrated under the mulched areas where soil moisture was prevalent and soil temperature reduced (Spiers, 1998). These findings were consistent with the results derived from the RDW of the substrate layers (below all mulch treatments), regardless of cultivar (Fig. 4, Fig. 5). Though the RDW was similar in the quadrants with PBS and aged pecan shell mulch for both cultivars, we hypothesize that had the PBS treatment been a true bare-ground treatment imposed in a field-production setting, the RDW would have likely been lower. Plant height, shoot growth, and root growth were greater for blueberry plants that were mulched than for those that were grown without mulch (Clark and Moore, 1991; Gough, 1980, Patten et al., 1988, and Spiers, 1995).

Another observation derived from the root distribution in this study was the general lack of roots that grew into the pine bark mulch layer as compared to the aged pecan shell mulch layer in both cultivars. This trend in root growth was similar to results of previous studies that evaluated blueberry root distribution under sawdust mulch (Gough, 1980; Shutak and Christopher, 1952). No roots were found growing in the undecomposed layers of sawdust mulch, which was approximately 10 cm thick (Gough, 1980). Rather, greater amounts of feeder roots were found growing below the mulch, beginning at a depth of 11 cm and increasing in density to a depth of 13 cm. These findings indicated that the depths at which the roots were found corresponded with the lower layers of undecomposed mulch and the upper layers of partially decomposed mulch. Similarly, Shutak and Christopher (1952) found limited blueberry root growth within the sawdust mulch layer itself; rather most roots were found growing in the lower, decomposed layers of the mulch closest to the soil surface.

Root distribution trends in this study showed that for 'Brightwell', root development within the aged shell mulch resulted in a higher RDW than that achieved

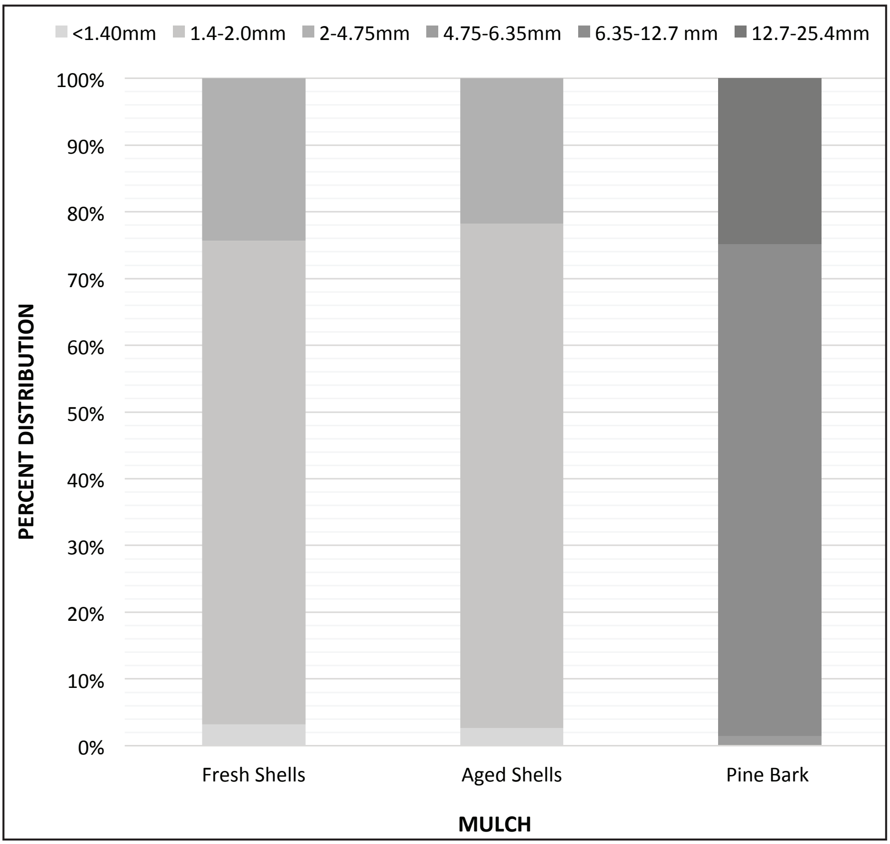

Figure 6. Particle size distribution by mulch type.

in the fresh shell and pine bark mulches. While differences in RDW in 'Premier' were not as prominent as those for 'Brightwell', more roots established within the aged pecan shell mulch layer than in the pine bark mulch layer. Considering the aged pecan shells used in this study were partially decomposed, it is hypothesized that the smaller particle size (Fig. 6) of the aged shell mulch, coupled with the level of decomposition, created a more hospitable environment for roots to develop than did the pine bark mulch.

Conclusions

Pecan shells are an underutilized waste product of the pecan industry, and much of the pecan production in the United States is in relatively close proximity to regions growing blueberries. An objective of this research was to ascertain the potential for pecan shells to be used as mulch for rabbiteye blueberry production, or more specifically, to determine whether pecan shells negatively affected rabbiteye blueberry root growth. Horhizotrons™ were chosen for this experiment because they provided a nondestructive means for examining how blueberry root growth was influenced by treatments, and because each individual plant grew into the separate treatments simultaneously. This experiment indicated that the growth and development of the rabbiteye blueberry root system is not hindered by fresh pecan shell mulch or aged pecan shell mulch as compared with milled pine bark.

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