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What's in your Douglas-fir Bark?

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ABSTRACT
Douglas-fir bark is a common waste product of forest industry, and has potential use as a substrate in container nurseries. Douglas-fir bark (DFB) is strongly acidic and contains amounts of phosphorus, potassium, iron, copper and manganese within or above the levels recommended for growing container crops. As the pH of DFB decreases, electrical conductivity and amounts of extractable phosphorus, calcium, magnesium, boron, and iron increase. Although liming unfertilized DFB with calcium carbonate up to 3 kg/m^3 (5 lb/yd^3) is effective at raising pH, the resulting pH is higher than desired for container plants after 6 incubation weeks. Native phosphorus in aged DFB leaches quickly under typical nursery conditions, but it may still be a reliable phosphorus source for plant growth for at least a month, providing pH is kept low.

Bark screen size seems to have a stronger effect on the uniformity of DFB chemical properties throughout the year than does bark age. Non-amended fresh and aged DFB provided sufficient micronutrients for the growth of annual vinca for up to 2 months when pH was kept low (< 5.7).

KEY WORDS
Pseudotsuga menziesii, fresh bark, aged bark, container growing media, macronutrients, micronutrients, phosphorus

Introduction

Douglas-fir (*Pseudotsuga menziesii*) bark (DFB) is considered by many nursery managers to be an excellent growing medium (substrate) for container production, hence its widespread use in Oregon and other regions where DFB constitutes a significant portion of the forest products industry. DFB is sold fresh or aged for use in container nurseries. Fresh DFB is sold soon after it is removed from the tree, ground to smaller particle sizes, and screened. Aged DFB goes through the same process, then sits undisturbed in large piles (7 to 12 m [23 to 39 ft] tall) for an average of 7 months before use. Although nursery managers are equally divided in their preference for fresh or aged bark (Hoeck 2006), some who prefer fresh material do so believing it has more consistent properties throughout the year. No research supports this statement.

Despite widespread use, little information is available on the chemical properties of either fresh or aged DFB as a growing medium for use in containers, whereas pine bark-based substrates commonly used in the southeastern US and sphagnum peat-based substrates have been more thoroughly studied. In general, the pH of pine bark is strongly acidic, ranging from 3.4 to 4.8 (Odgen and others 1987; Tucker 1995). The pH of sphagnum peat-based substrates can range between 3.5 and 5.5 (Williams and others 1988). Liming pine bark or peat with either calcitic ($CaCO_3$) or dolomitic ($CaCO_3$ - $MgCO_3$) lime is a common practice. The typical range of lime added to pine bark is 3.0 to 15.0 kg/m^3 (5 to 25 lb/yd^3), depending on the pH correction required (Prasad 1979; Nelson 1998). Williams and others (1988) showed that pH of sphagnum peat increased quadratically with increasing lime rates up to 7.0 kg/m^3 (11.6 lb/yd^3).

Based on Warncke's (1998) water-extractable macronutrient standards for container crops, non-amended pine bark has low ammonium (NH_4-N) (0.3 ppm) and nitrate (NO_3-N) (0.7 ppm) (Pokorny 1979), high phosphorus (P) (11 to 23 ppm) and potassium (K) (134 to 215 ppm) (Tucker 1995), and low calcium (Ca) (21 to 39 ppm) and magnesium (Mg) (7 ppm) (Starr and Wright 1984). In general, non-amended pine bark contains sufficient micronutrients for woody plant production (Niemiera 1992; Svenson and Witte 1992; Thomas and Latimer 1995; Rose and Wang 1999; Wright and others 1999).

Bollen (1969) showed that pH and nutrient content of DFB differs from other conifers, therefore research conducted on nursery use of pine bark cannot be extrapolated to DFB. Lacking information on DFB chemistry, we conducted a one-year survey of fresh and aged DFB from the 2 primary suppliers (bark sources) for Oregon nurseries; for practical purposes, we will present the 25% to 75% quartiles of the data collected for each chemical variable measured. We conducted experiments to discern: 1) the effect of liming on DFB pH; 2) how aging affects DFB chemistry; and 3) how those changes affect growth of annual vinca (*Catharanthus roseus* 'Peppermint cooler'). We used vinca because it is responsive to variable micronutrient nutrition. Although the complete results are presented in detail in Buamscha and others (2007a,b) and Altland and Buamscha (2008), here we present a summary of our important findings that may be used as a starting point for managers of forest and conservation nurseries interested in trying DFB in their production system.

DFB pH and Liming

Throughout the year, we found that pH of DFB was about 4.0 to 4.7 when fresh, and 3.5 to 4.5 after aging 7 months. These values were below the recommended range (5.0 to 6.0) for container crops (Yeager and others 2000), but similar to the range of pH reported for non-amended pine bark (Odgen and others 1987). This low pH is why most ornamental nurseries in Oregon amend DFB with lime. We conducted a separate study to understand the effect of liming DFB with increasing rates of calcitic lime ($CaCO_3$) (Altland and Buamscha 2008). We found that, after 6 weeks, non-amended aged DFB had a pH of 5.7, whereas amending it with 0.6, 1.5, 3.0, and 4.5 kg $CaCO_3$/m^3 (1.0, 2.5, 5.0, and 7.5 lb $CaCO_3$/yd^3) raised pH to 6.1, 6.7, 7.0, and 7.1 respectively. Although some Oregon growers use rates up to 20 lb/yd^3 (personal observations), we found that pH did not increase appreciably above the 5 lb rate; pH was 7.2 when adding 12kg/m^3 (20 lb/yd^3). Our results agree to similar research conducted in peat (Williams and others 1988). Most ornamental species grow well in containers with pH between 5 and 6. Our work with DFB indicates that even low (1.5 kg/m^3 [2.5 lb/yd^3]) rates of $CaCO_3$ after 6 weeks of production seem to raise pH values above the recommended range in the absence of other fertilizer additions. Growers may still wish to add lime, particularly if they use fertilizers with a strong acid reaction. Our results suggest that adding 3.0 to 4.5 kg $CaCO_3$/m^3 (5.0 to 7.5 lb/yd^3) would be sufficient for amending

DFB pH to near neutral, but the short duration of our study failed to provide much insight on the question of how the pH of container media changes over the course of an entire growing season in Oregon nurseries. More research is needed to quantify this aspect of DFB pH.

Macronutrients and Salts

Throughout our one-year survey, we found that electrical conductivity (EC) and sodium (Na) levels were low (data not shown) in fresh and aged DFB. As expected, NH_4-N and NO_3-N levels were also consistently low and similar between bark ages (average 1.3 and 0.3 ppm, respectively), concurring with Bollen (1969) for DFB and Pokorny (1979) for pine bark. We found extractable P levels in fresh and aged DFB were several times higher than those recommended by Warncke (1998) and higher than a pine/hardwood bark amended with a P fertilizer (Rose and Wang 1999) (Table 1). Potassium levels in DFB were generally within Warncke's (1998) recommendation. Unlike NO_3-N and P, K is not considered a pollutant or a cause of surface water eutrophication (Mengel and Kirkby 2001), but these significant K levels should be considered when developing fertility programs. Further research should address the availability and fate of K in DFB substrates throughout a growing season.

For the secondary macronutrients Ca, Mg, and SO_4^-, we found that the values in fresh and aged DFB (Table 1) were below those suggested by Warncke (1998). Our low levels of native Ca and Mg were similar to those found by Yeager and others (1983) and Starr and Wright (1984) in pine bark. In addition, Ca and Mg salts dissolved in irrigation water can be a significant source of these nutrients for plant growth (Whitcomb 1984) and should be accounted for when designing fertility programs. The low native secondary macronutrients we found in DFB are probably not much of a concern because growers typically amend DFB bark with dolomitic lime and S fertilizers.

Micronutrients

The extractable amount of the micronutrient iron (Fe) was adequate in fresh DFB and high in

Table 1. Parts per million (ppm) of macro- and micronutrients found in fresh and aged DFB and optimum amounts recommended by Warncke (1998) for container plants.

Nutrient	Fresh	Aged	Recommended (Warncke 1998)
		ppm	
P	8 to 17	12 to 35	3 to 5
K	64 to 131	40 to 157	60 to 149
Ca	12 to 28	8 to 64	80 to 199
Mg	5 to 14	3 to 34	30 to 69
SO_4^-	11 to 16	6 to 23	30 to 150
Fe	19 to 29	56 to 103	15 to 40
Cu	0.4 to 0.5	0.3 to 0.4	0 to 0.4
Mn	7 to 13	8 to 13	5 to 30
B	0.2 to 0.3	0.3 to 0.6	0.7 to 2.5

aged DFB compared to recommendations (Warncke 1998); these values are much higher than the trace amounts found in pine bark (Pokorny 1979; Odgen 1982). Extractable copper (Cu) in our DFB was at the high end of recommendations (Warncke 1998) and higher than those reported for pine bark (Pokorny 1979; Odgen 1982). Extractable manganese (Mn) was at the low end, but within recommendations (Warncke 1998), and much higher than that reported for pine bark (Pokorny 1979; Odgen 1982). Extractable boron (B) was well below recommendations (Warncke 1998); pine bark levels have been reported as either lower (Pokorny 1979) or higher (Neal and Wagner 1983) than those measured in DFB.

Although both fresh and aged DFB contain significant amounts of micronutrients, 2 new questions arose: 1) whether these micronutrients are available for plant growth; and 2) whether DFB age has an effect on micronutrient availability. To answer these questions, we grew annual vinca in fresh or aged DFB amended with one of these 3 micronutrient sources: 1) a standard micronutrient fertilizer (Micromax®, The Scotts Company, Marysville, Ohio); 2) yard debris compost; and 3) a non-amended control (Buamscha and others 2007a). We repeated the experiment twice; both times all plants looked healthy and none developed growth or foliar color symptoms that could be related to micronutrient deficiency or toxicity.

The first experiment lasted 6 weeks and we detected no differences in growth (shoot dry weight) between fresh or aged DFB or among the 3 micronutrient sources (Figure 1). The second experiment lasted 8 weeks (Figure 2); plants in non-amended fresh DFB were smaller than plants growing in fresh DFB amended with Micromax® or compost. Nevertheless, micronutrient nutrition failed to explain these growth differences because: 1) compost and non-amended plants had similar foliar nutrient levels with the exception of B (data not presented); and 2) Micromax®-amended plants had higher Ca, Mg, S, Mn, Cu, and zinc than non-amended plants. The same trend occurred in aged DFB and did not affect plant growth. In addition, plants growing in aged DFB tended to be larger than those in fresh bark. These growth differences could be attributable to higher foliar N in plants growing in aged compared to fresh bark (4.7% versus 3.2%, respectively). Differences in physical properties between fresh and aged bark might be another contributing factor in the differential plant growth between fresh and aged DFB; we documented a consistently higher water-holding capacity in aged compared to fresh DFB (Buamscha and others 2007b).

Based on our results, we cannot state which DFB age provided greater micronutrient nutrition, but it appears that both fresh and aged, non-amended DFB provided sufficient micronutrients for annual vinca grown for up to 8 weeks. Research in pine bark substrates has found similar results (Niemeira 1992; Svenson and Witte 1992; Rose and Wang 1999). We do not necessarily recommend that growers remove micronutrient amendments from their fertility programs, but rather we suggest that native micronutrients in DFB should be considered when developing a fertilizer management plan.

Effects of Aging

Aged DFB, especially bark with larger particles sizes (2.2 cm [≤ 0.87 in]), tended to have a lower pH (3.5 to 4.1) than fresh DFB (4.1 to 4.4). These results are unlike those of Pokorny (1979) and Harrelson and others (2004) who found no effect of pine bark age on substrate pH, and Cobb and Keever (1984) who found a higher pH in aged compared to fresh pine bark. This again confirms that pine bark research cannot be directly extrapolated to DFB.

There is a relationship between DFB pH, age, and extractable nutrients; as pH decreases, EC and amounts of extractable P, Ca, Mg, B, and Fe increase. Not surprising, aged DFB, which had lower pH than fresh DFB, also had higher levels of each of these parameters. It may be that during

Figure 1. Annual vinca growth (shoot dry weight) resulting from 2 bark ages and 3 micronutrient sources at 6 weeks after planting (Experiment 1). No significant differences in growth between fresh and aged bark, or the 3 micronutrient sources.

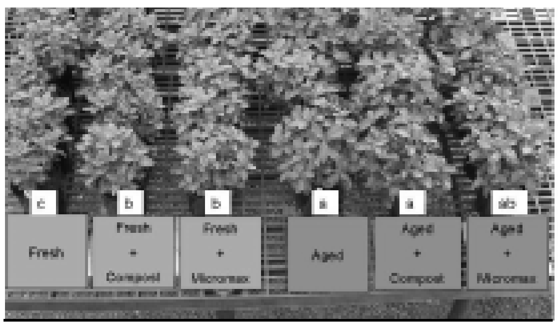

Figure 2. Annual vinca growth (shoot dry weight) resulting from 2 bark ages and 3 micronutrient sources at 8 weeks after planting (Experiment 2). Means with different letters within a treatment are significantly different, separated by LSD test ($\alpha = 0.05$).

the aging process, bark particles break down, bacterial activity increases, and, as a consequence, nutrients and H^+ ions are released. As the H^+ concentration increases, pH decreases, and the availability of key plant macro- and micro-nutrients increases (Lucas and Davis 1961; Odgen and others 1987).

Douglas-fir Bark Consistency Through 1 Year

In our work (Buamscha and others 2007b), we tested the growers' hypothesis that fresh DFB had more uniform chemical properties than aged DFB. We calculated coefficients of variation for each nutritional parameter measured in fresh and aged DFB to estimate data consistency over time. Our results indicated that bark age seemed to be less important in terms of consistency than the source from which it was collected. In general, we found nutritional parameters of the coarser bark source tended to have less variation than the finer source, and this was true for both fresh and aged DFB. Considering the primary difference in bark sources is the screening size (0.9 cm [≤0.37 in] for fine; 2.2 cm[≤0.87 in] for coarse), this implies that chemical properties of DFB might be more uniform or consistent throughout the year in coarser bark grades.

Phosphorus Leaching from DFB Substrates

Phosphorus leaching from DFB substrates may be of concern because high levels of P discharged from the nursery can lead to serious water quality issues, including surface water eutrophication. Unlike mineral soils, P in soilless container substrates leaches readily under standard nursery overhead irrigation practices (Marconi and Nelson 1984). Because we found high levels of P in fresh and aged DFB (Buamscha and others 2007b), we examined the fate of this native P during the course of a 24-week growing season and assessed the effect of pH on P availability and leaching from the containers. We monitored water-extractable P levels in 1-gal containers filled with fresh and aged DFB, amended with either 0 or 6 kg/m^3 (0 or 10 lb/yd^3) dolomitic lime, that were placed under typical nursery conditions with daily overhead irrigation. Adding lime increased fresh DFB pH from 4.0 to 7.5, whereas it increased aged DFB pH from 3.4 to 6.5, similar to results reported in Altland and Buamscha (2008).

Throughout the experiment and regardless of lime rate, we measured P levels in fresh DFB below 3 ppm; these seemed unusually low considering we detected 8 to 17 ppm P in fresh DFB (Buamscha and other 2007b). Further, we failed to see any relationship between fresh DFB pH and extractable P, perhaps because our P levels were so low. Overall, P in fresh DFB declined slowly over time, and was less than 2 ppm after 24 weeks.

Phosphorus in aged DFB was initially high (9 to 17 ppm). When amended with dolomitic lime, P was reduced by roughly 50% compared to the non-amended control. A similar relationship between increased substrate pH and reduced availability of P has been reported for a peat/pine bark substrate (Peterson 1980) and non-fertilized DFB (Altland and Buamscha 2008). After 7 weeks in a typical nursery environment, P was reduced 60% and 53% in non-amended and amended aged bark, respectively, from their original values. After 12 weeks, even non-amended aged bark had only 3 ppm P, which is close to the lower limit of what is recommended for container fertility by Warncke (1998).

After 18 weeks, P in fresh and aged DFB was less than 2 ppm, concurring with Yeager and Wright (1982) who, after amending pine bark with superphosphate fertilizer, measured a decline in water extractable P from 248 ppm to less than 10 ppm (96% reduction) in only 5 weeks. This is not too surprising as Marconi and Nelson (1984) reported P leaches readily from container substrates under typical nursery irrigation management.

Although aged DFB contains relatively high levels of water-extractable P at the onset of the growth cycle, irrigation rates and leaching events typical of container nurseries reduce those levels below that necessary to sustain plant growth. Lime additions appear to contribute to reducing P availability in aged DFB. Based on this work, it appears that aged DFB without a lime amendment has sufficient P to support plant growth for a month, suggesting that the industry-wide practice of incorporating high levels of water-soluble P as a "starter" fertilizer may not be necessary, assuming lime rates and substrate pH are kept low. Further research should be conducted to increase P retention in DFB substrates to maximize plant nutrient use efficiency and minimize environmental impact from P in nursery water runoff. Amending container substrates with clay minerals may have a promising future; Owen (2006) reported increased water buffering capacity, buffer substrate solution pH, and P retention when amending pine bark with a clay mineral.

Summary

Douglas-fir bark appears to be a reliable container substrate with fairly consistent chemical properties throughout the year. DFB is strongly acidic. Without additional fertilizer, increasing lime rates above 3 kg $CaCO_3/m^3$ (5 lb/yd^3)in DFB does not translate into appreciably increasing pH values during the first 6 weeks of the growing season. DFB contains significant amounts of plant nutrients, in particular P, K, Fe, Cu, and Mg. As DFB ages, pH tends to decrease and EC and extract-ability of P, Ca, Mg, B, and Fe increases. Coarser DFB has more uniform chemical properties over the course of a year than the finer source. Our results do not support the belief of some growers bark consistency is a factor of bark age throughout the year. When fresh and aged DFB pH is kept low (< 5.7), micronutrient nutrition was adequate for annual vinca for up to 2 months, indicating that growers should consider native micronutrients when developing fertilizer management plans.

Native P leaches quickly from DFB substrates under typical overhead irrigation regimes. Nevertheless, native P in aged DFB bark may be a reliable source of P for plant growth for at least a

month, providing substrate pH is kept low. Under these conditions, growers should re-evaluate the practice of incorporating high levels of water-soluble P as a "starter" fertilizer. Although the average DFB screen size offered by Oregon bark companies (approximately 1.6 cm [0.62 in]) is too large for the small volume cells used in forest nurseries for reforestation, this product may have utility for conservation and native plants grown in larger volume containers. Moreover, bark companies could grind and sieve DFB to smaller screen sizes that would fit containers typical of reforestation stock.

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