A tricky topic

Research suggests it's best to aim low when managing substrate pH

Research conducted this past year has shed more light on how pH affects container nutrition in Douglas fir hark substrates. This article will review some of our findings and how they relate to fertilizer decisions at the nursery. All of this research was generously funded by the Oregon Association of Nurseries and the Oregon Department of Agriculture.

Previous articles have addressed basic concepts in substrate pH. I will not review that information here, but I will reiterate the distinction between substrate pH and irrigation water pH. Substrate pH refers to the pH of the water held by the container substrate. The pH of this solution is governed primarily by the substrate and fertilizer amendments. Substrate solution pH affects many aspects of nutrient availability, some of which will be addressed in this article. Irrigation water pH refers to the pH of water coming from the irrigation head. The influence of irrigation water pH on substrate pH is negligible and will not be discussed further.

Table 1 presents data from an experiment we conducted in order to measure pH effects on micronutrient availability for woody plants in containers. We amended Douglas fir bark with two rates of lime (0 or 10 lb/yd^3) and three rates of Micromax micronutrient fertilizer (0, 0.75, and 1.5 lb/yd^3). All containers received the same rate of a controlled-release fertilizer. Six months after potting, we harvested the plants and measured substrate nutrition levels, foliar nutrients (not shown here) and growth of hydrangea, Japanese maple and *Leucothoe* (Table 1).

Nitrogen

Substrate pH has a distinct and profound effect on nitrogen availability in container substrates. Nitrogen is the most limiting nutrient in container substrates and the most difficult nutrient to manage correctly. Nitrogen is available in many forms, and it changes form quickly once applied to containers. A quick review of nitrogen dynamics in containers is prudent before we discuss the implications of substrate pH on nitrogen availability.

Nitrogen is generally applied to containers in one of three forms: urea, ammonium (NH_4^+) or nitrate (NO_3^-). Urea is common in many controlled-release fertilizers. It is water-soluble and leaches readily; however, under growing conditions it is released slowly from controlled-release fertilizers and rapidly converted to ammonium via a biological reaction called *urea hydrolysis.*

Ammonium (NH_4^+) ions have positive charges and are attracted to negatively charged organic molecules (in bark and peat moss). These bonds are beneficial because they result in greater nitrogen retention than do other forms of nitrogen bonds. However, ammonium not absorbed by plants can be converted to nitrate in a biological process called *nitrification.*

Nitrate (NO_3^-) has a negative charge, so is not adsorbed by organic matter and moves readily in soil or container media. Nitrate leaches quickly from containers, especially with excessive precipitation or irrigation. Even though ammonium does not leach readily from containers, under certain conditions it

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is quickly converted to nitrate, which does leach.

Regardless of what fertilizer is used or how it is applied, most nitrogen in the container is quickly converted to either ammonium or nitrate. Plants can absorb either ammonium or nitrate, with little or no absorption of other nitrogen forms. Even when compost teas and other organic nitrogen sources are applied, those products must be converted (decomposed) to ammonium or nitrate prior to being absorbed by plants.

Substrate pH has a dramatic effect on nitrogen form and availability in containers (Table 1). In our experiment, all containers had similar levels of nitrate, regardless of lime or micronutrient amendments. However, ammonium levels were relatively high in non-limed containers and almost nil in containers with lime.

Depletion of ammonium in limed containers is likely a result of higher substrate pH. As pH exceeded 5.2 in this experiment, ammonium levels plummeted. A separate experiment that Jim Owen and I conducted observed a similar nitrogen response to lime rate (substrate pH). But we weren't the first to observe this phenomenon. R.J. Ogden described a similar nitrogen response to pH in a review of pine bark chemical properties, and he attributed the response to greater activity of nitrifying bacteria in higher pH substrates.

A series of experiments at Virginia Tech demonstrated that low lime rates (0 to 3 lb/yd^3) resulted in optimal plant growth. They attributed the growth response to greater ammonium levels in low pH substrates. They further demonstrated that nitrifying bacteria were largely responsible for loss of ammonium in container substrates with high pH. Nitrifying bacteria that convert ammonium to nitrate function more efficiently at higher pH.

Differences in nitrogen availability resulted in lower foliar nitrogen levels

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From left, Yong Peng, Magdalena Zazirska and Gabriela Buamscha prepare bark samples for nutrient extraction.

Figure 1

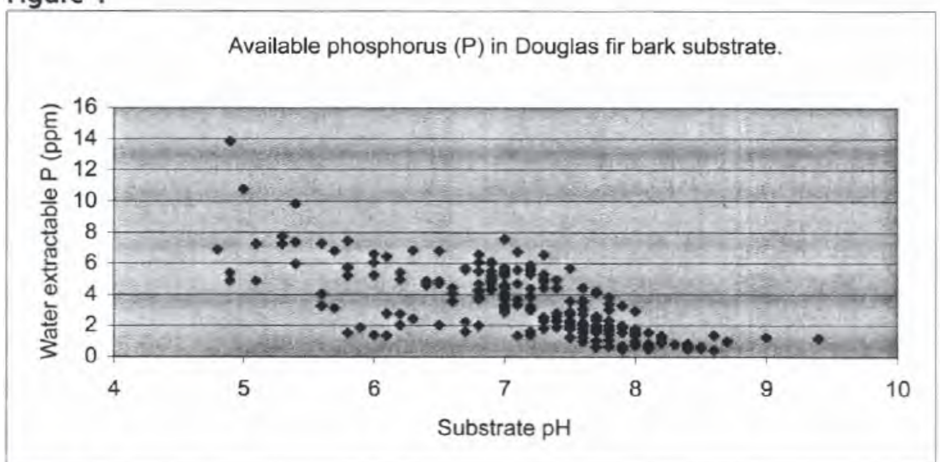

Figure 2

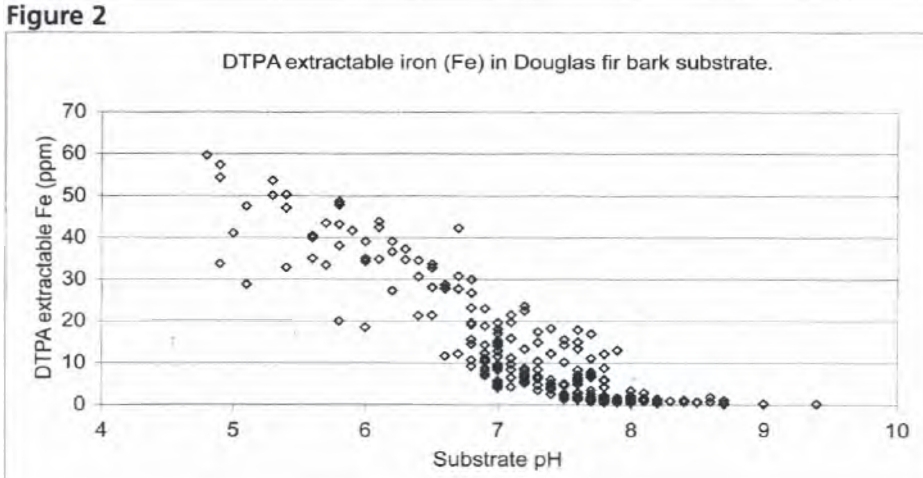

Table 1.
Substrate nutrition and plant response to lime rate and micronutrient amendment.

Lime rate	Micro-nutrient rate	pH	Container nutrient levels (ppm) NO_3^-	NH_4^+	P	Mn	Fe	Zn	Cu	Plant shoot dry weight (g) Hydrangea	Japanese maple	Leucothoe
0	0	4.3	41.4	44.5	17.1	0.3	46.2	1.5	0.5	46.4	40.3	16.7
	0.75	4.4	37.9	43.8	19.2	0.3	66.3	3.1	3.2	48.0	35.4	20.0
	1.5	4.5	43.4	54.4	26.6	0.4	87.4	3.6	5.5	39.9	33.0	21.9
10	0	5.8	40.2	1.1	11.9	0.1	25.2	4.3	0.4	30.7	19.9	7.4
	0.75	5.5	46.4	1.1	13.8	0.2	41.9	8.1	3.9	28.5	28.6	14.6
	1.5	5.6	46.3	1.2	14.9	0.3	52.0	11.5	6.7	19.1	27.9	13.6

NO_3^-, NH_4^+, P and Mn were extracted with water; Fe, Zn and Cu were extracted with DTPA chelate.
Lime and micronutrient rates are in lb/yd^3.

of plants grown in our study (data not shown). This also translated into drastic differences in growth for hydrangea, Japanese maple and *Leucothoe*. While lime rate and substrate pH affected availability of other nutrients (discussed later), nitrogen was most affected and likely responsible for differences in plant growth.

Phosphorus

Phosphorus levels were reduced by substrate pH (Table 1). Phosphorus levels from 5 to 9 ppm are considered sufficient for production of most nursery and greenhouse crops. Typical controlled-release fertilizer rates yield an abundance of phosphorus. While lime rate (substrate pH) affected phosphorus availability, phosphorus levels were relatively high regardless of treatment.

A previous *Digger* article (June 2006) discussed phosphorus levels in non-amended Douglas fir hark. Levels were initially high but dramatically affected by substrate pH (Figure 1). Data in Figure 1 were generated by amending Douglas fir bark with varying rates of calcitic lime ($CaCO_3$) and calcium hydroxide (CaOH). Over time (eight weeks after potting), phosphorus levels in Douglas fir hark were lower, but they were still high enough in low pH containers to be of consequence to plant fertility decisions.

Micronutrients

Potassium, calcium, magnesium and sulfur are largely unaffected by substrate pH, according to my research. In addition, I found nothing in the literature reporting that these nutrients should respond to pH.

In Table 1, manganese, iron and boron responded as expected with decreasing availability in the limed containers. Copper and zinc levels, on the other hand, were slightly higher in limed containers. Across all treatments, boron levels were low, but this did not cause boron deficiency in plants. Substrate zinc levels for most treatments would also be considered low compared with the recommended range, but again, all plants had sufficient foliar zinc (data not shown).

We also examined micronutrient availability in non-amended Douglas fir hark by amending with increasing rates of lime (as described for phosphorus).

We found that iron, manganese, boron and copper become decreasingly available (extractable) in container substrates with increasing substrate pH (Figure 2 on iron availability is an example). As lime rate and substrate pH increase concomitantly, availability- of these nutrients decrease. Zinc did not respond to substrate pH. Substrate manganese generally decreases with increasing substrate pH, but the rate of decline is never consistent from one sampling to the next. I have found substrate manganese a frustrating nutrient to measure and interpret.

The micronutrients _ iron, manganese, boron and copper are dependent on substrate pH. Similar to nitrogen and phosphorus, lower pH yields higher availability of these micronutrients. When pH of Douglas fir bark is lowest (nonamended bark), availability of these nutrients is acceptable for container plant production. We have never documented excessive or plant phytotoxic levels of these nutrients. Increasing substrate pH only reduces their availability.

Conclusions

The jury is still out on how to manage substrate pH. Based on research I've conducted as well as problems I've seen at production nurseries, I lean far to the side that says "lower is better." Nonamended Douglas fir bark pH is initially low, between 4 and 4.5. Amending bark with lime at typical nursery use rates (up to 10 lb/yd^3) will raise pH as high as 6.5 to 7. Alkalinity in irrigation water can cause pH to rise further. Measure pH in your containers soon after potting, and track pH throughout the growing season. If initial pH in your containers is too high, a change in pre-plant amendments should remedy that problem (lower lime rates). If irrigation water and fertilizer amendments affect substrate pH over weeks or months, modification of your irrigation system to reduce alkalinity should remedy that problem. An upcoming *Digger* article will address how to maintain a low substrate pH with pre-plant incorporation of elemental sulfur. e

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