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Effect of fertilizer potential acidity and nitrogen form on the pH response in a peat-based substrate with three floricultural species

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ABSTRACT

The potential of a water soluble fertilizer (WSF) to raise or lower substrate-pH is estimated in calcium carbonate equivalents (CCE) of acidity or basicity per unit mass of fertilizer. The CCE is currently estimated using Pierre's Method, PM, which is based on assumptions as to the effects of nitrogen and other ions in field soils that may not apply in container substrates. In a greenhouse experiment, the substrate-pH change was measured with 18 WSFs that varied in the concentration of NH_4-N, NO_3-N, urea-N and other nutrients. 'Ringo Deep Red' *Pelargonium* × *hortorum* (Bailey. L.H.), 'Super Elfin Bright Orange' *Impatiens wallerana* (Hook. F.), and 'Ultra Red' *Petunia* × *hybrida* seedling plugs were grown in 70%:30% (v:v) peat:perlite substrate amended with dolomitic hydrated limestone. Plants in 900 mL, 6-celled containers were top-irrigated with a total of 3.07 L over 4 weeks at 100 mg L^{-1} N without leaching. Plant species varied in their pH effect, in the order from acidic to basic of *Pelargonium*, *Impatiens*, and *Petunia*. Fertilizer CCE was positively correlated with substrate-pH, with r^2 between 0.54 and 0.80 depending on the species. Multivariate regression also quantified NH_4-N, NO_3-N, and urea-N concentration effects on substrate-pH and CCE of applied fertilizer. Estimated mequiv. of acid (negative values) or base (positive values) per mmol of each nitrogen form applied were NH_4-N −0.6678, −0.6143, −0.8123; NO_3-N 0.0713, 0.2746, −0.1296; and urea-N −0.2038, −0.1445, −0.2711 for *Impatiens*, *Petunia*, and *Pelargonium*, respectively. Ammonium-N therefore had a strong acid effect, nitrate-N was a weak base or acid, and urea-N was a weak acid. Calculation of CCE based on PM or nitrogen alone provided a similar R^2 with observed pH, despite a wide range in concentrations of macronutrients other than N in the fertilizer blends. Pierre's Method and nitrogen estimates of CCE for fertilizer blends were similar to each other (R^2 = 0.97). However, PM estimates were biased compared with experimental results, over-predicting acidity of high-ammonium fertilizers, and over-predicting basicity of high-nitrate fertilizers. Results indicate that nitrogen form and concentration may provide a simple estimation of the acidity or basicity of blended fertilizers, although research under other growing conditions would be required. Accurate estimation of CCE is important to help growers formulate appropriate fertilizers to balance other factors such as water alkalinity and plant species.

1. Introduction

Selection of a water soluble fertilizer (WSF) type and concentration is a key pH management decision for container-grown floricultural crops after planting. Maintaining substrate-pH between 5.6 and 6.4 provides adequate nutrient availability in root substrate for most floricultural species (Argo and Fisher, 2002). Outside this pH range, deficiencies or toxicities of nutrient such as iron, manganese and boron are likely to arise. In container production, WSF recommendations typically specify the nitrogen concentration and form, and the NPK balance (Nelson, 2003; Styer and Koranski, 1997). Fertilizer selection aims to balance water alkalinity and the tendency of particular crop species to raise or lower pH. Predicted pH effect of a fertilizer is described either by the potential acidity or basicity (Pierre, 1933; Ståhlberg, 1981) or the proportion of total N in the form of NH_4-N (Argo and Biernbaum, 1996; Styer and Koranski, 1997).

Challenges exist when applying Pierre's Method ["PM", Pierre (1933)] to fertilizer decision-making in floriculture production. First, the units of PM are kg of $CaCO_3$ equivalents (CCE) per ton

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(based on application to field soils) whereas WSF are applied as a concentration (mg L^{-1}) of N in solution. Second, although the percentage of N in the NH_4-N form is considered to have a dominant effect on fertilizer acidity or basicity in floriculture production (Styer and Koranski, 1997, p. 207), the relationship between PM and N form is not directly apparent. The PM assumes that (1) the acidifying effect is caused by all the S and Cl, one-third of the P, and one-half of the N contained in the fertilizer; (2) Ca, Mg, Na, and K are base forming elements; and (3) ammonium-N is completely nitrified and nitrate-N combined with bases such as sodium or calcium will have a net basic effect (Pierre, 1933; Tisdale and Nelson, 1966). As a consequence of these assumptions, PM predicts that ions such as Cl^- in a blended WSF will sometimes have a greater effect on fertilizer acidity than N (Johnson et al., 2010).

It can be hypothesized that N would contribute a major proportion of the observed substrate pH effect of a blended WSF. Epstein and Bloom (2005) indicated that on average, crop plants take up 250 atoms of K, less than 125 atoms of all other essential macronutrients, and less than 3 atoms of each essential micronutrient for every 1000 atoms of N. Fertilization with NH_4-N causes substrate-pH to decrease because of H^+ release during root uptake and nitrification of NH_4^+-N to NO_3^--N (Lang and Elliott, 1991). Rapid nitrification occurs in container substrate above pH 5.5, which is the typical growing range for most container crops (Argo and Biernbaum, 1997; Lang and Elliott, 1991). As a microbial process, nitrification rate is affected by multiple factors such as pH, temperature, oxygen, moisture, weeks of cropping, substrate components, nitrogen form and concentration (Lang and Elliott, 1991). Ammonium uptake is energetically favored over nitrate uptake when both N forms are supplied (Engels and Marschner, 1995; von Wiren et al., 2001). Ammonium-N is therefore likely to have greater influence on substrate-pH than the two other common forms of N in WSF, which are NO_3-N and Urea-N. Fertilization with NO_3^- increases substrate-pH resulting from OH^- or HCO_3^- secretion associated with balancing ion uptake (Marschner, 1995; Argo and Biernbaum, 1997). The pH effects of urea nitrogen vary depending on the dynamics of urea hydrolysis and the subsequent fate of $NH_4^+$and NO_3^-. Urea hydrolysis consumes protons whereas the process of plant uptake of NH_4^+ produces protons. Therefore, urea nitrogen would have a net basic effect in the absence of nitrification or plant uptake of NH_4^+ ions, a net neutral effect if the resulting NH_4^+ ions from urea hydrolysis are taken up by plant roots, or a net acidic effect if the resulting NH_4^+ ions are nitrified, producing a net of $2H^+$ (Verburg et al., 2003):

$$(NH_2)_2CO + H_2O + 2H^+ \rightarrow 2NH_4^+ + CO_2[\text{Ureahydrolysis}]$$

$$2NH_4^+ + 4O_2 \rightarrow 2NO_3^- + 2H_2O + 4H^+[\text{Nitrification}]$$

Plant species is also an important factor to consider in N uptake. Plant species adapted to soils that are acidic or with low redox potential tend to have a greater rate of uptake of ammonium (Marschner, 1995, p. 247). In contrast, plant species adapted to calcareous soils (where nitrification of ammonium to nitrate is favored) have greater uptake of nitrate-nitrogen. Floricultural crop species can also be categorized by their efficiency of iron (Fe) and manganese (Mn) uptake (Argo and Fisher, 2002). Iron-efficient plants (for example, zonal *Pelargonium*) are efficient at manipulating substrate-pH in the root zone to increase the solubility and uptake of Fe and Mn. Fe and Mn toxicity often occurs when substrate-pH decreases below 5.6. Iron-inefficient species (for example, *Petunia*) experience Fe and Mn deficiencies when substrate-pH increases above 6.5. Iron-intermediate plants (for example, seed *Impatiens*) are less susceptible to micronutrient toxicities and deficiencies and can be successfully grown over a larger pH range.

The objective of this study was to quantify the relationship of PM estimation of CCE with both substrate-pH and N form in blended WSF used in container plant production of bedding plants. Three experiments were run, including a trial with three floriculture crops that differed in reported iron efficiency (*Pelargonium*, *Impatiens*, and *Petunia*), and two additional experiments with *Impatiens only*. Several hypotheses were tested related to fertilizer CCE, nitrogen form, and substrate-pH. We hypothesized that increasing acidity of CCE predicted by PM would be correlated with decreasing pH in a container substrate. It was further expected that the classification of an "acidic", "neutral", or "basic" fertilizer as predicted by CCE would be only a relative measurement given the influence of other factors such as plant species. The CCE on a mequiv. of acidity or basicity per L basis was expected to be more closely correlated with substrate-pH than CCE on a kg/metric ton basis when WSF are applied in solution at a specific N concentration. The response in substrate-pH was related to the dose of a strong mineral acid or base using a methodology developed by Johnson et al. (2010). The substrate-pH change in a greenhouse experiment with fertilizers that varied in CCE predicted by PM could therefore be compared with the substrate-pH dose response from a mineral acid or base. A close relationship was hypothesized between the ratio of N forms and substrate-pH, whereby NH_4-N would have an acid effect on substrate-pH, NO_3-N would have a basic effect, and urea-N would have an intermediate effect. Estimations of mequiv. of acidity or basicity based on nitrogen form or fertilizer CCE were compared. Should N form alone provided a close approximation of CCE and effects on substrate-pH, this may assist growers in interpreting and selecting WSF formulations.

2. Materials and methods

2.1. Multiple species experiment

In spring 2010 at the University of Florida, Gainesville, FL (Latitude: 29.65° N), a 70%:30% (v:v) peat:perlite substrate was mixed with dolomitic hydrated limestone (97% $Ca(OH)_2 \cdot MgO$, 92% of which passed through a 45-μm screen, National Lime and Stone, Findlay, Ohio, reported acid neutralizing value of 161% CCE) at a rate of 2.01 kg m^{-3} to raise substrate-pH to approximately 6.0. The peat source used in the research substrates was Canadian Sphagnum peat moss (Sun Gro Horticulture, Vancouver, Canada) with long fibers and little dust (von Post scale 1–2; Puustjarvi and Robertson, 1975). The substrate was placed in 900 mL, 6-celled (TJ606, 150 mL per cell) containers. The substrate was moistened using 300 mL of a 100 mg L^{-1} N 17.0N-2.2P-14.2K low potential basicity fertilizer solution (7.5 kg/metric ton CCE basicity estimated using PM) per 6-cell container. Seedling plugs of 'Ringo Deep Red' *Pelargonium* × *hortorum* (Bailey. L.H.), 'Super Elfin Bright Orange' *Impatiens wallerana* (Hook. F.), and 'Ultra Red' *Petunia* × *hybrida* seedling plugs were transplanted into the 6-celled containers. The *Pelargonium* had been seed-propagated in 288-celled plug trays and the *Impatiens* and *Petunia* in 512-celled trays.

A total of 18 fertilizers were evaluated that ranged from 205 kg/metric ton CCE basicity to 780 kg/metric ton CCE acidity estimated using PM (Table 1). After transplanting, the plugs were allowed to grow for 2 weeks before treatments started. During this time, plants were top irrigated with 200 mg L^{-1} N from a 17.0N-2.2P-14.2K fertilizer solution (Table 1) as needed. After the 2-week pre-treatment period, at which time the substrate-pH averaged 6.2, the 18 fertilizer treatments were applied for the following 4 weeks. Cell packs were irrigated overhead by hand with fertilizer solutions mixed with deionized water, with nutrients applied at each irrigation. A total volume of 3.07 L (0.81 gal) of fertilizer solution was applied to each cell-pack over 4 weeks. Saucers were placed