Fertilizer Selection as a pH Management Tool in Floriculture Production

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The acid or base potential of fertilizer is an important factor to consider in pH management of floriculture crops. The potential of water-soluble fertilizer (WSF) to decrease or increase substrate-pH is expressed in calcium carbonate equivalents (CCE) of acidity or basicity per unit weight of fertilizer. The objective was to quantify the effect of 18 WSFs with varying CCE values and nitrogen ratios (% NH₄-N, NO₃-N, or urea-N) on substrate-pH response of Pelargonium ×hortorum Bailey ‘Ringo Deep Red’, Impatiens walleriana Hook ‘Super Elfin Bright Orange’, and Petunia ×hybrida ‘Ultra Red’ grown in 70% : 30% (v:v) peat : perlite substrate amended with dolomitic hydrated limestone. Six plants per 900 mL (54.92 cubic inch), 6-celled container, were top-irrigated with a total of 3.07 L (0.81 gal) over 4 weeks using one of 18 WSFs applied at 100 mg·L⁻¹ (ppm) N without leaching. Fertilizer CCE explained 67% to 91% of the variation in substrate-pH observed. Nitrogen accounted for 66% to 89% of the variation in substrate-pH change, whereby NH₄-N and urea-N had acidic reactions and NO₃-N had a basic reaction. Acid or base reaction of fertilizer varied across species, with the most basic reactions in petunia, the most acidic in pelargonium, and with impatients having intermediate pH-responses.

Maintaining substrate-pH between 5.8 and 6.2 is essential to provide proper nutrient availability in soilless root medium for most floricultural species (Argo and Fisher, 2002). Outside this optimum pH range, nutrient deficiencies or toxicities of iron, manganese, and zinc can arise. Water-soluble fertilizers (WSFs) are a common method of delivering nutrients to plants grown in soilless media in greenhouse floriculture production. Fertilizers differ in their formulation and affect root media-pH through ion exchange with plants and by acidification caused by nitrification (Lang and Elliott, 1991). Fertilization with NH₄⁺ causes media-pH to decrease because of H⁺ secretion during root uptake and nitrification of NH₄⁺-N to NO₃⁻-N, which also releases H⁺. Fertilization with NO₃⁻ increases substrate-pH resulting from OH⁻ or HCO₃⁻ secretion associated with balancing ion uptake (Argo and Biernbaum, 1997; Marschner, 1995). pH effects of urea nitrogen vary depending on the dynamics of urea hydrolysis and the subsequent fate of NH₄⁺ and NO₃⁻.

Currently, the potential of a fertilizer to acidify or increase pH is estimated using Pierre’s Method (PM) expressed in calcium carbonate equivalents (CCE) of acidity or basicity per unit weight of fertilizer (Pierre, 1933). The CCE is rated as kg (or lb) CaCO₃ required to neutralize (potentially acidic) or equal (potentially basic) the reaction of applying one metric ton (or US ton) of the WSF. Pierre’s Method assumes nitrogen in fertilizers is provided as nitrate or is converted to nitrate through nitrification (Pierre, 1933). Rapid nitrification does occur 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). However, PM does not take into consideration acidification resulting from plant NH₄⁺ uptake or acidity (H⁺) produced during the nitrification process. Therefore, PM may underestimate the calcium carbonate lime equivalent values required to neutralize the acid formed by the various nutrient salts in the fertilizer (Tisdale and Nelson, 1966; Tisdale et al., 1999). Pierre considered that NH₄⁺ uptake was possible but the amount was insignificant under normal agricultural conditions (Pierre, 1933). However, ammonium uptake is energetically favored over nitrate uptake when both N forms are supplied (Engels and Marschner, 1995; von Wieren et al., 2001). Pierre’s Method was developed using mineral field soil systems that could provide further inaccuracies to the PM model for quantifying fertilizer acidity in containerized plant production given the widespread use of soilless substrates and fertigation in floriculture production.

The ratio of nitrogen to other macronutrients and micronutrients across various fertilizer formulations can vary greatly from the ratios actually taken up or required by the crop (Epstein and Bloom, 2005). However, the bulk of plant nutrient requirement and fertilizer nutrient formulation is nitrogen. Therefore it can be assumed that nitrogen, including plant root uptake and exudation and associated soil microbial processes, has one of the greatest influences on substrate pH change. As the percentage of ammonium increases, the more acidic the pH effect, with the opposite trend for nitrate (Argo and Biernbaum, 1997). Urea hydrolysis consumes protons whereas the process of plant uptake of NH₄⁺ produces protons. Therefore, urea nitrogen will be neutral (if the resulting NH₄⁺ ions from urea hydrolysis are taken up by plant roots) or acidic in effect (if the resulting NH₄⁺ ions are nitrified, producing a net of 2H⁺) (Verburg et al, 2003).

Plant species is an important factor to consider in nitrogen uptake preference. For instance, plant species adapted to soils that are acidic or with low redox potential tend to have a greater rate of...
uptake of ammonium, whereas plant species adapted to calcareous soils have greater uptake of nitrate-nitrogen (Marschner, 1995, p. 247). Plant 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 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 acid or base reactions of 18 water-soluble fertilizers with varying calcium carbonate equivalency (CCE) values and ratio of nitrogen forms (ammonium, nitrate, and urea) in a peat-based substrate using three different floriculture crops.

Materials and Methods

In spring 2010, a 70% : 30% (v:v) peat : perlite substrate was mixed with dolomitic hydrated limestone at a rate of 2.01 kg·m⁻³ (3.39 lb per cubic yard) to raise substrate pH to approximately 6.0. The substrate was placed in 900 mL (54.92 cubic inch), 6-celled (TJ606) containers and moistened using 300 mL of a 100 mg·L⁻¹ (ppm) N 17.0N–2.2P–14.2K “neutral” fertilizer solution per 6-cell container. Seedling plugs of ‘Ringo Deep Red’ pelargonium [Pelargonium × domesticum (L.H. Bailey)], ‘Super Elfin Bright Orange’ impatiens [Impatiens walleriana (Hook. F.)], and ‘Ultra Red’ petunia [Petunia × hybrida] were transplanted into the 6-celled containers.

After transplanting, the plugs were allowed to grow for 2 weeks before treatments started. During this time, plants were irrigated with a 200 mg·L⁻¹ N (ppm) 17.0N–2.2P–14.2K “neutral” reaction fertilizer solution as needed. After the 2-week pre-treatment period, fertilizer treatments began and continued for the next 4 weeks. Cell packs were irrigated overhead by hand when substrate dried to approximately 50% container capacity. Saucers were placed under each 6-celled container to allow reabsorption of any leachate. A total of 18 fertilizers ranging from 205 kg/metric ton (or 410 lb/US ton) CCE basicity to –780 kg/metric ton (or –1560 lb/US ton) CCE acidity were evaluated (Table 1). The fertilizer solutions were applied at 100 mg·L⁻¹ (ppm) N with an additional 0.5 mg·L⁻¹ (ppm) of 6.48% Fe-EDDHA-chelate in deionized water. The plants were grown in a polycarbonate-covered greenhouse for 4 weeks with average temperatures of 24.2 °C (75.6 °F), and daily average PAR light accumulation of 9.3 mol·m⁻²·d⁻¹.

The greenhouse experiment was a randomized complete-block design with a factorial of 18 water-soluble fertilizers × three plant species × three blocks. Each block consisted of two greenhouse benches, and included two replicates (or cell packs) of all species and fertilizers for a total of 6 replicates (cell packs) per variable measured. Substrate solution extracts were collected by adding 320 mL of deionized water, and squeezing out approximately 50 mL of solution, based on the plug press method (Scoggins et al., 2002). Substrate-pH and electrical conductivity (EC) were measured at 2 weeks after planting (start of fertilizer treatments), and at the end of the experiment 4 weeks later.

The effect of fertilizer and plant species on substrate-pH was analyzed with ANOVA using PROC GLM (SAS Institute, 2001). Means were separated using Tukey’s HSD (α = 0.05). PROC Mixed was used to quantify parameters for the acid or basic effect of the concentration of each nitrogen form (ammonium, nitrate, and urea) on change in substrate-pH, and the interaction of these parameters with plant species, with the block as the random variable. The r² was compared for the correlation between either CCE or the PROC Mixed parameters multiplied by the applied concentrations of each nitrogen form, with substrate-pH.

Results and Discussion

The average initial substrate-pH of all three species was 6.2 after 2 weeks grown with a “neutral” 17.0N–2.2P–14.2K fertilizer. Initial electrical conductivity (EC) was 1.09 mS/cm. A total volume of 3.07 L (0.81 gal) of fertilizer was applied to each cell-pack over 4 weeks.

Plant species and fertilizer significantly affected substrate-pH at week 6 on ANOVA analysis, with respect to both main effects (plant species, P < 0.0001; fertilizer, P < 0.0001) and their interaction (P = 0.0008) (Table 1). Substrate-pH in pelargonium, impatiens, and petunia decreased from an initial pH of 6.2 to either 4.6, 4.7, or 4.9, respectively, with the most “acidic” fertilizer (14.8N–1.9P–12.3K, 780 kg/metric ton (or 1560 lb/US ton) CCE acidity) and finished with pH 6.2, 6.3, or 6.8 with the most “basic” fertilizer (12.4N–1.6P–10.3K, 205 kg/metric ton [410 lb/US ton] CCE basicity) (Table 1). Substrate-pH was 5.5, 6.2, or 6.5 with the “neutral” fertilizer (17.0N–2.2P–14.2K, 0 kg/metric [0 lb/US ton] CCE acidity) for pelargonium, impatiens, and petunia, respectively. The average substrate-pH across all fertilizers was 5.6 in pelargonium, 6.0 in impatiens, and 6.3 in petunia (Table 1). This pattern in pH reduction or increase is consistent with classification by Argo and Fisher (2002) for pelargonium, impatiens, and petunia as iron-efficient, intermediate, and iron-inefficient, respectively.

Change in iron and manganese content per plant from the start to end of the experiment (“uptake”) also indicated a range in iron-efficiency between species tested. Iron (Fe) uptake ranged from 0.04 to 0.21 mg per plant in impatiens, 0.06 to 0.54 mg in pelargonium, and 0.03 to 0.09 mg in petunia. Manganese (Mn) uptake ranged from 0.02 to 0.11 mg per plant in impatiens, 0.04 to 0.14 mg in pelargonium, and 0.03 to 0.06 mg in petunia. There were symptoms of Fe/Mn toxicity after 4 weeks of treatment on pelargonium grown at the lowest pH levels and Fe/Mn deficiency on petunia at the higher pH levels.

Whether a given fertilizer had a neutral (zero pH change over time), basic (increase in pH), or acidic (decrease in pH) effect depended upon the plant species grown (Fig. 1). Using straight line regression, a fertilizer with approximately –200 kg/metric ton (or –400 lb/US ton) CCE acidity was estimated and would have been needed for a neutral reaction (zero pH change) for petunia and 150 kg/metric ton (or 300 lb/US ton) CCE basicity for the impatiens. A straight line regression indicated that 495 kg/metric ton (or 990 lb/US ton) CCE basicity would be required for a neutral reaction for pelargonium; however, the data points for the fertilizers with a very basic CCE (close to 100% of N as ammonium, nitrate, and urea) indicated a non-linearity in the CCE:pH response (Figs. 1 and 2).

Analysis using PROC MIXED found that the applied mg·L⁻¹ of NH₄⁺ (P < 0.0001), NO₃⁻ (P = 0.0016) and urea (P = 0.0005) significantly affected change in substrate-pH. Estimated parameters for each nitrogen form were –0.0123 for NH₄⁺, +0.001519 for NO₃⁻, and –0.00488 for urea-N, where negative values for NH₄⁺ and urea-N indicated a tendency for that nitrogen form
Table 1. Final substrate-pH in impatiens, pelargonium, and petunia grown in peat-based soilless substrate for 28 d with 18 different fertilizer treatments at 100 mg·L⁻¹ N (ppm); [3.07 L (0.81 gal) total volume applied to each 900 mg·L⁻¹ (54.92 cubic inch), 6-celled container]. Day 0 substrate pH for each plant species was 6.2.

<table>
<thead>
<tr>
<th>Fertilizer (N–P–K)</th>
<th>Kg/metric ton CaCO₃ equivalent (CCE)</th>
<th>Final pH</th>
<th>Impatiens</th>
<th>Pelargonium</th>
<th>Petunia</th>
<th>Avg species pH</th>
</tr>
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<tr>
<td>14.8N–1.9P–12.3K</td>
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<td>25.1N–4.4P–8.3K</td>
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<td>5.7</td>
<td>5.6</td>
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<td>5.7</td>
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<td>20.0N–0.9P–16.7K</td>
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<td>6.3</td>
<td>6.3</td>
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<td>13.0N–0.9P–10.8K–(G)</td>
<td>165</td>
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<td>6.4</td>
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<td>13.0N–0.9P–10.8K–(S)</td>
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<td>6.1</td>
<td>5.9</td>
<td>6.5</td>
<td>6.1</td>
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<tr>
<td>12.4N–1.6P–10.3K</td>
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<td></td>
<td>6.3</td>
<td>6.2</td>
<td>6.8</td>
<td>6.4</td>
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<tr>
<td>Avg Fertilizer pH</td>
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<td></td>
<td>6.0</td>
<td>5.6</td>
<td>6.3</td>
<td>6.3</td>
</tr>
</tbody>
</table>

Significance:
- Fertilizer: *** <0.0001
- Species: *** <0.0001
- Fertilizer × Species: *** <0.0008

To convert kg/metric ton calcium carbonate equivalent (CCE) acidity or basicity to lb/US ton, multiply by 2. Negative values indicate potentially acidic fertilizers.

Substrate-pH values within species column or within fertilizer row were significantly different if difference between compared substrate-pH values were greater than 0.2828 using Tukey’s HSD test.

Fig. 1. Change in substrate pH after 28 d of treatment vs. the reported calcium carbonate equivalent (CCE, kg/metric ton) fertilizer acidity or basicity calculated using Pierre’s Method. Petunia: change in pH = 0.0015 × (CCE) + 0.2809; impatiens: change in pH = 0.0011 × (CCE) – 0.1514; pelargonium: change in pH = 0.0009 × (CCE) – 0.4965.
Fig. 2. Change in substrate pH of impatiens, pelargonium, and petunia grown in peat-based soilless substrate after 28 d vs. the ratio of percent NH$_4$-nitrogen to percent total nitrogen in 13 water-soluble fertilizers that only contained ammonium or nitrate nitrogen (no urea). Petunia: change in pH = –2.0523 (% NH$_4$-N : % total N) + 0.7905; impatiens: change in pH = –1.5957 (% NH$_4$-N : % total N) + 0.2406; pelargonium: change in pH = –1.4701 (% NH$_4$-N : % Total N) – 0.1392.

Conclusions

Regression and PROC MIXED analysis indicated close correlation of either PM CCE or percent of each nitrogen form with the observed substrate-pH effect of WSF. Pierre’s Method CCE explained 67% to 91% of the variation in substrate-pH observed (Fig. 1), compared with $r^2$ values of 66% to 89% for the PROC MIXED analysis of nitrogen form. Ammoniacal nitrogen was strongly acidic, urea-nitrogen was somewhat acidic, and nitrate was a weak base. The pH effect of urea may vary under different growing conditions, depending on the fate of N products. For example, if the NH$_4$-N resulting from urea hydrolysis is taken up and not nitrified, there would be a net acidic reaction. Of the three nitrogen forms, the statistical analysis indicated that substrate-pH would be most influenced by ammoniacal-nitrogen. This assumption is supported by Argo and Biernbaum (1996) who observed that ammonium-nitrogen uptake was the primary factor causing substrate acidification in Impatiens treated with 50%, 25%, and 3% NH$_4$-N fertilizers. The greater the ammonium content of the fertilizer, the lower the resulting substrate-pH.

Plant species and fertilizer CCE were both found to significantly influence substrate-pH; however, only one-third of the fertilizers evaluated were significantly different from the “neutral” fertilizer using Tukey’s HSD test. The acidic, basic, or neutral effect of each fertilizer was ultimately dependent upon the species that was grown. The most basic reactions were observed in petunia, the most acidic in pelargonium, and impatiens was the intermediate pH species. Based on Fe and Mn content in plant tissue, pelargonium was the most Fe-efficient of the three species evaluated, petunia was the Fe-inefficient species, and impatiens was the Fe-intermediate species, consistent with the classification of each species by Argo and Fisher (2002).

In this study, the use of deionized water and a substrate that lacked residual lime also would affect the observed change in substrate-pH. Further studies are needed to quantify the effect of irrigation water source alkalinity in association with fertigation and plant species on substrate-pH over time. By quantifying the
meq of acidity or basicity supplied by a fertilizer, growers can match the WSF to their water alkalinity and substrate to achieve a stable substrate-pH and thereby avoid nutrient imbalances associated with pH drift.

**Literature Cited**


