Plant species effects on acidity and basicity

Research update with a hydroponic study

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Executive Summary:

- Different floriculture species have the ability to raise and lower substrate-pH even when grown with the same fertilizer and substrate type. Seed Pelargonium tends to lower pH (leading to iron/manganese toxicity), Petunia tends to raise pH (leading to iron deficiency), and Impatiens is intermediate.

- Understanding the physiology of how species influence pH will reduce crop losses related to pH problems and help growers maintain optimal growing conditions.

- Seed Pelargonium, Impatiens, and Petunia were grown hydroponically for one week in complete nutrient solutions that varied in ammonium (NH$_4^+$):nitrate (NO$_3^-$) ratios (0:100, 10:90, and 20:80). Solution-pH was monitored and kept within a range of 5.5 to 6.5 by additions of acid and base to the culture containers. Species effect on pH was determined from the net additions of acid or base.
Cations are positively-charged ions such as NH$_4^+$, K$^+$ and Ca$^{2+}$. Anions are negatively-charged ions such as NO$_3^-$, and SO$_4^{2-}$. When a plant takes up a cation, the root tends to exude an acid (H$^+$) to maintain electrical neutrality and pH drops. In contrast, when a plant takes up an anion, the roots tend to exude a base (OH$^-$), and pH increases.

Species effects:

- With 20% ammonium there were minor differences between species in cation and anion uptake and pH effects. There were big species differences with 0% ammonium, with *Petunia* raising pH much more than *Pelargonium*.
- *Pelargonium*: The overall tendency was to take up more cations than anions and drop pH, except in the 0% ammonium solution where cation and anion uptake were similar and pH increased slightly.
- *Petunia*: Cation and anion uptake and pH effects were greatly affected by the fertilizer solution. With 20% Petunia was slightly acidic. With no ammonium, Petunia produced the most basic response of the three species.
- *Impatiens*: Effects of fertilizer solution on cation and anion uptake and pH were intermediate between the other species.

Overall, acidic or basic pH responses were closely matched with greater cation or anion uptake, respectively. When pH change was converted to milliequivalents (meq) of acid or base, the meq in the solution closely matched the net meq of cations minus anions taken up by plants.

Research with hydroponics confirmed results in peat substrates with no residual lime and zero alkalinity, showing that *Pelargonium* is likely to drop pH unless the fertilizer contains very little to no ammonium.

The pH trend with *Petunia* and *Impatiens* is highly responsive to ammonium concentration, acidifying with high ammonium, or raising pH with low ammonium.

Remember that this experiment had zero alkalinity, no substrate, and no limestone. In container production, substrate cation exchange, residual lime and water alkalinity will increase substrate-pH and buffer pH drop.

Future rounds of experiments will look at effects of fertilizer iron, phosphorus, and total nitrogen concentrations on how species raise or lower pH.

**Research Objectives:**

1. Evaluate the species effect of *Pelargonium*, *Impatiens*, and *Petunia* on solution acidity or basicity in hydroponic nutrient solutions that varied in ammonium:nitrate ratio.

2. Determine if the uptake of cations and anions by plants from the nutrient solution was correlated with acidity or basicity of the solution.
**Background:**
Grower experience and research shows that different crop species may raise or lower substrate-pH when grown with the same fertilizer solution. For example, *Petunia x hybrida* tends to increase pH, *Pelargonium x hortorum* drops pH, and *Impatiens wallerana* is intermediate.

Based on our understanding of plant physiology, there are two probable mechanisms for this species effect on pH.

1. A general non-adaptive response where plants that take up more cations (such as NH$_4^+$, K$^+$, Ca$^{2+}$, Mg$^{2+}$, Na$^+$, Fe$^{2+}$) than anions (such as NO$\text{}_3^-$, SO$_4^{2-}$, and Cl$^-$) drop pH, whereas plants that take up more anions than cations would increase pH.

2. An adaptive response (such as iron-efficiency) where plants may change pH (particularly dropping pH) under conditions of low iron, or other nutrients such as phosphorus, in order to increase solubility and availability of the deficient nutrients.

Research has shown that marigolds, for example, are able to increase iron reductase activity (Albano and Miller, 1996), which is an iron efficiency mechanism. Taylor and Nelson (2008) found that Pelargonium tended to drop pH in response to low phosphorous.

However, if it was only an adaptive response (II above), why are Petunias “dumb enough” to push themselves into high pH issues and iron deficiency, whereas Pelargonium tends to push pH down into a range where iron and manganese are so soluble that toxicity occurs?

The general processes on how cation and anion uptake affect pH (I above) are as follows:

(A) When roots take up a charged cation from the soil solution (in this case ammonium, NH$_4^+$), they compensate for the charge imbalance by exuding H$^+$ protons of equal charge. The release of H$^+$ (acid) from the roots into the soil solution lowers the substrate-pH.

(B) Microbes in the substrate can also convert ammonium nitrogen to nitrate nitrogen through a process called nitrification. During nitrification, free H$^+$ is released and lowers pH. This conversion is favored above pH 5.5, and with high biological activity (warm, moist, but not water-logged).
(C) When roots take up an anion (in this case nitrate, NO$_3^-$), they may exude an equally charged hydroxyl (OH$^-$) or bicarbonate anion (HCO$_3^-$). The release of hydroxyl and/or bicarbonate anion from the roots is basic and increases substrate-pH.

(D) The simultaneous uptake of a cation and anion of equal charge does not create a charge imbalance and roots do not have to compensate by extruding ions. In this case, there are no hydrogen, hydroxyl, or bicarbonate ions released by roots and there is no effect on substrate-pH.

Materials and Method:

Growing conditions
In the Spring of 2013, 128-cell seedling plugs of *Pelargonium x hortorum* ‘Ringo 2000 Red Deep’, 206-cell *Petunia x hybrida* ‘Ultra Red’, and 206-cell *Impatiens wallerana* ‘Super Elfin Orange Bright’ were received from Knox Nursery, Apopka FL. Plants were transplanted into hydroponic systems located on greenhouse benches at the University of Florida, Gainesville FL.

At transplant, roots were washed with deionized water in order to remove any peat/perlite particles sticking to root surfaces. Seedlings were grown for 4 weeks in a modified 0.5x Hoagland’s solution at 100 mg N/L containing 10% of the total nitrogen as ammonium and 90% as nitrate with 1 mg Fe/L prior to the start of the experiment. The solution was mixed with reagent grade salts and zero alkalinity de-ionized water. The solution-pH was adjusted to 6.0 prior to transplant using HCl or NaOH at 0.1 N. Solution-pH in each container was monitored every 2 days and maintained within a range of 5.5 to 6.5 using HCl and NaOH at 0.1 N. Every 7 days the nutrient solution in each container was emptied and replenished with 4.5 L of fresh solution.

The hydroponic culture vessels were 4.9 Liter white plastic containers with snap-on plastic lids. The stems of the seedlings were supported by black neoprene stoppers (5-cm diameter) held inside plastic baskets that fit inside circular holes cut into the container lids. The plastic containers held the nutrient solutions and the basket-neoprene stopper-plastic lid combination supported the seedlings and allowed roots to grow down into the solution.
The neoprene stoppers fit around plant stems but did not constrict growth and reduced evaporation of the nutrient solution. Plastic containers, lids, baskets, and neoprene stoppers were washed in a phosphate-free detergent and rinsed with de-ionized water before use in this experiment. A clear plastic tube fitted with an aquarium airstone was inserted through a 0.75cm hole cut into the center of each container lid and provided continuous aeration of the nutrient solution. The plastic containers were painted silver to reduce light transmission to the interior, reduce algae growth in the nutrient solution, and to help maintain a stable solution temperature. Each hydroponic system contained Pelargonium, Impatiens, or Petunia and occupied a 30-cm x 30 cm (1 square foot) area of greenhouse bench space.

Table 1. Concentrations of modified 0.5x Hoagland’s solutions with 100 mg N/L and 1 mg Fe/L containing 0%, 10%, and 20% of total nitrogen in ammonium (NH₄) form. Nutrient salts included ammonium sulfate, calcium nitrate, potassium nitrate, magnesium sulfate, potassium sulfate, potassium phosphate (monobasic), calcium chloride, iron-EDTA, manganese sulfate, zinc sulfate, copper sulfate, boric acid, and sodium molybdate.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>0% NH₄</th>
<th>10% NH₄</th>
<th>20% NH₄</th>
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*Experimental design*

There were two factors in a factorial design:
(a) plant species (*Pelargonium*, *Impatiens*, or *Petunia*) and
(b) fertilizer solution (modified Hoagland solutions with 0%, 10%, or 20% of total nitrogen as ammonium and 100%, 90%, or 80% of total nitrogen as nitrate, respectively).

Each treatment combination was replicated four times (3 x 3 x 4=36 containers). Each replicate was comprised of two plants in a plastic container for a total of 2 x 4 x 3=24 plants per species. Additional control containers with no plants were set up for each of the nutrient solution types and were also replicated 4 times (3 x 4=12 control containers).
Each container held 4.5 L of nutrient solution. Each fertilizer solution contained 100 mg N/L and 1 mg Fe/L. Hydroponic containers were placed on a single greenhouse bench arranged in a completely randomized design. The treatments ran for one week before collecting final data. Average day and night temperatures were 25.2±1.4 ºC (daily mean ± standard deviation) and 19.4±0.8ºC, respectively. Average solution temperature was 20±1.4ºC and daily light integral was 14.7±3.8 mol m⁻² d⁻¹.

Solution-EC and solution-pH were monitored every second day until final data collection. Solution-pH was maintained within a 5.5-6.5 range using 0.1 N HCl or 0.1 N NaOH.

Plant samples were destructively sampled at the start and end of the trial so that differences in root and shoot growth could be measured. Root and shoot samples were also washed in 0.5 N HCl and rinsed with de-ionized water to remove salt coatings before being dried and sent to Quality Analytical Laboratories (QAL, Panama City, FL) for tissue nutrient analysis (data not shown). Solution samples from the start and end of the trial for each species-fertilizer solution combination plus controls were sent to QAL for nutrient analysis using inductively-coupled plasma (ICP) atomic emission spectrophotometry, and the IFAS Soil Testing Laboratory for ammonium and nitrate nitrogen analysis by semi-automated and automated colorimetry, respectively.

At the end of the trial, the volume remaining in each container was measured so that the amount of water used by plants could be calculated, ranging from 940 to 2260 mL per container (data not shown). The solution-pH was then adjusted back to 6.0 using HCl or NaOH at 0.5 N. The amounts of acid and base added during the trial and for final pH adjustment were converted to total milliequivalents (meq) of acid and base added to each container. The meq of acid or base added to the control containers for each solution was subtracted from the meq of acid or base added to each container containing plants. This net meq of acid or base per container represented the acid and base released by the plants as a result of growing in a particular nutrient solution. For example, if a net of 1 meq NaOH (base) was needed after final pH adjustment to bring the solution-pH back to 6.0, then the plants released 1 meq of acid (HCl) over the course of the trial. In the growing situation, net acid response by plants would equate to a drop in substrate-pH whereas a net basic response would equate to an increase in substrate-pH.

The net meq of cations versus anions taken out of the different solutions by plants was calculated from the lab analysis of nutrient concentration and the change in volume for solutions with and without plants. Final meq (concentration in mmol *charge * volume) was calculated for each nutrient. The Initial meq and the change in meq for control containers were subtracted from the final meq for containers containing plants to calculate the net change in meq of cations or anions.
Cations and anions and assumed charge for plant uptake in this analysis were NH$_4^+$, NO$_3^-$, H$_2$PO$_4^-$, K$^+$, Ca$^{2+}$, Mg$^{2+}$, SO$_4^{2-}$, Fe$^{2+}$, Mn$^{2+}$, Zn$^{2+}$, Cu$^{2+}$, MoO$_4^{2-}$, H$_2$BO$_3^-$, Na$^+$, Cl$^-$, and Al$^{3+}$.

Regression analysis across and by species was then used to evaluate whether there was a relationship between net cation minus anion uptake and the effect on solution acidity or basicity.

**Results:**

Figure 1. Effect of meq of cations minus anions taken up by the plant (horizontal axis) compared with the acidity or basicity of the nutrient solution (vertical axis) after 7 days. Each data point represents one replicate container. Negative values on the horizontal axis indicate more meq of cations were taken up than anions. Positive values on the horizontal axis indicate excess uptake of anions. Negative values on the vertical axis indicate that solution pH dropped, whereas positive values indicate that solution pH increased. The regression had an adjusted-$R^2$ of 0.739, with a 1:1 relationship for the two variables (intercept equalled 0.140 ± 0.478 slope equaled 0.962 ± 0.195).

- There was a close relationship between cation minus anion uptake and solution acidity or basicity (Figure 1).
- When more cations were taken up than anions, pH dropped. When more anions were taken up than cations, pH increased.
- The relationship between meq of cations minus anions and meq of solution acidity or basicity was 1:1.
Figure 2. Effect of milliequivalents (meq) of cations minus anions taken up by the plant (horizontal axis) compared with the acidity or basicity of the nutrient solution (vertical axis) after 7 days. See Figure 1 caption for more details.

- In the 0% ammonium solution, all species took up more anions and raised pH (Figure 2A). Pelargonium took up almost equal cations and anions and increased pH slightly whereas Petunia took up the most net anions and had the most basic pH response. Impatiens had an intermediate effect on pH and took up an intermediate amount of net anions. Figure 2A demonstrates differences in species effect, where Pelargonium was the most acidic, Petunia the most basic, and Impatiens intermediate.

- When solution ammonium increased to 10% Petunia increased pH whereas Impatiens and Pelargonium only slightly increased and slightly decreased pH, respectively (Figure 2B). The lowering of pH by Pelargonium was coupled with greater cation uptake.

- In the 20% ammonium solution all species took up more cations and produced a net acid response lowering pH (Figure 2C). In this solution Petunia dropped pH only slightly whereas Impatiens had the lowest drop in pH, however, all species had similar cations minus anions uptake.

- Species responded differently to solution ammonium (Figure 2A, B, and C). Pelargonium ranged from a slight increase in pH with 0% ammonium to moderately decreasing pH with 20% ammonium, and was the species least affected by ammonium level. On the other hand, Petunia greatly increased pH in the 0% solution but decreased pH in the 20% solution and showed the greatest response to ammonium. Impatiens had an intermediate effect.
Figure 3. Effect of species on milliequivalents (meq) of cations and anions taken out of solution after 7 days. Stacked columns (horizontal axis) are separated into nutrient ions. The vertical axis shows the amounts taken up by plants in meq. Fe²⁺, Mn²⁺, Zn²⁺, Cu²⁺, MoO₄²⁻, H₂BO₃⁻, and Al³⁺ had minimal impact on total uptake and were grouped together under “Micronutrients.”

- Pelargonium and Impatiens overall had greater cation than anion uptake (Figure 3). Petunia had greater uptake of anions than cations overall.

- Uptake of nitrate nitrogen exceeded that of any other nutrient, and was the primary component of total anion uptake for all three species.

- Impatiens used the greatest amount of ammonium nitrogen, followed by Petunia and then by Pelargonium.

- Sodium and chloride in the solutions came from the NaOH and HCl used to adjust solution pH.
Figure 4. Effects of increased ammonium levels in solution on uptake of cations and anions milliequivalents (meq) after 7 days. Refer to Figure 3 caption for more details.

- All plants took up more anions in the 0% ammonium solution (Figure 4A) and more cations in the 20% ammonium solution (Figure 4C). Increased ammonium nitrogen increased cation uptake in all species.

- With 10% ammonium Petunia had greater anion uptake, whereas Pelargonium and Impatiens had greater cation uptake (Figure 4B). Pelargonium, Impatiens, and Petunia took up similar amounts of ammonium in the 10% solution (Figure 4B).

- Impatiens and Petunia roughly doubled their ammonium uptake when going from the 10% to the 20% ammonium solution. Pelargonium had almost no increase in ammonium uptake when going from 10% to 20% ammonium in solution.
Figure 5. Effect of species on percent uptake of cations and anions. “Cations” and “Anions” in each column equal 100%, representing total cations and anions uptake after 7 days. The higher the percent of total ion uptake (vertical axis) for a particular ion indicates higher uptake preference. Fe**, Mn**, Zn**, Cu**, MoO₄⁻², H₂BO₃⁻, and Al³⁺ were grouped together under “Micronutrients.”

- Nitrate nitrogen made up the majority (approximately 80%) of anion uptake across all species. Phosphorus and sulfate contributed most of the remaining anion uptake. The ratio of anions did not differ greatly between species. These trends were consistent with different solutions (Figure 6 below).

- Overall, ammonium contributed between 10% and 20% of total cation uptake (Figure 5). The proportion of ammonium uptake increased as ammonium level increased in the fertilizer (Figure 6).

- Potassium tended to contribute more meq of cation uptake than ammonium in all species and especially Petunia (Figure 5), even in the solution with 20% ammonium (Figure 6C).

- Calcium and magnesium contributed less to cation uptake for Petunia than other species, but consistently represented almost all the cation uptake other than ammonium and potassium.
Figure 6. Effects of increased ammonium in solution on species preferences for certain cations and anions after 7 days. Refer to Figure 5 caption for more details. Results are discussed on previous page.
Figure 7. Effect of increased ammonium levels in solution on $\text{NH}_4^+$ and $\text{NO}_3^-$ uptake expressed as percentages of total nitrogen uptake. Horizontal axis shows increasing ammonium in solution across species. Vertical axis shows percent ammonium and nitrate uptake out of total nitrogen. Increased percentages of ammonium uptake equate to increased preference.

- In the 10% and 20% ammonium solution all species took up greater than this percentage of ammonium into plant tissue. This implied that ammonium uptake tended to be favored over nitrate nitrogen (Figure 7).
- As shown in Figure 8 below, Pelargonium did not completely deplete all ammonium, but Impatiens removed almost all ammonium from the solution and Petunia was intermediate.
Figure 8. Control and species effect on measured concentration of ammonium (A, left) and nitrate (B, right) in the nutrient solutions. “Initial” or “Final” descriptions on the horizontal axis refer to measurements at the start of the experiment or after 7 days, respectively. Solution nitrogen is given in mg N/L along the vertical axis. Lines show solution nitrogen for 0%, 10%, and 20% ammonium solutions. Controls represented containers without plants.

- There was slight depletion of ammonium and nitrate in the control solutions from day 0 to 7, presumably lost to the atmosphere through denitrification.
- Almost no ammonium (average 0.3 mg N/L for both the original 10% and 20% NH₄-N solutions) was left in solution after 7 days with Impatiens (Figure 8A).
- Petunia also depleted most of the ammonium, leaving only 0.9 or 2.4 mg N/L in the 10 and 20% NH₄-N solutions, respectively.
- Pelargonium showed less depletion of NH₄-N. This was in part because Pelargonium took up less total nutrients (Figure 4A) than the other species.
- None of the three species depleted nitrate level below 25 mg /L (Figure 8B).
Literature Cited:

