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Solution Ammonium: Nitrate ratio and cation/anion uptake affect acidity or basicity with floriculture species in hydroponics

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ABSTRACT

Floriculture crops affect substrate-pH and resulting solubility of micronutrients in the root zone during commercial production. Two hydroponic experiments and tissue data from a container study were analyzed to determine whether (1) cation or anion uptake was related to solution acidity and basicity in the root zone for three floriculture crops [geranium (*Pelargonium* × *hortorum*, Bailey. L.H.), petunia (*Petunia* × *hybrid*, Vilm.-Andr.), and impatiens (*Impatiens wallerana*, Hook. F.)] and whether (2) the proportion of NH_4^+-N versus NO_3^--N uptake differed between these three floriculture species. In the container study, where >96% of nitrogen (N) was provided primarily as NO_3^--N, substrate-pH did not change over time when geranium or impatiens were grown, whereas substrate-pH increased with petunia. Geranium had a higher cation/anion uptake ratio than petunia based on analysis of tissue nutrient levels, and impatiens was intermediate. In the hydroponic experiments, the three species were grown in nutrient solutions that varied in ammonium:nitrate (NH_4^+:NO_3^-) ratio from 0:100 to 50:50. In the first hydroponic experiment, there was an approximately 1:1 relationship between net anion minus cation uptake and net solution acidity or basicity, (milliequivalent (mEq) solution acidity or basicity = 0.972 ± 0.195*(net mEq of anions—cations taken up) + 0.140 ± 0.478; adjusted-R^2 = 0.739) over all species, which indicated a strong correlation between solution-pH change and net cation or anion uptake. Geranium had the highest cation/anion uptake ratio (1.06) and produced greater acidity than petunia, which had the lowest cation/anion uptake ratio (0.94). Cation/anion uptake ratio increased as applied NH_4^+:NO_3^- ratio increased. In the second hydroponic experiment, uptake of NH_4^+-N versus NO_3^--N exceeded the ratio that was supplied in the 10:90 and 20:80 NH_4^+:NO_3^- solutions for all species, but not in the 50:50 solution. Although some results were inconsistent between experimental runs, petunia overall had a lower NH_4^+:NO_3^- uptake ratio than the other two species. A NH_4^+:NO_3^- ratio of 10% NH_4^+-N for geranium and impatiens and 20% NH_4^+-N for petunia would be expected to result in a neutral pH response in a hydroponic solution with zero alkalinity. Evaluating cation/anion uptake ratio across a range of NH_4^+:NO_3^- ratios could be used to predict the relative acidity or basicity of other plant species to assist in pH management.

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1. Introduction

The solubility of nutrients in a hydroponic solution or soilless growing substrate is affected by pH, particularly for metal micronutrients which become less available for root uptake as pH increases (Lindsay, 1979; Peterson, 1981). Many factors influence pH change over time during soilless plant production, including water alkalinity, addition of mineral or organic acid or base, plant species, nitrogen form, nutrient concentration, acidity and cation exchange capacity of substrate components, and lime source and concentration (Argo and Fisher, 2002; Sonneveld and Voogt, 2009, Ch. 13). Both nutrient solutions and soilless substrates have low buffering capacity. Drift in pH is therefore a common occurrence that leads to production losses resulting from nutrient deficiencies or toxicities. A major process by which plants change rhizosphere-pH is an imbalance in root uptake of either cations or anions (Haynes, 1990; Lea-Cox et al., 1996; Marschner, 2012, Ch. 14.4; Rengel, 2003). Charge balance is accomplished by a plant taking up equal

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but oppositely-charged nutrient ions, or by effluxing ions with a charge equal to the net charge taken up by roots (Lea-Cox et al., 1996; Marschner, 2012, Ch. 2). Net cation uptake is compensated for by H^+ efflux from roots, whereas net anion uptake is balanced by OH^-/HCO_3^- efflux (Kirkby and Knight, 1977; Lea-Cox et al., 1996; Marschner, 2012, Ch. 2).

Nitrogen uptake plays a pivotal role in the cation/anion balance of the plant. Approximately 70–80% of the total cation and anion uptake by plants is estimated to result from the uptake of NH_4^+-N or NO_3^--N (Lea-Cox et al., 1996; Marschner, 2012, Ch. 2). Plants have a cation/anion ratio >1 (net cation uptake) when given NH_4^+-N, resulting in an efflux of acids from roots, which lowers substrate-pH. Plants often have a cation/anion ratio <1 (net anion uptake) when given NO_3^--N, resulting efflux of bases, which raises substrate-pH (Marschner, 2012, Ch. 2). Fertilizer effects on substrate-pH with geranium, petunia, and impatiens [*Impatiens wallerana* (Hook. F.)] grown in peat/perlite substrate were closely related to the concentration of nitrate, ammonium, or urea-N (Fisher et al., 2014b; Johnson et al., 2013). In hydroponics, adjustment of the NH_4^+:NO_3^- ratio in the nutrient solution is used as a pH management tool, whereby increasing the applied NH_4^+-N concentration results in greater cation/anion uptake and more acidic pH response (Conesa et al., 2009; Lea-Cox et al., 1999; Savvas et al., 2003, 2006). When NH_4^+-N is depleted in hydroponic solutions, subsequent NO_3^--N uptake tends to raise solution-pH (Lea-Cox et al., 1999). In crop culture in substrate, the rapid conversion of NH_4^+-N–NO_3^--N through nitrification, and subsequent release of protons into solution, must also be considered when evaluating the influence on NH_4^+:NO_3^- ratio on root zone pH (Argo and Biernbaum, 1997; Lang and Elliot, 1990).

Measurement of cation/anion uptake has been based on depletion of ions from a nutrient solution, analysis of cation and anion levels in plant tissue, or ash alkalinity of plant tissues (Rengel, 2003). When measuring cation/anion uptake, nitrogen is the most complex nutrient given that it is taken up in both cationic and anionic forms, and also because microbial processes including nitrification affect substrate-pH. The complexity of N uptake can be accounted for in hydroponic solutions that have minimal microbial activity (Padgett and Leonard, 1993), or by using labeled N (Taylor et al., 2010).

Species differ in their cation/anion uptake ratio, and subsequent effect on substrate-pH. Rengel (2003) characterized the cation/anion uptake ratio of legumes and cereal crops, and the acid production per kg of dry mass gain. The effect of ammonium (NH_4^+) and nitrate (NO_3^-) on cation/anion uptake in hydroponic solutions has been studied on lettuce, spinach, tomato, and other crop species (Conesa et al., 2009; Haynes, 1990; Kirkby and Mengel, 1966; Kirkby and Knight, 1977; Lea-Cox et al., 1999; Savvas et al., 2003, 2006; van Beusichem et al., 1988). However, cation/anion uptake ratio has not been characterized across a range of floriculture crops.

Floriculture species differ in tendency to interact with the substrate and raise or lower substrate-pH. In a study with seedlings grown in a peat:perlite substrate, pansy (*Viola* × *wittrockiana* Gams.), petunia, and vinca (*Catharanthus roseus* G. Don) resulted in raised substrate-pH, whereas celosia (*Celosia cristata* L.), tomato (*Lycopersicon esculentum* Mill.), and zinnia (*Zinnia elegans* Jacq.) had lowered substrate-pH (Huang et al., 2001). Johnson et al. (2013) found that geranium was more acidic and lowered substrate-pH compared to petunia which was more basic and resulted in higher pH, with impatiens being intermediate to geranium and petunia. “Sudden pH drop syndrome” in geranium was described by Taylor et al. (2010) as a rapid decrease in substrate-pH triggered by phosphorus (P) deficiency. Reduced P in soilless container substrate and a lack of P in hydroponic solution were correlated with rapid decreases in root zone pH, the suppression of NO_3^--N uptake, and a shift towards greater cation/anion uptake compared to plants grown with adequate P (Taylor et al., 2008a,b, 2010). Intense efflux of H^+ from roots can be an adaptive response to solubilize P in mineral soils when tissue levels become deficient (Marschner, 2012, Ch. 14.4). However, it remains unclear whether the pH drop observed by Taylor et al. (2010) in geranium under low P conditions was an adaptive response resulting from P deficiency, or was a consequence of greater cation/anion uptake after the supply of a macronutrient anion was limited.

The first objective of this study was to determine if net cation or anion uptake was related to solution acidity and basicity in the root zone for three floriculture crops (geranium, impatiens, and petunia). To address this objective, tissue nutrient and substrate-pH data were analyzed from a container study by Johnson et al. (2013) for three basic fertilizers (low NH_4^+-N, high NO_3^--N) applied to geranium, impatiens, and petunia. An experiment was also conducted using hydroponic culture as a model system so that cation/anion uptake over a seven day period could be easily measured by depletion from the nutrient solution. Hoagland’s nutrient solutions were modified so that NH_4^+:NO_3^- ratios of 0:100, 10:90, and 20:80 could be adjusted with little effect on remaining nutrient concentrations. Acidity and basicity produced in milliequivalents (mEq) was calculated by titrating solutions with strong mineral acid or base and was compared to mEq of nutrient ion uptake.

The second objective was to determine whether the proportion of NH_4^+ versus NO_3^- uptake differed between species. Previous research has found that plant species differ in their “preference” for each N form. For example, species that are adapted to low pH soils have greater NH_4^+-N uptake whereas species adapted to high pH calcareous soils have greater utilization of NO_3^--N (Marschner, 2012, Ch. 6.1). To measure depletion of NH_4^+-N versus NO_3^--N from nutrient solutions, geranium, impatiens, and petunia were grown over a broader range of NH_4^+:NO_3^- ratios (0:100, 10:90, 20:80, and 50:50). The experiment was run for two days to ensure that NH_4^+-N was not completely depleted from the 10 to 50% NH_4^+-N solutions.

2. Materials and methods

2.1. Johnson et al. (2013) study (cation/anion balance)

Experimental conditions were described in detail by Johnson et al. (2013). In Spring 2010 at the University of Florida, Gainesville, FL (Latitude: 29.65°N), seedling plugs of geranium ‘Ringo Deep Red’, impatiens ‘Super Elfin Bright Orange’, and petunia ‘Ultra Red’ were transplanted into 6-celled (TJ606, 150 mL per cell) containers. The containers held 70%:30% (v:v) peat:perlite substrate 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% calcium carbonate equivalent (CCE)] at a rate of 2.01 kg m^{-3} to raise substrate pH to approximately 6.0. The peat source was a Canadian sphagnum peat moss (Sun Gro Horticulture, Vancouver, Canada) with long fibers and little dust (von Post scale 1–2; Puustjarvi and Robertson, 1975). At the time of planting, the substrate in each container was moistened with 300 mL of a 7.14 mEq L^{-1} N solution of (in% by mass) 17.0N–2.2P–14.2K–4Ca–1Mg–0.085Fe–0.042Mn–0.021B–0.021 Cu–0.042Zn–0.008Mo (25 NH_4^+:75 NO_3^-) commercial fertilizer solution (Greencare Fertilizers, Kankakee, IL) and plants were top-irrigated as needed with 14.28 mEq L^{-1} N of the same formulation for two weeks prior to starting different fertilizer treatments. Saucers placed underneath each container collected leachate and allowed for re-absorption into the substrate. Species were then grown and irrigated with 18 commercial water-soluble fertilizers ranging in potential acidity and basicity at 7.14 mEq L^{-1} N for four