Influence of nutrient solution pH on hydroponic basil (*Ocimum basilicum*) plant growth and nutrient content

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Abstract

The optimum pH range typically considered for hydroponic nutrient solution is 5.5-6.5. Outside this range, plants tend to show specific nutrient disorders due to nutrient availability and ion competition. Root diseases such as *Pythium* and *Phytophthora* spp. have been shown to be negatively affected by acidic conditions (e.g., pH <5.0). We hypothesize that if nutrient concentrations are adjusted properly based on availability levels at selected low pH, plants can be grown without nutrient disorders while certain root diseases may be suppressed. As the first step towards development of a new nutrient solution management strategy, we determined the influence of lower-than-conventional pH on plant growth and nutrient content as well as the efficacy of mitigating nutrient disorders by adjusting micronutrient concentrations in solution based on known availability levels. 'Nufar' basil plants were grown in a greenhouse hydroponic system. pH was maintained at 5.5, 5.0, 4.5 or 4.0. Two nutrient solutions (with and without micronutrient adjustments) were applied at each pH level, where concentrations of Cu, Zn, Mn, and B were decreased by one-half and Mo concentration was doubled in the adjusted solution. After 20-21 days, plants were harvested for analysis. Leaf concentration of P, Ca, Mg, S, Fe, Mn, B, Cu, and Zn decreased with decreasing pH, whereas K displayed the opposite trend, and N and Mo concentration did not display a consistent trend across selected pH. Micronutrient adjustments were effective in decreasing uptake of Mn and Cu. To our surprise, basil plants can grow at pH as

low as 4.0 without showing significant reduction in growth (shoot mass, root mass, stem mass, height and number of leaves) or symptoms of nutrient disorders. A follow-up study is currently underway to determine if this management strategy of growing basil at pH 4.0 is effective in limiting growth of pathogenic organisms in nutrient solution.

INTRODUCTION

In the United States, 94.7% of leafy greens are grown in California and Arizona and 62% of fresh herbs are grown in California, New Jersey, and Texas (Farming Leafy Greens, 2012; USDA NASS, 2012). This consolidation of production necessitates long distance transportation to consumers across the country, contributing to greenhouse gas emissions and food waste due to the highly perishable nature of leafy greens and fresh herbs. Hydroponic leafy green and herb production in controlled environments combats this problem by allowing fresh produce to be grown in densely populated areas, closer to the point of consumption. In addition to localized production, this form of agriculture allows year-round production, high yields and quality, ergonomic working conditions, reduced pesticide and water use, and sanitary growing conditions that reduce the risk of produce being contaminated by food borne illnesses like *E. coli.* In recent years, technological and scientific advances, like the increased efficiency of light emitting diodes have made leafy green and herb production in controlled environments more profitable and viable than ever before.

One of the biggest challenges faced in hydroponic leafy green production is the occurrence of root disease from pathogenic oomycete species of *Pythium* and *Phytophthora*. Once these pathogenic organisms establish an infection, control and treatment options are minimal for edible crops. As a result, growers often suspend production and disinfect growing systems, leading to decreased yields and profit, changes to crop schedules, and increased labor (Stanghellini, 1996).

While these pathogens can infest virtually all leafy greens, certain species such as basil (*Ocimum basilicum*) and spinach (*Spinacia oleracea*) are known to be more susceptible than others (Mattson, 2018).

In vitro and *in vivo* studies have documented the effect of environmental conditions on *Pythium* and *Phytophthora* spp. growth and reproduction, but few *in vivo* studies have documented the effect of pH on these organisms in hydroponic systems. For example, *in vitro* pH studies on *Pythium* and *Phytophora* spp. have shown that growth and development of these pathogens are negatively affected by acidic conditions (pH < 5.0) (El-Sharouny, 1983; Ho and Hickman, 1967). However, this acidic pH range is typically avoided for hydroponic nutrient solution, since lower-than the conventional pH (5.5-6.5) tends to induce specific nutrient disorders due to availability of nutrients in hydroponic nutrient solution and ions competing for uptake and cellular binding sites on plant roots (Mengel et al., 2001; Fageria, 1983; Peterson et al., 1984; Hawf and Schmid, 1967). For example, Voogt and Sonneveld (2009) found that there was a tendency for Mn, Zn, and Cu contents to increase and for Mo content to decrease with decreasing pH when rose plants were grown in rockwool and provided nutrient solution (pH 7.0, 5.8, and 4.0 were tested in referred study). Of interest, according to Bugbee (2004) the effect of pH on plants roots is not detrimental, rather issues occur due to nutrient availability outside the typical pH range of 5.5-6.5 and although some nutrient's availability may become reduced outside the typical pH range, this does not always lead to nutrient disorder. If plants can grow under a pH lower than 5.0, the risk of crop failure due to these water-borne pathogens might be largely reduced. Nevertheless, specific responses of leafy greens to low pH and possible mitigation of nutrient disorder under low pH by adjusting nutrients likely causing disorders are not known.

In the present experiment, we examined lower-than-conventional nutrient solution pH with selected micronutrient adjustment for 'Nufar' basil plants grown hydroponically in a greenhouse. Our hypothesis was that basil plants will not exhibit nutrient disorders or yield reductions, when adjustments are made to micronutrient concentrations in nutrient solution to account for decreased/increased availability of nutrients.

MATERIALS AND METHODS

Experimental Design

This study was conducted in a 93 m^2 glass glazed greenhouse in Columbus, Ohio. The experiment was conducted twice (July 2018 and September 2018) using a randomized complete block design with a 2 x 4 factorial treatment structure. Treatments included two nutrient solutions (standard and adjusted, as described below) for each of four pH levels (4.0, 4.5, 5.0, 5.5) with two replications (containers) in each trial.

Water Treatment

Municipal water was used as the water source but was disinfected with ultraviolet (UV) radiation (D4+ Whole Home UV Water Disinfection System; Viqua, Guelph, Ontario, Canada). In addition, all water provided to seedlings at the germination and pre-transplant stage was treated with reverse osmosis (RO) and 0.5 mg L^{-1} Kleengrow fungicide. Water used in the hydroponic deep-water culture (DWC) units was only treated with UV. In addition, water used in DWC units was dechlorinated by addition of 2.5 mg L^{-1} of sodium thiosulfate. This was done to avoid chlorine phytotoxicity from municipal source water that has been observed in past experiments.

Plant Material, Propagation, and Greenhouse Environment

'Nufar' seeds (Johnny's Selected Seeds, Fairfield, Maine, USA) were sown in 2.5-cm rockwool plug sheets (Grodan AO plugs 25x40; Grodan, Roermond, The Netherlands). Rockwool sheets were then placed in white plastic undertrays and hydrated with RO water containing 0.5 mg L^{-1} Kleengrow fungicide and allowed to drain prior to seeding. After seeding, trays were placed in a dark environment inside the growth chamber (Model 2015; VWR International, Radnor, PA, USA) with an air temperature of 23 °C. After radical emergence was observed, Rockwool sheets were covered with sifted vermiculite and moved to the greenhouse for the remainder of the experiment. Greenhouse day and night air temperatures were targeted at 24/16 °C respectively. Seedlings were sub-irrigated as needed until transplant, with RO water containing 0.5 mg L^{-1} Kleengrow fungicide. pH of water provided to seedlings prior to transplant was ~6.4. When cotyledons were fully expanded, 12 uniform plants were transplanted into each DWC unit.

Hydroponic Systems and Nutrient Solution

Each DWC unit consisted of 0.78 m long, 0.51 m wide, and 0.37 m tall black plastic container (Centrex Plastics, LLC Commander 27-Gallon Black Tote; Centrex Plastics, Findlay, OH, USA) and a polystyrene foam raft (Beaver Plastics 72"; Beaver Plastics, Acheson, Alberta, Canada) cut to match the size of container. Each DWC unit contained 90 liters of nutrient solution made using dechlorinated and UV radiated water as described previously. The large volume to plant ratio (3.75 L $plant^{-1}$) was to act as a buffer in attempts to minimize pH fluctuations. Nutrient solution was continuously aerated by one air stone connected to a small aquarium air pump.

One-half strength University of Arizona leafy crop nutrient solution recipe (Jensen, unpublished) (electrical conductivity ~1.4 dS m^{-1}) was used as the basal formula in this experiment.

Elemental concentrations are shown in Table 1. For the adjusted nutrient solution, Mn, B, Zn and Cu, concentrations were decreased by one half, while Mo concentration was doubled. Prior to transplant, nutrient solution pH was adjusted to setpoints 5.5 (control), 5.0, 4.5, and 4.0 and was manually adjusted thereafter as needed by the addition of sulfuric acid or sodium hydroxide to maintain pH within range of ± 0.25 of target pH. Nutrient solution was discarded and replaced 11 days after transplant in trial 1 and 14 days after transplant in trial 2 in order to maintain nutrient concentrations in solution close to target levels.

Table 1. Elemental concentrations of nutrient solutions (all values in mg L^{-1}).

Nutrient Solution	**NO_3-N**	**P**	**K**	**Ca**	**Mg**	**S**	**Fe**	**Cl**	**Mn**	**B**	**Zn**	**Cu**	**Mo**
Standard Nutrient Solution	90	25	100	120	20	26	1.20	30	0.27	0.16	0.10	0.03	0.02
Adjusted Nutrient Solution	90	25	100	120	20	26	1.20	30	0.13 (50%)	0.08 (50%)	0.05 (50%)	0.01 (50%)	0.05 (100%)

Data Collection

T-type thermocouples were placed in the center of each block at plant canopy level for monitoring air temperature (gauge 36; Omega Inc., Stamford, CT, USA) and submerged in nutrient solution (gauge 24; Omega Inc., Stamford, CT, USA) of the middle DWC unit of each block for monitoring nutrient solution temperature. Relative humidity was measured with an aspirated temperature and humidity probe (HMP60 Humidity and Temperature Probe; Vaisala Corporation, Helsinki, Finland) located in the middle of the growth chamber at plant canopy level. A quantum sensor (LI-800, LI-COR Biosciences, Lincoln, NE, USA) was placed at the center of each block

to measure photosynthetic photon flux density (PPFD) and daily light integral (DLI). Sensors were connected to dataloggers (CR10X and CR1000 dataloggers; Campbell Scientific, Logan, UT) and sensor readings were scanned every 10 seconds to record averages each 15 min.

Basil plants were grown for 20 days (trial 1) 21 days (trial 2) after transplanting and harvested for quantifying shoot and root growth and assessing visible symptoms of nutrient disorders and stunted growth. Fresh and dry leaf, stem, and root mass, and number of leaves per plant were recorded for 8 plants per replication (excluding border plants). Plant material was dried in a drying oven at 55 °C for a minimum of one week. Additionally, once dry weights were recorded, leaf tissue samples of 8 plants were combined into one sample and sent to a commercial analytical lab (JR Peters, Allentown, PA, USA) to determine nutrient concentrations of leaf tissue. Nutrient solution samples were also analyzed three times per trial: immediately following transplant and pH adjustment, before discarding the solution in the middle of experiment, and at the conclusion of the trial.

Data analysis

As no interaction between plant growth responses and trial were present, two trial data were compiled and analyzed as one data set. Plant growth data (fresh/dry mass, height, and leaf number) were evaluated with a two-way ANOVA using Tukey HSD mean separation ($P < 0.05$) for analyzing main factors and interaction. Fresh root mass data were transformed using a box-cox transformation ($\lambda = -0.921$) to better fit the assumptions of ANOVA. Regression analysis was performed for pH effect on plant growth responses but is not presented due to lack of significance and trend observed. All statistical analyses were performed using JMP software (SAS Institute, Cary, N.C.). Leaf tissue samples results were also complied and analyzed as one data set but were

not statistically analyzed due to the small sample size and the fact that biological significance does not always agree with statistical significance when observing nutrient content data.

RESULTS AND DISCUSSION

Greenhouse environment and experimental solution pH

Table 2. Mean environmental parameters ± standard deviation.

	Air temperature (°C)	**Nutrient solution temperature (°C)**	**DLI (mol m^{-2} d^{-1})**	**VPD (kPa)**
Trial 1	Day: 24.45 ± 1.77 Night: 22.63 ± 1.80	Day: 26.19 ± 2.14 Night: 26.00 ± 2.29	14.09 ± 6.37	Day: 0.80 ± 0.28 Night: 0.40 ± 0.19
Trial 2	Day: 24.21 ± 3.00 Night: 22.45 ± 2.94	Day: 26.28 ± 3.01 Night: 26.40 ± 2.86	14.18 ± 7.02	Day: 0.87 ± 0.42 Night: 0.41 ± 0.22

Table 3. Mean pH, electrical conductivity, and dissolved oxygen of nutrient solution in trial 1.

Treatment	**pH**	**Electrical conductivity**	**Dissolved oxygen**
4.0-A	4.10 ± 0.15	1.39 ± 0.03	7.62 ± 0.55
4.0-S	4.13 ± 0.16	1.39 ± 0.02	7.77 ± 0.43
4.5-A	4.55 ± 0.20	1.39 ± 0.02	7.73 ± 0.38
4.5-S	4.50 ± 0.19	1.4 ± 4.56 x 10^{-16}	7.63 ± 0.31
5.0-A	4.96 ± 0.23	1.38 ± 0.04	7.63 ± 0.43
5.0-S	4.97 ± 0.21	1.39 ± 0.02	7.26 ± 0.73
5.5-A	5.41 ± 0.13	1.38 ± 0.04	7.44 ± 0.38
5.5-S	5.44 ± 0.14	1.39 ± 0.03	7.47 ± 0.54

Table 4. Mean pH, electrical conductivity, and dissolved oxygen of nutrient solution in trial 2.

Treatment	pH	Electrical conductivity	Dissolved oxygen
4.0-A	4.02 ± 0.13	1.46 ± 0.05	7.84 ± 0.48
4.0-S	4.02 ± 0.11	1.46 ± 0.05	7.79 ± 0.49
4.5-A	4.49 ± 0.09	1.41 ± 0.04	7.84 ± 0.52
4.5-S	4.51 ± 0.08	1.41 ± 0.07	7.81 ± 0.42
5.0-A	4.91 ± 0.15	1.41 ± 0.03	7.84 ± 0.48
5.0-S	4.91 ± 0.12	1.41 ± 0.04	7.81 ± 0.48
5.5-A	5.38 ± 0.25	1.39 ± 0.04	7.82 ± 0.53
5.5-S	5.49 ± 0.10	1.41 ± 0.03	7.78 ± 0.42

Plant Growth

Throughout the duration of both trials no difference in growth or symptoms of nutrient disorders were observed across treatments (Table 4., Fig. 1., and 2.). These data show that basil can be grown in pH as low 4.0 without reducing shoot and root mass, number of leaves per plant, and plant height.

Research has shown that soil solution pH limits are rather wide and that if pH exceeds 3.0 (at pH below 3.0 cell membranes typically become impaired and more permeable), soil pH is usually not the primary factor limiting growth, but one or more pH dependent secondary factors are responsible for limiting growth (Mengel and Kirkby, 1982). pH dependent factors that may limit plant growth in acidic soils include, increased solubility and toxicity of polyvalent ions (Al^{3+}, Fe^{3+}, Mn^{3+}) in soil solution, and decreased concentration of plant available nitrogen due to decreased activity of nitrogen fixing microorganisms (Mengel and Kirkby, 1982). For example, Vlamis, (1953) showed that barley yields decreased by 214 mg at pH 4.2 and Al^{3+} concentration

of 1.8 mg L^{-1} in the nutrient medium compared to pH 5.8 and Al^{3+} concentration of 0.30 mg L^{-1}, but yield was only decreased by 38 mg at pH 4.2 when Al^{3+} concentration was lowered to 0.35 mg L^{-1}. These results clearly demonstrate that reduced growth was mainly attributed to Al^{3+} concentration in this situation. Another example of this kind of relationship was shown in *Picea*, which grows poorly in acidic soils, but can grow well in nutrient solution maintained at pH 3.3 if nitrate nitrogen is provided (Evers, 1963 *apud* Mengel and Kirkby, 1982). In this case, poor growth in acidic soils was due to the decreased activity of soil microorganisms responsible for the production of nitrate (Evers, 1963 *apud* Mengel and Kirkby, 1982). In addition to these factors, acidic soils are typically deficient in most major elements (N, P, K, Ca, and Mg), further supporting the argument that pH dependent secondary factors play a large role in limiting plant growth in acidic soils (Rorison, 1980). The extent in which these pH dependent factors affect plant growth is largely species specific (Mengel and Kirkby, 1981). Klapp (1951) determined the optimum pH of various crop species grown in a temperate climate soil. Optimum pH ranges were rather wide, with alfalfa (*Medicago sativa*) growth optimized at pH 6.5-7.4 and lupin (*Lupinus* spp.) growth optimized at pH 4.1-5.5 (Klapp, 1951 *apud* Mengel et al. 2001).

One reason that certain plants may be able to grow in these acidic conditions could be due to low nutrient requirements or efficient uptake of nutrients, or a combination of both (Rorison, 1980), which may be the case for basil. Basil's low nutrient requirement is further supported by the work done by Walters and Currey (2018), which showed that basil growth in terms of fresh and dry mass, height, and node and branch number were not affected by electrical conductivities levels of 0.5-4.0 dS m^{-1}, tested at 0.5 increments. These data coupled with the results of the present study, indicate that basil's low nutrient requirement may explain its tolerance to acidity and that nutrient solution pH and EC do not play a large role in influencing basil plant growth. Basil's

seemingly low nutrient requirement may be advantageous if lower-than-conventional nutrient solution pH is effective in limiting pathogenic organism growth.

It should also be noted that the present studies' data were collected after 21 days of growth, which is around the typical time most commercial operations will cut and harvest basil in a way that allows for successive harvests. It would be interesting to determine if these results could be replicated after performing multiple harvests and allowing plants to grow for a longer duration.

Table 4. P value generated for each parameter using two-way ANOVA

Factor	Height	Number of leaves	Fresh leaf mass	Fresh stem mass	Fresh root mass[2]	Dry leaf mass	Dry stem mass	Dry root mass
pH	0.90	0.18	0.35	0.69	0.62	0.30	0.54	0.14
Nutrient solution	0.51	0.96	0.24	0.31	0.69	0.68	0.52	0.68
pH*Nutrient solution	0.98	0.95	0.78	0.93	1.00	0.97	0.89	0.74

[1]two-way ANOVA

[2] Fresh root mass transformed using box-cox transformation (λ=-0.921)

Figure 1. ‘Nufar’ grown in pH 5.5-standard nutrient solution

Figure 2. ‘Nufar’ grown in pH 4.0-standard nutrient solution

Nutrient Solution Adjustment and Leaf Nutrient Concentration

As, stated previously no symptoms of nutrient disorders were observed across treatments. Micronutrient adjustments made to the nutrient solution proved to be effective in decreasing leaf concentration of Mn and Cu but was not effective in decreasing leaf concentration of B and Zn or increasing leaf concentration of Mo (Table 5.). In fact, B and Zn leaf concentration increased and Mo leaf concentration decreased in the adjusted nutrient solution. It is not clear what caused these results, but in the case of Zn, target concentration in solution was exceeded and was only decreased by 26% (average decrease of trial 1 and 2) in adjusted solution as opposed to the targeted 50% reduction. This is likely a result of Zn contamination from other fertilizer salts and likely contributed to this unexpected outcome.

Table 5. Mean leaf nutrient concentration ± standard error (all values in mg kg^{-1}).

Nutrient solution	Mn	B	Cu	Zn	Mo
Standard nutrient solution	79.27 ± 5.84	26.05 ± 1.03	10.58 ± 1.64	86.49 ± 6.85	10.77 ± 2.43
Adjusted nutrient solution	59.79 ± 4.76	28.42 ± 1.12	9.23 ± 1.44	91.49 ± 7.92	9.75 ± 1.96

Leaf concentration of P, Ca, Mg, S, Fe, Mn, B, Cu, and Zn showed a consistent decrease in concentration as pH decreased (Table 6. and 7.). Leaf concentration of K displayed the opposite trend, where concentration increased with decreasing pH (Table 6. and 7). Nitrogen and Mo did no display a consistent trend, but leaf concentration of N was highest at pH 4.0 and lowest at pH 5.0 and Mo concentration was highest at pH 5.0 and lowest at pH 4.0 (Table 6. and 7.). It was unexpected to observe a consistent decrease of Mn, B, Cu, and Zn with decreasing pH, as known availability levels and reports of toxicities of these nutrients suggest that leaf concentration of these nutrients would increase as pH decreased (Voogt and Sonneveld, 2009). As stated previously, the adjustment made to the nutrient solution was effective in decreasing Mn and Cu leaf concentration of plants grown in the adjusted nutrient solution, which could contribute to this result, but this does not explain the decrease in B and Zn concentration. In substrate and soil solution, toxicities of positively charged metal ions at low pH occur due to decreased adsorption to negatively charged colloids as pH decreases. This is not the case for water culture hydroponic systems and the decrease in nutrient content is likely due to increased competition for uptake and cellular bindings sites on root surfaces brought on by the increased concentration of H^+ ions as pH decreases, similar to what Peterson, Healey, and Wagemann (1984) observed with algae uptake. For this reason, hydroponic water culture specific nutrient availability charts are necessary to develop.

Although leaf concentration of most nutrients did decrease with decreasing pH, no visible nutrient disorders or differences in growth were observed, indicating that adjusting micronutrient concentrations in nutrient solution was not necessary to avoid nutrient disorders or impact plant growth. The fact that reduced nutrient content did not correlate with a reduction in growth, further supports the assertion that basil's apparent low requirement is responsible for its tolerance to the acidic conditions tested in the present study.

It should be noted that Al leaf concentration of plants grown in pH 4.0 were relatively higher than plants grown at other pH levels tested. It is well documented that Al toxicity occurs in plants grown in acidic soils, but this is not a common issue in hydroponic crop production. However, if Al is present in source water or components of hydroponic systems, this may be a cause for concern and should be accounted for if crops are being grow in similar low pH conditions.

Table 6. Mean leaf nutrient concentration ± standard error (N, P, K, Ca, and Mg in %, S in mg kg^{-1}).

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (mg L^{-1})
4.0-A	6.05 ± 05.4	1.20 ± 0.04	4.94 ± 0.15	1.18 ± 0.07	0.32 ± 0.02	2721.50 ± 137.51
4.0-S	5.70 ± 0.59	1.06 ± 0.04	4.75 ± 0.15	1.07 ± 0.04	0.29 ± 0.01	2472.00 ± 196.52
4.5-A	4.97 ± 0.09	1.26 ± 0.05	4.77 ± 0.13	1.40 ± 0.05	0.37 ± 0.02	2705.25 ± 124.72
4.5-S	5.32 ±0.10	1.14 ± 0.03	4.97 ± 0.15	1.39 ± 0.13	0.37 ± 0.01	2539.00 ± 205.83
5.0-A	5.47 ± 0.48	1.35 ± 0.02	4.50 ± 0.14	1.89 ± 0.20	0.42 ± 0.03	3608.50 ± 257.61
5.0-S	4.71 ± 0.26	1.27 ± 0.04	4.56± 0.07	1.86 ± 0.08	0.38 ± 0.01	3281.00 ± 189.28
5.5-A	4.98 ± 0.28	1.44 ± 0.05	4.13 ± 0.06	2.51 ± 0.04	0.43 ± 0.03	4196.25 ± 216.21
5.5-S	5.76 ± 0.50	1.36 ± 0.06	4.37 ± 0.07	2.47 ± 0.03	0.43 ± 0.02	4106.00 ± 221.19

Table 7. Mean leaf nutrient concentration ± standard error (mg kg^{-1}).

Treatment	Fe (mg L^{-1})	Mn (mg L^{-1})	B (mg L^{-1})	Cu (mg L^{-1})	Zn (mg L^{-1})	Mo (mg L^{-1})	Na (mg L^{-1})	Al (mg L^{-1})
4.0-A	94.33 ± 6.35	40.24 ± 2.69	26.52 ± 2.16	8.61 ± 3.06	55.97 ± 6.85	9.60 ± 5.33	618.21 ± 118.74	61.97 ± 26.13
4.0-S	91.47 ± 11.42	52.07 ± 3.56	23.31 ± 2.16	7.95 ± 3.05	54.75 ± 3.20	8.41 ± 4.98	674.18 ± 170.39	50.62 ± 10.66
4.5-A	96.48 ± 10.02	52.14 ± 5.65	27.16 ± 2.33	8.12 ± 3.03	77.98 ± 7.29	9.93 ± 2.88	969.92 ± 283.76	33.37 ± 20.09
4.5-S	93.08 ± 12.10	74.11 ± 8.79	26.86 ± 2.75	9.34 ± 3.07	80.17 ± 8.83	10.71 ± 3.81	582.85 ± 168.12	20.35 ± 6.30
5.0-A	103.41 ± 9.98	68.11 ± 9.91	29.48 ± 3.18	8.91 ± 3.38	104.48 ± 9.86	11.61 ± 4.03	1268.55 ± 762.11	20.61 ± 8.80
5.0-S	97.52 ± 8.29	87.31 ± 8.06	26.56 ± 1.79	10.68 ± 4.17	94.57 ± 9.36	12.50 ± 7.51	703.09 ± 346.89	19.82 ± 7.16
5.5-A	118.36 ± 7.16	78.67 ± 5.27	30.52 ± 1.18	11.3 ± 3.09	127.55 ± 9.23	7.87 ± 4.64	819.98 ± 331.16	40.37 ± 32.14
5.5-S	110.75 ± 4.11	103.58 ± 7.26	27.47 ± 1.56	14.3 ± 3.18	116.46 ± 9.64	11.48 ± 4.40	509.34 111.29	26.39 ± 19.27

CONCULSION

The results of the present study indicate that ‘Nufar’ basil plants can be grown at pH as low as 4.0 without significantly reducing plant growth and without the occurrence of visible nutrient disorders. With the exception of N, K, and Mo, leaf nutrient concentration decreased with decreasing pH, however this decrease did not result in reduced plant growth or visible nutrient disorders, which may be attributed to basil’s seemingly low nutrient requirement. The decrease in nutrient content as pH decreased is likely due to increased cation uptake competition as pH decreased and H^+ concentration in solution increased. Adjustments made to the nutrient solution were effective in decreasing leaf concentration of Mn and Cu but were not effective in decreasing B and Zn concentration and increasing Mo concentration. However, micronutrient adjustments to nutrient solution do not seem to be necessary, as nutrient disorders were not observed in either nutrient solution and adjustment did not impact plant growth. More work in this area is needed to determine if these results can be replicated over a longer growing duration and to develop nutrient availability ranges specific for hydroponic water culture systems.

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