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Lime, Water Source, and Fertilizer Nitrogen Form Affect Medium pH and Nitrogen Accumulation and Uptake

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Abstract. **Hybrid impatiens (*Impatiens wallerana* Hook. F.) were planted into media containing two dolomitic liming materials {hydrated [$Ca(OH)_2$ and $Mg(OH)_2$] or carbonate ($CaCO_3$ and $MgCO_3$) lime} and subirrigated for 17 weeks with four irrigation water sources (IWS) and three water-soluble fertilizers (WSF). The WSF contained 200N–20P–200K mg·L^{-1} but varied in NH_4^+-N content (50%, 25%, or 3%, respectively). Depending on the IWS and lime type used in the media, root-medium pH ranged from 4.5 to 6.0, 4.8 to 7.1, and 6.0 to 8.5 when treated with WSF containing either 50%, 25%, or 3% NH_4^+-N, respectively, between 8 and 17 weeks after planting. The accumulation of NH_4^+-N and NO_3^--N in the root medium was different for treatments receiving the same WSF and depended on root-medium pH. The critical root-medium pH for NH_4^+-N accumulation was between 5.4 and 5.7, and for NO_3^--N, accumulation was between 5.3 to 5.9. Above this pH, minimal NH_4^+-N concentrations were measured in the medium, even with 50% or 25% NH_4^+-N WSF, while below this pH, NH_4^+-N began to accumulate in the medium with a corresponding decrease in the NO_3^--N concentration. The NH_4-N : NO_3-N ratios in the WSF had minimal effect on shoot fresh and dry weights. Tissue N concentration was higher with the higher NH_4-N : NO_3-N ratio WSF at all four sampling dates. There was a linear relationship between higher tissue N and lower root-medium pH with the same WSF, possibly due to differences in the ratio of NH_4-N : NO_3-N actually taken up by the plant.**

The pH of container root media influences macronutrient and micronutrient solubility and uptake (Lucas and Davis, 1961; Peterson, 1981). One of the most important aspects of pH management in container-grown crops is the ratio of NH_4-N : NO_3-N in the water-soluble fertilizer (WSF). Fertilization with NO_3^--N can cause the medium pH to increase because of OH^- or HCO_3^- transport associated with balancing ion uptake. In comparison, fertilization with NH_4^+-N can cause the medium pH to decrease because of H^+ transport during ion uptake and nitrification of NH_4^+-N to NO_3^--N within the medium, which also releases H^+ (Barker and Mills, 1980; Bunt, 1988; Marschner, 1986).

The pH of peat- and bark-based container media in turn affects nitrification rates. Niemiera and Wright (1986b) found that the application of a dolomitic carbonate lime at 3 or 6 kg·m^{-3} before planting resulted in a pH >5.5 and an increase in NO_3^--N concentrations in the medium of plants periodically fertilized with NH_4^+-N at 100 mg·L^{-1} from $(NH_4)_2SO_4$. In comparison, the medium pH for lime at 0 kg·m^{-3} was <5.5 and there were no measurable levels of NO_3^--N. Lang and Elliott (1991) reported that ammonium oxidation rate in a peat-based medium was insignificant at a pH of <5.6. However, tissue N was not reported in either of these two studies.

Nitrogen availability reportedly is unaffected by root-medium pH (Lucas and Davis, 1961; Peterson, 1981). However, N uptake and assimilation can be influenced by the N form, ion balance in the soil solution, and carbon status of the plant (Barker and Mills, 1980; Marschner, 1986). In bark-based media containing a nitrification inhibitor, Niemiera and Wright (1986a) measured higher medium NH_4^+-N concentrations and higher tissue N in two of three woody plant species compared to that of plants grown in the same medium without the nitrification inhibitor. In addition, N form can affect plant morphology. Bailey et al. (1996) suggested that plants grown with WSF containing 15% to 40% NH_4^+-N will have larger leaves and longer internodes than plants fertilized with a WSF containing <15% NH_4^+-N.

Argo and Biernbaum (1996) grew impatiens using three WSF (50%, 25%, or 3% NH_4^+-N) in conjunction with four water sources and two media containing different types of lime to obtain root-medium pHs from 4.5 to 8.5 after 8 weeks of growth. The higher the NH_4^+-N content of the WSF, the lower the pH. However, because of the interactive effects of the WSF with the irrigation-water source (IWS) and lime type, medium pH varied by >2.5 units in treatments receiving the same WSF. Shoot dry weight was similar for all treatments. The objective of this report is to present relationships between root-medium pH, NH_4^+-N and NO_3^--N accumulation, and N uptake by impatiens.

Materials and Methods

Lime. The two liming materials varied in reactivity and incorporation rate. A microfine dolomitic hydrated lime [97% $Ca(OH)_2$·MgO; National Lime and Stone, Findlay, Ohio], in which 92% of the material passed through a 45-µm (#325) screen, was incorporated at 1.5 kg·m^{-3}. A superfine dolomitic carbonate lime (99.5% $CaCO_3$·$MgCO_3$; National Lime and Stone), in which 65% of the material passed through a 75-µm (#200) screen, was incorporated at 8.4 kg·m^{-3}.

The root medium used was (by volume) 70% Canadian sphagnum peat (Fisons professional black bale peat; Sun Gro Horticulture, Bellevue, Wash.) with long fibers and little dust (Von Post scale 1–2; Puustjarvi and Robertson, 1975), and 30% perlite. A preplant nutrient charge (PNC) consisting of 0.6 kg each of $Ca(NO_3)_2$, KNO_3, triple superphosphate (0N–19.8P–0K), and gypsum; 0.3 kg $MgSO_4$; 0.07 kg fitted trace elements (FTE 555; Scotts, Marysville, Ohio); and 0.2 L of a wetting agent (Aquagro 2000 "L"; Aquatrols, Pennsaulken, N.J.) per cubic meter of medium, in addition to the lime, were added at mixing. Sufficient water obtained by reverse osmosis (RO) purified water was added at mixing to bring the moisture content of the medium to 40% to 50% of container capacity, and the medium was allowed to equilibrate for 3 days before planting. At planting, the hydrated lime treatments had a pH of 6.1, NO_3^--N at 220 mg·L^{-1}, and NH_4^+-N at 14 mg·L^{-1}; while the carbonate lime treatments had a pH of 5.5, NO_3^--N at 220 mg·L^{-1}, and NH_4^+-N at 13 mg·L^{-1}, based on the saturated-medium extract (SME) method with RO water as the extractant (Warncke, 1986).

Irrigation-water source (IWS). The high-alkalinity water source (well water) had a pH of 7.8 and a titratable alkalinity to pH 4.5 (Chau, 1984) with $CaCO_3$ at 320 mg·L^{-1}. The low-alkalinity water source was RO purified well water, which had a pH of 5.5 and a titratable alkalinity to pH 4.5 with $CaCO_3$ at <20 mg·L^{-1}. The third type of water (acidified water) was produced by adding H_2SO_4 (93%) to the well water and had a pH of 5.8 and a titratable alkalinity to pH 4.5 with $CaCO_3$ at 120 mg·L^{-1}. The fourth irrigation water (well + RO water) was produced by blending well and RO water (1:1.5 by volume) and had a pH of 6.8 and a titratable alkalinity to pH 4.5 with $CaCO_3$ at 130 mg·L^{-1}.

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Water-soluble fertilizer (WSF). Fertilizer concentrations of N–P–K were maintained at (in mg·L^{-1}) 150N–15P–150K for the first 2 weeks and increased to 200N–20P–200K for the remainder of the experiment. The three WSF varied in the ratio of NH_4-N : NO_3-N, with WSF 1 containing 50% NH_4^+-N and 50% NO_3^--N; WSF 2, 25% NH_4^+-N and 75% NO_3^--N; and WSF 3, 3% NH_4^+-N and 97% NO_3^--N.

Plant culture. The experiment was started on 15 Feb. 1994 at Michigan State Univ., East Lansing, in two well-ventilated glass greenhouse sections with constant air circulation and cement floors. One hybrid impatiens plug ('Super Elfin Violet') from a 512-cell plug tray was planted in a 9-cm-tall × 12.5-cm-wide (0.75-L) plastic pot containing medium with one of the two lime types. Twenty-five pots containing medium with each lime type were placed on one of 12 flood subirrigation bench sections in each of the two greenhouses. Both lime types were placed on the same bench section.

Plants on each bench section were irrigated as needed. The time to irrigate was determined gravimetrically when the average mass of six randomly selected pots containing plants and medium (three from each lime treatment) reached a target mass based on a loss of 40% to 50% of the available water. The same six pots were checked daily for the target mass, and when it was reached, nutrient solutions were applied. During an irrigation, benches were filled from a 70-L reservoir for 2 min to a maximum depth of 2.5 cm and drained in 6 min to the same reservoir. The difference between the mass of the pots before and after the irrigation was the amount of water absorbed by the medium. The amount of nutrients applied per pot was calculated as the sum of the absorbed nutrient solution multiplied by the concentration applied for each irrigation. The nutrient solutions in the 70-L reservoirs were emptied and prepared fresh weekly.

Root media were sampled initially and collected from four randomly selected pots (two per treatment from each bench section) at 1, 4, 8, 12, and 17 weeks after planting. All the medium was removed from each pot and separated horizontally into two samples, one containing the top 2.5 cm (top layer) and the other containing the remaining medium from the pot (root zone). Nutrients contained in each medium sample were tested using the SME method with RO purified water as the extractant (Warncke, 1986). Medium pH was determined by inserting the pH electrode directly into the paste. Medium NO_3^--N and NH_4^+-N were determined colorimetrically (Diamond, 1986a, 1986b) in the extracted solution. The NH_4^+-N and NO_3^--N concentrations in the nutrient solutions after 1 week in the reservoirs also were tested three times during the course of the experiment and showed no change.

Shoot dry mass and shoot-tissue nutrient analysis were determined for the same four sample plants per treatment at 4, 8, 12, and 17 weeks after planting. At week 4, the entire plant was sampled. For the remaining plants for later sample dates, all shoots were pinched, leaving one internode per stem and four to six stems per plant. At all subsequent sampling dates, only growth after the pinch was sampled. Total tissue N was determined with column chromatography at Fafard Analytical Laboratories, Athens, Ga.

Shoot-tissue N data were analyzed using SAS's analysis of variance (ANOVA) procedures (SAS Institute, Cary, N.C.) as a 2 × 4 × 3 split-plot factorial with lime type as the main plot and the other factors as subplots at each sampling date. Statistical relationships were developed between root-medium pH and shoot-tissue N using the linear regression procedure (REG) from SAS. Relationships were developed between root-medium pH and root-medium NH_4^+-N and NO_3^--N using the intersecting straight line model proposed by Anderson and Nelson (1975), with multiphase functions proposed by Fisher (1995). The functions used were

$$X_{intersection} = \frac{I_2 - I_1}{S_1 - S_2} \quad [1]$$

$$\text{If: } X < X_{intersection}, \text{ then: } Y = S_1X + I_1 \quad [2]$$

$$\text{If: } X > X_{intersection}, \text{ then: } Y = S_2X + I_2 \quad [3]$$

where the X value is root-medium pH, Y is the root-medium NH_4^+-N concentration in mg·L^{-1}, and $X_{intersection}$ is the intersection point of the two lines where the Y values are equal. The $X_{intersection}$ was calculated using Eq. [1], and S and I are the slope and Y-intercept of Eqs. [2] and [3], respectively. Initial estimates for the parameters were obtained from a graph of the observed data. Estimates for S_1, I_1, S_2, and I_2, based on root-medium pH, were obtained using SAS's nonlinear regression procedure (NLIN).

Results and Discussion

A total of 1.6 to 1.8 g N per pot was applied over the 17 weeks of the experiment (data not shown). However, there were no consistent differences in the total amount of N applied between treatments. The total concentration of N (NH_4^+-N and NO_3^--N) in the root zone decreased from an average of 234 mg·L^{-1} at planting to 88 mg·L^{-1} at week 1, with a corresponding increase in the top layer of the pot. Argo and Biernbaum (1996) and Yelanich (1995) found that nutrients contained in the top layer of the pot had minimal influence on the root-zone nutrient concentrations and plant uptake with subirrigation. After week 1, the total concentration of N in the root zone increased for the remainder of the experiment, reaching an average concentration of 153 mg·L^{-1} at the end of the experiment.

After week 4, the accumulation of NH_4^+-N and NO_3^--N in the root medium differed for treatments receiving the same WSF and depended on root-medium pH (Fig. 1, Table 1). For example, for the treatments receiving the WSF containing 50% NH_4^+-N and 50% NO_3^--N, the concentration of NH_4^+-N measured in the root medium ranged from 2 to 55 mg·L^{-1}, and that of NO_3^--N ranged from 60 to 160 mg·L^{-1} by the week 17 sampling date. The critical root-medium pH for NH_4^+-N accumulation was between 5.4 and 5.7, and for NO_3^--N, it was between 5.3 to 5.9 (Table 1). Above this pH, minimal NH_4^+-N concentrations were measured in the medium, even with 50% or 25% NH_4^+-N WSF, while below this pH, NH_4^+-N began to accumulate in the medium with a corresponding decrease in the NO_3^--N concentration. The critical medium pH represents the point at which nitrification within the medium was inhibited in this experiment and is similar to 5.5 to 5.6 reported in other studies (Lang and Elliott, 1991; Niemiera and Wright, 1986b).

The ratio of NH_4-N : NO_3-N in a WSF is an important indicator of the type of reaction (either acidic, neutral, or basic) as well as the intensity of that acidic or basic reaction (measured in kg of acidity or basicity per 1000 kg fertilizer) produced in the root medium. We interpret the results of this experiment to indicate that below a pH of 5.3 to 5.9, NH_4^+-N

Table 1. Parameters of nonlinear regression analysis from fitting Eqs. [1], [2], and [3] to root-medium NH_4^+-N and NO_3^--N, based on root-medium pH at 8, 12, and 17 weeks after planting. I and S are the intercept and slope for Eqs. [2] and [3], respectively. The number of observations per sampling date was 96. Data are presented in Fig. 1. The analysis of the week 4 data was not included because of nonsignificance caused by limited differences in root-medium pH among the 24 treatments.

	Root-medium NH_4^+-N			Root-medium NO_3^--N			
	Week of sampling						
Estimated parameters	8	12	17	8	12	17	Units
Intercept (I_1)	232 ± 443[z]	150 ± 27	170 ± 33	−214 ± 149[z]	−129 ± 53	−187 ± 85	mg·L^{-1}
Slope (S_1)	−41 ± 93	−27 ± 6	−29 ± 7	54 ± 27	48 ± 11	60 ± 39	mg·L^{-1}/pH unit
Intercept (I_2)	29 ± 8	4 ± 8	9 ± 17	18 ± 40	124 ± 67	36 ± 40	mg·L^{-1}
Slope (S_2)	−3 ± 1	0 ± 1	−1 ± 2	14 ± 6	6 ± 9	18 ± 6	mg·L^{-1}/pH unit
Calculated parameters							
$X_{intersection}$	5.4	5.4	5.7	5.8	5.9	5.3	pH

[z]Ninety-five percent confidence intervals were calculated as the parameter standard error * $t_{0.025,n}$ distribution.

uptake is the primary factor causing acidification of the root medium with NH_4^+-N fertilizers. Bunt (1988) found that an increasing amount of NH_4^+-N was converted to NH_3 and lost from the medium as gas as the pH increased above 7.0. The greatest effect on acidification of the root medium would be expected within a pH range of 5.9 to 7.0 because, outside this range, <100% of the applied fertilizer is involved in acidifying-type reactions (plant uptake and nitrification). Even within the optimal pH range for nitrification, it is doubtful that 100% of NH_4^+-N is used in acidifying reactions because a percentage of the N is removed from the root zone by the rapid stratification of fertilizer salts with all irrigation methods (Argo and Biernbaum, 1996; Yelanich, 1995); also, some N may be leached out the bottom of the pot with surface-applied irrigation methods (Yelanich and Biernbaum, 1993).

The total amount of shoot dry matter produced by the impatiens over the 17 weeks of the experiment was not affected by the various treatments and averaged 17.5 g (Argo and Biernbaum, 1996). The higher the percentage of NH_4^+-N in the WSF, the higher the shoot-tissue N at each sampling date (Fig. 2, Table 2) (50% NH_4^+-N WSF average: 6.6%, 5.4%, 5.0%, and 5.2%; 25% NH_4^+-N WSF average: 6.1%, 5.1%, 5.0%, and 5.0%; 3% NH_4^+-N WSF average: 5.2%, 4.3%, 4.2%, and 4.5% at weeks 4, 8, 12, and 17, respectively). By week 8, the IWS also affected shoot-tissue N (Table 3), probably because of the effects of IWS and the interactive effects of IWS and WSF on root-medium pH. In general, the lower the medium pH, the higher the measured shoot-tissue N at weeks 8, 12, and 17 (Fig. 2, Table 2), contrary to the predicted N availability found by Lucas and Davis (1961) and Peterson (1981). Perhaps the difference measured in shoot-tissue N for treatments receiving the same percentage of NH_4^+-N in the applied WSF was due to the amount of NH_4^+-N that was converted to the NO_3^--N form before plant uptake.

We interpret the results of this experiment to show that medium pH in itself did not affect N uptake, but rather medium pH affected the nitrification rate. The ratio of NH_4-N : NO_3-N in the WSF applied to the medium and that taken up by the plant may be different, depending upon medium pH.

The NH_4-N : NO_3-N ratio in the WSF did not affect plant morphology, unlike the predictions of Bailey et al. (1996). However, the plants in this experiment were fertilized with N at 200 mg·L^{-1} at every irrigation and shoot-tissue N was not limiting in any treatment. There might have been differences in plant morphology caused by the NH_4-N : NO_3-N ratio in the WSF if N availability had been limiting. Medium pH also may influence the effect of the NH_4-N : NO_3-N ratio in the WSF on plant morphology because of its effect on the nitrification rate (Fig. 1).

Further study is needed to determine the effects of medium pH on the ratio of NH_4^+-N to NO_3^--N taken up by plants given the same WSF. Quantification of the effect of the WSF NH_4-N : NO_3-N ratio on medium NH_4^+-N and NO_3^--N accumulation, medium pH, and N uptake with diverse species also is needed. Future experiments should be performed with consideration of the interactive effects of WSF and irrigation-water alkalinity, lime, and root-medium components on maintenance of a stable root-medium pH.

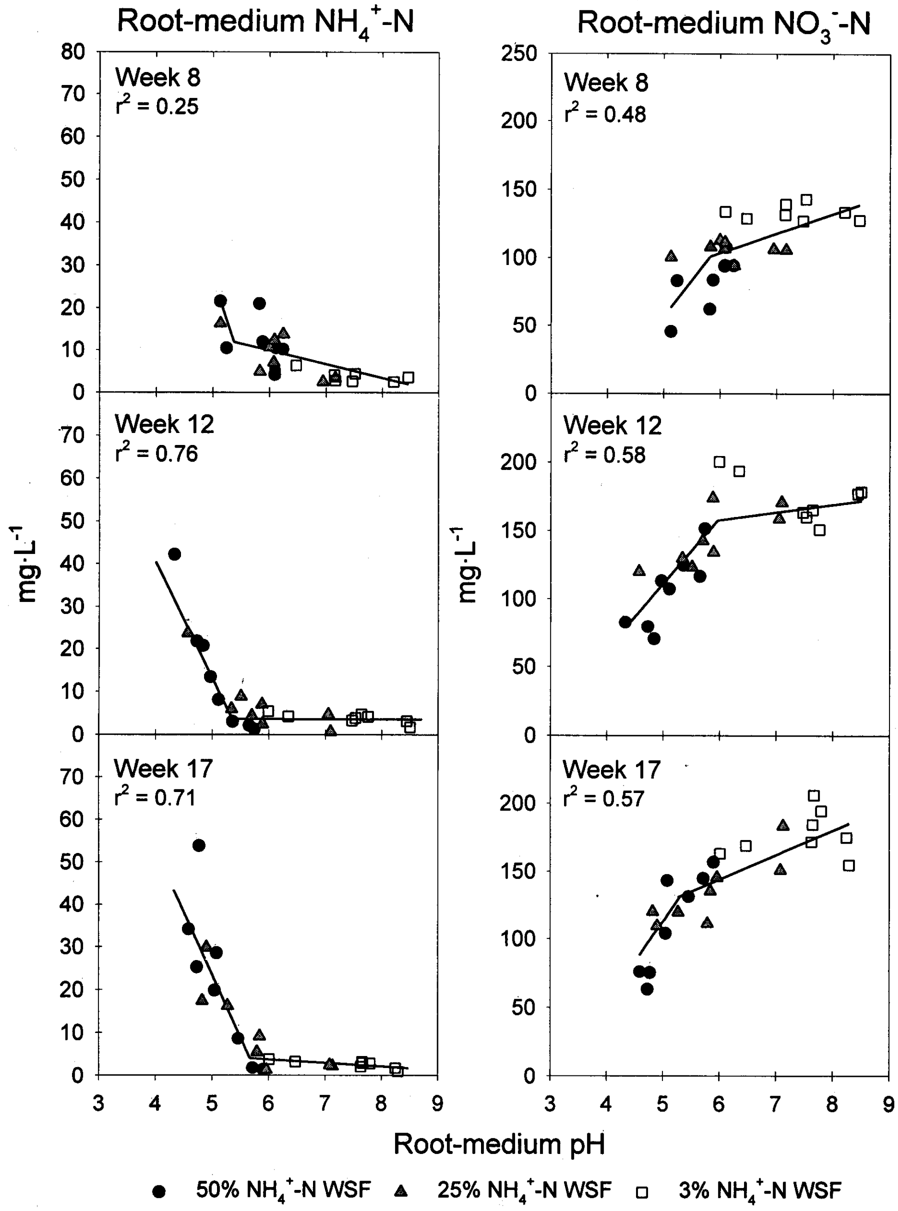

Fig. 1. Relationship between root-medium pH and the concentration of NH_4^+-N and NO_3^--N measured in the root zone of impatiens grown with four irrigation-water sources, three water-soluble fertilizers, and two types of lime at the weeks 8, 12, and 17 sampling dates. The week 4 sampling date was not included because of nonsignificance. The solid line (———) represents the predicted NH_4^+-N or NO_3^--N concentration based on medium pH as calculated with Eqs. [1], [2], and [3], respectively. The r^2 was calculated as $1 - SS_{residual}/SS_{corrected\ total}$, while the remaining parameters (S_1, I_1, S_2, and I_2) and the calculated intersection points of the two lines are presented in Table 1. Data are the mean of four plants.

Table 2. Parameters of linear regression analysis for tissue N, based on root-medium pH. The week four data are not presented because of nonsignificance caused by limited differences in root-medium pH among the 24 treatments. The number of observations was 96. Data are presented in Fig. 2.

Estimated parameters	Week of sampling 8	12	17	Units
Intercept	7.3 ± 0.6[z]	6.4 ± 0.3	6.7 ± 0.4	Dry mass (%)
Slope	–0.37 ± 0.09	–0.27 ± 0.05	–0.30 ± 0.06	Dry mass (%)/unit pH

[z]Ninety-five percent confidence intervals were calculated as the parameter standard error * $t_{0.025,n}$ distribution.

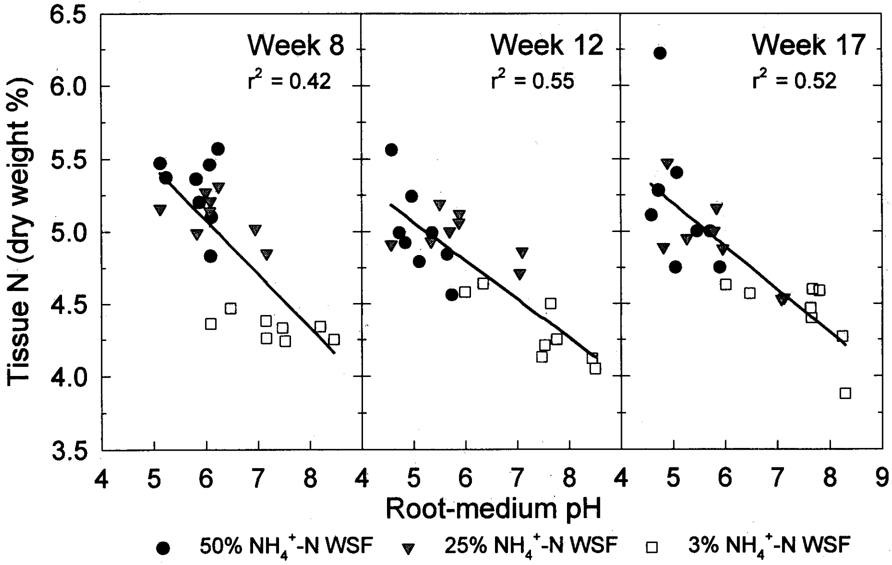

Fig. 2. Relationship between root-medium pH and shoot-tissue N of impatiens sampled at 8, 12, and 17 weeks after planting. The week 4 analysis was not included because of nonsignificance. Only shoot material grown over the previous four weeks was used in the tissue analysis. The solid line (——) represents the predicted shoot-tissue N based on root-medium pH. The parameters for the linear regression analysis are presented in Table 2. Data are the mean of four plants.

Table 3. Degrees of freedom (df), F value (A), level of significance (B), and mean square error a and b (MSE a or b) from the analysis of variance for tissue N concentrations in impatiens at 8, 12, and 17 weeks after planting.

		Week of sampling					
		8		12		17	
Factor	df	A	B	A	B	A	B
Lime (L)	1	0.5	NS	0.1	NS	1.8	NS
MSE a	1	0.07		0.01		0.09	
IWS[z]	3	4.7	*	8.2	***	39.5	***
L × IWS	3	0.3	NS	0.7	NS	0.8	NS
WSF[y]	2	201.4	***	70.6	***	57.1	***
L × WSF	2	0.9	NS	0.9	NS	1.4	NS
IWS × WSF	6	0.7	NS	2.7	*	3.3	**
L × IWS × WSF	6	0.5	NS	0.6	NS	1.8	NS
MSE b	70	3.88		6.91		5.66	

[z]Irrigation-water source.
[y]Water-soluble fertilizer.
NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

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