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Effectiveness and assessment of ammonium impact of Daniels soybean-base liquid fertilizer for bedding plants

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ADDITIONAL INDEX WORDS. Dianthus, pansy, petunia, salvia, snapdragon, verbena, vinca, floriculture, ammonium toxicity, substrate pH, electrical conductivity.

SUMMARY. A greenhouse study was conducted to compare the effectiveness of Daniels $10N:4P_2O_5:3K_2O$ fertilizer to two inorganic, greenhouse-type formulations across seven bedding plant taxa and to assess the likeliness of these crops to develop NH_4 toxicity and K deficiency from Daniels fertilizer. Both inorganic fertilizers supplied $N:P_2O_5:K_2O$ in a 2:1:2 ppm ratio similar to 20-10-20 commercial fertilizer with the first containing 25% and the second 75% of N in the NH_4 form, referred to as 25% and 75%, respectively. Crops tested included *Dianthus chinensis* L. x *D barbatus* L. 'Floral Lace', *Viola wittrockiana* Gams. 'Crystal Bowl Orange', *Petunia x hybrida* Hort. Vilm – Andr. 'Dreams Red', *Salvia farinacea* Benth. 'Victoria Blue', *Antirrhinum majus* L. 'Bell Mix', *Verbena xhybrida* Voss. Quartz Group, and *Catharanthus roseus* (L.) G. Don Cooler Group 'Grape Cooler'. Foliage was deeper green when fertilized with Daniels. Plants were desirably more compact (shorter, lighter, and less leaf area) when fertilized with Daniels and 75% compared to 25%. In spite of the high proportion of N in reduced forms (81%), no taxa developed NH_4 toxicity from Daniels fertilizer when grown at commercial substrate pH levels. At excessively low pH levels (below 5), employed to stimulate NH_4 toxicity, toxicity occurred in only pansy from Daniels

and all seven taxa from inorganic fertilizer formulations. Ammonium toxicity in pansy induced from Daniels was lighter than that caused by the inorganic fertilizers. Ammonium toxicity symptoms common to all taxa occurred in young leaves and included interveinal chlorosis, curling of the tips or margins of leaves either upward or downward depending on taxa, and eventual necrosis in the chlorotic regions. Root systems were smaller. The pH suppression by Daniels fertilizer was less than from 75% and similar to 25% when all fertilizers were applied at equal N concentrations. Daniels fertilizer applied at double the N concentration of the inorganic formulations resulted in the highest substrate pH levels of all treatments. This explained in part the resistance to NH_4 toxicity associated with Daniels fertilizer. The K content of Daniels fertilizer was adequate to meet the requirements of the seven taxa tested. Leaf tissue K concentrations, however were lower than in plants treated with the inorganic formulations. Substrate salt levels were lower when treated with Daniels compared to inorganic formulations at the same N concentration and similar in salt level when treated with Daniels at double the N concentration of inorganic formulations.

Daniels fertilizer is available in one grade, 10N:4P_2O_5:3K_2O. Yet, this fertilizer has for several years been applied to the full range of crops in greenhouse firms. Eighty one percent of its N is in reduced forms including 37.0% NH_4, 36.5% urea, and 7.5% organic N. Inorganic greenhouse fertilizers such as 20-20-20 (N:P_2O_5:K_2O, with 70% of N in the urea form, have been problematic with regards to ammonium toxicity. Yet, organic fertilizers, with their typically high proportions of reduced N, do not tend to lead to ammonium toxicity. Daniels is not officially classified as an organic fertilizer. But, Daniels fertilizer contains the biodegradable soluble organic compounds that occur in soybean seed extract. This should give it many of the properties of an organic fertilizer.

Biodegradable carbon in Daniels fertilizer may be beneficial for the greenhouse/ornamental industries. Organic matter additions to soils and soilless substrates can promote soil microbial shifts that suppress pathogenic plant diseases (Hoitink and Boehm, 1999). Soil organic matter can supply nutrients as well as increase cation exchange capacity for holding nutrients for plant use (Chaney, et al., 1992). For example, soil microbes fostered by compost additions to root substrate can produce organic chelators that hold Fe available to plants in otherwise unavailable situations (Chen, et al., 1998). Microbial assimilation of nutrients during organic matter degradation and subsequent release during mineralization serves to prolong nutrient availability and minimize loss to the environment (Parnes, 1990). This latter dampening process could lead to a lower rate of release of free NH_4 from organic nutrient sources as well as Daniels fertilizer thereby rendering these less inductive to NH_4 toxicity.

The objectives of this study were to test the efficacy of the single grade of primary macronutrients in Daniels fertilizer over a range of seven bedding plant taxa and to assess the propensity of this fertilizer for causing NH4 toxicity in these plants.

Materials and methods.

Dianthus 'Floral Lace', pansy 'Crystal Bowl Orange', petunia 'Dreams Red', salvia 'Victoria Blue', snapdragon 'Bell Mix', verbena 'Quartz Mix', and vinca ' Grape Cooler' plug seedlings from Ball Seed Co. (West Chicago, Ill.) were transplanted on 17 July 1998 into 48-cell bedding plant flats. Research was conducted in Raleigh, NC at 35 °N latitude in a glass greenhouse. Root substrate consisted of 3 sphagnum peat moss plus 1 horticultural perlite (v:v) amended with 3.33 or 10 lbs. (low or high substrate pH) finely ground dolomitic limestone, 1 lb. Micromax micronutrient mix (The Scotts Co., Marysville, Oh.), and 1.5 lbs. gypsum per cubic yard of mix (2 or 6, 0.6, and 0.9 $g \cdot L^{-1}$, respectively). Cells were removed from flats and a block of 12 cells of each taxa was assigned to each experimental unit. The night/cloudy day/clear day greenhouse temperatures were set at 65/75/80 °F (18/24/27 °C).

A separate experiment was conducted for each taxa and all were conducted simultaneously. A randomized complete block experimental design was used in each experiment with three blocks. Data were analyzed by ANOVA and means were separated by LSD (SAS Inst., Cary, NC).

Treatments consisted of a factorial arrangement of two substrate pH levels and four fertilizer sources. The low pH level was designed to fall below the acceptable lower limit to stimulate NH_4 toxicity. Fertilizer formulations included two inorganic formulations that supplied $N:P_2O_5:K_2O$ in a 2:1:2 ppm ratio similar to 20-10-20 commercial fertilizer. The ratio of ammoniacal to nitrate N in the first was 25:75 (25% treatment) and in the second it was 75:25 (75% treatment). The first formula was typical of commercial formulations on the market while the second contained a reduced N (NH_4) content similar to the level of reduced N

(NH_4 + urea + organic N) in Daniels fertilizer. The higher NH_4 formulation was also selected to enhance NH_4 toxicity. Both formulations were applied at a N concentration of 98 ppm ($mg \cdot L^{-1}$). These fertilizers were formulated with KNO_3, KH_2PO_4, $NH_4H_2PO_4$, $Ca(NO_3)_2 \cdot 4H_2O$, $Mg(NO_3)_2 \cdot 6H_2O$, $(NH_4)_2SO_4$, and NH_4NO_3. The third and fourth fertilizers consisted of Daniels fertilizer applied at N concentrations of 98 (D98) and 196 ppm (D196). The higher concentration was included in the experiment to induce NH_4 toxicity. Fertilizers were applied with each irrigation to the top of the substrate with an approximate 20% leaching fraction. The low substrate pH and high reduced N concentrations used in this study to induce NH_4 toxicity have been reported to be associated with increased incidence of NH_4 toxicity (Barker, et al., 1966; Brady, 1990; Forde and Clarkson, 1999).

The experiment for each taxa was terminated when plants reached a marketable state in the 25% treatment. Marketable date was determined as the number of days required to reach 25 percent as many blooms as plants for salvia, 50 percent for dianthus, pansy, snapdragon, verbena, and vinca and 75 percent for petunia. At market date, plant height was measured from the substrate surface to the top of the plant. Foliar green color was visually assessed only in the high pH series of treatments since these were the treatments produced in a commercial fashion. All replications were composited prior to color evaluation. A scale of 1 to 6 was used with 1 being chlorotic and 6 very deep green. A value of 3 was assigned to the 25% treatment since that treatment was accepted as the commercial norm. The numbers of flowers and buds were counted. Presence of foliar NH_4 toxicity symptoms was assessed on a scale of 0 to 3 where 0 was assigned to no toxicity, 1 to initial toxicity and 3 to extensive symptoms. Additionally, root balls were removed from flat cells and were visually evaluated for root system density. All treatments were included in the toxicity assessment, however replications were again composited before assessment. The four youngest expanded leaves were removed and their area was measured using a Monochrome Agvision System 286 Image Analyzer (Decagon Devices, Inc., Pullman, Wash.). The same four leaves were washed in 0.2N HCl for 30 seconds, rinsed in deionized water, dried for 24 hours at 70°C, and weighed. These leaves from pansy, petunia, salvia, and vinca were analyzed for nutrient content. Nutrient analysis was restricted to the high pH series and to the three fertilizer sources at 98 ppm ($mg \cdot L^{-1}$) N because the goal was to obtain a comparative assessment of the facility of these fertilizers to supply adequate nutrition under commercial conditions. The remainder of the shoot was removed at the substrate surface, dried at 70°C, and weighed. Weights of the four recently expanded leaves and the remainder of the shoot were combined for total shoot dry weight. Substrate extract was obtained from all taxa by the saturated media extract procedure (Warncke and Krauskopf 1983) and analyzed for pH and EC. Macronutrients were determined only in pansy, petunia, salvia, and vinca.

Leaf tissue harvested foliar analysis was ground to 1 mm particle size in a stainless steel Wiley mill. Total N was analyzed using a Kjeldahl procedure (Fleck, 1974). Tissue for the remaining nutrients was dry-ashed at 500 °C. After addition of 6 N HCl, the ash was heated to dryness at 100 °C to dehydrate it and then dissolved in 0.5 N HCl. PO_4-P was determined by colorimetric analyses (Chapman and Pratt, 1961) using a UV/VIS spectrophotometer (Perkin-Elmer, Norwalk, Conn.). K, Ca, Mg, Fe, Mn, Zn, and Cu were analyzed by atomic absorption spectroscopy.

Root substrate extracts were analyzed as follows. A model 695 pH/conductivity/TDS/temperature meter (Extech Instruments, Waltham, Mass) was used for pH and soluble salt (EC) determination. Colorimetric analysis was employed for NO_3-N (Caltado et al., 1975), NH_4-N (Chaney and Marbach, 1962), and PO_4-P (concentrations under 10 $\mu g \cdot mL^{-1}$, Murphy and Riley, 1962; and above 10 $\mu g \cdot mL^{-1}$, Chapman and Pratt, 1961) on a Model Lambda 3 UV/VIS spectrophotometer (Perkin and Elmer, Norwalk, Conn). Atomic absorption stectroscopy was used for Ca, Mg, and K analyses.

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Results and discussion.

GROWTH. The experiment for each species was terminated when plants reached a marketable state in the 25% treatment. The number of days for this to occur for each species was dianthus – 41, pansy - 18, petunia – 26, salvia – 18, snapdragon – 42, verbena – 41, and vinca – 40.

Depth of color in the high pH treatments was as follows. The 75% NH_4 treated plants, compared to 25% NH_4 plants (rating 3), was similar in dianthus, salvia, and verbena, deeper in petunia (rating 4), and lighter in pansy, snapdragon, and vinca (rating 2). Lighter color is generally expected with high ammoniacal N proportions in fertilizer (Nelson and Hsieh, 1971). Daniels fertilizer resulted in deeper green color in all species except dianthus where color was similar. Color ratings for Daniels at 98 ppm N were 3.5 for salvia, 4 for pansy, snapdragon, verbena, and vinca, and 5 for petunia. Ratings for Daniels at 196 ppm N were the same as those for Daniels at 98 ppm N except for deeper color in pansy (rating 5) and petunia (rating 6). Deeper color has a commercial advantage.

No symptoms of NH_4 toxicity developed in shoots or roots in any species or fertilizer treatment in the high pH series (data not shown) but did develop in the low pH treatments as anticipated due to low substrate pH. Light foliar symptoms (rating 1) and a moderately smaller root system developed in pansy and petunia while none of these symptoms developed in the other species when fertilized with 25% NH_4. In the 75% NH_4 treatment, moderate (rating 2) foliar symptoms developed in dianthus, petunia, salvia, and snapdragon and heavy (rating 3) symptoms developed in pansy, verbena, and vinca. All species in the 75% NH_4 treatment developed smaller root systems with the exceptions of dianthus where roots were normal and verbena where roots had a tan-brown discoloration and root hairs were fewer and shorter. By contrast, NH_4 toxicity did not develop in plants fertilized with Daniels at the same 98 ppm N rate in any species except pansy. Pansy developed fewer foliar symptoms (rating 2) and root systems that were only modestly smaller (between the effects of 25% NH_4 and 75% NH_4) when treated with 98 and 196 ppm N Daniels. Even though Daniels fertilizer contains slightly more reduced N than in the inorganic 75% NH_4 fertilizer, little or no NH_4 toxicity was caused by it. Although it was anticipated that raising Daniels fertilizer concentration from 98 to 196 ppm N would increase NH_4 toxicity, this did not occur. The margin of safety for NH_4 toxicity is very large in Daniels fertilizer.

Foliar symptoms of NH_4 toxicity exhibited some general as well as some specific features across taxa. Dianthus developed interveinal chlorosis on young leaves. Ends of these leaves curled in a downward direction in excess of 360°, giving a "pig-tail" appearance. Young leaves on lateral shoots became generally chlorotic. Young leaves of pansy developed chlorosis along the margins that progressed inward into an interveinal pattern. Margins of these leaves rolled upward, sometimes before chlorosis and other times during or after. Young leaves of petunia became chlorotic between veins. Salvia plants developed chlorosis along the margins of young leaves that spread inward to form an interveinal pattern. Moderate distortion occurred on these leaves. Pin point necrotic spots appeared in the chlorotic areas. Snapdragon leaves developed chlorotic blotches 1 mm wide by 2-4 mm long in interveinal regions toward the terminal end of young leaves. As these blotches increased in number and size and spread toward the base of leaves, necrotic spots developed a short distance from the tip of these leaves. The same syndrome later occurred on young leaves of lateral shoots. Young leaves of verbena developed interveinal chlorosis and margins curled upward. Interveinal chlorosis and upward curling of margins appeared on young leaves of vinca. With time chlorosis spread from the interveinal areas to the entire leaf and faded to a lemon-green color. The terminal ends of these leaves were slightly deeper green.

There were no interactive effects of substrate pH by fertilizer on the number of days to flower, number of flowers, or number of flower buds (data not shown). There was only one effect of the main factor of fertilizer type. This occurred in vinca, where there were more buds in the 196 ppm N Daniels treated plants than in the other three treatments, which were all equal to each other. The main effect of substrate pH was significant in pansy and petunia where there were fewer flowers at low compared to high substrate pH, 0.8 versus 1.4 in pansy and 1.2

versus 1.5 in petunia. Overall, performance of Daniels fertilizer relative to flowering was equivalent to the inorganic formulations.

When ever analyses of variance indicated a significant substrate pH by fertilizer type interactive effect on height, shoot dry weight, or leaf area, these results were tabulated in Table 1. When the interaction was not significant but main substrate pH or fertilizer type effects were, these results were presented in Table 2. Since too many comparisons exist in these tables for this text, only those relevant to the objectives are covered here.

In general, low pH, compared to high pH, treatments resulted in lower height, shoot dry weight, and leaf area levels for each given fertilizer type comparison (Tables 1 & 2). The interactive effect was seen in those treatments (D98, D196, and 75%) that lowered substrate pH below the higher levels of the 25% treatment (Table 1). The negative impact of these three treatments on height, shoot dry weight, and leaf area levels was larger in the low substrate pH series.

The 25% treated plants were considered to be the more typical representation of commercial production conditions. Thus, impacts of the 75%, D98, and D196 treatments were compared to the 25% treatment. Since the high pH treatments in Table 1 were the only pH conditions under which a commercial crop would be grown, these and the main effects in Table 2 were used to assess the effects of the 75%, D98, and D196 treatments relative to production needs. The 75% treatment resulted in shorter petunia, salvia, snapdragon, and vinca plants, lighter shoots in dianthus, pansy, petunia, salvia, and vinca plants, and lower total leaf area in petunia, salvia, and vinca. Generally speaking, 75%

treated plants were more compact in all species except verbena where there was no difference. Plants treated with D98 were equivalent to 75% treated plants in all comparisons except height in petunia where the D98 plants were not shorter than the 25% plants as was the case for the 75% plants. Compared to 25% plants, those treated with D196 were taller with heavier shoots for dianthus and salvia and had greater leaf area for salvia, while in snapdragon they were shorter and in vinca had less leaf area. This higher rate of Daniels fertilizer resulted in excessive growth in the former species. In the latter species it showed signs of being excessive. The D196 treatment was included to induce NH_4 toxicity rather than to find a superior rate of fertilizer.

ROOT SUBSTRATE pH AND EC. There were main effects of substrate pH and fertilizer type on pH level of the substrate in all species and interactive effects in all species except pansy and petunia (Table 3). Substrate pH levels were mainly in a good range for production in the high pH series of treatments but were adversely low in the low pH series. The low levels were intentional to stimulate NH_4 toxicity. The 75% fertilizer compared to 25% treatment lowered substrate pH in all but pansy in the high pH series and in all but pansy and petunia in the low ph series. When compared to 25%, D98 lowered substrate pH only in verbena and vinca in the high pH series and vinca in the low series. Where both 75% and D98 lowered pH, the depressive effect of D98 was significantly less than that of 75%. D98 actually raised the substrate pH above that in the 25% treatment in pansy and salvia in the low pH series. This accounted in part for the interactive effect. The effects of D196 on substrate pH were fairly similar to D98 in the high pH series. However, in the low pH series more of the pH by fertilizer type interaction was seen in the effects of D196. Unlike D98 that raised substrate pH above the 25% levels only in pansy and salvia, D196 raised substrate pH in all species except vinca.

Although Daniels fertilizer resulted in shoot compaction similar to that from 75% fertilizer, it did not have the pH lowering effect of 75%. This would account in part for the large margin of safety from NH_4 toxicity in Daniels fertilizer. Ordinarily, an increase in concentration of a high NH_4 fertilizer causes a further decrease in substrate pH. This was not the case for Daniels fertilizer where an increase in its concentration had the opposite effect of an increase in pH. Further, the elevating effect of Daniels fertilizer was fortuitously greater in the lower substrate pH range.

There were interactive effects of substrate pH by fertilizer type on substrate EC for each species (Table 4). The 75% treatments resulted in similar salt levels to those in the 25% treatments regardless of pH series with the exceptions of lower values in the 75% treatment for pansy at both pH levels and salvia at the low ph level. The lowest salt levels occurred in the D98 substrates in both the high and low substrate pH treatment series. The high concentration D196 fertilizer within the high pH series treatments resulted in substrate salt levels equal to the lower concentration 25% fertilizer with the exception of pansy where the D196 salt level was lower. The interactive effect was seen for dianthus, pansy, and verbena in the low pH series where the D196 treatment resulted in substrate salt levels lower than in the 25% treatment. Overall, Daniels at the same N concentration as the inorganic formulations resulted in lower substrate salt levels and at double the N concentration of the inorganic formulations resulted in equal or lower substrate salt levels.

SHOOT NUTRIENT CONCENTRATIONS. Leaf nutrient concentrations for 25%, 75%, and D98 in the high pH series are presented in Table 6. Since 25% is the more customary fertilization system, the nutrient supplying capacity of 75% and Daniels are compared to it.

Leaf concentrations of Ca and Mg were lower in all four species in the 75% treated plants. This would be due to the fact that 75% supplied neither of these nutrients while 25% supplied both. Leaf concentrations of K were higher in petunia, salvia, and vinca treated with 75%. Low substrate concentrations of Ca and Mg in turn would have relieved antagonistic pressure on K allowing for increased uptake (Moss, 1963). Plants treated with 75% were higher in P (petunia and salvia) as well as Zn and Cu (petunia, salvia, and vinca). Lower substrate pH caused by the high NH_4 proportion of N in 75% lowered substrate pH which would be expected to raise phosphate (Riley and Barber, 1971) and cationic micronutrient solubility (Shuman, 1988).

Plants fertilized with D98 tended to be lower in K, Ca, and Mg and higher in Fe compared to 25% plants, undoubtedly due to differences in content of these nutrients in the two fertilizers. Other changes caused by Daniels fertilizer included less N in salvia, higher P in petunia and vinca, less Zn in pansy and vinca, and more Cu in petunia and salvia. Lower Cu concentration could have been the result of an antagonism from the higher Fe concentration (Pendias and Pendias, 1984).

Shoot concentrations of N, P, Mg, and micronutrients were adequate in all treatments while K and Ca were suspect as indicated by survey ranges of Mills and Jones (1983). However their survey ranges did not identify the minimum critical levels of these nutrients. Minimum critical levels were identified by Pitchay (2002) for K and Ca in pansy, petunia, salvia, and vinca. In all of these situations these nutrients were adequate. Daniels fertilizer provided adequate K, although leaf concentrations were lower than in the organic fertilizer treated plants.

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Table 1. Interactive effects of substrate pH by fertilizer type on height (Ht), dry weight (DW), and leaf area (Area), where it was found to be significant in seven species of bedding plants.

		Pansy	Petunia		Salvia			Snapdragon	Vinca
pH	Fertilizer[z]	Ht[y] (cm)	DW[x] (g)	Area (cm^2)	Ht (cm)	DW (g)	Area (cm^2)	Ht (cm)	Ht (cm)
High	25%	7.9	0.79	52.3	17.6	1.20	69.0	14.3	22.7
	75%	7.3	0.69	40.1	15.6	1.03	57.9	12.5	18.3
	D98	7.2	0.67	37.9	15.7	0.99	60.4	12.3	19.7
	D196	7.9	0.90	54.3	19.7	1.18	78.0	13.0	20.0
Low	25%	7.8	0.79	54.2	17.9	1.16	82.0	12.3	17.0
	75%	5.7	0.59	38.2	14.4	0.69	52.2	12.3	17.3
	D98	6.6	0.63	35.6	13.4	0.63	52.7	13.0	16.7
	D196	5.9	0.74	45.8	15.5	0.87	71.7	14.0	18.7
Interaction $LSD_{0.05}$		1.0	0.06	4.2	1.7	0.14	6.6	1.1	2.8

[z] Fertilizer sources were inorganic 2-1-2 ($N:P_2O_5:K_2O$) with 25%NH_4:75%NO_3 at 98 ppm N (25%), or 75%NH_4:25%NO_3 at 98 ppm N (75%), and Daniels fertilizer at 98 ppm N (D-98) or 196 ppm N (D-196).

[Y] 1 inch = 2.5 cm

[x] 1 ounce = 28.35 g

Table 2. Main effects of fertilizer type and substrate pH on height (Ht), dry weight (DW), and leaf area (Area) where it was found to be significant in seven species of bedding plants.

	Dianthus		Pansy		Petunia	Vinca	
Fertilizer [z]	Ht [y] (cm)	DW [x] (g)	DW (g)	Area (cm^2)	Ht (cm)	DW (g)	Area (cm^2)
25%	17.2	1.28	0.43	26.4	13.9	1.28	68.1
75%	17.5	1.13	0.33	19.6	11.9	1.07	53.6
D98	17.0	1.07	0.36	20.0	14.3	0.94	51.8
D196	21.7	1.51	0.41	26.3	15.9	1.18	60.5
$LSD_{0.05}$	1.1	0.12	0.04	3.7	2.4	0.18	5.8
High pH	18.8		0.43	26.0			
Low pH	17.9		0.33	20.1			

[z] Fertilizer sources were inorganic 2-1-2 ($N:P_2O_5:K_2O$) with 25%NH_4:75%NO_3 at 98 ppm N (25%), or 75%NH_4:25%NO_3 at 98 ppm N (75%), and Daniels fertilizer at 98 ppm N (D-98) or 196 ppm N (D-196).

[Y] 1 inch = 2.5 cm

[x] 1 ounce = 28.35 g

Table 3. Interactive effects of initial substrate pH by fertilizer type on resulting substrate pH for dianthus, salvia, verbena, and vinca as well as main effects of fertilizer type and initial substrate pH on pansy and petunia at the end of the experiments.

Treatment						Treatment		
pH	Fertilizer[z]	Dianthus	Salvia	Verbena	Vinca		Pansy	Petunia
High	25%	5.79	6.28	5.60	5.94	25%	5.08	4.69
	75%	5.40	5.06	4.71	5.03	75%	4.91	4.67
	D98	5.69	6.10	5.35	5.53	D98	5.31	4.75
	D196	6.21	6.29	5.47	5.37	D196	5.33	4.82
Low	25%	4.17	4.69	4.25	4.69	$LSD_{0.05}$	0.23	0.13
	75%	3.89	3.95	3.88	3.66			
	D98	4.32	5.68	4.37	4.14	High pH	5.57	5.37
	D196	4.79	6.69	4.90	4.85	Low pH	4.61	3.97
Interaction $LSD_{0.05}$		0.25	0.26	0.20	0.40	$LSD_{0.05}$	0.13	0.07

[z] Fertilizer sources were inorganic 2-1-2 ($N:P_2O_5:K_2O$) with $25\%NH_4:75\%NO_3$ at 98 ppm N (25%), or $75\%NH_4:25\%NO_3$ at 98 ppm N (75%), and Daniels fertilizer at 98 ppm N (D-98) or 196 ppm N (D-196).

Table 4. Substrate EC levels at the end of the experiments.

Treatment							
pH	Fertilizer[z]	Dianthus	Pansy	Petunia	Salvia	Verbena	Vinca
High	25%	2.12	3.52	1.61	1.29	1.41	1.34
	75%	2.04	2.15	1.54	1.66	1.47	1.15
	D98	0.98	1.90	1.17	0.72	0.83	0.69
	D196	1.84	2.19	1.23	1.32	1.23	1.39
Low	25%	2.09	3.59	1.48	1.55	1.56	1.32
	75%	1.72	2.60	1.28	1.18	1.47	1.35
	D98	0.92	1.48	0.78	0.66	1.05	0.67
	D196	1.22	2.30	1.28	1.34	1.01	1.04
Interaction $LSD_{0.05}$		0.52	0.61	0.40	0.32	0.37	0.38

[z] Fertilizer sources were inorganic 2-1-2 ($N:P_2O_5:K_2O$) with $25\%NH_4:75\%NO_3$ at 98 ppm N (25%), or $75\%NH_4:25\%NO_3$ at 98 ppm N (75%), and Daniels fertilizer at 98 ppm N (D-98) or 196 ppm N (D-196).

Table 5. Nutrient concentrations in the four youngest fully expanded leaves of pansy, petunia, salvia, and vinca in the high substrate pH series of treatments that supplied 98 ppm N.

Fertilizer[z]	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
				Pansy					
25%	4.45	0.58	3.78	1.83	1.36	279	2517	393	10.3
75%	4.18	0.55	3.91	0.81	0.87	274	1677	344	9.7
D98	4.95	0.65	2.88	0.83	0.90	619	1116	183	11.0
$LSD_{0.05}$	NS	NS	0.56	0.28	0.24	181	532	93	NS
				Petunia					
25%	5.70	0.43	1.99	1.97	1.63	105	562	100	17.7
75%	5.14	0.57	3.81	0.91	0.72	109	510	154	21.3
D98	5.67	0.63	2.08	0.92	0.69	251	420	114	23.0
$LSD_{0.05}$	0.28	0.11	0.27	0.29	0.09	83	NS	18	2.9
				Salvia					
25%	4.91	0.39	2.21	1.64	1.68	80	762	110	11.3
75%	4.04	0.38	2.83	1.05	1.00	151	1205	220	16.3
D98	4.43	0.39	1.81	1.42	1.33	552	1242	146	16.3
$LSD_{0.05}$	0.39	NS	0.20	0.21	0.32	110	212	42	2.1
				Vinca					
25%	6.09	0.50	1.81	2.22	1.19	113	441	119	14.0
75%	5.80	0.61	2.60	1.30	0.62	111	552	170	17.3
D98	5.76	0.57	1.41	1.24	0.62	129	367	102	15.7
$LSD_{0.05}$	NS	0.06	0.26	0.17	0.13	10	89	15	1.9

[z] Fertilizer sources were inorganic 2-1-2 ($N:P_2O_5:K_2O$) with 25%NH_4:75%NO_3 at 98 ppm N (25%), or 75%NH_4:25%NO_3 at 98 ppm N (75%), and Daniels fertilizer at 98 ppm N (D-98).