THESIS

BEDDING PLANT NUTRITION

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY PATRICIA A. TEWSCHROCK ENTITLED BEDDING PLANT NUTRITION BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

BEDDING PLANT NUTRITION

Three nutrition experiments were conducted to determine the nitrogen, phosphorus, and potassium nutrient levels necessary to obtain quality bedding plant growth. A soil medium of equal parts (by volume) Fort Collins Clay Loam, Canadian peat moss, and perlite, and soilless medium of equal parts (by volume) Canadian peat moss and vermiculite were used in all experiments.

Pelargonium hortorum 'Sprinter Scarlet' and *Petunia hybrida* 'Candy Apple' seedlings were grown in the 2 media and watered with 5 nutrient solutions containing varying ratios of $NO_3^-:NH_4^+$, each resulting in a total NO_3^- plus NH_4^+ concentration of 15 meq l^{-1}. There were no significant differences in height, fresh and dry weights, or number of vegetative breaks in soil-grown plants due to the N sources. Plant growth in the soilless medium was substantially reduced as the proportion of NH_4^+ increased above 50%.

Plant quality of *Pelargonium hortorum* 'Sprinter Scarlet' and *Petunia hybrida* 'Candy Apple' were also evaluated in the 2 media when watered with 12 nutrient solutions containing 4 nitrogen concentrations (half NO_3^-, half NH_4^+) of 7.0, 11.5, 14.0, and 17.5 meq l^{-1}, and 3 potassium concentrations of 2, 4, and 6 meq l^{-1}. Potassium concentrations above 2 meq l^{-1} had little or no affect on plant growth in either media. Increasing nitrogen rates caused increased plant height, and fresh and dry weights. The 7.0 meq l^{-1} nitrogen-grown plants showed signs of nitrogen deficiency. Maturity, in terms of flowering and number of vegetative breaks, was not affected by the nutrient regime. Optimum plant growth in both media was produced with 11.5 meq l^{-1} nitrogen and 2 meq l^{-1} potassium treatment.

Seedlings of Pelargonium hortorum 'Sprinter Scarlet', Petunia hybrida 'Pink Magic', Impatiens holstii 'Elfin Red', and Tagetes patula 'Goldie' were grown in the 2 media with 4 phosphorus treatments consisting of 0 kg m^{-3} treble superphosphate preplant plus a continuous feed using 25-0-25 (1.408 meq l^{-1} $H_2PO_4^-$, 200 ppm P_2O_5), and 0, 3, and 6 kg m^{-3} treble superphosphate preplant plus a continuous feed of 20-20-20 (1.408 meq l^{-1} $H_2PO_4^-$, 200 ppm P_2O_5). All species, except impatiens, showed increased growth with increased phosphorus levels; impatiens gave little or no response to phosphorus treatments. Flowering time of all species was unaffected by the treatments. The 3 kg m^{-3} treble superphosphate plus a continuous feed of 20-20-20 (1.408 meq l^{-1} $H_2PO_4^-$, 200 ppm P_2O_5) gave the best plant response in both media.

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INTRODUCTION

Bedding plants are classed as annual or perennial plant materials that are propagated during the winter and spring months, grown in a protected environment, and then transplanted outdoors during late spring or early summer. While flowering annuals are the majority, vegetable plants, such as tomato, cabbage, cauliflower, etc., are becoming a larger part of bedding plant sales each year. As a crop, bedding plants rank second only to chrysanthemums in value for the total commercial floriculture industry (68).

The bedding plant industry is expanding more each year. Ball (3) reported growth to be nearly 10% per year with prices up 8-10%. While the industry has been growing rapidly, research to support bedding plant production has been limited, especially in the area of nutrition. There are a wide variety of opinions regarding N-P-K fertilization programs, recommendations, and sources in the culture of bedding plants (Table 1). There is also a lack of information on specific crops, although petunias and geraniums have received some attention.

The paucity of information on specific bedding plants, and the knowledge that bedding plant growth and quality are directly related to the growing media and fertilizer program used, pointed to the need for further research. The objectives of this study were:

1) Determine the ratio of $NO_3^-:NH_4^+$ necessary to obtain quality growth of Pelargonium hortorum 'Sprinter Scarlet' and Petunia hybrida 'Candy Apple' when grown in equal parts of Fort Collins clay loam, Canadian peat moss, and perlite and equal parts of Canadian peat moss and vermiculite.
2) Determine the ratio of total nitrogen and potassium necessary to obtain quality plant growth of Pelargonium hortorum 'Sprinter Scarlet' and Petunia hybrida 'Candy Apple' when grown in equal parts of Fort Collins clay loam, Canadian peat moss, and perlite and equal parts of Canadian peat moss and vermiculite.
3) Determine the effect of high levels of phosphorus on plant growth and the level of phosphorus necessary to obtain quality plant growth of Pelargonium hortorum 'Sprinter Scarlet'. Petunia hybrida 'Pink Magic', Impatiens holstii 'Elfin Red', and Tagetes patula 'Goldie' when grown in equal parts of Fort Collins clay loam, Canadian peat moss, and perlite and equal parts of Canadian peat moss and vermiculite.

A review of literature concerning plant nutrition is presented in Chapter 1. A series of 3 papers follows in Chapters 2 through 4 and deals with specific plant nutrition experiments performed.

Table 1. Fertilization recommendations for bedding plants.

Ref.	Bedding plant	Material	Rate	Rate ($kg\ m^{-3}$)	Remarks
94	General	LF:[a] N and K or	200 ppm		Each watering
		Dry:[b] MagAmp 7-40-6 or	10 lb yd^{-3}	6.0	Dry application of complete
		Osmocote 18-9-13 or	10 lb yd^{-3}	6.0	fertilizers not recommended
		Osmocote 14-14-14 and	13 lb yd^{-3}	7.8	
		Superphosphate or	0.5 lb ($2\frac{1}{2}$ bu)$^{-1}$	3.0	
		Treble superphosphate	0.25 lb ($2\frac{1}{2}$ bu)$^{-1}$	1.5	
112	General	Dry: Superphosphate	4-in pot (3 bu)$^{-1}$	4.0	Use slow release fertilizer at half recommended rate plus liquid feed
37	General	LF: 25-0-25 or	$\frac{1}{2}$ oz (3 gal)$^{-1}$		"Fertilize frequently but lightly"
		KNO_3 plus	3/4 oz (5 gal)$^{-1}$		
		NH_4NO_3	$\frac{1}{2}$ oz (5 gal)$^{-1}$		
2	General	LF: 20-20-20	2 lb (100 gal)$^{-1}$		Weekly application
86	General	LF: 20-20-20 or	$\frac{1}{2}$-3/4 lb (100 gal)$^{-1}$		Each watering
		15-30-15 or	$\frac{1}{2}$-3/4 lb (100 gal)$^{-1}$		Each watering
		20-20-20	2 lb (100 gal)$^{-1}$		Every 2 weeks
77	General	LF: 25-5-20	3 lb (100 gal)$^{-1}$		Every 2 weeks, or some fertilized at each watering
68	General	pH	5 to 7		Fertilize according to soil test maintain at levels given
		EC[c]	0.4 to 1.4 mmhos cm^{-1}		
		NO_3^-	50-250 ppm		
		P	125-450 ppm		
		K^+	0.75-1.5 meq (100 g)$^{-1}$ and 3.0-7.5% of CEC[d]		
		Ca^{+2}	8-13 meq (100 g)$^{-1}$ and 52-85% of CEC		
		Mg^{+2}	1.2-3.5 meq (100 g)$^{-1}$ and 7.5-21.0% of CEC		
4	General				"Watch plants and use judgement"

Table 1. Continued.

Ref.	Bedding plant		Material	Rate	Rate (kg m^{-3})	Remarks
59	General	Dry:	Superphosphate and	5-8 lb yd^{-3}	3.0-4.8	
			Osmocote 14-14-14 or	4-5 lb yd^{-3}	2.4-3.0	
			MagAmp	3 lb yd^{-3}	1.8	
			Gypsum	2 lb yd^{-3}	0.9	
15	General	Dry:	Superphosphate	1-2 lb yd^{-3}	0.6-1.2	Recommendations for peat-lite
97			$Ca(NO_3)_2 \cdot 7H_2O$ or	1 lb yd^{-3}	0.6	mixes
			KNO_3	1 lb yd^{-3}	0.6	
			Limestone (ground)	5 lb yd^{-3}	3.0	
51	Petunia	LF:	Nitrogen and	175 ppm		Apply at each watering
	'Pink		Phosphorus and	100 ppm		
	Cascade'		Potassium and	140 ppm		
			Osmocote 14-14-14	20 g ft^{-3}	0.7	Preplant
25	Petunia	LF:	Nitrogen and	200 ppm		Not clear if recommendation
	'Pink		Phosphorus and	200 ppm		refers to 200 ppm for each
	Magic'		Potassium or	200 ppm		separately or for all totally
			Osmocote 14-14-14	8 lb yd^{-3}	4.8	
89	Seed	LF:	Nitrogen and	200 ppm		See comment for Ref. 25
	Geranium		Phosphorus and	200 ppm		
			Potassium or	200 ppm		
			Alternate:			
			KNO_3 and	2 lb (100 gal)$^{-1}$		Alternate every week
			15-15-15	2 lb (100 gal)$^{-1}$		
61	Seed	LF:	Nitrogen and	200 ppm		See comment for Ref. 25
	Geranium		Phosphorus and	200 ppm		
	'Carefree'		Potassium	200 ppm		
27	Geranium	LF:	25-0-10 and	150 ppm		Apply at each watering
	(cutting)		Superphosphate and	4 oz ft^{-3}	4.0	
			Calcitic limestone	6 oz ft^{-3}	6.1	

[a]LF = liquid feed through irrigation system.

[b]Dry = dry feed only, either preplant addition or during growth.

[c]EC = electrical conductivity or soluble salts.

[d]CEC = cation exchange capacity of the soil, generally in meq per 100 g soil.

CHAPTER 1

LITERATURE REVIEW

Nitrogen

Function

Nitrogen, an essential macronutrient, comprises 40-50% of the living substance in plant cells (68). It occurs in organic and inorganic forms, the latter making up only a small proportion of the total. Most of the organic N is present as proteins and amino acids which, in turn, are an integral part of enzymes, nucleoproteins, DNA, RNA, hormones, chlorophyll, and ATP. Thus, N serves as both a catalyst and director in plant metabolism. Because of its role as a principal component in amino acids and proteins, N is considered the major element governing plant growth (11, 48).

Growth Effects

Under conditions of N deficiency, leaves will generally develop a pale, yellowish-green color because of limited chlorophyll synthesis; as deficiency persists, yellow, red, and purple colors from anthocyanin pigments may develop. Other common symptoms include reduction in leaf size and thin, upright stems with few lateral shoots. Since N is a mobile element within the plant, symptoms will begin in the older leaves and progress to the younger leaves as N deficiency intensifies (11, 48).

Plant succulence, the production of soft, lush growth, can be attributed to high N supplies. Under such conditions plants tend to use carbohydrates to form more protoplasm and cells rather than for cell wall deposition and thickening. Cell production in hemp is greater with high supplies of N, but fiber strength decreases (11). Letham (62) found that fruit from apple trees fertilized with N had increased cell sizes, but a greater incidence of injury and degradation than trees receiving no additional N.

Nitrogen also affects plant fruiting and time to maturity. It has been substantiated that tomato plants fed excess N become excessively vegetative and unfruitful (11). Similar results were reported with McIntosh apple trees as N increased from 1 to 1.5 lbs. per tree (16). Glover (38) found that sweet corn supplied with adequate, but not excessive, N matured earlier; timothy and oats (11) responded similarly. However, increased N supplies can delay maturity, as demonstrated with wheat (100) and peaches (17).

<u>Uptake and Utilization</u>

The majority of plants cannot fix N_2, but will absorb N as ions in the form of nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+), or amide ($-NH_2^+$); NO_3^- and NH_4^+ are the dominant forms absorbed. Many factors influence the uptake and utilization of NO_3^- and NH_4^+, including variations in plant species responses. Bean and sweet corn (70), pea and cucumber (7, 70), potato (84), tomato (106), viburnum (31), lemon seedlings (108), and white mustard (55) have been found to have increased growth as the proportion of NO_3^- to NH_4^+ increased; NH_4^+ was detrimental to these plants. Carnation (95), rose (92), apple (40), and sunflower (109) showed superior growth when both NO_3^- and NH_4^+ were present. Azalea (26), blueberry (21, 22), and cranberry (42) plants grew best with an all NH_4^+ source. Plant species that are normally sensitive to NH_4^+ nutrition could usually withstand higher proportions of NH_4^+ if the pH of the nutrient solution or growing media was properly controlled. Lemon seedlings maintained at pH 5.8 to 6.0 were found to have comparable growth in all NH_4^+ concentrations except the 100% NH_4^+ source (98, 108). Tomato plants maintained at pH 6.8 grew equally well in either NO_3^- or NH_4^+ sources (29). Similar results occurred in studies involving beans (9, 70), viburnum (31), peas (70, 92), and sweet corn and cucumbers (70).

Seasonal solar radiation also influences the $NO_3^-:NH_4^+$ ratio required. Under low radiation conditions carnations may be grown with 1/3 NH_4^+, while under high radiation conditions all NO_3^- provides the best growth (41). Crater, Kiplinger, and Tayama (28) have recommended the use of a 100% NO_3^- source for the growing of 'Giant No. 4 Indianapolis White' chrysanthemums during the fall and winter months and NH_4NO_3 the rest of the year. Hewitt (47) observed that plants were more tolerant to low light conditions when fed NO_3^-.

Carbohydrate supplies to the roots have been reported to influence uptake and utilization of NO_3^- and NH_4^+ (56, 73, 74). Michael et al. (73) observed that young potato plants attached to parent tubers take up both NO_3^- and NH_4^+. When the parent tuber was removed, NO_3^- uptake increased. They also found that girdled bean plants took up less total N, but NO_3^- uptake exceeded NH_4^+. Tiedjens (103) and Kirkby (56) also concluded that plants containing larger quantities of carbohydrates assimilate NH_4^+ more rapidly.

pH Effects

The absorption of NO_3^- and NH_4^+ by roots is known to affect the pH of the nutrient solution or growing media. The ionic equilibrium within the plant is maintained by the exchange of OH^- and HCO_3^- ions for absorbed NO_3^- ions, causing an increase in pH outside the root. In a similar manner, H^+ ions are exchanged for the NH_4^+ ions absorbed, resulting in a decrease in pH outside the root (12, 47, 70, 90, 110). The pH of a nutrient solution or growing media will also affect nitrogen absorption. Plants grown in NO_3^- or NH_4^+ solutions at concentrations of 8 meq l^{-1} or more, absorb NO_3^- more readily at pH values in the range of 4.5 to 6.0 while NH_4^+ is favored between 6.0 and 7.5 (47). Lycklama (65) also found complex temperature-pH affects for perennial ryegrass. NH_4^+ absorption was highly temperature dependent between pH 4.0 and 6.5, with an optimum temperature of 27° C. Between pH 6.5 and 8.0, temperature had little effect. In the absence of NH_4^+, NO_3^- uptake was highly temperature dependent, optimum temperatures being greater than 35° C. In the presence of NH_4^+, NO_3^- uptake decreased, and became almost independent of temperatures above 20° C. Wander and Sites (108) found that pH will also affect the cation exchange capacity (CEC) of rough lemon seedling roots. Without pH control, the CEC of treatments of 1 NH_4^+:1 NO_3^-, 1 NH_4^+:3 NO_3^-, and 0 NH_4^+:1 NO_3^- were 10, 22, and 37 meq (100 g dry weight)$^{-1}$, respectively. With pH controlled at 5.8 to 6.0, the treatments of 1 NH_4^+:0 NO_3^-, 1 NH_4^+:1 NO_3^-, 1 NH_4^+:3 NO_3^-, and 0 NH_4^+:1 NO_3^- had CEC's of 12, 15, 25, and 36 meq (100 g dry weight)$^{-1}$, respectively. The lower CEC's found with added NH_4^+ would probably contribute to the lower concentrations of Ca^{+2}, Mg^{+2}, and K^+ found in NH_4^+-fed plants. The pH shift caused by NO_3^- and NH_4^+ will also alter the solubility and availability of P. The P content of soybean roots and shoots was positively correlated with the pH of the rhizocylinder and not the pH of the bulk soil. NH_4^+ caused a decrease in the pH, thereby increasing the availability of P (90). Other researchers have also found increased P levels in NH_4^+-fed plants (5, 12, 30, 43, 67, 83, 84, 98).

N Metabolism

Nitrogen metabolism is a complex process. When NO_3^- is absorbed by the plant, it is reduced to NH_4^+ by nitrate reductase and nitrite reductase. The process requires 8 electrons which are delivered by the reductase enzymes from NADH or NADPH formed during photosynthesis. Both enzymes are well suited for electron transfer since nitrate reductase contains riboflavin (FAD) and Mo^{+3}, and nitrite reductase contains Fe^{+2} (93). The site of NO_3^- reduction will vary according to the species in question. Cocklebur roots have almost no ability to reduce NO_3^- as evidenced by the concentration of NO_3^- found in the xylem transport stream. At the other extreme, the white lupin assimilates nearly all of the absorbed NO_3^- in its roots (93). Studies by Wallace and Pate (107) revealed that nitrate reductase activity was restricted to the leaves of cocklebur, but in both the leaves and roots of field pea. Weissman (110) found similar differences in nitrate reductase activity sites in soybean and sunflower. Soybean nitrate reductase activity was found in both leaves and roots while in sunflower it was almost exclusively confined to the roots. Synthesis of nitrate reductase can be stimulated by various factors, especially NO_3^- and light (93). Due to this enzyme induced phenomenon, diurnal variations are often found in nitrate reductase activity (75). Variations in nitrate reductase activity are also found with plant age; activity decreased in soybean (101) and alfalfa (35) with increasing age, while it increased in sugarbeet and bean (73).

The NH_4^+ derived from NO_3^- reduction, or the NH_4^+ absorbed from the medium, is incorporated into organic compounds via glutamate dehydrogenase, glutamine synthetase, or glutamate synthase. NADH, ATP, or ferridoxin and NADH or NADPH are required for these reactions (93). Carbohydrate metabolism is directly related to this process since carbohydrates are used both as a source of C skeletons and as a source of respiratory energy for reductive amination. In the case of NO_3^- absorption, production of NH_4^+ is metabolically regulated by the oxidation of the co-enzymes (reductases). In NH_4^+ absorption, however, there is relatively less control, which may lead to a rapid depletion of carbohydrates (55, 56). If this happens, NH_4^+ begins to accumulate with its ensuing toxic effects. In the presence of adequate carbohydrate supplies, NH_4^+ absorption-assimilation should proceed at a faster rate than NO_3^- absorption-assimilation. Thus, higher concentrations of N are found in NH_4^+-fed plants (55, 67, 84, 98, 108, 115). Wander and Sites (108) reported a higher per cent N in NH_4^+-grown than in NO_3^--grown rough lemon seedlings; but the total N utilized, as evidenced by the dry weights of leaves, was greater when NO_3^- was used. Other ion concentrations in plant tissue will also vary according to the form of N absorbed. NH_4^+ nutrition typically yields higher concentrations of P and S while NO_3^-

nutrition yields higher levels of Ca^{+2}, Mg^{+2}, and K^{+} (12, 29, 84, 98, 108, 115). This is thought to be indicative of a predominantly cation-anion balance effect (12).

NH_4^+ Toxicity

The toxic effects of NH_4^+ on different plant species is well documented (55, 78, 83, 93, 98, 108). Chlorotic leaves followed by necrotic leaf spots and stem lesions occurred on tomato plants (6, 8, 71, 87). Other plant symptoms include leaf roll of potato (84), necrotic leaf spots and thickened, leathery leaves of chrysanthemum (78), necrosis in viburnum (31), and symptoms of Mo^{+3} deficiency (98) or Fe^{+2} and Mn^{+2} deficiency (108) in lemon seedlings. Reduced root growth and/or discoloration has been reported in pea and cucumber (7), lemon seedling (108), citrus (98), and chrysanthemum (78). In relation to reduced root and shoot growth, water absorption has been found to be adversely affected in poinsettia (13), potato (84), tomato (83, 88), sugarbeet (102), and rough lemon seedlings (108) by NH_4^+ excesses.

All of the foregoing symptoms are manifestations of physiological processes. One of the major effects of NH_4^+ is on photophosphorylation. NH_4^+ acts as a ferryboat-type uncoupler, inhibiting ATP formation while permitting electron flow (60, 87, 93). This effectively limits photosynthesis and thereby limits the carbohydrate pool. Carbohydrates are not only needed for protein and cell wall synthesis, but also for further NH_4^+ assimilation.

Lower levels of Ca^{+2} and K^+ may often account for some observed plant symptoms. The loss of membrane integrity (83) and chloroplast structural changes (87) of tomato plants may be due to the lower levels of Ca^{+2} associated with NH_4^+-fed plants. Since K^+ functions in osmotic processes, protein synthesis and stability, stomatal opening, membrane permeability, and pH control, its deficiency in the plant would certainly disrupt many processes (48). Studies performed with tomato plants indicate that excess NH_4^+ accumulation (1, 71, 106) and resultant toxicity symptoms (1, 6, 8, 71, 106, 113) can be reduced or eliminated by increasing K^+ concentrations. Nelson and Hsieh (78) found that the critical meq NH_4^+:K^+ ratio in fresh chrysanthemum tissue, indicative of NH_4^+ toxicity, ranged from 0.025 to 0.026. Similar results have been obtained with alfalfa and orchardgrass (67). Barker et al. (8) explained the NH_4^+-K^+ relationship in terms of protein stability. K^+ is bound to proteins and since NH_4^+ and K^+ share many similar properties, they may substitute for one another. When NH_4^+ replaces K^+, hydrogen bonding with adjacent OH^- groups in the protein molecule is possible. If this occurs, the tertiary structure changes leaving the protein molecule open to proteolytic action. Maynard et al. (71) and Evans and Sorger (36) report similar conclusions.

NH_4^+ toxicity may also be affected by poor aeration of the growing media. Kirkby (56) and Black (11) noted that NH_4^+ assimilation causes a greater demand for O_2. Hewitt (47) found that poor media aeration was tolerated more under conditions of NO_3^- nutrition programs.

Phosphorus

Function

With the possible exception of nitrogen, no other element is as frequently deficient for plant growth as phosphorus (18). Phosphorus has 5 electrons in its M shell which bond with oxygen to give a stable tetrahedral structure to the phosphate ion (44). This stable structure makes the phosphate ion essentially non-reactive during its addition to and removal from compounds in the metabolic process. Phosphorus, as the phosphate ion, is responsible for trapping, conserving, transporting, and donating energy in metabolism. The primary carrier of this energy is adenosine triphosphate, ATP. The initial reaction, in which water is split during photosynthesis, involves the presence of ADP, inorganic P, and coenzymes. Some of the light energy is transferred to ADP, plus inorganic P, to form ATP. Energy present in ATP is then available for use in the synthesis of more complex organic compounds. Conversely, during respiration some of this transferred energy is again recaptured by ADP to form ATP as the various organic compounds are broken down. Phosphorus also appears in such storage, structural, and organic molecules as phytin, phospholipids, nucleic acids, sugar phosphates, and coenzymes. It is interesting to note, as a phospholipid, P is thought to play an important role in selective membrane permeability and ion transport (11, 18, 44, 48, 93).

Availability

The availability of inorganic P is largely determined by media pH, Fe^{+2}, Al^{+3}, and Mn^{+2} in the acid pH range, Ca^{+2} and Mg^{+2} in the alkaline pH range, the amount and decomposition of organic matter, the activity of microorganisms, and soil temperature. The pH of the soil solution will determine the ionic form of phosphorus available to the plant. H_3PO_4 is the predominant form at pH < 2 while PO_4^{-3} is the predominant form at pH > 12. Between pH 4 and 7 $H_2PO_4^-$ will be the dominant ionic form, with increasing proportions of $HPO_4^=$ present as the pH rises above 6 (18). The pH-P relationship is further complicated by the presence or absence of other ions. As the pH decreases, there is a rise in activity of Fe^{+2}, Al^{+3}, and Mn^{+2}, and under certain conditions, the soluble phosphates will form insoluble complexes with them. If the pH rises much over 7 and Ca^{+2} is present, insoluble calcium phosphates are formed. Between pH 6 and 7, phosphorus fixation is at a minimum, and conversely, phosphorus availability is at a maximum. In addition to the pH and related effects, organic matter and microorganisms will affect P availability. Rapid decomposition of organic matter results in a temporary tying up of inorganic phosphorus in microbial tissues which will eventually become available as the microorganisms die (18, 44). Field observations indicate that low soil temperatures may decrease yield and/or accentuate P deficiencies (10, 11). Two species of clover were grown at 10.0°, 15.6°, and 21.1°C with P applications of 0.5 and 20 kg ha^{-1}. The resulting data showed an increase in yield as temperature and P levels increased (72). Several conjectures have been made regarding temperature effects including rate of P uptake, translocation of P from roots to shoots, change in area of root-soil contact due to root growth, mineralization of organic P in the soil, and the reaction rate of fertilizer P at increased soil temperatures (11).

Growth Effects

Several researchers (11, 48, 59) have reported numerous effects of P deficiency on plant growth. The most common deficiency symptom is the formation of anthocyanins that give the plant a purple tint. Since P is needed for cell division, stunted plants with small, dark green leaves may develop. Lateral buds can be inhibited resulting in prolonged dormancy. General growth may tend to be thin (spindly) and erect. Severe cases of P deficiency may cause a general yellowing of the leaves, a symptom often confused with N deficiency. Olsen (80) found P deficiency symptoms with corn when phosphorus was known to be adequate, and symptoms of Fe^{+2} or Zn^{+2} deficiency developed.

It was concluded that the condition was due to a deficiency of these micronutrients, phosphorus interacting with Fe^{+2} and Zn^{+2} and causing an induced deficiency.

Plant growth, development, and maturity are affected by P availability. If phosphorus is readily available, young plants will absorb phosphorus rapidly, absorbing 50% of their seasonal total by the time they have accumulated 25% of their seasonal total dry matter (11). Adequate supplies of phosphorus appear to promote rapid plant development. Glover (38) found that corn reached the tassel and silk stage at an earlier date where phosphorus was ample compared to when it was deficient. The first flower cluster of tomato differentiated at progressively earlier dates when the supply of P was increased (114). Payne (82), using rooted 'Sincerity' geranium cuttings and 6 levels of phosphoric acid ranging from 0 to 400 ppm P, noted that plant height, leaf diameter, and number of flowering branches increased as concentration increased from 0 to 100 ppm, then decreased. Joiner (52) reported that 'Indianapolis White No. 3' chrysanthemums increased in stem length and flower diameter as P increased from 10 to 120 ppm (source of P not given). Poinsettia bract size was found to increase when P increased from 1 to 10 lb treble superphosphate yd^{-3}, but no appreciable height difference was noted (54). The number of Rhododendron flower buds increased as P levels were elevated by adding 0.22 to

1.31 lb treble superphosphate yd^{-3} (91). Bean, mustard, and potato plants increased in height as P nutrient concentrations were raised to 1 meq l^{-1} (81). Poole et al. (85), however, observed that P had no effect on the growth of the bromeliad *Aechmea fasciata* 'Baker'.

Species Response

The difference in species response to P noted above is not uncommon. Lilleland et al. (63) found marked P reaction differences among a number of plant species grown on the same field with and without superphosphate additions. The ratios of yield without-to-with superphosphate for squash, cucumber, corn, wheat, oats, alfalfa, wax bean, and almond were 0.03, 0.07, 0.21, 0.38, 0.41, 0.57, 0.63, and 1.0, respectively.

Black (11) proposes that theories explaining plant P response differences may be grouped into 3 categories: 1) The Ionic-Equilibrium Theory is based on differences among species in their effect on the equilibrium of ions in the soil solution and hence their availability for absorption. Soybean plants, grown with NH_4^+ nutrient sources, exchanges H^+ ions for absorbed NH_4^+ ions and thus decreased the pH of the rhizosphere (90). The pH shift changed the solubility and availability of adjacent nutrient elements in the medium. Root excretion of readily decomposed compounds such as amino acids and the sloughing of root tissue stimulated the microflora in the rhizosphere, thereby increasing organic phosphorus mineralization (18). 2) The Root Character Theory is based on the differences in P absorbing characteristics and extent of the root system of various species. Lyness (66) grew 21 varieties of maize in sand culture and found differences in yield, which he attributed to the different amounts of phosphorus absorbed from the medium. Noggle and Fried (79) studied the short term uptake of phosphorus by detached roots of millet, barley, and alfalfa. The quantity of phosphorus absorbed was greatest in millet, intermediate in barley, and least in alfalfa. Since plants with more extensive root systems have more surface area in contact with the growing media, they should have a greater foraging and absorption capacity for phosphorus as well as other elements. 3) The Phosphorus Requirement Theory indicates that slow growing species, which require less P, are better adapted to growth under low phosphorus conditions than those species that grow faster and require more phosphorus. Lilleland et al. (63) observed such a response in slower growing almond trees which required no additional phosphorus to obtain good growth for the season, compared to faster growing annual plants which showed deficiency symptoms at the same phosphorus levels.

Potassium

Function

Potassium is 1 of the 3 major nutrients required by plants. Its presence appears to be essential for many processes within the plant, primarily as an activator of numerous enzymes. Monovalent cations such as Ru^+, Li^+, Na^+, and NH_4^+ may be substituted for K^+, but are usually less effective and may even prove to be inhibitory (34). K^+ is well suited for its role as an enzyme activator since it does not have a high affinity for organic ligands, including the enzymes for which it is a cofactor.

Potassium has been indirectly linked to photosynthesis in 3 ways. First, when K^+ is present in "luxury" amounts, the absorption and/or translocation of other ions may be depressed. Specifically, Cain (23) found low Mg^{+2} levels in apple leaves under "luxury" K^+ concentrations. Since Mg^{+2} plays a key role in photosynthesis, anything interfering with its distribution would also affect photosynthesis. Second, K^+ is known to function in stomatal opening and closing which influences the rate of gas exchange and therefore affects photosynthesis (11, 34, 48). Third, K^+ affects photosynthesis by promoting the translocation of photosynthates from leaves. As photosynthates accumulate in the leaf, photosynthesis slows down. Therefore, rapid export of these photosynthates from the leaf is important for maintenance of a high net photosynthetic rate. Hartt (46), using ^{14}C in sugar cane, presented evidence that K^+ accelerated the movement of assimilates from the leaves. Humbert (50) also found an increase in sugar and protein translocation with higher K^+ concentrations.

Nitrogen and carbohydrate metabolism are both affected by K^+-activated enzymes. When plants become deficient in K^+, soluble forms of N, amino acids, and amides accumulate in the tissues (14, 50, 71) with a decrease in protein content (67, 106). K^+ is also known to maintain some protein configurations; its absence leads to proteolysis and increases in the soluble N fractions (8, 71). Generally, starch and sugars begin to accumulate at the onset of K^+ deficiency and decrease as low K^+ levels persist. The starch and sugar accumulation probably occurs because of a greater limitation on protein synthesis than on net carbohydrate production. However, as K^+ deficiencies persist, respiration begins to increase, resulting in decreased carbohydrate levels.

K^+ is also known to function in water relations of plants. Increased K^+ contributes to greater water content and turgidity (50). Such an occurrence could result from high K^+ plants containing more water and/or from high K^+ plants losing less water. Black (11) reports evidence for both possibilities, but observations were inconsistent. Since stomatal opening and closing is directly related to K^+ concentrations, Humbert (50) explains the increased turgidity in terms of water conservation due to the size of the stomatal opening.

Growth Effects

K^+ deficiency symptoms will generally involve a shortening of stems and/or necrotic leaf tissues developing around the margins, at the tip, or interveinally (11). Epstein (34) attributed the necrotic symptoms to the accumulation of soluble N compounds, particularly putrescine. Leaves may be narrow and crinkled with a tendency for the margin to curl toward the upper or lower surfaces (11). Since K^+ is a mobile element in the plant, deficiency symptoms first appear on the older leaves and progress to the younger leaves as K^+ deficiency persists.

Plant response to increasing levels of K^+ is generally one of increased height, fresh weight, and dry weight. Holcomb (49), grew chrysanthemums and found a significant increase in fresh and dry weights and plant height as K^+ increased from 1.9 ppm to 190 ppm. Similar results have been reported involving 'Blue Chip' chrysanthemum (53), Kentucky blue grass (76), alfalfa and orchardgrass (67), and tomato (1, 8, 71, 106). Plant response to K^+ may be confounded by the interaction of K^+ with N. Greater K^+ responses are often associated with NH_4^+ nutrient programs (5, 71, 78). MacLeod and Carlson (67) reported that the N-by-K^+ interaction varied with the rate of K^+ supply and the source of N at each level of K^+.

K^+ can also be considered as the quality builder. According to Black (11), K^+ deficient potatoes are low in starch and tend to be hollow-centered. Tomato fruit drop prematurely, are lower in acidity, and have poor coloration if K^+ is low. Inadequate K^+ supplies also lead to cabbage heads that were not solid and peas with toughened seed coats. Humbert (50) also noted increased quality of grapes, peaches, citrus, rice, alfalfa, corn, pineapple, and bananas with higher levels of K^+. This is not surprising since K^+ plays such an essential role in the physiological processes of the plant.

Growing Media

Plants can be grown in almost any type of substrate as long as it is free from pests and toxins and provides support and availability of nutrients and water. In recent years there has been a movement towards the use of soilless growing media containing combinations of peat moss, vermiculite, perlite, sand, bark, or other available substances (68). Each media has its own chemical and physical properties; thus, growers using various growing media will also have to use different cultural practices accordingly, to obtain good plant growth.

Amendments

The 3 most commonly used media amendments are peat moss, vermiculite, and perlite. There are many types of peat (19), but most growers in the USA use the sphagnum type (68). Peat decomposes with time, but the growing period for bedding plants is short enough to eliminate this as a cultural consideration. Physical and chemical properties of sphagnum peat moss vary, but general specifications for a column 17.8 cm deep include: dry bulk density, 0.11 g cm^{-3}; wet bulk density, 0.70 g cm^{-3}; volume moisture capacity, 58.8%; total porosity, 84.2%; free-air porosity, 25.4%; (45) and CEC, 110-130 meq $(100\ g)^{-1}$ (19). Vermiculite is an expanded micaceous mineral consisting of many plate-like layers. The layered structure gives vermiculite a high porosity value and good air-water relationships. However, with time the structure collapses, resulting in reduced aeration and drainage. Specifications of horticultural grade vermiculite for a column 17.8 cm deep include: dry bulk density, 0.11 g cm^{-3}; wet bulk density, 0.65 g cm^{-3}; volume moisture capacity, 53.0%; total porosity, 80.5%; free-air porosity, 27.5% (45); and CEC, 100-150 meq $(100\ g)^{-1}$ (19). Perlite, an expanded volcanic aluminosilicate, is a porous aggregate that will not break down in the growing media. Its properties (1/4 to 5/16 inch) for a column 17.8 cm deep include: dry bulk density, 0.10 g cm^{-3}; wet bulk density, 0.29 g cm^{-3}; volume moisture capacity, 19.5%; total porosity, 73.6%; a free-air porosity, 53.9% (45); and CEC, up to 1.5 meq $(100\ g)^{-1}$ (19).

Nutrient Availability

Differences in the amendment properties of a growing media, as well as the soil, will influence the type of nutrient program needed.

Dunham (32) grew 'Little America' chrysanthemums in 3 media containing, by volume, 3:1 sand-soil, 1:2:2 sand-soil-sphagnum peat moss, and 1:2:2 sand-soil-vermiculite. A loam soil of the Sassafras series and a local yellow concrete sand were used in the media. Soil tests indicated that the added vermiculite increased soil pH, K^+, Ca^{+2}, Mg^{+2} and decreased P, whereas the addition of sphagnum peat moss decreased soil pH, soluble salts, P, and K^+. Tissue analysis revealed that the vermiculite increased total K^+, but decreased Mg^{+2} and Mn^{+2} in the plant. Peat moss additions decreased P, K^+, and Ca^{+2}, but increased Mn^{+2} in the tissue. He also noted that peat-amended soils required more frequent replenishment of nutrient cations, especially K^+. Boodley and Sheldrake (15) reported on nutrient requirements for 2 "peat-lite" mixes (peat-vermiculite and peat-perlite) and found in some instances that when $(NH_4)_2SO_4$ was the N source, NH_4^+ toxicity developed. However, if at least 50% of the total N supply was in the NO_3^- form, plant growth was satisfactory. Seeley (96) grew poinsettias in the 2 "peat-lite" mixes and found the peat-perlite medium required additional K^+ for good growth. Bunt (20) reported a large season by nutrient absorption interaction. The greatest response occurred in the 75% peat:25% sand medium and to a lower degree in a 59% loam:25% peat:16% grit medium. Dunham (33) has also noted that fertilizer applications interacted with the growing media moisture content.

Summary

Nitrogen, phosphorus, and potassium are the 3 primary macronutrients that govern plant growth. The concentration and preparation of each in a fertilization program, plus the type of growing media, will often determine the amount and quality of plant growth. The bedding plant industry, a division of floriculture, has grown rapidly in the last 2 decades. As a crop, bedding plants rank second only to chrysanthemums in value for the entire commercial floriculture industry. After reviewing the literature concerning plant nutrition, it may be noted that a variety of opinions exist for general bedding plant fertilization recommendations with very little information available for specific bedding plant species. In general, recommendations are neither consistent nor founded on good physical principles. It is apparent that additional research is necessary to determine optimum nutrient levels that will insure quality plants for the consumer and minimum costs for the grower.

CHAPTER 2

GROWTH RESPONSES OF SEED GERANIUM AND PETUNIA TO N SOURCE AND GROWING MEDIA

Bedding plant growth and quality are frequently influenced by the nutritional program and type of growing medium used. Present fertilizer recommendations for bedding plants, in general, are variable, and often include preplant dry fertilizers, liquid feeds, and slow release materials. Limited nutrition research has been conducted using petunias and seed geraniums. Johnson and Skelton (51) grew 'Pink Cascade' petunias and recommended a liquid feed of 175 ppm N, 100 ppm P, and 140 ppm K plus 14-14-14 (N-P_2O_5-K_2O) Osmocote at 20 g ft^{-3} (0.7 kg m^{-3}). Carlson and Carpenter (25) recommended a continuous liquid feed of 20-20-20 at 200 ppm N or 14-14-14 Osmocote at 8 lbs yd^{-3} (4.8 kg m^{-3}) for 'Pink Magic' petunias. The Pan American Seed Company (61) suggested a liquid feed of 200 ppm N-P-K for their 'Carefree' seed geranium series. Reilly (89) recommended a constant feed of 200 ppm N-P-K or alternate KNO_3 and 15-15-15 at 2 lbs per 100 gals every week for seed geraniums. For vegetatively propagated geraniums, White (69) suggests the use of soil and tissue analysis to regulate N-P-K levels, with half the N source as NO_3^- and the other half as NH_4^+.

Plants commonly absorb N as NO_3^- and/or NH_4^+ ions. The proportion of each needed by a plant to attain optimum growth will depend on the plant species in question. Bean and sweet corn (70), pea and cucumber (7, 70), potato (84), tomato (106), viburnum (31), lemon seedlings (108), and white mustard (55) exhibited increased growth responses as the proportion of NO_3^- to NH_4^+ increased. Species such as azalea (26), cranberry (42), and blueberry (21, 22) thrived on an all NH_4^+ source. Other plants including carnation (95), rose (92), apple (40), and sunflower (109) showed superior growth when both forms were present. Some plants that are normally sensitive to NH_4^+-nutrition often respond to increasing proportions of NH_4^+ if the media pH is controlled. Lemon seedlings maintained at pH 5.8 to 6.0 were reported to have comparable growth in all NH_4^+ treatments except the 100% NH_4^+ nutrient solution (108). Similar results have been obtained for bean (9), viburnum (31), pea (29, 70) and bean, cucumber, and sweet corn (70).

The adverse effects of abundant NH_4^+ supplies on plant growth are well documented (70, 78, 87, 93, 104). NH_4^+ acts as a ferryboat-type uncoupler during photophosphorylation, inhibiting ATP formation while permitting electron flow (60, 87, 93). This effectively limits photosynthesis and thereby limits the carbohydrate pool. These carbohydrates are not only needed for protein and cell wall synthesis, but also for further NH_4^+ assimilation. NH_4^+ assimilation into organic compounds may also lead to a depletion of carbohydrates and metabolic energy, thus limiting plant growth (71).

Plants can be grown in almost any type of substrate as long as it is free from pests and toxins and provides support, nutrients, water, and oxygen. Substrates may include such materials as soil, sand, peat moss, vermiculite, perlite, bark, styrofoam, or other available substances. The majority of growers are still using soil as a component of their growing media, although there is a trend towards soilless media as sources of reliable soil dwindle (68). Cultural practices, including fertilization, must be adjusted to the media being used since each will have its own chemical and physical properties. For example, adding vermiculite to a growing media will generally cause an increase in pH, K^{+}, Ca^{+2}, and Mg^{+2} while decreasing P. On the other hand, adding peat moss to a growing media will decrease the pH, soluble salts, P, and K^{+} (32). Peat moss amended media generally require more frequent replenishment of cations, especially K^{+} (32, 33).

A lack of information on N fertilization programs for bedding plant culture prompted this study to determine the ratio of $NO_3^-:NH_4^+$ that would provide quality growth of seed geraniums and petunias when grown in a soil and a soilless (peat-lite) media.

Materials and Methods

Five combinations of N sources and two growing media were factorially combined in a randomized complete block design with 2 replicates. The experiment was repeated 3 times between October, 1978 and April, 1979. The 5 N treatments ranged from 1 NO_3^-:0 NH_4^+ to 0 NO_3^-:1 NH_4^+ (Table 2). Total NO_3^- + NH_4^+ was kept constant at 15 meq l^{-1} and K^+ at 4.25 meq l^{-1}. All solutions had a cation plus anion concentration of 44.5 meq l^{-1}. Each nutrient solution was applied, as required, with a plastic watering can, to the saturation point. The soil medium consisted of 1:1:1 Fort Collins clay loam, Canadian peat moss, and perlite, by volume. The soilless medium (peat-lite) was composed of 1:1 Canadian peat moss and vermiculite, by volume. Both substrates had a preplant addition of treble superphosphate, 0-46-0, at 3 kg m^{-3} (5 lb yd^{-3}). The soilless medium had 191 ml m^{-3} (3 oz yd^{-3}) of X-77 wetting agent added to it.

Pelargonium hortorum 'Sprinter Scarlet' and Petunia hybrida 'Candy Apple' seeds were germinated and transplanted at the 2 to 3 leaf stage into cell packs, 32 geranium plants per treatment and 48 petunia plants per treatment (Table 3). Plants were grown in a glass covered greenhouse heated to 16°C (62°F) day and night and cooled to 21°C (70°F) during the day. Carbon dioxide was injected to maintain 1000 ppm on clear days with no ventilation. Ten randomly selected plants from each treatment were harvested, when the first treatment became salable, and data recorded. Data included fresh and dry weights and heights of geraniums and fresh and dry weights, stem length, number of breaks, and total flowers and buds of petunias. In addition, soil and tissue samples were taken at the termination of each experiment. Soil samples were analyzed at the Colorado State University Soil Testing Laboratory using an NH_4HCO_3-DTPA extraction method (99). Tissue analyses were performed at the Plant Testing Laboratory, Horticulture Department, Pennsylvania State University. Data were subjected to analysis of variance and Tukey's HSD mean separation at the 5% level.

Results

The results reported are of the third repetition of the experiment which were comparable to the timing in the bedding plant industry and were consistent with the 2 previous repetitions.

Geraniums

Fresh and dry weights and plant height responses varied with the growing media (Table 4). Plants growing in the soil medium grew well with all NO_3^- and NH_4^+ nutrient treatments. The 100% and 75% NO_3^- treatments were, however, significantly taller than the 100% NH_4^+ treatment. Foliage of all plants was dark green. Root development of plants receiving 50% or more NO_3^- was greater than those in the 75 to 100% NH_4^+ treatments.

Plants growing in the soilless medium were greatly affected by the form of N nutrition. In all cases, fresh and dry weights and plant height decreased gradually from 100% to 25% NO_3^-. A highly significant reduction occurred in the 100% NH_4^+ treatment. Plants receiving 100% NH_4^+ were stunted with interveinal chlorosis and occasional development of red pigments in the leaves. The 75% NH_4^+ treatment showed signs of mild chlorosis. All other treatments were dark green. Vigorous root development was observed in plants receiving at least 50% or more NO_3^-, less vigorous in 75% NH_4^+, and very poor root growth in the 100% NH_4^+ treatment.

Petunias

The growing media also affected petunia growth under the different N treatments (Table 5). Soil-grown plants showed no significant differences when grown under the various N treatments. All plants looked normal except the 100% NH_4^+ treatment which had slightly thickened leaves, a distinct yellowing of the leaf margin, and slightly reduced root growth.

Plants grown in the soilless substrate were affected much more by the form of N nutrition. All measured parameters -- fresh and dry weights, height, total flowers and buds, and number of breaks -- were considerably less in the 100% NH_4^+ treatment. Height, fresh and dry weights, and the number of breaks showed no statistical difference in treatments ranging from 100% to 25% NO_3^-. The total flower and bud yield in the 75% and 100% NH_4^+ treatments were significantly lower than in the other treatments. Plants growing with 50% or more NO_3^- looked normal. The 75% NH_4^+ treatment had slightly thickened leaves that tended to cup upwards with a definite yellow margin. The 100% NH_4^+ grown plants were very stunted with thickened leaves that were light green and cupped upwards with a distinct yellow margin. Root development was very poor in the 100% NH_4^+ treatment, improved in the 75% NH_4^+ treatment, and quite vigorous in the 50% or more NO_3^- treatments.

Soil and Tissue Analysis

Chemical analysis revealed that the soilless medium was more sensitive to the form of N supplied (Table 6). Definite trends in NO_3^- and NH_4^+ occurred in both media, the soilless substrate having a much greater range. The pH of the soil medium was consistently higher than the soilless medium. In both cases, the pH tended to decrease as the proportion of NH_4^+ in the nutrient solution increased. The concentrations of K^+, Fe^{+2}, and Zn^{+2} were higher in the soilless substrate while Mn^{+2} and the electrical conductivity were greater in the soil mixture.

Tissue analyses of plants grown in both media were similar, the concentration range for the soilless mixture being greater than those for the soil medium (Table 7). In general, K^+, Ca^{+2}, and Mg^{+2} decreased as the proportion of NH_4^+ in the nutrient solution increased.

P levels remained the same or decreased slightly with increased NH_4^+.

Discussion

Both geraniums and petunias showed reduced growth in the soil-less medium with NH_4^+ levels greater than 50% of the total nitrogen supply (Tables 4 and 5). The results were in agreement with other researchers (55, 70, 108). Reduced root growth was also noted in both species tested as NH_4^+ increased from 50 to 100% of the total nitrogen supply. Wander and Sites (108) report similar results for rough lemon seedlings; as the 200 ppm N nutrient solution changed from 100% NO_3^- to 100% NH_4^+, roots became short, thickened, brown colored, and fewer in number. They observed that the NH_4^+ fed plant roots were inferior, which was substantiated by the reduction in root CEC as the proportion of NH_4^+ increased. Reduced root growth with increased NH_4^+ has also been observed in other species (7, 78, 98). Water absorption, due to root development, has also been found to be adversely affected by increased NH_4^+ in poinsettia (13) and other crops (83, 84, 88, 102, 108). While no quantitative measurements on water absorption were made on the petunias and geraniums studied, it was observed that the 75 and 100% NH_4^+ nutrient solutions needed replenishment less often than the other solutions. The reduced root development plus lower water absorption apparently limited the plants' nutrient foraging capacity, thereby contributing to the reduced shoot growth.

The tissue analyses of both geranium and petunia foliage tended to have decreased concentrations of Ca^{+2} and Mg^{+2} when subjected to increasing NH_4^+ levels, particularly in the soilless substrate (Table 7). This same phenomenon has been found in other plants (56, 57, 83, 84) and is thought to be a predominately cation-anion balance effect (12). The loss of membrane integrity (83) and chloroplast structural changes (87) of tomato are thought to be due to the lower levels of Ca^{+2} associated with NH_4^+ fed plants. This coupled with the lower Mg^{+2} levels and thus lower chlorophyll concentrations, probably lead to lower rates of photosynthesis, reduced plant growth, and chlorotic leaves observed in this study.

Tissue analysis also revealed decreasing K^+ concentrations with increasing proportions of NH_4^+ in both species tested (Table 7). The approximate incipient deficiency K^+ concentration for geranium 'Irene' was found to be 0.62% of dry weight, with an optimum concentration between 2.5 to 4.3% of dry weight (58). Such information is not available for petunias. K^+ deficiency symptoms were not apparent on either species. However, studies performed with tomato indicate that NH_4^+ accumulation (1, 71, 106) and toxicity symptoms (1, 8, 71, 106) can be reduced or eliminated by increasing K^+ concentrations.

The soilless medium had greater fluctuations in NO_3^- and NH_4^+ which were positively related to the type of N nutrition given the plants (Table 6). The lack of increased substrate NH_4^+ with increased solution NH_4^+ in the soil medium may, in part, be attributed to the presence of active nitrifying bacteria that oxidize NH_4^+ to NO_3^-. Black (11) discussed the soil pH-NH_4^+ oxidation relationship and pointed out that NH_4^+ oxidation decreased as the pH decreased. Dirr (31) noted that the nitrifying bacteria are most active at pH values greater than 5.5. Soil analysis revealed that the soilless medium pH was below pH 5.5 while the soil medium pH was above 5.5. Thus, even if the nitrifying bacteria were present in the soilless mixture they would be less active and a higher NH_4^+ level would be expected.

There was a trend in both media for the pH to decrease as the proportion of NH_4^+ in the nutrient solution increased (Table 6). This trend would be expected since NO_3^- absorption occurs with an exchange of OH^- or HCO_3^- ions causing pH to increase, and NH_4^+ absorption is accompanied by the exchange of H^+ ions causing pH to decrease (12, 70). The shift in pH not only affects the nitrifying bacteria, but also changes the availability of other nutrients. Riley and Barber (90) have shown that soybean root and shoot P content was positively correlated with pH of the rhizocylinder; NH_4^+ caused a decrease in the pH of the rhizocylinder and thereby increased the availability of P. Many other workers have also found increased P levels in NH_4^+-fed plants (12, 83, 84). Contrary to these findings, Yoshida (115) noted no difference in amount or distribution of labeled ^{32}P in tobacco plants in NO_3^- and NH_4^+ nutrition studies. Both the petunias and geraniums in this study had fairly constant P levels regardless of N source (Table 7). However, geraniums grown in the lower pH, soilless medium consistently had higher P concentrations in the foliage.

In summary, the soilless medium used in this experiment was much more sensitive to the form of N supplied, 50% or more NO_3^- giving superior plant growth. The soil media had a greater "buffering" capacity and gave good plant growth over a wider NO_3^-:NH_4^+ range. Soilless grown plants were generally taller and heavier than soil grown plants when supplied with 50% or more NO_3^-. Further work is needed in the area of pH control to determine its effect on the growth of bedding plants in the various N treatments.

Table 2. Nutrient solution composition used at each irrigation on petunia 'Candy Apple' and seed geranium 'Sprinter Scarlet' grown in soil and soilless media.

Treatment[a]	Cations (meq l^{-1})				Anions (meq l^{-1})		
(NO_3^-:NH_4^+)	K^+	Ca^{+2}	Mg^{+2}	NH_4^+	NO_3^-	SO_4^{-2}	Cl^-
1. 1:0	4.25	13.00	5.50	0.00	15.00	4.50	3.25
2. 3:1	4.25	10.50	4.25	3.75	11.25	6.00	5.50
3. 1:1	4.25	8.00	3.00	7.50	7.50	8.00	7.25
4. 1:3	4.25	5.00	2.25	11.25	3.75	10.00	9.00
5. 0:1	4.25	2.50	1.00	15.00	0.00	12.00	10.75

[a]All solutions contained the following micronutrients per liter (45): boric acid, 2.86 mg; manganese chloride, 1.81 mg; zinc sulfate, 0.22 mg; copper sulfate, 0.08 mg; molybdic acid, 0.02 mg; and FeEDTA (sequestrene 330), 5 mg.

Table 3. Sowing, transplanting, and harvesting dates for seed geranium 'Sprinter Scarlet' and petunia 'Candy Apple' subjected to 5 NO_3^-:NH_4^+ ratios and grown in soil and soilless media.

Plant	Crop	Sown	Transplanted	Harvested
Geranium	1	10-17-78	11-10-78	1- 3-79
	2	1-16-79	2- 7-79	3-23-79
	3	2-13-79	3- 9-79	4-30-79
Petunia	1	10-17-78	11-28-78	1-10-79
	2	1-16-79	2-21-79	4- 2-79
	3	2-13-79	3-16-79	4-24-79

Table 4. Effect of $NO_3^-:NH_4^+$ ratio on the mean height, fresh and dry weight of geranium 'Sprinter Scarlet' when grown in soil (S) and soilless (SL) media.

Treatment ($NO_3^-:NH_4^+$)	Height (cm)		Fresh weight (g)		Dry weight (g)	
	SL	S	SL	S	SL	S
1. 1:0	11.43	9.22	17.43	10.89	10.20	6.50
2. 3:1	10.82	8.97	16.86	10.26	9.05	6.15
3. 1:1	10.23	8.71	15.47	10.19	8.10	6.05
4. 1:3	8.97	8.54	13.18	10.83	6.85	6.05
5. 0:1	4.80	7.58	4.80	10.51	3.55	5.60
HSD (5%)	1.26	1.26	3.61	3.61	2.36	2.36

Table 5. Effect of $NO_3^-:NH_4^+$ ratio on the mean height, fresh weight, dry weight, number of breaks, and flowers and buds of petunia 'Candy Apple' grown in a soil (S) and soilless (SL) media.

Treatment ($NO_3^-:NH_4^+$)	Height (cm)		Fresh weight (g)		Dry weight (g)		Breaks		Flowers + buds	
	SL	S	SL	S	SL	S	SL	S	SL	S
1. 1:0	17.74	16.50	24.89	21.75	1.87	1.59	5.10	4.20	1.70	1.50
2. 3:1	18.10	18.90	27.57	25.91	1.82	1.89	4.60	3.60	1.65	2.00
3. 1:1	15.88	19.10	24.65	26.23	1.78	1.84	4.60	3.80	1.90	1.85
4. 1:3	13.98	17.25	21.01	25.46	1.39	1.89	3.50	3.70	0.70	1.80
5. 0:1	3.45	14.75	7.16	24.60	0.59	1.90	0.20	3.10	0.50	1.50
HSD (5%)	5.87	5.87	4.75	4.75	0.46	0.46	2.62	2.62	0.92	0.92

Table 6. Effect of $NO_3^-:NH_4^+$ ratios on soil analysis of geranium 'Sprinter Scarlet' and petunia 'Candy Apple' when grown in a soil and soilless media.

Treatment $NO_3^-:NH_4^+$	NO_3^- ppm	NH_4^+ ppm	P ppm	K^+ ppm	Fe^{+2} ppm	Zn^{+2} ppm	Mn^{+2} ppm	Cu^+ ppm	pH	EC[a]
Geranium										
Soil										
1. 1:0	64	15	1180	1000	77	9.0	63	2.3	6.1	4.9
2. 3:1	68	28	1120	1396	80	9.0	83	2.6	5.8	5.5
3. 1:1	92	4	1140	1320	85	9.6	96	2.6	5.5	4.9
4. 1:3	62	14	1060	1484	91	10.0	96	2.8	5.4	6.2
5. 0:1	66	138	1040	1376	92	12.0	98	3.1	5.6	6.2
Soilless										
1. 1:0	300	39	560	2436	244	11.0	29	1.2	4.2	1.8
2. 3:1	172	472	730	2862	316	17.0	29	1.7	3.9	1.7
3. 1:1	132	1460	720	3504	292	14.6	32	1.7	3.9	2.2
4. 1:3	24	2150	460	3372	251	16.1	45	2.1	3.7	2.7
5. 0:1	24	4080	500	5208	297	27.0	61	2.0	3.3	3.4
Petunia										
Soil										
1. 1:0	640	10	1160	514	92	8.5	122	2.5	6.7	3.9
2. 3:1	270	11	950	488	79	8.6	108	2.9	6.4	3.9
3. 1:1	760	92	850	516	82	7.9	113	2.4	5.9	3.5
4. 1:3	760	83	900	600	84	8.2	118	3.1	5.7	4.7
5. 0:1	760	77	870	456	86	8.2	111	3.9	5.8	4.3

Table 6. Continued.

Treatment $NO_3^-:NH_4^+$	NO_3^- ppm	NH_4^+ ppm	P ppm	K^+ ppm	Fe^{+2} ppm	Zn^{+2} ppm	Mn^{+2} ppm	Cu^+ ppm	pH	EC[a]
Petunia										
Soilless										
1. 1:0	880	11	560	996	181	6.4	33	3.5	5.5	2.1
2. 3:1	580	32	420	1110	261	12.6	29	3.0	4.5	1.9
3. 1:1	380	272	470	1092	274	8.9	34	3.0	3.7	2.5
4. 1:3	152	914	440	744	268	10.0	31	2.5	3.3	2.9
5. 0:1	24	1500	530	1482	290	7.9	32	2.0	4.2	1.2
Soil, pretreatment										
	22	93	1560	760	85	7.5	88	2.2	6.7	1.9
Soilless, pretreatment										
	16	58	960	642	128	11.0	32	1.9	4.3	2.1

[a] Electrical conductivity = millimhos cm^{-1}, saturated paste.

Table 7. Effect of $NO_3^-:NH_4^+$ ratio on the tissue analysis of geranium 'Sprinter Scarlet' and petunia 'Candy Apple' grown in a soil and soilless media.

Treatment ($NO_3^-:NH_4^+$)	Per cent of dry weight				
	N	P	K^+	Ca^{+2}	Mg^{+2}
Geranium					
Soil					
1. 1:0	3.88	0.56	4.30	2.98	0.64
2. 3:1	3.42	0.63	3.96	3.24	0.64
3. 1:1	3.85	0.66	4.30	3.17	0.56
4. 1:3	4.42	0.84	4.39	3.10	0.52
5. 0:1	4.33	0.82	4.21	2.80	0.37
Soilless					
1. 1:0	3.78	0.89	4.13	2.84	0.96
2. 3:1	4.58	0.92	4.11	2.26	0.78
3. 1:1	4.60	1.16	3.69	1.49	0.68
4. 1:3	4.66	1.29	3.27	1.14	0.48
5. 0:1	4.80	1.07	4.16	1.97	0.76
Petunia					
Soil					
1. 1:0	4.00	0.58	5.00	4.05	1.10
2. 3:1	4.58	0.71	4.99	3.55	1.01
3. 1:1	4.80	0.78	5.00	3.50	0.81
4. 1:3	4.68	0.70	4.84	3.62	0.72
5. 0:1	5.20	0.72	4.94	3.18	0.60
Soilless					
1. 1:0	5.08	0.63	5.10	2.90	0.99
2. 3:1	5.36	0.59	5.29	2.41	0.98
3. 1:1	5.98	0.68	4.12	2.01	0.99
4. 1:3	6.28	0.70	4.14	1.54	0.86
5. 0:1	6.36	0.66	4.16	1.03	0.65

CHAPTER 3

N-K NUTRITION OF SEED GERANIUM AND PETUNIA GROWING IN A SOIL AND SOILLESS MEDIA

Available recommendations on bedding plant fertilization programs is quite variable, but most sources recommend a complete fertilizer at each watering and/or a slow release fertilizer (6, 25, 27, 51, 59, 61, 89, 94). While little attention has been given to species variability with regard to nutritional needs, some work has been conducted using petunias and geraniums. Johnson and Skelton (51), growing 'Pink Cascade' petunias, recommended a liquid feed of 175 ppm N, 100 ppm P, and 140 ppm K plus 14-14-14 Osmocote at 20 g ft^{-3} (0.7 kg m^{-3}). Carlson and Carpenter (25) grew 'Pink Magic' petunias and recommended a liquid feed of 20-20-20 at 200 ppm N or 14-14-14 Osmocote at 8 lb yd^{-3} (4.8 kg m^{-3}). Reilly (84) recommends using 200 ppm N-P-K for seed geraniums as a constant feed or alternate KNO_3 and 15-15-15 at 2 lb $(100\ gal)^{-1}$ every week. The Pan American Seed Company (61) recommends 200 ppm N-P-K for their 'Carefree' seed geranium series.

The importance of nitrogen and potassium to plant growth and development is well known. Nitrogen, because of its structural role in amino acids and proteins, is considered the major element governing plant growth. Deficiencies generally lead to decreased cell division and expansion (reduced size), decreased chlorophyll production, increased anthocyanin production in some species, repressed lateral buds, and premature senescence. Potassium, because it functions in osmotic processes, protein synthesis and stability, stomatal opening, membrane permeability, pH control, and enzyme activation, also affects plant growth. Deficiency generally leads to short, bushy plants and/or necrotic leaf tissues developing around the margins, at the tip, or interveinally, giving a scorched appearance to the plant (48). While deficiencies of both N and K^+ are detrimental to plant growth and quality, excesses may also lead to undesirable plant growth. Over fertilization may be costly to the grower, not only in terms of fertilizer, but also in terms of additional pinching needs, growth retardant applications, and special care in shipping and handling.

Plants can be grown in almost any type of substrate as long as it is free from pests and toxins and provides support, nutrients, water and oxygen. Substrates may include such materials as soil, sand, peat moss, vermiculite, perlite, bark, styrofoam, or other available substances. The majority of growers are still using soil as a component of their growing media, although there is a trend towards the use of soilless media as the sources of reliable soil dwindle (68). Cultural practices must be adjusted to the media being used since each will have its own chemical and physical properties. For example, adding vermiculite to a growing media will generally cause an increase in pH, K^+, Ca^{+2}, and Mg^{+2} while decreasing P. The addition of peat moss will decrease the pH, soluble salts, P, and K^+ (32). Peat moss amended media generally require more frequent replenishment of cations, especially K^+ (32, 33).

The objective of this study was to determine the levels of N and K^+ needed to produce quality plant growth of geranium 'Sprinter Scarlet' and petunia 'Candy Apple' plants when grown in a soil and soilless media.

Methods and Materials

Four levels of N, 3 levels of K^+, and 2 growing media were factorially combined in a randomized complete block design with 2 replicates. The experiment was conducted twice between January, 1979, and May, 1979. The N levels were 7.0, 10.5, 14.0, and 17.5 meq l^{-1} and consisted of half NO_3^- and half NH_4^+ (Table 8). K^+ concentrations were 2, 4, and 6 meq l^{-1}. All solutions had a cation plus anion concentration of 35.5 meq l^{-1}. Each nutrient solution was applied, as required, with a plastic watering can, to the point of saturation. The soil growing medium consisted of 1:1:1 Fort Collins clay loam, Canadian peat moss, and perlite, by volume. The soilless medium consisted of 1:1 Canadian peat moss and vermiculite, by volume. Both media had a preplant addition of treble superphosphate, 0-46-0, at 3 kg m^{-3} (5 lb yd^{-3}). The soilless medium had 191 ml m^{-3} (3 oz yd^{-3}) of X-77 wetting agent added to it.

Pelargonium hortorum 'Sprinter Scarlet' and Petunia hybrida 'Candy Apple' seeds were germinated and transplanted at the 2 to 3 leaf stage into cell packs, 32 geranium and 48 petunia plants per treatment (Table 9). Plants were grown in a glass covered greenhouse heated to 16.7° C (62°F) day and night and cooled to 21.1° C (70°F) during the day. Carbon dioxide was injected to maintain 1000 ppm on clear days during periods of no ventilation. Ten randomly selected plants from each treatment were harvested when the first treatments became salable, and data recorded. Geranium height, fresh and dry weights, and total flowers and buds were measured, and petunia height, fresh and dry weights, number of breaks, and total flowers and buds were measured. In addition, soil and tissue samples were taken at the termination of the experiments. Soil samples were analyzed at the Colorado State University Soil Testing Laboratory using an NH_4HCO_3-DTPA extraction method (99). Tissue analyses were performed by the Pennsylvania State University Plant Tissue Testing Laboratory. Data were subjected to analysis of variance and Tukey's HSD mean separation at the 5% level.

Results

The experiment was conducted twice with only minor variations in plant growth occurring from experiment to experiment. The results reported are of the last experiment and are representative of both.

Geraniums

There were no effects of K^+ levels on plant height, fresh and dry weights, or total flowers and buds (Table 10). N levels, however, did affect plant growth. Soil-grown plants showed no significant differences in plant growth as N increased, except N_4 (17.5 meq l^{-1}) plants were shortest. There was a tendency for the growth parameters to decrease from N_2 (10.5 meq l^{-1}) to N_4 (17.5 meq l^{-1}). Plants grown in the soilless medium had a greater response to N levels. N_2 (10.5 meq l^{-1}) and N_3 (14.0 meq l^{-1}) treatments yielded taller plants than N_1 (7.0 meq l^{-1}) and N_4 (17.5 meq l^{-1}) levels. There was a general trend for fresh and dry weights and total flowers and buds to increase from N_1 (7.0 meq l^{-1}) to N_3 (14.0 meq l^{-1}) and then decrease. Soil-grown plants were slightly taller and had more flowers and buds, while plants grown in the soilless medium had greater mean fresh and dry weights. There was an N-by-K interaction for plant height that was attributed to a spurious N_3K_3 (14.0, 6 meq l^{-1}) value. All plants grown in the N_1 (7.0 meq l^{-1}) treatments were light green in appearance.

Petunias

The two growing media gave comparable plant growth at each nutrient level (Table 11). K levels had little or no effect on plant growth, except K_3 (6 meq l^{-1}) plants were taller than K_1 (2 meq l^{-1}) and K_2 (4 meq l^{-1}) treatments. N concentrations did influence plant growth. Plant height and fresh and dry weights increased with increasing N; N_4 (17.5 meq l^{-1}) plants were significantly taller and heavier than N_1 (7.0 meq l^{-1}) plants. The number of breaks and flowering time were not affected by the nutrient program. There was an N-by-K interaction for height which could be attributed to a spurious N_3K_2 (14.0, 4 meq l^{-1}) value. Plants grown in N_4K_2 (17.5, 4 meq l^{-1}) and N_4K_3 (17.5, 6 meq l^{-1}) had brittle lateral breaks that were easily damaged. All plants in the N_1 (7.0 meq l^{-1}) treatments were light green.

Soil and Tissue Analysis

Soil analyses revealed that as N and K increased in the applied nutrient solution they also increased in the growing media (Table 12). P, Zn^{+2}, Fe^{+2}, Mn^{+2}, Ca^{+2}, pH, and soluble salts varied somewhat, but did not show a distinct pattern in relation to nutrient regime. There was, however, a distinct difference between media. The mean soilless medium pH, 3.7, and soluble salts, 1.9 millimhos cm^{-1}, were lower than the soil medium pH, 6.0, and soluble salts, 3.5 millimhos cm^{-1}. P was generally higher in the soil substrate while K^+ and Fe^{+2} were higher in the soilless mixture.

Tissue analyses showed that the N and K^+ fertilization treatments affected the ion concentrations in geranium and petunia plant tissue (Table 13). Both species showed an increase in N, P, and Ca^{+2} and a decrease in K^+ as N concentrations increased. Increasing nutrient solution K^+ caused an increase in tissue K^+, a decrease in Ca^{+2} and Mg^{+2}, and had no effect on P. Ca^{+2} concentrations were higher in soil-grown plants.

Discussion

Increasing N concentrations had a much greater effect on plant growth than increasing K^+ concentrations (Tables 10 and 11). Lunt and Kofranek (64), in an N and K^+ nutrient study on 'Albatross' and 'Good News' chrysanthemums, observed similar results; K^+ had no substantial affect on plant height, flower fresh weight, or flower diameter. Monroe et al. (76) noted little effect on plant growth of Kentucky bluegrass with K concentrations above 100 ppm (2.6 meq l^{-1}), while N concentrations of 65 (4.6 meq l^{-1}) and 130 (9.3 meq l^{-1}) ppm caused increases in vigor, tillering, rhizome length, blade width, and dry weight. Poole et al. (85) noted that the effect of 50 to 150 mg K^+ per 10 cm pot was not as pronounced as the effect of 50 to 150 mg N per 10 cm pot on bromeliad grade and color. In contrast, Joiner and Smith (53) grew 'Blue Chip' chrysanthemums with N concentrations ranging from 50 to 400 ppm (3.6 to 28.5 meq l^{-1}) and K concentrations of 41.5 to 332 ppm (1.1 to 8.5 meq l^{-1}). They reported that both N and K^+ affected plant height, stem length and diameter, number of flowers, and keeping quality.

Plant maturity, measured by flowering in geranium and number of breaks and flowering in petunia, was not affected by the nutrient treatments (Tables 10 and 11). This is in agreement with Johnson and Skelton (51) who observed that the number and size of 'Pink Cascade' petunia flowers were not influenced by fertilizer treatment. Similar results were reported by Lunt and Kofranek (64) with 'Albatross' and 'Good News' chrysanthemums grown during fall months; however, those grown during summer months and subjected to warmer temperatures showed delayed flowering with increasing N and K^+. Black (11) reviewed N and K^+ supplies in relation to plant behavior. He concluded that N and K^+ fertilization may hasten, delay, or not affect plant maturity responses depending upon the degree of deficiency, the quantity and time of nutrient application, and the nature of the plant.

Plant quality was influenced by the nutrient program. All plants grown in the N_1 (7.0 meq l^{-1}) treatments had reduced growth and light green foliage, which are signs of nitrogen deficiency. Kofranek and Lunt (58) observed decreased growth and light green foliage in geranium 'Irene' at 7.5 meq l^{-1} NO_3^- and normal growth at

15 meq l^{-1}. Breaks on petunias grown at N_4K_2 (N:K^+, 1.5) and N_4K_3 (N:K^+, 0.83) became very brittle and were easily damaged during handling. This condition has also been observed in chrysanthemums as N (NH_4NO_3) levels increased from 10 to 50 meq l^{-1}; K increments appeared to have an additive, but less intense effect (64). Joiner and Smith (53) stressed the need for the proper N:K^+ balance to avoid adverse growth effects. They noted that an N:K^+ ratio of 0.63 gave best results for 'Blue Chip' chrysanthemums. Monroe et al. (76) reported that Kentucky bluegrass required an N:K^+ ratio of 0.63. Other researchers have also pointed out the need for a balance between N and K^+ (5, 38, 59).

The growing media tested in this study gave comparable petunia growth, and only slight differences in geranium growth (Tables 10 and 11). Coorts et al. (27) grew 'Irene' and 'Improved Richard' geranium cuttings in 7 growing media. They observed optimum growth in soil-peat-perlite and soil-peat-calcined clay, but noted that all media produced acceptable plant growth. Dunham (33) found that, when 'Little America' and 'Indianapolis White' chrysanthemums were given a full complement of nutrients, there were no differences in plant growth in soil-sand, soil-sand-peat, and soil-sand-vermiculite growing media. Higher soil medium pH, soluble salts, and P values were observed in this study (Table 12). This is in agreement with Dunham (32) who found greater P concentrations and higher pH and soluble salt values in media containing higher proportions of soil. Bunt (19) reported similar observations.

Petunia and geranium tissue analyses showed similar trends in both media and with the various nutrient treatments (Table 13). Increasing nutrient solution N resulted in increased tissue N, P, and Ca^{+2} and decreased K^+. As K^+ levels increased, tissue K^+ increased while Ca^{+2} and Mg^{+2} decreased. Joiner and Smith (53) observed similar results in 'Blue Chip' chrysanthemums, except P also decreased with increasing K^+. Monroe et al. (76) noted that nutrient solution K^+ had no significant effect on tissue P in Kentucky bluegrass, while increasing N resulted in higher tissue N and K^+ concentrations. Holcomb and White (49), in a K^+ fertilization study of 'No. 4 Indianapolis White' chrysanthemums, reported depressed N, P, Ca^{+2}, and Mg^{+2} tissue concentrations with increasing K fertilization.

In summary, good plant growth was obtained in both growing media and in all but the N_1 (7.0 meq l^{-1}) treatments. K^+ had little or no effect on plant growth, and no deficiency symptoms developed in the K_1 (2 meq l^{-1}) treatment. Based on the data obtained in this study, the fertilization level necessary to produce quality plants of 'Sprinter Scarlet' geranium and 'Candy Apple' petunia, in a soil and soilless media, is 10.5 meq l^{-1} N and 2 meq l^{-1} K (N_2K_1), or approximately 150 ppm N and 100 ppm K_2O (83 ppm K).

Table 8. Nutrient solution concentration (meq l^{-1}) for soil and soilless grown geranium 'Sprinter Scarlet' and petunia 'Candy Apple'.

	Cations (meq l^{-1})				Anions (meq l^{-1})		
Treatment[a]	Ca^{+2}	Mg^{+2}	K^{+}	NH_4^{+}	NO_3^{-}	SO_4^{-2}	Cl^{-}
1. N1K1	6.25	6	2	3.50	3.50	8.00	6.25
2. N2K1	5.50	5	2	5.25	5.25	7.00	5.50
3. N3K1	4.75	4	2	7.00	7.00	6.00	4.75
4. N4K1	4.00	3	2	8.75	8.75	5.00	4.00
5. N1K2	5.25	5	4	3.50	3.50	5.00	5.75
6. N2K2	4.50	4	4	5.25	5.25	4.00	4.50
7. N3K2	3.75	3	4	7.00	7.00	3.00	3.75
8. N4K2	3.00	2	4	8.75	8.75	2.00	3.00
9. N1K3	4.25	4	6	3.50	3.50	7.50	6.75
10. N2K3	3.50	3	6	5.25	5.25	8.25	4.25
11. N3K3	2.75	2	6	7.00	7.00	8.00	2.75
12. N4K3	2.00	1	6	8.75	8.75	7.00	2.00

[a]All solutions contained the following micronutrients per liter (45): boric acid, 2.86 mg; manganese chloride, 1.81 mg; zinc sulfate, 0.22 mg; copper sulfate, 0.80 mg; molybdic acid, 0.02 mg; and FeEDTA (sequestrine 330), 5 mg.

Table 9. Sowing, transplanting, and harvesting dates for seed geranium 'Sprinter Scarlet' and petunia 'Candy Apple' grown in 4 N level, 3 K^{+} levels, and a soil and soilless growing media, during 1979.

	Geranium		Petunia	
	Crop 1	Crop 2	Crop 1	Crop 2
Sown	1-16	2-13	1-16	2-13
Transplanted	2- 7	3- 9	2-21	3-16
Harvested	3-23	5- 1	4- 4	4-26

Table 10. Effect of N and K^+ on geranium 'Sprinter Scarlet' mean height, fresh weight, dry weight, and flowers and buds when grown in a soil (S) and soilless (SL) growing media.

Treatment	Height		Fresh weight		Dry weight		Flowers + buds	
	S	SL	S	SL	S	SL	S	SL
N1	12.48	10.95	16.24	15.39	1.53	1.56	1.68	1.17
N2	12.54	12.35	16.28	16.69	1.61	1.86	1.67	1.37
N3	12.26	12.53	15.57	19.29	1.56	1.87	1.77	1.57
N4	11.60	11.71	14.34	17.32	1.46	1.64	1.57	1.40
HSD (5%)	0.79	0.79	4.41	4.41	0.33	0.33	0.50	0.50
K1	12.19	11.75	15.62	17.42	1.57	1.72	1.65	1.38
K2	12.27	11.81	15.41	16.05	1.49	1.70	1.56	1.33
K3	12.18	12.10	15.79	18.05	1.57	1.77	1.80	1.43
HSD (5%)	0.64	0.64	3.57	3.57	0.27	0.27	0.41	0.41

Table 11. Effect of N and K^+ on petunia 'Candy Apple' mean height, fresh weight, dry weight, flowers and buds, and number of breaks when grown in a soil (S) and soilless (SL) growing media.

Treatment	Height (cm)		Fresh weight (g)		Dry weight (g)		Flowers + buds		Breaks	
	S	SL	S	SL	S	SL	S	SL	S	SL
N1	14.43	13.08	20.35	17.98	1.55	1.27	3.92	3.17	4.03	4.15
N2	14.86	15.57	21.60	22.50	1.63	1.56	3.68	4.07	4.48	4.38
N3	16.73	16.68	22.68	22.75	1.73	1.68	3.42	3.23	4.15	4.28
N4	17.03	17.94	24.40	25.26	1.86	1.84	3.10	3.38	4.07	4.22
HSD (5%)	1.20	1.20	3.28	3.28	0.28	0.28	1.10	1.10	0.53	0.53
K1	15.38	15.86	22.70	21.98	1.72	1.57	3.68	3.26	4.43	4.19
K2	15.03	15.15	20.77	21.21	1.60	1.58	3.21	3.83	4.08	4.56
K3	16.88	16.43	23.31	22.85	1.76	1.63	3.70	3.30	4.05	4.03
HSD (5%)	0.98	0.98	2.65	2.65	0.23	0.23	0.89	0.89	0.43	0.43

Table 12. Effect of N and K^+ on soil analysis of geranium 'Sprinter Scarlet' and petunia 'Candy Apple' when grown in a soil and soilless media.

Treatment	NO_3^--N (ppm)	P ppm	K^+ ppm	Zn^{+2} ppm	Fe^{+2} ppm	Mn^{+2} ppm	pH	EC[a]
Geranium								
Soil								
N1K1	80	960	588	9.2	84	71	6.7	3.4
N2K1	225	880	580	8.8	87	77	6.8	3.9
N3K1	395	1040	592	8.6	84	69	6.7	4.7
N4K1	510	1040	648	9.0	85	74	6.6	3.8
N1K2	80	920	876	8.9	88	64	7.0	3.6
N2K2	215	880	876	8.4	79	59	6.8	3.9
N3K2	365	1200	896	8.8	80	63	6.7	4.4
N4K2	560	1160	984	9.3	87	67	6.6	4.6
N1K3	80	960	1172	10.6	82	68	6.9	3.9
N2K3	190	1080	1232	9.5	84	64	6.8	4.6
N3K3	340	1080	1328	9.3	88	56	6.7	5.1
N4K3	455	1160	1292	9.8	92	66	6.7	4.6
Soilless								
N1K1	212	72	362	11.4	432	35	4.6	3.2
N2K1	460	410	525	8.8	280	38	4.3	3.1
N3K1	620	260	738	12.4	81	35	4.7	3.9
N4K1	960	72	575	12.6	466	42	4.7	2.7
N1K2	76	260	1056	9.4	165	32	4.6	2.7
N2K2	192	250	1362	12.4	85	31	4.2	3.9
N3K2	380	170	1452	9.2	80	31	4.8	4.2
N4K2	860	250	1914	9.7	75	34	5.0	5.3
N1K3	124	320	2046	11.8	194	38	4.5	3.6
N2K3	136	230	2694	16.6	76	31	4.6	4.6
N3K3	520	60	1824	10.0	465	35	4.5	3.6
N4K3	540	250	2934	11.4	99	32	4.7	3.9

Table 12. Continued.

Treatment	NO_3^--N (ppm)	P ppm	K^+ ppm	Zn^{+2} ppm	Fe^{+2} ppm	Mn^{+2} ppm	pH	EC[a]
Petunia								
Soil								
N1K1	12	800	236	7.1	79	107	6.4	2.9
N2K1	13	880	208	8.3	84	107	6.4	2.6
N3K1	28	880	178	8.1	80	98	6.7	2.2
N4K1	108	840	191	7.4	84	98	6.7	2.2
N1K2	8	960	366	7.5	73	105	6.3	3.1
N2K2	10	920	349	8.0	82	110	6.6	2.8
N3K2	22	840	273	7.2	80	108	6.6	2.0
N4K2	86	640	330	7.6	81	99	6.7	2.6
N1K3	6	920	608	6.9	80	112	6.4	3.0
N2K3	8	840	576	8.4	81	108	6.5	2.3
N3K3	24	760	624	7.7	86	106	6.5	2.7
N4K3	57	800	632	8.2	88	112	6.6	2.5
Soilless								
N1K1	24	258	1002	10.1	161	37	4.6	1.2
N2K1	40	300	792	8.2	170	36	4.3	1.0
N3K1	216	486	424	10.7	169	33	4.6	1.1
N4K1	512	498	385	10.7	154	34	4.4	1.5
N1K2	28	450	1254	13.0	167	40	4.7	3.0
N2K2	40	400	990	9.7	160	38	4.4	2.8
N3K2	76	440	750	8.7	179	38	4.2	2.7
N4K2	204	400	584	8.8	148	38	4.4	2.4
N1K3	28	440	1524	9.5	137	37	4.5	2.8
N2K3	32	460	1374	14.1	155	38	4.3	2.6
N3K3	76	420	1314	9.5	182	38	4.3	2.4
N4K3	100	660	1092	9.5	173	36	4.3	2.2

[a] EC = electrical conductivity in millimhos cm^{-1}, saturated paste.

Table 13. Effect of N and K^+ on tissue analysis of geranium 'Sprinter Scarlet' and petunia 'Candy Apple' when grown in a soil and soilless media.

	Per cent of dry weight				
Treatment	N (%)	P (%)	K^+ (%)	Ca^{+2} (%)	Mg^{+2} (%)
Geranium					
Soil					
N1K1	3.92	0.83	3.57	2.80	0.84
N2K1	4.14	0.87	3.70	2.96	0.79
N3K1	4.28	0.85	3.70	3.19	0.75
N4K1	4.48	0.84	3.62	3.53	0.66
N1K2	3.72	0.78	4.70	2.45	0.68
N2K2	3.98	0.78	4.36	2.79	0.69
N3K2	4.38	0.72	3.80	2.66	0.55
N4K2	4.88	0.78	3.79	3.07	0.58
N1K3	4.04	0.80	5.15	2.52	0.68
N2K3	4.20	0.81	4.93	2.72	0.64
N3K3	4.32	0.81	4.75	2.79	0.55
N4K3	4.84	0.78	4.32	2.97	0.50
Soilless					
N1K1	4.24	1.31	3.18	1.79	1.12
N2K1	4.95	1.37	2.97	2.01	1.05
N3K1	5.50	1.37	2.61	2.01	0.98
N4K1	5.93	1.42	2.62	2.00	0.94
N1K2	3.83	1.08	4.02	1.53	0.88
N2K2	4.56	1.29	3.40	1.79	0.92
N3K2	5.12	1.38	3.25	1.80	0.86
N4K2	5.63	1.34	3.09	1.69	0.78
N1K3	4.09	0.86	3.16	1.21	0.63
N2K3	4.70	1.28	3.64	1.58	0.77
N3K3	5.28	1.37	3.66	1.64	0.68
N4K3	5.56	1.39	3.38	1.48	0.67

Table 13. Continued.

Treatment	Per cent of dry weight N (%)	P (%)	K^+ (%)	Ca^{+2} (%)	Mg^{+2} (%)
Petunia					
Soil					
N1K1	3.05	0.67	4.04	2.46	0.78
N2K1	4.04	0.80	3.48	2.88	1.06
N3K1	4.47	0.84	3.36	3.19	1.06
N4K1	5.20	0.85	3.36	3.46	0.90
N1K2	3.14	0.69	5.03	2.41	0.62
N2K2	3.85	0.81	4.31	2.68	0.70
N3K2	4.28	0.94	4.32	2.82	0.68
N4K2	5.01	0.92	4.08	3.43	0.73
N1K3	2.88	0.70	4.79	2.24	0.51
N2K3	4.06	0.77	4.80	2.51	0.58
N3K3	4.88	0.85	4.95	2.76	0.54
N4K3	5.38	0.81	4.30	2.91	0.50
Soilless					
N1K1	3.34	0.62	6.09	1.57	0.85
N2K1	4.00	0.69	5.43	1.41	0.99
N3K1	5.50	0.58	2.68	1.19	0.88
N4K1	7.29	0.96	2.25	1.62	1.17
N1K2	3.48	0.67	6.29	1.36	0.82
N2K2	4.17	0.75	0.88	1.21	0.81
N3K2	4.60	0.79	5.30	1.30	0.95
N4K2	6.28	0.89	3.78	1.37	0.94
N1K3	3.14	0.43	4.24	0.91	0.46
N2K3	4.19	0.67	6.24	1.24	0.77
N3K3	4.64	0.75	5.00	1.11	0.67
N4K3	5.55	0.71	5.04	1.05	0.69

CHAPTER 4

THE EFFECT OF PHOSPHORUS LEVELS ON BEDDING PLANT GROWTH

Fertilization programs and growing media play an important role in the growth and quality of bedding plants. Present fertilization recommendations for bedding plants in general are quite variable and often include preplant dry fertilizers, liquid feeds, and slow release materials. Superphosphate (SP), 0-20-0, and treble superphosphate (TSP), 0-46-0, are common preplant additions to greenhouse growing media. Recommended rates include a 4-in pot of SP per 3 bushels of media (approximately 4 kg m^{-3}) (112), 4 oz SP ft^{-3} (4 kg m^{-3}) (27), 5-8 lb SP yd^{-3} (3-4.8 kg m^{-3}) (59), and 1-2 lb SP yd^{-3} peat-lite (0.6-1.2 kg m^{-3}) (97). Suggested TSP levels are approximately half the SP levels. In addition to the preplant P used, complete soluble fertilizers are often applied at 200 ppm P_2O_5.

Plants can be grown in almost any type of substrate as long as it is free from pests and toxins and provides support, nutrients, water, and oxygen. Substrates may include such materials as soil, sand, peat moss, vermiculite, perlite, bark, styrofoam, or other available substances. The majority of growers are still using soil as a component of their growing media, although there is a trend towards soilless media as the sources of reliable soil dwindle (68). Cultural practices, including fertilization, must be adjusted to the media being used since each will have its own chemical and physical properties. For example, adding vermiculite to a growing media will generally cause an increase in pH, K^{+}, Ca^{+2}, and Mg^{+2} while decreasing P. On the other hand, adding peat moss to a growing media will decrease the pH, soluble salts, P, and K^{+} (32). Peat moss amended media generally requires more frequent replenishment of cations, especially K^{+} (32, 33).

The availability of inorganic P is largely determined by media pH, Fe^{+2}, Al^{+3}, and Mn^{+2} in the acid pH range, and Ca^{+2} and Mg^{+2} in the alkaline pH range. At pH values below 6, inorganic P forms insoluble compounds with Al^{+3}, Fe^{+2}, and Mn^{+2}, rendering P unavailable for plant growth. As the pH rises above 7, precipitation of Ca^{+2} compounds begins and P becomes unavailable to the plant. Between pH 6 and 7, P fixation is at a minimum and P availability at a maximum. P availability in growing media containing soil, is often relatively low due to the formation of such insoluble compounds as Fe^{+2}, Al^{+3}, and Ca^{+2} phosphates. Applied P may also revert to these unavailable forms (18). Materials used in soilless media have relatively little Fe^{+2}, Al^{+3}, or Ca^{+2}; their capacity for fixing P in insoluble compounds is generally considered insignificant. Instead, P availability may be reduced due to the leaching of P from the media (19).

Adequate supplies of P promote plant growth and development. P concentrations beyond this level may cause decreased plant growth (52, 81) or continued increases in plant height (39). These observations in conjunction with present fertilizer practices and changes in growing media prompted this study. The objectives were to determine the effects of high P levels on bedding plant growth and to determine the P level necessary to obtain quality plant growth when using a soil and a soilless growing media.

Methods and Materials

Four levels of P and 2 growing media were factorially combined in a randomized complete block design with 3 replicates. P levels were obtained using combinations of treble superphosphate (TSP), 0-46-0, as a preplant addition, plus a liquid feed of 25-0-25 (28% NO_3^-) or 20-20-20 (25% NO_3^-) at 1.408 meq l^{-1} $H_2PO_4^-$ (200 ppm P_2O_5) at each watering. Solutions were applied, using a 1:100 injector, as required and in sufficient quantity to cause some leaching with each irrigation. The 4 treatments were 1) control, no preplant + 25-0-25, 2) no preplant + 20-20-20, 3) 3 kg m^{-3} (5 lb yd^{-3}) TSP + 20-20-20, and 4) 6 kg m^{-3} (10 lb yd^{-3}) TSP + 20-20-20. The soil medium consisted of equal parts Fort Collins clay loam, Canadian peat moss, and perlite, by volume. The soilless medium consisted of equal parts Canadian peat moss and vermiculite, by volume. The soilless medium had a preplant addition of 3 kg m^{-3} (5 lb yd^{-3}) ground limestone and 119 ml m^{-3} (3 oz yd^{-3}) X-77 wetting agent.

Seeds of Pelargonium hortorum 'Sprinter Scarlet', Petunia hybrida 'Pink magic', Impatiens holstii 'Elfin Red', and Tagetes patula 'Goldie' were germinated and transplanted at the 2 to 3 leaf stage into cell packs, 32 plants per treatment for geraniums and 48 plants per treatment for all others (Table 14). A second phase of the geranium evaluation was initiated to determine the treatment effect on flowering. When the cell pack geraniums were harvested, 5-2-78, 7 randomly selected plants from each flat were shifted into 10 cm (4 in) standard plastic pots in their respective growing media and treatments continued. Plants were grown in a glass-covered greenhouse heated to 16°C (62°F) day and night and cooled to 21.1°C (70°F) during the day. CO_2 was injected to maintain 1000 ppm on clear days during periods of no ventilation. Five randomly selected plants from each treatment were harvested when the first treatment became salable and data recorded. Data included height, dry weight, leaf area, and total flowers and buds of geranium, height, dry weight, number of breaks, and total flowers and buds of petunia, and height, dry weight, and total flowers of impatiens and marigolds. In addition, soil and tissue samples were taken at the termination of each experiment. Soil samples were analyzed at the Colorado State University

Soil Testing Laboratory using an NH_4HCO_3-DTPA extraction method (99). Tissue analyses were performed at the Plant Testing Laboratory, Department of Horticulture, Pennsylvania State University. Data were subjected to analysis of variance and Tukey's HSD at the 5% level.

Results

Geranium

P treatment effects on plant growth responses of cell pack grown geraniums were the same in both media (Table 15). Plant height and dry weight increased as P increased from Treatment 1 to 3, and then decreased. Total leaf area of plants grown in the soilless medium increased with P additions; Treatments 3 and 4 had significantly greater leaf area than the control or Treatment 2. Plants grown in the soil medium showed a similar trend, but there were no statistically significant differences between treatments.

Geraniums shifted to 10 cm (4 in) standard pots and grown in the soil medium had responses similar to the cell pack grown plants (Table 16). Plants grown in the soilless medium had no height differences, but Treatment 4 yielded significantly heavier plants than the control or other P treatments. Total flowers and buds were not affected by P treatments.

Petunia

Plant height increased with increasing P for soil-grown plants, but decreased with increasing P when plants were grown in a soilless substrate (Table 17). Dry weight, number of breaks, and total flowers and buds were relatively constant; the soilless medium values were consistently lower than the soil mixture.

Impatiens

Plant height and dry weight of soilless-grown plants, except for a low Treatment 2 value, tended to decrease with increased P treatments (Table 18). They remained comparatively constant for soil-grown plants, but again Treatment 2 values appeared abnormally low. Total flowers were unaffected by P treatment.

Marigold

Plant height and dry weight of soil-grown plants showed no consistent pattern in relation to P treatment (Table 19). Soilless-grown plants were unaffected by added P. No difference was observed in total flowers and buds.

Soil and Tissue Analysis

Soil analysis revealed that P content in both media increased as treatment P increased (Table 20). There were random variations in NO_3^-, K^+, Zn^{+2}, Fe^{+2}, and electrical conductivity, but no definite pattern emerged. Media pH were independent of P treatments, but did vary according to the type of media; soilless pH values averaged 5.4 (standard error, 0.12) while soil pH values average 6.4 (standard error, 0.12). Tissue P also increased with increasing P treatments; soilless-grown plants had a greater per cent P content (Table 21). Per cent N, K^{+}, Ca^{+2}, and Mg^{+2} levels were not affected by P treatments, but per cent Ca^{+2} was higher in soil-grown plant tissues.

Discussion

Plant growth, development, and maturity are often affected by P (11). In general, plant height and dry weight of geranium, petunia, and marigold increased with increasing P applications, but had no effect on plant height and dry weight of impatiens (Tables 15, 16, 17, 18 and 19). Similarly, Payne (82), used rooted 'Sincerity' geranium cuttings and 6 levels of phosphoric acid ranging from 0 to 400 ppm P (0 to 12.9 meq l^{-1} $H_2PO_4^-$). He noted that plant height, leaf diameter, and number of flowering branches increased as P concentrations ranged from 0 to 100 ppm P (0 to 3.2 meq l^{-1} $H_2PO_4^-$), then decreased. Joiner (52) reported that 'Indianapolis White No. 3' chrysanthemums increased in stem length and flower diameter as P increased from 0 to 120 ppm P (0 to 3.7 meq l^{-1} $H_2PO_4^-$) (source of P not given). Similar responses have been found with bean, mustard, and potato (81). Treble superphosphate applications ranging from 0.6 to 6 kg m^{-3} (1 to 10 lb yd^{-3}) had no appreciable affect on poinsettia height (54). Poole et al. (85) also observed that P, supplied as phosphoric acid, had no effect on the growth of the bromeliad Aechmea fasciata 'Baker'.

In terms of flowering, all species evaluated in this study showed no differences in maturity in response to P treatments. This is in contrast to reports of increased P concentrations promoting rapid development of flowering in corn (38) and tomato (114). Black (11), in a review of literature on P supply and plant behavior, concluded that plant maturity responses to P applications are species dependent.

The differences in plant species responses noted in this experiment are not uncommon. Lilleland et al. (63) found marked P reaction differences among a number of plant species grown on the same field with and without superphosphate additions. The ratios of yield without-to-with added superphosphate for the production of squash, cucumber, wheat, oats, alfalfa, wax bean, and almonds were 0.03, 0.07, 0.21, 0.38, 0.41, 0.57, 0.63, and 1.0, respectively. Whiteaker et al. (111) noted intraspecific differences in bean growth responses to various P concentrations. Others report similar results with different species (66, 105). Black (11) proposes that theories explaining the observed differences may be grouped into 3 categories: 1) species effect on the media and thus the availability of other ions; 2) the absorption characteristics and extent of the root system; and 3) species P requirement.

Generally, the 2 growing media in this study reacted similarly and gave comparable plant growth responses to the P treatments (Tables 15 to 19). Both media showed increased P content with additional applications of P; the soil medium yielded consistently higher P concentrations, higher pH, and greater electrical conductivity (Table 20). Dunham (32), growing 'Indianapolis White' chrysanthemums in soil-sand, soil-sand-peat, and soil-sand-vermiculite media, found higher P concentrations, greater salt content, and higher pH values in the soil-sand media. There were no differences in plant dry weight due to the different media. Bunt (20) found similar differences in pH and electrical conductivity in a loam based and peat-sand media, but noted that during the summer months that peat-sand grown plants had a greater plant fresh weight; winter values for the 2 media were comparable. Although the soil medium in this study had higher P concentrations, the per cent tissue P was lower than the soilless-grown plants (Table 8). Dunham (32) reports similar results. Insoluble P compounds are more likely to form in the soil media than in the soilless media (18, 19) rendering P unavailable to the plant. However, soil testing procedures could extract some of the insoluble P compounds resulting in higher P readings in the soil medium (11).

In short, the bedding plants tested showed some variability in response to increased P levels. Geranium, petunia, and marigold showed increased height and dry weight as P increased. Impatiens height and dry weight remained constant or decreased with increased P. Flowering in all 4 species was unaffected by P levels. Soil tests revealed a difference in nutrient content between the 2 media, but each produced similar plant growth. Overall, 3 kg m^{-3} treble superphosphate preplant plus 20-20-20 at 1.408 meq l^{-1} $H_2PO_4^-$ (200 ppm P_2O_5) (Treatment 3) provided better plant growth than the lower rates used (Treatments 1 and 2) and comparable growth to the highest rate (Treatment 4) used.

Table 14. Sowing, transplanting, shifting, and harvesting dates for geranium 'Sprinter Scarlet', petunia 'Pink Magic', impatiens 'Elfin Red', and marigold 'Goldie' grown with 4 P levels in a soil and soilless growing media during 1978.

	Geranium (cell pack)	Geranium (10 cm pot)	Petunia	Impatiens	Marigold
Sown	2-22	2-22	3-13	3-22	4-20
Transplanted	3-18	3-18	4-11	4-13	5-9
Shifted	--	5-2	--	--	--
Harvested	5-2	6-20	5-16	5-26	6-17

Table 15. Effect of 4 P levels on cell pack grown geranium 'Sprinter Scarlet' mean height, dry weight, and leaf area when grown in a soil (S) and soilless (SL) media.

Treatment[a]	Height (cm)		Dry weight (g)		Leaf area (cm^2)	
TSP + lf	S	SL	S	SL	S	SL
1. 0 + 25-0-25	4.32	3.98	1.27	1.26	191	157
2. 0 + 20-20-20	4.34	4.62	1.17	1.19	189	196
3. 3 + 20-20-20	5.29	5.47	1.36	1.38	225	241
4. 6 + 20-20-20	4.62	4.98	1.17	1.35	206	244
HSD (5%)	0.64	0.64	0.20	0.20	40	40

[a]TSP = treble superphosphate preplant (kg m^{-3})
lf = liquid feed at 1.408 meq l^{-1} $H_2PO_4^-$ (200 ppm P_2O_5)

Table 16. Effect of 4 P levels on 10 cm pot grown geranium 'Sprinter Scarlet' mean height, dry weight, and flowers plus buds when grown in a soil (S) and soilless (SL) media.

Treatment[a]	Height (cm)		Dry weight (g)		Flowers + buds	
TSP + lf	S	SL	S	SL	S	SL
1. 0 + 25-0-25	12.75	13.83	5.76	6.40	2.7	2.1
2. 0 + 20-20-20	13.39	14.71	7.09	7.33	2.8	2.1
3. 3 + 20-20-20	16.48	13.31	8.71	6.93	2.8	1.8
4. 6 + 20-20-20	16.99	14.39	8.64	8.50	2.5	2.7
HSD (5%)	2.63	2.63	1.11	1.11	1.1	1.1

[a]TSP = treble superphosphate preplant (kg m^{-3})
lf = liquid feed at 1.408 meq l^{-1} $H_2PO_4^-$ (200 ppm P_2O_5)

Table 17. Effect of 4 P levels on petunia 'Pink Magic' mean height, dry weight, number of breaks, and flowers plus buds when grown in a soil (S) and soilless (SL) media.

Treatment	Height (cm)		Dry weight (g)		Breaks		Flowers + buds	
TSP + lf[a]	S	SL	S	SL	S	SL	S	SL
1. 0 + 25-0-25	17.56	20.49	1.15	1.13	6.33	4.73	6.6	4.9
2. 0 + 20-20-20	14.94	16.42	1.10	0.96	6.60	4.40	6.8	4.7
3. 3 + 20-20-20	18.61	17.38	1.29	1.02	7.07	5.67	7.3	6.1
4. 6 + 20-20-20	19.16	16.49	1.33	0.94	7.33	4.73	7.5	5.1
HSD (5%)	2.13	2.13	0.30	0.30	2.47	2.47	4.5	4.5

[a]TSP = treble superphosphate preplant (kg m^{-3})
lf = liquid feed at 1.408 meq l^{-1} $H_2PO_4^-$ (200 ppm P_2O_5)

Table 18. Effect of 4 P levels on impatiens 'Elfin Red' mean height, dry weight, and flowers when grown in a soil (S) and soilless (SL) media.

Treatment TSP + lf[a]	Height (cm)		Dry weight (g)		Flowers + buds	
	S	SL	S	SL	S	SL
1. 0 + 25-0-25	16.67	20.57	0.72	0.94	1.20	1.13
2. 0 + 20-20-20	12.39	15.11	0.57	0.52	0.53	0.27
3. 3 + 20-20-20	16.78	18.38	0.71	0.67	0.73	0.67
4. 6 + 20-20-20	17.03	14.61	0.61	0.43	0.87	0.73
HSD (5%)	2.28	2.28	0.19	0.19	1.21	1.21

[a]TSP = treble superphosphate preplant (kg m^{-3})
lf = liquid feed at 1.408 meq l^{-1} $H_2PO_4^-$ (200 ppm P_2O_5)

Table 19. Effect of 4 P levels on marigold 'Goldie' mean height, dry weight, and flowers plus buds when grown in a soil (S) and soilless (SL) media.

Treatment TSP + lf[a]	Height (cm)		Dry weight (g)		Flowers + buds	
	S	SL	S	SL	S	SL
1. 0 + 25-0-25	13.42	14.19	1.45	1.07	1.5	1.4
2. 0 + 20-20-20	11.85	13.39	1.19	1.02	1.7	1.7
3. 3 + 20-20-20	13.54	13.63	1.11	1.18	1.7	1.6
4. 6 + 20-20-20	15.03	14.25	1.63	1.24	1.7	1.9
HSD (5%)	2.00	2.00	0.38	0.38	1.0	1.0

[a]TSP = treble superphosphate preplant (kg m^{-3})
lf = liquid feed at 1.408 meq l^{-1} $H_2PO_4^-$ (200 ppm P_2O_5)

Table 20. Effect of 4 P levels on soil analysis of geranium 'Sprinter Scarlet', petunia 'Pink Magic', impatiens 'Elfin Red', and marigold 'Goldie' when grown in a soil and soilless media.

Treatment (TSP + lf[b])	NO_3^--N ppm	P ppm	K^+ ppm	Zn^{+2} ppm	Fe^{+2} ppm	pH	EC[a]
Geranium (cell pack)							
Soil							
1. 0 + 25-0-25	168	180	1316	19.2	71.2	6.7	5.2
2. 0 + 20-20-20	460	400	1028	14.0	83.6	6.0	4.5
3. 3 + 20-20-20	520	1520	1028	14.2	90.8	5.6	6.4
4. 6 + 20-20-20	180	2400	1400	13.6	70.4	6.0	3.2
Soilless							
1. 0 + 25-0-25	960	80	3424	17.2	269.6	6.3	2.2
2. 0 + 20-20-20	48	680	2536	42.0	226.8	5.8	1.5
3. 3 + 20-20-20	20	1680	2112	22.0	128.8	5.4	2.5
4. 6 + 20-20-20	68	1880	1884	23.6	102.8	5.0	3.0
Geranium (pot)							
Soil							
1. 0 + 25-0-25	364	200	784	12.2	70.8	6.9	2.7
2. 0 + 20-20-20	556	440	956	12.0	93.2	5.9	3.8
3. 3 + 20-20-20	420	1240	856	11.6	90.8	5.9	3.6
4. 6 + 20-20-20	392	2160	876	13.9	81.2	5.8	4.9
Soilless							
1. 0 + 25-0-25	148	108	1596	15.0	320.0	6.1	0.9
2. 0 + 20-20-20	24	520	2092	18.3	172.0	5.4	1.4
3. 3 + 20-20-20	28	1120	2540	15.6	82.8	5.1	5.0
4. 6 + 20-20-20	8	1600	2200	19.8	95.2	5.1	3.4

Table 20. Continued.

Treatment (TSP + lf[b])	NO_3^--N ppm	P ppm	K^+ ppm	Zn^{+2} ppm	Fe^{+2} ppm	pH	EC[a]
Petunia							
Soil							
1. 0 + 25-0-25	66	160	480	15.6	60.8	7.5	0.9
2. 0 + 20-20-20	142	400	556	12.4	71.2	6.5	1.6
3. 3 + 20-20-20	126	1480	444	13.2	80.4	6.1	1.3
4. 6 + 20-20-20	1200	1480	504	11.6	32.0	5.5	1.4
Soilless							
1. 0 + 25-0-25	66	60	668	24.8	41.6	5.5	0.4
2. 0 + 20-20-20	20	560	1044	22.8	248.8	5.1	0.7
3. 3 + 20-20-20	30	800	1404	19.6	107.6	5.5	1.7
4. 6 + 20-20-20	30	1240	1360	22.0	92.0	5.4	2.0
Impatiens							
Soil							
1. 0 + 25-0-25	98	160	700	12.8	66.4	7.3	0.8
2. 0 + 20-20-20	260	280	1052	12.8	70.0	6.6	2.8
3. 3 + 20-20-20	320	1560	992	13.2	78.0	5.6	2.8
4. 6 + 20-20-20	280	1400	896	11.6	30.4	5.7	2.5
Soilless							
1. 0 + 25-0-25	52	80	568	14.8	444.0	5.0	0.3
2. 0 + 20-20-20	38	360	984	18.8	380.0	4.9	0.5
3. 3 + 20-20-20	92	840	782	19.2	173.6	4.6	1.2
4. 6 + 20-20-20	88	1480	956	26.0	130.8	4.7	1.7

Table 20. Continued.

Treatment (TSP + lf[b])	NO_3^--N ppm	P ppm	K^+ ppm	Zn^{+2} ppm	Fe^{+2} ppm	pH	EC[a]
Marigold							
Soil							
1. 0 + 25-0-25	200	188	776	13.3	62.8	7.5	2.1
2. 0 + 20-20-20	112	320	824	16.8	65.6	6.8	1.8
3. 3 + 20-20-20	116	1040	816	12.1	74.0	6.7	1.6
4. 6 + 20-20-20	68	1960	652	11.2	73.2	6.2	1.8
Soilless							
1. 0 + 25-0-25	336	168	2096	19.5	342.0	6.1	1.4
2. 0 + 20-20-20	208	560	1952	33.2	263.0	5.5	2.0
3. 3 + 20-20-20	180	680	1852	14.8	85.2	5.4	2.9
4. 6 + 20-20-20	292	920	1916	14.5	73.6	5.0	4.0

[a]Electrical conductivity = millimhos cm^{-1}, saturated paste.

[b]Treble superphosphate preplant (kg m^{-3}) plus liquid feed 1.408 meq l^{-1} $H_2PO_4^-$ (200 ppm P_2O_5).

Table 21. Effect of 4 P levels on tissue analysis of geranium 'Sprinter Scarlet', petunia 'Pink Magic', impatiens 'Elfin Red', and marigold 'Goldie' when grown in a soil and soilless media.

Treatment	Per cent of dry weight				
(TSP + lf[a])	N (%)	P (%)	K^+ (%)	Ca^{+2} (%)	Mg^{+2} (%)
Geranium (cell pack)					
Soil					
1. 0 + 25-0-25	3.41	0.29	4.23	2.45	0.30
2. 0 + 20-20-20	3.87	0.60	4.32	2.54	0.33
3. 3 + 20-20-20	4.16	0.85	4.35	2.59	0.36
4. 6 + 20-20-20	5.02	1.05	4.06	1.64	0.33
Soilless					
1. 0 + 25-0-25	5.24	0.19	2.57	0.73	0.23
2. 0 + 20-20-20	4.81	1.04	2.61	0.79	0.24
3. 3 + 20-20-20	5.66	1.52	3.80	1.33	0.38
4. 6 + 20-20-20	5.37	1.77	4.03	1.35	0.44
Geranium (pot)					
Soil					
1. 0 + 25-0-25	3.32	0.33	4.01	2.37	0.31
2. 0 + 20-20-20	3.59	0.59	3.86	2.64	0.32
3. 3 + 20-20-20	3.36	0.52	3.85	2.83	0.36
4. 6 + 20-20-20	4.09	0.97	4.21	2.11	0.36
Soilless					
1. 0 + 25-0-25	4.05	0.36	2.65	0.88	0.25
2. 0 + 20-20-20	4.94	1.28	2.88	0.99	0.29
3. 3 + 20-20-20	4.78	1.83	3.16	1.64	0.40
4. 6 + 20-20-20	4.98	2.34	2.95	1.28	0.36
Petunia					
Soil					
1. 0 + 25-0-25	3.77	0.42	5.99	2.14	0.40
2. 0 + 20-20-20	3.97	0.66	6.01	1.92	0.44
3. 3 + 20-20-20	3.85	0.78	5.39	1.26	0.36
4. 6 + 20-20-20	4.49	1.04	5.98	1.61	0.48
Soilless					
1. 0 + 25-0-25	5.51	0.51	5.78	0.61	0.29
2. 0 + 20-20-20	4.89	0.87	4.81	0.61	0.29
3. 3 + 20-20-20	5.54	1.73	5.11	1.09	0.49
4. 6 + 20-20-20	5.45	2.30	5.28	1.01	0.60

Table 21. Continued.

	Per cent of dry weight				
Treatment (TSP + lf[a])	N (%)	P (%)	K^{+} (%)	Ca^{+2} (%)	Mg^{+2} (%)
Impatiens					
Soil					
1. 0 + 25-0-25	3.62	0.65	5.70	3.56	0.39
2. 0 + 20-20-20	5.04	0.86	5.02	3.44	0.39
3. 3 + 20-20-20	4.07	0.80	4.83	3.27	0.43
4. 6 + 20-20-20	4.56	0.96	4.89	3.03	0.50
Soilless					
1. 0 + 25-0-25	4.66	0.63	5.57	1.25	0.55
2. 0 + 20-20-20	6.20	1.37	5.29	1.31	0.55
3. 3 + 20-20-20	5.16	1.67	5.78	1.79	0.53
4. 6 + 20-20-20	5.49	1.60	5.72	2.08	0.56
Marigold					
Soil					
1. 0 + 25-0-25	4.42	0.60	5.33	2.29	0.53
2. 0 + 20-20-20	4.58	0.89	4.83	2.25	0.54
3. 3 + 20-20-20	4.78	1.12	5.47	2.45	0.57
4. 6 + 20-20-20	5.15	1.33	5.51	2.30	0.64
Soilless					
1. 0 + 25-0-25	5.29	0.67	4.79	1.40	0.60
2. 0 + 20-20-20	4.82	1.23	4.88	1.54	0.62
3. 3 + 20-20-20	5.02	2.03	5.06	2.17	0.80
4. 6 + 20-20-20	5.61	2.28	5.08	2.09	0.88

[a]Treble superphosphate preplant (kg m^{-3}) plus liquid feed 1.408 meq l^{-1} $H_2PO_4^-$ (200 ppm P_2O_5).

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APPENDICES

APPENDIX A

SUPPLEMENTARY TABLES FOR EXPERIMENTAL DATA

Table 1. AOV of geranium 'Sprinter Scarlet' when subjected to 5 $NO_3^-:NH_4^+$ (N) ratios and grown in a soil and a soilless media (M), harvested 4-30-79.

Source	df	MS	F	P (F > comp F)
Height				
Reps	1	3.6125	37.2636	0.00018
M	1	2.0866	21.5235	0.00122
N	4	10.7070	110.4450	0.00000
MN	4	4.1109	42.4050	0.00001
Error	9	0.0969		
Fresh Weight				
Reps	1	8.6593	10.9268	0.00915
M	1	45.3607	57.2390	0.00003
N	4	26.6583	33.6391	0.00002
MN	4	26.7440	33.7472	0.00002
Error	9	0.7925		
Dry Weight				
Reps	1	2.0480	6.0592	0.03607
M	1	10.9520	32.4024	0.00030
N	4	8.1908	24.2330	0.00008
MN	4	5.0483	14.9357	0.00052
Error	9	0.3380		

Table 2. AOV of petunia 'Candy Apple' when subjected to 5 $NO_3^-:NH_4^+$ (N) ratios and grown in a soil and soilless media (M), harvested 4-24-79.

Source	df	MS	F	P (F > comp F)
Height				
Reps	1	8.7384	4.1830	0.07116
M	1	60.2045	28.8192	0.00045
N	4	56.5366	27.0634	0.00005
MN	4	22.6811	10.8572	0.00170
Error	9	2.0890		
Fresh Weight				
Reps	1	20.3401	1.9170	0.16965
M	1	348.5689	32.8516	0.00000
N	4	353.8179	33.3463	0.00000
MN	4	336.6924	31.7323	0.00000
Error	89	10.6104		
Dry Weight				
Reps	1	0.0769	5.9896	0.03692
M	1	0.5511	42.9370	0.00010
N	4	0.2380	18.5400	0.00023
MN	4	0.3755	29.2523	0.00004
Error	9	0.0128		
Breaks				
Reps	1	0.6480	1.5544	0.24396
M	1	0.0320	0.0768	0.78794
N	4	5.5070	13.2098	0.00083
MN	4	2.7170	6.5173	0.00955
Error	9	0.4169		
Flowers and Buds				
Reps	1	0.6125	11.9189	0.00725
M	1	1.4045	27.3308	0.00054
N	4	0.8383	16.3119	0.00037
MN	4	0.5138	10.0849	0.00221
Error	9	0.0514		

Table 3. AOV of geranium 'Sprinter Scarlet' when subjected to 4 nitrogen (N) treatments, 3 potassium (K) treatments, and grown in a soil and soilless media (M), harvested 5-1-79.

Source	df	MS	F	P (F > comp F)
Height				
Reps	1	4.0701	1.9941	0.15860
M	1	13.3333	6.5324	0.01091
K	2	1.1994	0.5876	0.55608
MK	2	1.8722	0.9173	0.40033
N	3	21.8640	10.7119	0.00000
MN	3	20.0961	9.8451	0.00000
KN	6	14.2460	6.9796	0.00000
MKN	6	6.5225	3.1956	0.00402
Error	455	2.0411		
Fresh Weight				
Reps	1	4.9473	0.9358	0.34342
M	1	29.4064	5.5622	0.02723
K	2	5.8513	1.1068	0.34771
MK	2	2.7845	0.5267	0.59750
N	3	6.8929	1.3038	0.29714
MN	3	13.7381	2.5986	0.07673
KN	6	4.2447	0.8033	0.57755
MKN	6	1.9765	0.3739	0.88801
Error	23	5.2868		
Dry Weight				
Reps	1	0.0035	0.1184	0.73390
M	1	0.4351	14.7135	0.00085
K	2	0.0235	0.7952	0.46352
MK	2	0.0038	0.1277	0.88074
N	3	0.1268	4.2876	0.01527
MN	3	0.0435	1.4703	0.24878
KN	6	0.0375	1.2663	0.31108
MKN	6	0.0066	0.2242	0.97479
Error	23	0.0296		

Table 3. Continued.

Source	df	MS	F	P (F > comp F)
Flowers and Buds				
Reps	1	0.0019	0.0272	0.87044
M	1	1.0502	15.2577	0.00071
K	2	0.1152	1.6738	0.20965
MK	2	0.0202	0.2936	0.74833
N	3	0.1274	1.8513	0.16609
MN	3	0.0747	1.0846	0.37536
KN	6	0.0358	0.5196	0.78743
MKN	6	0.1197	1.7383	0.15710
Error	23	0.0688		

Table 4. AOV of petunia 'Candy Apple' when subjected to 4 nitrogen (N) treatments, 3 potassium (K) treatments, and grown in a soil and soilless media (M), harvested 4-26-79.

Source	df	MS	F	P (F > comp F)
Height				
Reps	1	0.0227	0.0006	0.98047
M	1	0.3360	0.0700	0.79146
K	2	101.9460	21.6400	0.00000
MK	2	8.7817	1.8600	0.15685
N	3	327.4738	69.5300	0.00000
MN	3	31.1002	6.6000	0.00026
KN	6	46.4130	9.8500	0.00000
MKN	6	13.4033	2.8500	0.00981
Error	455	4.7100		
Fresh Weight				
Reps	1	4.2376	1.4509	0.24062
M	1	0.7306	0.2502	0.62169
K	2	17.9472	6.1452	0.00728
MK	2	1.5078	0.5163	0.60348
N	3	66.0998	22.6328	0.00000
MN	3	6.3341	2.1688	0.11917
KN	6	8.9324	3.0585	0.02382
MKN	6	5.6049	1.9191	0.12057
Error	23	2.9205		
Dry Weight				
Reps	1	0.0595	2.7921	0.10828
M	1	0.1292	6.0612	0.02174
K	2	0.0526	2.4662	0.10709
MK	2	0.0115	0.5405	0.58968
N	3	0.4105	19.2603	0.00000
MN	3	0.0435	2.0413	0.13608
KN	6	0.0378	1.7733	0.14927
MKN	6	0.0520	2.4378	0.05684
Error	23	0.0213		

Table 4. Continued.

Source	df	MS	F	P (F > comp F)
Breaks				
Reps	1	0.5333	0.5900	0.44246
M	1	0.6750	0.7400	0.39012
K	2	4.0396	4.4400	0.01231
MK	2	5.5563	6.1100	0.00241
N	3	2.7250	2.9900	0.03076
MN	3	0.4139	0.4500	0.71742
KN	6	1.7729	1.9500	0.07144
MKN	6	1.3618	1.4900	0.17974
Error	455	0.9100		
Flowers and Buds				
Reps	1	0.4033	1.2292	0.27901
M	1	0.0533	0.1625	0.69059
K	2	0.0102	0.0311	0.96942
MK	2	1.3840	4.2179	0.02752
N	3	0.9586	2.9216	0.05554
MN	3	0.8056	2.4551	0.08877
KN	6	0.3147	0.9590	0.47401
MKN	6	0.3679	1.1211	0.38105
Error	23	0.3281		

Table 5. AOV of cell pack geranium 'Sprinter Scarlet' subjected to 4 phosphorus (P) treatments and grown in a soil and soilless media (M), harvested 5-2-78.

Source	df	MS	F	P (F > comp F)
Height				
Reps	2	0.9631	2.9725	0.05530
P	3	8.1960	25.2963	0.00000
M	1	0.4320	1.3333	0.25072
PM	3	0.7636	2.3568	0.07571
Error	110	0.3240		
Dry Weight				
Reps	2	0.1441	2.2837	0.10672
P	3	0.1889	2.9937	0.03398
M	1	0.0853	1.3518	0.24748
PM	3	0.0547	0.8669	0.46065
Error	110	0.0631		
Leaf Area				
Reps	2	0.1605	1.2541	0.28935
P	3	2.3191	18.1232	0.00000
M	1	0.1391	1.0872	0.29938
PM	3	0.6882	5.3786	0.00173
Error	110	0.1280		

Table 6. AOV of 10 cm pot geranium 'Sprinter Scarlet' subjected to 4 phosphorus (P) treatments and grown in a soil and soil-less media (M), harvested 6-20-78.

Source	df	MS	F	P (F > comp F)
Height				
Reps	2	18.5886	3.4645	0.03442
P	3	32.3544	6.0485	0.00075
M	1	21.0841	3.9410	0.04961
PM	3	42.3128	7.9089	0.00008
Error	110	5.3500		
Dry Weight				
Reps	2	5.7681	6.0084	0.00338
P	3	33.3300	34.7188	0.00000
M	1	1.9763	2.0586	0.15419
PM	3	8.2943	8.6399	0.00003
Error	110	0.9600		
Flowers and Buds				
P	3	0.1133	0.7391	0.53093
M	1	1.7067	11.1331	0.00418
PM	3	0.4000	2.6093	0.05514
Error	16	0.1533		

Table 7. AOV of petunia 'Pink Magic' when subjected to 4 phosphorus (P) treatments and grown in a soil and soilless media (M), harvested 5-16-78.

Source	df	MS	F	P (F > comp F)
Height				
Reps	2	93.9218	26.5338	0.00000
P	3	63.9263	18.0598	0.00000
M	1	0.0701	0.0198	0.88835
PM	3	43.4436	12.2732	0.00000
Error	110	3.5397		
Dry Weight				
Reps	2	0.0916	1.3067	0.27488
P	3	0.1033	1.4736	0.04969
M	1	1.2813	18.2782	0.00004
PM	3	0.1882	2.6847	0.05015
Error	110	0.0701		
Flowers and Buds				
P	3	1.1400	0.4071	0.74999
M	1	20.1667	7.2024	0.00004
PM	3	0.4022	0.1436	0.93228
Error	16	2.8000		

Table 8. AOV of impatiens 'Elfin Red' when subjected to 4 phosphorus (P) treatments and grown in a soil and soilless media (M), harvested 5-26-78.

Source	df	MS	F	P (F > comp F)
Height				
Reps	2	90.0098	22.1817	0.00000
P	3	137.5336	33.8933	0.00000
M	1	64.5333	15.9034	0.00012
PM	3	56.6349	13.9569	0.00000
Error	110	4.0578		
Dry Weight				
Reps	2	0.1268	4.4011	0.01450
P	3	0.6183	21.4606	0.00000
M	1	0.0041	0.1423	0.70673
PM	3	0.2059	7.1466	0.00020
Error	110	0.0288		
Flowers and Buds				
P	3	0.6000	1.2080	0.33878
M	1	0.1067	0.2148	0.64927
PM	3	0.0133	0.0268	0.99384
Error	16	0.4967		

Table 9. AOV of marigold 'Goldie' subjected to 4 phosphorus (P) treatments and grown in a soil and soilless media (M), harvested 6-17-78.

Source	df	MS	F	P (F > comp F)
Height				
Reps	2	2.7636	0.8907	0.41331
P	3	20.6150	6.4440	0.00046
M	1	5.6768	1.8296	0.17895
PM	3	7.1228	2.2965	0.08174
Error	110	3.1028		
Dry Weight				
Reps	2	0.0878	0.7825	0.45979
P	3	0.6494	5.7873	0.00104
M	1	1.4083	12.5505	0.00058
PM	3	0.3459	3.0826	0.03038
Error	110	0.1122		
Flowers and Buds				
P	3	0.1128	0.7520	0.53708
M	1	0.0017	0.0113	0.91666
PM	3	0.0194	0.1293	0.94129
Error	16	0.1500		

APPENDIX B

NUTRIENT AND STOCK SOLUTIONS

A 1N solution, by definition, contains an equivalent weight of a substance in water to make a liter. Therefore, 1 ml of a 1N solution will contain 1 meq of substance. If the final solution calls for 10 meq l^{-1}, then 10 ml of a 1N stock solution in 990 ml of water would be required. Likewise, 2 ml of a 5N stock solution in 998 ml water would yield 10 meq l^{-1}.

The following stock solutions were used to prepare the nutrient solutions for the NO_3^- versus NH_4^+ and N-K experiments:

Chemical[a]	Concentration	MW	Equiv. Wt.	g/l final conc.
NH_4Cl	3N	53.49	53.49	160.47
$(NH_4)_2SO_4$	4N	132.14	66.07	264.28
$CaCl_2$	2N	110.99	55.50	110.99
$Ca(NO_3)_2 \cdot 4H_2O$	4N	236.15	118.08	472.30
$MgCl_2 \cdot 6H_2O$	3N	203.31	101.66	204.97
$MgSO_4 \cdot 7H_2O$	2N	246.48	123.24	246.48
KCl	4N	74.56	74.56	298.24
KNO_3	2N	101.11	101.11	202.22

[a]Reagent grade chemicals were used.