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Weight Changes of Radish and Marigold Exposed at Three Ages to NO_2, SO_2, and O_3 Alone and in Mixture[1]

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Abstract. **Radish (*Raphanus sativus* L. cv. Cherry Belle) and marigold (*Tagetes patula* L. cv. King Tut) were exposed 3 times (every other day), for 3 hours each time to NO_2, SO_2, and O_3, alone and in mixture at 0.3 ppm of each pollutant. Plants were exposed to the pollutant treatments at 3 ages. Radish was most sensitive to O_3 at 19–23 days from seeding. The response of marigold to the individual pollutants was not dependent on plant age. Pollutant treatments containing O_3 reduced radish root (hypocotyl) dry weight 48% per plant compared with plants exposed to treatments without O_3. Interactions of NO_2, SO_2, and O_3 on weight changes in marigold were significant. Sulfur dioxide, alone, reduced the dry weight of the marigold flower and roots, but the inhibitory effect of SO_2 was reversed in the presence of NO_2 or O_3.**

The atmosphere surrounding plants in both urban and rural areas frequently contains a mixture of phytotoxic gases (3), including NO_2, SO_2, and O_3. Interest concerning the effects of mixtures of air pollutants on plants increased after Menser and Heggestad (4) demonstrated the greater than additive effect of mixtures of SO_2 and O_3 on foliar injury of tobacco, *Nicotiana tabacum* L. Tingey et al., found that visible injury to 'Cherry Belle' radish, resulting from mixtures of either SO_2 and O_3 (13), or NO_2 and SO_2 (12), was greater than additive when compared to the injury of each pollutant alone.

Plant biomass as well as foliar injury may be influenced by mixtures of NO_2, SO_2, and/or O_3. The effects of SO_2 and O_3 on radish root (hypocotyl) weight were less than additive when plants were exposed to 0.05 ppm SO_2 and/or 0.05 ppm O_3 for 40 hr per week for 5 weeks (11). Reinert and Sanders (8) found that repeated exposure of marigold to 0.3 ppm NO_2, SO_2, and O_3, alone and in mixtures, resulted in less than additive effects of SO_2 and O_3 or SO_2 and NO_2 on root weight.

Plant age may affect plant response to air pollutants. Tingey et al. (10) found radish most sensitive to O_3 just prior to root expansion. Reinert and Henderson (7) found that foliar sensitivity ranking of 6 tomato cultivars was also influenced by plant age.

Plant age is one of the important variables influencing plant response to O_3.Thus a study was designed to determine if NO_2, SO_2, and O_3 alone or in mixtures influence biomass change in radish and marigold of varying plant ages at the time of exposure.

Materials and Methods

Five to 10 'Cherry Belle' radish seeds were seeded in each of 72, 10-cm-diameter plastic pots in a medium consisting of a commercial preparation of peat, perlite, and vermiculite (W.R. Grace Co.), steam pasteurized soil, and sand (4:2:1 by volume). Radish seedlings were thinned to one plant per pot about 4 days after seeding. 'King Tut' marigold seedlings were transplanted, 7 days after seeding, to each of 72, 10-cm-diameter plastic pots containing the medium described for radish. Both plant species were fertilized weekly with a solution (2.5 g/liter) of Peters' 20–20–20 (20N-8.6 P-16.6 K) soluble fertilizer applied by a "hose-on" proportioner. All plants were grown in a charcoal-filtered air greenhouse at a minimum night temperature of 18 ± 3°C and maximum day temperature of 27 ± 3°C. Relative humidity ranged from 50 to 70%. Supplemental lighting of 15 klux from 1000-W multivapor lamps was supplied during cloudy days and day length totaled 14 hr.

The 72 plants of each species were divided into 3 groups. Each group of radish and marigold was randomly assigned to 1 of 8 pollutant chamber treatments consisting of a charcoal filtered air control, NO_2, SO_2, NO_2 + SO_2, O_3, NO_2 + O_3, SO_2 + O_3, and NO_2 + SO_2 + O_3. Plants were exposed to 0.3 ppm of each pollutant. The duration of exposure for radish was 3 hr (0930–1230 HR) and marigold 6 hr (0930–1530 HR). Radish plants assigned to age group 1 were exposed on days 5, 7, and 9 after seeding; marigolds were exposed on days 14, 16, and 18 after seeding. Radish plants in age group 2 were exposed on days 12, 14, and 16 after seeding; marigolds were exposed on days 21, 23, and 25 after seeding. Radish plants in age group 3 were exposed on days 19, 21, and 23 after seeding; marigolds were exposed on days 28, 30, and 32 after seeding. A replicate of the experiment was started 30 days later.

The air pollutants were dispensed into continuous stirred tank reactor type chambers (2) located in a greenhouse. The air pollution monitoring equipment has been previously described (6). All monitoring instruments were calibrated by a portable model 8500 calibrator (Monitor Labs Inc., San Diego, Calif.).

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Visible injury of the plant foliage was estimated in 5% increments (0–100% scale) 2 days after the final exposure of each age group. Radish plants were harvested 30 days from seeding. Fresh weight of the root (hypocotyl) and oven dry (70°C for 48 hr) weights of foliage and roots were determined. Marigold plants were harvested at 58 days from seeding. Dry weights of shoots, flowers, and roots were determined after drying as described for radish. The experiment consisted of 2 replications, 8 pollutant treatments as whole plots, 3 age groups as subplots, and 3 plants per experimental unit to total 144 plants for each species. Data from radish and marigold were evaluated separately by an analysis of variance (ANOVA). Pollutant treatment sum of squares were partitioned into main and interaction effects and evaluated by an F-test (9).

Results

Effects on radish. No visible injury occurred on the control or NO_2-treated plants (Table 1). Plants in the SO_2 treatment had <5% injury regardless of plant age (Table 1). As plant age increased, foliar injury from the other pollutant treatments increased. For example, plants in age groups 1, 2, and 3 exposed to O_3 produced 8%, 33%, and 49% injury, respectively. Injury from mixtures of $NO_2 + O_3$, $SO_2 + O_3$ and $NO_2 + SO_2 + O_3$ appeared greater-than-additive on plants in age group 1, but generally less-than-additive, or additive on plants in age groups 2 and 3. Visible injury from a mixture of $NO_2 + SO_2$ was greater-than-additive in age groups 2 and 3 (Table 1). Injury symptoms caused by the pollutant treatments have been described previously (8).

There were no significant age by pollutant treatment interactions in root fresh weight or foliage and root dry weight (Table 2). However, when the age by pollutant treatment sum of squares was partitioned the effects of O_3 on root fresh and foliage dry weight were significantly dependent on age. Root fresh and foliage dry weight loss in radish due to treatments containing O_3 was greater in age groups 2 and 3 than in age group 1 (Table 3). A similar relationship was observed for root dry weight, but it was only significant at $P = 0.10$.

Due to the absence of age by pollutant treatment interactions (except for O_3) pollutant treatment sum of squares was partitioned into main and interaction effects of NO_2, SO_2, and O_3, averaged across all age groups (Table 2). The effects of O_3 on radish root dry weight were significantly dependent on the presence of SO_2. For example, radish plants exposed to pollutant treatments containing O_3 produced 47% (246 mg) less root dry weight compared to plants from treatments without O_3 (Table 4). When SO_2 was present in mixture with O_3, the 2 pollutants acted synergistically to reduce root dry weight 96 mg more than the additive effects of SO_2 or O_3, regardless of the presence of absence of NO_2 (Table 4). There were significant O_3 main effects on root fresh and dry weight, and foliage dry weight, but no significant effects of NO_2 or SO_2. For example, plants exposed to treatments containing O_3 averaged 5.23 gm less root fresh weight per plant than those plants not exposed to O_3. The dry weight loss of radish roots was larger than that of radish foliage.

Effects on marigold. No visible injury occurred on the control or NO_2-treated plants (Table 1). Less than 1% injury occurred on plants in the $NO_2 + SO_2$ treatment. Sulfur dioxide caused 10% or less injury. Ozone caused 15% or less injury. Injury from the $SO_2 + O_3$ and $NO_2 + SO_2 + O_3$ treatments was less than additive when compared to injury caused by SO_2 or O_3 alone. Injury symptoms to 'King Tut' have been previously described (8).

Partitioning the pollutant treatment sum of squares into main and interaction effects of NO_2, SO_2, and O_3 revealed $SO_2 \times O_3$ and $NO_2 \times SO_2$ interactions among the 3 pollutants (Table 5). Pollutant treatment and age effects were independent of each other; however there were differences in flower, root, and plant dry weight due to age. Plants which were exposed 3 times during the third week after transplanting had larger flower and root dry

Table 1. Foliar injury of 3 ages of radish and marigold plants exposed 3 times to 0.3 ppm NO_2, SO_2, and O_3 alone and in mixtures.[z]

	Foliar injury (%)					
	Radish			Marigold		
	Age groups[y]			Age groups[y]		
Treatments	1	2	3	1	2	3
Control	0	0	0	0	0	0
NO_2	0	0	0	0	0	0
SO_2	<1	<1	4	2	6	10
$NO_2 + SO_2$	0	8	16	0	0	<1
O_3	8	33	49	5	8	15
$NO_2 + O_3$	29	38	51	5	12	18
$SO_2 + O_3$	24	25	48	1	3	8
$NO_2 + SO_2 + O_3$	30	48	46	1	3	5

[z]The duration of each exposure was 3 hr for radish and 6 hr for marigold. Each value represents the mean of 6 plants.

[y]Radish plants in age group 1 were exposed on days 5, 7, and 9 after seeding; marigolds were exposed on days 14, 16, and 18 after seeding. Radish plants in age group 2 were exposed on days 12, 14, and 16 after seeding; marigolds were exposed on days 21, 23, and 25 after seeding. Radish plants in age group 3 were exposed on days 19, 21, and 23 after seeding; marigolds were exposed on day 28, 30, 32 after seeding.

Table 2. Mean squares from the analysis of variance of radish response variables.[z]

			Dry wt[y]	
Source	df	Root fresh wt	Foliage	Root
Replication (R)	1	155.15	0.02	2.23
Pollutants (P)	7	164.13**	0.84*	3.71**
NO_2 (N)	1	6.88	0.01	0.12
SO_2 (S)	1	4.95	0.42	0.10
N × S	1	22.16	0.01	0.05
O_3 (O)	1	985.53**	4.09**	21.80**
N × O	1	19.59	0.99	0.24
S × O	1	109.57	0.01	3.30*
N × S × O	1	0.25	0.37	0.37
Error	7	28.28	0.19	0.50
Age (A)	2	168.33**	0.33	4.13*
A × P	14	30.09	0.34	0.69
A × N	2	9.44	0.17	0.33
A × S	2	11.90	0.13	0.19
A × N × S	2	4.88	0.07	0.45
A × O	2	94.22*	1.16*	2.01
A × N × O	2	60.11	0.19	0.89
A × S × O	2	11.40	0.56	0.28
A × N × S × O	2	18.71	0.11	0.65
Error	16	22.95	0.22	0.66
Residual	96	16.16	0.25	0.40
Total	143			

[z]The experimental design consisted of 2 replications, 8 pollutant treatments, 3 plant ages and a 3-plant experimental unit. Levels of significance: P = 5% (*) and P = 1% (**).

[y]Mean square values and error mean square for radish foliage and root dry weight have been multiplied by 10.

Table 3. The influence of plant age and O_3 on radish root fresh weight and foliage and root dry weight.[z]

	Age groups								
	1			2			3		
	Fresh root wt	Dry wt (mg)		Fresh root wt	Dry wt (mg)		Fresh root wt	Dry wt (mg)	
Treatment	(g)	Foliage	Root	(g)	Foliage	Root	(g)	Foliage	Root
No ozone	11.6	517	581	9.8	501	474	10.7	568	522
Ozone	8.8	494	430	5.3	418	279	2.4	353	129

[z]Each value is the mean of 24 plants.

weights than plants exposed 3 times the first or the second week after transplanting.

The pollutant treatment effects were averaged over the 3 age groups since treatment and age were independent. Weight reduction in the flower, root, and total plant due to SO_2 alone was reversed by the presence of O_3 when averaged over the presence and absence of NO_2 (Table 6). NO_2 also reversed SO_2 effects on root dry weight and total plant growth. For example, NO_2 alone stimulated root dry weight 6% compared to the control plants, while SO_2 alone reduced root dry weight 20%. The presence of O_3 and/or NO_2 reversed the inhibitory effect of SO_2 on root weight. The NO_2 + SO_2, SO_2 + O_3, and NO_2 + SO_2 + O_3 treatments increased root weight 8%, 4%, and 20%, respectively, over the control (Table 6). Ozone and SO_2, alone, reduced flower dry weight 40% and 49%, respectively, compared to the control (Table 6). When SO_2 was present in mixture with O_3 the two pollutants acted antagonistically to increase flower weight 146 mg more than the additive effects of SO_2 or O_3 alone regardless of the presence or absence of NO_2 (Table 6).

Discussion

The response of radish or marigold to the pollutants was not influenced by age at the time of exposure, except for the effects of O_3 on radish root fresh weight and foliage dry weight. Tingey et al. (10) found 'Cherry Belle' radish was most sensitive to O_3 at 14 days from seeding under controlled temperature and light conditions. In the present study 'Cherry Belle' appeared to be more sensitive to O_3 at 19–23 days from seeding. Since radish roots grew less after exposure during the third week, either they were more sensitive at this stage of development or the plants exposed during weeks 1 or 2 had some chance for recovery.

Heagle (1) studying soybeans, found synergism for injury and shoot growth between SO_2 and O_3 when visible injury to the foliage from SO_2 and O_3 was slight to moderate or antagonism when visible injury from either gas, singly, was severe. In the present study, visible injury to radish foliage from SO_2 was slight, but visible injury from O_3 was between moderate and severe and little interaction among pollutants was found. Marigold exposed to NO_2, SO_2, and O_3 developed little visible injury. When pollutant concentrations in mixture produce little or no visible injury, pollutant interactions may be more common than when pollutants in mixture are at concentrations that alone produce excessive visible injury.

Except for an $SO_2 \times O_3$ interaction in root dry weight, there were no interactions among NO_2, SO_2, and O_3 in terms of foliage and root weight changes in radish. Reinert and Sanders (8) did not find an $SO_2 \times O_3$ interaction on radish root dry weight after

Table 4. Mean foliage dry weight and root fresh and dry weights of radish exposed to NO_2, SO_2, and/or O_3 with the significant factorial effects averaged across 3 plant ages.[z]

				Weight change Main and interaction effect[y]			
	Root fresh wt	Dry wt (mg)			Root fresh wt	Dry wt (mg)	
Treatment	(g)	Foliage	Root	Effect	(g)	Foliage	Root
Control	9.6	528	492				
NO_2 (N)	10.6	558	480	NO_2	− .43	5	− 18
SO_2 (S)	11.6	472	551	SO_2	− .37	− 34	− 17
NO_2 + SO_2	11.2	557	579	N×S	− .78	− 5	− 12
O_3 (O)	6.7	447	335	O_3	−5.2**	−107**	−246**
NO_2 + O_3	6.4	436	336	N×O	− .74	− 53	− 26
SO_2 + O_3	5.5	444	267	S×O	−1.74	− 6	− 96*
NO_2 + SO_2 + O_3	3.4	360	179	N×S×O	− .08	− 32	− 32

*, **Significant at the 5% (*) and 1% (**) levels.

[z]Each value is a mean of 18 plants: 2 replications, 3 ages, and a 3-plant experimental unit.

[y]The linear additive model used to evaluate these effects assumes that fixed treatments sum to zero. The main and interaction effects represent the deviation in fresh and dry weights of root and dry weight of foliage per plant from zero. The following example demonstrates how the main and interaction effects were determined using the 8 pollutant treatment means (5, 9);

Main effect of O_3 = 1/4[(NO_2 + SO_2 + O_3) − (NO_2 + SO_2) + (SO_2 + O_3) − (SO_2) + (NO_2 + O_3) − (NO_2) + (O_3) − (Control)].

Interaction of $SO_2 \times O_3$ = 1/4[(NO_2 + SO_2 + O_3) − (NO_2 + SO_2) + (NO_2) − (NO_2 + O_3) + (SO_2 + O_3) − (SO_2) + (Control) − (O_3)].

Interaction $NO_2 \times SO_2 \times O_3$ = 1/4[(NO_2 + SO_2 + O_3) − (NO_2 + SO_2) + (NO_2) − (NO_2 + O_3) ÷ (SO_2) − (SO_2 + O_3) + (O_3) − (Control)].

Table 5. Mean squares from the analysis of variance of marigold response variables.[z]

Source	df	Dry wt Shoot	Dry wt Flower	Dry wt Root	Dry wt Total Plant
Rep (R)	1	12.42**	0.03	2.62**	28.26**
Pollutants (P)	7	0.84	0.23	0.46**	3.68
NO_2 (N)	1	0.58	0.00	1.20**	3.26
SO_2 (S)	1	0.04	0.01	0.04	0.10
N × S	1	2.08	0.40	0.55**	7.93*
O_3 (O)	1	0.27	0.03	0.30*	0.79
N × O	1	0.13	0.04	0.14	0.29
S × O	1	1.84	0.77*	0.98**	10.41*
N × S × O	1	0.95	0.35	0.02	2.98
Error	7	0.56	0.09	0.04	1.17
Age (A)	2	0.19	0.82**	0.58*	3.24*
A × P	14	0.14	0.05	0.07	0.33
Error	16	0.20	0.07	0.11	0.78
Residual	96	0.16	0.05	0.06	0.36
Total	143				

[z]The experimental design consisted of 2 replications, 8 pollutant treatments, 3 plant ages, and a 3-plant experimental unit to total 144 plants. Levels of significance: P = 0.05 (*) and P = 0.01 (**).

9 repeated exposures to 0.3 ppm NO_2, SO_2, and O_3, alone and in combinations, over a 3-week period. Reinert and Gray (6) did not detect any interactions among NO_2, SO_2, and O_3 in 'Cherry Belle' after one exposure to 0.2 ppm or 0.4 ppm of each gas. Tingey et al. (11) found less than additive $SO_2 \times O_3$ interaction in root, fresh and dry weight, after chronic exposure to 0.05 ppm SO_2 and/or 0.05 ppm O_3. Apparently the interaction of SO_2 with O_3 on radish root weight is dependent on pollutant concentration, exposure duration, and the number of repeated exposures.

Interaction among the 3 pollutants, in terms of dry weight changes, was more common in marigold than in radish. SO_2 alone, reduced marigold flower, root and total plant weight, but in the presence of NO_2 or O_3, the effect of SO_2 was reversed. Reinert and Sanders (8) reported that 9 repeated exposures to SO_2 reduced marigold root and flower dry weight more than O_3 or NO_2, and also that the effect of SO_2 was reversed in the presence of O_3 and/or NO_2. Antagonism, in terms of the response of marigold, occurred between SO_2 and O_3 or NO_2 and SO_2, but the mechanism for these phenomena is not understood. 'King Tut' may be very useful in anatomical and physiological studies to determine the mechanism(s) involved in these interactions.

Reinert and Gray (6) discussed the use of treatment contrasts as an approach to evaluating the effects of pollutant mixtures on plants. Reinert and Sanders (8) have used a 2^3 factorial arrangement of 8 treatments to interpret the ability of one pollutant to influence another when only one concentration of each of 3 pollutants is used to provide all combinations of mixture treatments. Oshima and Bennett (5) also discuss the use of treatment contrasts for air pollution mixture studies. They point out that, "contrasts do not require a previous test of statistical significance as a prerequisite and can be applied regardless of the results of the overall ANOVA." All 3 papers address the fact that partitioning of the degrees of freedom and treatment sum of squares for evaluating the main and interacting effects of pollutants, singly and in mixture, has the advantage of using the power of the single degree of freedom comparison test rather than the multiple range comparison test, which is less efficient as the number of treatments increases. In this study the use of treatment contrasts demonstrated the highly dependent manner in which NO_2, SO_2, and O_3 changed the biomass of marigold and the nearly independent way O_3 reduced foliage and root weight of radish.

In conclusion, pollutant interactions may be limited in radish because of its extreme sensitivity to O_3. Pollutant interactions may be common in marigold until one of the pollutants produces an excessive amount of injury and thus eliminates the ability of one pollutant to influence the response to another pollutant. Plant age or stage of development did not have a pronounced effect on pollutant interactions in either species. The fact that the 2

Table 6. Mean shoot, flower, root, and total plant dry weight (g) of marigold exposed to NO_2, SO_2, and/or O_3 with the significant factorial effects averaged across the plant ages.[z]

Treatment	Dry wt (g) Shoot	Dry wt (g) Flower[x]	Dry wt (g) Root	Dry wt (g) Total plant	Effect	Main and interaction effects[y] Dry wt change (mg) Shoot	Flower[x]	Root	Total Plant
Control	3.07	0.75	1.44	5.27					
NO_2 (N)	2.86	0.50	1.54	4.90	NO_2	127	−9	183**	301
SO_2 (S)	2.48	0.38	1.16	4.02	SO_2	35	−15	34	54
$NO_2 + SO_2$	3.07	0.54	1.56	5.17	N×S	240	106	123**	469*
O_3 (O)	2.83	0.44	1.41	4.68	O_3	87	−30	92*	149
$NO_2 + O_3$	2.82	0.46	1.43	4.71	N×O	−59	33	−63	−89
$SO_2 + O_3$	3.01	0.56	1.51	5.09	S×O	226	146*	165**	538*
$NO_2 + SO_2 + O_3$	3.16	0.60	1.73	5.48	N×S×O	−163	−99	−26	−288

*, **Significant at the 0.05 and 0.01 levels, respectively.

[z]Each value is a mean of 18 plants: 2 replications, 3 ages, and a 3-plant experimental unit.

[y]The linear additive model used to evaluate these effects assumes that fixed treatments sum to zero. The main and interaction effects represent the deviation in shoot, flower, root and total plant dry weights per plant from zero. The following example demonstrates how the main and interaction effects were determined using the 8 pollutant treatment means (5, 9):

Main effect of O_3 = $1/4[(NO_2 + SO_2 + O_3) - (NO_2 + SO_2) + (SO_2 + O_3) - (SO_2) + (NO_2 + O_3) - (NO_2) + (O_3) - (\text{Control})]$.

Interaction of $SO_2 \times O_3$ = $1/4[(NO_2 + SO_2 + O_3) - (NO_2 + SO_2) + (NO_2) - (NO_2 + O_3) + (SO_2 + O_3) - (SO_2) + (\text{Control}) - (O_3)]$.

Interaction $NO_2 \times SO_2 \times O_3$ = $1/4[(NO_2 + SO_2 + O_3) - (NO_2 + SO_2) + (NO_2) - (NO_2 + O_3) + (SO_2) - (SO_2 + O_3) + (O_3) - (\text{Control})]$.

[x]Flower wt included flower buds as well as fully developed flowers.

species in this study differed in their response to NO_2, SO_2, and O_3, singly and in mixture, indicates the need for continued research on the effects of NO_2, SO_2, and O_3 in mixture on a wide range of species. This study would also support the need for more biochemical studies to determine why interactions of NO_2, SO_2, and O_3 are common in some species but not in others.

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Effect of Rootstocks and Interstems on Composition of 'Delicious' Apple Leaves[1]

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Abstract. **Leaf nutrient composition (N, P, K, Ca, Mg, Mn, Fe, Zn, and Cu) was determined for 10-year-old 'Delicious' apple trees (*Malus domestica* Borkh.) grown on 21 rootstock and interstem combinations classified according to vigor (standard, semi-standard, semi-dwarf, dwarf). Significant differences in leaf P, K, and Mn were observed between the 4 vigor classifications. P and K were higher in leaves of standard than in leaves of dwarf trees, but leaves of dwarf trees had higher Mn than those of the other size classifications had. "Delicious"/Malling (M)7/Alanarp (A) 2 (dwarf) and 'Delicious'/M7/Robusta (R) 5 (semidwarf) contained high K and low Mg levels. High Mg and low K were found in dwarf trees on M 2 and M 26 rootstocks. Calcium was higher in leaves of trees on Malling Merton (MM) 106 rootstock than in those on M 7/MM 104. Trees on M 26 had high Mn. Fruit yield was correlated negatively to tree size and leaf K and positively to leaf Mg and Mn. Other elements were unaffected by the rootstock systems tested, which suggested that the rootstock and interstem combinations had only a minor effect on nutritional status of scion leaves.**

Leaf analysis can be used to measure the nutritional status of trees and to determine the effect of rootstock systems on the nutrition of scion cultivars (1, 2, 13).

Each graft component on a grafted apple tree can influence the 5 major elements (N, P, K, Ca and Mg) in the tree (16). Apple trees on M 9 rootstocks, for example, had higher foliar Ca and Mg levels than did those on M 7; trees on M 2 had higher foliar P, Ca, and Mg levels than did those on M 7; trees on M 2 had higher foliar P, Ca, and Mg levels than did those on M 16; M 7 rootstocks considerably reduced foliar Mg (18). MM 106 rootstock caused higher foliar Ca than did MM 111 (10, 14); and trees on M 26 had significantly higher leaf Mn than did those on M 9/MM 106, M 2, or MM 109 (12). Transport rate of ^{45}Ca and ^{32}P to roots and scion is known to be related to the vigor class of the tree (4). Jones (7) found that xylem sap from above the interstem had a lower concentration of N, P, K, Ca, and Mg than that from below the interstem, and that difference increased with the dwarfing effect of the interstem.

Our evaluation of rootstock systems was concerned with the

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