The characteristic pod damage resulting when lepidopteran larvae feed through the pod into the seeds was probably done by the corn earworm *(H. zea)* which was the prevalent species found. 'Mississippi Silver' sustained almost 3 times as much of this type of damage as breeding line CR 22-2-21. The mulches had no effect on larval damage.

Yellow pan traps revealed that aphids were deterred by the aluminum and aluminized plastic mulches.

Discussion

Our research confirms the effect of reflective mulches in reducing aphid-borne virus diseases and repelling aphids (1, 2, 4, 5, 6, 8, 9 and 11). It also shows that *Diabrotica* spp. are repelled from cucurbits by these mulches, and that brown stink bug damage is reduced in tomatoes. This addition of *Diabrotica* to the list of arthropods that are repelled by reflective mulches may also mean that such mulches will reduce the incidence of bacterial wilt and cucumber mosaic of cucurbits; the vector (*Acalymma* sp.) is a beetle related to the genus *Diabrotica* that may have similar behavioral patterns relative to reflective mulches.

In general, reflective mulches hold promise in reducing insect populations and damage while increased yields may result. Also these mulches can be integrated easily into pest management programs. However, reflective mulches should not be recommended indiscriminantly until their impact on individual agriculture ecosystems is clearly understood.

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Adaptation of Ornamental Species to an Acid Soil High in Exchangeable Aluminum[1]

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Additional index words. aluminum toxicity, Ca deficiency, P deficiency, alkaline soil

Abstract. **Sixty-nine species of ornamental plants were screened for Al tolerance in greenhouse pots of acid Tatum subsoil adjusted to different pH levels by liming. Species differed widely in tolerance to the unlimed soil at pH 4.1-4.4. For example, in one experiment the relative top yield on unlimed vs. limed soil (pH 4.3/pH 5.2) was 71% for *Dolichos lablab* L. (hyacinth bean); 63% for *Tropaeolum majus* L. (nasturtium); 62% for *Cleome spinosa* Jacq. (cleome); 59% for *Calonyction aculeatum* L. (moonflower); 18% for *Tagetes erecta* L. (marigold); 11% for *Cosmos sulphureous* Cav. (cosmos); 4% for *Calendula officinalis* L. (calendula); and 0.8% for *Chrysanthemum coronarium* L. (garland chrysanthemum). With the exception of cleome, the acid-soil-tolerant species were larger seeded than the sensitive species. Ornamental species also differed in tolerances to neutral-alkaline Tatum soil (pH 7.0-7.2). For example, relative top yields on high lime vs. low lime soil (pH 7.1/5.1) were 89% for marigold, 87% for cleome, 79% for calendula, 78% for hyacinth bean, 54% for nasturtium and 11% for garland chrysanthemum. Ornamental plants were classified according to suitability for strongly acid (pH 4.1-4.4), moderately acid (pH 5.1-5.4) or neutral to alkaline (pH 7.0-7.2) Tatum subsoil.**

Frequently ornamental plants are needed that can grow in strongly acid soils which, for various reasons, cannot be limed. Steep roadside banks and abandoned mine spoils are examples of sites on which the correction of soil acidity, particularly in subsoils, may be difficult or not economically feasible (1, 4).

The acid soil "infertility complex" is composed of many factors, including excesses of Al, Mn and other metallic cations, and deficiencies or unavailabilities of certain essential elements, particularly Ca and P (6, 8, 9). Below about pH 4.0 the H ion (low pH, *per se*) may also directly limit plant growth; at higher soil pH (4.0-5.5) the harmful effects of low pH on higher

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plants are largely indirect and more likely due to excess soluble metals and their interactions with essential nutrients (6). Legume rhizobia may be more sensitive to acid soil factors than their host plants when the latter are supplied with abundant N (6). Acid soil factors may act independently or in conjunction with each other. Furthermore, these factors may be specific for plant species or genotypes within species (8). In many acid soils, particularly below pH 5.0, Al toxicity is perhaps the most important growth limiting factor (6). The literature contains general statements concerning the adaptation of some ornamental species (3, 13) to acid soil, but information regarding their tolerances to specific acid soil factors, such as excess soluble Al, is lacking.

The objective of our study was to determine the tolerances of some ornamental species to a strongly acid Tatum subsoil, which is used routinely (5, 7, 12) at Beltsville to screen a wide range of plants for Al tolerance. Classification authorities for plant species used in these studies were taken from Terrell (14) and from the nomenclature file of the Plant Taxonomy Laboratory at Beltsville, Maryland.

Materials and Methods

Experiment 1. In a preliminary survey, 69 ornamental species were grown for 36 days in single 1-kg containers of acid Tatum subsoil with no lime (pH 4.1) and with 3,000 ppm $CaCO_3$ added (pH 5.3). All species were thinned to 6 plants per container except hyacinth bean which had 4 plants. Tatum subsoil (clayey, mixed, thermic, typic Hapludult), described previously (7), was obtained from a wooded site near Orange, Virginia. The soil was fertilized with 100, 109, and 137 ppm of N, P and K, respectively, added as NH_4NO_3 and KH_2PO_4 in solution and mixed throughout the soil. Plants were grown in a greenhouse between September 30 and November 6. Supplemental incandescent lighting (200 watt bulbs at 15 cm intervals, positioned 19 cm above the bench) was used to provide a minimum day length of 16 hours. Plant tops were harvested, dried and weighed. Roots of 8 species were washed free of soil, dried and weighed. Selected plants were photographed. In rating plants for Al tolerance we used both absolute weights on the no lime and limed soil and relative weights (no lime/lime, %). Relative yield provides a good measure of tolerance when comparing plants with different growth habits, such as tall growing vs. dwarf genotypes.

Experiment 2. The 8 species that showed the widest differences in acid soil tolerance in the unreplicated Experiment 1 were grown in triplicate 1-kg containers of Tatum subsoil with either no lime (pH 4.3) or 3,000 ppm $CaCO_3$ (pH 5.2). All species were thinned to 6 plants per container except hyacinth bean which had 4 plants. For this test the unlimed Tatum subsoil of Experiment 1 was fertilized at half the original rate and reused. The experiment was conducted during January 15 to February 24, in the same greenhouse as Experiment 1. Forty-five days after seeding, the plants tops were harvested, dried, weighed and analyzed for Al by Aluminon (10), P by molybdate (10) and Fe, Ca and Mn by atomic absorption spectrophotometry.

Experiment 3. To test ornamentals for response to high lime soil, we grew 7 species in triplicate, 1-kg containers of Tatum subsoil treated with either 3,000 or 6,000 ppm $CaCO_3$ (pH 5.1 or 7.1). Unlimed soil from Experiment 1 was fertilized at half the original rate and reused. This experiment was conducted at the same time and in the same greenhouse section as Experiment 2. (Both employed a randomized block design with 3 replicates). Forty days after seeding, the plant tops were harvested, dried, weighed and analyzed for Fe, Mn, Zn and Cu by standard atomic absorption techniques.

Results

Experiment 1. The 69 species in this unreplicated study differed widely in survival and growth on the acid Tatum subsoil at pH 4.1 and in their response to lime (Fig. 1). (Detailed data are not reported but are available from the authors on request.) The range of acid soil tolerance found is represented by the following species and their relative top yields on unlimed vs. limed soils (pH 4.1/pH 5.3): Hyacinth bean (58%), moonflower (42%), cleome (41%), nasturtium (26%), marigold (14%), cosmos (6.2%), calendula (3.6%) and garland chrysanthemum (0%). Zinnia was similar to nasturium in acid soil tolerance, having a relative top yield on no lime vs. limed soil (pH 4.1/pH 5.3) of 25%. Relative root weights (pH 4.1/pH 5.3) ranged from 67% for hyacinth bean to 0% for garland chrysanthemum.

Experiment 2. Except for small shifts in order, the acid soil tolerance rankings in this replicated experiment were similar to those obtained in the unreplicated test of Experiment 1 (Table 1). Thus, based on relative yields of tops on unlumed vs. limed soil (pH 4.3/pH 5.2), moonflower (59%), hyacinth bean (71%), nasturtium (63%) and cleome (62%) were significantly more tolerant to the acid soil than marigold (18%), *Cosmos sulphureus* (11%), calendula (4.0%) and garland chrysanthemum (0.8%).

Experiment 3. Top yields of the 7 species were reduced to differing degrees as soil pH was increased from 5.1 to 7.1 (Table 2). With relative top yield on high lime vs. low lime soil as an index (pH 7.1/pH 5.1, %), hyacinth bean, marigold, *Cosmos sulphureus,* calendula and cleome were significantly more tolerant to the pH 7.1 soil than nasturtium, and nasturtium was significantly more tolerant than garland chrysanthemum

Plant Symptoms

On the unlimed Tatum soil (pH 4.1–4.3) of *Experiments 1* and *2* the plant species showed a variety of foliar symptoms that were prevented by liming the soil to 5.2–5.3. Plant symptoms on the unlimed soil included general chlorosis of young leaves (*Cosmos sulphureus* and morning glory); leaf cupping (morning glory); tip dying, resembling Ca deficiency (nasturtium); small, dark-green leaves (nasturtium, hyacinth bean); interveinal chlorosis of young leaves (moonflower); and a purple coloration resembling P deficiency (snapdragon). On Tatum soil limed to pH 7.1 stunting was the main symptom in sensitive species. Hyacinth bean, which was rather tolerant to pH 7.1, showed a chlorosis of lower leaves and wrinkling of young leaves.

Plant Composition

Experiment 2 (pH 4.3 vs. 5.2). On unlimed Tatum soil at pH 4.3, the acid-soil-sensitive *Cosmos sulphureus* contained significantly higher Al concentrations in its tops than did the much more tolerant moonflower and hyacinth bean (Table 3), but the Al contents of the rather sensitive marigold were no higher than those of the tolerant moonflower. Iron concentrations in plants were extremely variable and no consistent species differences were found. The high Fe value for cosmos in Table 3 is due largely to one high replicate. The acid-soil-sensitive *Cosmos sulphureus* and marigold contained significantly higher concentrations of Mn than did the more tolerant moonflower and hyacinth bean. The moderately acid-soil-tolerant cleome contained significantly higher P concentrations than the other 5 species, but P concentrations were not consistently related to acid soil tolerance. Calcium concentrations were not significantly higher in the acid-soil-sensitive marigold and cosmos than in the more tolerant moonflower, hyacinth bean, nasturtium and cleome.

On soil limed to pH 5.2, the 6 species did not differ significantly in Al concentration (Table 3). Marigold and cosmos still tended to contain higher Mn concentrations than the more tolerant moonflower and hyacinth bean; however, the moderately tolerant cleome contained Mn concentrations that were as

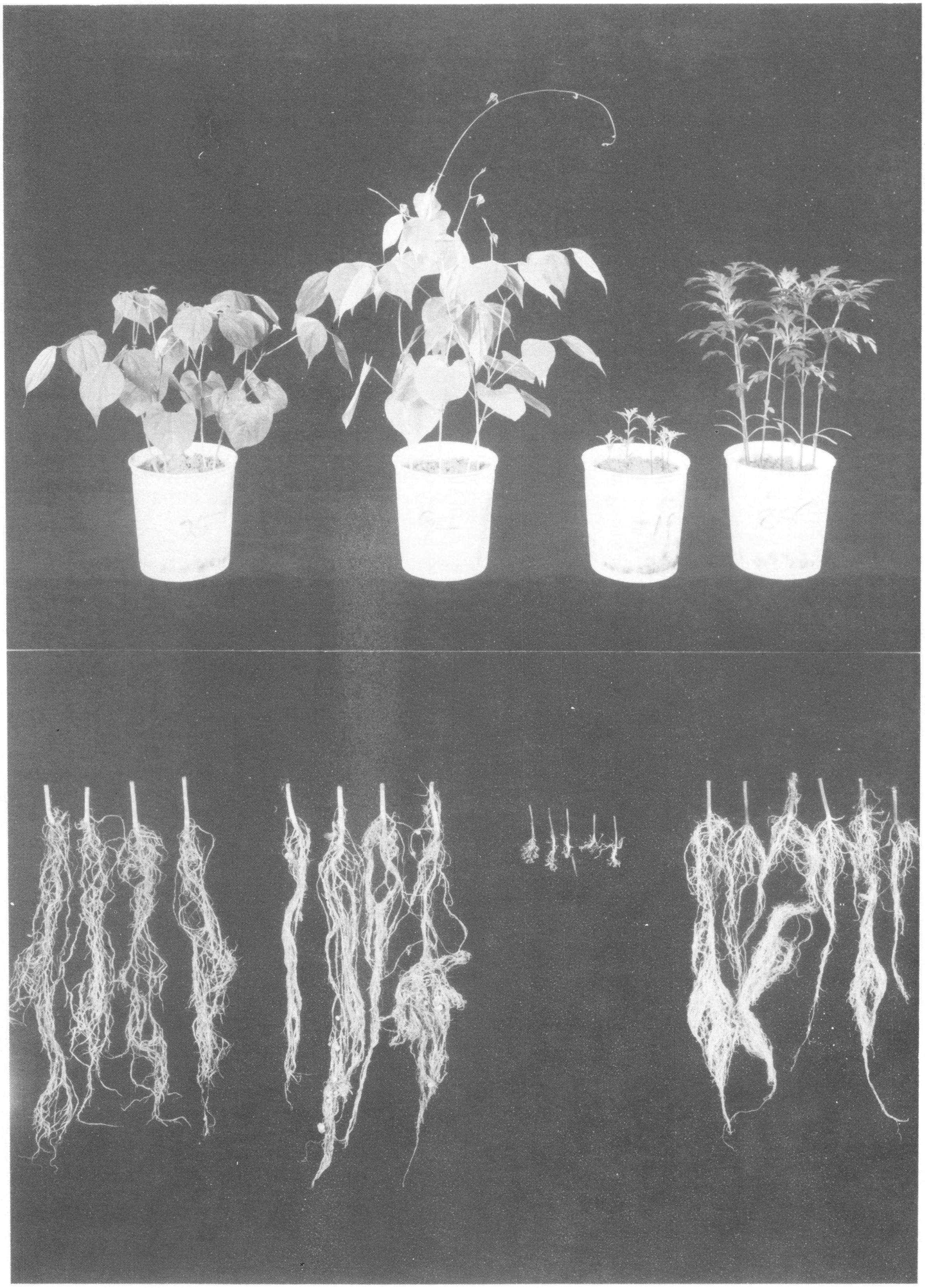

Fig. 1. Differential tolerances of two ornamental species to acid Tatum subsoil. Left: *Dolichos lablab* L., hyacinth bean, with no lime (pH 4.1) and 3,000 ppm $CaCO_3$ (pH 5.3). Right: *Cosmos sulphureus* Cav. with the same treatments. (Experiment 1).

Table 1. Top growth of ornamental species on acid Tatum subsoil with and without lime (Experiment 2).

Ornamental	Dry wt. of tops (g/plot) No $CaCO_3$ pH 4.3	Dry wt. of tops (g/plot) 3,000 ppm $CaCO_3$ pH 5.2	Relative top yields $\frac{\text{pH 4.3}}{\text{pH 5.2}} \times 100$
Moonflower	3.34 a^z	5.62 a^z	59.5 a^z
Hyacinth bean	3.28 ab	4.63 b	70.8 a
Nasturtium	1.85 ab	2.94 c	62.9 a
Cleome	0.65 b	1.05 d	62.3 a
Marigold	0.30 b	1.71 d	17.6 b
Cosmos	0.13 b	1.10 d	11.4 b
Calendula	0.04 b	0.98 d	4.2 b
Garland chrysanthemum	0.01 b	1.13 d	0.8 b

^{z}Mean separation, within a column, by Duncan's multiple range test, 5% level.

Table 2. Top growth of ornamental species on Tatum subsoil at 2 lime levels (Experiment 3).

Ornamental	Dry wt of tops (g/pot) 3,000 ppm $CaCO_3$ pH 5.1	Dry wt of tops (g/pot) 6,000 ppm $CaCO_3$ pH 7.1	Relative top yield $\frac{\text{pH 7.1}}{\text{pH 5.1}} \times 100$
Hyacinth bean	4.12 a^z	3.20 a^z	77.7 a^z
Nasturtium	3.07 b	1.65 b	53.8 b
Marigold	1.56 c	1.39 bc	89.1 a
Cosmos	1.16 cd	1.01 bcd	87.0 a
Calendula	0.96 cd	0.75 cde	78.7 a
Garland chrysanthemum	0.88 d	0.09 e	10.7 c
Cleome	0.72 d	0.62 de	86.7 a

^{z}Mean separation, within columns, by Duncan's multiple range test, 5% level.

Table 3. Mineral composition of ornamental plant tops grown on Tatum subsoil with 0 or 3,000 ppm $CaCO_3$ added (Experiment 2).

		Composition of plant tops									
		No $CaCO_3$ (pH 4.3)					3,000 ppm $CaCO_3$ (pH 5.2)				
Ornamental	Relative top yield $\frac{\text{pH 4.3}}{\text{pH 5.2}} \times 100$	Al (ppm)	Fe (ppm)	Mn (ppm)	P (%)	Ca (%)	Al (ppm)	Fe (ppm)	Mn (ppm)	P (%)	Ca (%)
Moonflower	59.5	419 b^z	239 a	132 c	0.06 c	0.10 b	183 a	113 a	101 c	0.04 d	0.71 d
Hyacinth bean	70.8	143 b	104 a	129 c	0.05 c	0.15 b	210 a	198 a	92 c	0.05 cd	0.89 c
Nasturtium	62.9	149 b	46 a	215 b	0.06 c	0.13 b	97 a	153 a	121 bc	0.08 bc	0.81 cd
Cleome	62.3	278 b	141 a	254 b	0.27 a	0.16 b	116 a	109 a	174 a	0.25 a	1.31 a
Marigold	17.6	449 b	179 a	427 a	0.05 c	0.30 a	82 a	390 a	162 ab	0.08 b	1.17 b
Cosmos	11.4	2114 a	1079 a	260 b	0.15 b	0.40 a	105 a	120 a	134 abc	0.08 bc	1.18 b

^{z}Mean separation, within a column, by Duncan's multiple range test at the 5% level.

Table 4. Mineral composition of ornamental plant tops grown on Tatum soil with 3,000 or 6,000 ppm $CaCO_3$ added (Experiment 3).

		Composition of plant tops									
		3,000 ppm $CaCO_3$ (pH 5.1)					6,000 ppm $CaCO_3$ (pH 7.1)				
Ornamental	Relative top yield $\frac{\text{pH 7.1}}{\text{pH 5.1}} \times 100$	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	P (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	P (%)
Marigold	89.1	90 ab^z	95 bc	37 cd	2.6 b	0.08 c	70 a	89 b	11 c	3.5 bc	0.08 c
Cosmos	87.0	83 ab	94 bc	22 d	1.2 b	0.05 d	81 a	83 b	14 c	5.8 a	0.07 c
Cleome	86.7	129 a	125 bc	53 bc	5.3 a	0.25 a	117 a	89 b	46 a	2.4 c	0.25 a
Calendula	78.7	75 ab	288 a	131 a	1.7 b	0.08 c	116 a	109 a	38 ab	4.1 b	0.10 b
Hyacinth bean	77.7	96 ab	40 c	26 d	1.9 b	0.04 e	90 a	38 cd	16 bc	2.3 c	0.05 d
Nasturtium	53.8	50 b	70 bc	38 cd	1.6 b	0.06 d	140 a	30 d	13 c	2.3 c	0.07 e
Garland chrysanthemum	10.7	83 ab	167 b	64 b	2.0 b	0.11 b	^{y}	87^x	36^x	6.0^x	0.22^x

^{z}Mean separation, within columns, by Duncan's multiple range test, 5% level.

^{y}Sample lost.

^{x}Data for composite samples. Insufficient sample for analytical replicates.

contained significantly higher Mn concentrations than other species, both at pH 5.1 and 7.1. Garland chrysanthemum also tended to contain higher Mn than several other species at pH 5.1.

Fig. 2. Differential lime responses of ornamental species on acid Tatum subsoil. Left to right: No lime (pH 4.2–4.4), 3,000 ppm $CaCO_3$ (pH 5.1–5.4) and 6,000 ppm $CaCO_3$ (pH 7.0–7.2). Top to bottom: *Dolichos lablab* L., hyacinth bean, *Tropaeolum majus* L., nasturtium, *Cosmos sulphureus* Cav., Cosmos, *Calendula officinalis* L., calendula, and *Chrysanthemum coronarium* L., garland chrysanthemum. Photos were made by combining Experiments 2 and 3 which were conducted on adjacent benches of the same greenhouse at the same time.

high as those in acid-soil-sensitive species. The acid-soil-sensitive species tended to contain higher concentrations of P and Ca than did tolerant species; however, Fe concentrations were not significantly different in the two groups.

Experiment 3 (pH 5.1 vs. 7.1). Plant composition data in Table 4 do not offer any clear explanation for yield depressions of nasturtium and garland chrysanthemum at pH 7.1 as compared with 5.1. There were no obvious deficiencies of Fe, Mn, Zn, or Cu in plant tops. Plant symptoms in garland chrysanthemum somewhat resembled B deficiency, but B was not determined on plant samples. The pH 7.1-sensitive garland chrysanthemum did tend to contain a higher P concentration (single sample) than did the more tolerant species; however, cleome which was rather tolerant to both acid and alkaline soil, was higher in P than other species at both pH 5.1 and 7.1. Calendula contained significantly higher Mn concentrations than other species, both at pH 5.1 and 7.1. Garland chrysanthemum also tended to contain higher Mn than several other species at pH 5.1.

Discussion

Our studies showed that ornamental species can be grouped into various classes according to their suitability for strongly acid, moderately acid, and neutral to alkaline Tatum subsoil. Different types of lime response (acid soil tolerance) are shown in Fig. 2. This is an assembly of containers from Experiments 2 and 3 which were conducted at the same time, on adjacent greenhouse benches. Hyacinth bean tolerated a pH range of 4.2 to 7.2, although its growth was somewhat reduced at the highest pH. This species grows well in the Bahama Islands on soils at pH 8.0 (A. J. Oakes, personal communication). Nasturtium grew well at pH 4.2–4.4 and at pH 5.1–5.4, but its growth was reduced at pH 7.0–7.2. *Cosmos sulphureus* was sensitive to Tatum subsoil at pH 4.2–4.4 but grew well at pH 5.1–5.4 and also at pH 7.0–7.2. Calendula was very sensitive to pH 4.2–4.4, grew best at pH 5.1–5.4 and was somewhat reduced in growth at pH 7.0–7.2. Garland chrysanthemum was extremely sensitive to pH 4.2–4.4, grew best at pH 5.1–5.4 and was severely injured by pH 7.0–7.2. With the exception of cleome, most of the acid-soil-tolerant species were larger seeded than sensitive species.

In some species, such as marigold (Fig. 3), there was considerable plant to plant variability within the same pot of strongly acid soil at pH 4.2–4.4. This suggests that greater acid soil tolerance might be obtained by selection and breeding within species.

Evidence from the current experiments, plus previous experience (5, 7, 12), indicated that Al toxicity was the primary growth-limiting factor for ornamental species on the strongly acid Tatum subsoil at pH 4.1–4.4. The observed plant symptoms, resembling Ca and P deficiencies, are known to be induced by Al in other species (8, 9). Hence, the differential tolerances of ornamental species to acid Tatum subsoil in our studies may be regarded primarily as differential tolerances to Al.

One acid-soil-sensitive species, *Cosmos sulphureus,* contained significantly higher concentrations of Al in its tops than did the more tolerant species, but this was not true for the acid-soil-sensitive marigold. Acid soil tolerance was also not consistently related to concentrations of Fe or P in plant tops. The tops of acid-soil-sensitive *Cosmos sulphureus* and marigold contained significantly higher concentrations of Mn and Ca than did those of the more tolerant moonflower and hyacinth bean when all were grown on unlimed soil (pH 4.1–4.4), but the physiological significance of this is unknown. At pH 5.1 garland chrysanthemum and calendula, both extremely sensitive to the strongly acid soil at pH 4.1–4.4 also tended to contain higher Mn concentrations than more tolerant species. In this concentration, Coorts (2) reported that calendula and chrysanthemum were sensitive to excess Mn in nutrient solutions and were suitable as indicator plants.

The causes of reduced growth of some species at pH 7.0–7.2 were not determined. Plant symptoms and composition indicated that there were no clear-cut deficiencies of Fe, Mn, Zn or Cu, but B deficiency could have caused the stunting observed in garland chrysanthemum (Fig. 2). Since our plants were not analyzed for B, further study will be needed to resolve this question.

Results obtained with Tatum subsoil may not apply to all acid soils having a similar pH range, because some soils may cause Mn toxicity or other mineral stress problems in plants. However, they do give a good estimate of Al sensitivity, which is probably the most widespread growth-limiting factor in many, if not most, acid soils of pH 5.0 or below.

Fig. 3. Lime response of *Tagetes erecta* L., marigold, on acid Tatum subsoil. Left to right: no lime (pH 4.3), 3,000 ppm $CaCO_3$ (pH 5.2) and 6,000 ppm $CaCO_3$ (pH 7.2). Variability in seedling tolerance to acid soil (extreme left) suggests that more tolerant strains may be selected or bred.

The ultimate adaptation of ornamentals to strongly acid, Al-toxic sites will, of course, also depend on climate. Because Al toxicity reduces root penetration, Al tolerance may be regarded as one measure of drought tolerance. Fortunately, the Al toxicity produced by Tatum soil is such an overwhelming factor that we can predict acid soil tolerance in the field by short-term, vegetative growth in small containers of soil in the greenhouse or growth chamber (5, 11, 12).

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