MICRONUTRIENT NUTRITION

OF CONTAINER-GROWN

ORNAMENTALS

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Submitted to the Faculty of the Graduate College
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in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
December, 1981

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PREFACE

The completion of my study for the Master's degree in Horticulture would not have been possible without the tremendous support of my wife Mariana and daughter Anneke. I thank you very much.

Dr. Carl Whitcomb, thank you for a unique learning experience and for guiding me in a competent manner towards my degree and a new beginning in my professional life.

Dr. Grant Vest, without your continuing mental support I most likely would not have been able to finish these difficult years.

I further wish to express my appreciation to Dr. Michael Smith and his graduate student Monica Washmon for their instruction in foliar analysis; to Dr. William Warde for his extensive help with the statistical analysis; to Dr. Lawrence Morrill for stimulating my interest in plant nutrition; and to Dr. Earl Mitchell for his mental and financial support.

I finally wish to thank the entire Horticulture faculty for their helpfulness and collegiality.

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CHAPTER I

INTRODUCTION

The term "micronutrient", when applied to nutrition of cultivated plants, is somewhat misleading. The fact that only small amounts of iron, manganese, copper or zinc accumulate in the plant should not suggest that they are to be applied in equally minute quantities. Studies on nutrition of plants grown in soilless media demonstrate the positive effect of relatively large applications of micronutrients on plant size and vigor. Since healthy plant growth and development is attained, among many other factors, by a finely tuned interplay of electrochemically related elements, any increase of one nutrient requires proportionate increases of cooperating nutrients.

This study attempts to establish optimal rates and ratios of Fe, Cu, Mn, and B. Zinc and molybdenum were held constant at a moderate level. Macronutrients and intermediate elements were apportioned uniformly to all treatment combinations. The synergistic effect of slowly released N, P, K, and gradually available Ca, Mg and micronutrients has been experimentally substantiated.

The overall objective of this experiment was to reach a new milestone on the road towards a well-balanced nutritional system for container plant production. This system will enable the grower to produce, in a shorter period of time and at a lower cost, ornamental plants that have a more evenly branched structure, stronger stems, deeper foliage color, and a more fibrous root system. Container plants fertilized with micronutrients in combination with slowly released macronutrients (1) compete favorably with weeds, (2) need less frequent pruning or no pruning at all, (3) are less easily damaged during grading, packing and shipping, (4) are more resistant to diseases, (5) are better adapted to stress in the landscape, and (6) produce cuttings that carry over their high nutrient content into better quality liners.

CHAPTER II

REVIEW OF LITERATURE

Chemical Functions of Mineral Elements

Mineral elements play a major role in the synthesis and degradation of matter in metabolic processes (Bowen, 2). Some are incorporated in inorganic structural materials, such as calcium (as calciumpectate) in the cell walls of seed plants. Others have electrochemical functions: calcium, magnesium, potassium and sodium, for example, allow the cell to simulate a storage battery with a potential difference across its bounding membrane. Elements such as iron, copper, and magnesium occur as central atoms of tetradentate ligands called porphyrins. Examples are the protein bound enzymatic porphyrins of cytochromes in mitochondria where iron controls redox processes by accepting electrons as Fe(III) or by repelling electrons as Fe(II).

Most naturally occurring mineral elements are bound by proteins. Depending on the nature of metal ion-protein interaction three types of compounds can be distinguished. First, there are metal-activated enzymes in which the loosely bounded, easily replaceable metal stabilizes the order of configuration of peptides (Mg^{+2}, Mn^{+2}) or aids in linking the substrate to the enzyme by interacting with both (Mg^{+2}, $B_4O_7^{2-}$). The second group consists of metalloproteins without enzyme activity that have the metal firmly bonded to the protein. And third are the metalloenzymes in which essential and irreplaceable metals such as Cu and Fe are firmly bonded to the protein. Copper and iron function primarily in electron transport during cellular redox processes, especially in photosynthesis and respiration where the following reversible reactions are involved:

$$Cu(II) + e^- \rightleftharpoons Cu(I)$$

$$Fe(III) + e^- \rightleftharpoons Fe(II)$$

Manganese is present in chloroplast proteins where it may be involved in photosynthetic redox reactions:

$$Mn(III) + e^- \rightleftharpoons Mn(II)$$

Molybdenum and iron are essential in redox reactions of N_2-fixation, because they form part of a substance similar to ferredoxin called the molybdoferredoxin protein.

Plant metabolic processes are thus controlled not merely by single elements acting independently of each other but rather by interaction of elements, for instance, Fe:Cu, Fe:Mn, Fe:Mo, and Ca/Mg:K.

Foliar Nutrient Status

Plant growth and development depends upon number, location, and activity of primary and secondary meristems or growing points. Meristematic activity is conditioned externally by light, temperature, water and nutrient supply and internally by hormonal and nutritive factors.

Unlike native plants that "mine" their geochemical environment directly for essential mineral elements, cultivated plants are almost totally dependent on man's ability to supply these elements to them.

In formulating the plant's fertilizer needs, the following relations are of interest: the relation between (a) yield and nutrient supply and uptake, (b) plant composition and nutrient supply, and (c) yield and plant composition (Hewitt, 9).

(a) According to the law of diminishing returns (Tisdale and Nelson, 15), the relation between nutrient availability and yield can be expressed as a hyperbolic curve with maximum gradient at low nutrient levels and approaching a maximum value at high quantities (Figure 1).

(b) Nutrition experiments with sand cultured barley show that the concentration within the plant of a nutrient in minimal supply will rise with increasing supply. As the concentration depends on the specific metabolic function of the nutrient, on the rate of uptake, and on the rate of utilization of this nutrient and its competing elements, the resulting curves are different from the previous one (Figure 2). The divergent curves in the barley experiment reflect the dynamic nature of the mineral composition of a tissue. Nitrogen, for instance, is present in high concentrations in young tissue (Curve I) and is diluted as the tissue enlarges (Curve II).

(c) Plant growth and structure <u>can</u> be highly correlated with nutrient content (Table I), (Ward and Whitcomb, 16). This type of correlation, however, is not necessarily a positive one. As a rule, it is expressed as a quadrumeric curve (Figure 3), (Smith, 13).

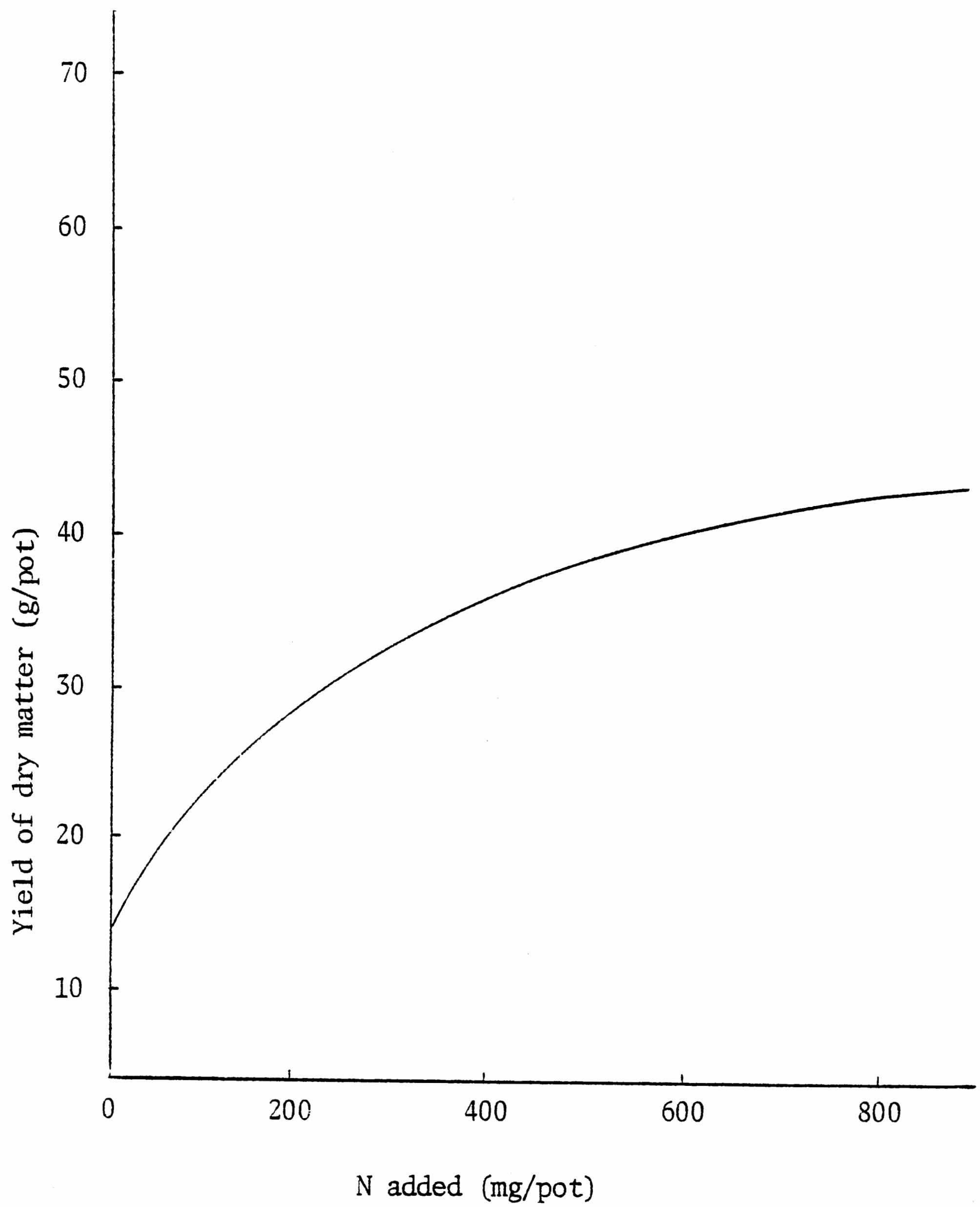
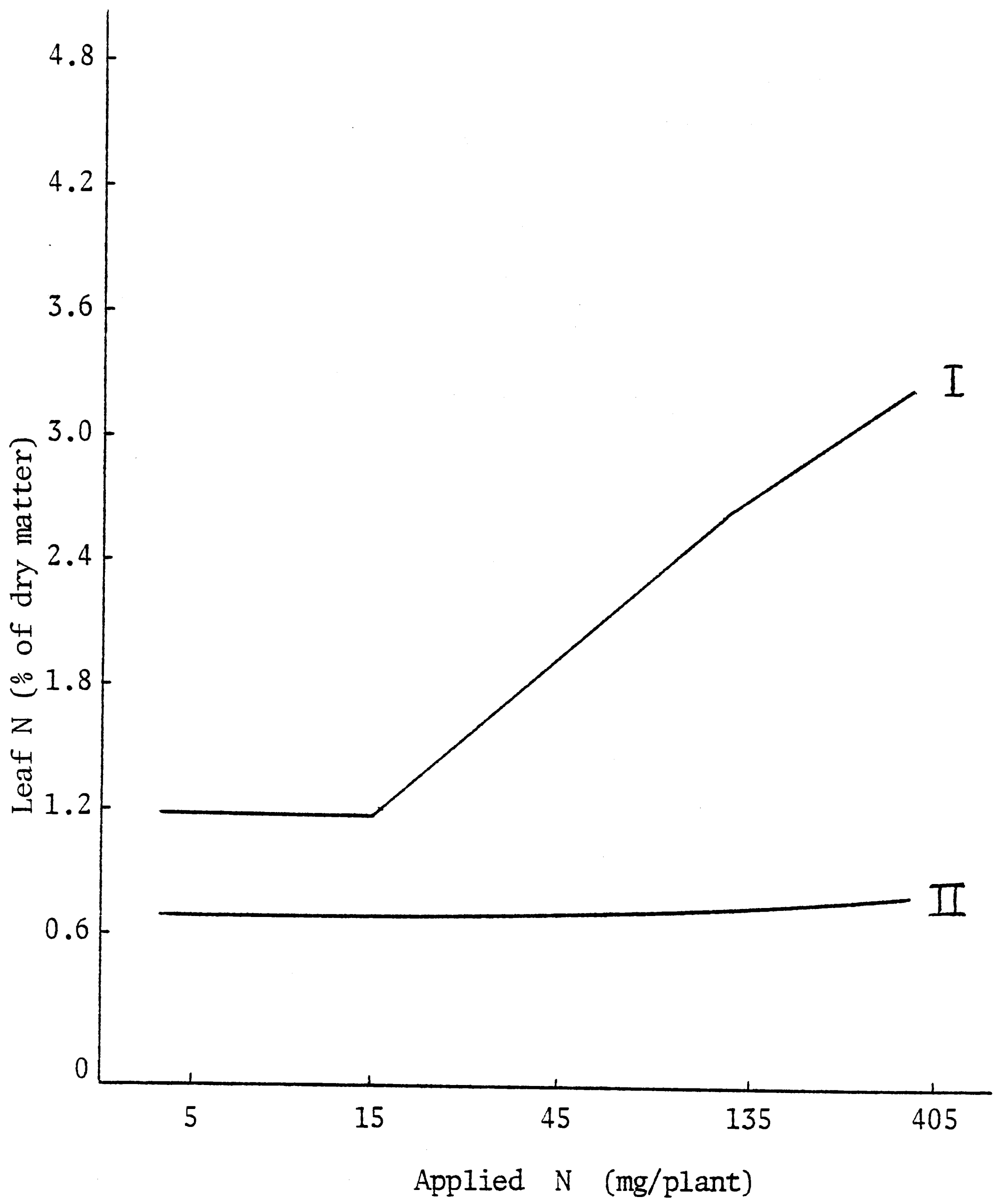


Figure 1. Effect of ammoniumnitrate (NH_4NO_3) on corn forage yield. Tisdale and Nelson (15).



I= sampling 2 weeks from germination
II= sampling 8 weeks from germination
P applied at 135 mg P_2O_5 per plant

Figure 2. Leaf-N content (% in dry matter) of sand cultured barley plants. Goodall (8).

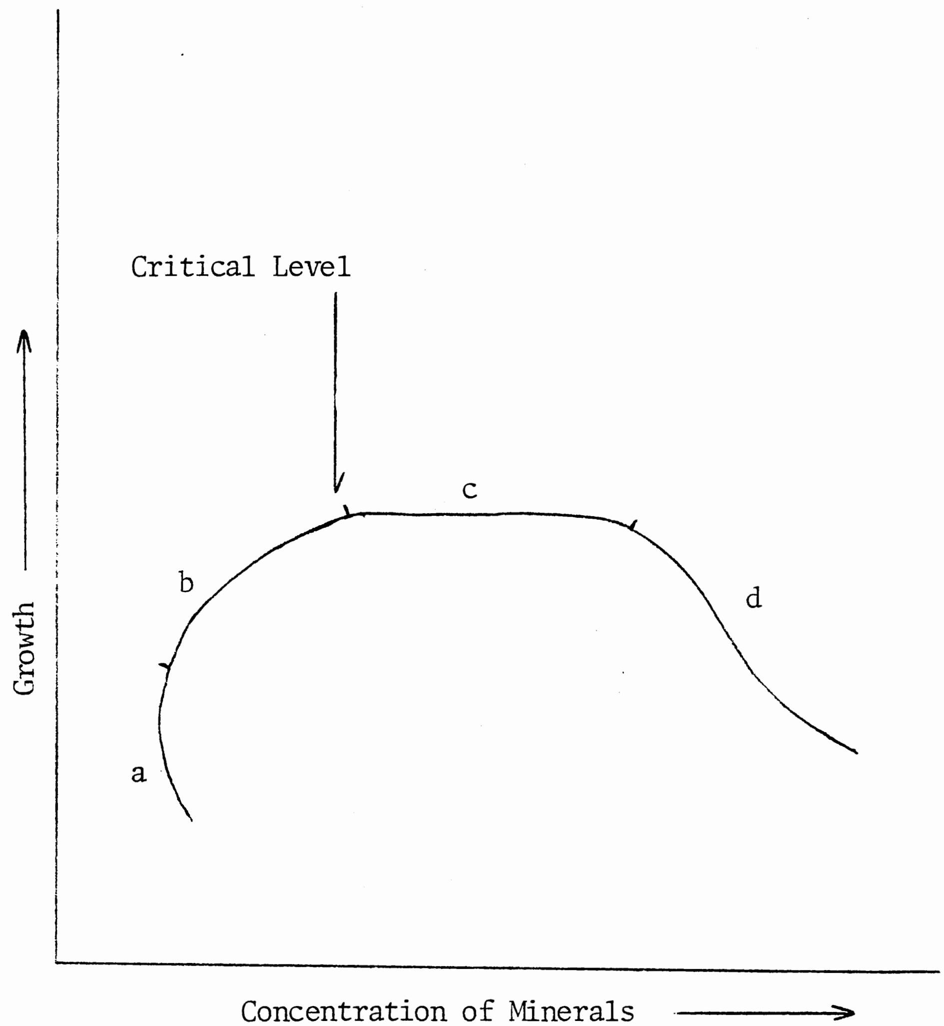
TABLE I

CORRELATIONS OF FOLIAR NUTRIENT CONTENT PER PLANT WITH TOP AND ROOT WEIGHT AND VISUAL GRADE OF 'HETZI' HOLLY[y]

	Correlation coefficient (r)[z]			
	Foliar Nutrient content(g/plant)			
Plant Variable	N	K	Ca	Mg
Top weight	.96	.88	.89	.85
Root weight	.83	.80	.96	.95
Visual grade	.93	.84	.87	.83

[y]Ward and Whitcomb (16).

[z]Coefficients significant at 0.1% level.



a=severe deficiency; b=mild deficiency;
c=luxury range; d=toxic range

Figure 3. Diagram showing the relation of mineral composition of tissue to growth. Smith (13).

In comparing the three types of relations described above, the difficulties in forecasting nutritional needs from foliar analysis data appear as nearly unsolvable in the case of multi-elemental factorial experiments. The use of plant composition data as the sole basis for formulating a fertilizer program ignores such intervening factors as (a) losses by leaching, (b) fixation of elements in an unavailable form by the growing medium, (c) genotypic differences among species and even varieties in selecting certain nutrients from the soil solution, (d) differences between solubility products of mineral compounds, and (e) shifts in solid $\rightleftharpoons$ solute equilibria due to different dissociation rates of compounds with the same anions (Tisdale and Nelson, 15).

Foliar analysis data have been compared with standards of reference for healthy plants. A survey of the foliar mineral content of 700 samples of ornamentals grown in Ohio nurseries (Smith, 12) shows that differences exist between levels of Mn and B in tissue of deciduous and evergreen plants (Table II). Within the evergreen group there are differences in Ca, B, and Mo concentrations in the foliage of broadleaf and narrowleaf evergreens (Table III). To evaluate the tissue composition of *Ilex crenata* 'Hetzi' Thunb. analyzed in the present study, data on a related cultivar are given as a standard of reference (Table IV). Compared to the average tissue composition of broadleaf evergreens *Ilex*-tissue has a high accumulation of N, Fe, and Mn. This variability in mineral composition of different species confirms the opinion of geneticists that species are not to be regarded as physiologically homogeneous populations (Burkholder and McVeigh, 3),

TABLE II

TISSUE COMPOSITION OF DECIDUOUS AND EVERGREEN PLANTS[z]

	Mineral Element										
	percent					ppm					
	N	P	K	Ca	Mg	Mn	Fe	B	Cu	Mo	Zn
Deciduous	2.30	.34	1.41	1.33	.34	130	222	36	11	2.1	40
Evergreen	2.14	.35	1.38	.84	.26	213	201	27	15	1.9	54

[z]Smith (12).

TABLE III

TISSUE COMPOSITION OF NARROWLEAF AND BROADLEAF EVERGREENS[z]

	percent					ppm					
	N	P	K	Ca	Mg	Mn	Fe	B	Cu	Mo	Zn
Narrowleaf	2.0	.36	1.41	.68	.19	198	159	22.8	12.7	1.2	44.5
Broadleaf	2.16	.26	1.16	1.43	127.00	182	189	31.0	17.0	2.7	46.0

[z]Smith (12).

TABLE IV

TISSUE COMPOSITION OF ILEX CRENATA 'CONVEXA'[z]

percent					ppm					
N	P	K	Ca	Mg	Mn	Fe	B	Cu	Zn	Mo
3.4	.33	1.43	.87	.48	342	317	23	19	89	3

[z]Smith (12).

and that it is therefore impossible to arrange the absorption of cations in any certain order that would be valid for all plant species (Collander, 5).

Fertilizer Rates and Ratios of Existing Micronutrient Products

Tissue content of container-grown ornamentals is not only dependent upon rates and ratios of nutrients but also on their source. Differences if availability of micronutrients from various mixtures - Perk, Vigor Supplement X and FRIT-503 - are evident in tissue content of Brassaia (Table V), (Conover et al., 6). Particularly striking is the presence of high foliar Fe (530 ppm) and Mn (388 ppm) due to the more soluble Perk, and of low foliar Fe (112 ppm) and Mn (77 ppm) due to the much less soluble fritted trace elements (FRIT-503).

A comparison of Perk, Esmigran, FRIT-503, and FRIT-504 underscores this variability in ratio and recommended rate of micronutrients. Perk and Esmigran contain three or four times as much elemental Fe as FRIT, but 90% less B (Table VI). The Mn-content of Perk is approximately three times higher than that of the other products (Table VI). These appreciable differences in nutrient rates lead to even larger differences in elemental ratios (Table VII).

In view of the low Fe and Mn concentration and the high B content of the FRIT products, it is not surprising that species like Ilex crenata Thunb. that have a high Fe and Mn requirement (Table IV) respond significantly better to Perk and Esmigran than to FRIT (Whitcomb et al., 18).

TABLE V

INFLUENCE OF MICRONUTRIENT SOURCE AND RATE ON TISSUE CONTENT OF BRASSAIA ACTINOPHYLLA[z]

	IRON		
	Rate in g/m^3 of actual element applied		
	25	50	75
Source	Fe-content in tissue (ppm)		
Perk	508	590	530(R)
Vigoro	147(R)[y]	60	64
FRIT-503	112(R)	126	87

	MANGANESE		
	Rate in g/m^3 of actual element applied		
	15	30	45
Source	Mn-content in tissue (ppm)		
Perk	167	211	388(R)
Vigoro	98(R)	92	82
FRIT-503	77(R) at 8 g/m^3	112 at 16 g/m^3	132 at 25 g/m^3

	COPPER		
	Rate in g/m^3 of actual element applied		
	1.5	3.0	4.5
Source	Cu-content in tissue (ppm)		
Perk	16	16	16(R)
Vigoro	6(R)	15	14
FRIT-503	19(R) at 3½ g/m^3	24 at 7 g/m^3	23 at 10 g/m^3

[z]Conover (6).

[y](R) = Tissue content associated with recommended micronutrient applications.

TABLE VI

RECOMMENDED RATES OF FOUR MICRONUTRIENT PRODUCTS

	PERK[z] 4 lbs./cu.yd. (2380 g/m³)		ESMIGRAN[y] 5.5 lbs./cu.yd. (3271 g/m³)		FRIT 503[x] .25 lbs./cu.yd. (149 g/m³)		FRIT 504[x] .25 lbs./cu.yd. (149 g/m³)	
	%	g/m^3	%	g/m^3	%	g/m^3	%	g/m^3
Fe	3.68	87.6	2	65.4	18	26.8	14	20.9
Mn	2.23	53.0	0.5	16.4	7.5	11.2	7	10.4
Cu	0.23	5.5	0.3	9.8	3.0	4.5	7	6.7
B	0.023	0.5	0.02	0.7	3.0	4.5	3.8	5.7

[z]Perk is manufactured by Wilson and Toomer Fertilizer Co., Jacksonville, Florida, and is composed of sulfate forms with 6% of the iron in chelated form.

[y]Esmigran is manufactured by Mallinckrodt Chemical Co., St. Louis, Missouri, and is composed of ferrous chloride, sulfates of zinc, manganese and copper, boric acid and ammoniummolybdate.

[x]FRIT is marketed by Frit Industries, Ozark, Alabama, and is manufactured by combining molten sand and micronutrients.

TABLE VII

RATIOS OF FOUR MICRONUTRIENT PRODUCTS

Ratio	PERK	ESMIGRAN	FRIT 503	FRIT 504
Fe:Mn	1.7	4.0	2.2	2.1
Fe:Cu	16.0	6.6	6.0	3.1
Fe:B	175.0	93.0	6.0	3.7
Mn:Cu	9.6	1.6	2.7	1.5
Mn:B	106.0	23.0	2.7	1.8
Cu:B	11.0	14.0	1.0	1.2

Micronutrient nutrition of container-grown nursery stock is also important during propagation. Perk enhanced germination and seedling development of Cedrus deodara (Roxb.) Loud. (Wheeless and Whitcomb, 17). Esmigran improved rooting of holly, juniper and azalea (Whitcomb et al., 18). The improved growth with Perk and Esmigran as compared with the FRIT products suggests a need for higher levels of iron with a commensurate increase in manganese and copper, and for a reduction in boron.

Since both rate and proportion of actual elements as well as the solubility of their compounds varies between products, it seemed appropriate to research a more refined and effective micronutrient fertilizer for container production.

In a previous experiment (Whitcomb et al., 19) excellent growth response of pyracantha and azalea was obtained from a level of Fe twice as high as that in Perk and Esmigran in combination with a slightly higher level of Cu than in Esmigan and with a rate of Mn in between that of Perk and Esmigran (Table VIII). Significant interactions between Fe and Cu, Fe and Mn, and between Cu and B were noted. Simultaneous increases of Fe from 43 to 174 g/m^3, of Cu from 3 to 12 g/m^3, and of B from 0.5 to 1.0 g/m^3 resulted in the greatest top weight of pyracantha when Mn was at the low rate of 27 g/m^3 (Figure 4). The rates and ratios of micronutrients suggested by these findings were used as a guideline in formulating a commercial micronutrient product (Table IX).

TABLE VIII

ELEMENTAL MICRONUTRIENT RATES IN THE OSU-MIX AS COMPARED TO THOSE IN PERK AND ESMIGRAN

	OSU-mix g/m^3	Perk g/m^3	Esmigran g/m^3
Iron	174	88	65
Manganese	27	53	16
Copper	11	5.5	10
Boron	1	0.5	0.7
Zinc	16	16	24

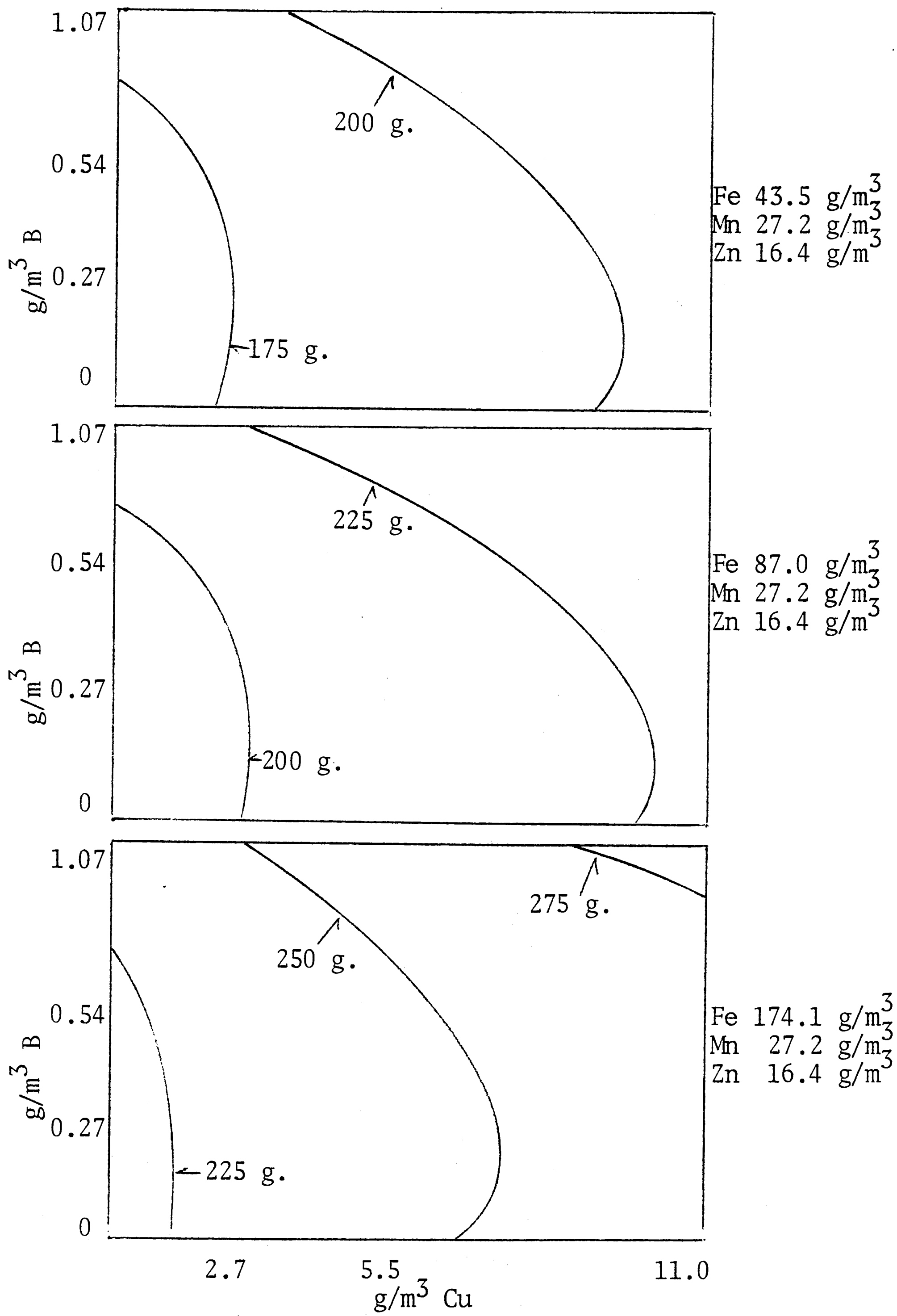


Figure 4. Quadratic response surface of pyracantha (fresh top weight) to Cu, B and Fe, with Mn and Zn held constant. Whitcomb et al. (19).

TABLE IX

ELEMENTAL AND COMPOUND RATES OF MICROMAX[z]

Element	g/m^3	Compound	g/m^3
Iron	112	$FeSO_4 \cdot 7H_2O$	560.00
Manganese	20.4	$MnSO_4 \cdot 3H_2O$	72.45
Copper	8.2	$CuSO_4 \cdot 5H_2O$	32.58
Zinc	9.9	$ZnSO_4 \cdot 1H_2O$	27.48
Boron	0.7	$Na_2B_4O_7$	3.44
Molybdenum	0.04	$Na_2MoO_4 \cdot 2H_2O$	0.06

[z]Micromax is a product of Sierra Chemical Corporation, Milpitas, California.

CHAPTER III

METHODS AND MATERIALS

The previous study on micronutrient interaction showed the importance of relatively high levels of Fe, Cu, and B, in combination with low levels of Mn, as well as significant trends of first order interactions between Fe:Cu, Fe:Mn, and Cu:B (Figure 4).

Based on these results, a fractional 4^4 factorial study with six replications for four species was begun in 1980. Iron, copper, boron and manganese were used at four equally spaced levels. Of the 256 possible treatment combinations in the 4^4 factorial, an inter-block subgroup of 64 was selected such that second and third order interactions would be confounded with main effects. The experiment provided four observations of each individual rate per replication per species. The 64 treatment combinations were randomized and placed in blocks of 8 x 8. The experimental units received constant amounts of nitrogen (10.5% nitrate and 7.5% ammoniacal), phosphorus and potassium from Osmocote 18-2.2-9.1 (18-5-11), calcium and magnesium (dolomitic limestone, ($CaMg(CO_3)_2$), gypsum ($CaSO_4$), zinc ($ZnSO_4$), and molybdenum (Na_2MoO_4). Nutrient levels are given in Table X, and treatment combinations in Table XI.

During the last week of October, 1979, cuttings were taken from azalea, holly, ligustrum and juniper. The broadleaf cuttings were

TABLE X

ONE-FOURTH REPLICATION OF THE 4^4 FACTORIAL
USED IN THIS STUDY

Trmt	Fe	Cu	B	Mn	Trmt	Fe	Cu	B	Mn	Trmt	Fe	Cu	B	Mn	Trmt	Fe	Cu	B	Mn
1	1	1	1	4	17	2	1	1	3	33	3	1	1	2	49	4	1	1	1
2	1	1	2	3	18	2	1	2	4	34	3	1	2	1	50	4	1	2	2
3	1	1	3	2	19	2	1	3	1	35	3	1	3	4	51	4	1	3	3
4	1	1	4	1	20	2	1	4	2	36	3	1	4	3	52	4	1	4	4
5	1	2	1	3	21	2	2	1	4	37	3	2	1	1	53	4	2	1	2
6	1	2	2	4	22[z]	2	2	2	3	38	3	2	2	2	54	4	2	2	1
7	1	2	3	1	23	2	2	3	2	39	3	2	3	3	55	4	2	3	4
8	1	2	4	2	24	2	2	4	1	40	3	2	4	4	56	4	2	4	3
9	1	3	1	2	25	2	3	1	1	41	3	3	1	4	57	4	3	1	3
10	1	3	2	1	26	2	3	2	2	42	3	3	2	3	58	4	3	2	4
11	1	3	3	4	27	2	3	3	3	43	3	3	3	2	59	4	3	3	1
12	1	3	4	3	28	2	3	4	4	44	3	3	4	1	60	4	3	4	2
13	1	4	1	1	29	2	4	1	2	45	3	4	1	3	61	4	4	1	4
14	1	4	2	2	30	2	4	2	1	46	3	4	2	4	62	4	4	2	3
15	1	4	3	3	31	2	4	3	4	47	3	4	3	1	63	4	4	3	2
16	1	4	4	4	32	2	4	4	3	48	3	4	4	2	64	4	4	4	1

[z]Best combination from the previous study (Whitcomb et al., 19).

TABLE XI

ELEMENTAL AND COMPOUND NUTRIENT RATES (g/m^3) USED IN THE 4^4 FACTORIAL COMBINATION OF TREATMENTS

Variable amounts:

Level	Fe	$FeSO_4$	Cu	$CuSO_4$	B	$Na_2B_4O_7$	Mn	$MnSO_4$
1	87	435	5.5	21.8	.54	2.6	9.1	33.3
2	174^z	870	11.0^z	43.6	1.08	5.2	18.2	66.6
3	261	1305	16.5	65.4	1.62	7.8	27.3^z	99.9
4	348	1730	22.0	87.2	2.16	9.4	36.4	133.2

Constant amounts:

Zn	$ZnSO_4$	Mo	Na_2MoO_4
16.4	45.5	.013	.03

Osmocote (N, P_2O_5, K_2)) 18-5-11:		8328
Dolomite ($CaCO_3$ + $MgCO_3$)	:	4760
Single superphosphate	:	2380

^{z}Levels of best combination of previous OSU study (Whitcomb et al., 19).

treated with indolebutyric acid in talc at a concentration of 3000 ppm (IBA-3), the junipers with IBA at 8000 ppm. The cuttings were stuck in 6 x 8 cm pots and placed under intermittent mist. The rooting medium was a 1:1 by volume ratio of sphagnum peat and coarse perlite. No fertilizer was added to the propagation medium in order that the transplants would more readily take up the nutrients in the growing-on phase of the study. The cuttings were placed on raised wire benches in a forced-air greenhouse with about 60% of the incident daylight. Day-temperatures averaged 35°C (95°F), night-time temperatures 19°C (66°F). During the day, the mist was set for four seconds every eight minutes. Analysis of the water used in the mist revealed EC 450 micromhos per cm^3, Na 37 ppm, Ca 43 ppm, Mg 22.5 ppm, and SAR 1.13. After an eight-week rooting period, the cuttings were removed from under the mist and hardened-off in a solar greenhouse where they were watered twice daily.

Between May 11 and 15, 1980, the liners were transplanted into 3.8 liter (one gallon)black and white poly bags that contained coarse uncomposted pine bark, sphagnum peat and coarse builder's sand in a 3:1:1 volume ratio. The media components were thoroughly moistened and mixed in a rotating mixer. The more light sensitive hollies and azaleas were placed under 30% saran shade on a graveled surface while the more light tolerant ligustrums and junipers were grown in full sun on black polyethylene. All transplants received 2.5 cm of water every day during the hot and dry summer and 2.5 cm every other day during the spring and fall. The lake water used for irrigation was of good quality: EC 393 micro-mhos per cm^3, Na 31 ppm, Ca 35 ppm, Mg 22.5

ppm, and SAR 1.0. In July, ligustrum and holly were pruned back to a height of 15 cm so that better lateral branching would develop. Weeds were controlled by applying 2% Ronstar (oxadiazon) granules at the rate of 9 kg active ingredient per hectare, once in May, and again in August. Leafrollers on azalea were controlled with malathion. To stimulate new flush growth during the fall, all species were top-dressed with Osmocote 19-2.6-10 (19-6-12) at a rate of 12 grams per plant.

Growth response was evaluated by fresh weight of tops and roots, number of branches, and visual grade means of four independent observations. Data on ligustrum, holly, and juniper were collected during late October, 1980. The azaleas were held over till May, 1981, when a flower count could be taken.

To study the relationship of plant performance to nutrient composition of leaf tissue, and of treatment effects on composition, a foliar analysis of holly was conducted. Leaf samples were collected during the late fall. In preparing the tissue for analysis, the dry ashing procedure was used. Leaf samples of current season's growth were ground after drying at $80^{o}C$ for 48 hours. One gram of dried tissue was ashed at $475\text{-}500^{o}C$ for six hours. The ash was dissolved in 5ml of 20% HCl and filtered. Lanthanum solution (.1%) was added to the filtrate to keep cations from complexing with sulphate and phosphate ions. Potassium, calcium, mangesium, zinc, iron, manganese and copper were determined by the atomic absorption spectrophotometer. Phosphorus absorption was determined by the ammoniummolybdate method. (Shelton and Harper, 11) Total nitrogen was analyzed by the macro-Kjeldahl method.

CHAPTER IV

RESULTS AND DISCUSSION

Greatest top weight of azalea was with Fe at 261 g/m^3 (level 3), Cu at 16.5 g/m^3 (level 3) or at 22 g/m^3 (level 4), and Mn at 36 g/m^3 (level 4), (Figures 5 and 6). Further increase in Fe had no effect on top weight of azalea (Figure 7). Visual quality of ligustrum increased as Fe increased from 87 g/m^3 (level 1) to 348 g/m^3 (level 4), and as copper increased from 5.5 g/m^3 (level 1) to 22 g/m^3 (level 4), when Mn was at 36 g/m^3 (level 4), (Figure 8). Manganese below 36 g/m^3 (level 4) reduced visual quality of ligustrum (Figure 9).

Results are in agreement with Whitcomb et al. (19) who observed that Mn at 27 g/m^3 (level 3) when used in combination with Fe at 174 g/m^3 (level 2), and Cu at 11 g/m^3 (level 2) achieved the greatest top weight of pyracantha (Figure 4). The predicted quadratic response surfaces show that an Fe:Mn ratio of 7:1 is necessary for greatest top weight of azalea. This is in agreement with Storjohann (14) even though different species were used and Fe and Mn levels were lower (Figure 4).

Enhanced plant performance at relatively high levels of micronutrients is also expressed in main effects. Iron levels of 261 (level 3) and 348 g/m^3 (level 4) increased top weight of holly compared to Fe levels of 174 g/m^3 (level 2), (Figure 10). This positive plant

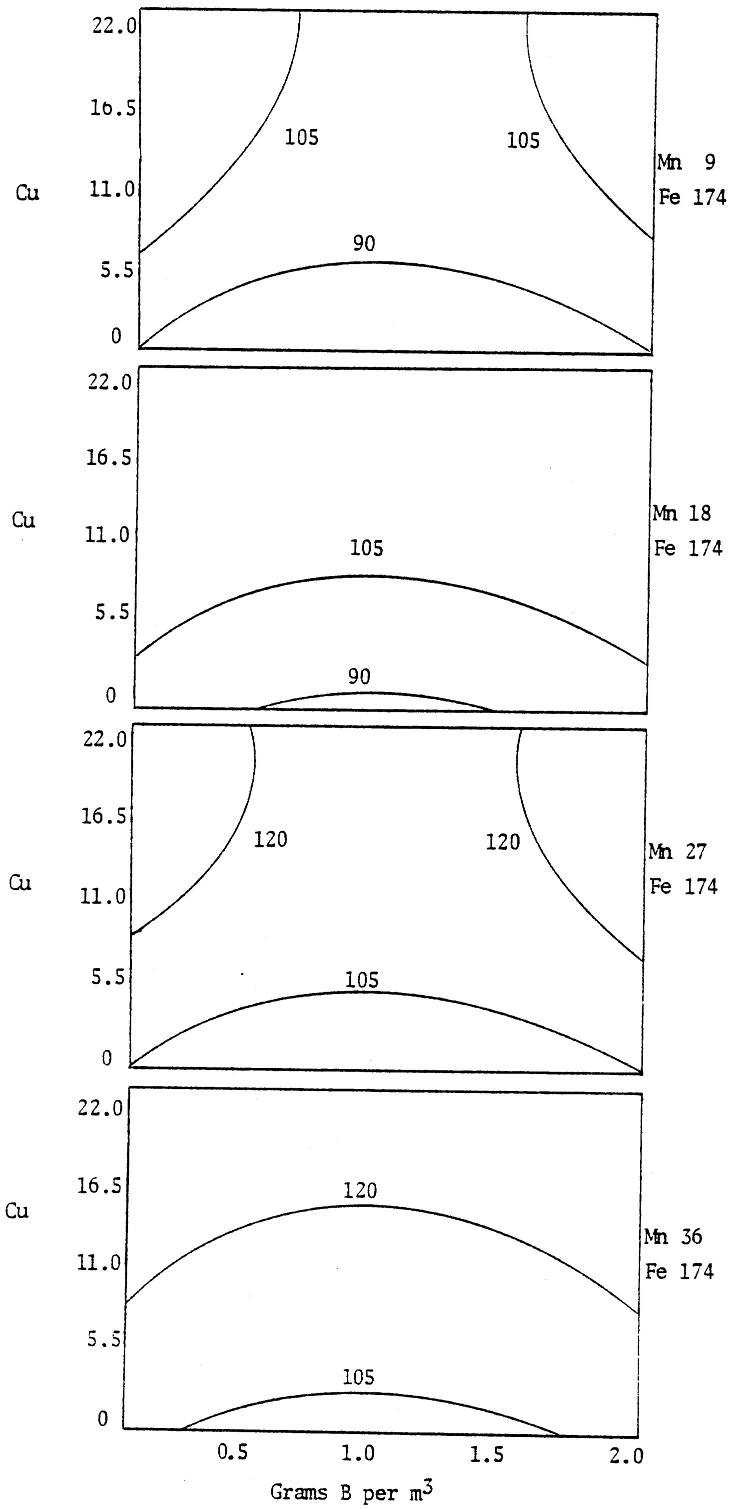


Figure 5. Quadratic response surface of azalea (fresh top weight) to B, Cu, and Mn, with Fe held constant. R^2=.26. Nutrient levels in g/m^3.

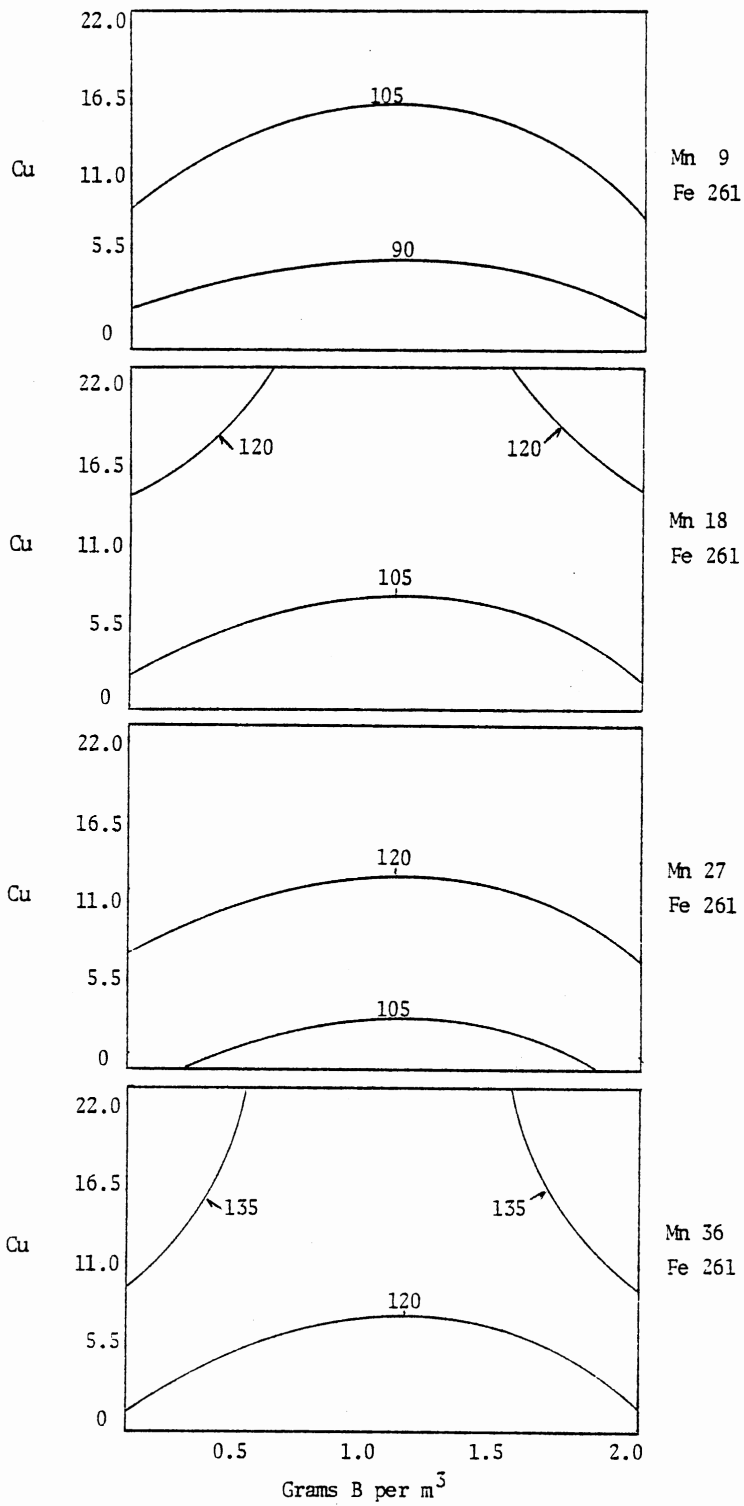


Figure 6. Quadratic response surface of azalea (fresh top weight) to B, Cu, and Mn, with Fe held constant. R^2=.26 Nutrient levels in g/m^3.

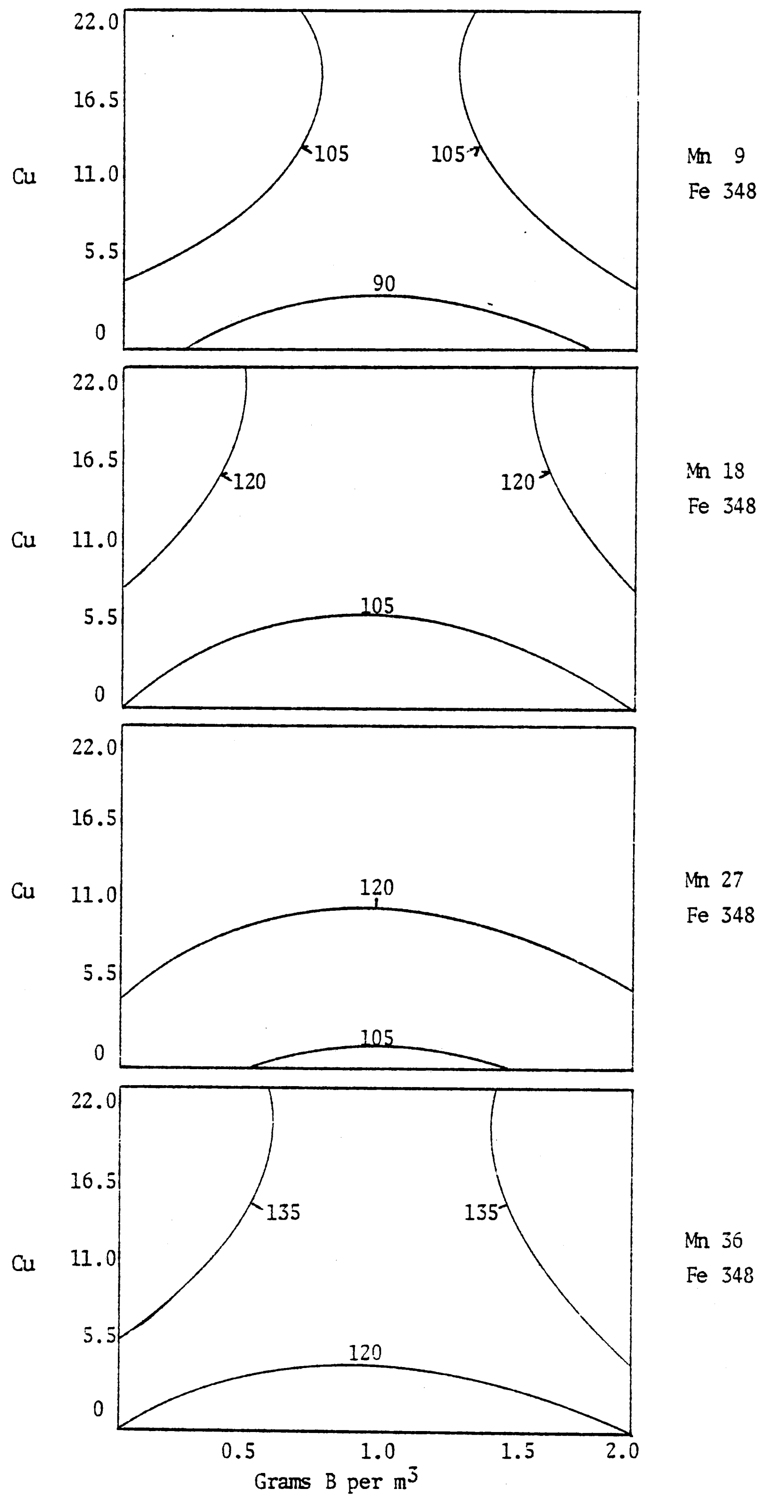


Figure 7. Quadratic response surface of azalea (fresh top weight) to B, Cu, and Mn, with Fe held constant. R^2=.26 Nutrient levels in g/m^3.

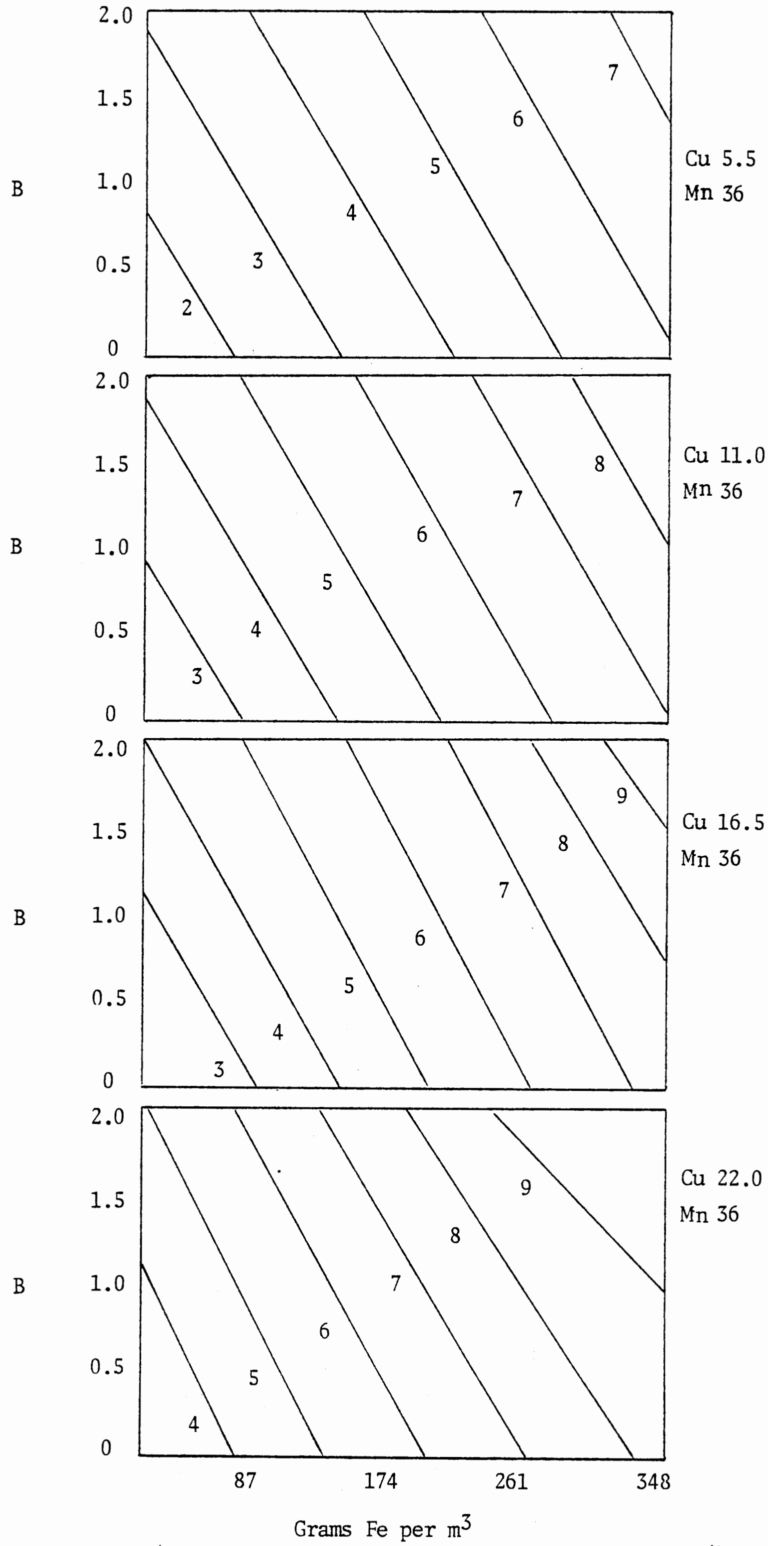


Figure 8. Quadratic response surface of ligustrum(visual quality) to Fe, B, and Cu, with Mn held constant R^2=.30. Nutrient levels in g/m^3.

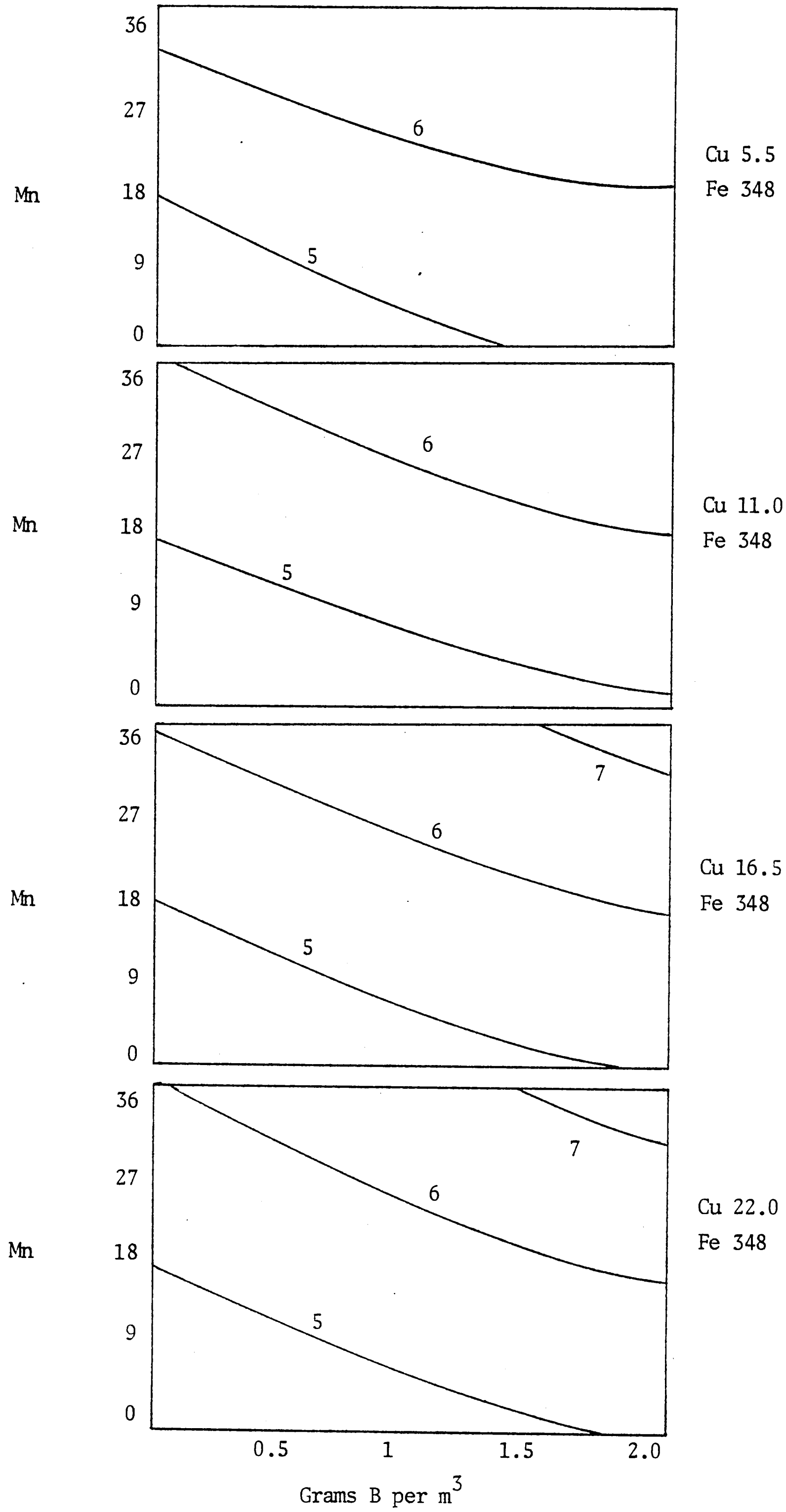


Figure 9. Quadratic response surface of ligustrum (visual quality) to B, Mn and Cu, with Fe held constant. R^2=.30. Nutrient levels are in g/m^3.

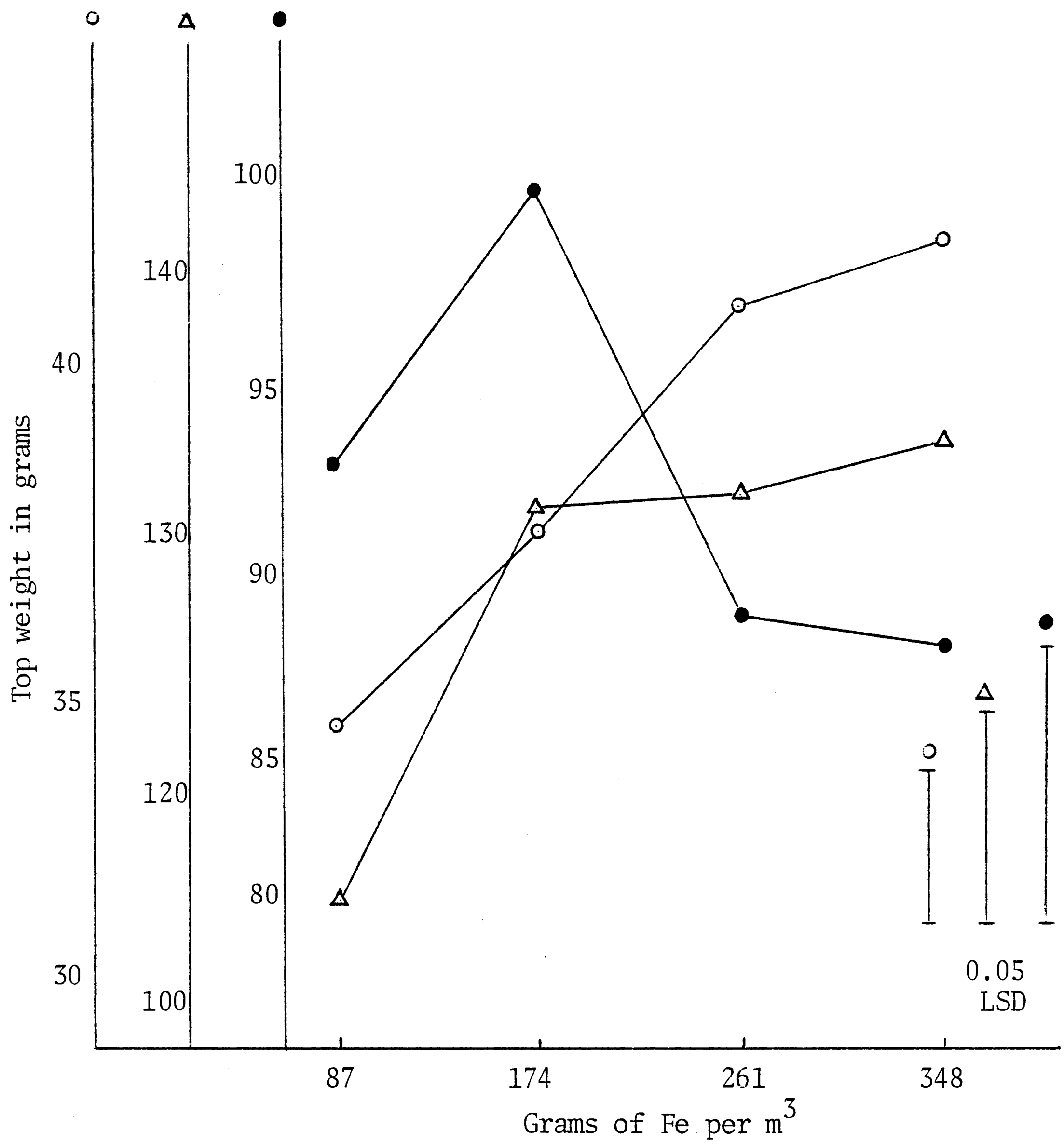


Figure 10. Plant top weight (grams) response to Fe:azalea (●), ligustrum (△), and holly (○).

response to increased levels of iron parallels the yield response of corn to increased amounts of ammoniumnitrate (Figure 1). Top weight of azalea and ligustrum was greatest when iron was at 174 g/m^3 (level 2), (Figure 10). This high level of iron may be due to the rapid oxidation of Fe^{+2}-ions in the very porous bark/peat/sand medium. Since only Fe^{+2}-ions are absorbed by the plant roots (Ambler et al., 1), large quantities of reduced iron must be supplied to offset formation of Fe^{+3}-ions. Copper at 22 g/m^3 (level 4) not only increased top weight of azalea (Figures 5 and 6) but also enhanced top weight and branching of juniper (Figure 11). Conversely, levels of B higher than 1 g/m^3 decreased top weight of azalea (Figures 5-7) and also reduced branching of juniper (Figure 12).

Tissue analysis data of holly were significant as main effects of Mn and Cu. Leaf-Mn increased significantly as Mn in the growing medium increased from 9 to 27 g/m^3 (Table XII). Copper in holly tissue increased slightly as copper in the growing medium increased (Table XII). Leaf Cu content (6-7 ppm) was a mere fraction of the copper concentration of related Ilex crenata cultivars as reported by Smith (12), (Table IV). It is possible that both Fe and Zn restricted copper release from binding sites on the organic matter in the growing medium. Similar antagonistic effects have been reported for wheat and barley on peat soils (Cheshire et al., 4, and Gilbey et al., 7). Top weight of holly increased with increased Fe in the medium, however, tissue levels of iron did not increase significantly (Table XII). Tissue levels of Mn decreased as Fe levels in the growing medium increased (Table XII).

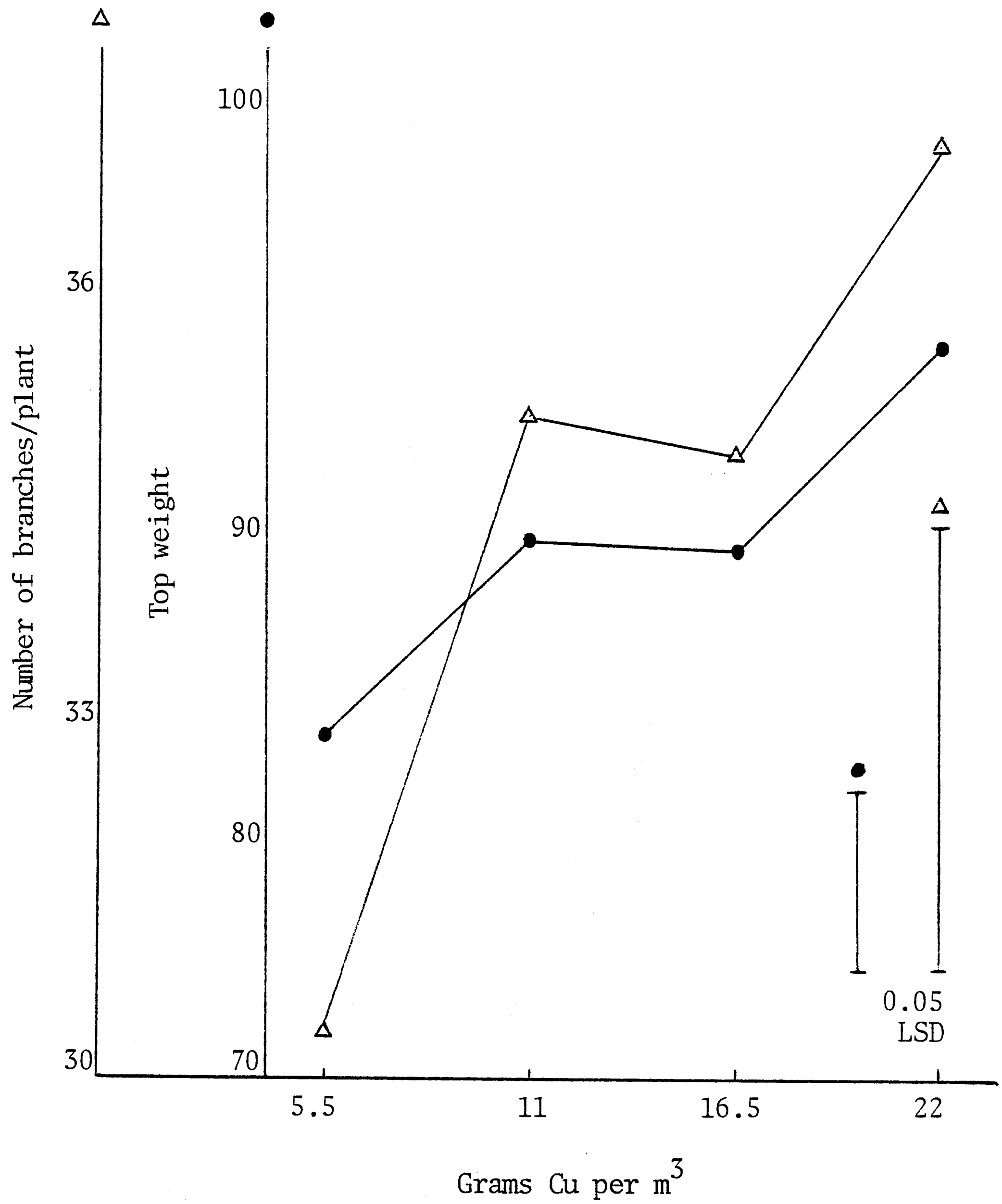


Figure 11. Effect of Cu on top weight (grams) (●) and number of branches (Δ) of juniper.

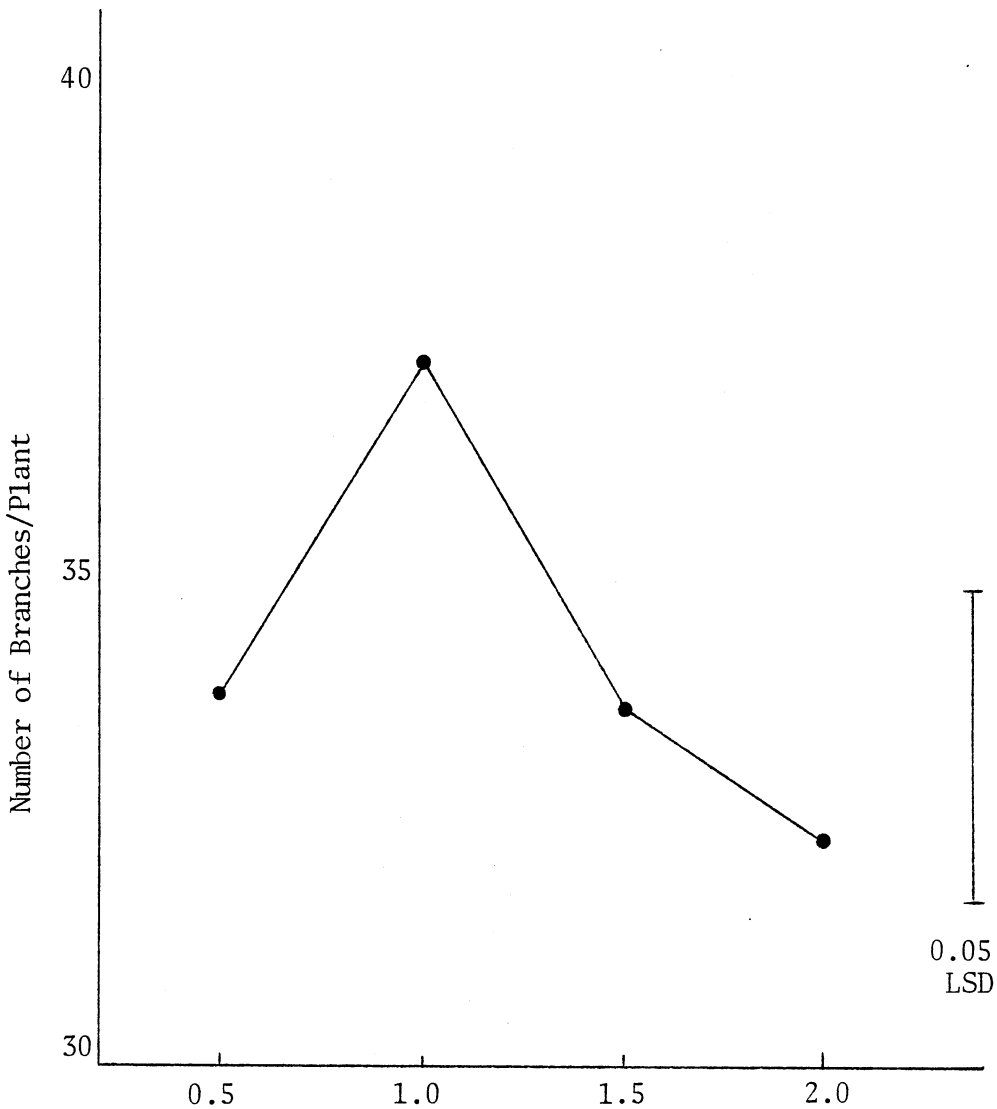


Figure 12. Effect of B on number of branches of juniper.

TABLE XII

ELEMENTAL CONCENTRATION (DRY WEIGHT) IN JAPANESE HOLLY AS EFFECTED BY NUTRIENT LEVEL (MAIN EFFECT MEANS)

Treatment Element	g/m^3	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Zn ug/g	Fe ug/g	Mn ug/g	Cu ug/g
Fe	87	3.0	.15	1.46	.70	.45	249	215	350	6.8
	147	3.0	.15	1.36	.68	.41	220	270	317	6.9
	261	3.1	.15	1.38	.65	.40	226	232	281	6.5
	348	3.1	.15	1.41	.64	.40	230	218	290	6.2
Cu	5.5	3.0	.15	1.39	.68	.42	237	231	310	5.5
	11.0	3.0	.15	1.38	.66	.41	225	218	299	6.3
	16.5	3.1	.15	1.43	.66	.40	234	271	321	7.1
	22.0	3.0	.15	1.40	.66	.41	229	215	308	7.5
B	0.5	3.0	.15	1.39	.68	.42	233	220	333	6.6
	1.0	3.0	.15	1.39	.65	.41	229	226	313	6.3
	1.5	3.0	.15	1.42	.67	.41	226	248	295	6.7
	2.0	3.1	.15	1.41	.67	.41	238	241	297	6.8
Mn	9.0	3.0	.15	1.39	.66	.41	233	248	249	6.5
	18.0	3.0	.15	1.42	.66	.41	231	185	280	6.5
	27.0	3.0	.15	1.42	.68	.42	241	247	350	6.9
	36.0	3.0	.15	1.37	.66	.41	220	254	359	6.4
	LSD	.05 *	.01 NS	.08 NS	.04 NS	.02 NS	13 *	81 NS	25 *	.6 *

Despite the great variation in rates and ratios of all supplied elements no visible deficiencies were observed on any of the four species nor detected in the holly leaf analysis. With all treatments the quantities and proportions of nutrients provided were within the range judged adequate by other researchers (Poole et al., 10). The fact that no visual or tissue level deficiencies developed should not imply that growth response can not be obtained from further nutritional refinement: between deficiency and toxicity there is much room for variation.

The present study has revealed that improvements in plant growth and development are to a great extent determined by precise ratios and rates of micronutrients.

CHAPTER V

SUMMARY AND CONCLUSIONS

A 4^4 fractional factorial of 4 levels of iron, copper, boron and manganese was implemented to study the effects of rate and ratios of micronutrients on quantitative and qualitative growth of evergreen plants in containers. Species used were waxleaf ligustrum, *Ligustrum japonicum* Thunb.; 'Hetzi' Japanese holly, *Ilex crenata* 'Hetzi' Thunb.; 'Festive' azalea, *Rhododendron* X 'Festive'; and Japanese garden juniper, *Juniperus procumbens* Miq.

After a seven-month growing period data on visual plant quality, fresh top and root weight, and number of branches were taken for all species. Leaf samples of holly were collected during the late fall and analyzed for nutrient content.

Excellent growth of azalea and good visual quality of ligustrum were achieved by treatments containing 261 g Fe, 22 g Cu, 36 g Mn, and 1 g B. Favorable ratios were 7:1 for Fe and Mn, 12:1 for Fe and Cu, and 2:3 for Cu and Mn. No visual or tissue level deficiencies were detected on any species at any time.

To formulate a micronutrient product on the basis of data collected from only four plant species during a single growing season would be premature. The present study suggests a need for further evaluation of rates and ratios of micronutrients. Studies on media proportions of organic constituents such as bark, woodchips, and peat are necessary to determine in which medium micronutrients are most readily available to the plants. Effects of Zn competition on release of Cu and Fe from artificial media need to be investigated, as well as behavior of Fe and Mn in media of different porosity.

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