GROWTH, LEAF COMPOSITION AND NUTRIENT-ELEMENT BALANCE OF MONTMORENCY CHERRY (*Prunus cerasus*, L.)--Effect of Varying Concentrations of Ten Nutrient-Elements

By

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Introduction

Several workers have investigated critical levels of certain nutrient-elements in relation to the appearance of deficiency symptoms. Goodall and Gregory (14) brought together the various leaf composition values reported to be associated with the occurrance of deficiency symptoms for certain nutrient-elements in various crops. They also summarized leaf composition values reported to be associated with plants not showing symptoms. The range in leaf composition for plants showing deficiency symptoms frequently included a portion of the range in leaf composition for plants not showing symptoms.

Field surveys in commercial cherry orchards show considerable variation in leaf composition. Many of the values correspond to those found for plants showing deficiency symptoms (17). Recent concepts and interpretations of nutrient-element balance (15, 16, 25, 26) point out that a nutrient-element can be considered to be deficient only in relation to the other nutrient-elements. Thus, as nutrient-element balance intensities vary, leaf composition values for normal plants likewise vary.

Concentrations of nutrient-elements have been found to influence plant growth significantly without causing visible symptoms of shortages or excesses. This influence may be considered to be associated with the balance or relationships of nutrient-elements or intensity of nutrient-elements, which may be called hidden deficiency or excess. According to these concepts, growth, leaf composition, and nutrient-element balance should be affected by varying concentrations of essential nutrient-elements.

Most of the investigations of this nature have been conducted on crops other than Montmorency cherry (*Prunus cerasus*, L.) and have dealt with only a few of the essential nutrient-elements. Many commercial cherry orchards show very low vigor. This low vigor is believed to be associated, in part, with hidden deficiencies, or with excesses of one or more nutrient-elements.

This study was initiated to determine the extent to which growth, leaf composition and nutrient-element balance might be affected by variations of individual nutrient-elements in nutrient solutions supplied Montmorency cherry trees.

Literature Review

The influence on growth of various concentrations of certain nutrient-elements has been reported by several workers. Brown (5), Cullinan and Batjer (9) and Waltman (28), working with peaches reported that nitrogen had a greater influence on growth than phosphorus. Brown (5) considered phosphorus to have less effect on growth than nitrogen, potassium, calcium or magnesium, while potassium and calcium were second to nitrogen. Waltman (28) found the peach to be more sensitive to phosphorus deficiency than was the apple.

Apple tree growth was increased as the nitrogen concentration increased to 168 ppm by Batjer and Degman (1), and Cullinan and Batjer (9). There was no significant difference in growth between 60 and 168 ppm (1). Cullinan, Scott and Waugh (10) obtained best peach tree growth at 60 ppm of nitrogen. Brown (5) found that a concentration of 1000 ppm of nitrogen produced less peach tree growth than did 100 ppm of nitrogen. The effect of this high concentration of nitrogen was reduced by increasing the concentration of phosphorus, potassium, or calcium.

Chapman and Liebig (7) found 6-7 ppm of nitrogen would maintain vigorous citrus tree growth. However, 420 ppm of nitrogen was not harmful to terminal growth, but reduced top/root ratio. Willcox (29) stated that application of phosphorus and potassium to agronomic crops relieved nitrogen toxicity.

Phosphorus concentrations from 4 to 40 ppm did not affect apple tree growth according to Batjer and Degman (1), while concentrations of 0 and 2 ppm reduced growth. Cullinan, Scott and Waugh (10) found peach growth not to be affected by phosphorus concentrations above 4 ppm. Cullinan and Batjer (9) stated that terminal growth of peaches was not reduced at 2 ppm if the levels of nitrogen and phosphorus were maintained. Brown (5) found with peaches that increasing phosphorus from 2 to 20 ppm resulted in increased growth, but further increase of phosphorus to 200 ppm did not increase growth. Increasing the concentration of nitrogen or potassium increased the growth produced by the higher concentrations of phosphorus.

Edgerton (12) found that growth of McIntosh apples increased as the potassium concentration increased to 200 ppm, while Delicious apple tree growth increased as potassium was increased to 100 ppm. Batjer and Degman (1) reported apple tree growth to decrease as the potassium concentrations were reduced below 117 ppm. A potassium concentration of 10 ppm resulted in the greatest growth of peach trees in a study by Cullinan, Scott and Waugh (10). Brown (5) found that a concentration of 800 ppm of potassium did not reduce growth except when calcium was high, or phosphorus or nitrogen was low.

Cullinan and Batjer (9) found that terminal growth of peach trees was not reduced by using 2 ppm of potassium if a proper level of nitrogen and phosphorus was maintained. When potassium was high, Davidson and Blake (11) found that increased calcium concentrations would increase growth, but would not prevent calcium deficiency symptoms. Boynton and Burrell (3), and Cain (6) found a reciprocal relationship between the concentration of potassium and magnesium in that high concentrations of one would result in deficiency symptoms of the other. Balanced multiple deficiencies were reported by Nightingale (23) to result in a normal appearing pineapple plant of reduced size.

Many relationships have been reported to exist between nutrient-elements contained in the leaves. Brown (5) stated that fundamentally, each nutrient-element is antagonistic, at least potentially, to the accumulation of each of the other elements. This would imply that as one element increased in the leaves there is a corresponding increase or decrease in the other nutrient elements.

Boynton and Compton (4), Cain (6) and Kenworthy and Benne (18) found that applications of nitrogen fertilizers increased leaf nitrogen, calcium and magnesium, but decreased leaf phosphorus and potassium. Beeson (2) found that concentrations of nitrogen would reduce the concentrations of other elements.

Brown (5) found that increasing the nitrogen content of the nutrient solution resulted in decreased absorption of phosphorus, potassium, and calcium, but increased magnesium absorption. Leaf analysis for potassium, however, was reported by Batjer and Degman (1) not to be influenced by nitrogen concentration of the nutrient solution. Chapman and Liebig (7) found that increased nitrogen concentrations did not depress phosphorus absorption, but that decreased nitrogen concentrations resulted in increased phosphorus absorption. Cullinan, Scott and Waugh (10) also found that phosphorus absorption was highest with low nitrogen concentrations. Nightingale (23) reported that low nitrate absorption resulted in free absorption of phosphorus by pineapple plants in soils low in phosphorus. Lilleland and Brown (22) found poor growth (which may be due to low nitrogen) was frequently associated with low phosphorus, and many good orchards were low in phosphorus. Kenworthy and Gilligan (19) found a positive relationship between leaf nitrogen and leaf phosphorus when the availability of phosphorus was very low, but with high phosphorus availability this relationship was negative.

Increasing the phosphorus concentration in the nutrient solution according to Brown (5), had little affect upon nitrogen absorption, but decreased the absorption of potassium, calcium, and magnesium. The decreased absorption of potassium caused by increased phosphorus was eliminated by increasing nitrogen and potassium concentrations. Evans, Lathwell, and Mederski (13) in work with soybeans found that phosphorus deficiency increased potassium and calcium absorption, but had little effect upon the absorption of the minor elements. Phosphorus applications were found by Kenworthy and Benne (18) to increase nitrogen, potassium, and manganese absorption, while calcium and magnesium absorption decreased.

Increasing the potassium concentration did not influence the leaf analysis for potassium in the work reported by Batjer and Degman (1) and Cullinan, Scott and Waugh (10). Brown (5) found that increasing potassium concentrations had little effect upon nitrogen absorption, but decreased the absorption of calcium and magnesium. Increasing the calcium concentration did not relieve the reduced calcium absorption associated with high potassium. Chapman and Liebig (7) found that increasing calcium and potassium simultaneously resulted in decreased calcium and increased potassium absorption. When Davidson and Blake (11) increased potassium concentrations from 140 to 590 ppm there resulted in only a slight increase in potassium absorption, but decreased absorption of calcium and magnesium. Nightingale (23) found that additional potassium was needed for nitrate absorption if both carbohydrates and nitrates were high. Reeve and Shive (24) reported that as potassium supply was increased boron accumulation increased. A deficiency of potassium resulted in increased absorption of calcium and phosphorus, and decreased absorption of manganese, copper, iron, and boron, according to Evans, Lathwell and Mederski (13).

Kenworthy and Benne (18) found that potassium applications to peach trees, when potassium was deficient, resulted in increased absorption of potassium, calcium, and manganese, and decreased absorption of nitrogen, phosphorus, and magnesium.

Increased calcium concentration, according to Davidson and Blake (11), caused a slight decrease in potassium and increased phosphorus absorption. Reeve and Shive (24) found that calcium tended to check boron injury on tomatoes, and that high absorption of calcium and boron increased the requirement for each other. Evans, Lathwell, and Mederski (13) reported that with soybeans a calcium deficiency resulted in increased analysis for magnesium, phosphorus, potassium, and boron, but decreased the analysis for manganese, copper, iron, and calcium. Their work also showed that a deficiency of magnesium increased potassium, and decreased phosphorus and boron absorption; while magnesium excess resulted in decreased absorption of potassium, and calcium. Boron deficiency increased calcium and magnesium. Manganese deficiency increased phosphorus, potassium, and boron, but had no effect on minor element absorption.

Materials and Methods

This experiment was conducted at the Horticultural farm at Michigan State College during the summer of 1949. The trees were grown from May 26 to September 15. The experimental lay-out is shown in Figure 1.

One-year-old Montmorency cherry trees were used. The trees were selected in the nursery for uniformity in size and growth, and small sizes were taken in order to reduce the carry-over of nutrients.

The containers were 50-pound berry cans, having a diameter of 12 3/8 inches, and a height of 13 inches, with a capacity of approximately one cubic foot. They were enamel coated on the inside, and before use were painted with a water-proof asphalt emulsion. A drainage outlet was made on the side of the container near the bottom to facilitate drainage of any excess water or nutrient solution.

Each tree was washed free of soil before planting. The shoots were pruned to approximately 12 inches or higher if necessary so as to leave a minimum of three leaf buds. All broken roots were removed. Each tree was then weighed and planted in an Oshtemo sand--a soil of low fertility.

The trees were planted with the bud union at, or just below, the soil level, and immediately watered. Deionized water (20, 21) obtained by the use of synthetic resins (Amberlite I-R 4 B and I-R 120*) was used throughout the

*Manufactured by Rohm and Haas Company, Philadelphia 5, Pa.

Figure 1. Experimental Layout at the Horticultural Farm.

Trees used in this study are located in the back portion of the foreground.

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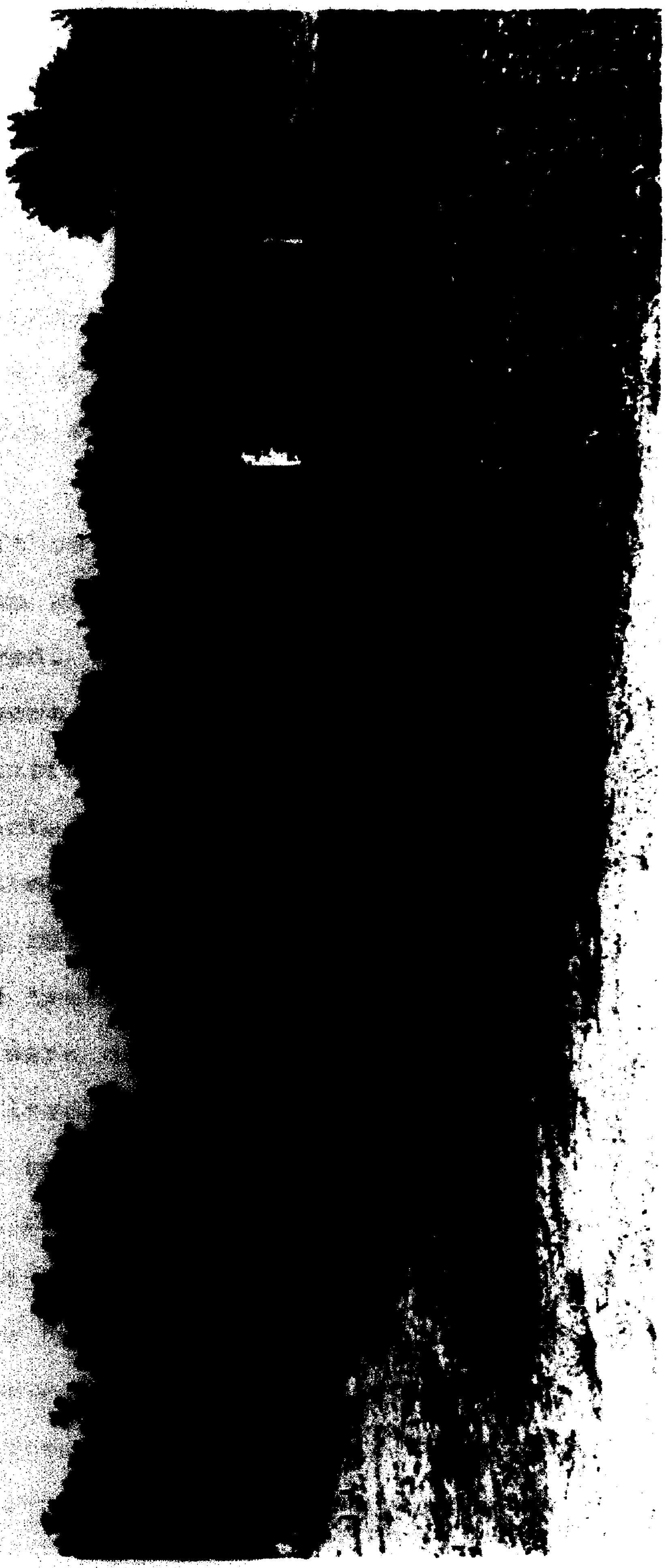

Figure 1

experiment. A set of de-ionizing towers, using 4-inch plexiglas tubes was constructed, and the water passed through I-R 120 to absorb all cations, and on through I-R 4 B to absorb all anions. The anion exchange resin was regenerated with 4 per cent sodium carbonate, and the cation exchange resin regenerated with 4 per cent hydrocloric acid when the de-ionized water contained more than 6 ppm soluble salts.

All leaf buds were left on the tree after planting until approximately 4 cm of growth was made. At this stage all but three shoots were removed.

Five replicate trees were planted for each treatment. Also, twenty-one additional trees were used to calculate the dry weight of the trees planted. This was accomplished by determining the per cent moisture of the twenty-one additional trees, and using this as an index of the moisture content of the planted trees.

Ten nutrient-elements were used with five different levels for each. A median level, or so-called "optimum" concentration was used as a basis for comparison. This median level was determined from published work concerning nutrient solutions for fruit trees (5) (28). Each nutrient-element was varied from this "optimum" concentration by increasing or decreasing the amount used. The optimum concentration contained twice the amount of the 1/2X optimum level, and the 2X optimum level contained four times the amount of the 1/2X optimum; while the fourth level, 4X optimum, contained eight times that of the 1/2X optimum. A zero level was used in which the nutrient-element was omitted. This arrangement provided for nutrient-element levels corresponding to the ratios 0, 1, 2, 4, and 8.

This plan for each of the ten nutrient-elements made a total of 41 treatments, using one median level, or optimum treatment, for all nutrient-elements. An additional treatment was planted which received only de-ionized water.

Stock solutions of chemically pure NH_4NO_3, H_3PO_4, KCl, $CaCl_2$, $MgSO_4$, H_3BO_3, $MnSO_4$, $CuSO_4$, $ZnSO_4$, and $FeSO_4$ were prepared individually for each of the nutrient-elements. From these stock solutions a dilute solution for each treatment was prepared in which the elements were combined in definite proportions. The dilute solutions were kept in 5-gallon bottles, and the solutions were replaced when algae growth became evident. The initial pH of the solutions was approximately 4.5-5.0, but no attempt was made to adjust this value. The concentration of the nutrient-elements at the different levels is shown in Table 1.

One quart of nutrient solution was applied each day throughout the growing season. Late in the season when the weather was cooler, nutrient solutions were not applied as frequently as earlier in the season. Since the rain was not kept out of the cans, an application of nutrient solutions was made after each rain in order to maintain the desired concentration.

Table 1. Concentration of the Various Nutrient-Elements Used in the Nutrient Solutions for the Different Treatments

Compound used	Nutrient-Element	Nutrient-Element Concentration or Level				
		Omitted	1/2X optimum	Optimum	2X optimum	4X optimum
		ppm	ppm	ppm	ppm	ppm
NH_4NO_3	Nitrogen	0	112.0	224.0	448.0	896.0
H_3PO_4	Phosphorus	0	34.0	68.0	136.0	272.0
KCl	Potassium	0	43.0	86.0	172.0	344.0
$CaCl_2$	Calcium	0	88.0	176.0	352.0	704.0
$MgSO_4$	Magnesium	0	29.0	58.0	116.0	232.0
$MnSO_4$	Manganese	0	2.5	5.0	10.0	20.0
H_3BO_3	Boron	0	1.5	3.0	6.0	12.0
$FeSO_4$	Iron	0	1.0	2.0	4.0	8.0
$ZnSO_4$	Zinc	0	1.0	2.0	4.0	8.0
$CuSO_4$	Copper	0	1.0	2.0	4.0	8.0

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The experiment was terminated during the week of September 15, 1949. The three most uniform trees were selected to obtain growth records and leaf analysis. Two trees from each treatment were carried throughout the winter for additional observations. Each of the three selected trees was harvested as follows: leaves removed from the shoots; shoots severed from the main trunk, and the trunk separated from the roots; roots then washed carefully; shoots, trunk and roots cut into smaller pieces to facilitate drying; various parts of each tree placed separately in a paper bag, and put immediately in the forced draft dehydrator regulated to 60 degrees centigrade. After the samples had been in the dehydrator for several days, each sample was weighed.

The leaves were ground with a Wiley mill, using a 40-mesh screen. The various replications were composited, mixed thoroughly, and then divided into duplicate samples. One sample was sent to the chemical laboratory for nitrogen analysis, using the Kjeldahl method, and the other sample sent to the National Spectrographic Laboratories, Cleveland, Ohio, for spectrographic analysis for P, K, Ca, Mg, Fe, Cu, B, and Mn.

Presentation of Results

Growth

Altering the concentration of any one nutrient-element and keeping all other nutrient-elements at the optimum concentration resulted in a considerable variation in growth. The results of growth measurements are presented in Tables 2 to 11, inclusive. Dry weight increase and shoot growth in relation to varying concentrations of nutrient-elements are presented in Figures 2 and 3.

Maximum growth was obtained when the nutrient-solution contained the median or optimum concentration of all nutrient elements. Significantly less tree growth, as measured by dry weight increase of the entire tree, dry weight of the various tree parts, and length of terminal growth, was obtained when the concentration of a nutrient-element was reduced 50 per cent (1/2X optimum), or increased 100 per cent from optimum (2X optimum). Omitting the nutrient-element, or increasing the concentration to 4X optimum usually resulted in less tree growth than reducing the concentration of the nutrient-element to 1/2X optimum, or increasing the concentration to 2X optimum. This reduction in growth, however, was not significant.

Net increase in dry weight of shoots and length of terminal growth was influenced significantly by varying the concentration of any one of the ten nutrient-elements.

Table 2. Influence of Varying Nitrogen Concentration in Nutrient Solution upon Net Increase in Dry Weight, Dry Weight of Various Tree Parts, and Length of Terminal Growth

Nitrogen concentration	Dry weight of entire tree: When planted	Dry weight of entire tree: After growth	Dry weight of entire tree: Net increase	Dry weight of various tree parts after growth: Roots	Trunk	Shoots	Leaves	Terminal growth
	gm	gm	gm	gm	gm	gm	gm	cm
Omitted	35.3*	71.6	36.3**	44.7	12.3**	5.2**	9.4*	68.3**
1/2X optimum	45.4	95.5	49.8*	52.1	18.1	9.6**	15.6	79.6**
Optimum	48.5	119.5	71.0	60.7	20.7	16.5	21.6	179.7
2X optimum	48.2	84.0	35.7**	42.1	17.8	8.2**	15.8	92.8**
4X optimum	46.9	77.2	30.3**	38.1	14.9*	10.6**	13.4	124.1*
Least significant difference								
* --5%	13.2	---	20.0	30.0	5.4	4.5	11.2	46.7
** --1%	17.5	---	26.5	39.9	7.2	6.0	14.8	62.0

To accompany Page 13

Table 3. Influence of Varying Phosphorus Concentration in Nutrient Solution upon Net Increase in Dry Weight, Dry Weight of Various Tree Parts, and Length of Terminal Growth

Phosphorus concentration	Dry weight of entire tree: When planted	Dry weight of entire tree: After growth	Dry weight of entire tree: Net increase	Dry weight of various tree parts after growth: Roots	Trunk	Shoots	Leaves	Terminal growth
	gm	gm	gm	gm	gm	gm	gm	cm
Omitted	40.2	68.3	28.1**	39.2	12.9**	5.2**	11.0	61.5**
1/2 optimum	50.1	91.8	41.7**	48.7	20.0	7.9**	15.2	86.6**
Optimum	48.5	119.5	71.0	60.7	20.7	16.5	21.6	179.7
2X optimum	44.6	88.1	43.5**	46.6	16.1	8.9**	16.5	95.1**
4X optimum	41.0	87.3	46.2*	44.3	16.6	9.4**	16.8	98.6**
Least significant difference								
* --5%	13.2	---	20.0	30.0	5.4	4.5	11.2	46.7
** --1%	17.5	---	26.5	39.9	7.2	6.0	14.8	62.0

To accompany Page 13

Table 4. Influence of Varying Potassium Concentration in Nutrient Solution upon Net Increase in Dry Weight, Dry Weight of Various Tree Parts, and Length of Terminal Growth

Potassium concentration	Dry weight of entire tree: When planted	Dry weight of entire tree: After growth	Dry weight of entire tree: Net increase	Dry weight of various tree parts after growth: Roots	Dry weight of various tree parts after growth: Trunk	Dry weight of various tree parts after growth: Shoots	Dry weight of various tree parts after growth: Leaves	Terminal growth
	gm	gm	gm	gm	gm	gm	gm	cm
Omitted	45.0	71.0	26.0**	38.9	15.5	5.9**	10.6	81.3**
1/2 optimum	46.2	83.1	36.9**	44.7	16.5	7.6**	14.2	110.8**
Optimum	48.5	119.5	71.0	60.7	20.7	16.5	21.6	179.7
2X optimum	46.4	96.9	50.5*	50.4	18.4	10.2**	17.9	118.5**
4X optimum	41.2	81.0	39.8**	44.7	14.7*	7.4**	14.2	114.0**
Least significant difference								
* --5%	13.2	---	20.0	30.0	5.4	4.5	11.2	46.7
** --1%	17.5	---	26.5	39.9	7.2	6.0	14.8	62.0

To accompany Page 13

Table 5. Influence of Varying Calcium Concentration in Nutrient Solution upon Net Increase in Dry Weight, Dry Weight of Various Tree Parts, and Length of Terminal Growth

Calcium concentration	Dry weight of entire tree: When planted	Dry weight of entire tree: After growth	Dry weight of entire tree: Net increase	Dry weight of various tree parts after growth: Roots	Trunk	Shoots	Leaves	Terminal growth
	gm	gm	gm	gm	gm	gm	gm	cm
Omitted	41.2	79.0	37.8**	41.4	15.0	7.3**	15.2	97.1**
1/2 optimum	44.7	87.7	43.0**	49.2	15.8	8.2**	14.4	81.8**
Optimum	48.5	119.5	71.0	60.7	20.7	16.5	21.6	179.7
2X optimum	33.5*	79.7	46.2*	43.1	12.8**	8.9**	14.8	113.8**
4X optimum	38.1	81.0	42.9**	44.8	13.3**	8.3**	14.6	111.6**
Least significant difference								
* --5%	13.2	---	20.0	30.0	5.4	4.5	11.2	46.7
** --1%	17.5	---	26.5	39.9	7.2	6.0	14.8	62.0

To accompany Page 13

Table 6. Influence of Varying Magnesium Concentration in Nutrient Solution upon Net Increase in Dry Weight, Dry Weight of Various Tree Parts, and Length of Terminal Growth

Magnesium concentration	Dry weight of entire tree: When planted	Dry weight of entire tree: After growth	Dry weight of entire tree: Net increase	Dry weight of various tree parts after growth: Roots	Trunk	Shoots	Leaves	Terminal growth
	gm	gm	gm	gm	gm	gm	gm	cm
Omitted	36.9	87.0	50.0*	49.5	14.0*	8.3**	15.1	88.3**
1/2 optimum	43.3	89.7	46.4*	48.9	16.3	10.2**	14.3	123.0*
Optimum	48.5	119.5	71.0	60.7	20.7	16.5	21.6	179.7
2X optimum	41.6	116.3	74.7	58.3	19.5	15.8	22.7	141.3
4X optimum	46.4	101.3	54.9	56.6	18.3	9.9**	16.5	118.3*
Least significant difference								
* --5%	13.2	---	20.0	30.0	5.4	4.5	11.2	46.7
** --1%	17.5	---	26.5	39.9	7.2	6.0	14.8	62.0

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Table 7. Influence of Varying Manganese Concentration in Nutrient Solution upon Net Increase in Dry Weight, Dry Weight of Various Tree Parts, and Length of Terminal Growth

Manganese concentration	Dry weight of entire tree: When planted	After growth	Net increase	Dry weight of various tree parts after growth: Roots	Trunk	Shoots	Leaves	Terminal growth
	gm	gm	gm	gm	gm	gm	gm	cm
Omitted	44.4	103.4	59.0	55.0	18.4	11.4*	18.6	129.7*
1/2 optimum	37.8	82.7	44.8*	42.6	17.6	8.7**	13.7	73.1**
Optimum	48.5	119.5	71.0	60.7	20.7	16.5	21.6	179.7
2X optimum	43.6	90.6	47.0*	49.8	16.4	9.3**	15.1	111.3**
4X optimum	51.5	104.5	53.0	59.4	17.1	10.5*	17.4	100.1**
Least significant difference								
* --5%	13.2	---	20.0	30.0	5.4	4.5	11.2	46.7
** --1%	17.5	---	26.5	39.9	7.2	6.0	14.8	62.0

To accompany Page 13

Table 8. Influence of Varying Boron Concentration in Nutrient Solution upon Net Increase in Dry Weight, Dry Weight of Various Tree Parts, and Length of Terminal Growth

	Dry weight of entire tree			Dry weight of various tree parts after growth				
Boron concentration	When planted	After growth	Net increase	Roots	Trunk	Shoots	Leaves	Terminal growth
	gm	gm	gm	gm	gm	gm	gm	cm
Omitted	52.9	114.3	61.3	63.6	20.8	11.3*	18.5	102.1**
1/2 optimum	40.4	90.0	49.6*	47.7	16.3	9.9**	16.0	96.0**
Optimum	48.5	119.5	71.0	60.7	20.7	16.5	21.6	179.7
2X optimum	42.1	105.8	63.6	50.5	23.1	13.0	19.0	150.0
4X optimum	46.1	81.4	35.2**	42.4	17.6	7.9**	13.4	108.6**
Least significant difference								
* --5%	13.2	---	20.0	30.0	5.4	4.5	11.2	46.7
** --1%	17.5	---	26.5	39.9	7.2	6.0	14.8	62.0

To accompany Page 13

Table 9. Influence of Varying Iron Concentration in Nutrient Solution upon Net Increase in Dry Weight, Dry Weight of Various Tree Parts, and Length of Terminal Growth

Iron concentration	Dry weight of entire tree: When planted	Dry weight of entire tree: After growth	Dry weight of entire tree: Net increase	Dry weight of various tree parts after growth: Roots	Trunk	Shoots	Leaves	Terminal growth
	gm	gm	gm	gm	gm	gm	gm	cm
Omitted	43.3	85.1	41.8**	49.1	14.6	7.3**	14.0	83.3**
1/2 optimum	36.2	88.9	52.7	47.0	16.3	9.6**	16.0	101.0**
Optimum	48.5	119.5	71.0	60.7	20.7	16.5	21.6	179.7
2X optimum	35.5	77.5	42.0**	39.8	15.4	8.0**	14.2	91.0**
4X optimum	35.9	72.6	36.7**	40.3	13.0	7.1**	12.2	97.0**
Least significant difference								
* --5%	13.2	---	20.0	30.0	5.4	4.5	11.2	46.7
** --1%	17.5	---	26.5	39.9	7.2	6.0	14.8	62.0

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Table 10. Influence of Varying Copper Concentration in Nutrient Solution upon Net Increase in Dry Weight, Dry Weight of Various Tree Parts, and Length of Terminal Growth

Copper concentration	Dry weight of entire tree: When planted	After growth	Net increase	Dry weight of various tree parts after growth: Roots	Trunk	Shoots	Leaves	Terminal growth
	gm	gm	gm	gm	gm	gm	gm	cm
Omitted	35.4	79.8	44.4**	44.3	15.4	7.3**	12.8	87.3**
1/2 optimum	32.3*	75.9	43.6**	38.1	15.1	7.8**	14.9	104.3**
Optimum	48.5	119.5	71.0	60.7	20.7	16.5	21.6	179.7
2X optimum	39.4	89.4	50.0*	49.2	16.1	9.1**	14.9	112.5**
4X optimum	41.9	94.2	52.3	44.5	20.7	10.7*	18.2	146.6
Least significant difference								
* --5%	13.2	---	20.0	30.0	5.4	4.5	11.2	46.7
** --1%	17.5	---	26.5	39.9	7.2	6.0	14.8	62.0

To accompany Page 13

Table 11. Influence of Varying Zinc Concentration in Nutrient Solution upon Net Increase in Dry Weight, Dry Weight of Various Tree Parts, and Length of Terminal Growth

Zinc concentration	Dry weight of entire tree: When planted	Dry weight of entire tree: After growth	Dry weight of entire tree: Net increase	Dry weight of various tree parts after growth: Roots	Trunk	Shoots	Leaves	Terminal growth
	gm	gm	gm	gm	gm	gm	gm	cm
Omitted	39.8	94.7	54.8	45.2	20.4	11.3*	17.6	121.3*
1/2 optimum	32.8*	92.8	60.0	43.1	17.7	12.3	19.6	132.5*
Optimum	48.5	119.5	71.0	60.7	20.7	16.5	21.6	179.7
2X optimum	35.7	89.7	54.0*	45.2	16.8	10.6*	17.0	117.0**
4X optimum	43.6	83.3	39.7**	42.3	19.3	8.0**	13.6	84.3**
Least significant difference								
* --5%	13.2	---	20.0	30.0	5.4	4.5	11.2	46.7
** --1%	17.5	---	26.5	39.9	7.2	6.0	14.8	62.0

To accompany Page 13

Figure 2. Length of Shoot Growth and Dry Weight Increase for Varying Concentrations of Nitrogen, Phosphorus, Potassium, Calcium, and Magnesium.

To accompany Page 13

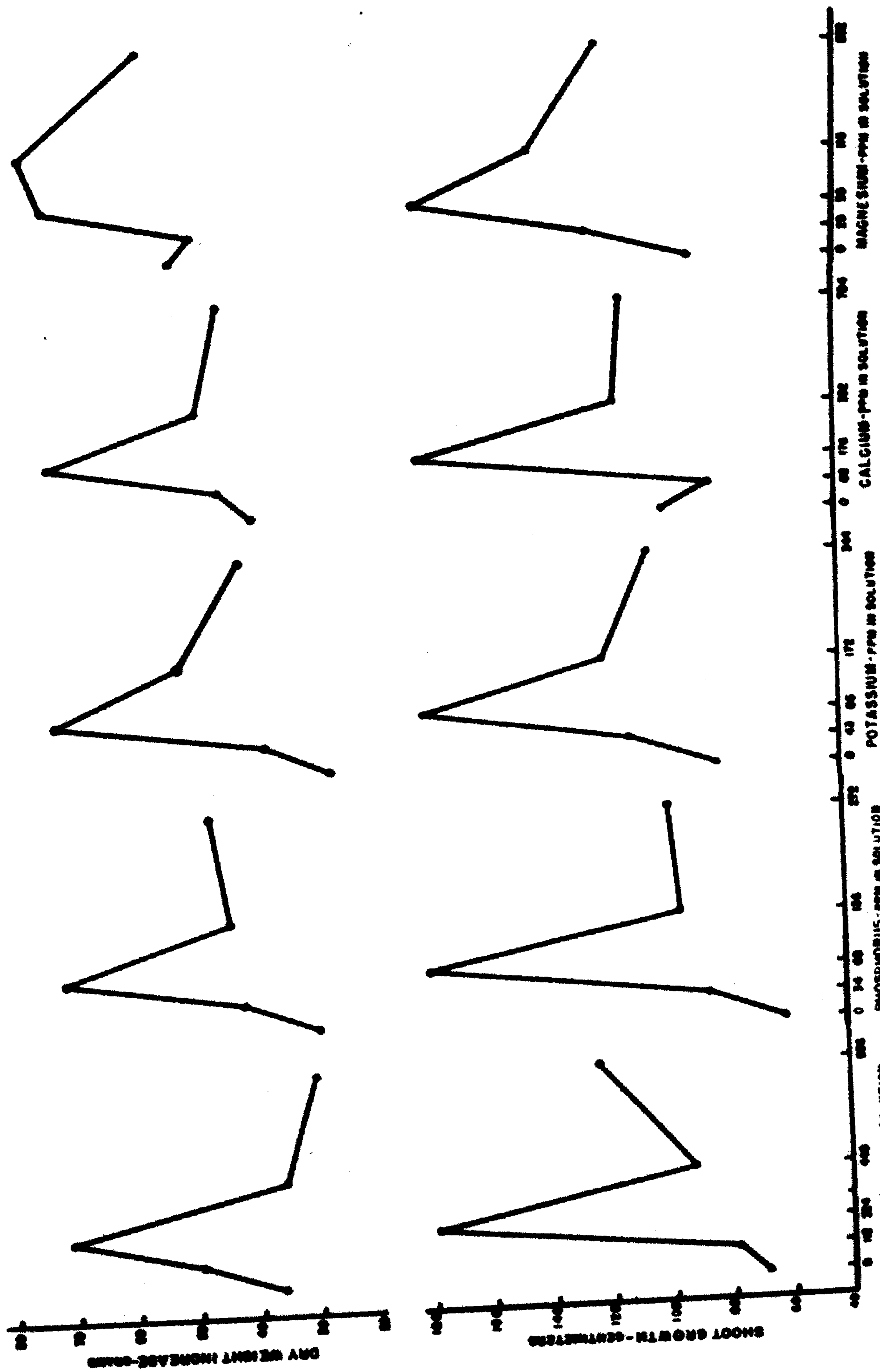

Figure 2

Figure 3. Length of Shoot Growth and Dry Weight Increase for Varying Concentrations of Manganese, Boron, Iron, Zinc, and Copper.

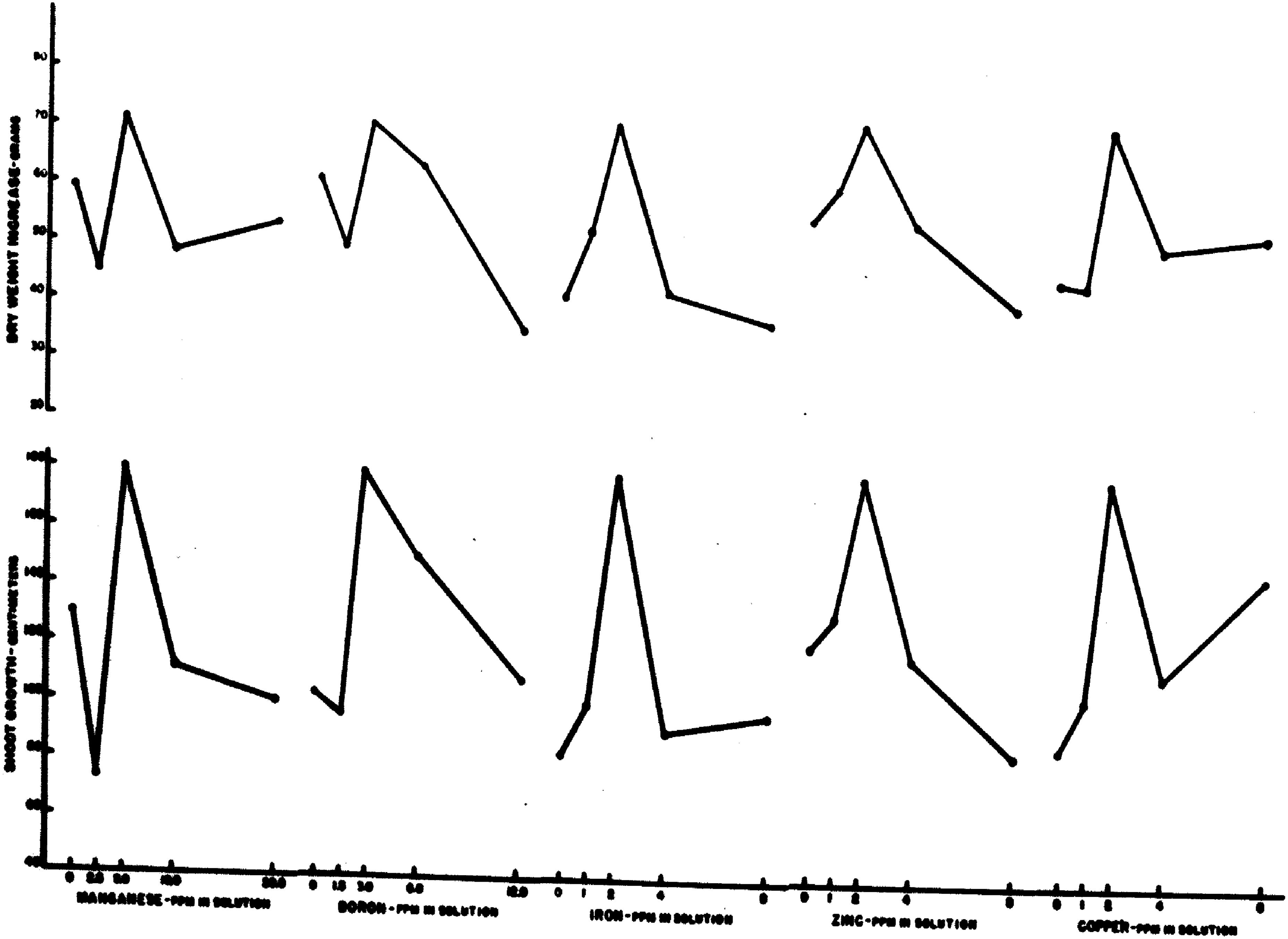

Figure 3

To accompany Page 13

Root or trunk growth, or dry weight of leaves produced, was not affected significantly by altering the concentration of any one of the various nutrient-elements.

A number of exceptions were found from the above generalizations. Net increase in dry weight was not significantly below maximum when iron and zinc were 1/2 optimum or when manganese, boron, or zinc were omitted from the nutrient solution. Net increase in dry weight produced by a concentration 2X optimum for magnesium or boron was not significantly below maximum. Concentrations 4X optimum for magnesium, manganese, or copper did not reduce the net increase in dry weight significantly below maximum.

Dry weight of shoots was significantly below maximum when all of the nutrient-elements except zinc were used in concentrations 1/2X optimum. A significant reduction in dry weight of shoots resulted with the omission of any one of the nutrient-elements. Concentrations 2X optimum of magnesium or boron did not produce shoot growth significantly less than maximum. Concentrations 4X optimum for each nutrient-element produced shoot growth significantly below maximum.

Terminal growth significantly below maximum was produced when any one of the nutrient-elements was 1/2X optimum or omitted. Concentrations 2X optimum produced terminal growth significantly below maximum except for magnesium and boron. Concentrations 4X optimum produced terminal growth significantly below maximum in all cases, except for copper.

None of the variations in nutrient-element concentration resulted in a significant variation in dry weight of roots or leaves, except where nitrogen was omitted. Trunk growth, however, was significantly below maximum in the following cases: nitrogen omitted or 4X optimum, phosphorus omitted, potassium 4X optimum, calcium 2X, or 4X optimum, magnesium omitted, and iron 4X optimum.

Dry Weight Increase: Table 12 shows the relative effects of the ten nutrient-elements upon dry weight increase, shoot growth and the other measurements of growth.

Potassium, when omitted, resulted in less dry weight increase than obtained when any one of the other nine nutrient-elements were omitted. The other nine, when omitted, produced dry weight increases in the following increasing order: phosphorus, nitrogen, calcium, iron, copper, magnesium, zinc, manganese, and boron. This order of nutrient-elements was rearranged as follows when the concentration was 1/2X optimum: potassium, phosphorus, calcium, copper, manganese, magnesium, boron, nitrogen, iron, and zinc. Nutrient-element concentrations above optimum showed that the effect of the different elements was dependent upon concentration. Nitrogen resulted in less dry weight increase at both 2X optimum and 4X optimum than produced by the other elements. The other nutrient elements, when used at concentrations 2X of optimum, produced dry weight in the following increasing order: iron, phosphorus, calcium,

Table 12. Relative Effect of Various Concentrations of Several Nutrient-Elements Upon Increase in Dry Weight

Nutrient-element	Omitted		1/2X optimum		2X optimum		4X optimum	
	Dry wt. increase	Rank	Dry wt. increase	Rank	Dry wt. increase	Rank	Dry wt. increase	Rank
	gm		gm		gm		gm	
Nitrogen	36.3	3	49.8	8	35.7	1	30.3	1
Phosphorus	28.1	2	41.7	2	43.5	3	46.2	7
Potassium	26.0	1	36.9	1	50.5	7	39.8	5
Calcium	37.8	4	43.0	3	46.2	4	42.9	6
Magnesium	50.0	7	46.4	6	74.7	10	54.9	10
Manganese	59.0	9	44.8	5	47.0	5	53.0	9
Boron	61.3	10	49.6	7	63.6	9	35.2	2
Iron	41.8	5	52.7	9	42.0	2	36.7	3
Copper	44.4	6	43.6	4	50.0	6	52.3	8
Zinc	54.8	8	60.0	10	54.0	8	39.7	4

Dry weight increase at optimum concentration--71.0 grams

To accompany Page 15

manganese, copper, potassium, zinc, boron, and magnesium. Concentrations 4X optimum resulted in the following order in regard to increasing dry weight production: nitrogen, boron, iron, zinc, potassium, calcium, phosphorus, copper, manganese, and magnesium.

Shoot Growth: Table 13 shows the relative effects of various concentrations of several nutrient-elements upon shoot growth. The amount of shoot growth produced when each element was omitted fell into a very narrow range. The same amount of shoot growth was produced when either nitrogen or phosphorus was omitted; however, when potassium was omitted, slightly more shoot growth was produced. Calcium, iron, and copper ranked third in shoot growth production. Magnesium ranked fourth, while boron, and zinc ranked fifth in the production of shoot growth.

As the concentration of the nutrient-elements was reduced to 1/2X optimum, copper had the greatest effect in suppressing shoot growth. The other nutrient-elements may be arranged in the following order with regard to their suppressing shoot growth: potassium, phosphorus, calcium, manganese, nitrogen, iron, boron, magnesium, and zinc. When used at concentrations of 1/2X optimum, nitrogen and iron resulted in the same amount of shoot growth.

When the concentration was 2X optimum, nitrogen produced less shoot growth than produced when the other nutrient-

Table 13. Relative Effect of Various Concentrations of Several Nutrient-Elements upon Shoot Growth

Nutrient-element	Omitted		1/2X optimum		2X optimum		4X optimum	
	Shoot growth	Rank	Shoot growth	Rank	Shoot growth	Rank	Shoot growth	Rank
	gm		gm		gm		gm	
Nitrogen	5.2	1	9.6	6	8.2	1	10.6	9
Phosphorus	5.2	1	7.9	3	8.9	3	9.4	6
Potassium	5.9	2	7.6	2	10.2	7	7.4	2
Calcium	7.3	3	8.2	4	8.9	3	8.3	5
Magnesium	8.3	4	10.2	8	15.8	9	9.9	7
Manganese	11.4	6	8.7	5	9.3	5	10.5	8
Boron	11.3	5	9.9	7	13.0	8	7.9	3
Iron	7.3	3	9.6	6	8.0	2	7.1	1
Copper	7.3	3	7.8	1	9.1	4	10.7	10
Zinc	11.3	5	12.3	9	10.6	6	8.0	4

Shoot growth at optimum--16.5 grams

To accompany Page 16

nts were used at the 2X optimum concentration. The ning nutrient-elements may be arranged in the following of suppressing effects: iron, phosphorus, calcium, r, manganese, zinc, potassium, and boron.

The greatest depressing effect upon shoot growth, re-ng from increasing the concentration of the nutrient-nts to 4X optimum, was associated with iron and the effect was associated with copper. The depressing ef- of the remaining elements may be arranged in the fol-ng order: potassium, boron, zinc, calcium, phosphorus, sium, manganese, nitrogen, and copper.

Terminal Growth: Terminal growth was affected differ- by the various concentrations of the nutrient-ele- studied (Table 14 and Figures 4 to 8, inclusive). Phosphorus produced less terminal growth than the nutrient-elements when the various nutrient-elements omitted. The other nutrient-elements produced ter-l growth when omitted in the following increasing r: nitrogen, potassium, iron, copper, magnesium, cal-, boron, zinc, and manganese. When the concentration of nutrient-element was reduced to 1/2X optimum, the test reduction in terminal growth was associated with anese, nitrogen, and calcium. The remaining nutrient-ents had the following order of decreasing effects: phorus, boron, calcium, iron, copper, potassium, zinc, magnesium.

elements were used at the 2X optimum concentration. The remaining nutrient-elements may be arranged in the following order of suppressing effects: iron, phosphorus, calcium, copper, manganese, zinc, potassium, and boron.

The greatest depressing effect upon shoot growth, resulting from increasing the concentration of the nutrient-elements to 4X optimum, was associated with iron and the least effect was associated with copper. The depressing effects of the remaining elements may be arranged in the following order: potassium, boron, zinc, calcium, phosphorus, magnesium, manganese, nitrogen, and copper.

Terminal Growth: Terminal growth was affected differently by the various concentrations of the nutrient-elements studied (Table 14 and Figures 4 to 8, inclusive).

Phosphorus produced less terminal growth than the other nutrient-elements when the various nutrient-elements were omitted. The other nutrient-elements produced terminal growth when omitted in the following increasing order: nitrogen, potassium, iron, copper, magnesium, calcium, boron, zinc, and manganese. When the concentration of each nutrient-element was reduced to 1/2X optimum, the greatest reduction in terminal growth was associated with manganese, nitrogen, and calcium. The remaining nutrient-elements had the following order of decreasing effects: phosphorus, boron, calcium, iron, copper, potassium, zinc, and magnesium.

Table 14. Relative Effect of Various Concentrations of Several Nutrient-Elements upon Terminal Growth

Nutrient-element	Omitted		1/2X optimum		2X optimum		4X optimum	
	Terminal growth	Rank	Terminal growth	Rank	Terminal growth	Rank	Terminal growth	Rank
	cm		cm		cm		cm	
Nitrogen	68.3	2	79.6	2	92.8	2	124.1	9
Phosphorus	61.5	1	86.6	4	95.1	3	98.6	3
Potassium	81.3	3	110.8	8	118.5	7	114.0	7
Calcium	97.1	7	81.8	3	113.8	6	111.6	6
Magnesium	88.3	6	123.0	10	141.3	9	118.3	8
Manganese	129.7	10	73.1	1	111.3	4	100.1	4
Boron	102.1	8	96.0	5	150.0	10	108.6	5
Iron	83.3	4	101.0	6	91.0	1	97.0	2
Copper	87.3	5	104.3	7	112.5	5	146.6	10
Zinc	121.3	9	132.5	9	117.0	8	84.3	1

Terminal growth at optimum--179.7 centimeters

To accompany Page 17

Figure 4. Growth in Relation to Varying Concentrations of Nitrogen (above) and Phosphorus (below). (Center--Optimum; Increasing Concentration from Left to Right).

To accompany Page 17

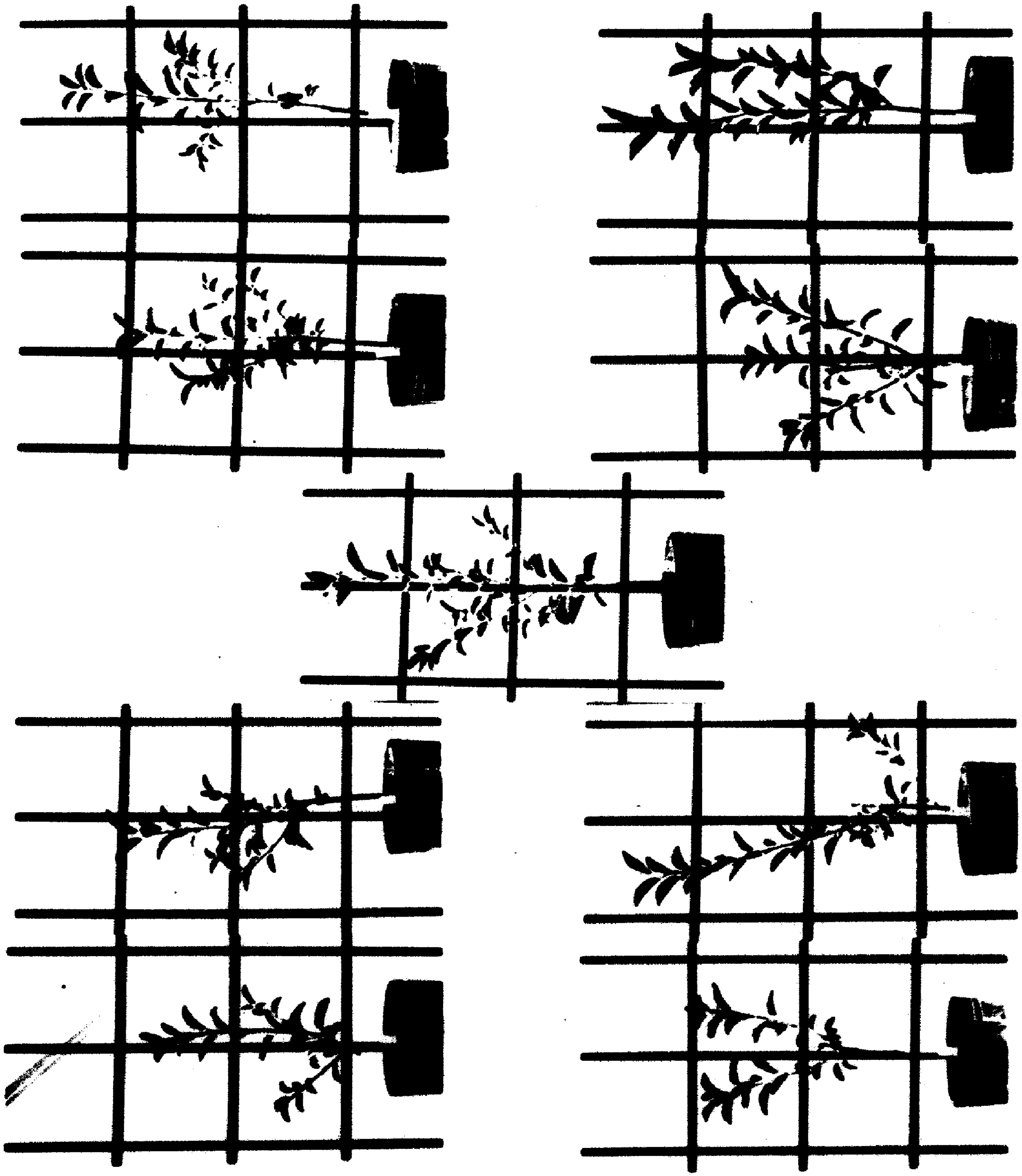

Figure 4

Figure 5. Growth in Relation to Varying Concentrations of Potassium (above) and Calcium (below). (Center --Optimum; Increasing Concentration from Left to Right).

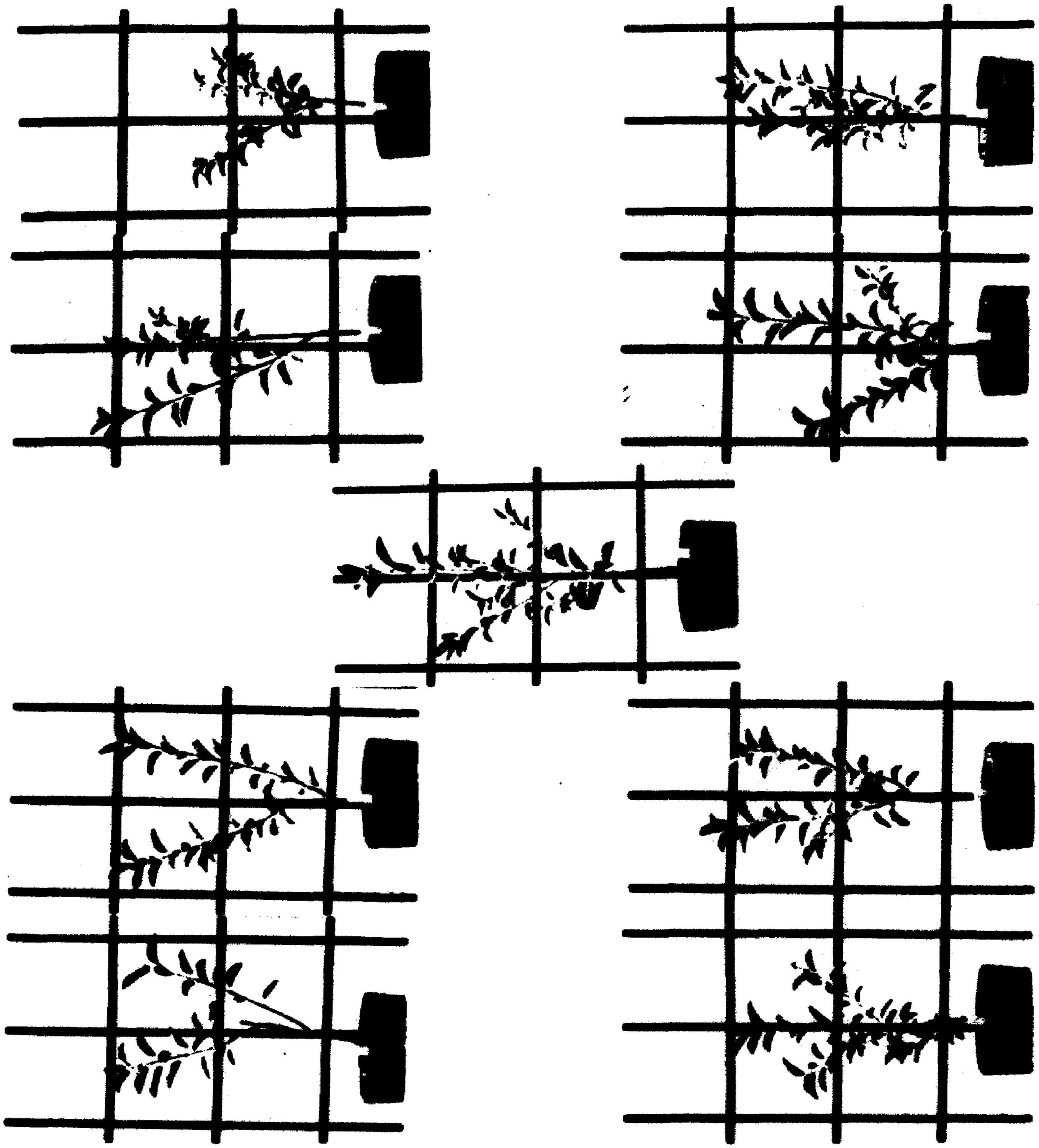

Figure 5

Figure 6. Growth in Relation to Varying Concentrations of Magnesium (above) and Manganese (below). (Center -- Optimum: Increasing Concentration from Left to Right).

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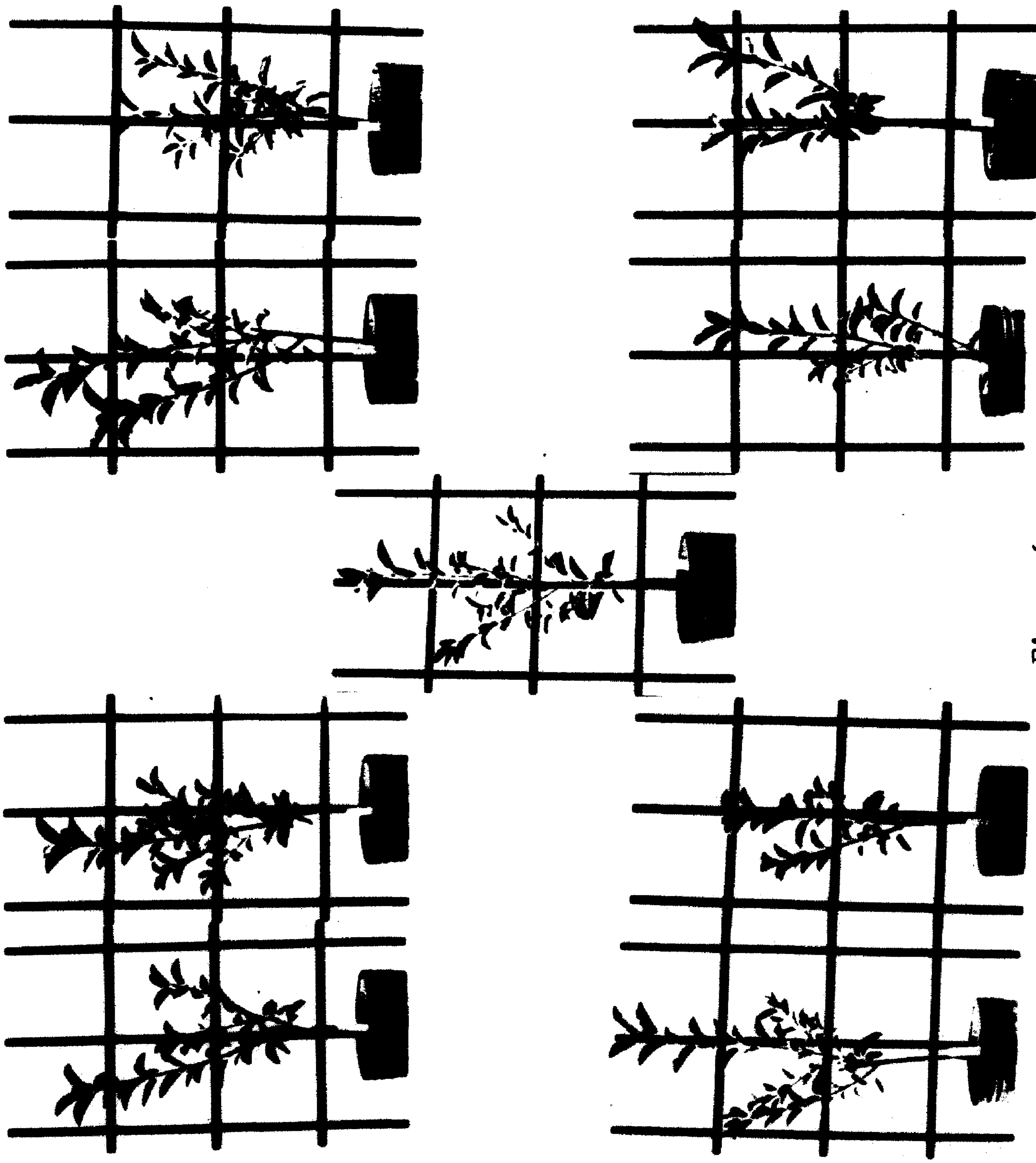

Figure 6

Figure 7. Growth in Relation to Varying Concentrations of Boron (above) and Iron (below). (Center -- Optimum; Increasing Concentration from Left to Right).

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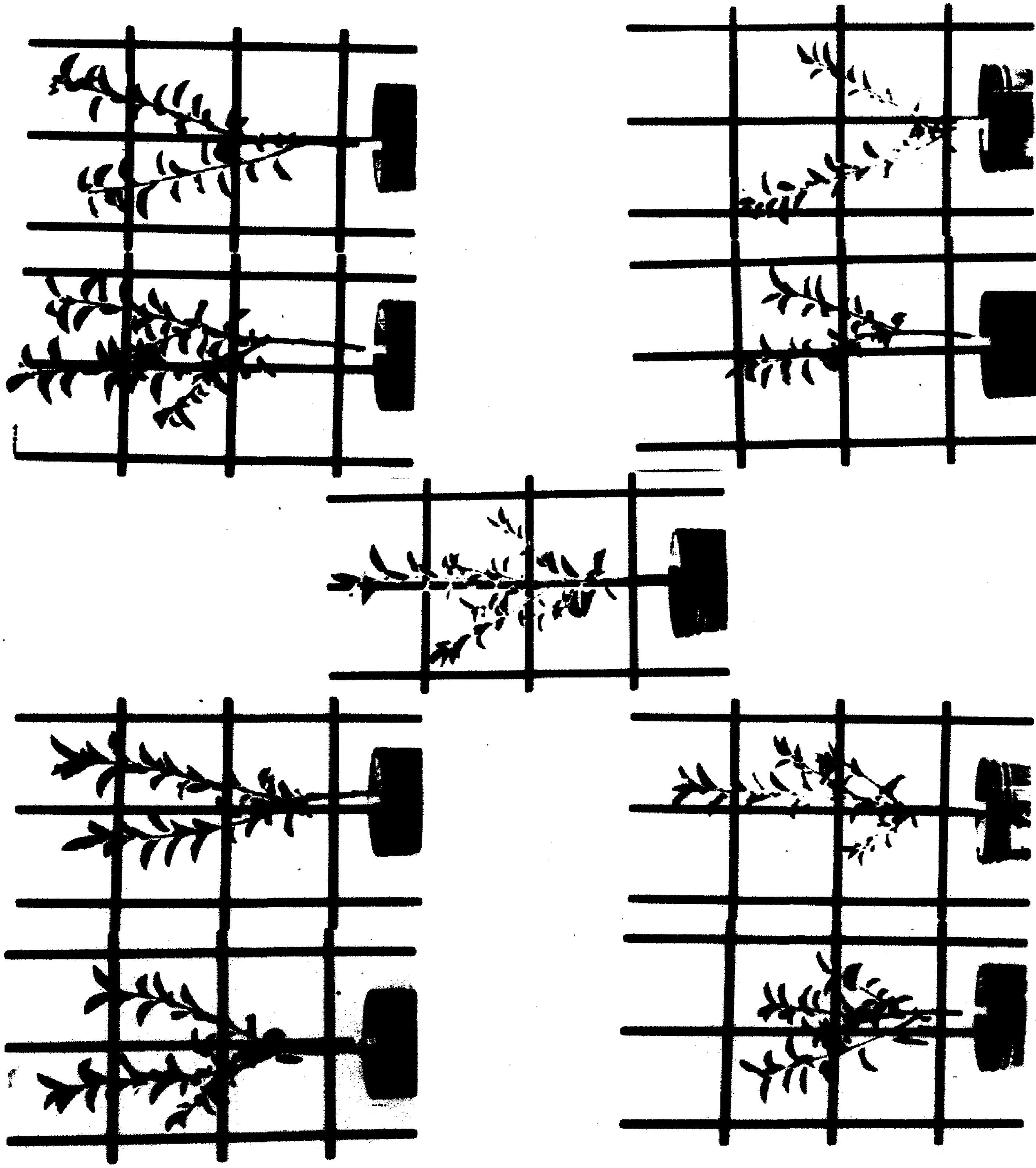

Figure 7

Figure 8. Growth in Relation to Varying Concentration of Zinc (above) and Copper (below). (Center --Optimum; Increasing Concentration from Left to Right).

To accompany Page 17

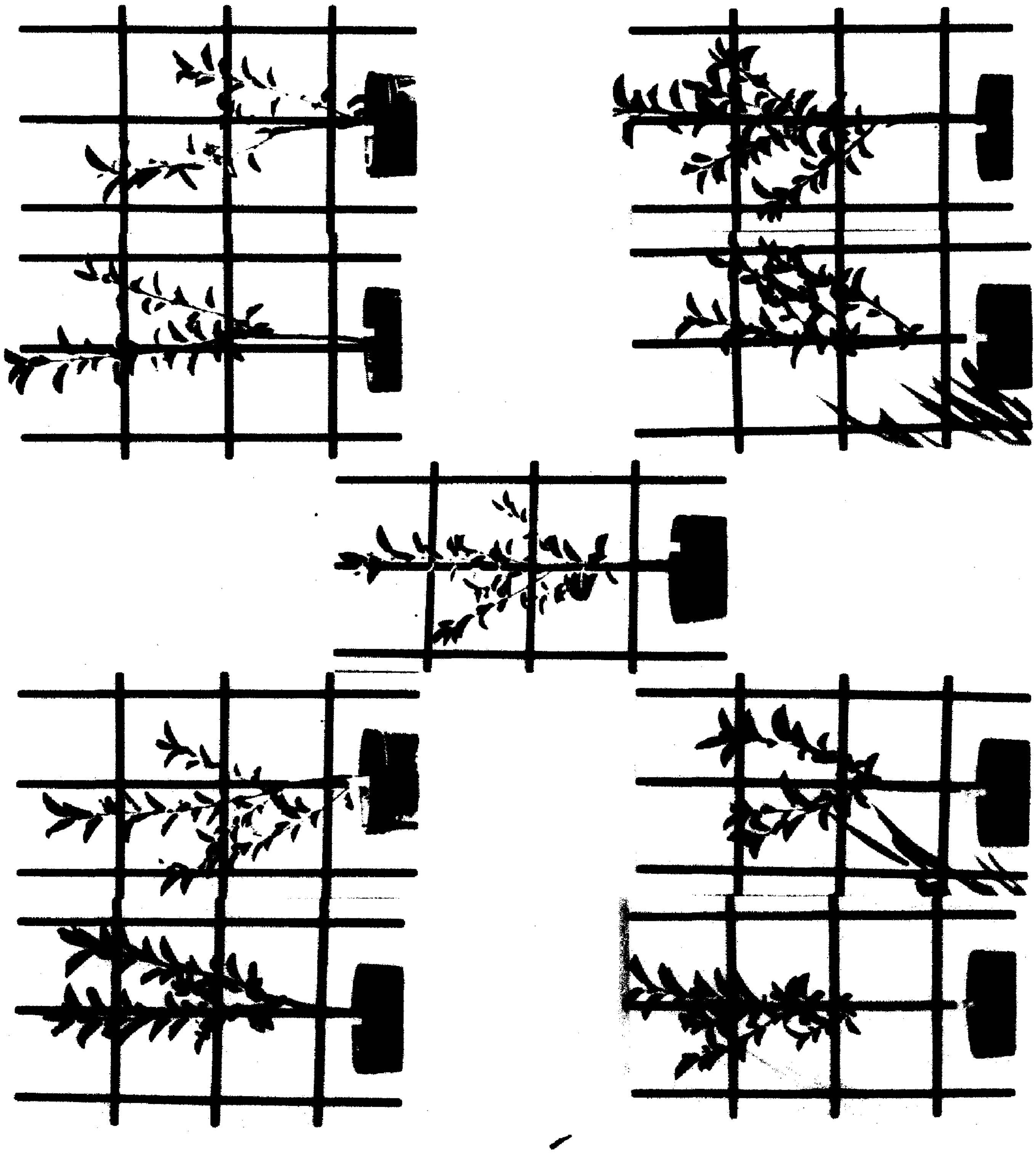

Figure 8

Increasing the concentration of iron to 2X optimum resulted in less terminal growth than produced for the other nutrient-elements. Other nutrient-elements produced terminal growth in the increasing following order: nitrogen, phosphorus, manganese, copper, calcium, potassium, zinc, magnesium, and boron.

When the concentration of the nutrient-elements was increased to 4X optimum, zinc produced the least terminal growth. The other nutrient-elements produced terminal growth in the following increasing order: iron, phosphorus, manganese, boron, calcium, potassium, magnesium, nitrogen, and copper.

Root Growth: Although root growth (Table 15) was not affected significantly by the various concentrations of the different nutrient-elements, there were some differences that should be noted.

As the optimum concentration of each element was reduced to 1/2X optimum, the least amount of root growth resulted from copper. The other nutrient-elements produced progressively increased root growth in the following order: manganese, zinc, potassium, iron, boron, phosphorus, magnesium, calcium, and nitrogen. The amount of root growth produced with magnesium, manganese, boron, iron, copper, and zinc at 1/2X optimum was less than when these nutrient-elements were omitted from the nutrient solution.

Table 15. Relative Effect of Various Concentrations of Several Nutrient-Elements upon Root Growth

Nutrient-element	Omitted		1/2X optimum		2X optimum		4X optimum	
	Root growth	Rank	Root growth	Rank	Root growth	Rank	Root growth	Rank
	gm		gm		gm		gm	
Nitrogen	44.7	5	52.1	10	42.1	2	38.1	1
Phosphorus	39.2	2	48.7	7	46.6	5	44.3	6
Potassium	38.9	1	44.7	4	50.4	8	44.7	7
Calcium	41.4	3	49.2	9	43.1	3	44.8	8
Magnesium	49.5	8	48.9	8	58.3	10	56.6	9
Manganese	55.0	9	42.6	2	49.8	7	59.4	10
Boron	63.6	10	47.7	6	50.5	9	42.4	4
Iron	49.1	7	47.0	5	39.8	1	40.3	2
Copper	44.3	4	38.1	1	49.2	6	44.5	5
Zinc	45.2	6	43.1	3	45.2	4	42.3	3

Root growth at optimum--60.7 grams

To accompany Page 18

As the nutrient-elements were increased to the 2X optimum concentration, iron produced the least root growth. The other nutrient-elements produced root growth in the following increasing order: nitrogen, calcium, zinc, phosphorus, copper, manganese, potassium, boron, and magnesium.

At 4X optimum level all nutrient-elements decreased root growth in relation to optimum. The nutrient-elements produced root growth in the following ascending order: nitrogen, iron, zinc, boron, copper, phosphorus, potassium, calcium, magnesium, and manganese. Increasing the concentration to 4X optimum, as compared to the rate of 2X optimum, resulted in a reduction of root growth for the following nutrient-elements: nitrogen, phosphorus, potassium, magnesium, boron, copper, and zinc. A slight increase in root growth followed the use of calcium and iron, and there was a marked increase for manganese.

<u>Trunk Growth</u>: As the elements were omitted individually, trunk growth (Table 16) was produced in the following ascending order: nitrogen, phosphorus, magnesium, iron, calcium, copper, potassium, manganese, zinc, and boron. When the concentration of each nutrient-element was reduced to 1/2X optimum, trunk growth occurred in the following increasing order: copper, calcium, iron, magnesium, boron, potassium, manganese, zinc, nitrogen, and phosphorus.

When the concentration of the nutrient-elements was increased to 2X optimum, calcium produced the least trunk

Table 16. Relative Effect of Various Concentrations of Several Nutrient-Elements upon Trunk Growth

Nutrient-element	Omitted		1/2X optimum		2X optimum		4X optimum	
	Trunk growth gm	Rank	Trunk growth gm	Rank	Trunk growth gm	Rank	Trunk growth gm	Rank
Nitrogen	12.3	1	18.1	9	17.8	6	14.9	4
Phosphorus	12.9	2	20.0	10	16.1	3	16.6	5
Potassium	15.5	7	16.5	6	18.4	7	14.7	3
Calcium	15.0	5	15.8	2	12.8	1	13.3	2
Magnesium	14.0	3	16.3	4	19.5	8	18.3	8
Manganese	18.4	8	17.6	6	16.4	4	17.1	6
Boron	20.8	10	16.3	5	23.1	9	17.6	7
Iron	14.6	4	16.3	3	15.4	2	13.0	1
Copper	15.4	6	15.1	1	16.1	3	20.7	10
Zinc	20.4	9	17.7	8	16.8	5	19.3	9

Trunk growth at optimum--20.7 grams

To accompany Page 19

growth. The other nutrient-elements produced trunk growth in the following increasing order: iron, phosphorus, copper, manganese, zinc, nitrogen, potassium, magnesium, and boron.

As the concentration of the nutrient-elements was increased to 4X optimum, iron produced less trunk growth than the other nutrient-elements. Trunk growth increased progressively for the other nutrient-elements as follows: calcium, potassium, nitrogen, phosphorus, manganese, boron, magnesium, zinc, and copper.

Leaf Growth: For treatments in which the nutrient-elements were omitted individually, nitrogen resulted in the least production of leaves, while phosphorus and potassium ranked next (Table 17). The remaining elements produced increasing amounts of leaf growth as follows: copper, iron, magnesium, calcium, zinc, boron, and manganese. Omitting nitrogen, phosphorus, potassium, iron, copper, and zinc produced less leaf growth than when used at 1/2X optimum, while calcium, magnesium, manganese, and boron increased leaf growth.

When the optimum concentration was reduced to 1/2X optimum, manganese produced the least leaf growth, while zinc showed the greatest amount. The other elements produced increasing amounts of leaves as follows: potassium, magnesium, calcium, copper, phosphorus, nitrogen, boron, and iron.

As the concentrations were increased to 2X optimum, iron produced less leaf growth than the other nutrient-

Table 17. Relative Effect of Various Concentrations of Several Nutrient-Elements upon Leaf Production

Nutrient-element	Omitted		1/2X optimum		2X optimum		4X optimum	
	Leaf growth	Rank	Leaf growth	Rank	Leaf growth	Rank	Leaf growth	Rank
	gm		gm		gm		gm	
Nitrogen	9.4	1	15.6	7	15.8	5	13.4	2
Phosphorus	11.0	3	15.2	6	16.5	6	16.8	7
Potassium	10.6	2	14.2	2	17.9	8	14.2	4
Calcium	15.2	7	14.4	4	14.8	2	14.6	5
Magnesium	15.1	6	14.3	3	22.7	10	16.5	6
Manganese	18.6	10	13.7	1	15.1	4	17.4	8
Boron	18.5	9	16.0	8	19.0	9	13.4	2
Iron	14.0	5	16.0	8	14.2	1	12.2	1
Copper	12.8	4	14.9	5	14.9	3	18.2	9
Zinc	17.6	8	19.6	9	17.0	7	13.6	3

Leaf growth at optimum--21.6

To accompany Page 20

elements, while calcium ranked next in leaf production. The other nutrient-elements resulted in increased leaf production in the following order: copper, manganese, nitrogen, phosphorus, zinc, potassium, boron, and magnesium. When the concentration was increased to 4X optimum, iron had the same magnitude of effect as when the concentration was increased to 2X optimum. Nitrogen and boron produced the next lowest amount of leaf growth, while the other elements had the following increasing order in regard to their leaf production: zinc, potassium, calcium, magnesium, phosphorus, manganese, and copper.

Leaf Composition and Nutrient-Element Balance

The analysis of the leaves from those trees making maximum growth was considered to represent optimum leaf composition and nutrient-element balance.

Any deviation of a nutrient-element from the optimum concentration resulted in considerable variation in leaf analysis and a corresponding variation in the nutrient-element balance. Some nutrient-elements showed a definite relationship between nutrient solution concentration and leaf analysis. Other nutrient-elements, however, exhibited no definite relationship between nutrient solution concentration and leaf analysis. Also, certain nutrient-elements had an influence on nutrient-element balance and interrelationships proportional to concentration.

<u>Nitrogen</u>: The influence of varying the concentration of nitrogen in the nutrient solution is shown in Table 18 and Figure 9. Phosphorus and iron, as well as nitrogen, decreased while calcium, magnesium, and boron increased in the leaves when the nitrogen content of the nutrient solution was reduced below optimum. Potassium decreased when the nitrogen concentration was 1/2X optimum, but increased when nitrogen was omitted. Using a 1/2X optimum concentration of nitrogen in the nutrient solution resulted in an increase in the analysis of copper and manganese, but copper decreased to the optimum level when nitrogen was omitted, while manganese decreased below optimum.

Phosphorus, potassium, magnesium, iron, and manganese decreased, while boron, and copper, as well as nitrogen, increased when the nitrogen concentration of the nutrient-solution was increased above optimum. Calcium increased as the nitrogen concentration was increased to 2X optimum, but decreased when the nitrogen concentration was 4X optimum.

Decreasing the nitrogen concentration in the nutrient solution resulted in greater total deviations from optimum balance than increasing nitrogen. There was a general trend for the positive deviations from optimum balance to decrease without much change in the negative deviations as the nitrogen concentration was increased. A 4X optimum concentration of nitrogen resulted in the negative devia-

Table 18. Leaf Composition and Nutrient-Element Balance as Influenced by Varying Concentrations of Nitrogen in the Nutrient Solution

Nitrogen concentration		Leaf Composition N	P	K	Ca	Mg	Fe	Cu	B	Mn
Omitted	% Dry weight	1.54	0.10	1.47	1.74	0.78	0.008	0.0005	0.011	0.011
	Chart index	47	62	120	139	125	61	100	275	84
1/2 optimum	% Dry weight	2.76	0.14	1.00	1.73	0.93	0.008	0.0008	0.012	0.016
	Chart index	84	87	81	138	150	61	160	300	123
Optimum	% Dry weight	3.26	0.16	1.22	1.25	0.62	0.013	0.0005	0.004	0.013
	Chart index	100	100	100	100	100	100	100	100	100
2X optimum	% Dry weight	3.80	0.13	0.76	1.73	0.57	0.008	0.0008	0.007	0.012
	Chart index	116	81	62	138	91	61	160	175	92
4X optimum	% Dry weight	4.47	0.05	0.88	0.63	0.60	0.010	0.0006	0.007	0.010
	Chart index	137	31	72	50	96	76	120	175	76

Concentration	Deviation of chart index from optimum balance Positive	Negative	Difference	Total
Omitted	259	146	+ 113	405
1/2 optimum	371	87	+ 284	458
Optimum	0	0	0	0
2X optimum	189	113	+ 76	302
4X optimum	132	199	- 67	331

To accompany Page 22

Figure 9. Nutrient-Element Balance in Relation to Varying the Concentration of Nitrogen in the Nutrient Solution.

Upper left - omitted, upper right - 1/2X optimum, center - optimum, lower left - 2X optimum, lower right - 4X optimum. The various bands on each chart (from the edge toward center) represent excess, approaching excess, optimum, hidden deficiency and deficiency.

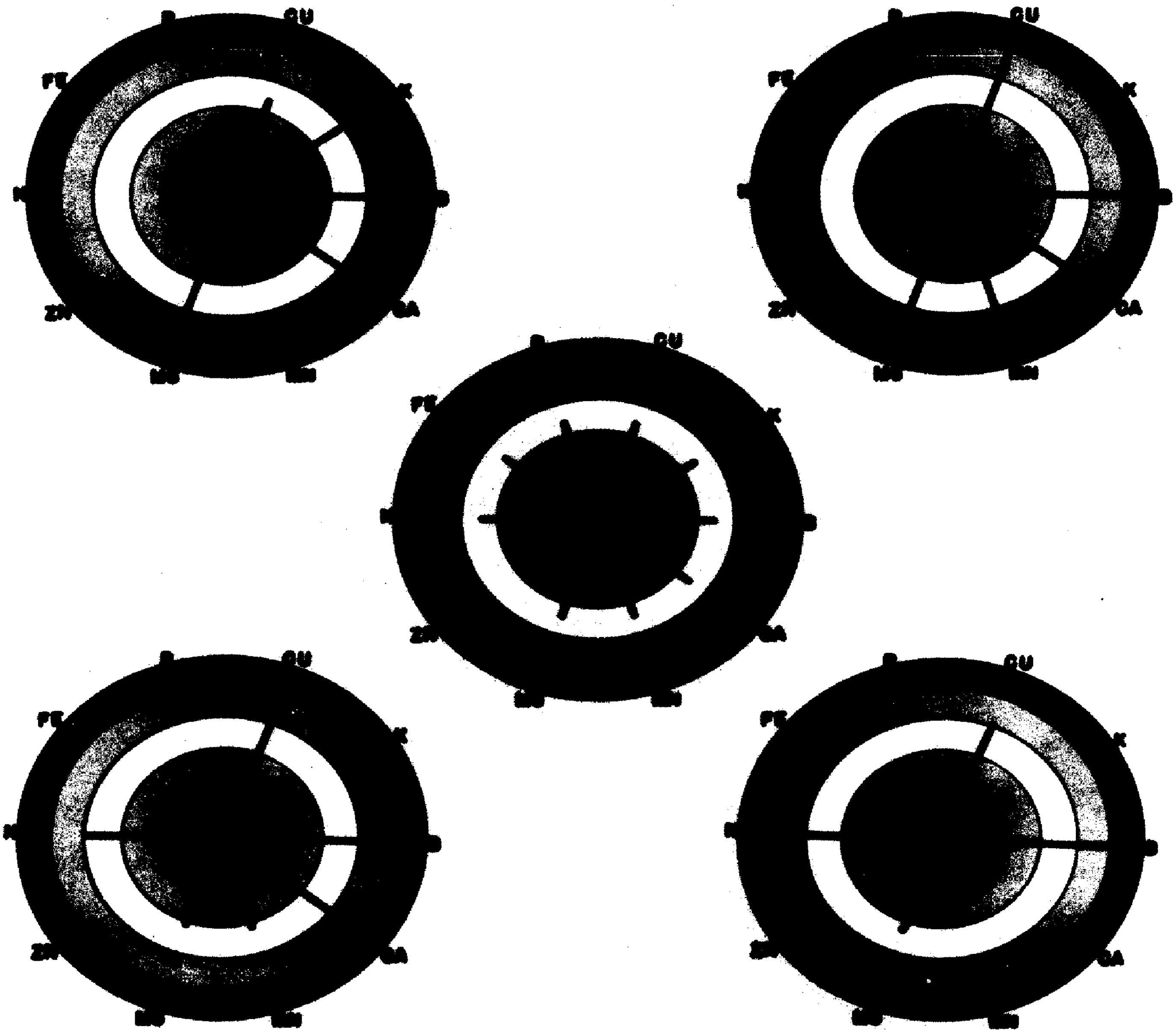

Figure 9

tions exceeding the positive deviations from optimum balance. Apparently, when the nitrogen concentration was 1/2 optimum the nutrient-element composition deviated more from optimum balance than when nitrogen was omitted. Also, with the 1/2 optimum nitrogen concentration, the positive deviations exceed the negative deviations from optimum balance much more than when nitrogen was omitted from the nutrient solution.

Phosphorus: The influence of varying the concentration of phosphorus is shown in Table 19, Figure 10. Iron, copper, boron, and magnesium increased in the leaves, while potassium, calcium, manganese decreased when the phosphorus content of the nutrient solution was reduced below optimum. Phosphorus reduced in leaf composition along with a simultaneous reduction in nitrogen. By omitting phosphorus from the nutrient solution, nitrogen increased to optimum level, and phosphorus decreased to a very low level, but copper approached the optimum level, while iron, manganese, potassium, magnesium, and calcium were decreased below optimum.

Iron and potassium decreased while phosphorus, copper, boron, calcium, and magnesium increased when the phosphorus concentrations of the nutrient-solution were increased above optimum. Nitrogen and manganese remained at the optimum level.

Table 19. Leaf Composition and Nutrient-Element Balance as Influenced by Varying Concentrations of Phosphorus in the Nutrient Solution

Phosphorus concentration		Leaf Composition N	P	K	Ca	Mg	Fe	Cu	B	Mn
Omitted	%Dry weight	3.35	0.06	0.92	1.11	0.49	0.008	0.0006	0.007	0.008
	Chart index	102	37	75	88	79	61	120	175	61
1/2 optimum	%Dry weight	2.89	0.09	1.06	0.95	0.73	0.016	0.0008	0.008	0.008
	Chart index	88	56	86	76	117	123	160	200	61
Optimum	%Dry weight	3.26	0.16	1.22	1.25	0.62	0.013	0.0005	0.004	0.013
	Chart index	100	100	100	100	100	100	100	100	100
2X optimum	%Dry weight	3.46	0.19	0.94	1.39	0.76	0.010	0.0009	0.008	0.013
	Chart index	106	118	77	111	122	76	180	200	100
4X optimum	%Dry weight	3.61	0.22	1.07	1.87	0.84	0.011	0.0007	0.008	0.018
	Chart index	110	137	87	149	135	84	140	200	138

Concentration	Deviation of Chart Index from Optimum Balance: Positive	Negative	Difference	Total
Omitted	97	199	- 102	296
1/2 optimum	200	133	+ 67	333
Optimum	0	0	0	0
2X optimum	237	47	+ 190	284
4X optimum	309	29	+ 280	338

To accompany Page 23

Figure 10. Nutrient-Element Balance in Relation to Varying the Concentration of Phosphorus in the Nutrient Solution.

Upper left - omitted, upper right - 1/2X optimum, center - optimum, lower left - 2X optimum, lower right - 4X optimum. The various bands on each chart (from the edge toward center) represents excess, approaching excess, optimum, hidden deficiency, and deficiency.

To accompany Page 23

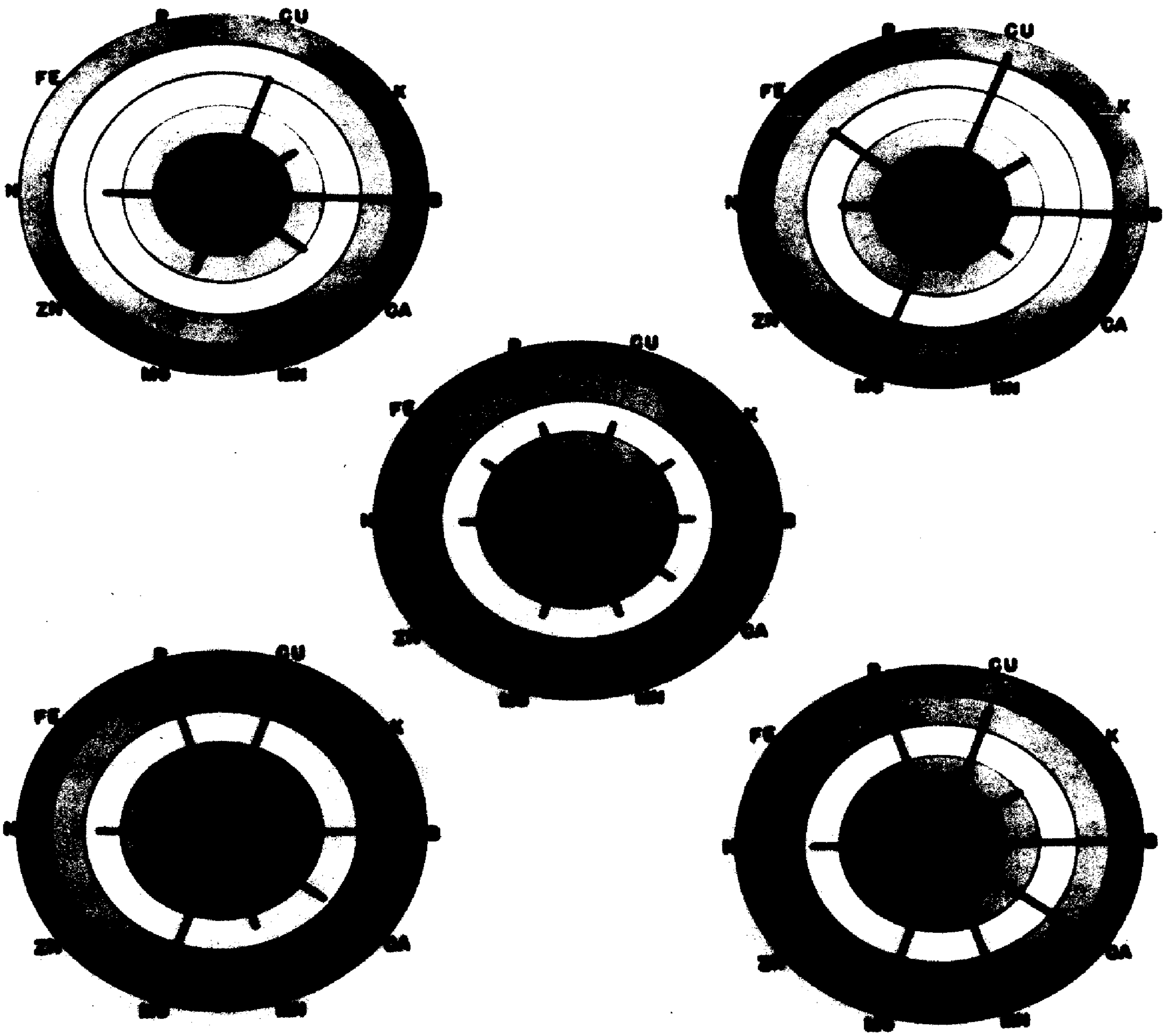

Figure 10

When the phosphorus concentration was increased to 4X optimum, phosphorus, copper, boron, calcium, manganese, and magnesium increased, while iron and potassium decreased. There was a slight increase in nitrogen.

Decreasing the phosphorus concentration in the nutrient-solution resulted in deviations from optimum which are comparable to the increase of phosphorus above the optimum level. As the phosphorus concentration was increased to 4X optimum, the nutrient-element balance deviated more from optimum than when phosphorus was omitted. However, positive deviations exceeded negative deviations except when phosphorus was omitted.

Potassium: The influence of varying the concentration of potassium in the nutrient solution is shown in Table 20, Figure 11. Phosphorus and iron, as well as potassium, decreased and boron and copper increased when the potassium concentration of the nutrient solution was reduced to 1/2X optimum. Nitrogen, manganese, and calcium remained at the optimum level, while there was an increase in magnesium. As compared to the 1/2X optimum concentration, potassium, and phosphorus continued to decrease, manganese decreased, while copper increased when potassium was omitted from the nutrient solution.

Boron and magnesium increased, while iron and phosphorus decreased when the potassium concentration of the nutrient solution was increased above optimum. Nitrogen, calcium, and manganese remained near the optimum level.

Table 20. Leaf Composition and Nutrient-Element Balance as Influenced by Varying Concentrations of Potassium in the Nutrient Solution

Potassium concentration		Leaf Composition								
		N	P	K	Ca	Mg	Fe	Cu	B	Mn
Omitted	% Dry weight	3.29	0.08	0.71	1.14	0.76	0.010	0.0007	0.009	0.007
	Chart index	100	50	58	91	122	76	140	225	53
1/2 optimum	% Dry weight	3.53	0.13	0.84	1.25	0.84	0.009	0.0006	0.008	0.013
	Chart index	108	81	68	100	135	69	120	200	100
Optimum	% Dry weight	3.26	0.16	1.22	1.25	0.62	0.013	0.0005	0.004	0.013
	Chart index	100	100	100	100	100	100	100	100	100
2X optimum	% Dry weight	3.38	0.14	0.97	1.20	0.97	0.008	0.0007	0.006	0.012
	Chart index	103	87	79	96	156	61	140	150	92
4X optimum	% Dry weight	3.80	0.13	1.69	0.98	0.77	0.009	0.0004	0.006	0.014
	Chart index	116	81	138	78	124	69	80	150	107

Concentration	Deviation of Chart Index from Optimum Balance			
	Positive	Negative	Difference	Total
Omitted	187	172	+ 10	359
1/2 optimum	163	82	+ 81	245
Optimum	0	0	0	0
2X optimum	149	85	+ 64	234
4X optimum	135	92	+ 43	227

To accompany Page 24

Figure 11. Nutrient-element Balance in Relation to Varying the Concentration of Potassium in the Nutrient Solution.

Upper left - omitted, upper right - 1/2X optimum, center - optimum, lower left - 2X optimum, lower right - 4X optimum. The various bands on each chart (from the edge toward center) represent excess, approaching excess, optimum, hidden deficiency and deficiency.

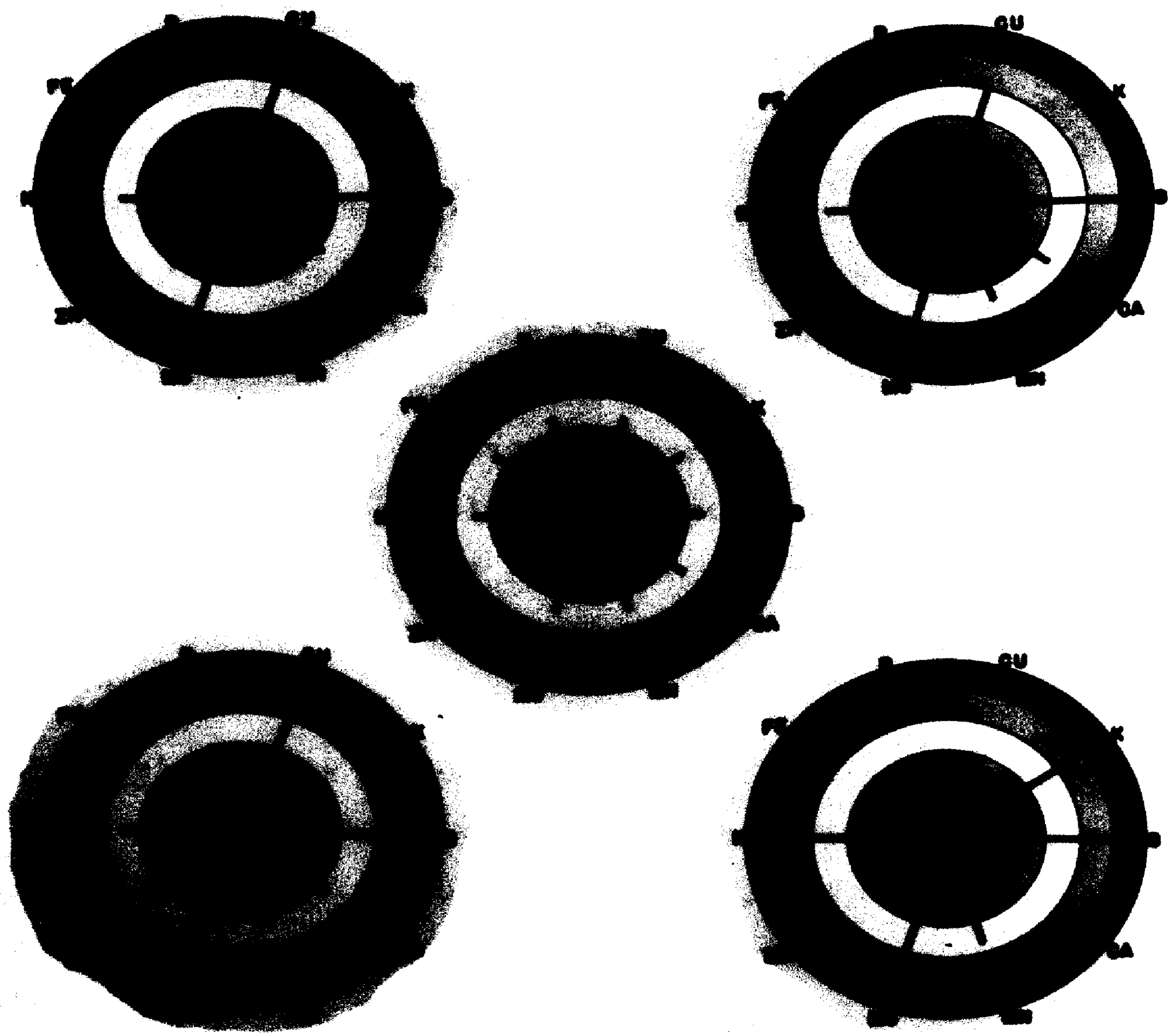

Figure 11

Potassium increased when the concentration was 4X optimum, but showed a decrease at 2X optimum. Copper increased when the potassium concentration was 2X optimum, but decreased when the concentration was 4X optimum. Magnesium was lower when the potassium concentration was 4X optimum than when the concentration was 2X optimum.

Decreasing the potassium concentration in the nutrient solution resulted in greater total deviations from optimum balance than increasing potassium. Positive deviations from the optimum balance were prevalent for all levels of potassium. Greater total deviations from the optimum balance were observed with O optimum concentration. Nutrient element composition deviated less from optimum when the potassium concentration was 1/2X optimum than when potassium was omitted.

Calcium: The influence of varying the concentration of calcium in the nutrient-solution is shown in Table 21, Figure 12. Copper and boron increased, and all other nutrient-elements decreased except nitrogen and magnesium when the calcium content of the nutrient solution was reduced below optimum. Nitrogen, phosphorus, potassium, and iron were higher when calcium was omitted than when the calcium concentration was 1/2X optimum. However, copper was lower when calcium was omitted than when at 1/2X optimum. Omitting calcium from the nutrient solution caused the calcium to continue to decrease.

Table 21. Leaf Composition and Nutrient-Element Balance as Influenced by Varying Concentrations of Calcium in the Nutrient Solution

Calcium concentration		N	P	K	Ca	Mg	Fe	Cu	B	Mn
		Leaf Composition								
Omitted	% Dry weight	3.36	0.12	1.13	0.62	0.60	0.011	0.0006	0.006	0.009
	Chart index	103	75	92	49	96	84	120	150	70
1/2 optimum	% Dry weight	3.12	0.11	1.04	0.83	0.59	0.009	0.0007	0.010	0.009
	Chart index	95	68	85	66	95	70	140	250	70
Optimum	% Dry weight	3.26	0.16	1.22	1.25	0.62	0.013	0.0005	0.004	0.013
	Chart index	100	100	100	100	100	100	100	100	100
2X optimum	% Dry weight	3.76	0.15	0.95	1.25	0.54	0.010	0.0005	0.009	0.010
	Chart index	115	93	77	100	87	76	100	225	76
4X optimum	% Dry weight	3.23	0.17	0.92	1.78	0.66	0.009	0.0006	0.008	0.012
	Chart index	99	106	75	142	106	69	120	200	92

Concentration	Deviation of Chart Index from Optimum Balance			
	Positive	Negative	Difference	Total
Omitted	73	134	- 61	207
1/2 optimum	190	151	+ 39	341
Optimum	0	0	0	0
2X optimum	140	91	+ 49	231
4X optimum	174	65	+109	239

To accompany Page 25

Figure 12. Nutrient-Element Balance in Relation to Varying the Concentration of Calcium in the Nutrient Solution.

Upper left - omitted, upper right - 1/2X optimum, center - optimum, lower left - 2X optimum, lower right - 4X optimum. The various bands on each chart (from the edge toward center) represent excess, approaching excess, optimum, hidden deficiency and deficiency.

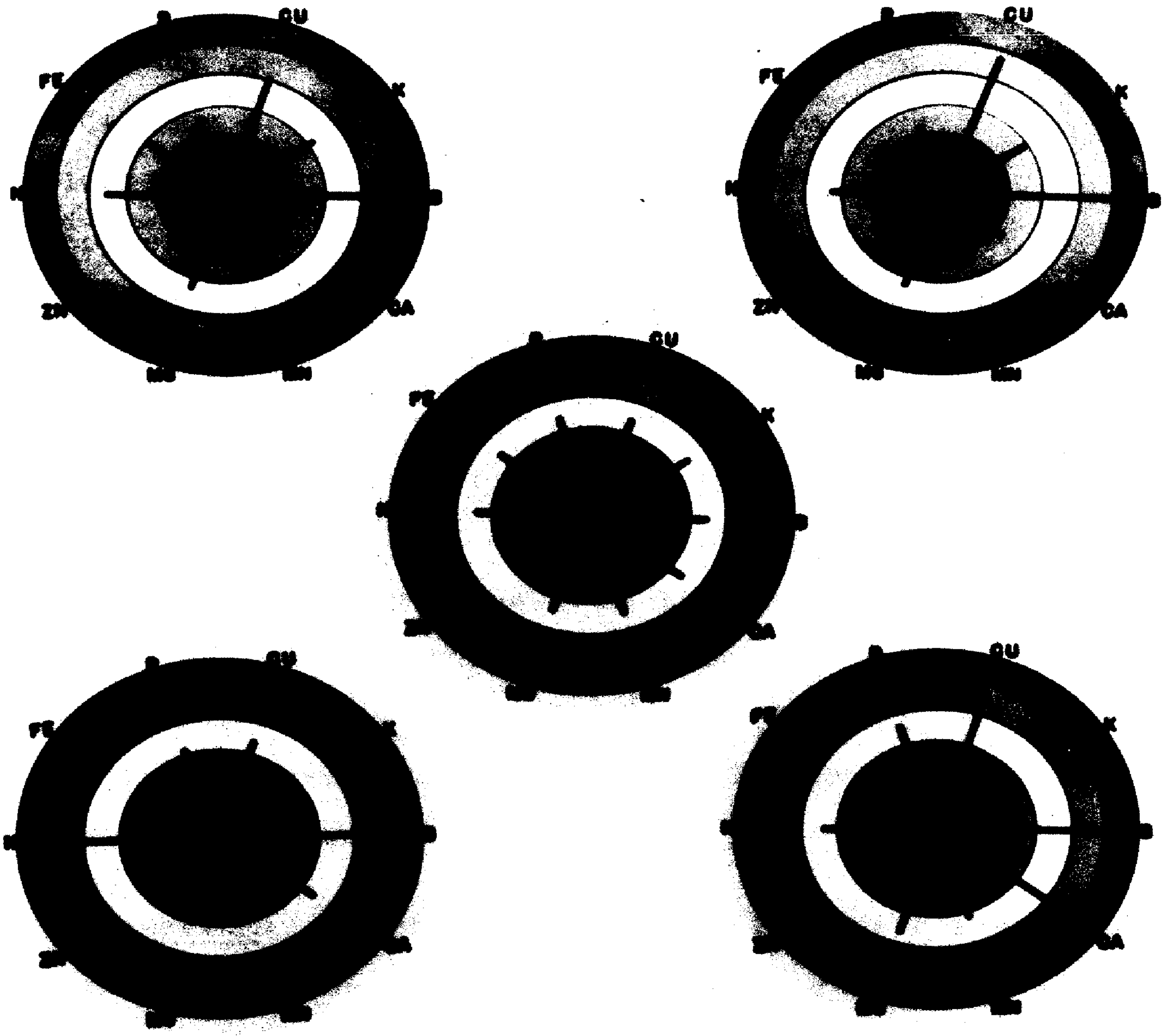

Figure 12

Potassium, iron, and manganese decreased and boron increased when the calcium concentration was increased, while nitrogen, phosphorus, magnesium, and copper remained near the optimum level.

Calcium increased in the leaves as the concentration was increased 4X optimum. Phosphorus, magnesium, manganese, and copper increased, while nitrogen, iron and boron decreased in the leaves when the 4X concentration is compared to the 2X concentration of calcium.

Decreasing the calcium concentration in the nutrient solution produced greater total deviations from optimum balance than increasing calcium. There was a general trend for the positive deviations from optimum balance to increase and the negative deviations to decrease as the calcium concentration was increased. Negative deviations from optimum balance exceeded the positive deviations only when calcium was omitted.

<u>Magnesium</u>: The influence of varying the concentration of magnesium in the nutrient solution is shown in Table 22, Figure 13. Phosphorus, potassium, calcium, iron, manganese, as well as magnesium decreased, copper increased, and nitrogen remained near the optimum level as the magnesium content of the nutrient solution was reduced below optimum. Copper remained within the limits of the optimum level at

Table 22. Leaf Composition and Nutrient-Element Balance as Influenced by Varying Concentrations of Magnesium in the Nutrient Solution

Magnesium concentration		Leaf Composition								
		N	P	K	Ca	Mg	Fe	Cu	B	Mn
Omitted	% Dry weight	3.42	0.14	1.00	0.92	0.52	0.010	0.0008	0.006	0.008
	Chart index	104	87	81	73	83	76	160	150	61
1/2 optimum	% Dry weight	3.25	0.10	1.01	1.22	0.64	0.011	0.0005	0.008	0.011
	Chart index	99	62	82	97	103	84	100	200	84
Optimum	% Dry weight	3.26	0.16	1.22	1.25	0.62	0.013	0.0005	0.004	0.013
	Chart index	100	100	100	100	100	100	100	100	100
2X optimum	% Dry weight	3.21	0.13	1.21	1.18	0.76	0.011	0.0006	0.010	0.010
	Chart index	98	81	99	94	122	85	120	250	76
4X optimum	% Dry weight	3.04	0.14	1.04	1.00	0.81	0.007	0.0007	0.007	0.010
	Chart index	93	87	85	80	130	53	140	175	76

Concentration	Deviation of Chart Index from Optimum Balance			
	Positive	Negative	Difference	Total
Omitted	114	139	- 25	253
1/2 optimum	103	92	+ 11	195
Optimum	0	0	0	0
2X optimum	192	67	+ 125	259
4X optimum	145	126	+ 19	271

To accompany Page 26

Figure 13. Nutrient-element Balance in Relation to Varying the Concentration of Magnesium in the Nutrient Solution.

Upper left - omitted, upper right - 1/2X optimum, center - optimum, lower left - 2X optimum, lower right - 4X optimum. The various bands on each chart (from the edge toward center) represent excess, approaching excess, optimum, hidden deficiency and deficiency.

To accompany Page 26

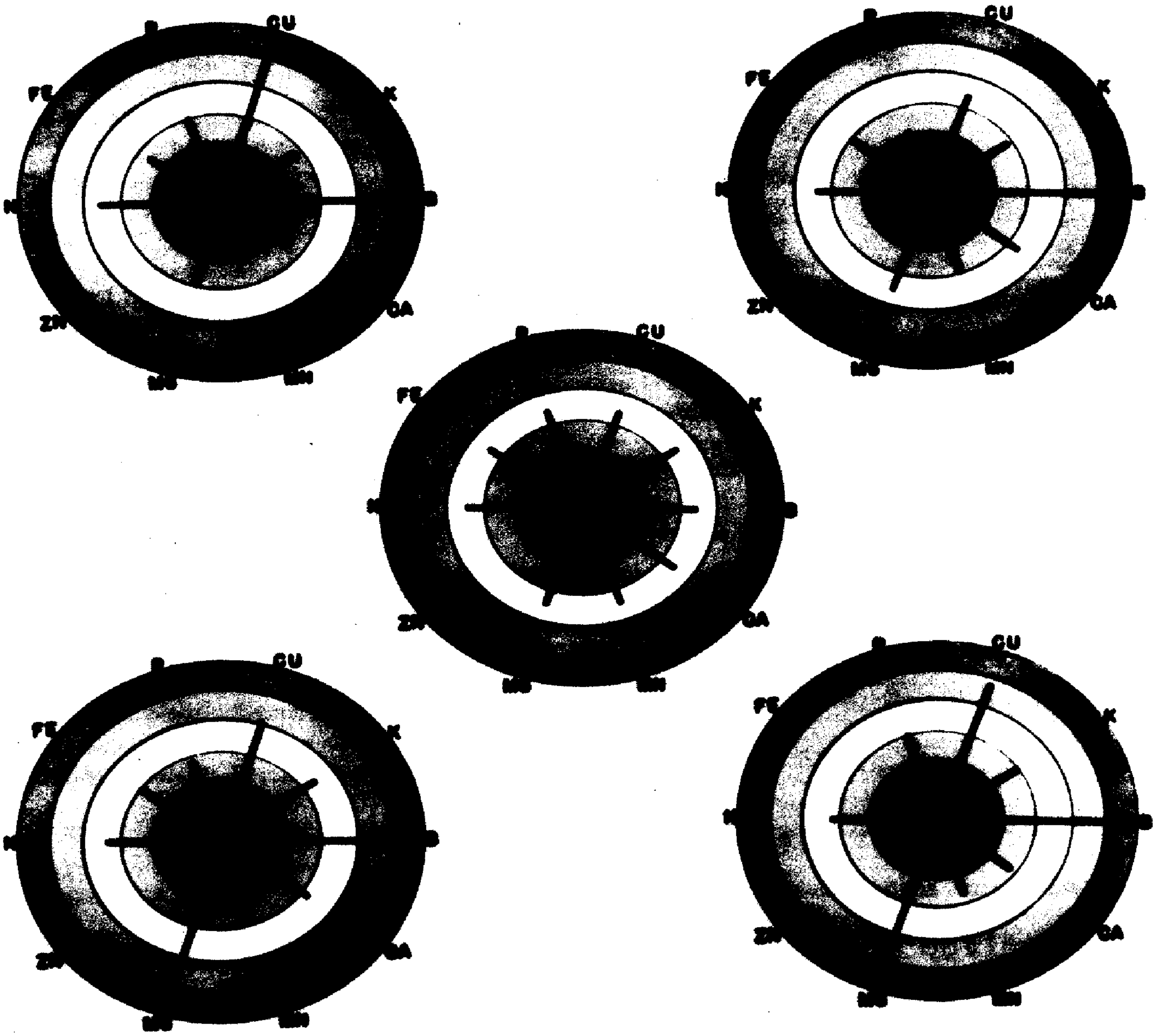

Figure 13

1/2X optimum, but increased when magnesium was omitted. Also boron tended to decrease slightly when none of the element was added as compared to 1/2X optimum.

Phosphorus, iron, and manganese were reduced when a concentration of 2X optimum level was used. However, an increase of copper, boron, and magnesium was noted, although nitrogen, potassium, and calcium remained near the optimum level.

Using magnesium concentrations 4X optimum, magnesium continued to increase, while there was only a slight reduction in calcium. Potassium, manganese, iron, and phosphorus were likewise reduced, while copper and boron increased when the magnesium concentration of the nutrient solution was increased to the 4X optimum level.

Decreasing the magnesium concentration of the nutrient-solution resulted in less total deviations from optimum balance than increasing magnesium.

The greatest total deviations from optimum balance was obtained with the magnesium concentration of the nutrient-solution at 4X optimum. Total deviations from optimum balance when calcium was omitted were essentially the same as at the 4X optimum concentration. Negative deviations from optimum balance exceeded the positive deviations only when magnesium was omitted from the nutrient-solution.

Manganese: The influence of varying the manganese concentration in the nutrient-solution is shown in Table 23, and Figure 14. Phosphorus, potassium, iron, and manganese decreased when the manganese concentration was below optimum, while copper, and boron increased. However, nitrogen remained near the optimum level when the manganese content of the nutrient solution was reduced below optimum. Phosphorus, calcium, and manganese were higher when manganese was omitted than when manganese was 1/2X optimum, but potassium, magnesium, iron, copper, and boron were lower when manganese was omitted than when used at 1/2X optimum concentration.

Using manganese concentrations 2X optimum, iron, phosphorus, potassium, calcium, and manganese decreased, while boron, and magnesium increased. Nitrogen and copper continued to remain near the optimum level.

With applications of manganese at the 4X optimum level, iron was the only element that was decreased significantly. Manganese, copper, and boron continued to increase in the leaves at this very high level. Nitrogen, phosphorus, potassium, calcium, and magnesium were near the optimum level when the manganese concentration was 4X optimum.

Decreasing the manganese concentration in the nutrient-solution resulted in less total deviations from optimum balance than increasing manganese to the 4X optimum concentration which resulted in the greatest positive and total deviations from the optimum.

Negative deviations from optimum balance exceeded positive deviations when manganese was omitted from the

Table 23. Leaf Composition and Nutrient-Element Balance as Influenced by Varying Concentrations of Manganese in the Nutrient Solution

Manganese concentration		Leaf Composition								
		N	P	K	Ca	Mg	Fe	Cu	B	Mn
Omitted	% Dry weight	3.50	0.14	0.98	1.28	0.48	0.007	0.0006	0.006	0.010
	Chart index	107	87	80	102	77	53	120	150	76
1/2 optimum	% Dry weight	3.48	0.08	1.01	1.13	0.72	0.010	0.0007	0.008	0.009
	Chart index	106	50	82	90	116	76	140	200	69
Optimum	% Dry weight	3.26	0.16	1.22	1.25	0.62	0.013	0.0005	0.004	0.013
	Chart index	100	100	100	100	100	100	100	100	100
2X optimum	% Dry weight	3.29	0.05	1.00	1.12	0.83	0.010	0.0005	0.005	0.011
	Chart index	100	31	81	89	133	76	100	125	85
4X optimum	% Dry weight	3.22	0.15	1.14	1.32	0.72	0.010	0.0007	0.009	0.025
	Chart index	98	93	93	105	116	76	140	225	192

Concentration	Deviation of Chart Index from Optimum Balance			
	Positive	Negative	Difference	Total
Omitted	79	127	- 48	206
1/2 optimum	162	133	+ 39	295
Optimum	0	0	0	0
2X optimum	58	138	- 80	196
4X optimum	278	40	+ 238	318

To accompany Page 28

Figure 14. Nutrient-Element Balance in Relation to Varying the Concentration of Manganese in the Nutrient Solution.

Upper left - omitted, upper right - 1/2X optimum, center - optimum, lower left - 2X optimum, lower right - 4X optimum. The various bands on each chart (from the edge toward center) represent excess, approaching excess, optimum, hidden deficiency and deficiency.

To accompany Page 28

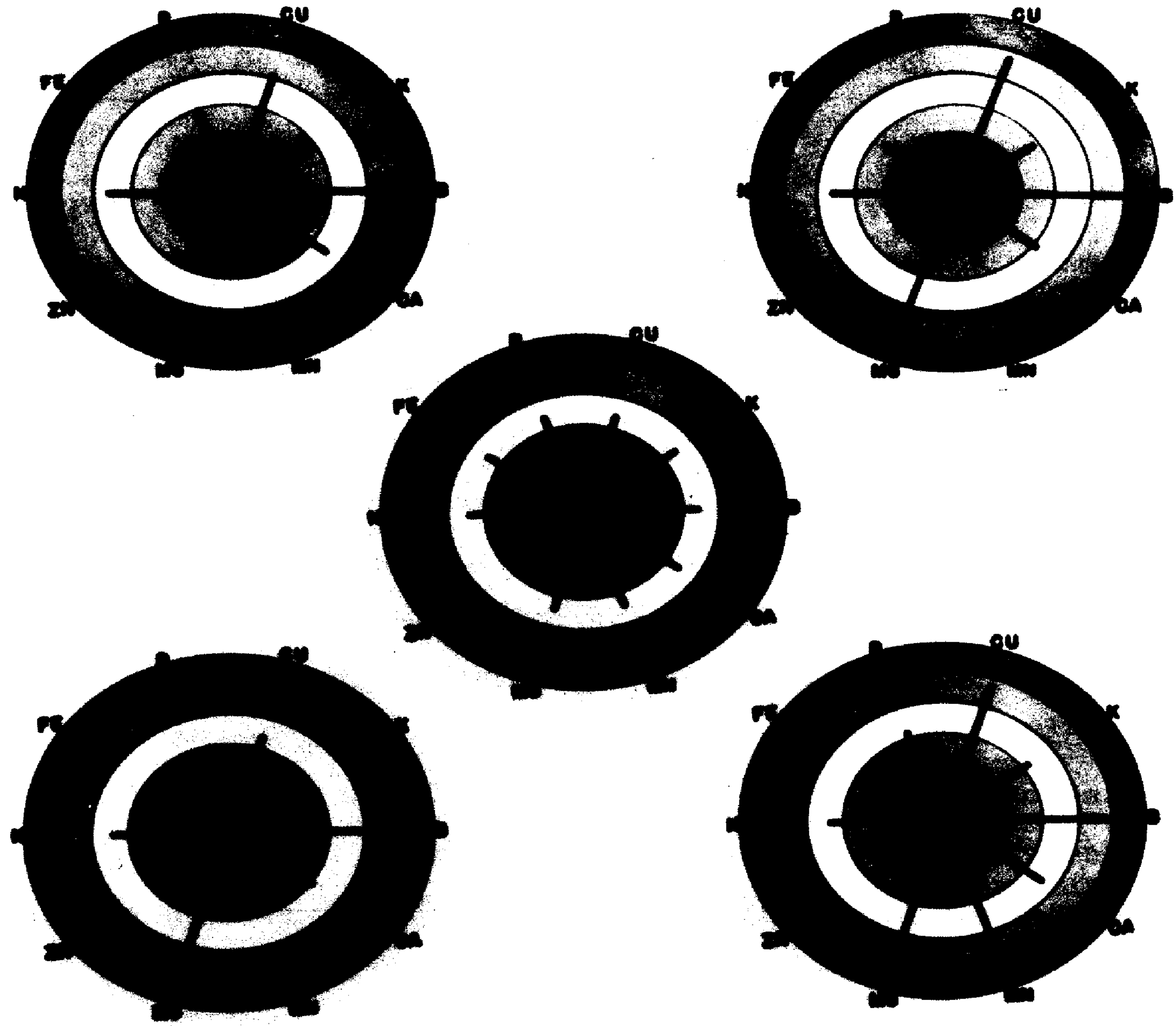

Figure 14

nutrient solution and where applied at the rate of 2X optimum concentration. Positive deviations from optimum balance were very pronounced, and the negative deviations were very low for the 4X optimum concentration.

Boron: The influence of varying the concentration of boron in the nutrient solution is shown in Table 24, Figure 15. Phosphorus, iron, potassium, and manganese decreased while copper and boron increased when the boron content of the nutrient solution was reduced below optimum. Nitrogen, however, remained near the optimum level. The increase in copper at 1/2X optimum was decreased when boron was omitted from the nutrient solution. When boron was omitted, there was an increase of calcium, manganese, and magnesium as compared to using boron at 1/2X optimum.

Iron, phosphorus, copper, potassium, calcium, manganese and magnesium decreased while boron increased when the boron concentration of the nutrient solution was increased above optimum. Nitrogen was decreased slightly, but remained near the optimum level. Iron, phosphorus, potassium, calcium, manganese, and magnesium decreased more at the 4X optimum than at the 2X optimum concentration of boron. When the boron concentration was increased 4X optimum, boron remained at a very high level, and copper increased as the boron concentration increased. Nitrogen decreased slightly, but remained within the optimum range.

Decreasing the boron concentration in the nutrient-solution resulted in less total deviations from optimum

Table 24. Leaf Composition and Nutrient-Element Balance as Influenced by Varying Concentrations of Boron in the Nutrient Solution

Boron concentration		N	P	K	Ca	Mg	Fe	Cu	B	Mn
		Leaf Composition								
Omitted	% Dry weight	3.03	0.12	1.11	1.67	0.66	0.010	0.0006	0.007	0.011
	Chart index	92	75	90	133	106	76	120	175	85
1/2 optimum	% Dry weight	3.22	0.11	1.07	1.09	0.45	0.009	0.0009	0.007	0.006
	Chart index	98	68	87	87	72	69	180	175	46
Optimum	% Dry weight	3.26	0.16	1.22	1.25	0.62	0.013	0.0005	0.004	0.013
	Chart index	100	100	100	100	100	100	100	100	100
2X optimum	% Dry weight	3.10	0.09	0.90	1.14	0.50	0.009	0.0004	0.015	0.006
	Chart index	95	56	73	91	80	69	80	375	46
4X optimum	% Dry weight	3.00	0.06	0.78	0.85	0.41	0.006	0.0007	0.019	0.004
	Chart index	92	37	63	68	66	46	140	475	30

Concentration	Positive	Negative	Difference	Total
	Deviation of Chart Index from Optimum Balance			
Omitted	134	82	+ 52	216
1/2 optimum	155	173	- 18	328
Optimum	0	0	0	0
2X optimum	275	210	+ 65	485
4X optimum	415	298	+ 117	713

To accompany Page 29

Figure 15. Nutrient-Element Balance in Relation to Varying the Concentration of Boron in the Nutrient Solution.

Upper left - omitted, upper right - 1/2X optimum, center - optimum, lower left 2X optimum, lower right - 4X optimum. The various bands on each chart (from the edge toward center) represent excess, approaching excess, optimum, hidden deficiency and deficiency.

To accompany Page 29

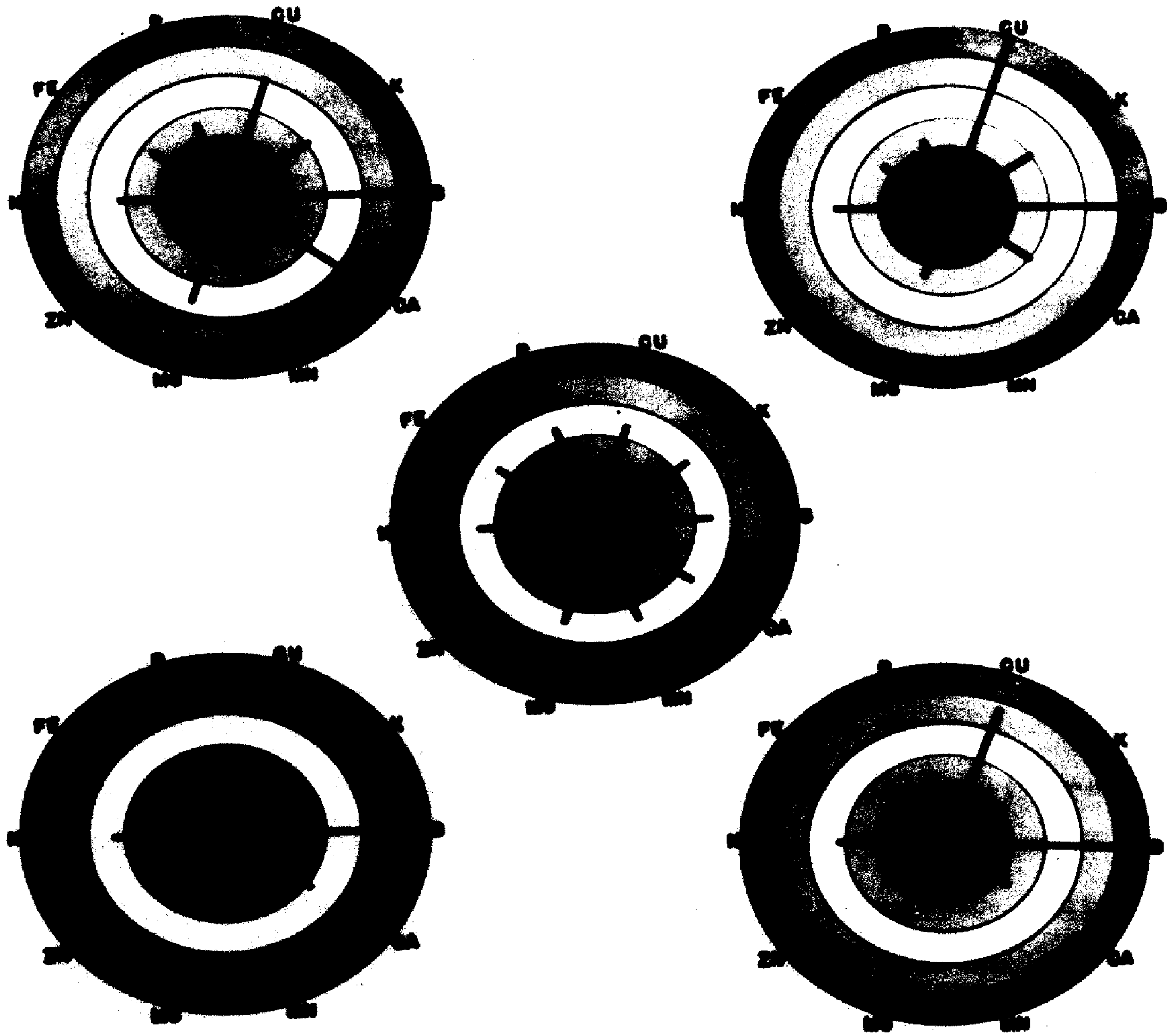

Figure 15

balance than increasing boron. When the concentrations exceeded optimum, there appears to be a general increase in positive, negative, and total deviations from the optimum balance. Positive, negative, and total deviations from optimum balance decreased as the boron concentration was reduced. Negative deviations only exceeded positive deviations from optimum balance when the boron concentration was 1/2X optimum.

Iron: The influence of varying the concentration of iron in the nutrient solution is shown in Table 25, Figure 16. Iron and potassium decreased while phosphorus, copper, and boron increased in the leaves when the iron content of the nutrient solution was reduced below optimum. Nitrogen and calcium remained near the optimum level. When iron was omitted magnesium and manganese decreased sharply, but iron increased slightly as compared to 1/2X optimum.

As iron was increased to the 2X optimum level, iron, calcium, and potassium were the only elements that decreased. Phosphorus, copper, boron, and magnesium increased while nitrogen, and manganese remained near the optimum level.

Iron, potassium, and phosphorus were at very low levels, while there was an increase in copper, boron, calcium, and magnesium when the iron concentration was increased to 4X optimum. Nitrogen and manganese remained near the optimum level.

Table 25. Leaf Composition and Nutrient-Element Balance as Influenced by Varying Concentrations of Iron in the Nutrient Solution

Iron concentration		Leaf Composition N	P	K	Ca	Mg	Fe	Cu	B	Mn
Omitted	% Dry weight	3.37	0.10	1.03	1.22	0.50	0.010	0.0008	0.018	0.009
	Chart index	103	62	84	97	80	76	160	450	70
1/2 optimum	% Dry weight	3.33	0.20	0.85	1.22	0.68	0.007	0.0008	0.008	0.016
	Chart index	102	125	69	97	109	54	160	200	123
Optimum	% Dry weight	3.26	0.16	1.22	1.25	0.62	0.013	0.0005	0.004	0.013
	Chart index	100	100	100	100	100	100	100	100	100
2X optimum	% Dry weight	3.61	0.20	0.86	1.15	0.80	0.009	0.0007	0.009	0.013
	Chart index	110	125	70	92	129	69	140	225	100
4X optimum	% Dry weight	3.50	0.13	0.73	1.61	0.72	0.008	0.0006	0.009	0.009
	Chart index	107	81	59	128	116	61	120	225	69

Concentration	Deviation of Chart Index from Optimum Balance: Positive	Negative	Difference	Total
Omitted	413	131	+ 282	544
1/2 optimum	219	80	+ 139	299
Optimum	0	0	0	0
2X optimum	229	69	+ 160	298
4X optimum	196	130	+ 66	326

To accompany Page 30

Figure 16. Nutrient-Element Balance in Relation to Varying the Concentration of Iron in the Nutrient Solution.

Upper left - omitted, upper right - 1/2X optimum, center - optimum, lower left - 2X optimum, lower right - 4X optimum. The various bands on each chart (from the edge toward center) represent excess, approaching excess, optimum, hidden deficiency and deficiency.

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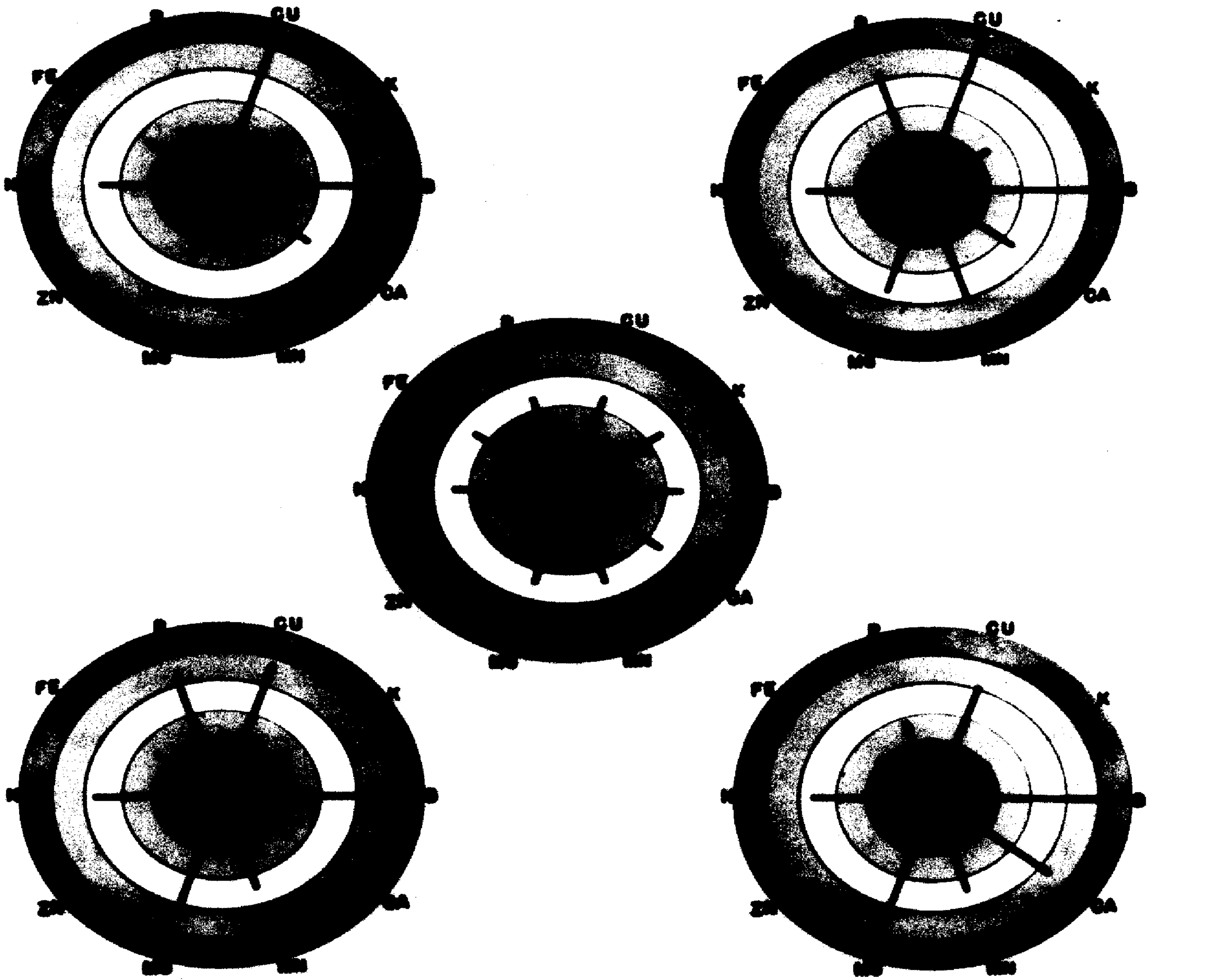

Figure 16

Omitting iron from the nutrient-solution resulted in greater total deviations from optimum balance than increasing iron. Total deviations from optimum balance were higher for the 4X than the 2X concentration of iron. Negative deviations from optimum did not exceed the positive deviations at any concentration. Negative deviations increased with each increment of increased or decreased iron concentration. Positive deviations from optimum increased at the lowest concentration, while the positive deviations were lower for the 4X optimum than for the 2X optimum concentration.

Zinc: The influence of varying the concentration of zinc in the nutrient-solution is shown in Table 26, Figure 17. Copper, potassium, and magnesium were reduced, and nitrogen, iron, calcium, and manganese remained near the optimum level when zinc concentrations of the nutrient-solution were reduced to 1/2X optimum. There was an increase for phosphorus and boron.

Iron, phosphorus, potassium, copper, and manganese were reduced and magnesium increased as zinc was omitted from the nutrient-solution. Boron, calcium, and magnesium were above the optimum level when zinc was omitted.

Increasing zinc to the 2X optimum concentration resulted in nitrogen, iron, phosphorus, copper, manganese, and magnesium remaining near the optimum level, while potassium was decreased. Boron and calcium were increased.

Table 26. Leaf Composition and Nutrient-Element Balance as Influenced by Varying Concentrations of Zinc in the Nutrient Solution

Zinc concentration		Leaf Composition N	P	K	Ca	Mg	Fe	Cu	B	Mn
Omitted	% Dry weight	3.32	0.13	0.83	1.70	0.81	0.007	0.0004	0.007	0.008
	Chart index	101	81	68	136	130	53	81	175	61
1/2 optimum	% Dry weight	3.57	0.19	1.03	1.32	0.51	0.013	0.0004	0.008	0.013
	Chart index	109	118	84	105	82	100	81	200	100
Optimum	% Dry weight	3.26	0.16	1.22	1.25	0.62	0.013	0.0005	0.004	0.013
	Chart index	100	100	100	100	100	100	100	100	100
2X optimum	% Dry weight	3.76	0.17	0.70	1.59	0.61	0.012	0.0005	0.009	0.013
	Chart index	115	106	57	127	98	92	100	225	100
4X optimum	% Dry weight	3.45	0.19	0.72	1.31	0.85	0.009	0.0006	0.013	0.010
	Chart index	105	118	59	104	137	69	120	325	76

Concentration	Deviation of Chart Index from Optimum Balance Positive	Negative	Difference	Total
Omitted	142	156	- 14	298
1/2 optimum	132	53	+ 79	185
Optimum	0	0	0	0
2X optimum	173	53	+ 120	226
4X optimum	309	96	+ 213	405

To accompany Page 31

Figure 17. Nutrient-Element Balance in Relation to Varying the Concentration of Zinc in the Nutrient Solution.

Upper left - omitted, upper right - 1/2X optimum, center - optimum, lower left - 2X optimum, lower right - 4X optimum. The various bands on each chart (from the edge toward center) represent excess, approaching excess, optimum, hidden deficiency and deficiency.

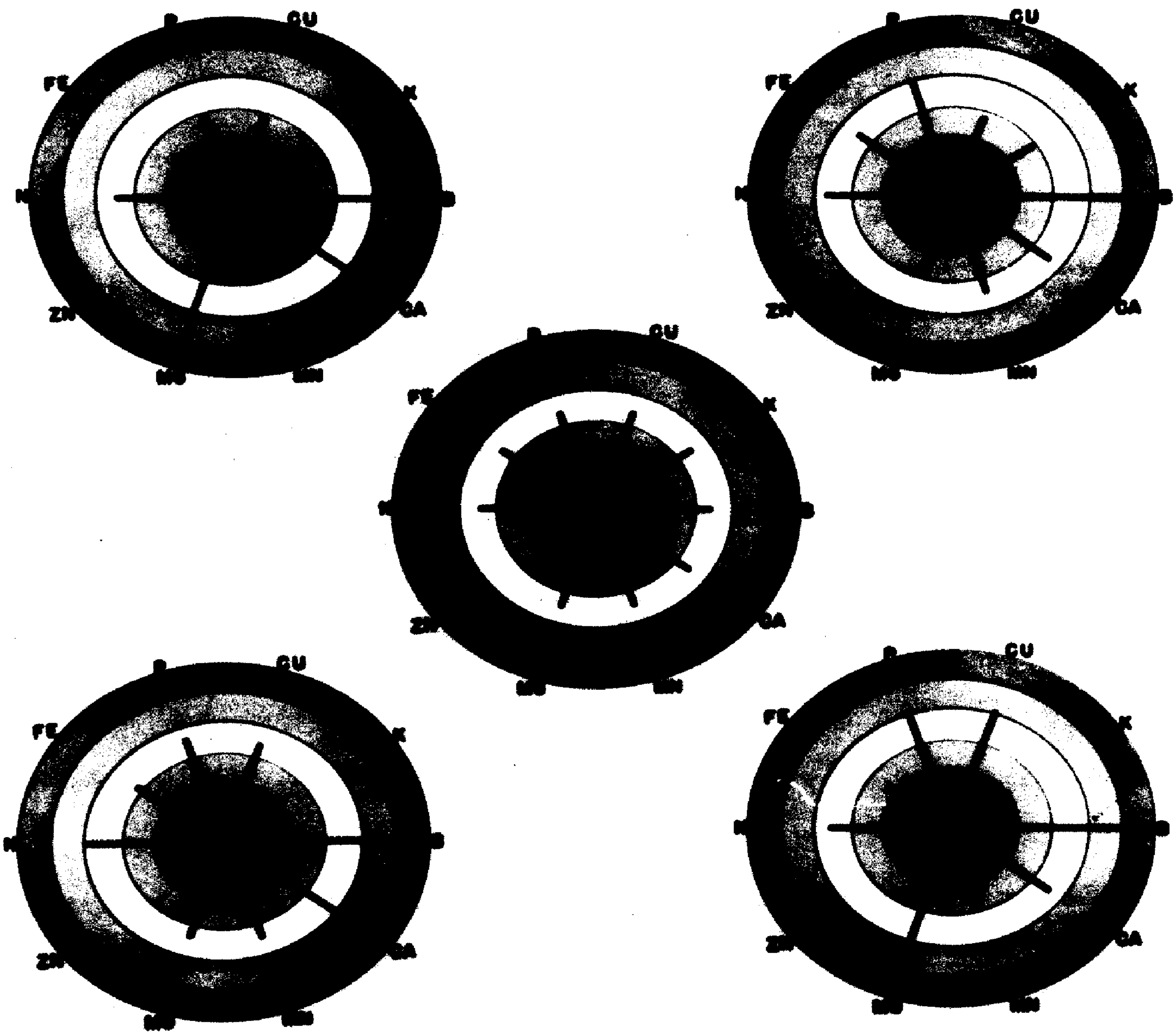

Figure 17

Phosphorus, copper, boron and magnesium were above optimum when zinc was applied at the rate of 4X optimum concentration, but a decrease occurred for calcium, manganese, and iron when compared to 2X concentration. Potassium did not change appreciably when the concentration of the nutrient solution was increased from 2X to 4X optimum.

Increasing the zinc concentration in the nutrient-solution resulted in larger total deviations from optimum balance than decreasing zinc. When none of the element was added, negative deviations exceeded positive deviations, but were not intense. The 1/2X optimum concentration resulted in positive deviations from optimum balance exceeding the negative deviations. As the concentration of zinc in the nutrient solution was increased 2X and 4X optimum, the net positive deviations increased.

Copper: The influence of varying the concentration of copper in the nutrient solution is shown in Table 27, Figure 18. When the copper concentration was reduced to 1/2X optimum, nitrogen, iron, phosphorus, manganese, as well as copper, remained near the optimum level range, but potassium decreased. Boron, calcium, and magnesium were at relatively high levels. As copper was omitted from the nutrient-solution nitrogen, phosphorus, boron, manganese, and magnesium were reduced, while calcium increased as compared to 1/2X optimum.

When copper was increased to the 2X optimum concentration, all of the nutrient-elements were about the same

Table 27. Leaf Composition and Nutrient-Element Balance as Influenced by Varying Concentrations of Copper in the Nutrient Solution

Copper concentration		Leaf Composition								
		N	P	K	Ca	Mg	Fe	Cu	B	Mn
Omitted	% Dry weight	2.93	0.11	0.87	2.02	0.80	0.013	0.0007	0.006	0.008
	Chart index	89	68	71	161	129	100	140	150	61
1/2 optimum	% Dry weight	3.55	0.16	0.87	1.58	0.94	0.013	0.0005	0.009	0.012
	Chart index	108	100	71	126	151	100	100	225	92
Optimum	% Dry weight	3.26	0.16	1.22	1.25	0.62	0.013	0.0005	0.004	0.013
	Chart index	100	100	100	100	100	100	100	100	100
2X optimum	% Dry weight	3.63	0.13	0.79	1.67	0.87	0.014	0.0009	0.010	0.014
	Chart index	111	81	64	133	140	107	180	250	107
4X optimum	% Dry weight	3.81	0.13	0.82	1.25	0.54	0.008	0.0008	0.009	0.010
	Chart index	116	81	67	100	87	61	160	225	76

Concentration	Deviation of Chart Index from Optimum Balance: Positive	Negative	Difference	Total
Omitted	180	111	+ 69	291
1/2 optimum	210	37	+ 173	247
Optimum	0	0	0	0
2X optimum	328	55	+ 273	383
4X optimum	201	128	+ 73	329

To accompany Page 32

Figure 18. Nutrient-Element Balance in Relation to Varying the Concentration of Copper in the Nutrient Solution.

Upper left - omitted, upper right - 1/2X optimum, center - optimum, lower left - 2X optimum, lower right - 4X optimum. The various bands on each chart (from the edge toward center) represent excess, approaching excess, optimum, hidden deficiency and deficiency.

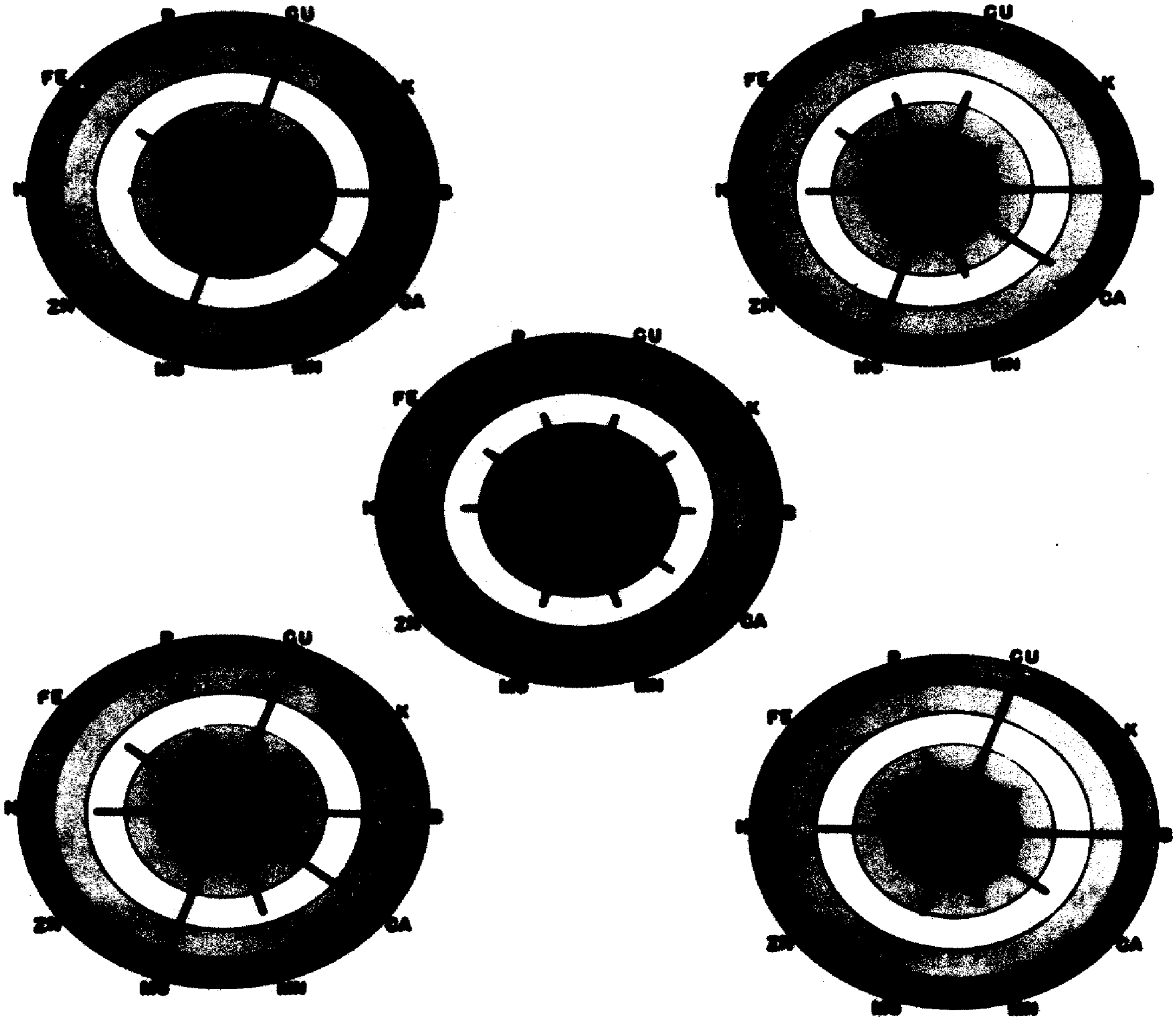

Figure 18

as using concentrations of 1/2X optimum, except for an increase in copper. Increasing the concentration of copper to 4X optimum resulted in below optimum values for iron, manganese, and magnesium, while calcium was near the optimum level. The remaining nutrient-elements were about the same as found for the 2X optimum concentration, except for a slight increase in nitrogen.

Increasing the concentration of copper in the nutrient-solution produced greater total deviations from optimum balance than by decreasing copper. Positive deviations exceeded negative deviations from optimum balance in all concentrations of copper. The greatest positive deviations occurred at 2X optimum concentration. Correspondingly, the next largest positive deviations from optimum balance occurred at 1/2X optimum concentrations.

Discussion

Growth of Montmorency cherry trees appears to be significantly affected by either shortages or excesses of all the nutrient-elements more commonly used as fertilizers before visible symptoms of shortages or excesses appear. Nightingale (23) indicated that a reduction in size of otherwise normal plant and fruit was brought about by varying the nutrient-elements. Nightingale believed that this condition was the result of balanced multiple deficiencies.

Also Shear, Crane and Meyers (25) believe that at any level of nutritional intensity, there exists a nutritional balance at which optimum growth for that intensity will result, and that at any given level of nutritional intensity, provided all nutrient-elements are in proper balance, it is possible to obtain plants that appear normal in every respect, and in which all metabolic processes are normal. They also state that plants may be grown at an apparently high level of intensity of nutrition which, in the absence of more vigorous or higher yielders for comparison, may appear to be making maximum growth and yield, and yet the plants may be capable of greater yields if a more favorable balance at a lower intensity is brought about.

When the amount of growth, as measured by dry weight increase, produced by using the various concentrations of a nutrient-element are added together, nitrogen is found to restrict growth more profoundly than the other nutrient-elements. Potassium, phosphorus, and calcium, in the order mentioned, restrict growth less than nitrogen. The minor elements, iron, copper, and manganese, zinc, and boron restrict growth less then nitrogen, phosphorus, potassium, or calcium. Magnesium appears to have the least effect on growth. This would indicate that a listing of nutrient-elements in order of their influence upon growth resulting from variations in nutrient-solution concentration would be as follows: nitrogen, potassium, phosphorus, calcium, iron, copper, manganese, zinc, boron, and magnesium.

The characteristic appearances of deficiency and excess symptoms, however, would indicate that this arrangement of nutrient-elements would be changed if visable symptoms were present.

The results of this study show (Table 12) that the effectiveness of a given deviation from optimum concentration depends upon the nutrient-element. For example, nitrogen restricted growth at high concentrations more than any of the other nutrient-elements, while at the lowest concentrations, potassium and phosphorus produced less growth than the other nutrient-elements. However, growth was not as proportionately reduced as at higher concentrations.

From these studies no one ranking, that would apply to both shortages and excesses of nutrient-elements may be made in regard to their influence on growth when out of balance in the nutrient solution. The order of listing given above would apply to combined effects of shortages and excesses. The listing, in ascending order for growth, which would apply to the combined shortages is as follows: potassium, phosphorus, nitrogen, calcium, copper, iron, magnesium, manganese, boron, and zinc. In regard to combined excesses, the listing in ascending order for growth would be as follows: nitrogen, iron, phosphorus, calcium, potassium, zinc, boron, manganese, copper, and magnesium. This would indicate that of the ten nutrient-elements studied, a shortage of potassium would more adversely affect growth than a shortage of any of the others, while an excess of nitrogen would more adversely affect growth than an excess of any of the other nutrient-elements.

Following Thatcher's classification of mineral elements (27), those nutrient-elements classified as energy storers, nitrogen and phosphorus, had the greatest effect in reducing growth. Those nutrient-elements classified as translocation regulators, potassium, calcium, and magnesium, had less effect upon growth than the energy storing elements. The oxidation-reduction regulators, which are iron, manganese, zinc, and copper, had the least effect upon growth. These generalizations would apply to shortages, excesses, and combined shortages and excesses.

At concentrations below optimum, phosphorus, of those nutrient-elements classified as energy storers, was more effective than nitrogen in reduction of growth, but as concentrations were increased above optimum, nitrogen reduced growth more than phosphorus. When the overall effect of deviations below and above optimum are combined, nitrogen was more effective than phosphorus. Of those nutrient-elements classified as translocation regulators, potassium was more effective than calcium, and calcium more effective than magnesium.

In general, iron was more effective in restricting growth than the other nutrient-elements classified as oxidation-reduction regulators. The effect of copper was greater than manganese, and the effect of manganese was greater than zinc, except with concentrations above optimum where the order was reversed.

According to Cooper (8), the influence on growth is directly related to the standard electrode potential. The results of the experiment indicate that for the translocation regulators, as classified by Thatcher (27), growth had a positive relationship to standard electrode potential. However, those nutrient-elements classified as oxidation-reduction regulators showed a negative relationship. Since the standard electrode potential for ammonia was not available, this relationship could not be determined for those nutrient-elements classified as energy storers.

If, however, all the nitrogen had been supplied as nitrates, there would be no appreciable difference between nitrogen and phosphorus in relation to growth, because their standard electrode potential is essentially equal. The work of Brown (5) indicates that nitrogen had a greater effect upon growth than the other elements. The results of this study indicate that nitrogen had a greater influence upon growth than phosphorus at high concentrations.

There is considerable evidence that nitrogen will affect the absorption of the other elements and indirectly influence growth. Several factors would bring about this variation in growth. Such variations may depend upon the form in which the element would be present in the substrate within the plant. Also growth variations would result from cationic or anionic unbalances after the elements have been absorbed and translocated to various parts of the plant. Continued applications of nitrogen increased the nitrogen accumulation in the leaves, according to Shear, Crane, and Myers (26), and a functional unbalance exists between nitrogen and some other element.

If a nutritional unbalance is created by shortages or excesses of an element, this unbalance will affect growth as the specific relationships of these various elements are disrupted. The effects of nitrogen upon phosphorus, phosphorus upon nitrogen, calcium upon magnesium, potassium upon copper, etc. are examples. With these various nutrient-element relationships, the intensity and balance of the nutrients would be affected within the plant. Any variation from optimum balance would bring about changes that would alter the metabolic and physiological processes within the plant.

Leaf analysis, however, in many instances failed to correlate with nutrient-solution concentration. Leaf analysis for nitrogen, phosphorus, potassium, calcium, magnesium, and manganese showed a good relationship to the concentration of these nutrient-elements in the nutrient-solution; while the leaf analysis for iron, boron, and copper failed to show any direct relationship to the concentration in the nutrient solution. Apparently the distortion of the balance of nutrient-elements within the leaves had a greater influence upon the absorption of iron, copper, and boron than the concentration in the nutrient solution. Nutrient-element balance in the leaves was also seriously altered with various concentrations of nitrogen, phosphorus, potassium, calcium, magnesium, and manganese, but here the absorption of one of these nutrient-elements apparently is influenced more by concentration in the nutrient-solution than by the distortion of nutrient-element balance.

Nutrient-element balance was disturbed more at the 1/2X optimum than when nitrogen, phosphorus, calcium, manganese, or boron was omitted. This would indicate that for these nutrient elements nutrient-element balance would be easily disturbed by a shortage of a nutrient-element, but when the shortage becomes more acute, the distrubance in nutrient-element balance is reduced because of the lack of sufficient quantities of the nutrient-element to seriously influence the absorption of the other nutrient-elements. For the other nutrient-elements (potassium, magnesium, iron, copper, zinc) there would appear to be a direct relationship between the shortage of the nutrient-element and its disturbance of nutrient-element balance.

Conversely, nutrient-element balance was disturbed more at 2X optimum than at 4X optimum concentrations for potassium, and copper. Apparently with excesses of potassium, and copper, the distrubance of balance is more nearly associated with nutrient-element inter-relationships than with an excess of the nutrient-element. The disturbance of nutrient-element balance by excesses of nitrogen, phosphorus, calcium, magnesium, manganese, iron, boron, and zinc would appear to be more dependent upon the excess quantity of the nutrient-element than upon nutrient-element inter-relationships.

Many workers have reported certain relationships between nutrient-elements. Kenworthy and Gilligan (19) showed a positive relationship between leaf nitrogen and leaf phosphorus, when phosphorus was low. However, Boynton and Compton (4) found a negative relationship between nitrogen and phosphorus, but this relationship existed at higher levels of phosphorus. As indicated by the data in Table 18, the relationship between nitrogen concentration and phosphorus absorption is positive when the nitrogen concentration is below optimum, and negative when nitrogen concentrations were above optimum.

Similarly, Shear, Crane and Myers (26) have reported that a negative relationship exists between potassium and manganese when manganese is above 200 ppm. Kenworthy (18) has found a positive relationship between potassium and manganese when manganese was below 200 ppm. The data in Table 23 show this relationship between manganese and potassium is positive when the manganese concentration is below optimum, and negative when manganese concentration is above optimum.

Several workers have reported many such relationships between nutrient-elements. For the most part, these relationships have been reported to be either positive or negative, but not of such a nature as indicated above, that is, where the type of relationship changes in regard to shortages and excesses of a nutrient-element.

As indicated by the data of this study, the relationships between nutrient-element absorption and concentration may be different for concentrations below optimum than for concentrations above optimum. In this respect, there are potentially nine different types of relationships which may occur. These nine types of relationships may be outlined as follows:

1. A positive correlation between nutrient-element absorption and nutrient-element concentration when the concentration is either below or above optimum.
2. A negative correlation between nutrient-element absorption and nutrient-element concentration when the concentration is either below or above optimum.
3. A positive correlation between nutrient-element absorption and nutrient-element concentration when the concentration is below optimum, and a negative correlation between nutrient element absorption and nutrient-element concentration when the concentration is above optimum.

4. A negative correlation between nutrient-element absorption and nutrient-element concentration when the concentration is below optimum, and a positive correlation between nutrient-element absorption and nutrient-element concentration when the concentration is above optimum.
5. No correlation between nutrient-element absorption and nutrient-element concentration when the concentration is below optimum, and a negative correlation between nutrient-element absorption and nutrient-element concentration when the concentration is above optimum.
6. No correlation between nutrient-element absorption and nutrient-element concentration when the concentration is below optimum, and a positive correlation between nutrient-element absorption and nutrient-element concentration when the concentration is above optimum.
7. Positive correlation between nutrient-element absorption and nutrient-element concentration when the concentration is below optimum, and no correlation between nutrient-element absorption and nutrient-element concentration when the concentration is above optimum.
8. Negative correlation between nutrient-element absorption and nutrient-element concentration when

the concentration is below optimum, and no correlation between nutrient-element absorption and nutrient-element concentration when the concentration is above optimum.

9. No correlation between nutrient-element absorption and nutrient-element concentration when the concentration is either below or above optimum.

The general trends of the relationships between the concentration of a given nutrient-element and the absorption of other nutrient-elements are shown in Tables 18 to 27, inclusive. These relationships may be classified in regard to the above types as presented in Table 28.

The relationship between the absorption of a nutrient-element and the concentration of nutrient-elements, in many cases, appears to be a characteristic of the nutrient-element. Nitrogen absorption does not appear to be influenced by the concentration of other nutrient-elements, excepting high copper. Phosphorus, potassium, iron, and manganese, in general, fall in Class 3, indicating that the absorption of these nutrient-elements is decreased when the concentration of any one of the other nutrient-elements is either above or below optimum. Copper and boron appear to be in Class 4, indicating that the absorption of these nutrient-elements is increased when the concentration of any one of the other nutrient-elements is either below or above optimum. Calcium

Table 28. Relative Type of Relationship* Between Various Concentrations of a Nutrient-Element and Nutrient-Element Absorption as Measured by Leaf Analysis.

Nutrient element varied in the solution	Nutrient-Element Absorbed								
	N	P	K	Ca	Mg	Fe	Cu	B	Mn
	Type of Relationship*								
Nitrogen	1	3	2	4	8	3	4	4	2
Phosphorus	9	1	3	1	1	3	4	4	1
Potassium	9	3	1	5	4	3	4	4	7
Calcium	9	7	3	1	9	3	4	4	3
Magnesium	9	3	3	3	1	3	4	4	3
Iron	9	3	3	6	1	3	4	4	3
Copper	9	3	3	4	4	5	4	4	3
Boron	9	3	5	2	3	3	4	4	3
Manganese	9	3	3	9	1	3	4	4	1
Zinc	9	9	3	4	4	3	1	4	3

* See Page 41

and magnesium do not fit any one class, which indicates that the absorption of these nutrient-elements has a relationship to concentration of other nutrient-elements which is dependent upon the nutrient-element whose concentration is being varied.

Summary

One-year-old Montmorency cherry trees were grown in nutrient-solutions, using five different levels of ten nutrient-elements. Growth was measured in terms of dry weight increase. Leaf composition was determined for nitrogen, potassium, calcium, magnesium, iron, boron, manganese, and copper.

Maximum growth of Montmorency cherry trees was obtained when all of the nutrient-elements were at optimum balance. Any deviations, as a shortage or excess, from optimum balance resulted in a significant reduction in growth without the appearance of visable symptoms of a deficiency or toxicity.

Reducing the concentrations below optimum, potassium reduced growth more than the other elements. The remaining elements produced growth in the following increasing order: phosphorus, nitrogen, calcium, copper, iron, magnesium, manganese, boron, and zinc.

Increasing the concentrations above optimum, nitrogen reduced growth more than the other elements. The remaining elements produced growth in the following increasing order: iron, phosphorus, calcium, potassium, zinc, boron, manganese, copper, and magnesium.

Combining the growth produced at all concentrations (below and above optimum), varying the concentration of nitrogen reduced growth more than the other elements. The remaining elements produced growth in the following increasing order: potassium, phosphorus, calcium, iron, copper, manganese, zinc, boron, and magnesium.

In regard to their influence on growth, the various nutrient-elements group themselves according to physiological function. The energy storing elements, nitrogen, and phosphorus, had the greatest influence on growth. The translocation regulators, potassium, calcium, and magnesium, had less effect upon growth than the energy storing elements. The oxidation-reduction regulators, iron, manganese, zinc, and copper, had the least effect upon growth.

At concentrations below optimum, phosphorus, of those elements calssified as energy storers, was more effective than nitrogen in reduction of growth, but as concentrations were increased above optimum, nitrogen reduced growth more than phosphorus.

Of those elements classified as translocation regulators, potassium was more effective than calcium, and calcium was more effective than magnesium.

Iron was more effective in restricting growth than the other nutrient-elements classified as oxidation-reduction regulators. The effect of copper was greater than manganese; manganese was greater than zinc when the concentration was below optimum. Above optimum, the order was reversed for copper, manganese, and zinc.

Leaf analyses for nitrogen, phosphorus, potassium, calcium, magnesium, and manganese showed a positive relationship to the concentration of these nutrient-elements in the nutrient-solution.

With concentrations below optimum, there was a direct relationship between the shortage of a given nutrient-element and the disturbance of nutrient-element balance for potassium, magnesium, iron, copper, and zinc.

Nutrient-element balance was disturbed more at 1/2X optimum for nitrogen, phosphorus, calcium, manganese, and boron than when omitted.

Excesses of nitrogen, phosphorus, calcium, magnesium, manganese, iron, boron, and zinc disturb nutrient-element balance in proportion to the excess quantities. Nutrient-element balance is disturbed more at 2X optimum than at 4X optimum concentration of potassium, and copper.

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APPENDIX

Table 1. Dry Weight of Leaves, Shoots, Trunk, Roots, Entire Tree, and Increase in Dry Weight as Influenced by Varying Levels of Nitrogen in Nutrient-Solutions*--grams

Nitrogen concentration	Tree number	When Harvested					When planted	Net increase
		Leaves	Shoots	Trunk	Roots	Tree		
ppm								
0	43	9.4	4.3	10.7	28.0	52.4	26.4	26.0
	85	11.0	5.5	13.0	61.8	91.3	44.8	46.5
	169	7.8	5.8	13.4	44.3	71.3	34.9	36.4
	Total --	28.2	15.6	37.1	134.1	215.0	106.1	108.9
	Average --	9.4	5.2	12.3	44.7	71.6	35.3	36.3
112.0	44	16.1	10.8	16.6	51.7	95.2	44.7	50.5
	86	13.6	8.0	17.5	43.4	82.5	37.1	45.4
	128	17.3	10.1	20.3	61.3	109.0	54.5	53.5
	Total --	47.0	28.9	54.4	156.4	286.7	136.3	149.4
	Average --	15.6	9.6	18.1	52.1	95.5	45.4	49.8
224.0	3	21.1	18.6	17.8	54.6	112.1	40.6	71.5
	87	21.1	14.1	18.3	47.2	100.7	42.7	58.0
	129	22.8	16.8	26.0	80.3	145.9	62.3	83.6
	Total --	65.0	49.5	62.1	182.1	358.7	145.6	213.1
	Average --	21.6	16.5	20.7	60.7	119.5	48.5	71.0
448.0	88	16.8	7.3	19.8	41.6	85.5	48.9	36.6
	130	10.9	5.3	16.8	45.6	78.6	63.8	14.8
	172	19.9	12.0	16.9	39.1	87.9	32.0	55.9
	Total --	47.6	24.6	53.5	126.3	252.0	144.7	107.3
	Average--	15.8	8.2	17.8	42.1	84.0	48.2	35.7
896.0	47	12.9	6.5	12.1	43.2	74.7	47.2	27.5
	89	12.8	7.8	15.7	38.7	75.0	47.1	27.9
	131	14.7	17.6	17.1	32.4	81.8	46.4	35.4
	Total --	40.4	31.9	44.9	114.3	231.5	140.7	90.8
	Average--	13.4	10.6	14.9	38.1	77.2	46.9	30.3

* All other nutrient-elements constant in nutrient solution

Table 2. Dry Weight of Leaves, Shoots, Trunk, Roots, Entire Tree, and Increase in Dry Weight as Influenced by Varying Levels of Potassium in Nutrient-Solution*--grams

Phosphorus concentration	Tree number	When Harvested					When planted	Net increase
		Leaves	Shoots	Trunk	Roots	Tree		
ppm								
0	48	7.3	2.3	8.1	23.3	41.0	25.1	15.9
	90	13.5	7.0	18.6	55.0	94.1	57.1	37.0
	174	12.3	6.3	12.0	39.4	70.0	38.6	31.4
	Total --	33.1	15.6	38.7	117.7	205.1	120.8	84.3
	Average --	11.0	5.2	12.9	39.2	68.3	40.2	28.1
34.0	91	13.7	6.9	17.6	53.6	91.8	56.3	35.5
	133	16.2	9.2	22.6	47.3	95.3	49.7	45.6
	175	15.7	7.6	19.8	45.3	88.4	44.4	44.0
	Total --	45.6	23.7	60.0	146.2	275.5	150.4	125.1
	Average --	15.2	7.9	20.0	48.7	91.8	50.1	41.7
68.0	3	21.1	18.6	17.8	54.6	112.1	40.6	71.5
	87	21.1	14.1	18.3	47.2	100.7	42.7	58.0
	129	22.8	16.8	26.0	80.3	145.9	62.3	83.6
	Total --	65.0	49.5	62.1	182.1	358.7	145.6	213.1
	Average --	21.6	16.5	20.7	60.7	119.5	48.5	71.0
136.0	50	9.8	5.0	12.3	36.7	63.8	43.5	20.3
	92	23.0	12.8	21.6	58.9	116.3	46.7	69.6
	176	16.8	8.9	14.4	44.2	84.3	43.7	40.6
	Total --	49.6	26.7	48.3	139.8	264.4	133.9	130.5
	Average --	16.5	8.9	16.1	46.6	88.1	44.6	43.5
272.0	9	18.3	12.5	17.7	48.0	96.5	37.4	59.1
	51	22.0	11.5	19.5	50.7	103.7	47.7	56.0
	177	10.3	4.3	12.7	34.4	61.7	38.1	23.6
	Total --	50.6	28.3	49.9	133.1	261.9	123.2	138.7
	Average --	16.8	9.4	16.6	44.3	87.3	41.0	46.2

* All other nutrient-elements constant in nutrient solution

Table 3. Dry Weight of Leaves, Shoots, Trunk, Roots, Entire Tree and Increase in Dry Weight as Influenced by Varying Levels of Potassium in Nutrient-Solution*--grams

Potassium concentration	Tree number	When Harvested					When planted	Net increase
		Leaves	Shoots	Trunk	Roots	Tree		
ppm								
0	94	12.5	7.0	16.5	31.6	67.6	38.3	29.3
	136	9.9	6.7	15.0	54.4	86.0	60.7	25.3
	178	9.5	4.0	15.2	30.9	59.6	36.1	23.5
	Total --	31.9	17.7	46.7	116.9	213.2	135.1	78.1
	Average --	10.6	5.9	15.5	38.9	71.0	45.0	26.0
43.0	53	12.1	5.6	11.8	46.5	76.0	45.5	30.5
	95	15.3	9.3	16.5	36.8	77.9	39.8	38.1
	137	15.2	8.1	21.2	51.0	95.5	53.4	42.1
	Total --	42.6	23.0	49.5	134.3	249.4	138.7	110.7
	Average --	14.2	7.6	16.5	44.7	83.1	46.2	36.9
86.0	3	21.1	18.6	17.8	54.6	112.1	40.6	71.5
	87	21.1	14.1	18.3	47.2	100.7	42.7	58.0
	129	22.8	16.8	26.0	80.3	145.9	62.3	83.6
	Total --	65.0	49.5	62.1	182.1	358.7	145.6	213.1
	Average --	21.6	16.5	20.7	60.7	119.5	48.5	71.0
172.0	12	15.1	7.7	13.1	41.2	77.1	42.1	35.0
	54	15.0	7.9	16.6	58.5	98.0	49.5	48.5
	138	23.6	15.1	25.5	51.5	115.7	47.6	68.1
	Total --	53.7	30.7	55.2	151.2	290.8	139.2	151.6
	Average --	17.9	10.2	18.4	50.4	96.9	46.4	50.5
344.0	13	11.6	4.8	10.7	38.0	65.1	34.7	30.4
	97	19.0	10.7	22.7	53.9	106.3	53.8	52.5
	181	12.0	6.7	10.8	42.2	71.7	35.1	36.6
	Total --	42.6	22.2	44.2	134.1	243.1	123.6	119.5
	Average --	14.2	7.4	14.7	44.7	81.0	41.2	39.8

*All other nutrient-elements constant in nutrient solution

APPENDIX

Table 4. Dry Weight of Leaves, Shoots, Trunk, Roots, Entire Tree and Increase in Dry Weight as Influenced by Varying Levels of Calcium in Nutrient-Solution*--grams

Calcium Concentration	Tree number	When Harvested: Leaves	Shoots	Trunk	Roots	Tree	When planted	Net increase
ppm								
0	56	17.9	7.5	15.1	48.3	88.8	47.7	41.1
	98	12.6	5.5	16.2	42.8	77.1	43.0	34.1
	182	15.2	9.0	13.7	33.3	71.2	33.0	38.2
	Total --	45.7	22.0	45.0	124.4	237.1	123.7	113.4
	Average --	15.2	7.3	15.0	41.4	79.0	41.2	37.8
88.0	57	19.0	10.6	16.5	53.5	99.6	43.0	56.6
	99	7.3	4.8	16.5	42.3	70.9	48.8	22.1
	183	17.1	9.2	14.6	51.9	92.8	42.5	50.3
	Total --	43.4	24.6	47.6	147.7	263.3	134.3	129.0
	Average --	14.4	8.2	15.8	49.2	87.7	44.7	43.0
176.0	3	21.1	18.6	17.8	54.6	112.1	40.6	71.5
	87	21.1	14.1	18.3	47.2	100.7	42.7	58.0
	129	22.8	16.8	26.0	80.3	145.9	62.3	83.6
	Total --	65.0	49.5	62.1	182.1	358.7	145.6	213.1
	Average --	21.6	16.5	20.7	60.7	119.5	48.5	71.0
352.0	16	14.1	9.6	11.3	48.0	83.0	34.7	48.3
	58	15.6	7.9	14.5	43.7	81.7	33.6	48.1
	184	14.8	9.4	12.6	37.8	74.6	32.3	42.3
	Total --	44.5	26.9	38.4	129.5	239.3	100.6	138.7
	Average --	14.8	8.9	12.8	43.1	79.7	33.5	46.2
704.0	17	16.3	9.6	14.2	57.3	97.4	44.5	52.9
	101	16.4	10.3	14.4	48.2	89.3	41.8	47.5
	185	11.2	5.2	11.3	28.9	56.6	28.1	28.5
	Total --	43.9	25.1	39.9	134.4	243.3	114.4	128.9
	Average	14.6	8.3	13.3	44.8	81.0	38.1	42.9

*All other nutrient-elements constant in nutrient solution

Table 5. Dry Weight of Leaves, Shoots, Trunk, Roots, Entire Tree and Increase in Dry Weight as Influenced by Varying Levels of Magnesium in Nutrient Solution*--grams

Magnesium concentration	Tree number	When Harvested: Leaves	Shoots	Trunk	Roots	Tree	When planted	Net increase
ppm								
0	18	16.0	8.3	13.6	35.7	73.6	32.3	41.3
	60	16.2	10.8	14.5	64.4	105.9	43.9	62.0
	186	13.2	5.8	14.0	48.5	81.5	34.6	46.9
	Total --	45.4	24.9	42.1	148.6	261.0	110.8	150.2
	Average --	15.1	8.3	14.0	49.5	87.0	36.9	50.0
29.0	103	10.8	7.2	10.8	47.1	75.9	41.2	34.7
	145	18.2	16.4	24.4	55.8	114.8	49.0	65.8
	187	13.9	7.1	13.7	43.8	78.5	39.8	38.7
	Total --	42.9	30.7	48.9	146.7	269.2	130.0	139.2
	Average --	14.3	10.2	16.3	48.9	89.7	43.3	46.4
58.0	3	21.1	18.6	17.8	54.6	112.1	40.6	71.5
	87	21.1	14.1	18.3	47.2	100.7	42.7	58.0
	129	22.8	16.8	26.0	80.3	145.9	62.3	83.6
	Total --	65.0	49.5	62.1	182.1	358.7	145.6	213.1
	Average --	21.6	16.5	20.7	60.7	119.5	48.5	71.0
116.0	20	23.5	15.1	17.3	53.4	109.3	27.1	82.2
	62	21.2	16.5	16.6	49.6	103.9	37.4	66.5
	146	23.5	15.8	24.6	72.0	135.9	60.4	75.5
	Total --	68.2	47.4	58.5	175.0	349.1	124.9	224.2
	Average --	22.7	15.8	19.5	58.3	116.3	41.6	74.7
232.0	21	16.7	10.1	13.3	54.3	94.4	41.2	53.2
	63	17.1	11.1	19.0	51.5	98.7	40.8	57.9
	147	15.8	8.6	22.6	64.0	111.0	57.3	53.7
	Total --	49.6	29.8	54.9	169.8	304.1	139.3	164.8
	Average --	16.5	9.9	18.3	56.6	101.3	46.4	54.9

*All other nutrient-elements constant in nutrient solution

Table 6. Dry Weight of Leaves, Shoots, Trunk, Roots, Entire Tree and Increase in Dry Weight as Influenced by Varying Levels of Manganese in Nutrient-Solution*--grams

Manganese concentration	Tree number	When Harvested					When planted	Net increase
		Leaves	Shoots	Trunk	Roots	Tree		
ppm								
0	64	20.3	11.9	18.6	56.4	107.2	40.4	66.8
	148	16.2	10.7	17.4	65.6	109.9	57.7	52.2
	190	19.3	11.6	19.3	43.0	93.2	35.2	58.0
	Total --	55.8	34.2	55.3	165.0	310.3	133.3	177.0
	Average --	18.6	11.4	18.4	55.0	103.4	44.4	59.0
2.5	23	10.6	7.6	14.4	32.4	65.0	31.2	33.8
	65	19.2	10.3	21.2	52.7	103.4	42.6	60.8
	191	11.4	8.4	17.3	42.7	79.8	39.8	40.0
	Total --	41.2	26.3	52.9	127.8	248.2	113.6	134.6
	Average --	13.7	8.7	17.6	42.6	82.7	37.8	44.8
5.0	3	21.1	18.6	17.8	54.6	112.1	40.6	71.5
	87	21.1	14.1	18.3	47.2	100.7	42.7	58.0
	129	22.8	16.8	26.0	80.3	145.9	62.3	83.6
	Total --	65.0	49.5	62.1	182.1	358.7	145.6	213.1
	Average --	21.6	16.5	20.7	60.7	119.5	48.5	71.0
10.0	24	14.7	10.7	17.4	52.3	95.1	45.2	49.9
	150	15.8	9.6	14.3	59.5	99.2	47.8	51.4
	192	14.8	7.7	17.5	37.6	77.6	37.8	39.8
	Total --	45.3	28.0	49.2	149.4	271.9	130.8	141.1
	Average --	15.1	9.3	16.4	49.8	90.6	43.6	47.0
20.0	109	19.7	14.4	13.6	67.4	115.1	48.4	66.7
	151	19.4	9.7	21.9	59.2	110.2	59.7	50.5
	193	13.1	7.6	16.0	51.7	88.4	46.5	41.9
	Total --	52.2	31.7	51.5	178.3	313.7	154.6	159.1
	Average --	17.4	10.5	17.1	59.4	104.5	51.5	53.0

*All other nutrient-elements constant in nutrient solution

Table 7. Dry Weight of Leaves, Shoots, Trunk, Roots, Entire Tree and Increase in Dry Weight as Influenced by Varying Levels of Boron in Nutrient-Solution*--grams

Boron concentration	Tree number	When Harvested					When planted	Net increase
		Leaves	Shoots	Trunk	Roots	Tree		
ppm								
0	26	17.4	12.4	19.4	57.7	106.9	46.6	60.3
	68	16.2	9.7	19.9	65.0	110.8	52.9	57.9
	152	22.0	11.9	23.1	68.2	125.2	59.3	65.9
	Total --	55.6	34.0	62.4	190.9	342.9	158.8	184.1
	Average --	18.5	11.3	20.8	63.6	114.3	52.9	61.3
1.5	69	16.9	11.3	15.5	51.4	95.1	35.5	59.6
	153	14.6	9.3	14.4	54.6	92.9	43.9	49.0
	195	16.6	9.2	19.2	37.1	82.1	41.9	40.2
	Total --	48.1	29.8	49.1	143.1	270.1	121.3	148.8
	Average --	16.0	9.9	16.3	47.7	90.0	40.4	49.6
3.0	3	21.1	18.6	17.8	54.6	112.1	40.6	71.5
	87	21.1	14.1	18.3	47.2	100.7	42.7	58.0
	129	22.8	16.8	26.0	80.3	145.9	62.3	83.6
	Total --	65.0	49.5	62.1	182.1	358.7	145.6	213.1
	Average --	21.6	16.5	20.7	60.7	119.5	48.5	71.0
6.0	112	18.9	16.1	25.5	53.0	113.5	40.2	73.3
	154	24.1	15.7	28.0	60.1	127.9	52.3	75.6
	196	14.2	7.3	16.0	38.6	76.1	34.0	42.1
	Total --	57.2	39.1	69.5	151.7	317.5	126.5	191.0
	Average --	19.0	13.0	23.1	50.5	105.8	42.1	63.6
12.0	29	11.1	5.7	18.2	40.7	75.7	49.5	26.2
	155	16.4	10.9	23.6	45.2	96.1	53.7	42.4
	197	12.8	7.1	11.2	41.4	72.5	35.3	37.2
	Total --	40.3	23.7	53.0	127.3	244.3	138.5	105.8
	Average --	13.4	7.9	17.6	42.4	81.4	46.1	35.2

*All other nutrient-elements constant in nutrient solution

Table 8. Dry Weight of Leaves, Shoots, Trunk, Roots, Entire Tree and Increase in Dry Weight as Influenced by Varying Levels of Iron in Nutrient-Solutions*--grams

Iron concentration	Tree number	When Harvested Leaves	Shoots	Trunk	Roots	Tree	When planted	Net increase
ppm								
0	30	15.3	7.6	13.0	52.3	88.2	42.6	45.6
	156	13.3	6.8	15.4	62.3	97.8	54.9	42.9
	198	13.5	7.5	15.4	32.9	69.3	32.4	36.9
	Total --	42.1	21.9	43.8	147.5	255.3	129.9	125.4
	Average --	14.0	7.3	14.6	49.1	85.1	43.3	41.8
1.0	73	20.5	12.1	18.1	54.4	105.1	38.4	66.7
	115	14.2	9.1	15.3	51.4	90.0	35.2	54.8
	199	13.3	7.6	15.6	35.3	71.8	35.2	36.6
	Total --	48.0	28.8	49.0	141.1	266.9	108.8	158.1
	Average --	16.0	9.6	16.3	47.0	88.9	36.2	52.7
2.0	3	21.1	18.6	17.8	54.6	112.1	40.6	71.5
	87	21.1	14.1	18.3	47.2	100.7	42.7	58.0
	129	22.8	16.8	26.0	80.3	145.9	62.3	83.6
	Total --	65.0	49.5	62.1	182.1	358.7	145.6	213.1
	Average --	21.6	16.5	20.7	60.7	119.5	48.5	71.0
4.0	74	11.5	4.3	14.1	42.0	71.9	39.4	32.5
	116	12.1	8.4	11.3	32.4	64.2	29.9	34.3
	200	19.1	11.5	20.9	45.1	96.6	37.2	59.4
	Total --	42.7	24.2	46.3	119.5	232.7	106.5	126.2
	Average --	14.2	8.0	15.4	39.8	77.5	35.5	42.0
8.0	75	11.9	6.8	9.7	36.4	64.8	27.8	37.0
	159	16.2	9.7	14.3	61.9	102.1	52.3	49.8
	201	8.5	4.9	15.1	22.6	51.1	27.8	23.3
	Total --	36.6	21.4	39.1	120.9	218.0	107.9	110.1
	Average --	12.2	7.1	13.0	40.3	72.6	35.9	36.7

*All other nutrient-elements constant in nutrient solution

Table 9. Dry Weight of Leaves, Shoots, Trunk, Roots, Entire Tree and Increase in Dry Weight as Influenced by Varying Levels of Zinc in Nutrient-Solution*--grams

Zinc concentration	Tree number	When Harvested Leaves	Shoots	Trunk	Roots	Tree	When planted	Net increase
ppm								
0	118	17.7	12.5	21.2	46.0	97.4	37.3	60.1
	160	19.9	14.1	24.5	43.5	102.0	42.3	59.7
	202	15.2	7.5	15.7	46.3	84.7	39.9	44.8
	Total --	52.8	34.1	61.4	135.8	284.1	119.5	164.6
	Average --	17.6	11.3	20.4	45.2	94.7	39.8	54.8
1.0	77	18.0	9.6	15.7	44.6	87.9	40.4	47.5
	119	21.7	14.2	22.2	45.5	103.6	28.9	74.7
	203	19.2	13.2	15.2	39.3	86.9	29.1	57.8
	Total --	58.9	37.0	53.1	129.4	278.4	98.4	180.0
	Average --	19.6	12.3	17.7	43.1	92.8	32.8	60.0
2.0	3	21.1	18.6	17.8	54.6	112.1	40.6	71.5
	87	21.1	14.1	18.3	47.2	100.7	42.7	58.0
	129	22.8	16.8	26.0	80.3	145.9	62.3	83.6
	Total --	65.0	49.5	62.1	182.1	358.7	145.6	213.1
	Average --	21.6	16.5	20.7	60.7	119.5	48.5	71.0
4.0	78	17.0	8.9	16.8	41.1	83.8	35.4	48.4
	120	13.5	9.2	15.5	45.3	83.5	29.1	54.4
	204	20.6	13.9	18.1	49.4	102.0	42.6	59.4
	Total --	51.1	32.0	50.4	135.8	269.3	107.1	162.2
	Average --	17.0	10.6	16.8	45.2	89.7	35.7	54.0
8.0	37	15.4	8.9	19.4	42.7	86.4	43.5	42.9
	163	11.1	4.9	21.0	49.1	86.1	53.1	33.0
	205	14.5	10.4	17.6	35.1	77.6	34.3	43.3
	Total --	41.0	24.2	58.0	126.9	250.1	130.9	119.2
	Average --	13.6	8.0	19.3	42.3	83.3	43.6	39.7

*All other nutrient-elements constant in nutrient solution

Table 10. Dry Weight of Leaves, Shoots, Trunk, Roots, Entire Tree and Increase in Dry Weight as Influenced by Varying Levels of Copper in Nutrient-Solution*--Grams

Copper concentration	Tree number	When harvested					When	Net
		Leaves	Shoots	Trunk	Roots	Tree	planted	increase
ppm								
0	38	16.1	9.7	16.9	52.4	95.1	47.1	48.0
	80	4.7	2.1	7.7	30.2	44.7	28.6	16.1
	122	17.6	10.1	21.8	50.3	99.8	30.6	69.2
	Total --	38.4	21.9	46.4	132.9	239.6	106.3	133.3
	Average --	12.8	7.3	15.4	44.3	79.8	35.4	44.4
1.0	39	14.2	7.1	14.6	43.6	79.5	33.5	46.0
	123	13.3	6.7	14.4	35.7	70.1	31.3	38.8
	207	17.2	9.6	16.4	35.0	78.2	32.2	46.0
	Total --	44.7	23.4	45.4	114.3	227.8	97.0	130.8
	Average --	14.9	7.8	15.1	38.1	75.9	32.3	43.6
2.0	3	21.1	18.6	17.8	54.6	112.1	40.6	71.5
	87	21.1	14.1	18.3	47.2	100.7	42.7	58.0
	129	22.8	16.8	26.0	80.3	145.9	62.3	83.6
	Total --	65.0	49.5	62.1	182.1	358.7	145.6	213.1
	Average --	21.6	16.5	20.7	60.7	119.5	48.5	71.0
4.0	82	13.0	7.5	12.5	47.5	80.5	34.0	46.5
	124	11.5	7.2	15.0	42.2	75.9	36.5	39.4
	166	20.4	12.6	21.0	58.0	112.0	47.7	64.3
	Total --	44.9	27.3	48.5	147.7	268.4	118.2	150.2
	Average --	14.9	9.1	16.1	49.2	89.4	39.4	50.0
8.0	41	14.0	9.0	19.6	42.0	84.6	36.8	47.8
	167	24.1	13.5	24.3	50.2	112.1	49.2	62.9
	209	16.5	9.7	18.3	41.4	85.9	39.7	46.2
	Total --	54.6	32.2	62.2	133.6	282.6	125.7	156.9
	Average --	18.2	10.7	20.7	44.5	94.2	41.9	52.3

*All other nutrient-elements constant in nutrient solution

GROWTH, LEAF COMPOSITION AND NUTRIENT-ELEMENT BALANCE OF MONTMORENCY CHERRY (*Prunus cerasus*, L.)--Effect of Varying Concentrations of Ten Nutrient-Elements

By

Roy Kenneth Simons

An Abstract of

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ABSTRACT

One-year-old Montmorency cherry trees (*Prunus cerasus* L.) were grown in sand culture for one season to study their response to ten different nutrient-elements when one element was varied at a time while the remaining elements were kept constant.

Stock solutions of chemically pure NH_4NO_3, H_3PO_4, KCl, $CaCl_2$, $MgSO_4$, H_3BO_3, $MnSO_4$, $CuSO_4$, $ZnSO_4$, and $FeSO_4$ were prepared individually for each of the nutrient-elements. From these stock solutions a dilute solution for each treatment was prepared in which the elements were combined in definite proportions.

The optimum concentration, as determined from the literature, was as follows:

Nitrogen	224 ppm	Manganese	5.0 ppm
Phosphorus	68.0 ppm	Boron	3.0 ppm
Potassium	86.0 ppm	Iron	2.0 ppm
Calcium	176.0 ppm	Zinc	2.0 ppm
Magnesium	58.0 ppm	Copper	2.0 ppm

Each nutrient-element was varied individually from this optimum concentration so as to provide, for each nutrient-element, levels corresponding to omitted, 1/2X, 2X, and 4X optimum.

Growth measurements were recorded for dry weight increase of tree parts and length of terminal growth. Leaf analysis for nitrogen was determined by the Kjeldahl method, and spectrographic analysis was used for the determination of P, K, Ca, Mg, Fe, Cu, B, and Mn.

The results show that maximum growth was obtained when all the nutrient-elements were at optimum concentration. Any deviations, as a shortage or an excess, from optimum concentration resulted in a significant reduction in growth without the appearance of visible symptoms of a deficiency or toxicity.

Reducing the concentration below optimum, potassium reduced growth more than did the other elements which produced growth in the following increasing order: P, N, Ca, Fe, Mg, Mn, B, and Zn. As concentrations were increased above optimum, nitrogen reduced growth more than the other nutrient elements which produced growth in the following increasing order: Fe, P, Ca, K, Zn, B, Mn, Cu, and Mg.

The nitrogen concentration, when varied below and above optimum, resulted in less total growth for the five levels than the other nutrient-elements. The remaining elements produced growth in the following increasing order: K, P, Ca, Fe, Cu, Mn, Zn, B, and Mg.

Leaf analysis for N, P, K, Ca, Mg, and Mn showed a positive relationship to the concentration of these nutrient-elements in the nutrient-solution.

With concentrations below optimum, there is a direct relationship between the extent of the shortage of a given nutrient-element and the disturbance of nutrient-element balance for K, Mg, Fe, Cu, and Zn. However, nutrient-element balance was disturbed more at 1/2X optimum for N, P, Ca, Mn, and B, than when these nutrient-elements were omitted.

Excesses of N, P, Ca, Mg, Mn, Fe, B, and Zn disturb nutrient-element balance in proportion to the extent of the excess.

The manuscript includes a discussion of the factors involved and the relationship between concentration of the nutrient-solution and absorption of the different nutrient-elements by the plant.