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Title: EFFECTS OF VARYING LEVELS OF NITROGEN AND ZINC ON GROWTH AND NUTRIENT COMPOSITION OF THE SWEET CHERRY (*Prunus avium* L.)

Abstract approved: ______________________
M. H. Chaplin

The effects of N and Zn treatments on growth and nutrient composition of sweet cherry trees were investigated in greenhouse and outdoor sand culture experiments. In these studies, one-year old clonal F12-1 sweet cherry trees were grown in dithizone purified nutrient solution consisting of three levels of N (30, 80, and 224 ppm N) in factorial combination with four levels of Zn (0, .025, 1.25, and 5 ppm Zn). Dry weights and the concentrations of the major and minor elements were measured for the roots, trunks, and leaves for each tree.

The results show that the N levels significantly increased the dry weights of all plant parts under the two study conditions. Increasing the Zn level from 0 to 1.25 ppm significantly increased the dry

weights of the various parts of trees from the two locations. Application of 5 ppm Zn produced significantly less increases in dry weights of the various parts of the outdoor trees, but slightly decreased the dry weights of all plant parts in the greenhouse.

The N levels significantly increased both the concentration and uptake of N by the leaves and various parts of trees from the two locations. The Zn treatments decreased the concentration of N in leaves of the greenhouse trees at the N_1 level but increased it outdoors. Both the N and Zn levels had variable effects on the concentrations of P, K, Ca, Mg, Mn, Fe, Cu, and B in the various parts of trees from the two locations, but generally increased their uptake by these plant parts. The N and Zn treatments consistently increased both the concentration and uptake of Zn by leaves and various parts of the greenhouse and outdoor trees. The hypothesis was proposed that N is antagonistic to Zn uptake by leaves of plants. The results of this investigation gave no evidence in support of this hypothesis. Instead, the data show some evidence that N is synergistic to Zn in that an incease in N uptake by the leaves resulted in a corresponding increase in Zn uptake. This phenomenon was also evidenced in the various sections of the trees analyzed. The conclusion reached was that N is synergistically related to Zn in plant and that this relationship can be effectively utilized to control Zn deficiency in the field, of practical significance in commercial fruit production.

Effects of Varying Levels of Nitrogen and Zinc on Growth and Nutrient Composition of the Sweet Cherry (*Prunus avium* L.)

by

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NOTE TO MY PhD COMMITTEE: The first 55 pages of this thesis are a condensed version to be submitted to the American Society for Horticultural Science and the HortScience for possible publication in their proceedings. Balance of the thesis is given under the Appendix and presents additional material.

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GENERAL INTRODUCTION

The production of sweet cherry in Oregon has become an important segment of the economy of the State, and a substantial factor of the agricultural industry. In 1970 the growers produced approximately 40, 000 tons of marketable crop, ranking second in production in the United States, with an estimated value to the farmers of around thirteen million dollars.

However, despite the efforts exerted by the growers to provide the best cultural and fertilizer practices for maximum production of this economically important crop, Zn deficiency presents a serious nutritional problem in many commercial sweet cherry orchards in the State, especially in eastern Oregon. In view of reports in the literature that N has an adverse effect on the Zn nutrition of plants, there has been much speculation about possible antagonistic effects of N on Zn in sweet cherries. This indicated the importance of establishing a study to ascertain whether N is antagonistic to Zn uptake by plants or whether suspected antagonistic effects are largely or a result of dilution effects resulting from increased growth when N is applied with or without Zn. The objectives of this study were:

1. To study the effects of varying levels of N and Zn on

growth and nutrient composition of sweet cherry trees.

2. To determine the effect of N on Zn concentration in the leaves, as well as in the various sections of the trees.

3. To determine the relation between N uptake and Zn uptake by the trees.

Hypothesis: N is antagonistic to Zn uptake by leaves of plants.

Assumption: The uptake of Zn by leaves of plants is independent of N uptake.

Prepared for submission to the American Society of Horticultural Science

EFFECTS OF VARYING LEVELS OF NITROGEN AND ZINC ON GROWTH AND LEAF COMPOSITION OF THE SWEET CHERRY (*Prunus avium* L.)

ABSTRACT. The effects of N and Zn treatments on one-year old F12-1 clonal sweet cherry trees were investigated in greenhouse and outdoor experiments. The results showed that the dry weights of roots, trunks, leaves, tree tops, and total trees of both the greenhouse and outdoor trees significantly increased linearly with increased N supply. The dry weights of the various tree parts significantly increased with increasing Zn supply up to 1.25 ppm. Application of 5 ppm Zn produced significantly less increases in dry weights of plant parts under the outdoor conditions, but slightly decreased the dry weights of all plant parts in the greenhouse. The N concentration and uptake by leaves of the greenhouse and outdoor trees increased linearly with increasing N rates; the increasing Zn levels decreased leaf N in the greenhouse but increased it outdoors. The N and Zn levels had variable effects in influencing the concentrations of P, K, Ca, Mg, Mn, Fe, Cu, Zn, and B in leaves of the greenhouse and outdoor trees, but generally increased their uptake by the leaves. There was no evidence of any antagonistic effects of N and Zn concentration or uptake by the leaves; instead, there was a linear increase in Zn concentration and

uptake with increasing N and Zn rates. The hypothesis that N is antagonistic to Zn uptake by leaves of plants was therefore rejected.

IT IS GENERALLY recognized that N significantly influences plant growth. Brown (10), Cullinan and Batjer (17), Waltman (37), and Cullinan *et al*. (18) found that peach tree growth was significantly increased with increased N application. Apple growth was increased with increasing N supply (2, 9, 17, 37). Similar findings have been reported for citrus (16, 28, 29, 33), for young tung trees (25), and for potato plants (34).

Rosell and Ulrich (30) grew sugar beet plants in solution containing varying levels of Zn and found that growth of the storage roots was retarded when the initial Zn concentration fell below 25 $\mu g/l$. Sucrose concentration of the storage roots reached a maximum value at this Zn concentration. Fresh and dry weights of the tops followed the same pattern as the roots relative to Zn supply.

Reed (27) observed maximum growth in bean plants when grown in solution culture containing 0.10 ppm Zn, but growth was decreased when the Zn concentration was increased above this level. He stated that there was threshold value for Zn below which bean plants produced only small, seedless pods, and above this value the weight of seeds bore a close relation to the amount of Zn applied. Barrows *et al*. (1) reported that linear top growth of tung trees was increased by increasing the Zn concentration from 0 to 10 ppm but reduced with further increases in Zn rates. However, root growth was increased with added increments of Zn up to 100 ppm.

Brown and Wilson (11) obtained marked responses in cotton growth from addition of 0.001 ppm Zn to purified solution cultures. Only 0.1 ppm Zn was needed in solution for normal growth of cotton and of pine seedlings (39). Jackson et al. (21) reported that increasing the supply of Zn from 0 to 1, 2, 4, and 8 lb/A not only increased growth but also increased the yield of no. 1 ears of sweet corn plants grown on Sifton soil series in the Willamette Valley of Western Oregon.

Many relationships have been reported to exist between nutrient-elements contained in the tissues, especially of the leaves. Applied N was reported to increase leaf Ca, N, and Mg, but decreased P and K (9, 23). Increasing the N content of the nutrient solution resulted in decreased absorption of P, K, and Ca, but increased Mg absorption (8). Chapman and Liebig (16) found that increased N concentration did not depress P absorption, but that decreased N concentration resulted in increased P absorption. Cullinan et al. (18) found that P absorption was highest with low N concentration.

One of the first suggestions that N might have an adverse effect on Zn nutrition of plants came from studies conducted by Haas (19) and Chapman et al. (15). They found that liberal applications of N fertilizers produced or increased Zn deficiency symptoms on citrus trees growing with a low Zn supply. Reuther and Smith (29), also working with citrus, reported a trial in which increasing the levels of applied N led to increasingly severe symptoms of Zn deficiency, but added that this Zn deficiency was partly induced by the increased growth with high N.

Thorne (40) observed that excessive applications of N on Zn-deficient soil caused severe Zn deficiency symptoms and decreased Zn concentration in aerial parts of subterranean clover. In contrast, other experiments indicated that the effect of N or Zn concentration in plants was complicated by the effect of the carrier on soil pH and the total amount of plant growth (5, 6, 7).

Viets et al. (36) studied the effect of various N sources on Zn availability. They found that pH changes accompanying the use of acidifying N fertilizers had the greatest effect on Zn uptake and plant growth. Boawn et al. (7) compared $(NH_4)_2SO_4$, NH_4NO_3, and $Ca(NO_3)_2$ as N carriers and found that pH changes exerted the greatest effect--(that is, N sources that reduced soil pH increased Zn availability) on Zn concentration and uptake by sorghum and potato plants. With sugar beets, however, pH had no significant effect on Zn concentration or uptake. Instead, the Zn concentration and uptake decreased with increasing rates of N independently of soil pH.

More recently, Ozanne (26) reported that subterranean clover growing on Australian soils low in available Zn showed increased Zn deficiency symptoms when the N supply increased. Adding N as

NH_4NO_3 or $(NH_4)_2SO_4$ decreased the amount of Zn in the plant tops but added that it was not due to increased growth. He concluded that Zn was being held in the roots by the formation of immobile Zn-protein complexes bringing about Zn retention in the roots under conditions of high N and low Zn.

Most of the investigations of this nature have been conducted on crops other than sweet cherry, and in most cases, have involved the use of soil as the growth medium.

Many commercial cherry orchards show varying degrees of nutrient composition, and in most cases Zn deficiency presents serious nutritional problems. This study was initiated to provide detailed information on growth of sweet cherry trees as affected by varying levels of N and Zn treatments. A further objective was to determine the effects of the N and Zn levels on leaf composition, in particular, to determine the effect of N on Zn concentration and uptake by the leaves. The hypothesis is proposed that N is antagonistic to Zn uptake by leaves of plants.

MATERIALS AND METHODS

A modification of half strength Hoagland no. 1 solution (20) was used, and was further modified to accommodate the N and Zn variables. Purification of all macronutrient stock solutions was accomplished utilizing a dithizone-CCl_4 procedure adapted from Snell and Snell (32) and Moore (24). Glass-distilled water was used in making up and maintaining the levels of the nutrient solutions. Reagent grade chemicals were used throughout the experiments.

Table 1 shows the ppm concentrations of the salts in the nutrient solutions for both the greenhouse and outdoor sand culture experiments. Treatments consisted of four Zn levels in factorial combination with three N levels. The general ranges of concentration of the nutrient elements, except Zn, were selected on the basis of information in the literature relating to Montmorency cherry nutrition.

The experiments consisted of a greenhouse- and outdoor sand culture-nutrient solution studies. In the greenhouse study, one-year old F12-1 clonal sweet cherries were selected on the basis of uniformity of tops and root systems. Small trees were selected to reduce the carry-over of nutrients. The tops were cut back to two or three buds above the root system and the roots were pruned severely and washed thoroughly before planting.

Approximately 96 plants were planted individually in one-gallon glazed crocks previously filled with acid-washed quartz sand

Table 1. Ppm concentration of salts in nutrient solutions for the greenhouse and outdoor experiments.

Treatment	Concentration (ppm) N	Zn
$N_1 Zn_0$	30	0.0
$N_1 Zn_1$	30	0.025
$N_1 Zn_2$	30	1.25
$N_1 Zn_3$	30	5.0
$N_2 Zn_0$	80	0.0
$N_2 Zn_1$	80	0.025
$N_2 Zn_2$	80	1.25
$N_2 Zn_3$	80	5.0
$N_3 Zn_0$	224	0.0
$N_3 Zn_1$	224	0.025
$N_3 Zn_2$	224	1.25
$N_3 Zn_3$	224	5.0

The concentration of invariant nutrients was as follows: 86 ppm K from K_2SO_4, 50 ppm P from NaH_2PO_4, 176 ppm Ca from $CaCl_2$, 58 ppm Mg from $MgSO_4$, 0.5 ppm Mn from $MnCl_2$, 1 ppm Fe from $FeSO_4 \cdot 7H_2O$, 0.5 ppm Cu from $CuSO_4$, $5H_2O$, 0.5 ppm Mo from $NaMoO_4 \cdot 2H_2O$, and 1.5 ppm B from H_3BO_3.

Additional Fe (as Fe^{++}-EDTA) was added at 2 day intervals at a level sufficient to increase the Fe concentration 0.10 ppm Fe/2 days.

Sources of the variables were:

N from NH_4NO_3

Zn from $ZnSO_4 \cdot$ 7H2O

and equipped with automatic sub-irrigation system. The N and Zn treatments were started ten days after planting.

Four replications of each of the 12 treatments were maintained in both the greenhouse and outdoor sand culture studies. Temperatures were not rigidly controlled, but were maintained at about 24° C (75° F) during the day and 15.6° C (60° F) at night. The nutrient solutions were brought to volume daily and changed fortnightly to insure a constant nutrient supply. The pHs of the nutrient solutions were initially adjusted to 6.4 and were readjusted to 6.4 once a week with dilute KOH. The trees were grown for two growing seasons. Leaf samples were collected at the end of the first growing season, and at the end of the experiment the entire trees were harvested by separating them into leaf, trunk, and root components. All plant materials were dried in an oven at 26.8° C (80° F), weighed, and saved for analysis.

The outdoor sand culture experiment was located at the Lewis-Brown Horticultural Farm of Oregon State University. About 96 one-year old F12-1 clonal sweet cherry trees were planted individually in four-gallon black plastic pots previously filled with acid-washed Del Monte White Sand. Each pot was set in a 10-inch deep hole with gravel drains. Nutrient solutions were applied at the rate of 5 liters per pot three times a week.

The trees were grown for one growing season after which they were harvested and handled in the same manner as the greenhouse-grown trees.

The oven-dried plant samples were ground in a Wiley mill equipped with a 40-mesh stainless steel sieve and steel cutting blades. Total N was determined utilizing the 303 Technicon Auto Analyzer after the procedures described by Warner and Jones (38). All other elements were determined by means of the Jarrell Ash 3/4 meter direct reading spark emission spectrometer of Oregon State University Plant Analysis Laboratory.

Statistical analysis of variance was carried out according to procedures outlined by Steel and Torrie (35), and, in addition, the Duncan's multiple range test (41) was employed to determine significant differences among individual means in cases where significant N-Zn interactions occurred.

RESULTS AND DISCUSSION

Dry weights. The responses of both the greenhouse and outdoor trees were similar and can be typified by a response surface of total dry weights (Fig. 1). It can be seen that the N treatments significantly increased the dry weights of the various parts of the trees at all Zn levels. Increasing the Zn levels from Zn_0 to Zn_2 (1.25 ppm Zn) significantly increased the dry weights of all plant parts at all N levels. Application of the Zn_3 level (5 ppm Zn) produced significantly less increases in dry weights of plant parts under the outdoor conditions, but slightly decreased the dry weights of all plant parts of the greenhouse trees, indicating that this level of Zn was above optimum (Tables 2 and 3).

The effects of the treatments on tree growth, as measured by the dry weights, were mostly as anticipated from work previously reported (1, 2, 9, 12, 13, 17), but not in full harmony with findings reported by Rosell and Ulrich (30) who observed increased growth in sugar beet plants growing in a Zn-deficient soil by successive additions of Zn up to 100 ppm. This difference may be due to use of soil as the growth medium by these workers.

The highly significant positive N-Zn interactions on dry weights observed under the greenhouse conditions appeared to result from the greater responses of the trees to Zn at all N levels, but most

Table 2. Effects of varying levels of N and Zn on the dry-weight yields of root, trunk, leaves, tree top and total tree of sweet cherry trees grown in nutrient solution, greenhouse experiment.

	Dry weights (grams of dry matter/plant part)				
Treatment	Root	Trunk	Leaves	Tree top	Total tree
$N_1 Zn_0$	136a	84a	67a	151a	287a
$N_1 Zn_1$	162b	98b	75b	173b	335b
$N_1 Zn_2$	164b	101bd	89cd	181c	345cd
$N_1 Zn_3$	163b	100bd	78b	178c	341c
$N_2 Zn_0$	171c	92c	83c	178c	346d
$N_2 Zn_1$	175c	105d	87c	192d	367e
$N_2 Zn_2$	182d	115e	93d	208e	390a
$N_2 Zn_3$	185d	118e	88e	206e	391a
$N_3 Zn_0$	190e	156f	110f	266f	456f
$N_3 Zn_1$	189e	167g	106g	273g	462g
$N_3 Zn_2$	209g	170g	109fg	279h	488h
$N_3 Zn_3$	201g	166g	111f	277h	478i
N means					
N_1	156	97	75	172	328
N_2	178	108	88	196	375
N_3	197	165	109	274	449
Zn means					
Zn_0	166	112	87	200	364
Zn_1	175	123	89	213	388
Zn_2	185	128	94	223	408
Zn_3	183	128	92	220	403
F Tests					
N	*	*	*	*	*
Zn	*	*	*	*	*
N X Zn	*	*	*	*	*
LSD					
N means .05	27.0	44.0	22.0	68.0	62.0
Zn means .05	11.0	4.0	3.0	8.0	12.0

Means within a column followed by the same letter are not significantly different at the P (.05) level as determined by the Duncan's Multiple Range Test.
* Means significantly different at the P (.05) level.
NS Means significantly different at the P (.05) level.

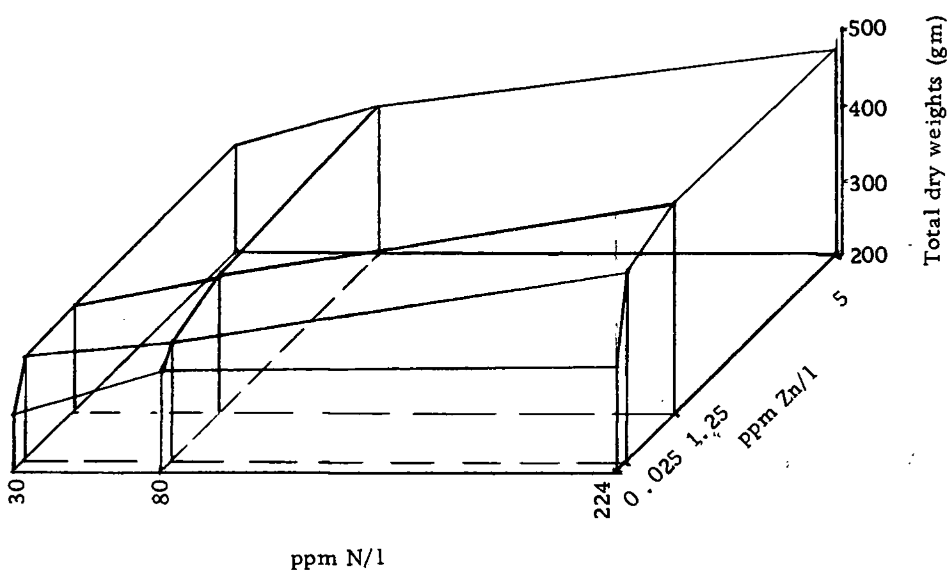

Figure 1. Total dry weights of sweet cherry trees as a function of nutrient solution concentration of nitrogen and zinc, greenhouse experiment.

Table 3. Effects of varying levels of N and Zn on the dry weights of root, trunk, leaves, tree top, and total tree of sweet cherry trees grown in nutrient solution, outdoor sand culture experiment.

Treatment	Root	Trunk	Leaves	Tree top	Total tree
	Dry weights (gms of dry matter/plant part)				
N_1Zn_0	58	58	39	97	154
N_1Zn_1	62	64	41	104	166
N_1Zn_2	66	64	44	105	171
N_1Zn_3	65	62	42	104	169
N_2Zn_0	72	73	44	117	189
N_2Zn_1	74	76	47	122	197
N_2Zn_2	75	76	47	129	198
N_2Zn_3	77	78	51	129	206
N_3Zn_0	91	91	51	142	232
N_3Zn_1	95	95	53	147	243
N_3Zn_2	95	102	56	158	252
N_3Zn_3	99	100	57	158	257
N means					
N_1	63	62	41	103	165
N_2	75	76	48	123	197
N_3	95	97	54	151	246
Zn means					
Zn_0	73	74	44	118	192
Zn_1	77	78	47	125	202
Zn_2	79	80	49	129	207
Zn_3	80	90	50	130	210
F Tests					
N	*	*	*	*	*
Zn	*	*	*	*	*
N X Zn	NS	NS	NS	NS	NS
LSD					
N means .05	21.0	15.0	8.0	25.0	39.0
Zn means .05	2.0	5.0	2.0	3.0	7.0

* Means significantly different at the P (.05) level.

NS Means not significantly different at the F (.05) level.

especially at the N_1 level. These responses demonstrated the effectiveness of the combined effects of nutrition on tree growth. For example, the mean total dry weights per tree ranged from 335 grams at N_1Zn_1 to 488 grams at N_3Zn_2 (Table 2). It should be further noted that the greenhouse trees were grown for two growing seasons as compared to the outdoor trees which were grown for only one growing season; this accounts for the large difference in dry weights between trees from the two locations.

The most favorable combination of treatments with respect to tree growth, as measured by the dry weights, was N_xZn_2 (N_1Zn_2, N_2Zn_2, N_3Zn_2). Despite the size of the trials, it was not possible to include sufficient level of application to indicate a precise optimum for each of the two nutrients. Most detailed information can only be given as opinions based on dry weights and appearance of the trees throughout the trials. Tables 2 and 3 show that the N_3 level gave the highest dry weights assuming that the levels of other nutrients were adequate. The appearance of the trees suggested that the N_3 level of N (224 ppm) was fully adequate. However, the fact that the trees from the low N treatments (30 ppm) made almost the same growth as those from the N_3 treatments implies that heavy fertilization with N for young sweet cherry trees may not be necessary for normal, vigorous growth, unless there is a definite need for this practice. Cooperative Extension Service pamphlet No. 25 states that sweet cherry trees less than ten years old do not normally benefit from applications of N.

No optimum level of Zn can be deduced from the present data but the importance of adequate Zn is clearly shown. A further experiment involving more than five levels of Zn needs to be carried out before a precise level can be determined.

The many similarities found in the behavior of the trees grown under the greenhouse and outdoor conditions with the same applied variables would seem to justify the extrapolation of information derived from greenhouse study to outdoors when both were under conditions similar to those of this investigation. This relationship would also apply to cherry orchards with some modifications since the variables involved Zn, the availability of which may be affected by soil factors.

Leaf analysis. The N concentration and uptake by the leaves of both the greenhouse and outdoor trees increased significantly with increasing N supply. The effect of the Zn levels on the concentration of N in leaves of the greenhouse trees was not consistent in that leaf N decreased consistently with increasing Zn rates at the N_1 level but showed irregular pattern at the two higher N levels (Table 4). The Zn treatments consistently increased the concentration of N in leaves of the outdoor trees (Table 6). N uptake by leaves of trees from the two locations increased linearly with increasing Zn rates, however.

Table 4. Effects of varying levels of N and Zn on the concentration and uptake of N, P, K, Ca, and Mg by sweet cherry leaves grown in nutrient solution, greenhouse experiment.

Treatment	N		P		K		Ca		Mg	
	%	Uptake gm	%	Uptake mg	%	Uptake gm	%	Uptake gm	%	Uptake mg
N_1Zn_0	2.72	1.83	.51	342	3.52a	2.36a	1.76	1.18	.54	362
N_1Zn_1	2.59	1.95	.39	293	3.31b	2.48b	1.23	0.92	.58	435
N_1Zn_2	2.57	2.29	.42	326	3.30b	2.64c	1.36	1.21	.53	424
N_1Zn_3	2.52	1.97	.40	312	2.88c	2.53d	1.38	1.08	.62	484
N_2Zn_0	2.84	2.36	.42	349	3.57d	2.96e	1.17	0.97	.51	424
N_2Zn_1	2.82	2.45	.46	401	3.16e	2.75e	1.21	1.05	.58	505
N_2Zn_2	2.97	2.60	.47	437	3.29b	3.06g	1.22	1.14	.54	502
N_2Zn_3	2.89	2.54	.58	511	3.54a	3.12g	1.20	0.97	.55	484
N_3Zn_0	3.01	3.31	.57	627	3.36f	3.69h	1.20	1.33	.58	638
N_3Zn_1	2.98	3.16	.53	562	3.52a	2.73hi	1.21	1.27	.60	636
N_3Zn_2	3.05	3.33	.59	643	3.40g	3.71i	1.24	1.28	.59	643
N_3Zn_3	3.18	3.53	.54	599	3.48h	3.86j	1.22	1.36	.63	638
N means										
N_1	2.64	1.98	.43	321	3.25	2.43	1.27	0.96	.57	526
N_2	2.84	2.49	.48	425	3.39	2.97	1.18	1.03	.55	479
N_3	3.06	3.33	.56	608	3.44	3.75	1.20	1.31	.60	652
Zn means										
Zn_0	2.86	2.50	.50	439	3.48	3.01	1.18	1.03	.54	475
Zn_1	2.80	2.52	.46	419	3.33	2.99	1.21	1.08	.55	523
Zn_2	2.80	2.66	.49	472	3.33	3.14	1.25	1.17	.55	523
Zn_3	2.92	2.72	.51	474	3.30	3.08	1.23	1.13	.60	552
F Tests										
N	*	*	*	*	*	*	*	*	NS	*
Zn	*	*	*	*	*	NS	NS	NS	NS	*
N X Zn	NS	NS	NS	NS	*	*	NS	NS	NS	NS
LSD (.05)										
N means	0.29	0.57	.09	287	.13	0.33	.02	0.23	NS	48.0
Zn means	0.14	0.15	.04	27	.13	NS	NS	NS	NS	39.0

Means within a column followed by the same letter are not significantly different at the P (.05) level as determined by the Duncan's Multiple Range Test.

* Means significantly different at the P (.05) level.

NS Means not significantly different at the P (.05) level.

Table 5. Effects of varying levels of N and Zn on the concentration and uptake of Mn, Fe, Cu, Zn, and B by sweet cherry leaves grown in nutrient solution, greenhouse experiment.

Treat-	Mn		Fe		Cu		Zn		B	
		Uptake		Uptake		Uptake		Uptake		Uptake
ment	ppm	mg	ppm	mg	ppm	mg	ppm	mg	ppm	mg
N_1Zn_0	145a	10	162	11	48	4	47	3	149	10
N_1Zn_1	171b	13	166	13	20	2	59	4	173	13
N_1Zn_2	164c	13	147	12	19	2	59	5	153	12
N_1Zn_3	152d	12	177	14	18	2	60	5	140	11
N_2Zn_0	131e	11	169	14	19	2	53	4	140	12
N_2Zn_1	142a	13	157	14	19	2	60	5	178	16
N_2Zn_2	137f	13	159	15	20	2	62	6	160	15
N_2Zn_3	155g	14	194	17	21	2	64	6	242	21
N_3Zn_0	128e	14	188	21	20	3	57	6	171	19
N_3Zn_1	149d	16	171	18	21	2	61	6	172	18
N_3Zn_2	133ef	15	162	18	21	3	58	6	142	16
N_3Zn_3	135f	15	167	19	20	3	63	7	149	17
N means										
N_1	158	12	163	12	26	2	56	4	154	12
N_2	141	13	169	15	20	2	60	5	180	16
N_3	136	13	172	19	20	3	60	7	158	17
Zn means										
Zn_0	135	12	173	15	29	3	52	5	154	14
Zn_1	154	14	165	15	20	2	60	5	174	16
Zn_2	145	14	156	15	20	2	59	6	152	14
Zn_3	147	14	179	17	20	2	63	6	177	16
F Tests										
N	*	NS	*	NS	NS	NS	NS	NS	*	NS
Zn	*	NS	*	NS	NS	NS	*	NS	*	NS
N X Zn	*	NS	NS	NS	NS	NS	NS	NS	NS	NS
LSD (.05)										
N means	12.0	NS	.09	NS	NS	NS	NS	NS	13.0	NS
Zn means	7.0	NS	.12	NS	NS	NS	.06	NS	17.0	NS

Means within a column followed by the same letter are not significantly different at the P (.05) level as determined by the Duncan's Multiple Range Test.

* Means significantly different at the P (.05) level.

NS Means not significantly different at the P (.05) level.

The previously described decrease in leaf N with increasing Zn rates at the N_1 level in the greenhouse study can be explained on the basis of a growth dilution of N as indicated by the absolute amount of N in the leaves (Table 4). The decrease in N concentration was real but the large increase in dry weights as Zn was increased was the cause of dilution of N concentration and not an antagonistic effect of Zn on leaf N. A true antagonism between two elements exists when an increased supply of one depresses both the uptake and concentration of the other. These observations are in general agreement with those of Neff et al. (25) who found many depressive effects of N, P, and K on N, Ca, Cu, Zn, and Mn through varying the supply of N, P, and K. Their calculations based on the dry weights, however, showed that N, Ca, Cu, Zn, and Mn were actually increasing in absolute amounts and total uptake of Mg was unaffected by increasing the supply of K.

The increase in N concentration with increased N supply observed in this investigation is in agreement with findings previously reported (2, 4, 8, 16, 25, 28).

A much closer relationship existed between total N and total dry weights than between leaf N and total dry weights (Table 8). This illustrates the caution required when interpreting concentration data alone without considering the increment of growth. Shear et al. (31) found instances in which addition of N sometimes lowered or had no

Table 6. Effects of varying levels of N and Zn on the concentration and uptake of N, P, K, Ca, and Mg by sweet cherry leaves grown in nutrient solution, outdoor sand culture experiment.

Treat-ment	N %	N Uptake gm	P %	P Uptake mg	K %	K Uptake gm	Ca %	Ca Uptake mg	Mg %	Mg Uptake mg
N_1Zn_0	2.68	1.05	.30	117	1.40	.60	1.78	694	.81	316
N_1Zn_1	2.69	1.10	.32	131	1.45	.65	1.43	586	.72	295
N_1Zn_2	2.73	1.20	.27	119	1.64	.73	1.58	695	.71	313
N_1Zn_3	2.77	1.16	.28	118	1.49	.65	1.45	609	.66	277
N_2Zn_0	2.87	1.26	.34	150	1.45	.69	1.62	713	.83	365
N_2Zn_1	2.89	1.36	.35	165	1.30	.64	1.52	715	.61	287
N_2Zn_2	2.88	1.35	.31	146	1.46	.71	1.56	733	.76	357
N_2Zn_3	2.90	1.48	.32	163	1.62	.81	1.47	730	.75	383
N_3Zn_0	3.08	1.57	.29	148	1.44	.77	1.48	755	.77	393
N_3Zn_1	3.07	1.63	.29	154	1.63	.86	1.55	822	.78	414
N_3Zn_2	3.13	1.75	.30	168	1.77	.98	1.43	801	.63	353
N_3Zn_3	3.15	1.80	.27	154	1.48	.80	1.49	849	.68	388
N means										
N_1	2.72	1.12	.29	119	1.50	.66	1.56	640	.73	299
N_2	2.86	1.37	.33	159	1.46	.71	1.54	739	.74	355
N_3	3.11	1.70	.29	157	1.58	.85	1.49	895	.72	389
Zn Means										
Zn_0	2.88	1.27	.31	137	1.43	.69	1.63	717	.80	352
Zn_1	2.90	1.36	.32	151	1.46	.72	1.50	705	.70	329
Zn_2	2.91	1.43	.29	142	1.62	.80	1.52	745	.71	348
Zn_3	2.93	1.47	.29	145	1.53	.76	1.47	735	.70	350
F Tests										
N	*	*	NS	*	*	*	*	*	NS	*
Zn	*	*	NS	*	*	*	*	*	*	*
N X Zn	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LSD (.05)										
N means	0.26	0.37	NS	28	0.09	.13	0.04	100	NS	60
Zn means	0.03	0.08	NS	13	0.13	.07	0.11	28	.06	17

* Means significantly different at the P (.05) level.

NS Means not significantly different at the P (.05) level.

Table 7. Effects of varying levels of N and Zn on the concentration and uptake of Mn, Fe, Cu, Zn, and B by sweet cherry leaves grown in nutrient solution, outdoor sand culture experiment.

Treat-	Mn		Fe		Cu		Zn		B	
		Uptake		Uptake		Uptake		Uptake		Uptake
ment	ppm	mg	ppm	mg	ppm	mg	ppm	mg	ppm	mg
N_1Zn_0	493a	21	182a	8	19	.81	43a	1.7	86	3
N_1Zn_1	423b	18	194bg	9	20	.89	45a	1.9	116	5
N_1Zn_2	438c	19	239c	11	18	.80	53b	2.3	97	4
N_1Zn_3	373df	16	179a	8	18	.80	56c	2.4	78	3
N_2Zn_0	430e	21	206d	10	19	.92	51b	2.2	84	4
N_2Zn_1	386f	19	207d	10	16	.81	63d	3.0	99	5
N_2Zn_2	462g	20	190e	9	19	.92	67e	3.2	84	4
N_2Zn_3	450h	23	240c	12	19	.94	71f	3.6	94	5
N_3Zn_0	490a	26	181a	10	16	.84	72f	3.7	95	5
N_3Zn_1	491a	26	291f	15	21	1.08	75gh	4.0	92	5
N_3Zn_2	366d	20	196g	11	20	1.07	78h	4.5	74	4
N_3Zn_3	540i	29	141h	8	14	.78	84i	4.8	95	5
N means										
N_1	432	19	198	9	19	.83	49	2.1	93	4
N_2	432	21	211	10	18	.90	63	3.0	90	5
N_3	472	26	202	11	18	.94	73	4.3	90	5
Zn means										
Zn_0	471	21	190	9	18	.86	49	2.5	88	4
Zn_1	433	21	231	12	19	.93	61	3.0	101	5
Zn_2	422	20	208	10	18	.93	66	3.3	85	4
Zn_3	455	23	193	9	17	.84	70	3.6	89	5
F Tests										
N	*	NS	NS	NS	NS	NS	*	NS	NS	NS
Zn	*	NS	NS	NS	NS	NS	*	NS	NS	NS
N X Zn	*	NS	*	NS	NS	NS	*	NS	NS	NS
LSD (.05)										
N means	28.0	NS		NS	NS	NS	11.0	NS	NS	NS
Zn means	32.0	NS		NS	NS	NS	8.0	NS	NS	NS

Means within a column followed by the same letter are not significantly different at the P (.05) level as determined by the Duncan's Multiple Range Test.

* Means significantly different at the P (.05) level.

NS Means not significantly different at the P (.05) level.

effect on the leaf concentration but in which increase in growth was realized. When total N per leaf instead of concentration was considered, there was a good correlation with growth (dry weights). Batjer and Westwood (3) found that rapidly enlarging fruit showed downward trends in mineral concentrations but upward trends in absolute amounts.

In general, the N and Zn levels had variable effects in influencing the concentrations of P, K, Ca, Mg, Mn, Fe, and B in leaves of the test trees (Tables 4, 5, 6, 7). Furthermore, the effects of the individual treatments on the concentrations of the various elements in the leaves showed considerable variations between trees from the two locations. For example, the N levels consistently increased leaf P in the greenhouse but had no such effect on it outdoors. Leaf K increased linearly with increased N supply in the greenhouse but showed no consistent pattern outdoors. The N levels consistently decreased leaf Ca outdoors but had inconsistent effect on it in the greenhouse. The reverse of this is true for leaf Mn in relation to N supply. The N treatments significantly and consistently increased leaf Fe in the greenhouse but had no consistent effect on it outdoors. The Zn levels consistently decreased leaf K in the greenhouse but had inconsistent effect on it outdoors. The Zn levels significantly decreased leaf Mg outdoors but had no significant effect on it in the greenhouse. Highly significant interaction occurred between N and

Zn in influencing leaf Fe outdoors but not in the greenhouse. Similarly, the N and Zn levels had significant effects on leaf B in the greenhouse but had only a slight effect on it outdoors.

These results indicate the complexity of ion accumulation in plant tissues, and that even in the same plant species variations in nutrient composition can occur. It should be kept in mind that the same nutrient solutions were used in each of the two experiments, with both utilizing the same clonal F12-1 sweet cherry trees. Thus, the observed differences in the behavior of the nutrient elements in the leaves of the trees are largely the result of factors external to the trees in their respective micro-environment. The outdoor trees were exposed to more fluctuating, and sometimes very high temperatures and intense sunlight than their greenhouse counterparts. These factors are known to affect the rate of mineral absorption by plants by their effects on the physiology of the plants, i. e. respiration, transpiration, photosynthesis, etc., and may be responsible for the differences in the behavior of the various nutrient elements in the leaves of trees from the two locations. All of this points out the importance of conducting nutritional studies concurrently in the greenhouse and outdoors so that results obtained from them can be compared and thereby providing a meaningful basis of extrapolating information from greenhouse to outdoors.

It seems appropriate to call attention to the magnitudes of the variability in the levels of the base elements (K, Ca, Mg) in the leaves of trees from the two locations. They show somewhat inconsistent reciprocation in both their concentration and uptake, and the main reciprocation shown shifts between Ca and K and Ca and Mg, probably because the trees were grown with N and Zn levels instead of Ca or K or Mg levels in which case the reciprocation would have been consistent and more marked. The shifts in concentration suggest chemical equivalence, but in some cases there is a tendency for the total base equivalents to increase as the Ca concentration in the leaf increases. This behavior of the bases has been observed by Smith _et al._ (33) in citrus leaves.

Similarly, Fe showed considerable variability in the leaves of both the greenhouse and outdoor trees, but the level of Fe in leaves of the greenhouse trees is of interest and is shown as a response surface in Fig. 2. It can be seen that the leaves of trees from the Zn_0 treatment contained elevated Fe level, and then it tended to decrease with increased Zn application. The increase in Fe content occurred at high Zn level, a phenomenon that is difficult to explain. But the elevated Fe level observed in the Zn_0 treatment gives some clues as to why Fe usually (but not always) accumulates in Zn-deficient plants. Jackson _et al._ (21) found an abnormally high level of Fe in Zn-deficient sweet corn plants.

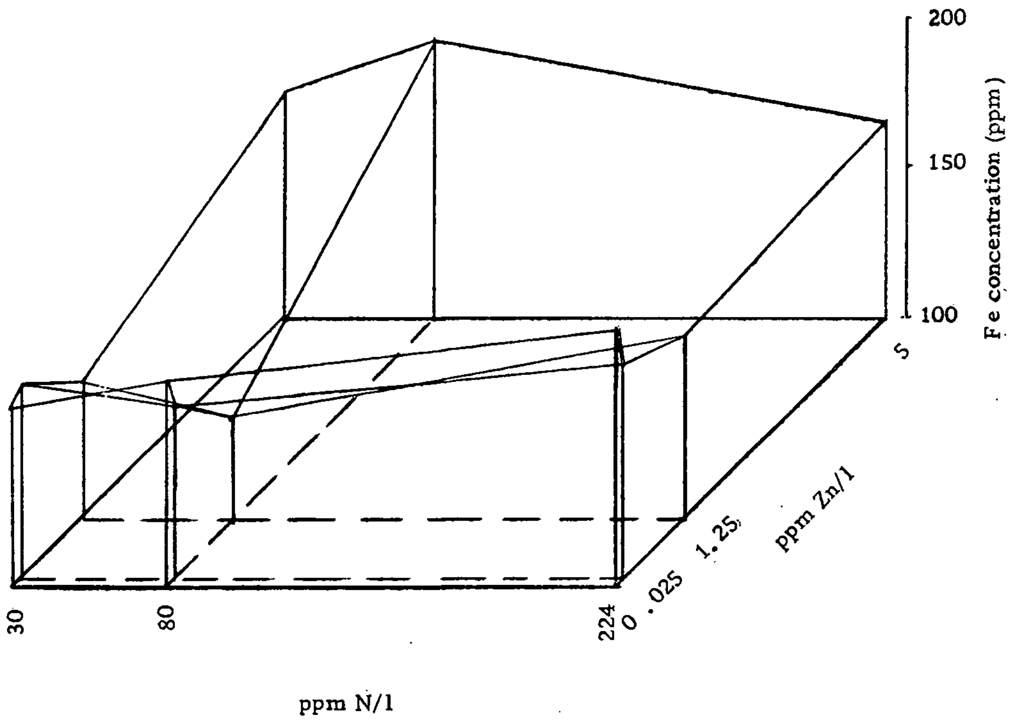

Figure 2. Fe concentration in sweet cherry leaves as a function of nutrient solution concentration of N and Zn, greenhouse experiment.

There were positive linear correlations between N and P, N and Ca, N and Mg, N and Mn, N and Fe, N and B, and N and Zn in leaves of trees from the two locations. There were negative correlations between N and Cu and N and K in the greenhouse study, but showed reciprocal relationships in the outdoor study. Similarly, there were positive linear correlations between Zn and P, Zn and K, Zn and Ca, Zn and Mg, Zn and Mn, Zn and Fe, and Zn and Cu in leaves of both the greenhouse and outdoor trees (Table 8). While some of the correlations were not high, even though highly significant, the consistency of the positive correlations between N and Ca, N and Mg, N and B, and N and Zn agrees with previous reports published on prune (14) and other tree crops (22, 23).

In general, the N and Zn treatments increased the uptake of all nutrient elements by the leaves of both the greenhouse and outdoor trees. Thus, this investigation places more emphasis on nutrient uptake, rather than on concentration, to lessen the complications brought about by differential plant growth and its attendant dilution effect resulting from larger plants in the one case, and concentration effect resulting from small plants in the other case.

One of the primary objectives of this study was to determine the effect of N on the level of Zn in the leaves of the sweet cherry trees. It was hypothesized that N is antagonistic to Zn uptake by leaves of plants. The results of this investigation show no evidence

Table 8. Correlation coefficients for total dry weights and element pairs in leaves of trees from the greenhouse and outdoor experiments.

Correlated items	Experiment: Green-house	Experiment: Out-door
Leaf N, total dry weights	.54*	.57*
Total N uptake, total dry weights	.60*	.66*
Leaf Zn, total dry weights	.43*	.68*
Total Zn uptake, total dry weights	.76*	.67*
N, Zn	.27	.74*
N, K	-.25	.37*
N, Ca	.30	.31
N, Mg	.20	.22
N, P	.22	.35*
N, Mn	.33	.27
N, Fe	.58*	.18
N, Cu	-.34	.26
N, B	.24	.21
Zn, Ca	.38*	.25
Zn, K	.15	.24
Zn, P	.30	.26
Zn, Mn	.30	.21
Zn, Fe	.47*	.36*
Zn, B	.25	.22
Zn, Cu	.27	.32

* Significant at the P (.05) level as determined from Table A 13 (35) using the appropriate D. F.

of any antagonistic effect of N on Zn concentration or uptake by the leaves of the trees studied. Tree growth stimulated by added increments of N consistently increased the Zn concentration and uptake by the leaves under both study conditions (Figs. 3 and 4), and may account for the highly significant correlation found between total Zn uptake and total dry weights (Table 8).

The linear increase in both Zn concentration and uptake with increasing N and Zn rates was not expected if N were antagonistic to Zn as maintained by some workers (15, 20, 26). Sweet cherry trees grown in this investigation without a supply of Zn showed no decrease in Zn concentration and uptake compared to trees which received a supply of this element.

Some researchers have attempted to explain N-induced Zn deficiencies on the basis of the decrease in Zn concentration observed after an N application. Although this decrease in Zn concentration has been observed in most of the cases reported in the literature, only in a limited number of cases has Zn uptake also been reduced with increasing N level. Boawn _et al_. (6) reported that both Zn content and uptake by sugar beet plants were reduced with increasing N application. Their data show that when N was applied, Zn content decreased from 15 to 10 ppm with uptake decreasing from 0.090 to 0.066 lb/ha for the Zn0 treatment. The decrease in Zn concentration was highly significant, but no significance levels were reported for Zn uptake.

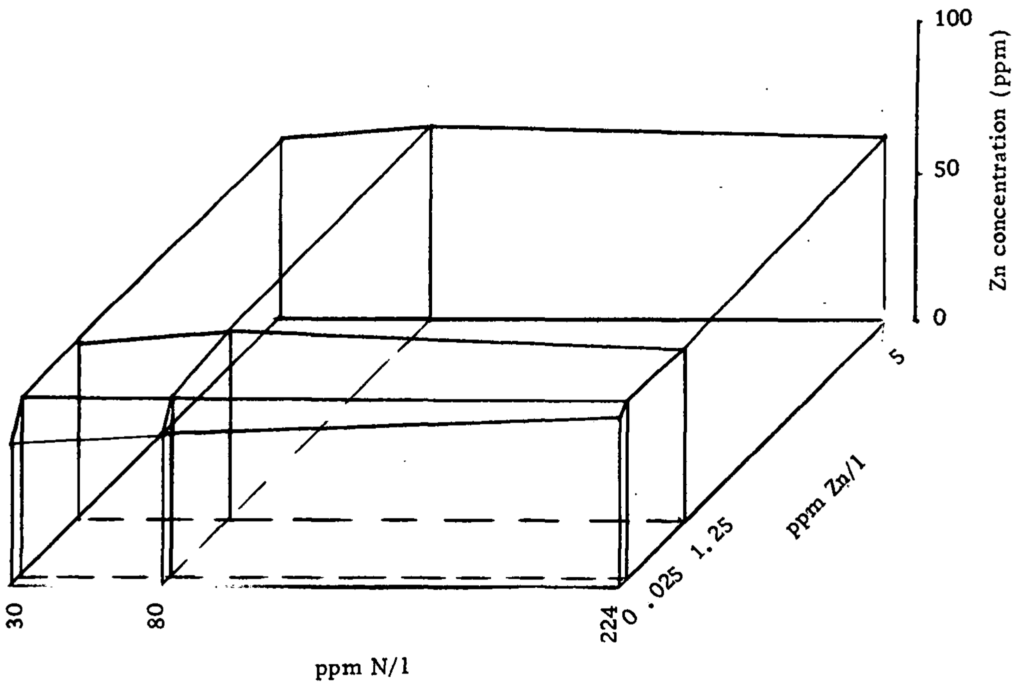

Figure 3. Zn concentration in sweet cherry leaves as a function of nutrient solution concentration of N and Zn, greenhouse experiment.

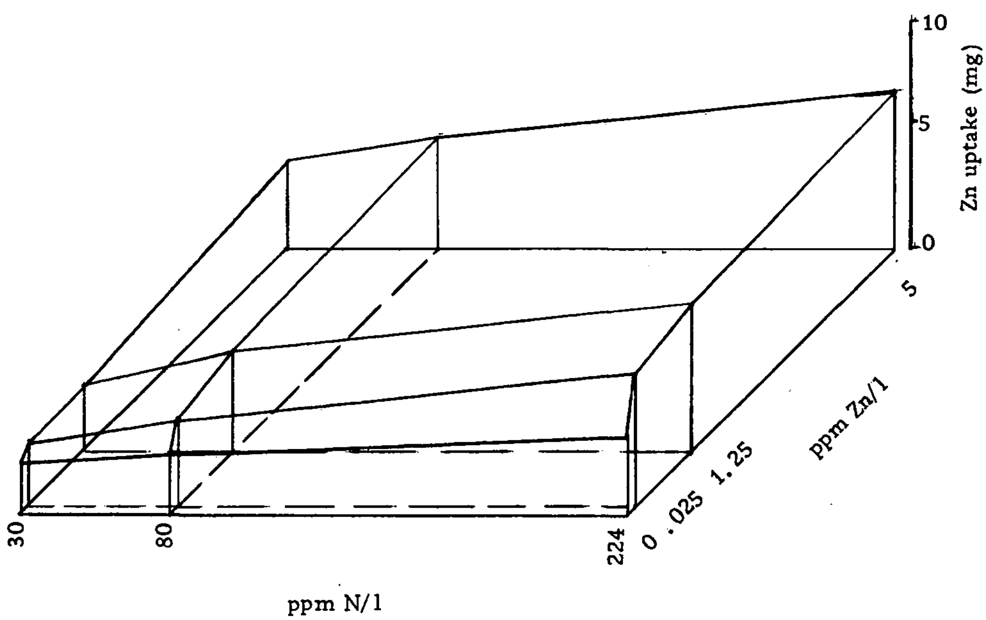

Figure 4. Zinc uptake by sweet cherry leaves as a function of nutrient solution concentration of N and Zn, greenhouse experiment.

Thorne's (40) experiment with subterranean clover grown on Zn-deficient soil showed that the plant Zn concentration increased with increasing Zn rates but decreased markedly with increasing N rates. However, no yield data were reported, and it is impossible to measure the responses of the plants to applied N. It appears that the decrease in Zn concentration with increased N supply noted by this worker may have been due to dilution effects resulting from increased plant growth.

Similarly, Ozanne (26) reported that the incidence and severity of Zn deficiency symptoms of subterranean clover increased as applied N increased successively from 0 to 15 mM. Unfortunately, he reported the dry weights of only the plant tops rather than total dry weights and total Zn uptake, and it is impossible to establish whether or not the plants were Zn-deficient prior to the appearance of Zn deficiency symptoms. In light of the fact that plants can be Zn deficient before Zn deficiency symptoms are observed, his conclusion that the Zn deficiencies were induced by N must be questioned.

From the foregoing discussions, it is clear that the so-called N-induced Zn deficiencies reported for some plants are nothing more than an expression of Zn deficiency symptoms in potentially Zn-deficient plants when their N needs are met.

The results of this investigation indicate the enhancement effect of N on Zn uptake by the plants and its potential usefulness in solving deficiency problems in the field of practical significance in commercial fruit production.

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SEASONAL CONCENTRATIONS OF NUTRIENT ELEMENTS IN LEAF AND LEAF BUD TISSUES OF FIELD-GROWN SWEET CHERRY TREES WITH SPECIAL EMPHASIS ON Zn DEFICIENCY DIAGNOSIS

ABSTRACT. A plant tissue analysis experiment was established to determine the trends in seasonal concentrations of elements in leaf and leaf bud tissues of field-grown sweet cherry trees with the objective of developing a diagnostic technique for diagnosing Zn deficiency. The results show that the levels of all elements, except Ca and B, showed varying degrees of seasonal decline in the leaves. Ca and B tended to accumulate in the leaves throughout the growth season. P, K, and Mg showed varying degrees of seasonal decline in the leaf buds, while all other elements tended to accumulate in the leaf buds throughout the growth season. The level of Zn found in the various plant samples studied varied considerably, with this tendency being more pronounced in the Zn-deficient leaves. The critical level of Zn may fluctuate even in the same variety, depending on other nutritional or environmental factors. There was no evidence relating directly to the effects of any of the elements on Zn to the incidence of Zn deficiency in the rated leaves. The results show that N and Zn are synergistically related in that an increase in N level in the plant tissues

studied resulted in a corresponding increase in Zn level. Leaf analysis values can be used effectively in predicting the onset of Zn deficiency before visible symptoms can appear. Leaf analysis is therefore the best diagnostic technique for diagnosing Zn deficiency. Leaf bud analysis may be as equally useful as leaf analysis to some extent, but further studies are needed before a more definite conclusion can be reached.

ZINC IS THE nutrient most often found deficient for growth and production of sweet cherries in eastern Oregon. Diagnosis has relied primarily on the observation of visible symptoms. After visible symptoms have appeared, damage to the plant has already occurred and thus it would be desirable to develop a diagnostic technique which would be able not only to identify the deficiency but also identify the onset of the deficiency prior to the occurrence of the visible symptoms.

Leaf analysis is used widely as a diagnostic method for the identification of nutrient disorders and their onset. There is, however, a wide variance in reported Zn values for a given level of plant performance. Gaddum et al. (17) found consistently lower Zn levels in Zn-deficient than healthy plants. Rosell and Ulrich (26), working with sugar beets, found consistently higher Zn concentration in young blades and all petioles from the most-deficient plants than those from less-deficient plants. They have established the critical value of leaf

Zn in sugar beet plants as being about 8 to 10 ppm; below this range of values the plants tend to be deficient in Zn, and above it they are well supplied. Boawn et al. (6) extended this study to Zn fertilization on Zn-deficient fields and could not establish critical levels for Zn in the tissues analyzed. Rogers et al. (25) found that native weeds growing on old cotton land contained as much as 700 ppm Zn averaging as a group 140 ppm, while Crotalaria growing normally on the same soil contained only 4 to 11 ppm Zn, and Benson (3) has indicated that leaf analysis is useless for Zn deficiency.

In view of these reports, a study was designed to determine the trends in seasonal concentrations of elements in leaf and bud tissues of sweet cherry with the objective of developing a diagnostic technique for the diagnosis of Zn deficiency.

METHODS

Seventy-five 5-year old mazzard F12-1 moderately vigorous, non-bearing sweet cherry trees at the Lewis Brown Horticultural Farm of Oregon State University were used. The trees had received normal fertilizer and other cultural practices prior to and during the study period. No nutrient deficiency was apparent in any of the trees.

Leaf and leaf bud samples were taken at 4-day intervals, beginning on May 14, or 14 days after first leaf open and continuing until leaf fall (or up to 140 days). About five leaves per tree were taken

Figure 1. Zn deficiency rating index of sweet cherry leaves sampled in eastern Oregon on August 28 (1972).

midway from the terminals and were composited and apportioned into duplicates of five samples. In collecting the leaf bud samples, five groups of 15 trees each were used and ten leaf buds per tree per group were composited separately making a total of five duplicate samples of leaf buds.

For comparative reasons, normal and Zn-deficient leaves were sampled on August 28, 1972, from sweet cherry orchards in eastern Oregon that were showing Zn deficiency symptoms. The leaf samples were divided into five groups and each group was assigned a rating number based on visual observation, No. 1 being the most Zn-deficient and No. 5 the least Zn-deficient leaves (Fig. 1). Between these two extremes were leaf samples showing Zn deficiency in varying degrees. Each set of the five groups of leaf samples was duplicated five times. For clarity, these leaf samples shall hereafter be referred to as rated leaves to distinguish them from the previously discussed leaf samples from Corvallis.

All the leaf and leaf bud samples were dried in a forced-draft oven at 26.7 °C, ground in a Wiley mill equipped with a 40-mesh screen and stainless steel cutting blades. Total N was determined utilizing the 303 Technicon Auto Analyzer after the procedures described by Warner and Jones (28). All other elements were determined by means of the Jarrell Ash 3/4 meter direct reading spark emission spectrometer of Oregon State University Plant Analysis Laboratory.

RESULTS AND DISCUSSION

Leaves. Except for Ca and B, all the elements determined showed varying degrees of decline during the growth season (Fig. 2). Ca and B tended to accumulate in the leaves throughout the season. With all elements, however, there were periods varying from 14 to 28 days in length during which there were no significant changes in level. These periods, which fell mostly between August 15 and 31, coincided with the time during which the influx or fluctuations in nutrient composition are at a minimum and seem to be an opportune time for leaf sampling for diagnostic purposes.

These results generally agree with those reported by others. Cain and Boynton (10) reported a seasonal decline in N, P, and K in McIntosh apple leaves. In the same variety, Reuther and Boynton (32) found a seasonal decline in N, and P percentage, and Boynton *et al.* (33) reported a seasonal decline on a percent basis of N, P, and K and an increase in Ca, particularly at the beginning and the end of the season. Batjer and Westwood (1) found that in leaves and flesh of Elberta peach Ca and Mg accumulated throughout the season while N, P, and K showed varying degrees of decline. With respect to Zn, Braford and Harding (8) observed a seasonal decline in Zn in Washington naval orange leaves. Mukherjee (21) observed seasonal decline in Zn in sugar cane leaves. A similar behavior of Zn was observed in leaves of the pea (4).

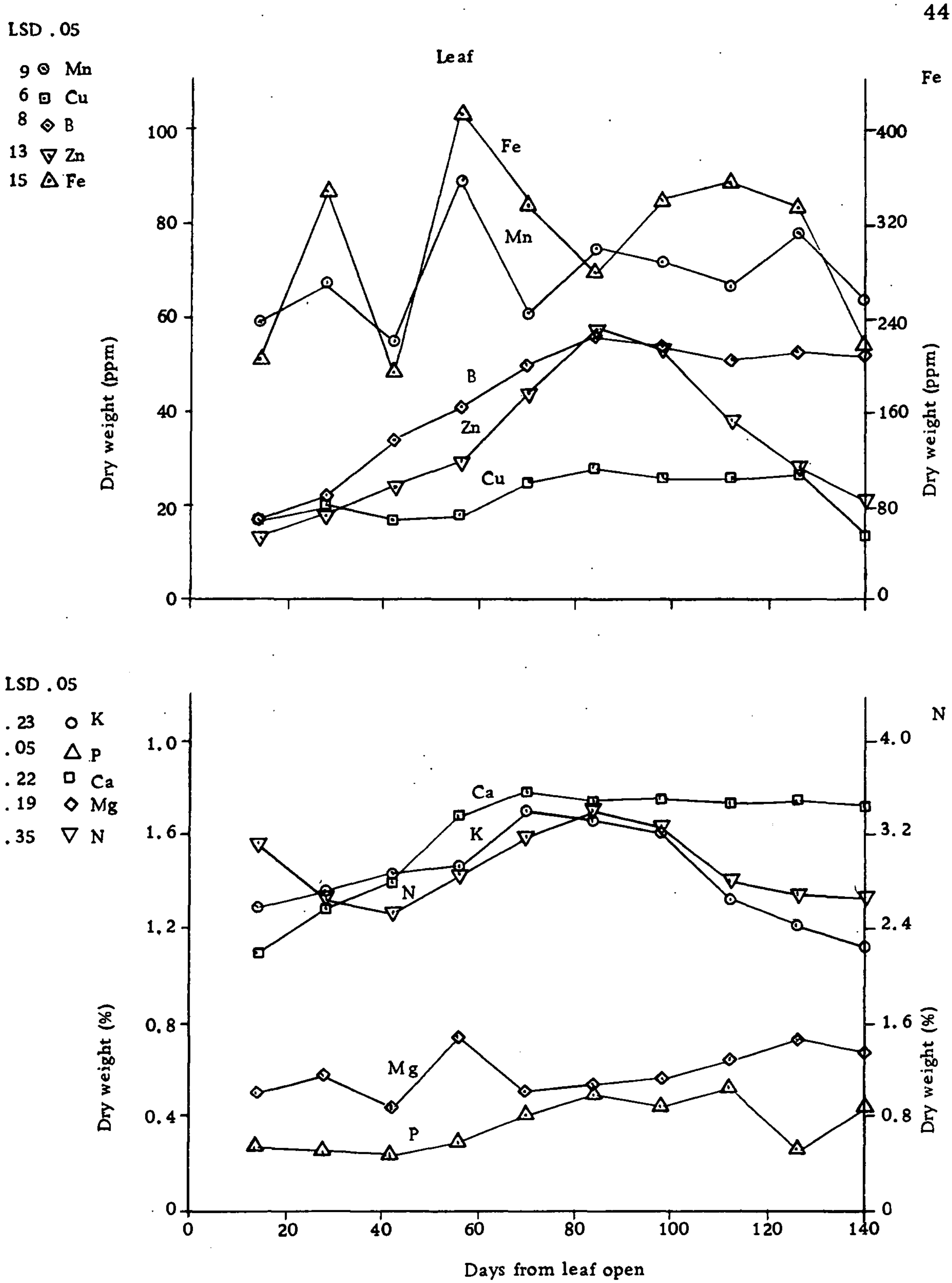

Figure 2. Changes in nutrient-element content of sweet cherry leaves at different ages.

It is of interest to note that the level of Zn (16 ppm) in the leaves sampled on the last sampling date (Fig. 2) was approximately the same as that found in the rated leaves showing mild Zn deficiency symptoms (Table 1) and yet the leaves showed no visible Zn deficiency symptoms. While the limits of deficiency are not too well defined, much data suggests a leaf analysis value of 20 or less accompanies visible deficiency symptoms. However, the data presented here shows that the critical level of Zn may fluctuate even in the same variety, depending on other nutritional or environmental factors.

The findings of other investigators are in harmony with the preceding interpretation. For example, Finch and Kinnison (16) found that leaves of healthy pecan trees contained from 13 to 16 ppm Zn. Rosetted leaves contained only 3 to 4 ppm. Zinc deficiencies in tung have been reported for trees with leaves containing less than 10 ppm (14). Deficient apple leaves in British Columbia were found to contain from 3 to 20 ppm Zn, and healthy leaves contained 6 to 40 ppm (31).

Leaf buds. There was a continual seasonal movement into the leaf buds of N and Zn (Figs. 3). This characteristic is in direct contrast to their behavior in the leaves which tend to migrate from the foliage very rapidly before leaf fall.

Calcium, Mg, Fe, Cu, and B movement into the leaf buds followed much the same pattern as did N and Zn in that they showed continual seasonal movement into the leaf buds, but the rate of

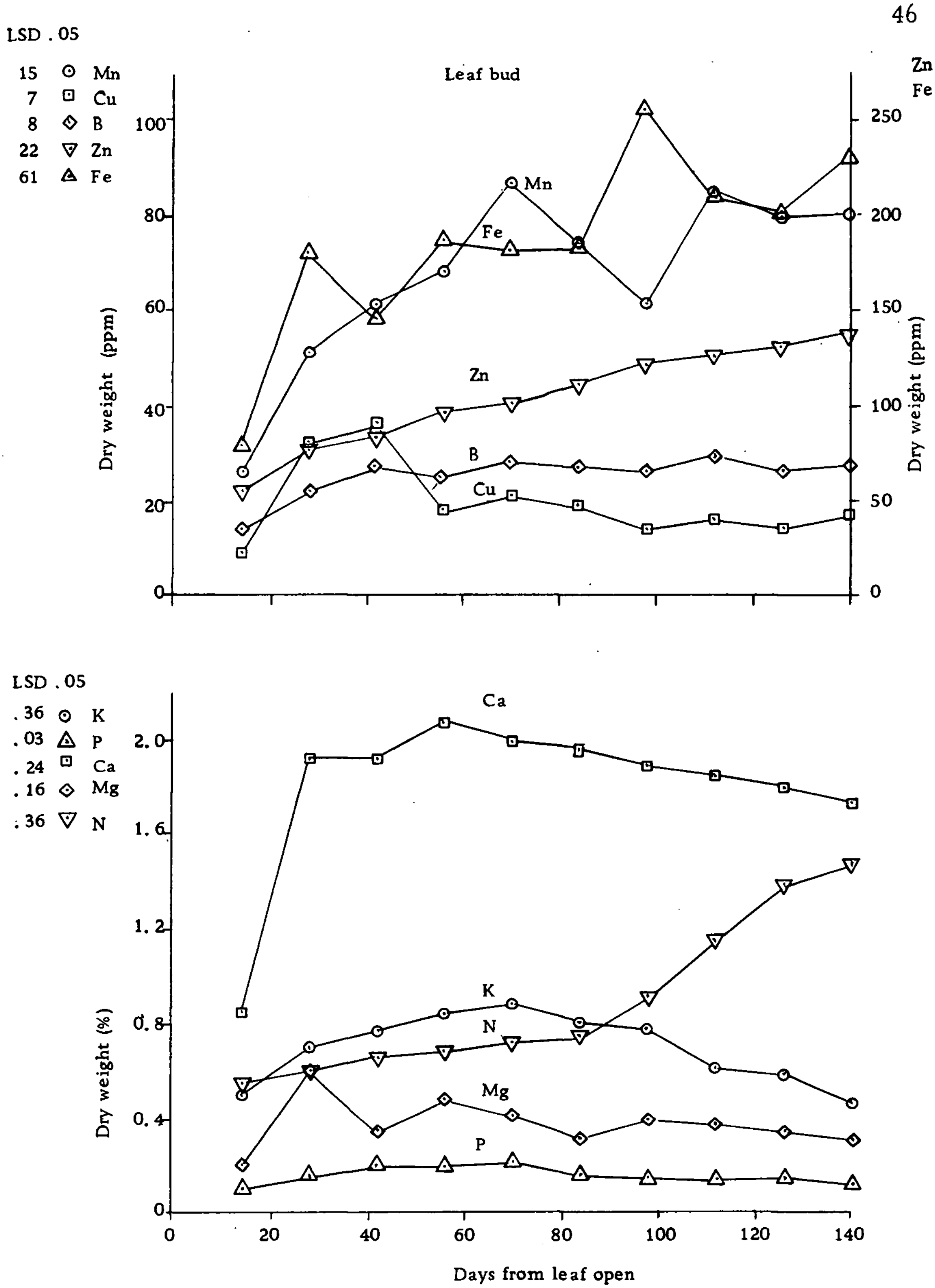

Figure 3. Changes in nutrient-element content of sweet cherry leaf buds at different ages.

movement was more steady in the case of N and Zn than this group of elements. The behavior of P and K in the leaf buds is similar to that in the leaves in that they showed varying degrees of decline during the season.

The continual seasonal movement of N and Zn into the leaf buds appears to be partly due to a transfer of the two elements from other plant parts to the leaf buds. Such a phenomenon has been reported for Zn in some plant species. Massey and Loeffel (20) reported a transfer of Zn by corn plants from the stalks and the leaves to the ears. Carolus (12) reported that senescent onion leaves lost about 70 percent of their Zn to the bulbs, and Mukherjee (21) found instances in which sugarcane plants transferred nearly 85 percent of the older leaves' Zn to the young growing tips. A similar behavior of Zn was observed in Algerian oats (29) and in oat plants grown in Australia (30), and by Biddulph (4) in pea plants. It is possible that N migrates from senescent leaves and twigs to leaf buds.

The level of Zn, as well as the levels of other elements, found in the leaf buds in this study indicates that the leaf bud may be important organ for mineral storage and function; further, it indicates that the leaf bud is a relatively sensitive indicator for Zn and it would seem that leaf bud analysis can be used effectively for diagnosing Zn deficiency.

Rated leaves. It will be recalled that these leaves were sampled

Table 1. Nutrient-element content of the rated sweet cherry leaves sampled in eastern Oregon on August 28, 1972.

Sample rating no.	N	K	P	Ca	Mg	Mn	Fe	Cl	B	Zn	Sample description
	Percent					ppm					
1	2.22	3.37	.20	2.40	.37	88	164	6	96	2	Very severely Zn deficient
2	2.85	2.96	.31	1.21	.34	84	122	12	130	5	Severely Zn deficient
3	3.36	3.37	.35	1.40	.46	144	218	16	120	7	Zn deficient
4	3.63	3.48	.39	1.13	.38	130	149	10	146	15	Mildly Zn deficient
5	3.67	2.85	.33	1.02	.36	98	211	18	102	28	Normal
LSD .05	0.29	1.21	.04	0.10	.05	36	55	4	27	5	

from Zn-deficient sweet cherry trees in eastern Oregon on August 28. The values of the elements for each rating index (Table 1) represent the means of five replicates. It can be seen from the data that the levels of N and Zn in the leaves increased consistently as the Zn deficiency symptom index decreased, showing the practical significance of determining the degree of Zn deficiency symptoms on a field observation basis.

It should be pointed out that the sampling date of the rated leaves (Aug. 28) coincides with the period of most constant nutrient level as indicated by the seasonal curves in Fig. 2 discussed earlier in this paper. This emphasizes the importance of proper timing of leaf sampling for diagnostic purposes.

The levels of other elements in the rated leaves reflect the adequate nutrition of the trees from which they were taken. Further, the data show no evidence relating directly to the effects of any of the elements on Zn to the incidence of Zn deficiency in the trees. This is important because some workers have associated the incidence of Zn deficiency in some plants with other ions. For example, high levels of available soil P have been implicated as contributing to Zn deficiency (2, 5, 22). High iron nutrition has also been implicated as interfering with the uptake and translocation or utilization of Zn (9). Similarly, liberal application of N has been reported as causing or increasing the severity of Zn deficiency symptoms in citrus

(11, 13, 18, 24). Ozanne (23) reported that subterranean clover growing under conditions of low Zn supply showed increased severity of Zn deficiency symptoms with increased N supply regardless of the N source.

However, the behavior of N and Zn in the rated leaves, as well as in the other plant materials studied, shows that the two elements are closely related, and that this relationship appears to be synergistic in nature in that an increase in N resulted in a corresponding increase in Zn (Fig. 3 and Table 1). This finding is in agreement with that reported by Boawn et al. (7) who found that the Zn concentration and uptake by sugar beet plants increased with increasing N rates. Recent greenhouse and outdoor sand culture studies by the author showed increased Zn concentration and uptake by sweet cherry trees with increasing N rates.

The highly significant correlation coefficients obtained between N and Zn in the various plant tissues studied (Table 2) serve as further evidence of the close relationship between the two elements in their movement into plant tissues. Further, there were positive correlations between N and between Zn and the various nutrient elements in the various plant parts studied (Table 2). These relationships, along with the individual nutrient intensities, may have important bearing on fertilizer practices as related to sweet cherry nutrition, since the proper Zn nutrition of the trees depends on the delicate balance

Table 2. Correlation coefficients for element pairs for the leaves and leaf buds sampled throughout the growth season, and for the rated leaves sampled in eastern Oregon on August 28 (1972).

Correlated elements	Leaf bud	Leaf	Rated leaf +
N, P	.48*	.51*	.42*
N, Ca	.37*	.45*	.30
N, K	.50*	.39*	.32
N, MG	.42*	.34	.47*
N, Mn	.38*	.37*	.28
N, Fe	.27	.38*	.56*
N, Cu	.44*	.31	.41*
N, B	.36*	.44*	.27
N, Zn	.85*	.71*	.69*
Zn, P	.49*	.36*	.43*
Zn, Ca	.33	.65*	.23
Zn, K	.57*	.34	.29
Zn, Mg	.46	.33	.36*
Zn, Mn	.39*	.41*	.50*
Zn, Cu	.30	.22	.29
Zn, Fe	.25	.45*	.37*
Zn, B	.50*	.35*	.49*

*Correlation coefficients significant at the P (.05) level as determined from Table A 13 (27) using the appropriate D. F.

+Leaves with assigned Zn deficiency symptom rating index number.

between Zn and the individual elements.

Under conditions of this investigation, the results show that various parts of plants differ considerably in the levels of Zn that accompany Zn deficiency. Furthermore, the critical level of Zn may fluctuate even in the same variety, depending on other nutritional or environmental factors. However, since the leaf is the best sensitive indicator for most elements, including Zn, leaf analysis values can be used effectively in predicting the onset of Zn deficiency before visible symptoms can appear. Leaf analysis is by far the most useful diagnostic technique for diagnosing Zn deficiency. Leaf bud analysis may be as equally useful as leaf analysis in diagnosing Zn deficiency. However, further field experiments need to be carried out to include a large number of leaf buds both from normal and Zn-deficient plants before a more definite conclusion can be reached.

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APPENDIX

GENERAL EXPERIMENTAL PROCEDURE

In designing an experiment to meet the objectives of this investigation previously outlined, several factors associated with both the growth medium and the plant species to be grown must be considered. The essential characteristics of the growth medium are as follows. First, it must allow the N to be varied over a wide range of levels and at the same time allow the Zn to be varied from deficient to adequate levels. Secondly, the system must hold other invariant elements constant, if necessary. Finally, it must allow for the harvesting of plant roots so that the total dry weights can be obtained and the effect of N on the translocation of Zn from the roots to the plant tops can be assessed. These requirements essentially eliminate the soil as the growth medium and suggest the use of a nutrient solution culture with N and Zn variables in factorial combination.

Although a nutrient solution culture was well suited to the objectives of this investigation, it was not without its associated problems. First, the nutrient solution had to be purified to remove all contaminating levels of Zn so that a growth response (dry weight) to Zn was obtained. Secondly, the nutrient solutions were not highly buffered and some provision had to be made for pH control since the rate of change of pH varied with the plant growth rate. Finally, the nutrient solutions had to be checked periodically to ascertain that the initial levels of Zn and N were maintained throughout the experimental period.

Selection of the plant species to be used in this investigation was governed by one basic consideration. The plant species and variety selected are known to suffer from a widespread deficiency of Zn under natural conditions. Of secondary consideration was the ease with which the plant could be grown in nutrient solution culture.

SAND PURIFICATION

Del Monte White Sand was used with #E18 for the greenhouse and a 3:1 mixture of 20 and 30-mesh for the outdoor experiments, respectively. Concentrated HCl of 18% was diluted to 12% with distilled water. The sand was treated with the acid and this concentrated for 2 day-runs of 7 hours each. The acid in distilled water was added to a large sand purifying apparatus until the sand was saturated and submerged below the acid to a depth of 3 inches.

Between each successive acid run the sand was thoroughly rinsed or leached with a distilled water. When the successive treatments were finished, the sand was soaked in distilled water overnight, after which it was again rinsed with distilled water and transferred to the culture vessels.

All other experimental procedures are the same as described in the condensed papers presented first in this thesis.

GENERAL RESULTS AND DISCUSSION

N concentration and uptake. The N concentration in the roots, trunks, tree tops, and total trees of both the greenhouse- and outdoor-grown trees increased linearly with increased N rates, however, the Zn levels had no significant effect on the N content of these tree parts. A response surface of total N (Fig. 1) as a function of the nutrient solution concentration of N and Zn further shows the similarities of response of the trees from the two locations in their absorption of N from the growth medium.

The N uptake by the various parts of the trees from the two locations showed an increased trend with increasing N and Zn rates (Tables 2 and 22), indicating that the reduction in N concentration noted in the different parts of the trees resulting from increasing Zn supply at the various N levels can be explained on the basis of dilution effect. This point is further strengthened by a response surface of total N uptake in Fig. 2 which shows a linear increased N uptake by the trees with increasing N and Zn applications.

P concentration and uptake. The concentration of P in the roots of the greenhouse trees decreased progressively with each increment of N supply, however, the N levels had reciprocal effect on P in the tree top (Table 3). This difference in P level in the two different parts of the trees may be due to rapid translocation of absorbed P to the aerial parts of the trees for some functional purposes.

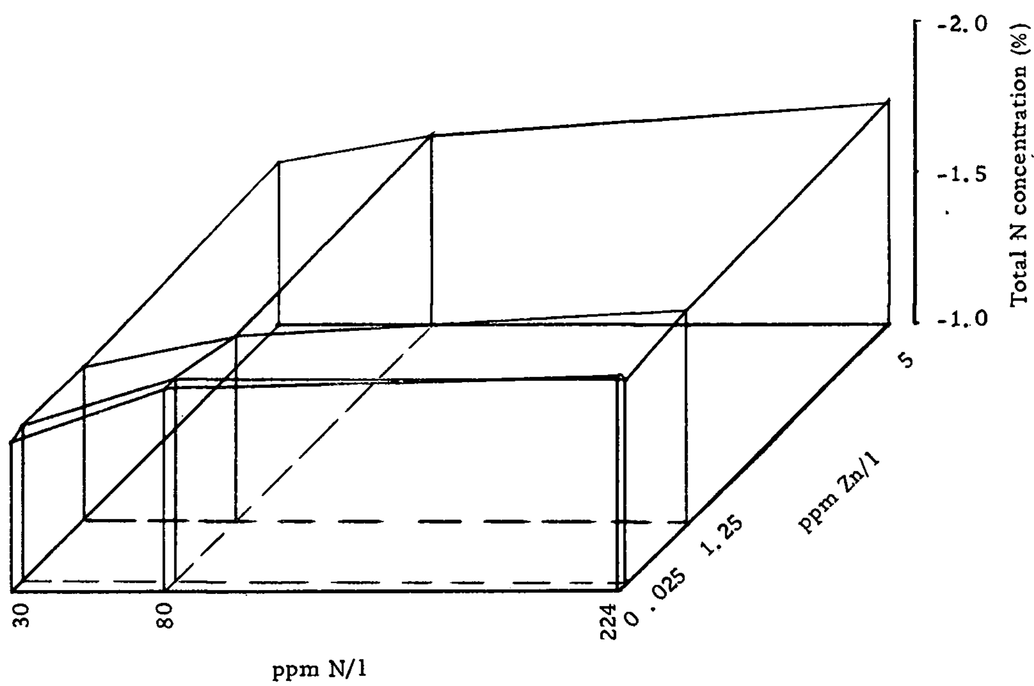

Figure 1. Total N concentration in sweet cherry trees as a function of nutrient solution concentration of N and Zn, greenhouse and outdoor experiments.

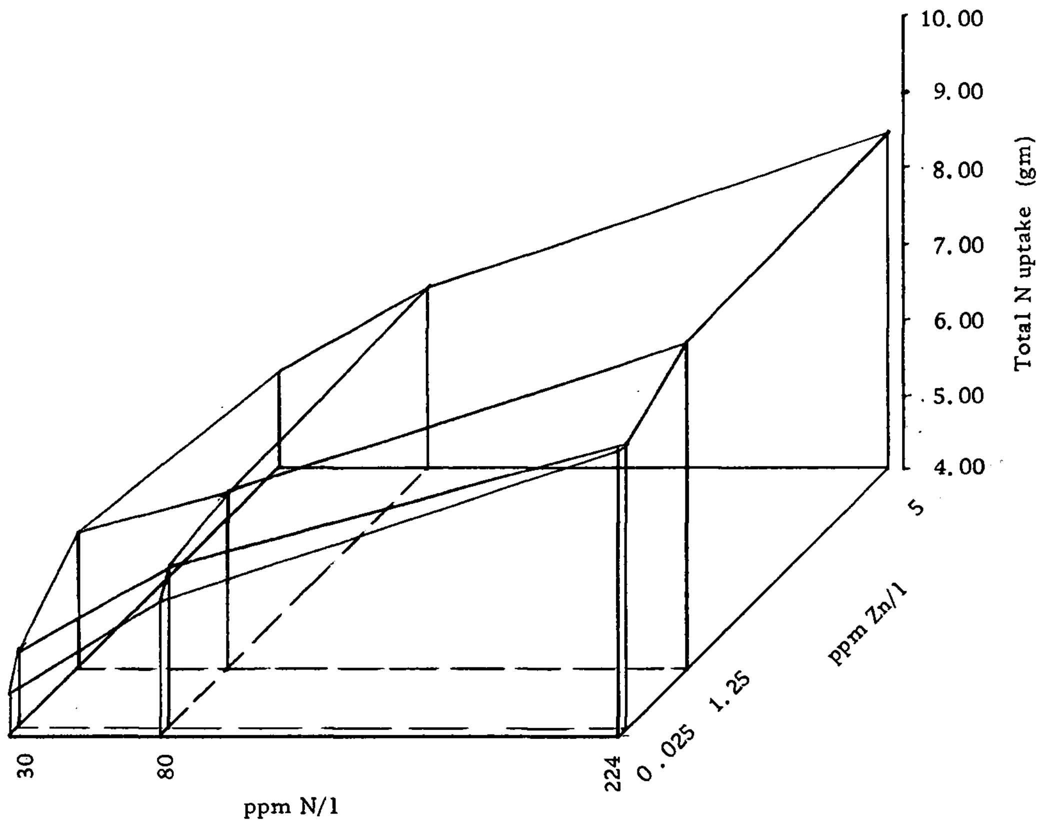

Figure 2. Total N uptake by sweet cherry trees as a function of nutrient solution concentration of N and Zn, greenhouse and outdoor experiments.

The P content of the roots, trunks, tree tops, and total trees of the outdoor trees was not significantly affected by the N and Zn treatments (Table 23).

Total P uptake by the greenhouse-grown trees was affected by a highly significant N X Zn interaction. The source of this interaction probably resulted from the significant increases of plant P uptake with increasing Zn rates at all N levels (Table 4). P uptake by the various parts of both the greenhouse and outdoor trees increased with increased N rate, but the Zn levels had no consistent effect on P uptake by these tree parts.

K concentration and uptake. It will be recalled that the nutrient solutions for the greenhouse experiment were adjusted twice a week with a dilute KOH. For this reason, the relatively high K values found in the various parts of the greenhouse-grown trees appeared to result from a luxury consumption of K and may lead one to make wrong conclusions regarding the effects of the N and Zn treatments on K.

The K uptake by the roots, trunks, tree tops, and total trees of the outdoor grown trees increased significantly with increasing N supply. This finding is not in agreement with that reported by Batjer and Degman (2) who stated that K uptake by apple trees was not influenced by the N concentration of the nutrient solutions. This difference may be due to the different capacity of apple trees in their regulation of K utilization.

Ca concentration and uptake. The N and Zn levels did not significantly influence the concentration of Ca in the roots, trunks, tree tops, and total trees of both the greenhouse- and outdoor-grown trees; however, the absolute amounts of this element in these tree parts increased with each increment of N supply, but showed no consistent pattern with the Zn levels.

Mg concentration and uptake. The Zn levels had no consistent effects on Mg uptake by the root, trunk, tree top, and total tree of the test trees. Under the greenhouse conditions, the highest rate of Zn (Zn_3) significantly decreased Mg uptake by the roots, but significantly increased the uptake of this element by the trunks and total trees. Under the outdoor conditions, the Mg uptake by the roots and total trees was significantly increased by the application of the highest rate of Zn. This Zn level decreased Mg uptake by the trunks and tree tops, however. Magnesium uptake by the various parts of the greenhouse- and outdoor-grown trees increased significantly with increasing N rates.

These findings are similar to those of Brown (5) who reported that increasing the N content of the nutrient solution resulted in an increased Mg absorption by apple trees. Barrow et al. (1) observed that application of higher Zn concentration had a depressive effect on Mg uptake by tung trees.

Mn concentration and uptake. The Mn concentration of the root and total tree of the outdoor-grown trees showed significant differences between treatments but all values were within normal range, indicating an adequate supply of this element (Table 31). The N and Zn levels had no consistent effects on root Mn and total Mn of the greenhouse-grown trees, however.

The Mn uptake by the roots and total tree of the outdoor-grown trees generally increased with increased N supply, but the Zn treatments caused somewhat inconsistent decreases in Mn uptake by these tree parts (Table 32). This shows that the inconsistent reduction in Mn concentration of these plant parts cannot be explained on the basis of a dilution effect. There appears to be a mutual antagonism between Zn and Mn in their uptake and accumulation within plants. Such a phenomenon between the two elements has been observed by other workers (3, 4, 7).

Fe concentration and uptake. The highest rate of N (N_3) significantly decreased root Fe of both the greenhouse- and outdoor-grown trees, while it significantly decreased total Fe in the latter group of trees but increased it in the former. The highest Zn level (Zn_3) significantly decreased the concentration of Fe in the roots of the greenhouse-grown trees but significantly increased both the root Fe and total Fe of the outdoor trees. The possible reasons for the inconsistent effects of high Zn on root Fe of trees from the two locations may be that the exposure of the outdoor trees to a wide range of environmental factors seems to have some influence on their capacity for Fe absorption and utilization.

Hewitt (8) and Brown and Tiffin (6) reported a decreased Fe concentration in corn and millet plants but not in kidney beans and tomatoes when zinc was applied; it should be noted that the studies by these workers involved use of distinctly different plant species as compared to this investigation where the same clone was used.

Zn concentration and uptake. The N and Zn treatments had no consistent effects in influencing the concentration of Zn in the roots, tree tops, and total trees of both the greenhouse and outdoor trees. For example, the concentration of Zn in these tree parts increased linearly with increasing N and Zn rates in the greenhouse, but showed irregular pattern outdoors. Highly significant interactions between N and Zn occurred in influencing the Zn concentration in the roots, tree tops, and total trees in the outdoor study, but showed no such interaction on Zn concentration in these plant parts in the greenhouse. However, Zn uptake by these tree parts increased linearly with increasing N and Zn rates under the two study conditions (Tables 18 and 36).

A visible synergistic effect between N and Zn was observed in Zn uptake by the roots, tree tops, and total trees of the trees from the two locations in that an increased N uptake resulted in a correspondingly increased Zn uptake by these plant parts. These findings are similar to those of Soltanpour (13) and Boawn et al. (4) who observed N-enhanced Zn uptake by potato plants despite substantial dilution caused by yield increase from N.

It is of interest to compare composition of the root and leaf tissues. The macronutrient elements determined tended to accumulate more in the leaves than in roots. The leaves contained approximately one and one-half times as much N, two times as much K, one and one-half times as much P, two times as much Ca, and two and one-half times as much Mg as the roots, respectively. The heavy-metals, except B, on the other hand, tended to be more concentrated in the roots. These findings are similar to those reported by Smith et al. (11) and Smith and Spechit (12) who found an abnormally high concentrations of heavy-metals in citrus roots; but not in complete agreement with those reported by Barrows and Gammon (1) who found that the concentrations of N and P were about the same in the leaves and feeding roots while K, Mg, and Zn were more highly concentrated in the roots of tung trees. Willihan (14) found in studies with tracer Zn that the foliage distribution of Zn was the same with either root absorption or leaf absorption. The work of Ozanne (9) showed that increased N supply increased the protein in the roots, causing increased metal accumulation in the roots, but decreased translocation of the heavy-metals to the foliage.

These comparisons show that an evaluation of either leaf or root composition, alone, may lead to different conclusions. It is possible for single element studies with N, P, or K almost any part of the plant would serve as satisfactory indication of nutritional level. This has been shown for citrus in the case of K (10). However, for total base relations or micro-element effects it would seem desirable to consider also root composition rather than to rely wholly on foliar composition in evaluating the nutritional status of plant.

The results of this investigation indicate that it is possible to increase Zn availability to sweet cherry trees by applying $ZnSO_4$ or other Zn fertilizers together with N fertilizers such as $(NH_4)_2SO_4$, especially in areas where Zn deficiency of sweet cherry is a serious nutritional problem.

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Table 1. Effects of varying levels of N and Zn on N concentration in root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, greenhouse experiment.

	N concentration (%)			
Treatment	Root	Trunk	Tree top	Total tree
N_1Zn0	1.51	0.71	1.61	1.56
N_1Zn_1	1.55	0.63	1.49	1.52
N_1Zn_2	1.57	0.55	1.48	1.51
N_1Zn_3	1.56	0.64	1.54	1.51
N_2Zn0	1.63	0.72	1.70	1.68
N_2Zn_1	1.66	0.76	1.69	1.68
N_2Zn_2	1.62	0.70	1.63	1.63
N_2Zn_3	1.64	0.71	1.64	1.64
N_3Zn0	1.68	0.86	1.75	1.72
N_3Zn_1	1.70	0.85	1.68	1.68
N_3Zn_2	1.69	0.87	1.72	1.71
N_3Zn_3	1.71	0.92	1.83	1.74
N means				
N_1	1.55	0.63	1.53	1.53
N_2	1.64	0.72	1.67	1.66
N_3	1.70	0.88	1.75	1.71
Zn means				
Zn0	1.61	0.76	1.69	1.65
Zn_1	1.64	0.75	1.62	1.63
Zn_2	1.63	0.71	1.61	1.62
Zn_3	1.64	0.76	1.66	1.64
F Tests				
N	*	*	*	*
Zn	NS	NS	NS	NS
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means	.13	0.11	0.12	0.10

*Means significantly different at the P(.05) level.

NS Means not significantly different at the P(.05) level.

Table 2. Effects of varying levels of N and Zn on N uptake by root, trunk, tree top, and total tree of sweet cherry grown in nutrient solutions, greenhouse experiment.

Treatment	N uptake (grams of dry matter/plant part) Root	Trunk	Tree top	Total tree
N_1Zn0	2.06a	.60a	2.42	4.48
N_1Zn_1	2.51b	.62a	2.56	5.07
N_1Zn_2	2.58c	.56b	2.61	5.19
N_1Zn_3	2.54b	.64ac	2.73	5.28
N_2Zn0	2.79d	.66c	3.02	5.81
N_2Zn_1	2.91e	.79d	3.24	6.15
N_2Zn_2	2.95f	.81de	3.40	6.35
N_2Zn_3	3.05g	.84e	3.38	6.42
N_3Zn0	3.19h	1.34f	4.68	7.85
N_3Zn_1	3.21h	1.42g	4.58	7.79
N_3Zn_2	3.53i	1.48h	4.81	8.34
N_3Zn_3	3.45j	1.53i	5.06	4.90
N means				
N_1	2.42	.60	2.58	5.01
N_2	2.92	.77	3.26	6.18
N_3	3.85	1.44	4.77	8.12
Zn means				
Zn0	2.68	.87	3.37	6.05
Zn_1	2.88	.94	3.46	6.34
Zn_2	3.02	.95	3.61	6.63
Zn_3	3.01	1.01	3.72	6.73
F Tests				
N	*	*	*	*
Zn	*	NS	*	*
N X Zn	*	*	NS	NS
LSD (.05)				
N means	0.95	0.56	1.79	2.11
Zn means	0.23	NS	0.16	0.48

Means within a column followed by the same letter are not significantly different at the P(.05) level as determined by the Duncan's Multiple Range Test.

*Means significantly different at the P(.05) level.

NSMeans not significantly different at the P(.05) level.

Table 3. Effects of varying levels of N and Zn on P concentration in root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, greenhouse experiment.

	P concentration (%)			
Treatment	Root	Trunk	Tree top	Total tree
N_1Zn0	.36	.18	.33	.34
N_1Zn_1	.40	.20	.28	.34
N_1Zn_2	.41	.17	.28	.34
N_1Zn_3	.35	.18	.27	.31
N_2Zn0	.30	.19	.29	.30
N_2Zn_1	.31	.18	.32	.31
N_2Zn_2	.45	.20	.32	.38
N_2Zn_3	.41	.21	.37	.39
N_3Zn0	.43	.19	.35	.38
N_3Zn_1	.33	.20	.34	.33
N_3Zn_2	.28	.22	.36	.37
N_3Zn_3	.34	.23	.36	.35
N means				
N_1	.38	.18	.29	.33
N_2	.37	.20	.33	.35
N_3	.35	.21	.35	.36
Zn means				
Zn0	.34	.19	.32	.34
Zn_1	.35	.19	.31	.33
Zn_2	.20	.32	.32	.36
Zn_3	.37	.21	.33	.35
F Tests				
N	*	NS	NS	NS
Zn	NS	NS	NS	NS
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means	0.1			

*Means significantly different at the P(.05) level.
NS Means not significantly different at the P(.05) level.

Table 4. Effects of varying levels of N and Zn on P uptake by root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, greenhouse experiment.

	P uptake (mg of dry matter/plant part)			
Treatment	Root	Trunk	Tree top	Total tree
N_1Zn0	490	152	494	984a
N_1Zn_1	648	196	489	1137b
N_1Zn_2	673	172	508	1181c
N_1Zn_3	571	180	492	1063d
N_2Zn0	513	175	524	1037e
N_2Zn_1	543	189	590	1133b
N_2Zn_2	819	230	667	1486f
N_2Zn_3	759	248	759	1518g
N_3Zn0	817	296	923	1740h
N_3Zn_1	624	334	896	1520g
N_3Zn_2	684	267	866	1550j
N means				
N_1	596	175	496	1092
N_2	659	211	635	1294
N_3	678	318	926	1603
Zn means				
Zn0	607	208	647	1254
Zn_1	605	240	658	1263
Zn_2	692	259	731	1263
Zn_3	672	232	706	1377
F Tests				
N	*	*	*	*
Zn	*	*	*	*
N X Zn	NS	NS	NS	*
LSD (.05)				
N means	55	92	286	340
Zn means	33	17	36	82

Means within a column followed by the same letter are not significantly different at the P (.05) level as determined by the Duncan's Multiple Range Test.

* Means significantly different at the P (.05) level.

NS Means not significantly different at the P (.05) level.

Table 5. Effects of varying levels of N and Zn on concentration in root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, greenhouse experiment.

	K concentration (%)			
Treatment	Root	Trunk	Tree top	Total tree
N_1 Zn0	1.11a	.88	2.05	1.61
$N_1 Zn_1$	1.39b	.93	1.96	1.69
$N_1 Zn_2$	1.09a	.87	1.94	1.54
$N_1 Zn_3$	1.26c	.91	1.77	1.53
N_2 Zn0	1.20d	.97	2.17	1.71
$N_2 Zn_1$	1.15e	.77	1.85	1.52
$N_2 Zn_2$	1.62f	.84	1.94	1.78
$N_2 Zn_3$	1.21d	.94	2.05	1.65
N_3 Zn0	1.24cd	.78	1.85	1.59
$N_3 Zn_1$	1.38fg	.92	1.93	1.71
$N_3 Zn_2$	1.15e	.93	1.89	1.58
$N_3 Zn_3$	1.35g	.96	1.97	1.71
N means				
N_1	1.21	.90	1.93	1.59
N_2	1.30	.88	2.00	1.67
N_3	1.28	.90	1.91	1.65
Zn means				
Zn0	1.18	.88	2.02	1.64
Zn_1	1.31	.87	1.91	1.64
Zn_2	1.29	.88	1.92	1.63
Zn_3	1.27	.94	1.93	1.63
F Tests				
N	*	NS	*	NS
Zn	*	NS	*	NS
N X Zn	*	NS	NS	NS
LSD (.05)				
N means	0.20		0.85	
Zn means	0.12		0.77	

Means within a column followed by the same letter are not significantly different at the P (.05) level as determined by the Duncan's Multiple Range Test.

* Means significantly different at the P (.05) level.

NS Means not significantly different at the P (.05) level.

Table 6. Effects of varying levels of N and Zn on K uptake by root, trunk, tree top, and total tree of sweet cherry grown in nutrient solutions, greenhouse experiment.

Treatment	K uptake (grams of dry matter/plant part) Root	Trunk	Tree top	Total tree
N_1Zn0	1.51a	.74	3.10a	4.61a
N_1Zn_1	2.25b	.91	3.40b	5.65b
N_1Zn_2	1.79c	.88	3.52c	5.31c
N_1Zn_3	2.06d	.91	3.16d	5.21d
N_2Zn0	2.05d	.89	3.86e	5.91e
N_2Zn_1	2.01d	.81	3.56f	5.57f
N_2Zn_2	2.95e	.97	4.03g	6.98g
N_2Zn_3	2.24b	1.11	4.23h	6.46h
N_3Zn0	2.36f	1.22	4.91i	7.27i
N_3Zn_1	2.61g	1.54	5.27j	7.88j
N_3Zn_2	2.41h	1.58	5.29j	7.69k
N_3Zn_3	2.72j	1.59	5.46k	8.17l
N means				
N_1	1.90	.86	3.29	5.19
N_2	2.32	.95	3.92	6.23
N_3	2.52	1.48	5.23	7.76
Zn means				
Zn0	1.97	.95	3.96	5.93
Zn_1	2.29	1.09	4.08	6.37
Zn_2	2.38	1.14	4.28	6.66
Zn_3	2.34	1.21	4.28	6.62
F Tests				
N	*	*	*	*
Zn	*	*	*	*
N X Zn	*	NS	*	*
LSD (.05)				
N means	0.41	0.42	0.96	1.71
Zn means	0.30	0.18	0.21	0.54

Means within a column followed by the same letter are not significantly different at the P (.05) level as determined by the Duncan's Multiple Range Test.

* Means significantly different at the P (.05) level.

NS Means not significantly different at the P (.05) level.

Table 7. Effects of varying levels of N and Zn on Ca concentration in root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, greenhouse experiment.

	Ca concentration (%)			
Treatment	Root	Trunk	Tree top	Total tree
N_1Zn0	.64	.32	.67	.66
N_1Zn_1	.60	.33	.72	.66
N_1Zn_2	.59	.24	.74	.67
N_1Zn_3	.46	.30	.77	.62
N_2Zn0	.50	.29	.70	.61
N_2Zn_1	.51	.27	.71	.61
N_2Zn_2	.55	.30	.71	.64
N_2Zn_3	.47	.26	.62	.55
N_3Zn0	.52	.21	.62	.58
N_3Zn_1	.54	.26	.63	.59
N_3Zn_2	.53	.28	.63	.59
N_3Zn_3	.56	.37	.72	.65
N means				
N_1	.57	.30	.73	.65
N_2	.51	.28	.69	.61
N_3	.54	.28	.65	.60
Zn means				
Zn0	.55	.27	.66	.62
Zn_1	.55	.29	.69	.62
Zn_2	.56	.27	.69	.63
Zn_3	.50	.31	.71	.61
F Tests				
N	NS	NS	NS	NS
Zn	NS	NS	NS	NS
N X Zn	NS	NS	NS	NS

NS Means not significantly different at the P (.05) level.

Table 8. Effects of varying levels of N and Zn on Ca uptake by root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, greenhouse experiment.

	Ca uptake (grams of dry matter/plant part)			
Treatment	Root	Trunk	Tree top	Total tree
N_1Zn0	0.87	0.27	1.01	1.88
N_1Zn_1	0.96	0.33	1.25	2.21
N_1Zn_2	0.99	0.25	1.38	2.32
N_1Zn_3	0.75	0.30	1.38	2.13
N_2Zn0	0.86	0.27	1.23	2.09
N_2Zn_1	0.89	0.29	1.34	2.33
N_2Zn_2	1.01	0.35	1.48	2.48
N_2Zn_3	0.87	0.31	1.28	2.15
N_3Zn0	0.99	0.33	1.67	2.65
N_3Zn_1	1.02	0.43	1.71	2.23
N_3Zn_2	1.11	0.48	1.75	2.86
N_3Zn_3	1.13	0.62	1.97	3.10
N means				
N_1	0.89	0.29	1.24	2.13
N_2	0.91	0.31	1.34	2.24
N_3	1.06	0.46	1.77	2.71
Zn means				
Zn0	0.91	0.29	1.30	2.21
Zn_1	0.96	0.38	1.43	2.20
Zn_2	1.03	0.36	1.52	2.55
Zn_3	0.92	0.41	1.54	2.46
F tests				
N	*	*	*	*
Zn	*	*	*	*
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means	0.11	0.12	0.35	0.39
Zn means	0.09	0.06	0.18	0.24

* Means significantly different at the P (.05) level.
NS Means not significantly different at the P (.05) level.

Table 9. Effects of varying levels of N and Zn on Mg concentration in root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, greenhouse experiment.

	Mg concentration (%)			
Treatment	Root	Stem	Plant top	Total plant
N_1Zn0	.22	.16	.33	.28
N_1Zn_1	.22	.15	.36	.29
N_1Zn_2	.21	.14	.31	.26
N_1Zn_3	.20	.15	.35	.28
N_2Zn0	.17	.16	.32	.25
N_2Zn_1	.19	.18	.36	.28
N_2Zn_2	.22	.20	.35	.29
N_2Zn_3	.21	.19	.36	.28
N_3Zn0	.20	.19	.35	.29
N_3Zn_1	.18	.18	.34	.28
N_3Zn_2	.21	.17	.35	.29
N_3Zn_3	.18	.20	.36	.29
N means				
N_1	.16	.15	.34	.28
N_2	.20	.18	35	.28
N_3	.19	.19	.35	.29
Zn means				
Zn0	.20	.17	.33	.27
Zn_1	.20	.17	.34	.28
Zn_2	.21	.17	.34	.28
Zn_3	.20	.18	.36	.28
F Tests				
N	NS	NS	NS	NS
Zn	NS	NS	NS	NS
N X Zn	NS	NS	NS	NS

NS Means not significantly different at the P (.05) level.

Table 10. Effects of varying levels of N and Zn on Mg uptake by root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, greenhouse experiment.

	Mg uptake (mg of dry matter/plant part)			
Treatment	Root	Trunk	Tree top	Total tree
N_1Zn0	229	135	497	796
N_1Zn_1	357	147	582	939
N_1Zn_2	345	142	566	911
N_1Zn_3	326	150	634	960
N_2Zn0	291	147	571	862
N_2Zn_1	333	189	694	1027
N_2Zn_2	401	230	732	1133
N_2Zn_3	389	224	708	1097
N_3Zn0	380	297	935	1315
N_3Zn_1	341	301	937	1278
N_3Zn_2	439	289	932	1371
N_3Zn_3	362	332	1020	1382
N means				
N_1	332	144	570	902
N_2	354	198	676	1030
N_3	381	305	956	1337
Zn means				
Zn0	323	193	668	991
Zn_1	344	212	738	1082
Zn_2	395	220	743	1138
Zn_3	359	235	787	1146
F Tests				
N	*	*	*	*
Zn	*	*	*	*
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means	25.0	56.0	193.0	212.0
Zn means	37.0	18.0	37.0	48.0

* Means significantly different at the P (.05) level.
NS Means not significantly different at the P (.05) level.

Table 11. Effects of varying levels of N and Zn on Mn concentration in root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, greenhouse experiment.

	Mn concentration (ppm)			
Treatment	Root	Trunk	Tree top	Total tree
N_1Zn0	69.4	55.4	95.1	82.9
N_1Zn_1	63.9	61.7	109.0	87.2
N_1Zn_2	53.0	51.7	101.4	78.2
N_1Zn_3	65.2	56.4	98.2	82.4
N_2Zn0	51.8	52.7	88.2	71.0
N_2Zn_1	52.3	44.9	89.0	75.8
N_2Zn_2	73.2	47.4	87.2	80.7
N_2Zn_3	53.3	56.4	98.7	77.2
N_3Zn0	59.1	54.2	84.6	74.0
N_3Zn_1	52.7	46.9	86.6	72.7
N_3Zn_2	90.8	53.3	84.5	87.2
N_3Zn_3	74.2	49.4	83.6	79.6
N means				
N_1	62.9	56.3	100.9	82.7
N_2	57.7	50.4	89.5	76.2
N_3	69.2	51.0	84.8	78.4
Zn means				
Zn0	60.1	54.1	89.3	76.0
Zn_1	56.3	51.2	94.9	78.6
Zn_2	72.3	50.8	91.1	82.0
Zn_3	64.2	54.1	93.5	79.7
T Tests				
N	*	NS	*	NS
Zn	*	NS	NS	NS
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means	8.0		8.0	
Zn means	9.0			

* Means significantly different at the P (.05) level.
NS Means not significantly different at the P (.05) level,

Table 12. Effects of varying levels of N and Zn on Mn uptake by root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, greenhouse experiment.

Treatment	Mn uptake (mg of dry matter/plant part) Root	Trunk	Tree top	Total tree
N_1Zn0	9.44	4.65	14.36	23.80
N_1Zn_1	10.35	6.05	18.86	29.21
N_1Zn_2	8.69	5.22	18.36	27.04
N_1Zn_3	10.63	5.64	17.48	28.11
N_2Zn0	8.86	4.85	15.70	24.56
N_2Zn_1	9.15	4.72	17.09	26.24
N_2Zn_2	13.32	5.45	18.15	31.47
N_2Zn_3	9.86	6.66	20.33	30.19
N_3Zn0	11.73	8.46	14.11	25.34
N_3Zn_1	9.96	7.83	23.64	33.60
N_3Zn_2	18.98	9.06	23.58	42.56
N_3Zn_3	14.91	8.20	23.15	38.06
N means				
N_1	9.78	5.64	17.26	27.04
N_2	10.30	5.42	17.82	28.12
N_3	13.77	8.39	21.12	34.89
Zn means				
Zn0	9.84	5.99	14.72	24.57
Zn_1	9.82	6.20	20.22	29.68
Zn_2	13.66	6.58	20.03	33.69
Zn_3	11.80	6.83	20.32	32.12
F Tests				
N	*	*	NS	*
Zn	*	NS	*	*
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means	2.0	2.0		4.0
Zn means	1.0		2.0	3.0

* Means significantly different at the P (.05) level.

NS Means not significantly different at the P (.05) level.

Table 13. Effects of varying levels of N and Zn on Fe concentration in root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, greenhouse experiment.

Treatment	Fe concentration (ppm) Root	Trunk	Tree top	Total tree
$N_1 Zn_0$	540	42	95	306
$N_1 Zn_1$	569	33	91	322
$N_1 Zn_2$	534	34	84	298
$N_1 Zn_3$	546	44	103	315
$N_2 Zn_0$	620	40	100	363
$N_2 Zn_1$	564	42	94	318
$N_2 Zn_2$	564	36	91	313
$N_2 Zn_3$	535	41	106	316
$N_3 Zn_0$	470	34	98	252
$N_3 Zn_1$	546	36	88	276
$N_3 Zn_2$	591	46	91	305
$N_3 Zn_3$	540	42	92	281
N means				
N_1	547	38	93	310
N_2	573	40	98	227
N_3	536	41	92	278
Zn means				
Zn_0	546	39	98	307
Zn_1	539	37	91	339
Zn_2	563	39	89	305
Zn_3	540	42	100	304
F Tests				
N	*	*	*	*
Zn	*	*	*	*
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means	31.0	1.50	3.0	44.0
Zn means	18.0	2.0	4.0	22.0

* Means significantly different at the P (.05) level.

NS Means not significantly different at the P (.05) level.

Table 14. Effects of varying levels of N and Zn on Fe uptake by root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, greenhouse experiment.

Treat-ment	Fe uptake (mg of dry matter/plant part) Root	Trunk	Tree top	Total tree
N_1Zn0	73.44	3.49	14.37	87.81
N_1Zn_1	92.23	3.22	15.70	107.93
N_1Zn_2	87.54	3.42	15.16	102.70
N_1Zn_3	89.03	4.43	18.26	107.29
N_2Zn0	107.69	3.73	17.73	125.41
N_2Zn_1	98.68	4.44	18.07	116.75
N_2Zn_2	102.70	4.12	18.86	121.56
N_2Zn_3	98.92	4.79	21.82	120.74
N_3Zn0	89.07	5.34	26.00	115.07
N_3Zn_1	103.19	5.93	24.10	127.29
N_3Zn_2	123.46	7.87	25.49	148.95
N_3Zn_3	105.52	6.99	25.54	131.06
N means				
N_1	85.56	3.64	15.87	101.43
N_2	102.00	4.27	19.12	121.12
N_3	195.31	6.52	25.28	130.59
Zn means				
Zn0	90.06	4.18	19.37	109.43
Zn_1	98.03	4.53	19.29	117.32
Zn_2	104.57	5.14	19.84	124.40
Zn_3	97.82	5.41	21.87	119.70
F Tests				
N	*	NS	NS	*
Zn	NS	NS	NS	NS
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means	9.0			10.0

* Means significantly different at the P (.05) level.
NS Means not significantly different at the P (.05) level.

Table 15. Effects of varying levels of N and Zn on Ca concentration in root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, greenhouse experiment.

Treat-ment	Cu concentration (Ppm) Root	Trunk	Tree top	Total tree
N_1Zn0	165	9	27	92
N_1Zn_1	215	9	14	111
N_1Zn_2	118	9	13	63
N_1Zn_3	103	9	13	56
N_2Zn0	106	8	13	59
N_2Zn_1	113	9	13	61
N_2Zn_2	114	10	14	61
N_2Zn_3	111	10	15	60
N_3Zn0	102	10	14	51
N_3Zn_1	112	10	14	54
N_3Zn_2	104	10	14	53
N_3Zn_3	103	11	15	52
N means				
N_1	150	9	17	81
N_2	111	9	14	60
N_3	106	10	14	53
Zn means				
Zn0	125	9	18	68
Zn_1	147	9	14	76
Zn_2	112	10	14	59
Zn_3	107	10	14	56
F Tests				
N	*	NS	NS	*
Zn	*	NS	NS	*
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means	21.0			11
Zn means	21.0			9

* Means significantly different at the P (.05) level.
NS Means not significantly different at the P (.05) level.

Table 16. Effects of varying levels of N and Zn on Ca uptake by root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, greenhouse experiment.

Treat-ment	Cu uptake (mg of dry matter/plant part) Root	Trunk	Tree top	Total tree
N_1Zn0	22.49	0.73	4.0	26.49
N_1Zn_1	34.82	0.88	2.34	37.16
N_1Zn_2	19.29	0.90	2.41	21.70
N_1Zn_3	16.84	0.90	2.27	19.11
N_2Zn0	18.14	0.74	2.33	20.47
N_2Zn_1	19.83	0.95	2.59	22.42
N_2Zn_2	20.75	1.15	3.00	23.75
N_2Zn_3	20.48	1.18	3.02	23.50
N_3Zn0	19.44	1.59	3.79	23.23
N_3Zn_1	21.34	1.59	3.80	25.14
N_3Zn_2	21.82	1.68	3.92	25.74
N_3Zn_3	20.84	1.83	4.03	24.87
N means				
N_1	23.36	0.85	2.76	26.12
N_2	19.80	1.01	2.74	22.54
N_3	20.86	1.67	3.89	24.75
Zn means				
Zn0	20.02	1.02	3.37	23.40
Zn_1	25.33	1.14	2.91	28.24
Zn_2	20.62	1.24	3.11	23.73
Zn_3	19.39	1.30	3.11	22.49
F Tests				
N	NS	*	*	NS
Zn	NS	*	*	NS
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means		0.50	.58	
Zn means		0.09	.33	

* Means significantly different at the P (.05) level.
NS Means not significantly different at the P (.05) level.

Table 17. Effects of varying levels of N and Zn on Zn concentration in root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, greenhouse experiment.

Treatment	Zn concentration (ppm) Root	Trunk	Tree top	Total tree
N_1Zn0	215a	39	43	124
N_1Zn_1	222b	45	51	133
N_1Zn_2	231 c	44	54	138
N_1Zn_3	254 d	50	55	150
N_2Zn0	213 a	37	44	128
N_2Zn_1	289 e	48	53	166
N_2Zn_2	329 f	44	52	181
N_2Zn_3	342 g	42	52	189
N_3Zn0	219 bh	48	52	121
N_3Zn_1	398 i	43	50	192
N_3Zn_2	408 j	46	51	204
N_3Zn_3	466 k	47	54	227
N means				
N_1	230	45	51	136
N_2	294	43	50	166
N_3	373	46	52	186
Zn means				
Zn0	216	42	46	124
Zn_1	303	54	51	164
Zn_2	323	45	52	164
Zn_3	356	47	54	187
F Tests				
N	*	NS	NS	*
Zn	*	*	*	*
N X Zn	*	NS	NS	NS
LSD (.05)				
N means	41.0			26.0
Zn means	38.0	7.0	4.0	21.0

Means within a column followed by the same letter are not significantly different at the P(.05) level as determined by the Duncan's Multiple Range Test.

* Means significantly different at the P (.05) level.

NS Means not significantly different at the P (.05) level.

Table 18. Effects of varying levels of N and Zn on Zn uptake by root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, greenhouse experiment.

Treat-ment	Zn uptake (mg of dry matter/plant part) Root	Trunk	Tree top	Total tree
N_1Zn0	29.24	3.29	6.43	35.67
N_1Zn_1	35.88	4.40	8.82	44.70
N_1Zn_2	37.87	4.46	9.17	47.04
N_1Zn_3	41.35	5.04	9.70	57.05
N_2Zn0	36.49	3.42	7.81	44.30
N_2Zn_1	50.56	5.19	60.75	60.75
N_2Zn_2	59.90	5.01	10.77	70.67
N_2Zn_3	63.34	5.02	10.67	74.01
N_3Zn0	41.55	7.50	13.80	55.35
N_3Zn_1	75.26	7.15	13.58	88.84
N_3Zn_2	85.36	7.86	14.13	99.49
N_3Zn_3	93.61	7.80	14.82	108.42
N means				
N_1	36.09	4.30	8.53	44.62
N_2	52.57	4.61	9.86	62.43
N_3	73.95	7.58	14.08	88.03
Zn means				
Zn0	35.76	4.74	9.35	45.11
Zn_1	53.90	5.52	10.86	64.76
Zn_2	61.04	5.78	11.36	72.40
N_3	66.10	5.95	11.73	77.83
F Tests				
N	*	*	*	*
Zn	*	*	*	*
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means	19.0	2.0	3.0	22.0
Zn means	15.0	1.0	3.0	18.0

* Means significantly different at the P (.05) level.
NS Means not significantly different at the P (.05) level.

Table 19. Effects of varying levels of N and Zn on B concentration in root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, greenhouse experiment.

	B concentration (Ppm)			
Treat-ment	Root	Trunk	Tree top	Total tree
N_1Zn0	51	42	89	71
N_1Zn_1	74	77	118	96
N_1Zn_2	65	39	89	77
N_1Zn_3	61	56	92	77
N_2Zn0	45	70	101	74
N_2Zn_1	50	56	111	81
N_2Zn_2	71	60	104	89
N_2Zn_3	63	69	142	106
N_3Zn0	62	60	106	87
N_3Zn_1	43	62	104	93
N_3Zn_2	35	59	91	67
N_3Zn_3	80	63	97	89
N means				
N_1	63	54	97	80
N_2	57	64	115	88
N_3	55	61	99	84
Zn means				
Zn0	53	57	99	77
Zn_1	55	65	111	90
Zn_2	57	53	95	78
Zn_3	68	63	110	91
F Tests				
N	*	*	*	*
Zn	*	*	NS	NS
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means	3.0	4.0	10.0	4.0
Zn means	5.0	7.0		

* Means significantly different at the P (.05) level.

NS Means not significantly different at the P (.05) level.

Table 20. Effects of varying levels of N and Zn on B uptake by root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, greenhouse experiment.

Treat-ment	B uptake (mg of dry matter/plant part) Root	Trunk	Tree top	Total tree
N_1Zn0	6.91	3.52	13.51	20.42
N_1Zn_1	11.94	7.54	20.51	32.45
N_1Zn_2	10.63	3.98	16.18	26.81
N_1Zn_3	10.01	5.58	16.49	26.50
N_2Zn0	7.64	6.46	18.11	25.75
N_2Zn_1	8.70	5.83	21.34	30.04
N_2Zn_2	12.99	6.88	21.79	34.78
N_2Zn_3	11.62	8.12	29.41	41.03
N_3Zn0	11.76	9.34	28.21	39.97
N_3Zn_1	8.09	10.42	28.59	36.68
N_3Zn_2	7.38	10.01	25.45	32.83
N_3Zn_3	16.04	10.44	26.94	42.98
N means				
N_1	9.87	5.16	16.67	26.55
N_2	10.24	6.83	22.66	32.90
N_3	10.82	10.05	27.30	38.12
Zn means				
Zn0	8.77	6.44	19.94	28.71
Zn_1	9.58	6.74	23.48	33.06
Zn_2	10.33	6.96	21.14	31.47
Zn_3	12.56	8.05	24.28	36.84
F Tests				
N	NS	*	*	*
Zn	NS	NS	NS	NS
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means		2.31	5.0	7.0

* Means significantly different at the P (.05) level.
NS Means not significantly different at the P (.05) level.

Table 21. Effects of varying levels of N and Zn on N concentration in root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, outdoor sand culture experiment.

Treatment	N concentration (%) Root	Trunk	Tree top	Total tree
N_1Zn0	0.97	.72	1.51	1.31
N_1Zn_1	0.99	.68	1.47	1.41
N_1Zn_2	0.95	.73	1.51	1.30
N_1Zn_3	1.04	.74	1.59	1.36
N_2Zn0	1.23	.80	1.60	1.47
N_2Zn_1	1.19	.87	1.63	1.46
N_2Zn_2	1.22	.86	1.62	1.47
N_2Zn_3	1.25	.88	1.65	1.50
N_3Zn0	1.24	.89	1.66	1.50
N_3Zn_1	1.28	.95	1.72	1.55
N_3Zn_2	1.23	.94	1.72	1.54
N_3Zn_3	1.31	.96	1.76	1.59
N means				
N_1	0.99	.72	1.52	1.35
N_2	1.19	.85	1.63	1.48
N_3	1.27	.94	1.72	1.55
Zn means				
Zn0	1.15	.80	1.59	1.43
Zn_1	1.14	.83	1.61	1.47
Zn_2	1.12	.84	1.62	1.47
Zn_3	1.18	.86	1.67	1.48
F Tests				
N	*	*	*	*
Zn	*	NS	*	NS
N X Zn	NS	NS	NS	NS
LST (.05)				
N means	.09	.11	.12	.10
Zn means	.04	NS	.05	

* Means significantly different at the P(.05) level.
NS Means not significantly different at the P(.05) level.

Table 22. Effects of varying levels of N and Zn on N uptake by root, trunk, tree top, and total tree of sweet cherry grown in nutrient solutions, outdoor sand culture experiment.

Treatment	N uptake (grams of dry matter/plant part) Root	Trunk	Tree top	Total tree
$N_1 Zn0$	0.56	.43	1.46	2.02
$N_1 Zn_1$	0.61	.44	1.53	2.14
$N_1 Zn_2$	0.63	.46	1.57	2.19
$N_1 Zn_3$	0.68	.46	1.62	2.29
$N_2 Zn0$	0.89	.58	1.84	2.73
$N_2 Zn_1$	0.86	.66	2.01	2.87
$N_2 Zn_2$	0.88	.65	2.02	2.90
$N_2 Zn_3$	0.93	.68	2.14	3.06
$N_3 Zn0$	1.12	.81	2.36	3.48
$N_3 Zn_1$	1.22	.89	2.51	3.73
$N_3 Zn_2$	1.19	.91	2.75	4.05
N means				
N_1	0.62	.45	1.54	2.16
N_2	0.89	.64	2.00	2.89
N_3	1.21	.89	2.57	3.78
Zn means				
Zn0	0.52	.61	1.89	2.74
Zn_1	0.90	.66	2.02	2.91
Zn_2	0.90	.68	2.09	2.99
Zn_3	0.97	.70	2.17	3.13
F Tests				
N	*	*	*	*
Zn	*	*	*	*
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means	0.39	.29	0.68	1.08
Zn means	0.27	.07	0.19	0.25

* Means significantly different at the P (.05) level.
NS Means not significantly different at the P (.05) level.

Table 23. Effects of varying levels of N and Zn on P concentration in root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, outdoor sand culture experiment.

Treat-ment	P concentration (%) Root	Trunk	Tree top	Total tree
N_1Zn0	0.23	.13	.20	.21
N_1Zn_1	0.24	.14	.21	.22
N_1Zn_2	0.37	.11	.17	.25
N_1Zn_3	0.25	.12	.19	.21
N_2Zn0	0.26	.13	.21	.23
N_2Zn_1	0.25	.15	.22	.23
N_2Zn_2	0.27	.14	.20	.23
N_2Zn_3	0.24	.12	.20	.21
N_3Zn0	0.28	.16	.20	.23
N_3Zn_1	0.23	.15	.20	.21
N_3Zn_2	0.27	.14	.21	.22
N_3Zn_3	0.29	.16	.20	.24
N means				
N_1	0.27	.13	.19	.23
N_2	0.26	.14	.21	.23
N_3	0.27	.15	.20	.23
Zn means				
Zn0	0.26	.14	.20	.22
Zn_1	0.24	.15	.21	.22
Zn_2	0.30	.13	.19	.23
Zn_3	0.26	.13	.20	.22
F Tests				
N	NS	NS	NS	NS
Zn	NS	NS	NS	NS
N X Zn	NS	NS	NS	NS

NS Means not significantly different at the P (.05) level.

Table 24. Effects of varying levels of N and Zn on P uptake by root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, outdoor sand culture experiment.

Treatment	P uptake (mg of dry matter/plant part) Root	Trunk	Tree top	Total tree
N_1Zn0	141	82	210	351
N_1Zn_1	165	100	243	408
N_1Zn_2	259	75	149	454
N_1Zn_3	178	75	197	375
N_2Zn0	198	98	260	459
N_2Zn_1	195	123	295	490
N_2Zn_2	207	110	260	468
N_2Zn_3	192	98	358	551
N_3Zn0	265	155	304	569
N_3Zn_1	218	143	296	514
N_3Zn_2	240	139	304	545
N_3Zn_3	271	147	294	565
N means				
N_1	186	83	200	397
N_2	198	107	293	492
N_3	248	146	299	548
Zn means				
Zn0	201	145	258	460
Zn_1	193	122	278	471
Zn_2	235	108	238	489
Zn_3	214	107	283	497
F Tests				
N	*	*	*	*
Zn	*	*	*	*
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means	35.0	34.0	41.0	84.0
Zn means	31.0	12.0	38.0	15.0

* Means significantly different at the P (.05) level.
NS Means not significantly different at the P (.05) level.

Table 25. Effects of varying levels of N and Zn on K concentration in root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, outdoor sand culture experiment.

Treatment	K concentration (%) Root	Trunk	Tree top	Total tree
N_1Zn0	0.68	.61	.93	.84
N_1Zn_1	0.60	.66	.96	.83
N_1Zn_2	0.67	.57	.98	.87
N_1Zn_3	0.79	.64	.99	.91
N_2Zn0	0.73	.66	.96	.87
N_2Zn_1	0.69	.63	.88	.81
N_2Zn_2	0.67	.61	.93	.83
N_2Zn_3	0.71	.70	1.05	.92
N_3Zn0	0.75	.58	.88	.83
N_3Zn_1	0.70	.62	.98	.87
N_3Zn_2	0.87	.65	1.05	.98
N_3Zn_3	0.63	.59	.92	.81
N means				
N_1	0.69	.62	.97	.86
N_2	0.70	.65	.96	.86
N_3	0.74	.61	.95	.87
Zn means				
Zn0	0.72	.62	.92	.85
Zn_1	0.66	.64	.94	.84
Zn_2	0.74	.61	.98	.89
Zn_3	0.71	.64	.99	.88
F Tests				
N	NS	NS	NS	NS
Zn	NS	NS	NS	NS
N X Zn	NS	NS	NS	NS

NS Means not significantly different at the P (.05) level.

Table 26. Effects of varying levels of N and Zn on K uptake by root, trunk, tree top, and total tree of sweet cherry grown in nutrient solutions, outdoor sand culture experiment.

Treatment	K uptake (grams of dry matter/plant part)			
	Root	Trunk	Tree top	Total tree
N_1Zn0	0.42	.39	0.99	1.41
N_1Zn_1	0.41	.43	1.08	1.45
N_1Zn_2	0.47	.39	1.12	1.59
N_1Zn_3	0.57	.40	1.05	1.62
N_2Zn0	0.56	.50	1.19	1.75
N_2Zn_1	0.54	.58	1.16	1.70
N_2Zn_2	0.52	.43	1.13	1.65
N_2Zn_3	0.57	.58	1.39	1.96
N_3Zn0	0.71	.56	1.33	2.04
N_3Zn_1	0.67	.60	1.45	2.12
N_3Zn_2	0.78	.65	1.62	2.40
N_3Zn_3	0.59	.55	1.35	1.94
N means				
N_1	0.47	.40	1.06	1.52
N_2	0.55	.51	1.22	1.76
N_3	0.69	.59	1.44	2.12
Zn means				
Zn0	0.56	.49	1.17	1.73
Zn_1	0.54	.51	1.23	1.77
Zn_2	0.59	.49	1.29	1.88
Zn_3	0.58	.51	1.26	1.84
F Tests				
N	*	*	*	*
Zn	NS	NS	*	*
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means	0.15	.12	0.25	0.40
Zn means	NS	NS	0.08	0.11

* Means significantly different at the P (.05) level.
NS Means not significantly different at the P (.05) level.

Table 27. Effects of varying levels of N and Zn on Ca concentration in root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, outdoor sand culture experiment.

Treatment	Ca concentration (%) Root	Trunk	Tree top	Total tree
N_1Zn0	0.50	.63	1.09	.88
N_1Zn_1	0.44	.73	1.00	.79
N_1Zn_2	0.68	.68	1.03	.88
N_1Zn_3	0.64	.70	1.01	.86
N_2Zn0	0.66	.79	1.11	.94
N_2Zn_1	0.60	.78	1.06	.90
N_2Zn_2	0.64	.75	1.06	.88
N_2Zn_3	0.67	.72	1.01	.88
N_3Zn0	0.65	.68	.96	.84
N_3Zn_1	0.60	.65	.97	.83
N_3Zn_2	0.60	.76	1.00	.85
N_3Zn_3	0.62	.57	1.01	.80
N means				
N_1	0.55	.69	1.03	.85
N_2	0.64	.76	1.06	.90
N_3	0.62	.67	.96	.83
Zn means				
Zn0	0.60	.70	1.05	.89
Zn_1	0.56	.72	1.01	.84
Zn_2	0.61	.73	1.03	.87
Zn_3	0.64	.66	.98	.85
F Tests				
N	*	*	*	*
Zn	NS	NS	*	*
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means	0.06	.03	0.07	.05
Zn means	NS	NS	0.04	.03

* Means significantly different at the P (.05) level.
NS Means not significantly different at the P (.05) level.

Table 28. Effects of varying levels of N and Zn on Ca uptake by root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, outdoor sand culture experiment.

Treatment	Ca uptake (mg of dry matter/plant part) Root	Trunk	Tree top	Total tree
N_1Zn0	307	401	1162	1469
N_1Zn_1	303	523	1161	1464
N_1Zn_2	449	467	1165	1614
N_1Zn_3	443	438	1072	1521
N_2Zn0	505	602	1373	1878
N_2Zn_1	500	642	1408	1908
N_2Zn_2	462	593	1345	1807
N_2Zn_3	538	588	1325	1863
N_3Zn0	616	661	1449	2065
N_3Zn_1	580	622	1437	2017
N_3Zn_2	534	757	1545	2079
N_3Zn_3	581	521	1335	1916
N means				
N_1	377	457	1140	1517
N_2	502	606	1363	1864
N_3	578	642	1442	2019
Zn0	476	545	1328	1804
Zn_1	461	596	1335	1796
Zn_2	482	606	1352	1833
Zn_3	523	518	1244	1767
F Tests				
N	*	*	*	*
Zn	*	*	*	*
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means	95.0	38.0	81.0	183.0
Zn means	18.0	64.0	17.0	36.0

* Means significantly different at the P (.05) level.
NS Means not significantly different at the P (.05) level.

Table 29. Effects of varying levels of N and Zn on Mg concentration in root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, outdoor sand culture experiment.

Treatment	Mg concentration (%) Root	Trunk	Tree top	Total tree
N_1Zn0	0.19	.12	.40	.32
N_1Zn_1	0.17	.13	.35	.28
N_1Zn_2	0.23	.13	.36	.31
N_1Zn_3	0.22	.14	.36	.30
N_2Zn0	0.21	.16	.42	.34
N_2Zn_1	0.24	.14	.32	.29
N_2Zn_2	0.21	.15	.29	.32
N_2Zn_3	0.24	.16	.38	.33
N_3Zn0	0.25	.14	.36	.32
N_3Zn_1	0.20	.14	.37	.30
N_3Zn_2	0.22	.17	.33	.29
N_3Zn_3	0.26	.16	.35	.32
N means				
N_1	0.21	.13	.37	.30
N_2	0.23	.15	.35	.32
N_3	0.24	.15	.35	.31
Zn means				
Zn0	0.22	.14	.37	.33
Zn_1	0.20	.14	.35	.29
Zn_2	0.22	.15	.33	.30
Zn_3	0.24	.15	.36	.32
F Tests				
N	NS	NS	NS	NS
Zn	NS	NS	NS	NS
N X Zn	NS	NS	NS	NS

NS Means not significantly different at the P (.05) level.

Table 30. Effects of varying levels of N and Zn on Mg uptake by root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, outdoor sand culture experiment.

Treat-ment	Mg uptake (mg of dry matter/plant part) Root	Trunk	Tree top	Total tree
N_1Zn0	116	76	422	538
N_1Zn_1	117	93	409	526
N_1Zn_2	161	89	407	568
N_1Zn_3	156	87	376	532
N_2Zn0	160	121	516	677
N_2Zn_1	187	115	414	602
N_2Zn_2	161	118	485	646
N_2Zn_3	192	130	506	699
N_3Zn0	236	135	545	782
N_3Zn_1	190	134	544	734
N_3Zn_2	195	169	516	712
N_3Zn_3	243	147	516	759
N means				
N_1	137	86	403	541
N_2	175	121	480	656
N_3	216	146	530	747
Zn means				
Zn0	171	111	494	666
Zn_1	164	114	456	620
Zn_2	172	125	469	642
Zn_3	197	122	466	664
F Tests				
N	*	*	*	*
Zn	*	*	*	*
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means	21.0	23.0	68.0	93.0
Zn means	11.0	9.0	30.0	41.0

* Means significantly different at the P (.05) level.
NS Means not significantly different at the P (.05) level.

Table 31. Effects of varying levels of N and Zn on Mn concentration in root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, outdoor sand culture experiment.

Treatment	Mn concentration (ppm) Root	Trunk	Tree top	Total tree
N_1Zn0	502a	131	276	358a
N_1Zn_1	329b	152	257	283b
N_1Zn_2	709c	133	252	427c
N_1Zn_3	534d	141	236	355d
N_2Zn0	551e	147	255	368e
N_2Zn_1	632f	135	228	379b
N_2Zn_2	550e	149	248	362eg
N_2Zn_3	637f	164	272	410h
N_3Zn0	611g	130	257	393i
N_3Zn_1	524h	122	252	359ag
N_3Zn_2	549e	124	209	333j
N_3Zn_3	596i	129	281	403k
N means				
N_1	518	139	255	356
N_2	592	149	251	380
N_3	570	162	250	372
Zn means				
Zn0	554	136	263	373
Zn_1	495	136	245	340
Zn_2	602	135	236	374
Zn_3	589	145	263	389
F Tests				
N	*	*	*	*
Zn	*	*	*	*
N X Zn	*	NS	NS	*
LSD (.05)				
N means	42.0	13.0	2.0	22.0
Zn means	56.0	2.0	11.0	25.0

Means within a column followed by the same letter are not significantly different at the P (.05) level as determined by the Duncan's Multiple Range Test.

* Means significantly different at the P (.05) level.

NS Means not significantly different at the P (.05) level.

Table 32. Effects of varying levels of N and Zn on Mn uptake by root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, outdoor sand culture experiment.

Treat-ment	Mn uptake (mg of dry matter/plant part) Root	Trunk	Tree top	Total tree
N_1Zn0	31	8	29	60
N_1Zn_1	23	11	29	52
N_1Zn_2	59	9	28	78
N_1Zn_3	38	9	25	63
N_2Zn0	42	11	31	73
N_2Zn_1	49	11	30	79
N_2Zn_2	42	11	31	74
N_2Zn_3	51	13	36	87
N_3Zn0	58	13	38	96
N_3Zn_1	50	12	37	87
N_3Zn_2	49	12	32	81
N_3Zn_3	56	12	41	97
N means				
N_1	35	9	28	63
N_2	46	32	78	
N_3	53	12	37	90
Zn means				
Zn0	43	13	33	76
Zn_1	40	11	32	73
Zn_2	47	11	30	77
Zn_3	48	11	34	82
F Tests				
N	*	NS	NS	*
Zn	*	NS	NS	*
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means	8.0			12.0
Zn means	2.0			3.0

* Means significantly different at the P (.05) level.
NS Means not significantly different at the P (.05) level.

Table 33. Effects of varying levels of N and Zn on Fe concentration in root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, outdoor sand culture experiment.

Treatment	Fe concentration (ppm) Root	Trunk	Tree top	Total tree
N_1Zn0	439	41	97	222
N_1Zn_1	558	56	109	276
N_1Zn_2	502	38	116	264
N_1Zn_3	471	41	98	247
N_2Zn0	527	42	105	266
N_2Zn_1	508	45	105	256
N_2Zn_2	491	39	96	245
N_2Zn_3	615	47	120	308
N_3Zn0	417	40	90	216
N_3Zn_1	424	40	129	244
N_3Zn_2	421	40	95	214
N_3Zn_3	463	36	74	226
N means				
N_1	492	44	105	252
N_2	536	43	106	269
N_3	431	39	97	225
Zn means				
Zn0	461	41	97	235
Zn_1	497	47	114	259
Zn_2	472	39	102	241
Zn_3	516	41	98	260
F Tests				
N	*	NS	*	*
Zn	*	NS	*	*
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means	72.0		2.0	32.0
Zn means	42.0		11.0	18.0

*Means significantly different at the P (.05) level.
NS Means not significantly different at the P (.05) level.

Table 34. Effects of varying levels of N and Zn on Fe uptake by root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, outdoor sand culture experiment.

Treat-ment	Fe uptake (mg of dry matter/plant part) Root	Trunk	Tree top	Total tree
N_1Zn0	26.9	2.6	10.4	37.3
N_1Zn_1	38.4	4.1	12.7	51.1
N_1Zn_2	35.3	2.6	13.1	48.4
N_1Zn_3	33.6	2.6	10.4	44.0
N_2Zn0	40.4	3.2	13.0	53.4
N_2Zn_1	39.7	3.7	13.9	53.6
N_2Zn_2	37.9	3.1	12.3	50.2
N_2Zn_3	49.4	3.9	16.0	65.4
N_3Zn0	39.5	4.0	13.6	53.1
N_3Zn_1	40.4	3.9	19.2	59.6
N_3Zn_2	37.5	4.0	14.7	52.2
N_3Zn_3	43.4	3.3	10.9	54.3
N means				
N_1	33.6	3.0	11.7	45.2
N_2	41.9	3.5	13.8	55.7
N_3	40.2	3.8	14.6	54.8
Zn means				
Zn0	35.6	3.3	12.3	47.9
Zn_1	39.5	3.9	15.3	54.8
Zn_2	36.9	3.2	13.4	50.3
Zn_3	42.1	3.3	12.4	54.6
F Tests				
N	*	NS	NS	*
Zn	*	NS	NS	NS
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means	2.0			3.0
Zn means	3.0			

* Means significantly different at the P (.05) level.
NS Means not significantly different at the P (.05) level.

Table 35. Effects of varying levels of N and Zn on Zn concentration in root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, outdoor sand culture experiment.

Treat-ment	Zn concentration (ppm) Root	Trunk	Tree top	Total tree
N_1Zn0	251ah	36a	40a	119a
N_1Zn_1	203b	40b	42a	102b
M_1Zn_2	218c	42bc	48b	114c
N_1Zn_3	206b	44d	4bd	110c
N_2Zn0	254a	40b	44ac	125d
N_2Zn_1	283d	43bcd	51bd	140e
N_2Zn_2	227e	45cd	56e	119a
N_2Zn_3	281d	46d	57e	141ef
N_3Zn0	236f	40b	52fd	125d
N_3Zn_1	271g	51e	61g	144ef
N_3Zn_2	247ah	56f	63g	133g
N_3Zn_3	265i	59f	68h	144f
N means				
N_1	220	40	45	111
N_2	261	43	52	131
N_3	255	52	61	137
Zn means				
Zn0	247	39	45	123
Zn_1	252	44	51	127
Zn_2	231	47	57	122
Zn_3	251	50	58	132
F Tests				
N	*	*	*	*
Zn	*	*	*	*
N X Zn	*	*	*	*
LSD (.05)				
N means	22.0	5.0	6.0	12.0
Zn means	18.0	4.0	4.0	5.0

Means within a column followed by the same letter are not significantly different at the P(.05) level as determined by the Duncan's Multiple Range Test.
* Means significantly different at the P (.05) level.
NS Means not significantly different at the P (.05) level.

Table 36. Effects of varying levels of N and Zn on Zn uptake by root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, outdoor sand culture experiment.

Treat-ment	Zn uptake (mg of dry matter/plant part) Root	Trunk	Tree top	Total tree
N_1Zn0	12.5	2.1	3.7	17.1
N_1Zn_1	12.3	2.5	4.1	16.5
N_1Zn_2	14.3	3.5	5.4	19.9
N_1Zn_3	13.3	2.7	5.1	18.4
N_2Zn0	14.1	3.0	5.1	19.2
N_2Zn_1	19.7	3.2	6.0	25.6
N_2Zn_2	20.2	3.4	6.3	26.5
N_2Zn_3	21.5	3.5	6.8	28.3
N_3Zn0	17.5	3.7	6.3	23.8
N_3Zn_1	26.3	5.0	9.0	35.2
N_3Zn_2	27.0	6.0	10.0	37.0
N_3Zn_3	26.3	6.0	10.3	37.1
N means				
N_1	13.1	3.0	5.0	18.0
N_2	18.8	3.2	6.1	25.0
N_3	24.3	5.1	9.1	33.3
Zn means				
Zn0	15.0	3.0	5.2	17.7
Zn_1	20.1	3.1	6.5	26.5
Zn_2	21.0	4.2	7.4	28.3
Zn_3	21.2	4.1	8.1	29.1
F Tests				
N	*	NS	*	*
Zn	NS	NS	NS	*
N X Zn	NS	NS	NS	NS
LSD (.05)				
N means	2.0		2.0	3.0
Zn means				2.0

* Means significantly different at the P (.05) level.
NS Means not significantly different at the P (.05) level.

Table 37. Effects of varying levels of N and Zn on B concentration in root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, outdoor sand culture experiment.

Treatment	B concentration (ppm) Root	Trunk	Tree top	Total tree
N_1Zn0	47	36	56	53
N_1Zn_1	52	45	70	63
N_1Zn_2	78	37	60	67
N_1Zn_3	49	38	54	52
N_2Zn0	54	37	55	55
N_2Zn_1	59	46	66	63
N_2Zn_2	62	49	62	62
N_2Zn_3	64	45	63	64
N_3Zn0	67	40	60	63
N_3Zn_1	43	38	57	52
N_3Zn_2	56	34	48	51
N_3Zn_3	61	42	62	62
N means				
N_1	57	39	61	59
N_2	60	44	62	62
N_3	57	38	57	57
Zn means				
Zn0	57	38	57	57
Zn_1	51	43	65	60
Zn_2	66	40	57	60
Zn_3	58	42	60	60
F Tests				
N	NS	NS	NS	NS
Zn	*	NS	NS	NS
N X Zn	NS	NS	NS	NS
LSD (.05)				
Zn means	4.0			

* Means significantly different at the P (.05) level.
NS Means not significantly different at the P (.05) level.

Table 38. Effects of varying levels of N and Zn on B uptake by root, trunk, tree top, and total tree of sweet cherry grown in nutrient solution, outdoor sand culture experiment.

Treatment	B uptake (mgs of dry matter/plant part) Root	Trunk	Tree top	Total tree
N_1Zn0	2.93	2.31	5.98	8.91
N_1Zn_1	3.58	3.97	8.21	11.79
N_1Zn_2	5.52	2.54	7.81	12.33
N_1Zn_3	3.53	2.39	5.80	9.33
N_2Zn0	4.15	2.82	6.79	11.94
N_2Zn_1	4.63	3.85	2.73	13.36
N_2Zn_2	4.81	3.88	7.92	12.73
N_2Zn_3	5.14	3.71	8.42	13.56
N_3Zn0	6.37	3.91	8.95	15.32
N_3Zn_1	4.16	3.71	8.52	12.68
N_3Zn_2	5.03	3.42	7.49	12.52
N_3Zn_3	5.78	3.91	9.08	14.86
N means				
N_1	3.89	2.62	6.70	10.59
N_2	4.68	3.57	7.97	12.65
N_3	5.34	3.74	8.51	13.85
Zn means				
Zn0	4.48	3.01	7.24	11.72
Zn_1	4.12	3.60	8.49	12.61
Zn_2	5.12	3.28	7.41	12.53
Zn_3	4.82	3.34	7.77	12.58
F Tests				
N	NS	NS	NS	NS
Zn	NS	NS	NS	NS
N X Zn	NS	NS	NS	NS

NS Means not significant at P (.05) level.