THE UNIVERSITY OF MANITOBA

EFFECT OF PHOSPHORUS LEVELS ON THE IRON, MANGANESE, ZINC AND COPPER UTILIZATION BY WHEAT AND FLAX

by

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ABSTRACT

Greenhouse studies were conducted in which various amounts (25 to 400 ppm) of phosphorus were added to calcareous and noncalcareous soils and the iron, manganese, zinc and copper utilization by wheat and flax studied. Wheat yields were significantly increased by phosphorus applications. Flax yields were not significantly influenced by the applications of phosphorus. Lower yields of both wheat and flax were obtained on the noncalcareous soils. Minor element content and uptake by wheat and flax were reduced in many instances when large amounts of phosphate were applied to the soils. The plants grown on the calcareous and noncalcareous soils had similar iron, manganese and copper contents, however, the plants grown on the calcareous soils contained lower amounts of zinc than did the plants grown on the noncalcareous soils.

Incubation of 10-g soil samples with phosphorus at rates of 0 to 0.8 g $NH_4H_2PO_2$ usually decreased the pH and increased the iron, manganese, copper and zinc content of soil-water extracts. The applications of phosphorus increased the minor element content of the extracts of the noncalcareous soils to a greater degree than that of the calcareous soils.

Phosphorus additions at rates of 2 to 100 ppm to nutrient solutions did not affect wheat yields whereas, the yields of flax tops and roots were significantly decreased at phosphate rates above 20 ppm. Zinc and copper contents of wheat and flax decreased with increasing amounts of phosphorus. Iron and manganese contents showed no definite trends. The total uptake of iron, manganese, zinc and copper by wheat and flax was usually reduced by high levels of phosphorus in solution. Except for copper in flax, translocation of minor elements was not reduced by high levels of added phosphorus.

Increasing the minor element content of nutrient solutions at various phosphate levels did not affect the yields of wheat. Increasing the minor element content of the solutions increased minor element uptake, indicating that ion antagonism was mainly responsible for the lower utilization of minor elements in high phosphate mediums.

Copper and/or zinc applications increased flax yields significantly on two Manitoba soils. Additions of copper or zinc increased the uptake of these elements by flax.

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I. INTRODUCTION

Phosphorus fertilizers have to be applied to most Manitoba soils if maximum yields of crops are to be attained. Yields of wheat and barley are usually increased by approximately six and eight bushels per acre, respectively, when 20 lb P_2O_5 per acre are added. Although the additions of phosphate fertilizers to most crops results in yield increases; it is possible that the continual use of phosphate fertilizers on Manitoba soils could result in nutritional problems. Spratt and McCurdy (52), in Saskatchewan, studied the long-term effects of phosphate fertilization on the yield of wheat. They found that the application of 40 lb of monoammonium phosphate per acre to previously unfertilized plots increased yields from 19.6 to 25.1 cwt per acre. The application of 40 lb of monoammonium phosphate per acre to plots previously fertilized with monoammonium phosphate at 20, 30, 40, 60, 80 and 100 lb. per acre per year for 20 years produced yields of 24.7, 23.8, 22.7, 22.6, 21.4 and 21.7 cwt per acre, respectively. These results indicate that repeated phosphate applications may create nutritional disorders in wheat.

Recent work conducted in the United States has shown that the addition of phosphate fertilizers can reduce the minor element content of plants. The reduction in minor element uptake by plants on phosphated soils has been attributed to the immobilization of minor elements in the soil by phosphate precipitation (3, 50). Other workers have suggested that the reaction external to the plant was not adequate to explain the reduction in minor element uptake by plants. Ion antagonism at or in the plant roots has been offered as an explanation for the reduction of minor element uptake from high phosphate substrates.

Since phosphate fertilizers have to be added to Manitoba soils to obtain high yields and since these fertilizers can cause minor element deficiencies, several experiments were conducted to study:

1. the effects of added phosphorus on the utilization of minor elements by wheat and flax on three noncalcareous soils (Stockton, Newdale and Red River) and three calcareous soils (Plum Ridge, Lakeland and Tarno).

2. the concentrations of minor elements in the soil solution of soils treated with phosphorus and incubated for 2, 14, or 28 days.

3. the minor element uptake by plants grown in solutions containing varying amounts of phosphorus. Wheat and flax were grown in nutrient cultures varying in phosphate concentrations and the minor element content of the tops and roots of the plants measured. The influence of varying the minor element content of nutrient cultures containing various levels of phosphorus was also investigated.

4. the effect of zinc and copper applications on the utilization of these elements by flax when grown on calcareous and noncalcareous soils.

II. REVIEW OF LITERATURE

Phosphorus-minor element interactions in plants and in soils have received considerable attention because of the increasing number of reports of deficiencies and toxicities of minor elements in various crops. Excessive or prolonged phosphate fertilization has been known to induce nutritional disorders in plants (5, 14, 15, 16, 30).

Phosphorus-Zinc Interactions

In 1948, Rogers and Wu (44) found that phosphate applications to a fine sand reduced the zinc content of oats. However, zinc applications did not produce any significant yield increases.

Loneragan (33) reported that the addition of phosphorus to soil increased the phosphorus content of flax but decreased the relative and absolute amounts of zinc. He suggested that applied phosphorus had some effect on the uptake of zinc by the roots, or on the translocation from the roots to the tops of flax plants. Similar results were obtained by Stukenholtz *et al*. (54). They suggested that the phosphorus-zinc interaction in corn plants occurred at the root surface or in the roots cells, and was not a chemical immobilization of zinc in the soil. High phosphate concentrations in the soil reduced zinc translocation from the roots to the tops of corn plants.

Seatz *et al*. (46) reported that zinc applications to a soil increased the zinc concentration but decreased the phosphorus content of flax. Burleson and Page (17) found that increasing the zinc or phosphorus content of a nutrient solution increased the content and uptake of the respective elements in the roots and tops of flax. They concluded that the immobilization of zinc took place within the plant root. Their results were in agreement with those of Soltanpour (49).

A decrease in the top to root zinc content ratio may be evidence of zinc precipitation or reduced translocation within the plant (56). However, Spencer (50) reported that translocation of zinc was not a problem, but that the reduced zinc uptake was due to immobilization of zinc in the soil by precipitation with phosphate.

Other workers (7, 38) also reported a reduction in zinc uptake by plants treated with large amounts of phosphorus. Langin _et al_. (30) concluded that the effect of phosphorus on zinc utilization was physiological within the plant, perhaps in plant root cells. Burleson _et al_. (16) reported zinc deficiency symptoms in both sweet and field corn when phosphorus fertilizers were applied. Their work also indicated that zinc uptake by bean plants was reduced by phosphate fertilization. Ganiron _et al_. (22) found that the phosphorus content in corn leaves was reduced by zinc fertilization. Similar results were obtained by Singh and Dartigues (47).

Heavy phosphorus applications generally induce a greater zinc deficiency on soils which contain free $CaCO_3$ and have a pH above 7.0 than on soils which do not contain $CaCO_3$ and are acidic (35). Lime applications to soils have been shown to reduce zinc uptake by oats (44).

In contrast to the literature cited, Boawn _et al_. (9) reported that phosphorus applications did not influence the availability of zinc or its utilization by bean plants. Field experiments indicated that phosphorus applications did not produce or accentuate zinc deficiency in beans. In a sand culture study, Bingham (4) found an increase in the zinc content of roots and leaves of bean plants with increased phosphate applications. Watanabe _et al_. (57) reported that the total zinc uptake by bean plants was increased with phosphorus fertilization.

Phosphorus-Iron Interactions

Brown and Tiffin (15) found that increasing the phosphorus in a soil could accentuate iron chlorosis in corn and millet. Brown and Bell (12) also noted that phosphorus accentuated iron chlorosis in corn. The chlorosis was associated with low iron and high phosphorus concentrations in the plant tops. Phosphate applications induced iron chlorosis in potato plants when the soil-iron supply was limiting (10). The iron content of citrus seedling leaves (51) and of rice leaves (13) was reduced by phosphorus applications.

Biddulph and Woodbridge (3) reported that ferric phosphate precipitated in or on the roots of bean plants and retarded the movement of phosphorus to the leaves. In addition to iron, it has been suggested that calcium may also precipitate phosphorus and reduce its transport to plant tops (45). DeKock (19) concluded that iron in roots may be present as an insoluble ferric phosphate. However, the activity of iron in plants was greater than that if ferric phosphate was present and thus phosphorus appeared to influence the metabolic reactions essential to the uptake of iron (12).

Foster and Russell (21) suggested that phosphorus was complexed by iron in plant roots. This iron was non-mobile, being bound to an organic radical (R) as follows:

$$RFe^{+} + H_2PO_4^{-} \longrightarrow RFeH_2PO_4$$

Work conducted by Bentley et al. (2) indicated that the additions of phosphorus to a nutrient solution did not have a consistent effect on the iron content of oats. Increasing the external iron content did not affect the iron content of oats. Bingham et al. (7) did not find any consistent trend between iron content of citrus leaves and varying amounts of applied phosphate.

At high phosphate levels, iron did not accumulate or precipitate as ferric phosphate within the plant roots (11). These results were in agreement with the work done by Bennett (1). Fiskel et al. (20) noted that phosphate levels did not change the iron to manganese content ratio. Also, the intake of iron and manganese was not affected by the level of applied phosphate.

The iron content of plants can also be increased by phosphorus applications. Singh and Dartigues (47) showed that the addition of polyphosphates and orthophosphates increased the iron content of maize. The iron content of wheat leaves (14) and soybeans (32) was increased by the application of phosphorus. Similar results were obtained by Watanabe et al. (57).

Phosphorus-Manganese Interactions

Bingham and Garber (5) reported that manganese uptake was greater, both in tops and roots of citrus plants when high phosphate rates were used. Spencer (50) also reported an increase in manganese uptake by citrus seedlings when increasing amounts of phosphate were added to the soil. There was no evidence of reduced translocation at the high phosphorus levels. He suggested that the increase in manganese availability following heavy applications of superphosphate was probably due to the increase in soil acidity, rather than to a genuine "phosphate" effect. Page et al. (40) also concluded that superphosphate would decrease the soil pH and therefore, increase the manganese uptake by plants. However, the pH change may not explain entirely the greater availability of manganese (5). Water extracts from soil treated with phosphate were found to contain more manganese than untreated soil and yet there was little change in pH.

Bingham (4) found that adding phosphorus at rates of 1 to 100 ppm to a sand culture increased the manganese content of bean leaves from 174 to 202 ppm and the root manganese content from 398 to 795 ppm. The manganese content of citrus leaves (7) and corn (57) was increased when phosphorus was added to the soil. Bentley _et al_. (2) reported an increase in the manganese content of oat leaves in one experiment and a decrease in the manganese content of oat leaves in another experiment when phosphorus was added. Larsen (31) reported an increase in the manganese content of oats and sugar beets which were grown on a phosphated acid soil.

Other workers found that the manganese content of several crops was either not affected or decreased when phosphorus was added. Bolle-Jones (10) found that an increased phosphorus supply decreased the uptake and concentration of manganese in the roots and tops of potato plants. The application of rock phosphate had little effect on the manganese uptake by grasses (48). Steckel _et al_. (53) showed that superphosphate added to an acid soil, without the addition of manganese sulfate, had no effect on the manganese content of oats and soybean crops.

A recent study by Messing (36) showed that increases or decreases in the manganese concentration in lettuce plants from the application of phosphate was dependent upon soil pH values. The manganese concentration in the plants decreased at low lime applications were adding phosphorus increased the soil pH from 4.4 to 5.5. The manganese concentration in the plants increased at high lime levels where adding phosphorus decreased soil pH from 7.0 to 6.0.

Phosphorus-Copper Interactions

Phosphorus-copper interactions have received much attention in areas where citrus crops are grown. Bingham and Garber (5) found that heavy applications of superphosphate reduced the uptake of copper by orange seedlings. A similar influence of phosphorus on copper was reported by other workers (6, 7).

Brown et al. (13) reported that the copper content of rice leaves could be reduced by phosphate applications. Spencer (50) found that the copper content of citrus leaves and roots was reduced by phosphorus fertilization. Added copper reduced the phosphorus content of roots as well as stems and leaves which would indicate that copper was interfering with the ability of plants to obtain phosphorus from the soil, rather than reducing translocation of phosphorus in the plants. Spencer (51) was unable to distinguish between soil and plant interaction effects of copper and phosphorus.

Copper and phosphorus were more effective in producing chlorosis if applied together than if either element was applied separately (14). However, Bingham (4) was unable to find any consistent trend that would indicate a phosphorus-copper interaction in a sand culture study.

The review of the literature indicates that the exact nature of phosphorus-minor element interactions are not fully understood. The application of phosphorus to soils has a variable effect on minor element content and uptake by plants. Reduced minor element uptake by plants has been attributed to precipitation of minor elements in the soil or on the plant root surfaces. More recent investigations have indicated that the phosphorus-minor element interactions were physiological in nature due to a root surface absorption phenomenon or reduced translocation within the plant. The effect of phosphorus on minor element utilization depends on soil type, crop grown, availability of soil minor elements and phosphorus, and other soil and plant factors.

III. MATERIALS AND METHODS

The experimental methods used for the individual studies reported in this manuscript are described with the results obtained in the appropriate subsections. The analytical procedures employed in the investigations and in characterizing the soils are outlined below.

(1) Soils

Six surface soils of varying texture, pH and carbonate content were selected (Table I and II). The Stockton, Newdale and Red River soils did not effervesce when treated with dilute (HCl)(noncalcareous) whereas the Plum Ridge, Lakeland and Tarno soils strongly effervesced (calcareous).

(2) Soil pH

The pH of the soil samples was determined electrometrically by use of the glass and calomel electrodes on an Orion Model 801 digital pH meter. A soil-water saturated paste was used in determining the pH.

(3) Soil Organic Matter

Soil organic matter was determined as described by Walkley and Black (56). Excess potassium dichromate was used to oxidize the organic matter and the unreacted dichromate back-titrated with ferrous sulphate using barium diphenylamine sulphonate as indicator.

(4) Conductivity

The electrical conductivity of a soil-water saturated paste extract was measured using a Conductivity Bridge, Model RC16B2.

(5) Inorganic Carbonate Content

The method described by Ridley (43) was used. A one-gram soil sample was digested in 10% HCl for ten minutes. The CO_2 evolved was sucked through a drying and adsorption train, then absorbed by Ascarite in a Nesbitt tube. The weight of CO_2 absorbed on the Ascarite was

TABLE I

SUBGROUP DESIGNATION AND TEXTURAL CLASS OF SOILS

Soil Name	Subgroup	Textural Class
Stockton	Orthic Black	Loamy Sand
Newdale	Orthic Black	Clay Loam
Red River	Gleyed Rego Black	Clay
Plum Ridge	Gleyed Carbonated Rego Black	Sandy Loam
Lakeland	Gleyed Carbonated Rego Black	Clay Loam
Tarno	Carbonated Rego Humic Gleysol	Clay

TABLE II

CHARACTERISTICS OF THE SOILS

Soil Name	pH	Organic Matter (%)	Cond. (mmhos/cm)	Inorganic CO_3 (%)	Moisture Content at f.c. (%)	$NaHCO_3$ extr. P (ppm)	Exch. K (ppm)	NO_3^-N (ppm)
Stockton	6.5	3.0	0.1	0.4	21.4	4	310	5
Newdale	7.5	7.5	0.8	1.2	30.0	15	720	62
Red River	7.6	7.2	0.5	0.4	36.1	13	490	7
Plum Ridge	8.2	4.9	0.5	19.0	19.4	7	65	35
Lakeland	7.9	5.6	0.5	18.2	25.2	4	125	12
Tarno	7.9	5.8	0.7	18.2	30.5	7	260	29

determined and the carbonate content of the soil calculated.

(6) Determination of Water Content at Field Capacity

Soil, sieved through a 2 mm sieve, was placed in 400 ml beakers and sufficient water added to wet the surface one-half of soil. The samples were enclosed in polyethylene bags and allowed to equilibrate for several days. Soil samples were taken above the wetting front, weighed and dried at 100°C for 24 hours. The loss in weight of the samples was measured and the moisture content of the soils calculated.

(7) $NaHCO_3$ Extractable Phosphorus

$NaHCO_3$ extractable phosphorus was determined as outlined by Olsen et al. (39). Five grams of soil were shaken with 100 ml of 0.5 M $NaHCO_3$ extracting solution for 30 minutes. A 50 ml aliquot of the extract was transferred to a 100 ml volumetric flask and acidified with HCl. Twenty millimeters of ammonium molybdate-HCl solution and 10 ml of dilute stannous chloride were added and the total volume made up to 100 ml with distilled water. The samples were allowed to stand for five minutes and the color intensity read on a Coleman Junior Spectrophotometer Model 6A at 660 mu. By comparison of these readings with those obtained for a standard curve, the phosphorus content of the soils was calculated.

(8) Exchangeable Potassium

A 2.5-g sample of soil was shaken with 25 ml of neutral, 1N NH_4Ac for 30 minutes. The potassium content of the filtrate was determined by use of a Baird Atomic Flame Photometer Modek KY2.

(9) Determination of NO_3-N

The NO_3^-N content of the soils was determined colorimetrically using the phenoldisulfonic acid method (8). Ten grams of soil were shaken with 50 ml of extracting solution (0.02N $CuSO_4 \cdot 5H_2O$ and 0.004N Ag_2SO_4). A 25 ml aliquot was evaporated to dryness on a hot plate and the residue treated with two ml of phenoldisulfonic acid. The extract was transferred to a 100 ml volumetric flask and dilute NH_4OH added until the solution was basic. The color intensity was measured on a Coleman Junior Spectrophotometer Model 6A at 415 mu and the readings compared to those obtained for a standard curve. The NO_3^-N content of the soils was then calculated.

(10) Water Extractable Phosphorus

The method outlined by Jackson (26) was used. A suitable aliquot of the extract, placed into a 50 ml volumetric flask, was adjusted to pH 3 with 2N H_2SO_4 or 4N Na_2CO_3 using 2, 4-dinitrophenol as indicator. Five milliliters of 2.5% ammonium molybdate-sulphuric acid solution was then added and the solution diluted to 50 ml. The phospho-molybdate complex was reduced by the addition of three drops of chlorostannous acid reductant solution. Six minutes after the initiation of color development, the color intensity was read on a Coleman Junior Spectrophotometer Model 6A at 660 mu. The readings were compared to those of a standard curve and the phosphorus content of the solutions calculated.

(11) Technique for Washing Plant Tops and Roots

Prior to analysis, plant tops were washed with deionized water several times. The intact plants obtained from the nutrient culture studies were washed with deionized water several times and the roots placed into an aerated solution of 10^{-3}M EDDHA (ethylenediamine di-(O-hydroxyphenol acetic acid)) to remove minor elements adhering to the external surface of the roots (28). After one hour, the roots were washed several times with deionized water and dried at 70°C.

(12) Total Phosphorus Content of Plants

The plant samples were ground and a 0.5-g sample digested in 17 ml of HNO_3 and 3 ml of $HClO_4$ by boiling until the volume of acid was reduced to approximately two ml. The digest was diluted to 50 ml and filtered. The phosphorus content of the plant digests was determined using the vanado-molybdate yellow color method (27). A suitable aliquot was placed into a 50 ml volumetric flask. Ten milliliters of vanadomolybdate reagent were added and the solution diluted to 50 ml with distilled water. The color intensity was read on a Coleman Junior Spectrophotometer Model 6A at 440 mu. The readings were compared to those obtained for a standard curve and the phosphorus content of the samples calculated.

(13) Determination of Iron, Manganese, Zinc and Copper in Plant Samples

A suitable aliquot (usually 10 ml) of the plant digests used for total phosphorus determinations was diluted to 50 ml with deionized water. The iron, manganese, zinc and copper contents of the solutions were determined by use of a Perkin-Elmer Model 303 Atomic Absorption Spectrophotometer (41).

IV. PRESENTATION OF EXPERIMENTAL RESULTS AND DISCUSSION

The Effect of Added Phosphorus on the Iron, Manganese, Zinc, Copper and Phosphorus Utilization by Wheat and Flax Grown in Noncalcareous and Calcareous Soils.

A greenhouse experiment was designed to gain information on the minor element utilization by wheat and flax grown in soils treated with varying amounts of phosphorus. Two kilograms of air dried soil were placed into one-half gallon pots. The experimental design was a randomized block with three replicates. Treatments used were as follows:

(a) no phosphorus added;

(b) 25 ppm phosphorus in a band one inch below the seed;

(c) 50 ppm phosphorus mixed with the soil;

(d) 100 ppm phosphorus mixed with the soil;

(e) 200 ppm phosphorus mixed with the soil;

(f) 400 ppm phosphorus mixed with the soil.

Phosphorus was added as $NH_4H_2PO_4$. All pots received 181 ppm nitrogen as $NH_4H_2PO_4$ and/or NH_4NO_3. Two test crops, wheat and flax were grown and after emergence these crops were thinned to four and eight plants per pot, respectively. Periodically the pots were rotated on the greenhouse bench to provide uniform lighting for all plants. Deionized water was added to the soil as required to bring the moisture level to field capacity. Above ground portions of the plants were harvested 42 days after planting. The plant material was washed, dried at 70^{o}C and weighed. The plant material obtained from the replicates was composited, ground, wet ashed and analyzed for iron, manganese, copper and zinc by atomic absorption spectrophotometry. Phosphorus content of the plant digest was determined colorimetrically.

The pH of the soils after cropping was also measured. Soil samples were taken from each pot; the various replicates for each crop and phosphate treatment were composited and air dried prior to analysis.

The yields of wheat on all soils were significantly increased when phosphorus was added (Table III). On several soils, maximum yields of wheat were not attained unless 100 or 200 ppm phosphorus was added. Application of 400 ppm phosphorus reduced the yield of wheat on several soils when compared to yields obtained when smaller amounts of phosphorus were added. The yields of flax on the noncalcareous soils increased with phosphorus fertilization. However, these increases were not statistically significant. On the noncalcareous soils, Stockton, Newdale, and Red River, maximum yields of flax were obtained when 100 ppm phosphorus was added. Flax did not respond to phosphorus additions on the Plum Ridge and Lakeland soils. Wheat and flax yields were lower on the calcareous than on the noncalcareous soils.

The phosphorus content of both wheat and flax increased when phosphorus was added (Table IV). The phosphorus content of wheat and flax grown on the Newdale and Lakeland soils was generally lower than on the other soils. At high levels of added phosphate, flax tissue contained higher concentrations of phosphorus than did wheat grown on the same soils. It is interesting to note that the phosphorus content of flax was as high as 0.91 and 0.94% when grown on the Tarno and Plum Ridge soils, respectively.

The iron content of wheat grown on the Red River and Lakeland soils decreased with increased rates of added phosphorus (Table V). Wheat grown on the Tarno and Stockton soils showed an increase in iron content when phosphorus was added. The iron content of flax decreased when grown on the Stockton, Red River and Plum Ridge soils and increased when grown on the Lakeland soils at higher levels of phosphorus. Added phosphate had

TABLE III

EFFECT OF ADDED PHOSPHORUS ON YIELDS OF WHEAT AND FLAX (g/pot)*

Treatment	Stockton	Newdale	Red River	Plum Ridge	Lakeland	Tarno
		Wheat				
No P added	2.2	2.4	1.9	0.8	1.3	1.4
25 ppm P (band)	3.9	3.0	4.7	1.6	2.4	2.6
50 ppm P (mixed)	4.0	3.4	4.8	1.3	2.5	2.6
100 ppm P (mixed)	4.4	3.5	4.8	1.6	2.7	3.3
200 ppm P (mixed)	4.2	3.6	5.2	1.3	2.9	3.5
400 ppm P (mixed)	4.2	3.4	2.5	1.4	2.8	3.2
LSD (0.05 P)	0.4	0.5	1.2	0.3	0.6	0.3
		Flax				
No P added	1.6	2.7	2.6	0.8	0.8	0.9
25 ppm P (band)	2.1	2.9	3.1	0.7	0.7	1.1
50 ppm P (mixed)	2.1	2.8	3.3	0.8	0.7	1.1
100 ppm P (mixed)	2.2	3.0	3.7	0.7	0.7	1.3
200 ppm P (mixed)	2.0	2.7	3.4	0.6	0.7	1.1
400 ppm P (mixed)	2.1	2.8	3.4	0.6	0.8	1.0
LSD (0.05 P)	NS	NS	NS	NS	NS	NS

* Yields are averages of three replicates.

TABLE IV

EFFECT OF ADDED PHOSPHORUS ON THE PHOSPHORUS CONTENT OF WHEAT AND FLAX (%)

Treatment	Stockton	Newdale	Red River	Plum Ridge	Lakeland	Tarno
			Wheat			
No P added	0.32	0.30	0.41	0.40	0.28	0.42
25 ppm P (band)	0.35	0.31	0.47	0.41	0.32	0.42
50 ppm P (mixed)	0.48	0.33	0.47	0.42	0.34	0.44
100 ppm P (mixed)	0.60	0.37	0.59	0.46	0.37	0.46
200 ppm P (mixed)	0.68	0.42	0.55	0.46	0.31	0.52
400 ppm P (mixed)	0.68	0.45	0.68	0.52	0.44	0.54
			Flax			
No P added	0.29	0.30	0.36	0.41	0.22	0.40
25 ppm P (band)	0.41	0.26	0.38	0.51	0.22	0.43
50 ppm P (mixed)	0.47	0.34	0.43	0.62	0.26	0.51
100 ppm P (mixed)	0.63	0.45	0.55	0.66	0.33	0.57
200 ppm P (mixed)	0.78	0.45	0.71	0.90	0.36	0.93
400 ppm P (mixed)	0.88	0.55	0.80	0.94	0.44	0.91

TABLE V

EFFECT OF ADDED PHOSPHORUS ON THE IRON CONTENT OF WHEAT AND FLAX (ppm)

Treatment	Stockton	Newdale	Red River	Plum Ridge	Lakeland	Tarno
			Wheat			
No P added	50	81	68	61	103	50
25 ppm P (band)	61	75	68	61	89	71
50 ppm P (mixed)	61	95	55	61	92	71
100 ppm P (mixed)	58	81	56	61	93	71
200 ppm P (mixed)	61	99	50	50	76	77
400 ppm P (mixed)	60	87	55	61	63	77
			Flax			
No P added	111	109	74	91	81	77
25 ppm P (band)	100	80	73	90	87	65
50 ppm P (mixed)	90	110	68	70	87	58
100 ppm P (mixed)	93	115	68	70	88	58
200 ppm P (mixed)	97	107	68	70	100	77
400 ppm P (mixed)	97	112	56	68	103	68

little or no effect on the iron content of flax grown on the Newdale and Tarno soils, except when 25 ppm phosphorus was banded into the Newdale soil and when 50 and 100 ppm phosphorus was added to the Tarno soil where the iron content was decreased. Except for the Lakeland and Tarno soils, the iron content of flax was greater than that of wheat. The iron content of both wheat and flax was generally within the range considered to be adequate for plant growth (18, 34) and indicated that the calcareous and noncalcareous soils supplied similar amounts of iron to the plants.

The pH of the Stockton, Newdale, Plum Ridge, Tarno and Lakeland soils decreased with increases in applied phosphorus (Table VI). However, only the iron content of wheat grown on the Stockton and Tarno soils and the iron content of flax grown on the Lakeland soil reflected this pH change. An increase in pH of the Red River soil was noted when phosphorus was added. The iron content of both wheat and flax grown on the Red River soil decreased with additions of phosphorus. Although the iron content of the plants on some soils reflected soil pH changes when phosphorus was added, the influence of added phosphorus on the iron content of the plants cannot be explained on the basis of soil pH changes alone.

The manganese content of wheat, except on the Stockton soil, usually decreased with increases in added phosphorus (Table VII). Addition of phosphorus to the Stockton soil increased the manganese content of wheat. Examination of the pH of the Stockton soil after cropping revealed that the addition of phosphorus decreased the pH from 6.3 to 5.5 (Table VI). Therefore, the increase in manganese content of wheat grown on the Stockton soil was probably due to increased soil manganese availability as a result of the reduction in soil pH. An increase in manganese content of wheat, however, did not occur on the Newdale, Lakeland and Tarno soils in spite

TABLE VI

pH* VALUES OF SOILS AFTER CROPPING

Treatment	Stockton	Newdale	Red River	Plum Ridge	Lakeland	Tarno
No P added	6.3	7.5	6.7	8.1	7.9	7.7
25 ppm P (band)	5.8	7.4	7.0	7.9	7.6	7.7
50 ppm P (mixed)	5.8	7.3	7.0	7.9	7.6	7.6
100 ppm P (mixed)	6.2	7.3	7.1	7.9	7.6	7.6
200 ppm P (mixed)	5.6	7.1	7.1	7.9	7.6	7.5
400 ppm P (mixed)	5.5	7.0	7.2	7.8	7.5	7.4

* soil-water ratio 1:5.

TABLE VII

EFFECT OF ADDED PHOSPHORUS ON THE MANGANESE CONTENT OF WHEAT AND FLAX (ppm)

Treatment	Stockton	Newdale	Red River	Plum Ridge	Lakeland	Tarno
			Wheat			
No P added	33	34	53	24	30	35
25 ppm P (band)	85	33	43	24	36	35
50 ppm P (mixed)	91	28	35	24	32	35
100 ppm P (mixed)	95	27	41	23	27	33
200 ppm P (mixed)	112	23	31	17	24	32
400 ppm P (mixed)	134	23	53	15	23	29
			Flax			
No P added	130	99	179	94	350	255
25 ppm P (band)	227	120	158	109	397	214
50 ppm P (mixed)	234	111	164	91	328	207
100 ppm P (mixed)	267	102	129	83	355	187
200 ppm P (mixed)	294	111	139	80	373	174
400 ppm P (mixed)	335	114	132	73	355	166

of the decrease in soil pH by 0.3 to 0.5 pH units. Phosphate applications increased the manganese content of flax grown on the Stockton and Newdale soils but decreased the manganese content of flax grown on the Red River, Plum Ridge and Tarno soils. The highest manganese content of flax grown on the Plum Ridge and Lakeland soils was obtained when 25 ppm of phosphorus was added in a band below the seed. It is possible that a localized decrease in soil pH near the phosphate band increased manganese availability to the plants. The variation in manganese content of flax plants from the Plum Ridge and Tarno soils could not be explained on the basis of pH variations for these soils. The manganese content of flax was considerably greater than that of wheat. Although the manganese content of the plant tissue varied widely, the levels of manganese found in the plants are within the range not considered to be toxic or deficient, except for the manganese content of wheat on the Plum Ridge soil. A growth stress may occur in wheat plants with a manganese level below 30 ppm (34). The manganese content of wheat grown on the Plum Ridge soil varied from 15 to 24 ppm. The amounts of manganese supplied by the soils differed but was not related to the carbonate content of the soils.

Except for the Stockton and Newdale soils, the zinc content of wheat decreased with added phosphorus, particularly at high levels of added phosphorus (Table VIII). Similar trends except for the Lakeland soil were observed when flax was grown. Decreased zinc content of crops with phosphate fertilization has been noted by other workers (33, 44, 49). The zinc content of wheat and flax grown on the calcareous soils receiving no or small amounts of added phosphate was usually lower than when grown on the noncalcareous soils. Similar observations have been reported by other workers (35, 46). Melsted et al. (34) stated that 15 ppm of zinc in wheat

TABLE VIII

EFFECT OF ADDED PHOSPHORUS ON THE ZINC CONTENT OF WHEAT AND FLAX (ppm)

Treatment	Stockton	Newdale	Red River	Plum Ridge	Lakeland	Tarno
			Wheat			
No P added	40	58	36	28	32	27
25 ppm P (band)	46	41	31	21	31	21
50 ppm P (mixed)	45	47	27	23	33	22
100 ppm P (mixed)	45	45	26	19	29	19
200 ppm P (mixed)	40	41	26	15	23	19
400 ppm P (mixed)	40	45	26	16	23	17
			Flax			
No P added	63	48	32	16	27	25
25 ppm P (band)	52	41	27	17	26	19
50 ppm P (mixed)	52	41	21	16	24	18
100 ppm P (mixed)	48	33	20	15	25	19
200 ppm P (mixed)	46	32	19	14	29	19
400 ppm P (mixed)	49	42	21	14	27	18

was near the level at which growth stress may occur. It is possible that a zinc deficiency, particularly on the Plum Ridge soil, may be partially responsible for the low yields on the calcareous soils.

The decrease in zinc content of the plants could not be explained on the basis of pH changes in the soil when phosphorus was added. Thus the reduction in zinc content was due to the effects of phosphorus _per se_.

The copper content of wheat and flax was not greatly influenced by phosphate additions except for flax grown on the Plum Ridge soil where a decrease in copper content occurred (Table IX). Wheat and flax grown on the calcareous and noncalcareous soils contained similar amounts of copper. Copper contents of 3.0 to 5.0 ppm in cereals have been suggested as possible critical values below which deficiency symptoms may occur (23, 34). Results of this study would indicate that a copper deficiency did not exist in most of the soils. However, the low copper content of flax grown on the Stockton and Plum Ridge soils indicate that these soils may be copper deficient.

A decrease in the minor element concentration of the plant tissue with an increase in added phosphorus may be regarded as a detrimental effect of phosphorus on minor element uptake by the plant. However, it is possible that the observed reductions in the minor element concentration were due to the increase in yield obtained when phosphorus was added. This would be particularly true if phosphorus was in extremely low low supply and the soil contained a limited supply of available minor elements. In an attempt to account for biological dilution effects, the total uptake by the above ground portion of the plant was calculated. A decrease in minor element uptake particularly when yields were not decreased would indicate a detrimental effect of added phosphorus on

TABLE IX

EFFECT OF ADDED PHOSPHORUS ON THE COPPER CONTENT OF WHEAT AND FLAX (ppm)

Treatment	Stockton	Newdale	Red River	Plum Ridge	Lakeland	Tarno
			Wheat			
No P added	10.0	10.0	12.0	10.0	14.0	12.0
25 ppm P (band)	7.0	9.0	10.5	8.0	12.0	9.5
50 ppm P (mixed)	7.0	9.0	8.0	8.0	13.0	12.0
100 ppm P (mixed)	7.0	12.0	9.5	8.0	15.0	10.0
200 ppm P (mixed)	11.0	12.0	8.0	7.0	15.0	11.0
400 ppm P (mixed)	11.0	10.0	9.5	11.0	12.0	11.0
			Flax			
No P added	5.5	9.0	9.5	13.0	12.0	13.5
25 ppm P (band)	5.5	5.0	8.0	7.0	10.0	9.5
50 ppm P (mixed)	5.5	10.0	8.0	5.5	8.0	9.5
100 ppm P (mixed)	4.0	5.0	8.0	5.5	8.0	11.0
200 ppm P (mixed)	5.5	5.0	8.0	5.5	12.0	11.0
400 ppm P (mixed)	5.5	8.0	7.0	5.5	9.0	12.0

absorption from the soil or translocation of the nutrient from the roots to the above ground portion of the plant.

Phosphorus uptake by wheat and flax increased with added phosphorus except when large reductions in yield occurred with high levels of added phosphorus (Table X). Generally the wheat crop was able to utilize more phosphorus than the flax crop. Phosphorus uptake by these crops was greater from the noncalcareous than from the calcareous soils.

Iron uptake by wheat was higher on the phosphorus treated than on the nontreated soils (Table (XI). Iron uptake by wheat on the Stockton, Red River, Plum Ridge and Lakeland soils decreased with levels of added phosphorus above 100 ppm. The iron uptake by flax grown on the Plum Ridge and Tarno soils decreased as the amount of phosphorus added was increased. The yields obtained did not vary greatly, thus the added phosphorus restricted the uptake of iron from these two soils. Little or no detrimental effect of added phosphorus on iron uptake was observed on the other soils. Iron uptake by both crops was greater from the noncalcareous than from the calcareous soils; this was due to greater yields obtained on the noncalcareous soils as the iron content in the plants was similar for both types of soils.

Manganese uptake by wheat on the Newdale, Red River, Plum Ridge and Lakeland soils was increased by the 25 ppm phosphate application but decreased when higher rates of phosphorus were added (Table XII). The manganese uptake by wheat on the Stockton soil increased when high rates of phosphorus were applied. High rates of added phosphorus reduced the manganese uptake by flax on the Red River, Plum Ridge and Tarno soils. Due to lower yields, the uptake of manganese by wheat and flax grown on the calcareous soils was less than when grown on the

TABLE X

EFFECT OF ADDED PHOSPHORUS ON THE UPTAKE OF PHOSPHORUS
BY WHEAT AND FLAX (mg/pot)

	Wheat					
Treatment	Stockton	Newdale	Red River	Plum Ridge	Lakeland	Tarno
No P added	7.0	7.2	7.8	3.2	3.6	5.9
25 ppm P (band)	13.7	9.6	22.1	6.6	7.7	10.9
50 ppm P (mixed)	19.2	11.2	22.6	5.5	8.5	11.4
100 ppm P (mixed)	26.4	13.0	30.2	7.4	10.0	15.2
200 ppm P (mixed)	28.6	15.1	30.2	6.0	9.1	18.2
400 ppm P (mixed)	28.6	15.3	17.0	7.3	12.3	17.3
	Flax					
No P added	4.6	8.1	9.4	3.3	1.7	3.6
25 ppm P (band)	8.6	7.5	11.8	3.6	1.5	4.7
50 ppm P (mixed)	9.9	9.5	14.2	5.0	1.8	5.6
100 ppm P (mixed)	13.9	10.5	20.4	4.6	2.3	7.4
200 ppm P (mixed)	15.6	12.2	24.1	5.4	2.5	10.2
400 ppm P (mixed)	18.5	15.4	27.2	5.6	3.5	9.1

TABLE XI

EFFECT OF ADDED PHOSPHORUS ON THE UPTAKE OF IRON BY WHEAT AND FLAX (ug/pot)

Treatment	Stockton	Newdale	Red River	Plum Ridge	Lakeland	Tarno
			Wheat			
No P added	110	194	128	49	133	70
25 ppm P (band)	238	225	317	98	212	185
50 ppm P (mixed)	244	323	264	79	229	185
100 ppm P (mixed)	255	284	269	98	251	234
200 ppm P (mixed)	256	358	260	65	219	270
400 ppm P (mixed)	252	296	138	85	176	246
			Flax			
No P added	178	293	191	73	65	69
25 ppm P (band)	210	232	226	63	61	72
50 ppm P (mixed)	189	308	223	56	61	64
100 ppm P (mixed)	205	345	250	49	62	75
200 ppm P (mixed)	194	289	230	42	70	85
400 ppm P (mixed)	204	314	190	41	82	68

TABLE XII

EFFECT OF ADDED PHOSPHORUS ON THE UPTAKE OF MANGANESE BY WHEAT AND FLAX (ug/pot)

Treatment	Stockton	Newdale	Red River	Plum Ridge	Lakeland	Tarno
			Wheat			
No P added	699	80	100	19	39	49
25 ppm P (band)	332	99	200	38	86	91
50 ppm P (mixed)	366	94	168	31	79	91
100 ppm P (mixed)	418	95	197	36	73	107
200 ppm P (mixed)	470	81	161	21	68	110
400 ppm P (mixed)	563	77	118	21	64	93
			Flax			
No P added	208	266	464	75	280	230
25 ppm P (band)	477	348	488	76	278	235
50 ppm P (mixed)	490	309	540	73	229	227
100 ppm P (mixed)	586	305	477	58	249	242
200 ppm P (mixed)	587	298	473	48	261	191
400 ppm P (mixed)	704	318	447	44	284	166

noncalcareous soils.

High rates of phosphorus had a detrimental effect on zinc utilization by wheat and flax on most soils (Table XIII). Generally, zinc uptake by wheat and flax was lower from the calcareous than from the noncalcareous soils. Highest zinc uptake by both crops occurred on the Stockton and Newdale soils. The Plum Ridge soil supplied the lowest amount of zinc to wheat and flax. Navrot and Ravikovitch (37) found an inverse relationship between native zinc absorption by tomato plants and soil calcium carbonate content. Their work also indicated that the quantity and nature of the soil calcium carbonate was important in determining zinc availability. Greater absorption of zinc on dolomite than on calcite (29) may be a partial explanation for the differences in zinc uptake by plants from carbonated soils containing similar amounts of carbonates.

The copper uptake by wheat was increased by phosphorus additions on all soils. Phosphorus applications had little or no effect on copper uptake by flax except for the Plum Ridge and Lakeland soils. On these soils copper uptake was reduced from 10 to 3 and 10 to 6 ug/pot, respectively.

Results of this study showed that minor element content and uptake by wheat and flax were reduced in many instances as phosphorus rates were increased above 25 ppm. The magnitude of these reductions varied with soil type and could not be attributed to pH changes in the soil when phosphorus was added. Minor element uptake by wheat and flax was usually lower from the calcareous than from the noncalcareous soils. The iron, manganese and copper content in the plants grown on the calcareous and noncalcareous soils was similar. A greater zinc content was found in plants grown on the noncalcareous than grown on the calcareous soils. The lower zinc content of plants grown on the carbonated soils may be due

TABLE XIII

EFFECT OF ADDED PHOSPHORUS ON THE UPTAKE OF ZINC BY WHEAT AND FLAX (ug/pot)

Treatment	Stockton	Newdale	Red River	Plum Ridge	Lakeland	Tarno
			Wheat			
No P added	87	138	68	22	41	38
25 ppm P (band)	179	122	146	34	73	53
50 ppm P (mixed)	180	158	127	29	83	56
100 ppm P (mixed)	198	158	125	30	77	61
200 ppm P (mixed)	166	146	135	20	65	67
400 ppm P (mixed)	166	153	65	22	64	64
			Flax			
No P added	100	128	83	13	22	22
25 ppm P (band)	109	119	82	12	18	21
50 ppm P (band)	109	113	69	13	24	19
100 ppm P (mixed)	105	99	74	11	18	25
200 ppm P (mixed)	92	86	63	8	20	20
400 ppm P (mixed)	103	116	71	8	22	18

TABLE XIV

EFFECT OF ADDED PHOSPHORUS ON THE UPTAKE OF COPPER
BY WHEAT AND FLAX (ug/pot)

Treatment	Stockton	Newdale	Red River	Plum Ridge	Lakeland	Tarno
			Wheat			
No P added	11	24	23	8	18	17
25 ppm P (band)	27	27	51	13	29	25
50 ppm P (mixed)	27	31	38	10	33	31
100 ppm P (mixed)	30	42	46	13	39	33
200 ppm P (mixed)	45	43	42	9	44	38
400 ppm P (mixed)	45	34	24	15	34	35
			Flax			
No P added	8	24	25	10	10	12
25 ppm P (band)	11	13	25	5	7	10
50 ppm P (mixed)	11	28	26	4	6	10
100 ppm P (mixed)	9	15	30	4	6	14
200 ppm P (mixed)	11	14	27	3	8	12
400 ppm P (mixed)	11	32	24	3	7	12

to lower amounts of naturally occurring zinc, adsorption of zinc on carbonates and/or the low solubility of zinc oxides in carbonated soils. Minor element deficiencies may be present in some of the soils as indicated by low yields of wheat and flax.

Solubility of Iron, Manganese, Zinc and Copper in Soils Treated with Phosphorus.

The reduction in minor element utilization by plants grown on soils treated with phosphate has been attributed to phosphorus-minor element reactions in the soil (3, 50). It has been postulated that the minor elements may be precipitated as insoluble phosphates. A study on the influence of added phosphorus on minor element concentrations in soil solutions was initiated. Phosphorus was added to the soils at varying rates, incubated and the amounts of minor elements extracted with water determined.

Ten-gram samples of the soils (Table I) were placed into porcelain crucibles. Levels of phosphorus approximating conditions found in the soil near a phosphate fertilizer pellet were selected. Phosphorus at the following rates was mixed with each soil:

(a) no phosphorus added;

(b) 0.1 g $NH_4H_2PO_4$;

(c) 0.2 g $NH_4H_2PO_4$;

(d) 0.4 g $NH_4H_2PO_4$;

(e) 0.8 g $NH_4H_2PO_4$.

The soils were moistened to field capacity moisture content and incubated for 2, 14 or 28 days at room temperature. After each incubation period, the ten-gram soil samples were placed into 50 ml of deionized water and equilibrated by shaking for 24 hours. The pH of each sample was measured and the suspension filtered through No. 42 Whatman filter paper. Water soluble phosphorus was determined colorimetrically and manganese, iron, zinc and copper contents of the extracts determined by atomic absorption spectrophotometry.

The application of monoammonium phosphate to the soils decreased the pH of all soils (Table XV). The pH of the noncalcareous soils decreased by 1.5 to 1.9 pH units and was below a value of 6.0 when 0.8 g of monoammonium phosphate was added. The pH of the calcareous soils was decreased by only 0.3 to 0.6 pH units.

Extremely high concentrations of iron were present in the water extracts of the Stockton soil. Phosphate applications decreased the iron content of the extract from 92.2 to 8.1 ppm. High phosphate applications increased the solubility of iron in the Newdale and Red River soils. More water soluble iron was present in the extracts of the calcareous soils treated with high levels of phosphorus than was present in the extracts of the soils not treated with phosphorus.

Manganese concentrations in the water extracts of most of the soils were increased by phosphate additions. The relative amounts of manganese in solution was greater for the noncalcareous than calcareous soils. Since the solubility of the manganese oxides increases with decreases in pH, more manganese would be found in the soils when the pH was lowered. This is generally verified by the data in Table XV. No water soluble manganese was detected in the Plum Ridge soil samples with pH values of 7.8 to 8.4.

Zinc solubility was increased by phosphate applications in all soils except the Tarno soil. Bingham and Garber (5) reported similar increases in zinc solubility with added phosphorus in two of three soils

TABLE XV

MINOR ELEMENT AND PHOSPHORUS CONCENTRATIONS AND pH OF WATER EXTRACTS OF SOILS TREATED WITH PHOSPHORUS AND INCUBATED FOR 2 DAYS

Soil	Treatment	pH	Fe(ppm)	Mn(ppm)	Zn(ppm)	Cu(ppm)	P(ppm)
Stockton	No P added	6.7	92.2	1.1	0.3	-*	0.10
	0.1 g $NH_4H_2PO_4$	6.0	27.5	1.3	0.3	-	1340
	0.2 g "	5.8	12.8	3.7	0.4	-	3330
	0.4 g "	5.5	11.1	11.0	1.2	-	8750
	0.8 g "	5.2	8.1	19.0	1.2	-	17000
Newdale	No P added	7.6	1.2	-	-	-	0.20
	0.1 g $NH_4H_2PO_4$	6.8	-	0.2	0.1	-	780
	0.2 g "	6.5	1.5	1.2	0.1	-	1580
	0.4 g "	6.1	2.0	3.8	0.3	-	4630
	0.8 g "	5.7	4.4	7.9	0.3	-	13000
Red River	No P added	7.6	-	-	-	-	0.10
	0.1 g $NH_4H_2PO_4$	6.6	0.2	0.4	0.1	-	980
	0.2 g "	6.1	2.9	0.7	0.1	-	2170
	0.4 g "	5.8	0.4	3.3	0.2	-	5380
	0.8 g "	5.9	0.4	4.3	0.2	-	13800
Plum Ridge	No P added	8.4	-	-	-	-	0.10
	0.1 g $NH_4H_2PO_4$	7.8	-	-	-	-	360
	0.2 g "	8.0	8.2	-	0.1	-	540
	0.4 g "	7.9	6.5	-	0.1	-	1000
	0.8 g "	8.1	1.0	-	0.1	-	1750
Lakeland	No P added	8.1	-	-	-	-	0.10
	0.1 g $NH_4H_2PO_4$	7.4	-	-	-	-	500
	0.2 g "	7.5	-	0.1	0.1	-	710
	0.4 g "	7.7	5.5	0.4	0.1	-	1880
	0.8 g "	7.5	2.5	1.2	0.9	-	5250
Tarno	No P added	8.1	0.3	-	0.1	-	0.10
	0.1 g $NH_4H_2PO_4$	7.5	-	-	0.1	-	500
	0.2 g "	7.5	-	-	0.1	-	750
	0.4 g "	7.8	6.5	0.4	0.1	-	1250
	0.8 g "	7.5	6.6	0.6	0.1	-	1980

* None detected.

that were used in their study. Zinc concentrations in the extracts were low and only the Stockton soil contained more than 1.0 ppm water soluble zinc.

The amounts of copper in the water extracts could not be detected in the soils incubated for two days.

Phosphate applications increased the water soluble phosphorus content of the soils. Lower amounts of phosphorus were recovered from the calcareous than from the noncalcareous soils. The variations in soil pH, particularly in the calcareous soils, may be an indication that equilibration with phosphate had not been attained after two days of incubation.

The results of the 14-day incubations indicated that phosphate applications did not produce as great a decrease in pH as was found for the two-day incubations (Table XVI). The calcareous soils treated with 0.1 g monoammonium phosphate had lower pH values than when treated with higher rates of phosphorus. At the high rates of added phosphorus, the pH values were close to the values of the untreated samples. The higher pH of soils treated with high levels of phosphorus as compared to soils treated with small amounts of phosphorus may be due to the formation of ammonium bicarbonate (42). This salt has a high pH in solution and could form in the presence of carbonates.

The Stockton soil extracts contained similar concentrations of iron for the two-day and 14-day incubations. More iron was present in extracts of the Newdale soil after 14 days than after two days of incubation. The iron content of the calcareous soils decreased with time of incubation. As was found for the two-day incubations, the iron content of the phosphate treated soils (except the Stockton soil) was usually

TABLE XVI

MINOR ELEMENT AND PHOSPHORUS CONCENTRATIONS AND pH OF WATER EXTRACTS OF SOILS TREATED WITH PHOSPHORUS AND INCUBATED FOR 14 DAYS

Soil	Treatment	pH	Fe(ppm)	Mn(ppm)	Zn(ppm)	Cu(ppm)	P(ppm)
Stockton	No. P added	6.5	100.5	1.6	0.8	0.1	2.0
	0.1 g $NH_4H_2PO_4$	6.4	50.0	2.2	0.7	0.2	1610
	0.2 g "	6.2	13.7	2.9	0.3	0.2	3230
	0.4 g "	6.2	77.9	4.8	0.2	0.3	7630
	0.8 g "	5.6	6.4	22.0	0.2	0.2	18500
Newdale	No P added	7.4	0.3	-*	-	0.2	3.0
	0.1 g $NH_4H_2PO_4$	6.7	24.8	0.6	0.2	0.2	720
	0.2 g "	6.8	31.7	1.4	0.3	0.2	1380
	0.4 g "	6.6	19.0	3.8	0.4	0.3	4450
	0.8 g "	6.5	16.2	5.9	0.2	0.7	12700
Red River	No P added	7.5	-	-	0.1	0.1	3.0
	0.1 g $NH_4H_2PO_4$	6.6	1.0	-	0.1	0.2	930
	0.2 g "	6.3	0.2	1.4	0.2	0.2	1810
	0.4 g "	6.3	0.3	3.8	0.2	0.4	4930
	0.8 g "	6.2	0.6	5.9	0.2	0.3	14500
Plum Ridge	No P added	8.2	-	-	0.1	0.2	1.0
	0.1 g $NH_4H_2PO_4$	7.5	-	-	-	0.2	360
	0.2 g "	7.7	-	-	-	-	340
	0.4 g "	8.0	-	-	0.1	0.2	400
	0.8 g "	8.1	1.0	-	-	-	500
Lakeland	No P added	7.7	-	-	0.2	0.1	1.0
	0.1 g $NH_4H_2PO_4$	7.3	0.2	-	0.1	-	540
	0.2 g "	7.5	0.2	-	0.1	0.2	980
	0.4 g "	7.5	7.0	0.7	0.1	0.3	1550
	0.8 g "	7.6	10.1	1.3	0.1	0.8	4300
Tarno	No P added	7.7	-	-	-	0.1	1.0
	0.1 g $NH_4H_2PO_4$	7.3	0.2	-	0.1	0.2	410
	0.2 g "	7.3	-	-	0.1	0.2	590
	0.4 g "	7.5	-	0.1	0.1	0.2	750
	0.8 g "	7.5	-	0.4	0.1	0.3	1750

* None detected.

greater than that of the untreated soils.

The manganese concentrations in the water extracts followed trends similar to those observed for the two-day incubations. That is, more manganese was usually present in treated than in untreated soils. Of the calcareous soils, only the highly phosphated Tarno and Lakeland soils contained detectable amounts of water soluble manganese.

The application of phosphorus to the Stockton soil reduced zinc solubility. Phosphating appeared to increase the solubility of zinc in the Newdale and Red River soils. Phosphating had little or no effect on zinc solubility in the calcareous soils. The zinc concentrations of extracts from the noncalcareous soils were higher than the zinc concentrations of extracts from the calcareous soils.

The solubility of copper was increased by phosphorus additions to all but the Plum Ridge soil. Similar studies by Bingham and Garber (5) indicated that phosphating soils increased the solubility of copper.

The water soluble phosphorus content of the extracts from the calcareous soils was lower than that of the noncalcareous soils after 14 days of incubation. Phosphate concentrations were similar to those obtained after two days of incubation except for the Plum Ridge soil treated with large amounts of phosphorus. The recovery of the added phosphate decreased with time of incubation for the Plum Ridge soil.

The results for the 28-day incubations are presented in Table XVII. The pH values of the soils were similar to those obtained for the 14-day incubations.

Iron and manganese contents of the extracts followed trends similar to those found for the 14-day incubations. The iron content of the extracts of the Stockton soil treated with small amounts of phosphorus

TABLE XVII

MINOR ELEMENT AND PHOSPHORUS CONCENTRATIONS AND pH OF WATER EXTRACTS OF SOILS TREATED WITH PHOSPHORUS AND INCUBATED FOR 28 DAYS

Soil	Treatment	pH	Fe(ppm)	Mn(ppm)	Zn(ppm)	Cu(ppm)	P(ppm)
Stockton	No P added	6.1	6.1	0.2	-*	-	1.0
	0.1 g $NH_4H_2PO_4$	6.4	6.0	3.3	0.2	-	1230
	0.2 g "	6.2	6.0	3.7	0.1	-	2580
	0.4 g "	6.3	17.1	4.8	0.2	0.2	5880
	0.8 g "	5.7	6.4	11.9	0.2	0.3	14000
Newdale	No P added	7.3	-	-	-	-	2.0
	0.1 g $NH_4H_2PO_4$	6.3	-	0.5	0.1	-	540
	0.2 g "	6.7	8.5	2.4	0.2	0.2	1360
	0.4 g "	6.6	11.1	5.0	0.3	0.4	2410
	0.8 g "	6.3	13.6	6.2	0.2	0.4	6340
Red River	No P added	7.3	-	-	-	-	2.0
	0.1 g $NH_4H_2PO_4$	6.5	-	-	0.1	-	690
	0.2 g "	6.5	-	1.3	0.1	0.1	1440
	0.4 g "	6.4	-	1.9	0.2	-	3800
	0.8 g "	6.2	1.4	2.5	0.2	0.3	9350
Plum Ridge	No P added	8.2	0.7	-	-	-	0.10
	0.1 g $NH_4H_2PO_4$	7.2	-	-	-	-	300
	0.2 g "	7.6	-	-	-	-	450
	0.4 g "	8.0	0.7	-	-	-	250
	0.8 g "	8.2	1.0	-	-	-	530
Lakeland	No P added	7.8	0.7	-	-	-	1.0
	0.1 g $NH_4H_2PO_4$	7.2	-	-	0.1	-	310
	0.2 g "	7.4	-	-	0.1	-	660
	0.4 g "	7.5	2.4	0.5	0.1	0.2	940
	0.8 g "	7.5	9.2	1.2	0.1	0.8	2410
Tarno	No P added	8.0	1.0	-	-	-	0.10
	0.1 g $NH_4H_2PO_4$	7.0	-	-	-	-	300
	0.2 g "	7.0	-	-	0.1	-	490
	0.4 g "	7.3	-	-	-	-	535
	0.8 g "	7.6	7.0	0.4	0.1	0.3	1260

* None detected.

or untreated, was much lower than that found for the samples incubated for 14 days.

In all but the Plum Ridge soil, larger amounts of zinc and copper were present in the extracts of the treated than untreated soils. Phosphating did not release any detectable amounts of water soluble zinc or copper in the Plum Ridge soil.

The application of monoammonium phosphate to the soils usually increased the water soluble minor element content of the soils. Phosphate applications increased the minor element concentration in the water extracts of the noncalcareous soils to a greater degree than that of the calcareous soils. The lower pH's produced by phosphating the noncalcareous soils was probably responsible for some of these differences. The data indicates that the reduced utilization of minor elements by plants on the phosphated soils was not due to soil minor element immobilization by phosphates.

The Influence of Varying Amounts of Phosphorus in Nutrient Solutions on the Phosphorus, Iron, Manganese, Zinc and Copper Utilization and Translocation by Wheat and Flax.

The previous study indicated that immobilization of soil minor elements by phosphate precipitation is not an adequate explanation for the reduced minor element uptake by plants. It has been suggested by some workers (17, 30) that the phosphorus-minor element relationship is physiological in nature. To further substantiate this view, nutrient culture experiments were designed to determine the effect of varying amounts of phosphorus on absorption and subsequent translocation of iron, manganese, zinc, copper and phosphorus by wheat and flax.

The basal Hoagland and Arnon (25) nutrient solution was used with some modification. Macro-elements were supplied by adding 5 ml of 1.0 M $Ca(NO_3)_2$, 5 ml of 1.0 M KNO_3 and 2 ml of 1.0 M $MgSO_4$ per liter of solution. One milliliter of micro-nutrient stock solution was added per liter of solution. The micro-nutrient stock solution contained 2.86 g H_3BO_3, 1.81 g $MnCl_2 \cdot 4H_2O$, 0.11 g $ZnCl_2$, 0.025 g $Na_2MoO_4 \cdot 2H_2O$ and 0.05 g $CuCl_2 \cdot 2H_2O$ per liter. Iron was added at a rate of 5 ppm as Sequestrene 138 Fe-chelate. Phosphorus as KH_2PO_4 was added at rates of 2, 5, 10, 20, 50 and 100 ppm. The pH of the nutrient solution was adjusted to 5.5. A randomized block design with three replicates was used. Approximately 1400 ml of nutrient solution were placed in plastic containers and 20 wheat or 30 flax seeds placed on screens held above the surface of the solution. The solutions were replaced every four or five days and constantly aerated. The plants were harvested after 21 days of growth. Plant tops and roots were washed, dried and weighed prior to analysis for manganese, iron, zinc, copper and phosphorus.

The yield of wheat tops and roots was not significantly influenced by the various levels of added phosphorus (Table XVIII). The yield of wheat tops was slightly reduced when 100 ppm phosphorus was added. The phosphorus content and uptake by wheat increased with increased phosphorus concentrations in solution.

The iron content of wheat tops and roots was decreased when the level of phosphorus in solution was increased. A reduction in the absorption of minor elements from solutions at high phosphate levels would be revealed by a reduction in total uptake of the element or elements by the plant. Interference with the internal translocation would be made apparent by changes in the relative composition of the roots versus the tops. The total uptake of iron by wheat decreased with added phosphate indicating

TABLE XVIII

YIELD AND IRON, MANGANESE, ZINC, COPPER AND PHOSPHORUS CONTENT OF WHEAT GROWN IN NUTRIENT SOLUTIONS VARYING IN PHOSPHORUS LEVELS

	P content of solution					
	2 ppm	5 ppm	10 ppm	20 ppm	50 ppm	100 ppm
Yield (g)* Tops‡	1.53	1.37	1.49	1.37	1.44	1.23
Roots	0.43	0.37	0.44	0.41	0.51	0.40
P (%) Tops	0.81	0.93	0.93	1.00	1.24	1.63
Roots	0.81	0.93	0.87	1.18	1.73	1.63
Ratio (Roots/Tops)	1.0	1.0	1.0	1.2	1.4	1.0
P uptake£ (mg/pot)	15.8	16.2	17.7	18.5	26.7	26.6
Fe (ppm) Tops	136	118	117	117	88	88
Roots	730	690	725	650	450	485
Ratio (Roots/Tops)	5.4	5.8	6.2	5.6	5.1	5.5
Fe uptake (ug/pot)	518	415	487	425	357	303
Mn (ppm) Tops	143	153	158	162	165	165
Roots	830	680	570	620	570	620
Ratio (Roots/Tops)	5.8	4.3	3.6	3.8	3.5	3.7
Mn uptake (ug/pot)	572	459	473	474	529	446
Zn (ppm) Tops	56	57	53	50	51	52
Roots	118	130	113	107	84	97
Ratio (Roots/Tops)	2.1	2.3	2.1	2.1	1.7	1.8
Zn uptake (ug/pot)	136	126	128	112	117	102
Cu (ppm) Tops	33	18	18	18	19	21
Roots	76	68	68	70	68	50
Ratio (Roots/Tops)	2.3	3.8	3.7	3.8	3.6	2.4
Cu uptake (ug/pot)	83	50	57	54	62	46

* Yields are a mean of three replicates.

£ Uptake by roots and tops.

‡ LSD (0.05P) Tops = NS ; Roots = NS.

that the absorption of iron was reduced by high levels of phosphorus. The relative composition of the roots versus tops was similar under low and high phosphate conditions indicating that translocation was not reduced.

Manganese uptake generally decreased with applied phosphorus except when 50 ppm phosphorus was added. Translocation of manganese appeared to be increased by high phosphate levels. The copper and zinc contents and total uptake were also reduced by high phosphate levels. Translocation of zinc was not influenced by phosphate applications. The data obtained for the copper content ratios for wheat was erratic and showed no definite trends.

The yields of flax tops and roots were significantly decreased by phosphate applications in excess of 20 ppm (Table XIX). Maximum yield of flax tops occurred in the solution containing 20 ppm phosphorus. The phosphorus content in tops and roots and phosphorus uptake by flax increased with increases in added phosphorus.

The iron content of flax tops and roots did not appear to be influenced by phosphate levels. However, iron uptake was greatest at the 10 ppm phosphorus level and decreased at higher phosphate rates. The manganese content and uptake by flax decreased with increases in phosphorus levels. Manganese uptake was reduced at the 20, 50 and 100 ppm rates of phosphorus but translocation appeared to be increased. Reductions in zinc and copper content and uptake occurred with increased levels of phosphorus in solution. The concentration of copper in the tops relative to the roots was decreased at phosphate levels above 5 ppm suggesting that the translocation of copper from the roots to the tops was reduced at higher phosphate levels.

Since the content and uptake of the minor elements were reduced by high phosphate levels in both soils and nutrient cultures and since the

TABLE XIX

YIELD AND IRON, MANGANESE, ZINC, COPPER AND PHOSPHORUS CONTENT OF FLAX GROWN IN NUTRIENT SOLUTIONS VARYING IN PHOSPHORUS LEVELS

	P content of solution					
	2 ppm	5 ppm	10 ppm	20 ppm	50 ppm	100 ppm
Yield *(g) Tops‡	0.92	0.87	1.03	1.07	0.84	0.52
Roots	0.18	0.16	0.27	0.20	0.15	0.14
P (%) Tops	0.90	1.09	1.18	1.31	1.72	2.42
Roots	1.01	1.63	1.83	2.21	2.91	3.53
Ratio (Roots/Tops)	1.1	1.5	1.6	1.7	1.7	1.5
P uptake£(mg/pot)	10.0	12.1	17.1	18.6	18.7	17.3
Fe (ppm) Tops	150	142	135	137	168	164
Roots	1263	1006	974	1123	1118	1480
Ratio (Roots/Tops)	8.4	7.1	7.2	8.2	6.7	9.0
Fe uptake (ug/pot)	366	328	404	374	309	285
Mn (ppm) Tops	175	166	156	143	93	64
Roots	886	688	709	205	153	120
Ratio (Roots/Tops)	5.1	4.1	4.5	1.4	1.6	1.9
Mn uptake (ug/pot)	320	256	354	194	101	49
Zn (ppm) Tops	95	100	84	80	72	53
Roots	125	153	119	96	94	77
Ratio (Roots/Tops)	1.3	1.5	1.4	1.2	1.3	1.5
Zn uptake (ug/pot)	110	112	119	107	74	37
Cu (ppm) Tops	45	53	16	13	16	12
Roots	48	41	38	35	35	38
Ratio (Roots/Tops)	1.1	0.8	2.4	2.7	2.2	3.2
Cu uptake (ug/pot)	50	53	27	21	18	11

* Yields are a mean of three replicates.

£ Uptake by roots and tops.

‡ LSD (0.05 P) Tops = 0.09; Roots = 0.05.

previous study had indicated that precipitation of minor elements by phosphate added to soils was unlikely, the influence of high levels of phosphorus on minor element uptake was physiological in nature, occurring on or in the root surface. High phosphate levels, possibly resulting in ion antagonism, reduced the absorption of minor elements by plant roots. Also, the translocation of copper in flax was reduced in solutions containing high levels of phosphorus.

The Influence of Phosphorus and Minor Element Levels on the Utilization of Phosphorus and Minor Elements by Wheat in Nutrient Solutions.

Burleson and Page (17) found that varying the zinc or phosphate concentration of nutrient solutions increased the concentration and uptake of the respective elements in the roots and tops of flax. The previous experiments showed that high phosphate levels restricted the uptake of minor elements in nutrient solutions and soils. Since the high levels of phosphate may have reduced absorption of the minor elements due to ion antagonism at root surfaces, an experiment was designed in which both the phosphorus and minor element levels were varied. If the minor element uptake at high phosphate levels could be increased by increasing the minor element content of the solutions, this would indicate that ion antagonism was probably responsible for the reductions in minor element uptake.

The treatments consisting of three levels of phosphorus and three levels of minor elements were replicated three times in a completely randomized design. The basic nutrient solution described in the previous study was used. Phosphorus as KH_2PO_4 was added at rates of 2, 10 and 100 ppm. Minor elements were added at the following levels:

(a) 1 ml of micro-nutrient stock solution/1;

(b) 2 ml of micro-nutrient stock solution/1;

(c) 4 ml of micro-nutrient stock solution/l.

Solutions were adjusted to a pH value of 5.5 and 20 wheat plants grown for 3 weeks as described in the previous experiment. The plants were then harvested, washed, weighed and analyzed.

The yield of wheat tops and roots was not significantly influenced by phosphorus or minor element levels (Table XX). As expected, high phosphorus levels increased the phosphorus content of tops and roots at all levels of minor elements.

The iron content of wheat tops decreased with increasing levels of phosphorus except at the highest level of minor elements. The iron content of wheat roots was decreased by phosphorus levels in excess of 2 ppm at all levels of minor elements. Iron uptake usually decreased with increases in phosphate levels but increased with increases in minor element levels. The P/Fe uptake ratio by the plants increased with increases in phosphate levels but decreased with increases in minor element levels. This would indicate that ion antagonism at root surfaces was responsible for reduced iron uptake at high phosphate levels.

Both, increased phosphorus and minor elements in solution were responsible for the increased manganese content of wheat tops. Manganese uptake was increased by higher minor element levels added, but decreased when high amounts of phosphorus were added except at the highest level of added manganese. The P/Mn uptake ratio by the plants paralleled the findings noted for iron. Examination of the root to top ratio indicated that translocation was not influenced by high phosphate or minor element levels.

The zinc content of wheat tops grown in the 10 and 100 ppm phosphorus solutions was usually higher than when grown in the 2 ppm phosphorus solution. This is in contrast to earlier findings. Zinc content of tops was usually increased by increased minor element levels; similar increases

TABLE XX

INFLUENCE OF PHOSPHORUS AND MINOR ELEMENT LEVELS ON YIELD, AND PHOSPHORUS, IRON, MANGANESE, ZINC AND COPPER UTILIZATION BY WHEAT IN NUTRIENT SOLUTIONS

Minor element level	1 ml			2 ml			4 ml		
Phosphorus level	2 ppm	10 ppm	100 ppm	2 ppm	10 ppm	100 ppm	2 ppm	10 ppm	100 ppm
Yield (g)* Tops‡	1.17	1.16	1.05	1.23	1.33	1.18	1.23	1.31	1.16
Roots	0.33	0.36	0.33	0.34	0.39	0.34	0.31	0.35	0.35
P (%) Tops	0.98	1.00	1.38	0.91	1.00	1.37	0.93	1.00	1.35
Roots	0.67	0.86	1.19	0.80	1.05	1.42	0.81	0.98	1.44
Ratio (Roots/Tops)	0.6	0.9	0.9	0.9	1.0	1.0	0.9	1.0	1.1
P uptake£(mg/pot)	13.6	14.7	18.5	13.9	17.4	21.0	13.9	16.5	20.7
Fe (ppm) Tops	127	126	97	157	158	150	183	213	187
Roots	713	631	631	1040	953	727	1010	850	860
Ratio (Roots/Tops)	5.6	5.0	6.5	6.6	6.0	4.9	5.5	4.0	4.6
Fe uptake (ug/pot)	384	373	310	546	582	424	538	595	518
Ratio(P uptake/Fe uptake)	35	39	60	25	30	50	26	28	40
Mn (ppm) Tops	190	215	215	202	222	223	225	245	252
Roots	725	530	550	850	590	690	850	665	725
Ratio (Roots/Tops)	3.8	2.5	2.6	4.2	2.7	3.1	3.8	2.7	2.9
Mn uptake (ug/pot)	462	440	407	537	525	498	540	554	546
Ratio(P uptake/Mn uptake)	30	33	45	26	33	42	26	30	38
Zn (ppm) Tops	71	71	83	72	79	88	75	98	81
Roots	242	218	215	238	281	313	330	455	318
Ratio (Roots/Tops)	3.4	3.1	2.6	3.3	3.6	3.6	4.4	4.6	3.9
Zn uptake (ug/pot)	163	161	158	169	215	210	195	288	205
Ratio (P uptake/Zn uptake)	84	91	117	82	81	100	71	57	101
Cu (ppm) Tops	26	21	22	27	28	20	28	25	21
Roots	60	56	82	71	69	128	76	76	136
Ratio (Roots/Tops)	2.3	2.7	3.7	2.6	2.5	6.4	2.7	3.0	6.5
Cu uptake (ug/pot)	50	46	50	57	64	67	58	59	72
Ratio (P uptake/Cu uptake)	272	330	369	244	271	313	240	279	288

* Yields are averages of three replicates.

£ Uptake by roots and tops.

‡ LSD (0.05 P) Tops = NS, Roots = NS.

were noted in the roots. The fact that zinc translocation was not reduced substantiated the results of the previous experiment. Zinc uptake was reduced by high phosphate levels only at the lowest level of added minor elements. The P/Zn uptake ratio by the plants parallel the findings noted for iron and manganese.

Increasing the levels of minor elements in solution did not influence the copper content of wheat tops. Phosphate additions reduced the copper content of tops at all levels of minor elements. More copper accumulated in the roots than in the tops particularly at high rates of phosphorus and minor elements indicating that the translocation of copper was reduced at these levels. Copper uptake by wheat increased with increased phosphate and minor element levels.

Except for copper, high phosphate levels did not influence the translocation of minor elements from the roots to the tops of the plants. The reduction in uptake of manganese, iron and zinc found in this and previous studies appeared to be due to the antagonistic effect of phosphate on minor elements at the root surface.

The Effect of Added Zinc and Copper on Yield and Zinc and Copper Utilization by Flax Grown in Soils.

A greenhouse study was designed to study the effect of added zinc and copper on yield and minor element content of flax grown on the Stockton, Newdale, Lakeland and Plum Ridge soils.

Two kilograms of air dried soil were placed in glazed one-half gallon pots. The experimental design was a randomized block with three replicates. The treatments used were as follows:

(a) no phosphorus or minor elements added;

(b) 100 ppm P;

(c) 100 ppm P & 5.7 ppm Zn;

(d) 100 ppm P & 6.4 ppm Cu;

(e) 100 ppm P & 5.7 ppm Zn & 6.4 ppm Cu.

All the phosphorus and/or minor elements were mixed throughout the soil. The phosphorus was added as $NH_4H_2PO_4$, zinc as $ZnSO_4 \cdot 5H_2O$ and copper as $CuSO_4 \cdot 7H_2O$. Adequate levels of nitrogen, potassium and sulfur were added to the soils. Flax was seeded and after emergence thinned to eight plants per pot. The pots were rotated periodically on the greenhouse bench to provide uniform lighting. Deionized water was added to the soil as required to bring the moisture level to field capacity. Above ground portions of the plants were harvested 50 days after planting. The plant material was washed, dried at 70°C and weighed. The plant material obtained from the various replicates was composited, ground, wet ashed and the zinc and copper contents determined by atomic absorption spectrophotometry. The phosphorus content of the plant digest was determined colorimetrically.

The yields of flax on the Stockton soil were significantly increased when copper and zinc plus copper were added (Table XXI). Additions of phosphate alone did not significantly increase yields on the Stockton soil. The Newdale soil responded to phosphate fertilization, while the Lakeland soil did not respond significantly to any of the applied nutrients. The yields obtained on the Plum Ridge soil were significantly increased when phosphorus with zinc and phosphorus with zinc and copper were added. The yields of flax as shown in earlier studies were lower on the calcareous than on the noncalcareous soils.

Zinc applications increased the zinc content of flax grown on the Stockton, Lakeland and Plum Ridge soils (Table XXII). The phosphorus

TABLE XXI

EFFECT OF ADDED PHOSPHORUS, ZINC AND COPPER ON FLAX YIELDS (g/pot)*

	Soil			
	Stockton	Newdale	Lakeland	Plum Ridge
Check[£]	4.3a[&]	5.5a	1.4a	2.1a
P	5.4a	9.0b	1.3a	2.7ab
P + Zn	5.4a	9.0b	2.3a	3.3b
P + Cu	7.1b	9.9b	1.6a	3.0ab
P + Zn + Cu	7.4b	8.8b	1.7a	3.5b

* Yields are averages of three replicates.

£ No phosphorus or minor elements added.

& Duncan's multiple range test, means of treatments for each soil followed by the same letter are not significantly different at P = 0.05.

TABLE XXII

EFFECT OF ADDED PHOSPHORUS, ZINC AND COPPER ON THE PHOSPHORUS, ZINC AND COPPER CONTENT OF FLAX.

Treatment	Stockton			Newdale			Lakeland			Plum Ridge		
	Zn (ppm)	Cu (ppm)	P (%)	Zn (ppm)	Cu (ppm)	P (%)	Zn (ppm)	Cu (ppm)	P (%)	Zn (ppm)	Cu (ppm)	P (%)
Check[£]	54	8.0	0.26	47	5.5	0.18	18	11.5	0.12	21	8.0	0.17
P	50	3.0	0.59	28	4.0	0.31	26	7.5	0.62	13	4.5	0.41
P + Zn	66	3.0	0.58	36	5.5	0.31	24	8.5	0.17	76	6.5	0.20
P + Cu	41	3.5	0.51	26	15.0	0.30	10	14.5	0.62	13	8.0	0.38
P + Zn + Cu	60	3.5	0.51	31	10.5	0.29	24	20.0	0.18	25	7.5	0.18

£ No phosphorus or minor elements added.

concentration in flax was reduced by zinc additions to the calcareous soils. A similar decrease was not evident in the phosphorus content of flax grown on the noncalcareous soils. The copper content of flax was increased on all soils when copper was added. Copper applications did not reduce the phosphorus content of flax on any of the soils. A reduction in the phosphorus content of flax on the calcareous soils receiving zinc plus copper was probably due to a phosphorus-zinc rather than to a phosphorus-copper interaction. The differences in the zinc, copper and phosphorus contents of flax may be explained by the promotion of growth with the application of these nutrients to the soil.

Additions of zinc or zinc plus copper increased the zinc uptake by flax on the soils studied (Table XXIII). Phosphorus uptake was reduced by applications of zinc or zinc plus copper to the calcareous soils. The presence of carbonates seemed to accentuate the phosphorus-zinc interaction.

Copper has been known to depress the absorption by plant roots in several systems studied. Copper depressed zinc absorption from soils in long term experiments with bean seedlings (24). This may be an explanation for the reduced zinc uptake by flax on the Newdale, Lakeland and Plum Ridge soils when zinc plus copper was added. It has been reported that copper had its greatest effect on zinc absorption when zinc was in limiting supply; where zinc was in luxury supply, copper actually enhanced zinc absorption (18). The application of copper increased the copper uptake on all soils. Addition of zinc plus copper increased the copper uptake as much or more than did the addition of copper alone on three of the four soils. Applied copper increased phosphorus uptake, the increases being larger on the noncalcareous than on the calcareous soils.

TABLE XXIII

EFFECT OF ADDED PHOSPHORUS, ZINC AND COPPER ON THE PHOSPHORUS, ZINC AND COPPER UPTAKE BY FLAX

Treatment	Stockton			Newdale			Lakeland			Plum Ridge		
	Zn (ug/pot)	Cu (ug/pot)	P (mg/pot)	Zn (ug/pot)	Cu (ug/pot)	P (mg/pot)	Zn (ug/pot)	Cu (ug/pot)	P (mg/pot)	Zn (ug/pot)	Cu (ug/pot)	P (mg/pot)
Check[£]	230	34	11.0	257	30	9.9	26	16	1.2	45	17	3.5
P	269	16	31.9	252	36	27.6	35	10	9.2	35	12	10.8
P + Zn	357	16	31.1	321	49	27.5	54	19	3.7	252	22	6.6
P + Cu	288	25	36.4	257	149	29.7	16	23	9.9	38	24	11.3
P + Zn + Cu	445	26	38.1	269	93	25.9	41	35	3.1	86	26	6.3

£ No phosphorus or minor elements added.

The P/Zn and P/Cu uptake ratios increased when phosphate was applied, but decreased when zinc or copper were added (Table XXIV). The addition of copper usually increased the P/Zn uptake ratio indicating that lower amounts of zinc were taken up in the presence of applied copper. The addition of zinc decreased the P/Cu uptake ratio. This was probably due to a phosphorus-zinc interaction which reduced phosphorus uptake thereby decreasing the P/Cu uptake ratio.

This study supplied further evidence of a phosphorus-zinc interaction. The presence of copper-zinc competition was also evident. These interactions tended to be more pronounced in carbonated soils than in noncarbonated soils.

TABLE XXIV

RATIO OF P/Zn AND P/Cu UPTAKE BY FLAX

	Soil							
	Stockton		Newdale		Lakeland		Plum Ridge	
Treatment	P/Zn	P/Cu	P/Zn	P/Cu	P/Zn	P/Cu	P/Zn	P/Cu
Check[£]	48	324	39	330	46	75	78	206
P	119	1994	110	767	263	920	309	900
P + Zn	87	1944	86	561	69	195	26	300
P + Cu	126	1456	116	199	619	430	297	471
P + Zn + Cu	86	1465	96	279	76	89	73	242

[£] No phosphorus or minor elements added.

V. CONCLUSIONS AND SUMMARY

In recent years, interest has been focused on phosphorus-minor element interactions due to numerous reports of minor element problems particularly in areas where high levels of phosphate or continual phosphate fertilization occurs. Earlier workers postulated that the formation of sparingly soluble phosphorus-minor element compounds was the cause of the minor element deficiencies. More recent evidence, however, has indicated that phosphate may reduce minor element uptake because of ion antagonism at the root surface.

In an attempt to gain more information on phosphorus-minor element interactions, several studies were conducted. A study was conducted to determine the influence of high levels of monoammonium phosphate added to several soils on the uptake of iron, manganese, zinc and copper by wheat and flax. The application of phosphorus increased wheat yields significantly on all soils, but flax yields were not increased. Wheat and flax yields were lower on the calcareous than on the noncalcareous soils. Added phosphorus decreased iron, manganese, zinc and copper concentration of wheat and flax in many instances. Iron, manganese, zinc and copper uptake by wheat and flax was also reduced when high rates of phosphorus were added to soils. The reduction of minor element uptake on the highly phosphated soils could not be attributed to soil pH changes in most soils. The low yields and minor element contents of wheat and flax grown on some of the soils indicated that zinc and copper deficiencies may exist in some Manitoba soils.

The solubility of iron, manganese, zinc and copper as affected by additions of phosphorus to soils was studied. Phosphating the soils decreased the soil pH and usually increased the minor element content of soil-water extracts. This effect was more pronounced on the noncalcareous than on the calcareous soils. In a few instances, the iron and zinc concentrations of the water extracts were reduced by phosphate applications. The general increase in the minor element content of the soil-water extracts with phosphating, indicated that the reduction in minor element uptake by wheat and flax was not the result of phosphorus-minor element precipitation.

The influence of high levels of phosphorus in nutrient solutions on minor element uptake by wheat and flax was studied. Wheat yields were not influenced by phosphate rates up to 100 ppm while flax yields were reduced by phosphate rates in excess of 20 ppm. The minor element content of wheat and flax decreased with increases in phosphorus concentration, except for manganese and iron in wheat and flax tops, respectively. High levels of phosphorus in the nutrient solutions reduced iron, manganese, zinc and copper uptake by wheat and flax. The translocation of copper in flax was found to be reduced by high amounts of phosphorus in the nutrient solutions. An experiment, using nutrient cultures, in which both phosphate and minor element levels were varied, indicated that ion antagonism was mainly responsible for reducing the minor element uptake by plants in soils or solutions containing high concentrations of phosphorus.

The effect of zinc and copper applications on yields and minor element uptake by flax grown on soils was studied. Flax yields were significantly increased by zinc and copper applications to two soils. The application of either of these nutrients increased their uptake by flax. There was evidence of a phosphorus-zinc and copper-zinc antagonism. These interactions were more pronounced on the calcareous than on the noncalcareous soils.

These studies suggest that reductions in minor element uptake from highly phosphated substrates are mainly due to ion antagonism effects. The translocation of copper from the roots to the above ground portion of the plant was also reduced by high phosphate levels. Although the minor element content of the plants was reduced when large amounts of phosphorus were added to the soils, the yields were usually not reduced at high levels of applied phosphate. Thus, it would appear from this study that only extremely large amounts of applied phosphate or the use of phosphate over a long period of time would result in phosphate induced minor element deficiencies in Manitoba soils. This study also showed that some Manitoba soils do not supply sufficient quantities of copper and/or zinc for the growth of crops such as flax. Addition of phosphorus to these soils, without the use of minor element fertilizers, may only increase the degree of deficiency and result in reduced yields.

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