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A STUDY OF THE COPPER AND ZINC STATUS OF SOME MANITOBA SOILS

by

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ABSTRACT

Greenhouse studies were conducted to determine the relationships between the copper and zinc content of flax and wheat, and selected soil properties. Yields of flax and wheat were lower on the calcareous soils than on the non-calcareous soils. The copper content of flax and wheat grown on fine textured soils was generally higher than the copper content of plants grown on the coarse textured soils. The zinc content of flax and wheat was generally higher on the coarse textured soils than on the fine textured soils. The copper content of flax increased with increases in soil pH, carbonate content, and organic matter content. The copper content of wheat was not significantly related to any of the above soil properties. The zinc content of flax decreased with increasing pH. However, the zinc content of flax was not significantly related to soil carbonate content or organic matter content. The zinc content of wheat decreased with increasing soil pH, carbonate content, and organic matter content.

Na_2DP was found to be the most suitable extractant to use in assessing the copper status of Manitoba soils. DPTA (pH = 8.0) was found to be the best extractant to use in assessing the zinc status of Manitoba soils. The inclusion of soil pH along with extractable zinc or copper as independent variables increased the R^2 values obtained

for the relationships between copper and zinc content of flax and wheat, and extractable copper and zinc.

Field trials showed that $Na_2CuEDTA$ and $Na_2ZnEDTA$ inhibited germination of flax when banded in with flax seeds at rates of 0.5 to 4.0 ppm copper or zinc.

In a greenhouse study, a Pine Ridge soil was found to be severely copper deficient. A Stockton soil was found to contain barely adequate quantities of copper for the growth of flax plants. A Plum Ridge soil was found to be moderately zinc deficient while an Almasippi soil was found to supply barely adequate quantities of zinc for flax plants.

It was found that soils containing 1.3 ppm Na_2DP extractable copper may be suspected of being copper deficient; a soil containing 0.1 ppm extractable copper was found to be severely copper deficient. The data showed that soils containing less than 1.3 ppm DPTA (pH=8.0) extractable zinc may be suspected of being zinc deficient while soils containing 0.8 ppm DPTA (pH=8.0) extractable zinc were moderately zinc deficient.

Plant analysis showed that eight week old flax plants containing about 3.0 ppm copper may be suspected of being copper deficient while plants containing 2.0 ppm copper are copper deficient. It was shown that eight week old flax plants containing less than about 13 ppm zinc may be suspected of being zinc deficient whereas flax plants containing 9.0 ppm zinc are moderately zinc deficient.

$Na_2CuEDTA$, CuO, CuS, $Cu_3(PO_4)_2 \cdot 3H_2O$, $CuSO_4$, $Cu_2P_2O_7$, $Na_2ZnEDTA$, ZnO, ZnS, $Zn_3(PO_4) \cdot 4H_2O$, $ZnSO_4$, ZnP_2O_7, and $ZnNH_4PO_4$ were evaluated as copper and zinc fertilizers using incubation studies. Of all the compounds studied, $Na_2CuEDTA$ and $Na_2ZnEDTA$ were found to be the best sources of water soluble copper and zinc, respectively. Both $Na_2CuEDTA$ and $Na_2ZnEDTA$ were found to be more soluble in calcareous soils than in noncalcareous soils. Copper phosphate appeared to be the best copper fertilizer of the inorganic copper compounds studied. Zinc sulphide appeared to be the best zinc fertilizer of the inorganic zinc compounds. Zinc oxide and zinc ammonium phosphate also proved to be good zinc fertilizers.

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I INTRODUCTION

Copper and zinc deficiencies in plants and soils have received considerable attention due to an ever increasing number of reports concerning the aforementioned deficiencies in various crops. Copper deficiencies tend to occur on acid sandy soils and on organic soils. Zinc deficiencies tend to occur on calcareous soils or on highly leached soils with low total zinc content. Manitoba, due to its geological history and large area of agricultural land, has arable soils which fall into the aforementioned categories. Agricultural practices common to Manitoba, such as the application of phosphate fertilizers to soils, also tend to accentuate copper and zinc deficiencies.

Although Manitoba contains soils which may not supply sufficient copper and/or zinc for the needs of some crops, very little research work has been conducted with these elements in Manitoba. It has been found in some greenhouse and field experiments, that sandy soils such as the Poppleton and Miniota may not supply sufficient quantities of copper for corn and vegetable crops. In other greenhouse studies, moderate responses to applications of zinc were noted when flax was grown. Deficiencies of copper and zinc have been noted by workers in Minnesota on soils similar to those found in Manitoba.

Since copper and zinc deficiencies occur in soils such as those found in Manitoba and instances of copper and zinc deficiencies have been noted in some Manitoba soils, experiments were conducted to:

1. assess the copper and zinc status of 14 Manitoba soils. Flax and wheat were grown, and copper and zinc contents of the plants determined. Relationships between the copper and zinc content of the plants and soil pH, soil carbonate content, and soil organic matter content were determined.
2. determine the relationship between the copper and zinc content of flax and wheat, and soil available copper and zinc as measured by various chemical extractants.
3. determine the effect of various rates of $Na_2CuEDTA$ and $Na_2ZnEDTA$ on the yield of flax grown on several soils.
4. determine the amounts of copper and zinc extracted by water from soils treated with various copper and zinc compounds and incubated for various periods of time. This experiment was conducted to assess the suitability of several copper and zinc compounds as fertilizers.

II REVIEW OF LITERATURE

A) Extractants for Assessing Plant Available Copper and Zinc in Soils

A useful extractant is one which efficiently extracts the element from those compounds in the soil considered to participate in its supply to the plant (92). The extractants generally used to assess copper and zinc availability in soils can be placed in approximately five categories. They are: (1) extractants which extract total amounts of copper or zinc from the soil, (2) biological extractants, (3) salt extractants, (4) dilute acid extractants, and (5) chelating agents.

(1) Total copper and zinc content of soils

The total copper content of soils has been used as a criterion for assessing the availability of copper to plants (81, 82, 87). However, most workers have found a poor correlation between total copper content of soils and plant available copper (81, 87). Mitchel (68) found that the total copper content of soils could serve as a guide to the possibility that a deficiency or toxicity exists, but was not a good measure of assessing the plant available copper content of soils.

Total zinc content of soils has been studied as a guide for assessing the availability of zinc to plants (47, 114, 116). In almost all instances, total zinc content of the soil was found to be poorly correlated with plant available zinc (64, 116, 124).

(2) *Biological extractants*

Aspergillus niger has been used as a common bioassay for assessing plant available copper in soils (25, 33, 43). *Aspergillus niger* extractable copper is generally considered to be adequately correlated with plant available copper and, thus, an adequate test for plant available copper (25, 33, 87). However, the bioassay is time consuming and, therefore, has been replaced by chemical extractants which are about as accurate but less time consuming (43). Also, tests for available copper using *Aspergillus niger* were found to be useful only on acid soils (119).

Aspergillus niger has been used as a bioassay for plant available zinc in soil (63, 64, 113). However, *Aspergillus niger* has an inherent disadvantage due to the fact that the test is not accurate at concentrations above six ppm Zn (112). Also, tests for available zinc using *Aspergillus niger* as a bioassay were found to be useful only on acid soils (119). Martens *et al.* (64) found that available zinc measured using *Aspergillus niger* did not reflect plant available zinc as well as available zinc measured using 0.1 N HCl, dithizone, or 0.2 M $MgSO_4$.

(3) Salt extractants

Copper extracted from soil by salt solutions has been used as a criterion for measuring the plant available copper status of soil (30, 65, 75, 84). Salts such as KCl, NH_4OAc, and NaOAc are considered to extract copper present on the exchange complex in the soil (30, 122). Salt solutions, however, generally fail to extract sufficient quantities of copper to make accurate analysis possible (30). NH_4OAc (1.0 N) extractable copper was found to be poorly correlated with the occurence of copper deficiency on Australian soils (65). Dolar *et al*. (26) found 1.0 N $Mg(NO_3)_2$ extractable copper not as well correlated with plant uptake of copper by oats as was 0.1 N HCl, 0.001 M EDTA, or 0.005 M DPTA extractable copper.

Acidified salt solutions have been used as extractants to measure the relative amounts of plant available copper in soils (4, 30, 33, 122). Gilbert (33) found that available copper measured using *Aspergillus niger* was better related to plant available copper than copper extracted by an acid salt extractant composed of HAc and NaOAc.

Zinc extracted from soil by salt solutions has been used as a criterion for assessing the plant available zinc status of soil (34, 72, 92, 108). Zinc extracted from soil by salts such as 1.0 N KCl and 1.0 N NH_4NO_3 has been found to be well correlated with the zinc content of plants (62, 92). Zinc extracted from the soil by 2.0 N $MgCl_2$ was found to be more closely correlated with the zinc content of millet than zinc extracted by 0.1 N HCl and NH_4OAc-dithizone (110). However, many workers have found salt solutions unsatisfactory for use in determining the plant available zinc status of soil (44, 103, 108, 118). Stanton and Burger (108) found that salt solutions did not extract sufficient zinc from the soil to make accurate analysis possible.

Zinc extracted by an acidified salt solution has also been used as a criterion for assessing plant available zinc content of soil (4, 108, 122, 124). Layman and Dean (61), using 1.0 N NH_4OAc acidified to pH 4.6, found that there was an apparent relationship between the degree of zinc deficiency and the amount of zinc extracted from the soil. Grewal <u>et al</u>. (36) found that zinc extracted from the soil by 1.0 N NH_4OAc at pH 4.6 was significantly correlated with the response of wheat to zinc applied on Indian soils. Hibbard (44) found an acidic salt solution (o.5 N KCl acidified to pH 3.2 with HAc) to be a good extractant for plant available zinc

(4) Dilute acid extractants

The amount of copper extracted from soil by dilute acid extractants has been used as a criterion for assessing the plant available copper status of soil (23, 81, 106, 109). The two most common dilute acid extractants used for the determination of plant available copper in soil are 0.1 N HCl (43) and 0.43 N HNO_3 (81, 106). Copper extracted from soil by 0.1 N HCl was found to be not as well correlated with plant available copper as was copper extracted by EDTA (23, 43). Steenbjerg and Boken (109) found a good correlation between copper extracted at a pH near 2.0 and plant response to copper fertilizer. Øien (81) found a good correlation between plant available copper and copper extracted by 0.43 N HNO_3.

Zinc extracted from soil by dilute acid extractants has been used to predict the plant available zinc content of soil (16, 52, 76, 116). The acid most commonly used is 0.1 N HCl. Marten _et al_. (64) found a correlation coefficient of 0.562 between 0.1 N HCl extractable zinc and uptake of zinc by corn. Dithizone extractable zinc was found to be more highly correlated with zinc uptake by corn than was 0.1 N HCl extractable zinc while total, _Aspergillus niger_, and 0.2 M $MgSO_4$ extractable zinc were not correlated as well. Trierweiller and Lindsay (116) found the correlation coefficients between the zinc content of corn and extractable zinc to decrease in the order: 1.0 M $(NH_4)_2CO_3$ + 0.01 M EDTA > NH_4OAc - dithizone > 0.1 N HCl > total zinc content of soils. Brown *et al.* (16) found 0.1 N HCl extractable zinc predicted the occurence of a response to zinc fertilizer in 73 percent of the instances where responses to zinc were obtained, whereas zinc extracted by Na_2EDTA, dithizone, and DPTA predicted the occurence of responses to zinc in 72, 79, and 83 percent of the instances, respectively.

(5) Chelating agents

Sequestering or chelating agents such as EDTA and DPTA have been used as extractants to assess the plant available copper content of soils. EDTA has been the most commonly used extractant for assessing the plant available copper content of soils (23, 43, 81, 93). McKenzie (65), working with 82 Australian soils, found that copper extracted from the soil by 0.02 M EDTA predicted the occurence of response to copper fertilization in 90 percent of the instances where response to copper occured. Henriksen (43) found that copper extracted from soil by 0.02 M EDTA was more closely related to plant copper content than was available copper as measured by 0.1 N HCl extraction at pH 2.0 or by *Aspergillus niger*. Viro (126) found that copper extracted from acid Finish soils by EDTA could be used for determining the copper status of acid forest soils. Other workers (89, 93) have found 0.05 M $(NH_4)_2EDTA$ at pH 4.0 or 0.05 M EDTA at pH 7.0 to be suitable extractants to assess plant available copper content of soils.

DPTA has also been used as an extractant for assessing the plant available copper content of soils (26). Dolar et al. (26) found that DPTA extractable copper was highly correlated ($r^2 = 0.77$) with copper uptake by oats grown for 23 days on 36 soils. He found the correlation coefficients between copper content of oats and extractable soil copper to decrease in the order: 0.001 M EDTA > 0.1 N HCl > DPTA > total soil copper > 1.0 N $MgNO_3$; the r^2 values were 0.83, 0.83, 0.77, 0.69, and 0.61, respectively.

Zinc extracted by EDTA has been used to evaluate the amount of plant available zinc in soil. EDTA has been used alone (72, 73, 114) or in combination with a salt solution which buffers the extractant-soil system at a constant pH (92, 116, 135). Zinc extracted by EDTA alone or in combination with various salts at various pH's was generally more highly correlated with plant available zinc than zinc extracted from the soil by other extractants except dithizone (116). However, a few workers have found that EDTA extractable zinc was not as well correlated to plant available zinc as was zinc extracted by 1.0 N HN_4NO_3, 1.0 N KCl (92), 0.1 N HCl (135), or 0.05 N HCl and 0.025 N H_2SO_4 (135).

DPTA has been used as an extractant for assessing the plant available zinc status of soil (16, 129). Wallace (129) showed that zinc extracted by 0.001 M NaDPTA at pH's of 8.0 and 10.0 was more highly correlated with plant zinc content than was zinc extracted from the soil by 0.001 M NaEDDHA at pH's of 8.0 and 10.0; the r^2 values were 0.70, 0.86, 0.52, and 0.35 respectively. Brown et al. (16) found DPTA extractable zinc predicted the occurrence of a response to zinc fertilization in 83 percent of the instances where responses were obtained whereas amounts of zinc extracted by dithizone, 0.1 N HCl, and Na_2EDTA predicted the occurrence of responses to zinc in 79, 73, and 72 percent of the instances, respectively. Although the data on the use of this soil test is limited, it has been used in assessing zinc availability in Nevada soils for the past three years (16).

Zinc extracted by Na_2DP or Na_2EDDHA [ethylenediamine di (-0-hydroxy phenyl acetic acid) disodium salt] has been used to evaluate the plant available zinc content of soils (92, 129). Ravikovitch et al. (92) used 0.01 M Na_2DP

in 1.0 N NH_4OAc as a soil extractant for plant available zinc. He found Na_2DP extractable zinc to be more closely correlated with the zinc content of six crops than zinc extracted by 1.0 N KCl, 1.0 N NH_4NO_3, 1.0 N $CaCl_2$, NH_4OAc-dithizone, 0.02 M NaCD, 0.02 M $Na_2CaEDTA$, or 0.01 M EN. Wallace (129) found that zinc extracted by Na_2DP at pH's 8.0 and 10.0 was not as well correlated with the zinc content of soybeans as was zinc extracted by DPTA at pH's 8.0 and 10.0.

Shaw and Dean (103) suggested the use of a NH_4OAc-dithizone extractant for determining the plant available copper content of soils. Blevins (11), using 34 Kentucky soils, found that NH_4OAc-dithizone extractable copper was more closely correlated with copper uptake by millet ($r = 0.62$) than was EDTA extractable copper ($r = 0.57$).

Zinc extracted from the soil by the NH_4OAc-dithizone method of Shaw and Dean (103) has generally been found to be more closely correlated with plant available zinc than zinc extracted from the soil by other methods (62, 64, 113). The NH_4OAc-dithizone method, however, is laborous and, therefore, has been replaced by other methods which predict the plant available zinc content of soils almost as well (16, 116).

B) The Effect of Chemical and Physical Soil Properties on Copper and Zinc Availability

The availability of native and applied copper and/or zinc has been observed to be governed by several chemical and physical properties of the soil. These properties are: (1) texture, (2) temperature, (3) organic matter content, (4) pH, (5) calcium carbonate content, and (6) phosphate content.

(1) Texture

Copper and zinc when applied to a sandy soil, are more available to the plant than when applied to a soil of finer texture (33, 79, 113). Most workers attribute this phenomenon to the fact that most of the applied copper or zinc is tightly adsorbed on the clay colloid, or is fixed within the clay lattices (32, 71, 77, 113).

(2) Temperature

As soil temperature increases to a normal high the amount of soluble copper in soil has been found to increase (3, 45, 87, 133). Zinc availability also increases with increasing soil temperature (3, 133).

(3) Organic Matter Content

Soils with high organic matter contents tend to be copper deficient (33, 95). Soils high in organic matter generally require more applied copper to correct copper deficiencies than soils low in organic matter (33, 115). Miller and Ohlrogge (67) concluded that soil organic matter holds copper in a form which is not plant available. However, Gupta and MacKay (39) have found a low correlation between soil organic matter and copper uptake for soils containing one to nine percent organic matter. This may indicate that low levels of organic matter in the soil do not affect copper uptake by plants.

Zinc deficiencies occur on soils high in organic matter content (22, 113). Miller and Ohlrogge (66, 67) found that organic matter can complex zinc and hold it in a form unavailable to the plant. However, Martens (62) found a very low correlation between soil organic matter content and the uptake of zinc by corn grown on mineral soils.

(4) pH

The uptake of copper from soil or fertilizer is only slightly decreased by an increase in soil pH (45, 85, 88, 139). The uptake of zinc from soil and fertilizer was found to decrease as soil pH increased (2, 59, 113, 134). These effects are attributed to the solubility of various pH dependent forms of copper and zinc (2).

(5) Calcium carbonate content

Beeson *et al.* (5) found that calcium carbonate only slightly reduced the uptake of naturally occuring compounds, but greatly reduced the uptake of copper added as copper sulphate. Other workers (13, 139) have also found that calcium carbonate reduced the availability of applied copper sulphate. Calcium carbonate applied to soil has also been found to reduce the availability of applied zinc and naturally occuring zinc (14, 51, 83, 120).

(6) Phosphorus

Phosphorus applied to a soil can reduce the uptake of copper by plants (8, 9, 10). Haluschak (41), however, found that applications of up to 400 ppm phosphorus had little or no effect on the copper content of flax or wheat. Phosphorus applied to soil has been shown to reduce zinc uptake by plants (19, 55, 58, 111). The effects of added phosphorus on copper and zinc uptake by plants are usually most pronounced on soils treated with phosphate over a long period of time or when a soil is treated with a large amount of phosphate fertilizer.

C) Critical Levels of Copper and Zinc in Soils and Plants

Soils

The amount of copper and zinc extracted from a soil varies with the method of extraction used. Methods used to approximate the total copper and zinc content of soil usually extract the greatest amounts of copper and zinc whereas salt solutions extract the lowest amounts of copper and zinc (108). Different plant species have different requirements and tolerances for copper and zinc (88, 106, 123). Thus, the values for critical levels of copper and zinc in soils is dependent on the extraction procedure used and the plant species studied.

Both flax and wheat are sensitive to copper deficiency (17, 88, 106). Henkens (42) found copper deficiency in wheat when grown on soil containing less than 10 ppm total copper. Wheat grown on soil containing less than three ppm *Aspergillus niger* extractable copper was found to be copper deficient (42, 87).

Although salt solutions have been used to determine the availability of copper in soils, no critical values could be found in the literature. Fiskell (30) found that copper deficiency could be expected to occur in soils containing less than 0.2 ppm copper extracted by 1.0 N NH_4OAc at pH 4.8.

Smilde and Henkens (106) found copper deficiency to occur in wheat when grown on soil containing less than

4.0 ppm of 0.43 N HNO_3 extractable copper. Henkens (42) found oats responded to added copper when grown on soils containing less than 3.0 ppm of 0.43 N HNO_3 extractable copper. Steinbjerg and Boken (109) found soils containing less than 3.1 ppm of 0.1 N HCl extractable copper to be copper deficient. Nelson *et al*. (78) found several plant species responded to copper fertilizers when grown on soil containing less than 3.3 ppm of 0.1 N HCl extractable copper

Responses of wheat to added copper have been noted when copper extracted by 0.05 M $(NH_4)_2EDTA$ at pH 4.0 was below 1.3ppm (89). Blevins and Massey (11) found millet was likely to be copper deficient on soils containing less than 0.3 ppm dithizone extractable copper.

The total zinc content of soils has proved to be a poor criterion for estimation of plant available zinc (64, 116). Therefore, critical values for the total zinc content of soils are meaningless.

Donald *et al*. (25) found soils containing less than 2.0 ppm *Aspergillus niger* extractable zinc to be zinc deficient. Tucker *et al*. (119) found soils containing less than 2.88 ppm *Aspergillus niger* extractable zinc to be zinc deficient.

Ravikovitch *et al*. (92) found zinc deficiency in corn occured when values for 1.0 N KCl and 1.0 N NH_4NO_3 extractable zinc were below 0.2 and 0.25 ppm, respectively.

Viets *et al*. (123) found that zinc deficiency in flax occured on soils containing less than 0.9 ppm of 0.1 N HCl extractable zinc. Wear and Sommer (136) found zinc deficiency to occur in corn grown on soils containing less than 1.0 ppm of 0.1 N HCl extractable zinc.

Brown *et al*. (16) found zinc deficiency to occur in corn grown on soils containing less than 1.25 ppm 1% EDTA extractable zinc. Trierweiller and Lindsay (116) found zinc deficiencies in corn grown on soils containing less than 1.4 ppm zinc as extracted by a solution 1.0 M in $(NH_4)_2CO_3$ and 0.01 M in EDTA at a pH of 8.6. Brown *et al*. (16) found the critical level for DPTA extractable soil zinc to be 0.5 ppm for corn. Ravikovitch *et al*. (92) found that corn grown on soils containing less than 1.0 ppm zinc extracted by a solution 1.0 N in NH_4OAc and 0.01 M in Na_2DP at pH=7.0 to be generally zinc deficient. Other workers (15, 16, 100, 116) have found that values of NH_4OAc -dithizone extractable zinc below 0.55 ppm usually indicate a zinc deficient soil.

Plants

The copper and zinc content of plants varies with stage of growth and plant species (53, 88, 137). Also, the copper and zinc content can vary among plant parts. Regardless of the above limitations, the copper and zinc content of plants is one of the better methods of assessing if a plant is deficient in these elements (95).

Reuther and Labanauskas (95) found wheat prior to heading responded to applied copper when the plant content was 8.0 ppm or less. Haluschak (41) found seven week old flax plants responded to applied copper when the plant copper content was 8.0 ppm.

Corn leaves, obtained from plants still in the vegetative stage, were found to be zinc deficient at zinc contents of less than 10 ppm (100). Wheat plants, analysed at the three to nine inch growth stage, were generally found to be deficient in zinc when the zinc content of the plant was less than 10 ppm (100). Flax plants, which were 71 days old, were found to be zinc deficient when the above ground portion of the plant contained 18.0 ppm zinc or less (22). Haluschak (41) found seven week old flax plants which contained less than 21 ppm zinc responded to applications of zinc.

D) Copper and Zinc Fertilizers

Copper and zinc fertilizers can be placed into three catagories, These categories are: 1) soluble salts of copper and zinc, 2) chelated copper and zinc, and 3) sparingly soluble salts of copper and zinc. The soluble salts include salts such as copper sulphate and zinc sulphate. The chelated compounds of copper and zinc are compounds such as $Na_2CuEDTA$ and $Na_2ZnEDTA$. Insoluble salts include the oxides, phosphates, ammonium phosphates, pyrophosphates, and sulphides of copper and zinc.

1) The Sulphates of Copper and Zinc

Copper sulphate has been commonly applied to copper deficient soils (6, 7, 117). Copper sulphate is an easily obtainable soluble copper salt (21.97 g in 100 ml H_2O at room temp.) (100). Copper sulphate is usually applied at rates of 2.5 - 50 lb/acre on mineral soils (6, 94, 95, 117). Acid sandy soils are usually fertilized with copper at the lower rates whereas soils of a heavier texture are fertilized at the higher rates mentioned above (32, 84). Copper sulphate has been applied to copper deficient organic soils at rates of about 50 to 200 lb/acre (33, 94, 95). Organic soils can usually be treated with large applications of copper sulphate but continued application of copper sulphate on mineral soils can lead to copper toxicities (94).

Zinc sulphate is a soluble zinc salt (8.65 g in 100 ml

H_2O at 20° C) (100). It has been applied to soils to correct zinc deficiencies (22, 100) at rates of 2.5 to 50 lb/acre of zinc sulphate (6, 113). Generally, smaller amounts are added to acid sandy soils than to heavy textured soils (22). One application of zinc sulphate at the above rates is usually sufficient to prevent zinc deficiencies for one to five years (125). Zinc sulphate is usually applied on organic soils at rates exceeding those mentioned above (22).

2) Copper and Zinc Na_2EDTA

Copper EDTA has been applied to soil to correct copper deficiencies (33, 35, 40) at rates of 0.5 to 3.0 lb Cu/acre. Zinc EDTA has been applied to mineral soils at rates of 0.5 to 5.0 lb Zn/acre (38, 17, 113, 131). Zinc and copper EDTA are more effective in correcting deficiencies than inorganic salts (45, 80, 132). The EDTA carrier is more effective than the inorganic carriers because the metal-EDTA complex remains as a neutral molecule in the soil and, thus, the metal chelate is not fixed by the soil as rapidly as the metal ion (45, 80, 106, 131). Zinc EDTA has been found to be three times more effective than zinc sulphate on acid soils and six times more effective than zinc sulphate on calcareous soils (46). However, copper and zinc on EDTA complexes can be replaced by iron or calcium (80), and the zinc or copper fixed by the soil.

The pH of the soil solution is important in determining the degree of replacement. Copper and zinc EDTA are generally stable in soils with pH's between 6.1 and 7.3 and increasingly unstable as the pH deviates from the above range. Care must be exercised when applying metal chelates to soil since they have been found to be toxic when applied in excess (130).

3) Sparingly Soluble Salts of Copper and Zinc

Sparingly soluble salts of copper and zinc have been investigated as sources of copper and zinc fertilizers. Sparingly soluble salts of copper and zinc are slowly weathered and, therefore, duplicate the natural processes of copper and zinc addition to soil. The sparingly soluble salts of copper and zinc can be added to soils without creating toxicities. Granual size of the sparingly soluble salt can act as a regulator for the amount of copper or zinc dissolved within a certain period of time. Therefore, regulating granual size can be useful in balancing the effects of soil pH and/or texture on the leaching and/or fixation of applied copper and zinc (13).

i. Oxides of Copper and Zinc

Copper oxide is a sparingly soluble salt with a solubility of 0.15 mg/liter H_2O (56). Copper oxide has been used as a copper fertilizer (33, 117) at rates of 5 - 25 lb CuO/acre on mineral soils (100). Copper oxide has been found to be as good a copper fertilizer as copper sulphate when equal amounts of copper are applied (54, 84, 117).

Zinc oxide is a sparingly soluble zinc salt with a solubility of 0.005 g/liter of H_2O at 25° C (57). Zinc oxide has been used as a zinc fertilizer (12, 50, 70, 104) at rates of 5 - 25 lb ZnO/acre (100). When similar amounts of zinc are applied as zinc oxide or zinc sulphate the responses obtained to zinc are similar (12, 100, 124).

ii. Copper and Zinc Salts of Ammonium Phosphate

Copper ammonium phosphate is a sparingly soluble inorganic copper salt (0.9 mg per 100 g H_2O at 25° C) (13). Copper ammonium phosphate has been used as a fertilizer for copper deficient soils (13, 100). It was shown that copper uptake by sorghum from copper ammonium phosphate was not reduced by liming while the uptake of copper from copper sulphate was reduced (13).

Zinc ammonium phosphate is a slightly soluble zinc salt (1.8 mg per 100 ml H_2O at 25° C) (13). Bridger *et al.* found zinc ammonium phosphate and zinc sulphate to be equally efficient as zinc fertilizers. Zinc ammonium phosphate is usually applied at a rate of approximately 22 lb/acre (46).

iii. Copper and Zinc Pyrophosphate

Copper pyrophosphate is a sparingly soluble salt with a pKsp value of 15.08 at 25° C (105). Copper pyrophosphate is usually obtained as a spent catylst from industrial operations and, therefore, serves as a low cost source of copper. Copper pyrophosphate has been used as a soil treatment to prevent copper deficiency in crops (1, 18) and has been found to be as effective a copper fertilizer as copper sulphate (1).

Zinc pyrophosphate is a sparingly soluble zinc salt. No literature could be found on the use of zinc pyrophosphate as a zinc fertilizer.

iv. Copper and Zinc Phosphate

Copper phosphate is a sparingly soluble salt with a pKsp value of 36.9 at 20° C (105). It was found to be an excellent source of copper when applied to copper deficient soils (31).

Zinc phosphate has a pKsp value of 32.04 at 20° C (105). It was found to be a good source of plant available zinc when applied as a fertilizer (12, 31). Bowan *et al.* (12)

grew Red Mexican bean plants on a neutral noncalcareous fine sandy loam soil and found the uptake of zinc from zinc phosphate approximately equal to the uptake of zinc from zinc sulphate.

v. Copper and Zinc Sulphide

Copper sulphide has a pKsp of 37.4 at room temperature (127). It has been applied to soils to correct copper deficiencies (79). Steinbjerg and Boken (109) found copper from copper sulphide to be slightly less available to plants than copper from copper sulphate.

Zinc sulphide has a pKsp value of 23.0 at room temperature (127). Swaby and Passey (112) found sphalerite to be a good source of *Aspergillus niger* available zinc when compared to other rocks. Holden and Brown (46) found ZnS to be 10 to 50 times less effective than zinc sulphate in supplying zinc to plants.

III MATERIALS AND ANALYTICAL 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.

(A) Description of Soils

Fourteen surface soils of varing texture, pH, organic matter content, and carbonate content were selected (Tables I and II). The Red River, Newdale, Wellwood, Altona, Stockton I, Stockton 2, and Pine Ridge soils did not effervesce when treated with dilute HCl (noncalcareous). The Tarno, Lakeland, Balmoral, Almasippi 1, Almasippi 2, Plum Ridge, and Berlo soils all effervesced when treated with dilute HCl (calcareous).

(B) Soil Analysis

(1) Soil pH

The pH of the soil samples was determined electrochemically on a Coleman Metrion III pH meter. A suspension of 25 g of soil in 25 ml of 0.01 M $CaCl_2$ was used in determining the pH of the soils.

(2) Soil Organic Matter Content

Soil organic matter was determined as described by

Table I. Subgroup Designation and Textural Class of Soils.

Soil Name	Subgroup	Textural Class
Tarno	Carbonated Rego Humic Gleysol	Clay
Lakeland	Gleyed Carbonated Rego Black	Clay Loam
Balmoral	Carbonated Rego Humic Gleysol	Silty Clay Loam
Plum Ridge	Gleyed Carbonated Rego Black	Fine Sandy Loam
Almasippi 1	Gleyed Carbonated Rego Black	Loamy Sand
Almasippi 2	Gleyed Carbonated Rego Black	Loamy Sand
Berlo	Gleyed Dark Grey Luvisol	Sand
Red River	Gleyed Rego Black	Clay
Newdale	Orthic Black	Clay Loam
Wellwood	Orthic Black	Clay Loam
Altona	Orthic Black	Fine Sandy Clay Loam
Stockton 1	Orthic Black	Fine Sandy Loam
Stockton 2	Orthic Black	Loamy Sand
Pine Ridge	Degraded Eutric Brunisol	Sand

Table II. Characteristics of the Soils.

Soil Name	pH ($CaCl_2$)	Organic Matter Content (%)	Inorganic CO_3 Content (%)
Tarno	8.0	8.4	12.5
Lakeland	8.0	8.1	19.5
Balmoral	8.1	6.3	11.2
Plum Ridge	8.1	3.4	19.0
Almasippi 1	7.7	3.4	2.0
Almasippi 2	7.8	3.0	1.2
Berlo	7.8	1.4	4.9
Red River	7.5	7.5	0.8
Newdale	7.3	6.4	0.5
Wellwood	6.2	5.1	0.0
Altona	7.0	4.9	0.5
Stockton 1	6.2	4.6	0.0
Stockton 2	7.0	2.6	0.3
Pine Ridge	6.2	3.2	0.0

Walkley and Black (128). 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.

(3) Inorganic Carbonate Content

The method described by Ridley (96) was used. A one-gram sample of soil was digested in 10 percent HCl for 10 minutes. The CO_2 evolved was sucked through a drying and absorption train, then absorbed by Ascarite in a Nesbitt tube. The weight of CO_2 absorbed on the Ascarite was determined and the carbonate content of the soil calculated.

(4) Determination of Water Content at Field Capacity

Soil, sieved through a two mm sieve, was placed in 600 ml beakers and sufficient water added to wet the top one-half of the soil. The samples were enclosed in polyethylene bags and allowed to equilibrate for two days. Soil samples were taken above the wetting front and dried at 105° C for 24 hours. The loss in weight of the samples was measured and the moisture content of the soils calculated.

(5) Soil Cation Exchange Capacity

Soil cation exchange capacity was determined by the ammonium saturation method outlined by Chapman (21). Exchange sites of a 10.0 g soil sample were saturated with ammonium by shaking for one hour in 100 ml of 1 N NH_4OAc solution containing 250 ppm lithium and adjusted to pH 7.0 with dilute HCl. The suspension was filtered under suction and washed with NH_4OAc until 250 ml was collected. The soil was washed with 250 ml of 95 percent ethanol. The adsorbed ammonium was displaced by leaching the soil with 250 ml of acidified 1 N NaCl. The filtrate was collected and transferred to an 800 ml Kjeldahl flask. Twenty-five ml of 10 N NaOH was added and the ammonia distilled into 50 ml of 2.0 percent boric acid solution using a Kjeldahl distillation apparatus. The absorbed ammonium was titrated with standardized 0.1 N H_2SO_4 and the cation exchange capacity of the soils calculated.

(6) Mechanical Analysis

The pipette method for particle size analysis was used. Duplicate 10.0 g samples were used. Organic matter was destroyed by the addition of 30 percent hydrogen peroxide. Ten ml of calgon solution was added and the samples stirred mechanically for 30 minutes. The sand fraction was obtained by seiving the suspension through a 300 mesh seive. The eluate was collected in a 1000 ml cylinder and made up to volume with distilled water. Aliquots were taken at a depth of 10 cm for an estimation of silt plus clay and clay fractions after allowing for the appropriate settling times. The percent sand, silt, and clay were then calculated.

(7) Chemical Extraction Procedures for Soil Copper and Zinc

Air dried soil was ground to pass through a one mm sieve. The concentrations of copper and zinc in all filtrates were determined by the use of a Perkin Elmer Model 303 Atomic Absorption Spectrophotometer. The standard solutions used for copper and zinc determinations were prepared using the same solutions as used for the extraction of the soils. Deionized water was used in all preparations.

i) Copper and Zinc Extracted from Soils by Concentrated Acid

One gram of soil was weighed and added to a micro-kjeldahl flask. Fifteen ml of 70% $HClO_4$ and 10 ml of conc. HNO_3 were added and the soil digested by boiling until the volume of acid was reduced to approximately three ml. The digest was allowed to cool and diluted with approximately 25 ml of deionized water. The digest was allowed to sit one hour, filtered into a 50 ml volumetric flask, and brought to volume with deionized water. Copper and zinc concentrations of the extracts were then determined and the copper and zinc content of the soils calculated.

ii) Copper and Zinc Extracted from Soil by 1.0 N NH_4NO_3

Ten g of soil were shaken with 50 ml of 1.0 N NH_4NO_3 for one hour. The suspensions were then filtered and the copper and zinc content of the extracts determined.

iii) Copper and Zinc Extracted from Soil by a Solution 1.0 N in KCl and 0.01 N in H_2SO_4

Five g of soil were shaken with 50 ml of solution for one-half hour. The suspensions were then filtered and the copper and zinc content of the extractants determined.

iv) Copper and Zinc Extracted from Soil by 0.1 N HCl

Five g of soil were shaken with 50 ml of 0.1 N HCl for one-half hour. The suspensions were filtered and the copper and zinc content of the extracts determined.

v) Copper and Zinc Extracted from Soil by a 1% Solution of Na_2EDTA

Five g of soil were shaken with 50 ml of 1% Na_2EDTA solution (ethylenediamine tetraacetic acid di-sodium salt) for one-half hour. The suspensions were filtered and the copper and zinc content of the extracts determined.

vi) Copper and Zinc Extracted from Soil by a Solution 1.0 M in NH_4OAc, 2% in Na_2EDTA, adjusted to pH=7.0

Five g of soil were shaken with 50 ml of extracting solution for one-half hour. The suspensions were filtered and the copper and zinc content of the extracts determined.

vii) Copper and Zinc Extracted from Soil by a Solution 0.01 M in Na_2EDTA and 0.67 M in $(NH_4)_2CO_3$ at pH= 8.65

Two soil to solution ratios, 5.0 g of soil in 50 ml of extractant and 10 g of soil in 20 ml of extractant, were used. The soil and extracting solution were shaken for one-half hour. The suspensions were filtered and the copper and zinc content of the extracts determined.

viii) Copper and Zinc Extracted from Soil by a Solution 0.01 M in Na_2EDTA, and 1.0 M in $(NH_4)_2CO_3$ at pH= 8.8

Ten g of soil were shaken with 20 ml of solution for one-half hour. The solutions were filtered and the amount of copper and zinc in the extracts determined.

ix) Copper and Zinc Extracted from Soil by a Solution 0.01 M in Na_2DP and 1.0 M in NH_4OAc at pH=7.0

An extracting solution was prepared using Na_2DP [ethylenediamine di(O-hydroxyphenyl acetic acid) di-sodium salt] and NH_4OAc. The pH of the solution was adjusted to 7.0 by the use of dilute NaOH. Five g of soil were shaken with 50 ml of solution for one hour. The suspensions were filtered and the copper and zinc concentration of of the filtrates determined.

x) Copper and Zinc Extracted from Soil by a Solution 0.005 M in DPTA, 0.01 M in $CaCl_2$, and 0.1 M in TEA

An extracting solution was prepared using DPTA (diethylenetriamine pentraacetic acid), $CaCl_2$, and TEA (triethanolamine). Ten g of soil were shaken with 20 ml of solution for one-half hour. Extractions were conducted at pH's of 7.0, 7.5, 8.0, and 8.5. Therefore, four extractions were performed on each soil. The pH of the extracting solutions was adjusted by the use of dilute HAc. The suspensions were filtered and the copper and zinc concentration of the extractants were determined.

(C) Plant Analysis

(1) Technique for Washing Plant Tops

Prior to analysis the plant tops were washed in dilute HCl (five ml conc. HCl to four liters deionized water) for approximately one minute. The plant tops were then washed in EDDHA [ethylenediamine di(O-hydroxyphenol acetic acid)] (approximately one gram in four liters of deionized water) for about one minute in order to remove minor elements adhering to the plant tops (49). The tops were then rinced in deionized water, allowed to air dry for two days, and then dried at 70° C for two days.

(2) Total Zinc, Copper, Iron, and Manganese Content of Plants

The dried plant samples were finely ground and 1.5 g of sample digested in 17 ml HNO_3 and three ml of $HClO_4$ by boiling until the volume of acid was reduced to approximately two ml. The digest was cooled, diluted to approximately 25 ml with deionized water, and allowed to sit one hour. The diluted digests were then filtered using Whatman No. 42 filter paper and brought to volume in 50 ml volumetric flasks. The copper, zinc, iron, or manganese concentrations in the solutions were then determined by use of a Perkin-Elmer Model 303 Atomic Absorption Spectrophotometer (86).

(D) Preparation of Copper and Zinc Fertilizers

(1) Copper Pyrophosphate ($Cu_2P_2O_7$)

Copper pyrophosphate was prepared by saturating boiling H_3PO_4 with CuO and heating until a precipitate of $Cu_2P_2O_7$ formed. X-ray and chemical analysis showed that the $Cu_2P_2O_7$ was successfully prepared. The product contained 41.0% Cu.

(2) Copper Phosphate ($Cu_3(PO_4)_2 \cdot 3H_2O$

Copper phosphate was prepared by mixing a solution of 46.58 g $CuSO_4$ in 80 ml conc. NH_4OH with a solution of 59 ml conc NH_4OH and 23.6 g of H_3PO_4 (99). The solution was mixed at room temperature, neutralized to pH = 6.0 with H_3PO_4 and NH_4OH, and heated for four hours at a low boil.

The percipitate was allowed to stand overnight, filtered, washed, dried at 105° C, and analyzed. X-ray analysis showed the compound to be $Cu_3(PO_4)_2 \cdot 3H_2O$. The compound contained 41.1% Cu and 1.5% NH_4^+. The NH_4^+ present was probably adsorbed on the surfaces of the precipitate.

(3) Zinc Ammonium Phosphate ($ZnNH_4PO_4$)

One g zinc as $ZnCl_2$ was placed in 250 ml of deionized water and neutralized with dilute NH_4OH (1 - 1) using methyl red as an indicator (127). The solution was heated to near boiling and 25 ml of 10% diammonium hydrogen phosphate slowly added. A flocculent precipitate of zinc phosphate formed. The solution was heated on a hot plate near boiling until the flocculent precipitate changed to crystalline zinc ammonium phosphate (about 60 minutes). The precipitate was allowed to cool to room temperature, filtered, and washed free of chloride ions with a solution of one percent diammonium hydrogen phosphate. The precipitate was then washed twice with deionized water and dried at 105° C.

(4) Zinc Pyrophosphate ($Zn_2P_2O_7$)

Zinc pyrophosphate ($Zn_2P_2O_7$) was prepared by heating $ZnNH_4PO_4$ in a muffle furnace at 900°C for 12 hours (127).

(5) Zinc Phosphate ($Zn_3(PO_4)_2 \cdot 4H_2O$)

Zinc phosphate was prepared by saturating a boiling solution of 150 g of 85 percent H_3PO_4 in 750 ml of H_2O with ZnO (27). The water lost by evaporation was replaced, the saturated solution cooled to room temperature, and then cooled in cracked ice. The solution was diluted to two liters with ice cold water and allowed to stand on a hot plate at a temperature just below boiling until shiny plates of $Zn_3(PO_4)_2 \cdot 4H_2O$ formed. The crystals were filtered and washed with hot deionized water. X-ray diffraction analysis showed the product to be $Zn_3(PO_4)_2 \cdot 4H_2O$. The product was found to contain 42.08 percent zinc.

(E) Analysis of Copper and Zinc Fertilizer Compounds

(1) X-ray Diffraction Analysis

The X-ray diffraction analysis was conducted as outlined by Jackson (48). The equipment used was a Philips X-ray generator equiped with a cobalt target tube, a Gieger counter spectrometer and a Philips recorder. Samples were finely ground with a mortar and pestle and placed into an aluminum box mount backed with masking tape. The samples were then placed on the X-ray apparatus and X-rayed over a range of 2 to 90 degrees.

(2) Copper Content of Fertilizers

The copper content of the various copper fertilizers was determined by the thiosulphate method (127). The samples were dried at 105° C for 24 hours. Triplicate samples were weighed and dissolved in three ml of conc. HNO_3 and six ml H_2O. The samples were then diluted with 25 ml of distilled water. One gram of urea was added and the solution boiled for one to two minutes. One N NaOH was added until a slight blue precipitate formed. Acetic acid was then added until the precipitate dissolved. Four drops of acetic acid was then added and the sample diluted to 100 ml. KI (2.5 g) was added to each sample. The liberated iodine was then titrated with 0.1 N $Na_2S_2O_3$ which had previously been standardized versus copper wire. Two ml of saturated starch solution were added when a light yellow color appeared, and the solution titrated with stirring. When the blue color faded, two g of ammonium thiocyanate were added and the solution titrated until the blue color disappeared for 10 - 20 seconds. The copper content of the sample was then calculated.

(3) Zinc Content Fertilizer

The zinc content of the various zinc fertilizers were determined using 0.1 M EDTA with Eriochrome Black T as an indicator (127). The EDTA was standardized using zinc sulphate. The zinc fertilizers were dissolved in conc. HCl and the solutions neutralized with 1.0 N NaOH. The solution was buffered at a pH of approximately 10 with two ml of NH_4OH-NH_4Cl buffer. A few drops of indicator were added and the solution titrated until the color changed from red to blue. The zinc content of the sample was calculated.

IV EXPERIMENTAL AND RESULTS

A. Yield and Copper and Zinc Content of Flax and Wheat as Affected by Soil Properties and Extractable Copper and Zinc

A greenhouse experiment was designed to:

1. study the relationships between the copper and zinc content of flax and wheat, and each of the following soil properties: texture, pH, carbonate content, and organic matter content.

2. evaluate 14 chemical extractants as a means of assessing plant available copper and zinc in soils. The relationship between the amounts of copper and zinc extracted from soils by each extractant and the copper and zinc uptake and content of flax and wheat was studied. Two multiple regression equations were generated to predict the copper and zinc content and uptake of flax and wheat. One equation used soil extractable copper or zinc and soil pH as independent variables; the other equation used extractable copper or zinc, soil pH, and soil organic matter content as independent variables.

The experimental design was a split block with one subgroup consisting of wheat grown on 14 Manitoba soils and the other subgroup consisting of flax grown on the same 14 soils. Within each subgroup the three replicates of each soil were randomized. Periodically, the pots were rotated within each subgroup on the greenhouse bench to ensure uniform lighting for all pots. Two kilograms of air-dried soil were placed into one-half gallon glazed porcelain pots. One-hundred ppm N as NH_4NO_3, 20 ppm S as K_2SO_4, 20 ppm P as KH_2PO_4, and 100 ppm K as KCl, K_2SO_4, or KH_2PO_4 were added to all pots. These nutrients were added in liquid form and banded approximately one-half inch below the seed. The seed was placed approximately one-half inch below the surface of the soil. Eight wheat or sixteen flax seeds were sown per pot. The soil was watered to field capacity with deionized water. The soils were kept at about field capacity by watering with deionized water when required. After emergence, the wheat plants were thinned to four plants per pot and the flax to eight plants per pot. The plants were grown for six weeks in the greenhouse, harvested, washed, dried, weighed, and analyzed for copper, zinc, iron, and manganese.

(i) <u>The relationships between yield, copper and zinc content of flax and wheat and soil properties.</u>

Flax and wheat grown on the calcareous soils produced less dry matter than the plants grown on the non-calcareous soils (Table III). Yields were not influenced by soil texture or organic matter content.

Flax and wheat grown on the calcareous soils contained less zinc than the plants grown on the non-calcareous soils (Table IV). The copper content of flax grown on the calcareous soils was generally higher than when grown on the non-calcareous soils. The calcium carbonate content of the soils did not noticably affect the copper content of wheat. Except for wheat grown on the Berlo soil, flax and wheat grown on the fine textured soils had a higher copper content than the plants grown on the coarse textured soils. Flax and wheat plants grown on the coarse textured soils appeared to have higher zinc contents than the plants grown on the fine textured

Table III

Yield of Flax and Wheat (g/pot)*

Soil	Flax	Wheat
Tarno	2.17	2.67
Lakeland	1.82	3.00
Balmoral	1.68	2.16
Plum Ridge	1.80	2.39
Almasippi I	1.56	2.06
Almasippi 2	1.19	2.32
Berlo	1.86	2.66
Red River	3.61	3.65
Newdale	2.15	3.13
Wellwood	2.40	3.20
Altona	2.32	3.04
Stockton I	1.91	3.42
Stockton 2	2.42	2.95
Pine Ridge	2.46	3.76

*Yields are averages of three replicates

Table IV

Copper and Zinc Contents of Flax and Wheat (ppm)

Soil	Flax		Wheat	
	Copper	Zinc	Copper	Zinc
Tarno	11.3	13.3	9.7	11.7
Lakeland	9.7	13.3	9.3	13.3
Balmoral	9.7	-	9.0	23.3
Plum Ridge	7.3	12.8	9.5	15.0
Almasippi I	6.0	15.0	-	19.3
Almasippi 2	6.3	-	8.0	20.0
Berlo	5.7	12.5	17.3	10.0
Red River	8.7	22.5	11.0	21.7
Newdale	7.7	25.0	9.0	22.5
Wellwood	-*	37.5	8.7	25.0
Altona	6.3	41.7	-	28.3
Stockton I	4.5	32.5	-	31.7
Stockton 2	5.3	35.8	9.5	31.0
Pine Ridge	4.5	32.5	5.3	23.3

* Samples appeared to be contaminated as values obtained were several fold greater than those reported above.

soils.

(ii) Relationships between copper and zinc content of flax and wheat, and soil pH, carbonate content, and organic matter.

The relationship between each of the dependent variables and each of the independent variables was calculated. The copper and zinc content of flax and wheat were used as the dependent variables and soil pH, carbonate content, and organic matter content were used as the independent variables for this experiment.

Copper content of flax was found to be significantly related to soil pH and carbonate content (Table V). The equations relating flax copper content to soil pH and carbonate content show that the copper content of flax increased with increases in soil pH and carbonate content (Appendix 2A). Wheat copper content was not significantly related to soil pH or carbonate content.

The copper content of flax increased with increases in the amount of organic matter in the soil (Table V and Appendix 2A). Other workers have found copper content of plants to decrease with increasing soil organic matter content (33, 67). However, the negative correlation between copper content of plants and soil organic matter content may not hold at the low organic matter contents (1.4 to 8.4) encountered in this study (39). The copper content of wheat was not significantly related to soil organic matter content. Although the rela-

Table V

Coefficients of Determination (r^2) for Relationships Between Copper and Zinc Content of Flax and Wheat and Soil pH, Carbonate,and Organic Matter Content

	pH	Carbonate Content	Organic Matter Content
Flax - Copper	0.516^{x}	0.545^{x}	0.776^{xx}
Wheat - Copper	0.245	0.191	0.484
Flax - Zinc	0.520^{x}	0.362	0.240
Wheat - Zinc	0.577^{xx}	0.514^{x}	0.550^{x}

xx Significant at 1% level of probability

x Significant at 5% level of probability tionship was not significant the equation for the relationship indicated that the copper content of wheat decreased with increases in soil organic matter content.

The zinc content of flax and wheat was found to significantly decrease with increases in soil pH (Table V and Appendix 2A). This is in agreement with the findings of other workers (102, 113). The zinc content of wheat was significantly related to soil carbonate content. The zinc content of flax was not significantly related to soil carbonate content. However, the equations relating plant zinc content to soil carbonate content showed that the zinc content of both flax and wheat decreased with increases in soil carbonate content. These findings are in agreement with those published by other workers (14, 83, 120).

The zinc content of flax was not significantly related to the organic matter content of the soil. A significant relationship was obtained for wheat; zinc content of wheat decreased with increases in soil organic matter content.

In several instances noted above, the relationships obtained between soil properties and plant content of copper and/or zinc depended upon the crop grown. This would indicate that flax and wheat may differ in their abilities to utilize native soil copper and/or zinc. Thus, results of studies using one crop to evaluate native soil copper or zinc availability may not be applicable to other crops.

2. Available Soil Copper and Zinc as Measured by Chemical Extractants

Fourteen extractants were used to assess the plant available copper and zinc content of 14 Manitoba soils. The suitability of each extractant was evaluated using the following criteria:

1. ability to extract copper and/or zinc in amounts that could be accurately measured using an atomic absorption spectrophotometer.
2. ability to extract copper and/or zinc from soils in amounts that would reflect the copper and zinc content and uptake by plants.

(i) Extractants which did not extract copper and/or zinc in amounts that could be accurately measured or interferred with the determination of copper and/or zinc via atomic absorption spectrophotometry.

NH_4NO_3 (1.0 N) did not extract measurable amounts of copper and zinc. Thus, a separation of the soils based on their NH_4NO_3 extractable copper or zinc content could not be conducted. A solution consisting of H_2SO_4 (0.01 N) and KCl (1.0 N) also proved to be a poor extractant for copper and zinc. Background interference from the extractant was high and measurement of the concentrations of copper and/or zinc in the extracts meaningless. The extractant, 0.01 M in Na_2DP, 1.0 M in NH_4OAc, adjusted to pH=7.0, contained sufficient quantities of zinc as impurities to make measurements meaningless. The contamination of the extractant appeared to be due to high levels of zinc in the Na_2DP used in the extractant.

(ii) Extractants which extracted measurable quantities of copper and/or zinc.

All extractants except those mentioned previously extracted adequate amounts of copper and/or zinc to allow separation of soils on the basis of extractable copper and/or zinc content. In nearly all cases, only a small portion of the zinc or copper extracted by a mixture of concentrated HNO_3 and 70% $HClO_4$ was extracted by the other solutions. Amounts of copper extracted by the various extractants decreased in the order: 0.67 M $(NH_4)_2CO_3$ + 0.01 M Na_2EDTA (1:2) $>$ 1% Na_2EDTA $>$ 0.01 M Na_2DP + 1.0 N NH_4OAc $>$ 0.67 M $(NH_4)_2CO_3$ + 0.01 M Na_2EDTA (1:10) $>$ 1.0 M $(NH_4)_2CO_3$ + 0.01 M Na_2EDTA $>$ 2% Na_2EDTA + 1.0 N NH_4OAc $>$ 0.005 M DPTA + 0.01 M $CaCl_2$ + 0.1 M TEA $>$ 0.1 N HCl (Table VI). Amounts of zinc extracted from the soils by various extractants decreased in the order: 0.1 N HCl $>$ 1% Na_2EDTA $>$ 0.67 M $(NH_4)_2CO_3$ + 0.01 M Na_2EDTA (1:2) $>$ 1.0 M $(NH_4)_2CO_3$ + 0.01 M Na_2EDTA $>$ 0.67 M $(NH_4)_2CO_3$ + 0.01 M Na_2EDTA (1:10) $>$ 2% Na_2EDTA + 1.0 N NH_4OAc $>$ 0.005 M DPTA + 0.01 M $CaCl_2$ + 0.1 M TEA (Table VII).

The concentrated acid extractable copper content of the soils varied with soil texture. The fine textured soils contained larger amounts of copper than the coarse textured soils

(Table VI). Copper extracted by other reagents was also related to soil texture; fine textured soils contained more extractable copper than coarse textured soils. The calcareous soils contained larger amounts of extractable copper than the non-calcareous soils.

The concentrated acid extractable zinc content of the soils varied with soil texture. The fine textured soils contained more zinc than the coarse textured soils (Table VII). Zinc extracted by other reagents was affected more by the carbonate content of the soil than by soil texture. Calcareous soils generally contained less extractable or plant available zinc than non-calcareous soils.

(iii) Relationships between amounts of copper and zinc extracted from soils and copper and zinc in plants.

Three types of equations: linear, logarithimic, and quadratic, were tested to determine which equation would best describe the relationships between the copper and zinc content of wheat and flax, and the copper and zinc extracted from the soils. A quadratic equation of the form, $Y = a_0 + a_1x_1 + a_2x_1^2$, gave the highest r^2 values for the above relationships. Therefore, only that data obtained using the quadratic equation is presented (Table VIII and Appendicies 3A - 10A).

The relationships between extractable copper and the copper uptake or content of wheat were not found to be significant at the 5% level (Table VIII).

Table VI. Extractable Copper Content of 14 Manitoba Soils (ppm).

Soil	Conc. HNO_3 +70% $HClO_4$	o.1 N HCl	1% Na_2EDTA	2% Na_2EDTA+ 1.0 N NH_4OAc at pH=7.0	0.01M Na_2DP +1.0 M NH_4OAc at pH=7.0	1.0M $(NH_4)_2CO_3$ +0.01M Na_2EDTA at pH=8.8	0.67M $(NH_4)_2CO_3$ +0.01M Na_2EDTA at pH=		0.005M DPTA+0.01M $CaCl_2$+0.1M TEA at			
							8.65 1:2	8.65 1:10	pH=7.0	pH=7.5	pH=8.0	pH=8.5
Tarno	27.3	0.3	3.4	1.7	5.0	2.3	2.5	4.6	1.8	1.8	1.7	1.6
Lakeland	15.0	0.3	1.8	1.3	3.1	2.2	2.6	4.2	1.0	1.0	1.0	0.9
Balmoral	13.5	0.3	1.2	1.2	2.5	2.1	2.4	3.6	1.1	1.0	1.1	0.9
Plum Ridge	6.3	0.3	1.1	0.8	1.7	1.6	1.7	2.6	0.7	0.7	0.7	0.5
Almasippi 1	6.3	0.3	1.5	0.5	0.7	0.9	0.9	1.4	0.4	0.3	0.3	0.3
Almassippi 2	3.9	0.4	1.7	0.6	0.9	1.0	1.0	1.8	0.4	0.4	0.4	0.3
Berlo	5.8	0.3	1.3	0.6	0.7	0.8	0.9	1.4	0.4	0.4	0.4	0.3
Red River	29.5	1.2	11.5	3.3	7.0	5.6	5.5	8.4	2.6	2.6	2.7	2.4
Newdale	18.8	0.6	4.4	2.3	2.5	1.8	2.0	2.9	1.0	0.9	1.0	0.8
Wellwood	18.8	0.9	3.3	1.4	2.3	2.0	3.8	2.0	1.0	1.0	1.1	1.0
Altona	12.8	0.9	5.0	1.6	2.4	1.9	2.2	4.1	1.2	1.4	1.4	1.2
Stockton 1	11.0	0.6	1.9	1.0	1.3	1.4	1.3	3.3	0.7	0.7	0.7	0.6
Stockton 2	5.5	0.4	0.8	0.6	0.4	0.8	0.7	1.3	0.3	0.3	0.3	0.2
Pine Ridge	3.0	0.3	0.6	0.4	0.1	0.4	0.3	0.8	0.2	0.2	0.3	0.2

Table VII. Extractable Zinc Content of 14 Manitoba Soils (ppm).

Soil	Conc. HNO_3 +70% $HClO_4$	0.1 N HCl	1% Na_2EDTA	2% Na_2EDTA+ 1.0 N NH_4OAc at pH=7.0	1.0M $(NH_4)_2CO_3$ +0.01M Na_2EDTA at pH=8.8	0.67M $(NH_4)_2CO_3$ +0.01M Na_2EDTA at pH =		0.005M DPTA+0.01M $CaCl_2$+0.1M TEA at			
						8.65 1:2	8.65 1:10	pH=7.0	pH=7.5	pH=8.0	pH=8.5
Tarno	73.0	1.3	3.0	1.3	1.3	1.6	1.5	1.1	1.1	0.9	0.8
Lakeland	58.5	1.9	1.4	1.9	2.1	1.1	1.8	1.0	1.1	0.9	0.9
Balmoral	44.0	1.0	2.0	1.0	0.6	1.1	1.0	0.7	0.7	1.3	0.6
Plum Ridge	31.5	0.3	1.9	0.7	0.6	0.8	1.2	1.0	0.9	0.8	0.6
Almasippi 1	33.0	4.2	2.6	3.6	2.2	2.3	2.0	1.5	1.3	1.3	1.2
Almasippi 2	40.0	4.0	3.7	1.9	2.5	2.4	2.2	1.7	1.4	1.3	1.1
Berlo	18.5	0.3	1.0	0.7	0.8	2.0	1.0	0.6	0.7	0.6	0.5
Red River	83.0	3.8	3.6	2.1	2.4	2.8	1.9	1.5	1.5	1.8	1.4
Newdale	73.0	7.1	5.4	3.8	4.0	4.2	4.3	2.7	2.7	2.5	2.5
Wellwood	83.0	6.4	4.8	3.5	4.1	1.1	4.5	3.6	4.1	3.2	3.2
Altona	50.1	5.4	5.2	3.5	4.0	3.4	4.2	3.1	3.3	2.5	2.6
Stockton 1	53.5	8.6	5.4	3.5	4.4	4.3	4.8	3.3	3.3	3.0	3.0
Stockton 2	42.0	6.9	3.7	3.2	4.4	4.3	5.2	2.8	3.1	3.3	2.3
Pine Ridge	9.5	1.4	1.3	1.0	1.3	0.9	1.1	1.2	0.8	1.5	0.8

Table VIII. Coefficients of Determination (r^2) for the Relationships Between Copper and Zinc Extracted From Soil by Chemical Extractants and the Copper and Zinc Content of and Uptake by Flax and Wheat.

	Conc. HNO_3 +70% $HClO_4$	0.1 N HCl	1% Na_2EDTA	2% Na_2EDTA+ 1.0 N NH_4OAc at pH=7.0	0.01M Na_2DP +1.0M NH_4OAc at pH=7.0	1.0M $(NH_4)_2CO_3$ +0.01M Na_2EDTA at pH=8.8	0.67M $(NH_4)_2CO_3$ +0.01M Na_2EDTA at pH =		0.005M DPTA+0.01M $CaCl_2$+0.1M TEA at			
							8.65 1:2	8.65 1:10	pH=7.0	pH=7.5	pH=8.0	pH=8.5
Copper												
Flax (Content)	0.58^{x}	0.18	0.15	0.45^{x}	0.75^{xx}	0.66^{xx}	0.69^{xx}	0.52^{x}	0.69^{xx}	0.66^{xx}	0.64^{xx}	0.63^{xx}
Wheat (Content)	0.01	0.03	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02
Flax (Uptake)	0.87^{xx}	0.59^{x}	0.66^{xx}	0.78^{xx}	0.93^{xx}	0.83^{xx}	0.85^{xx}	0.82^{xx}	0.91^{xx}	0.91^{xx}	0.91^{xx}	0.90^{xx}
Wheat (Uptake)	0.13	0.22	0.24	0.22	0.20	0.25	0.21	0.22	0.20	0.20	0.22	0.23
Zinc												
Flax (Content)	0.03	0.28	0.16	0.63^{x}		0.71^{xx}	0.30	0.35	0.78^{xx}	0.76^{xx}	0.84^{xx}	0.75^{xx}
Wheat (Content)	0.05	0.64^{xx}	0.45^{x}	0.42^{x}		0.63^{xx}	0.47^{x}	0.61^{xx}	0.61^{xx}	0.55^{x}	0.84^{xx}	0.60^{xx}
Flax (Uptake)	0.12	0.57^{x}	0.34	0.43		0.49^{x}	0.15	0.44	0.55^{x}	0.55^{x}	0.60^{x}	0.59^{x}
Wheat (Uptake)	0.03	0.58^{xx}	0.42^{x}	0.34		0.58^{xx}	0.44^{x}	0.55^{x}	0.64^{xx}	0.55^{x}	0.77^{xx}	0.60^{xx}

x Significant at 5% probability level

xx Significant at 1% probability level

The copper content of flax was best reflected by the amounts of copper extracted from the soil using Na_2DP. The copper content of flax was significantly related to amounts of copper extracted by all extractants except 1% Na_2EDTA and 0.1 N HCl. The r^2 values for signicant relationships decreased in the order: Na_2DP, DPTA at pH = 7.0, 0.67 M $(NH_4)_2CO_3$ + 0.01 M Na_2EDTA at pH = 8.65 (1:2), 1.0 M $(NH_4)_2CO_3$ + 0.01 M Na_2EDTA at pH = 8.8, DPTA at pH = 8.0, DPTA at pH = 8.5, Conc. HNO_3 + 70% $HClO_4$, 0.67 M$(NH_4)_2CO_3$+ 0.01 M EDTA at pH = 8.65 (1:10), 2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0.

In general the r^2 values obtained for the relationships between soil available copper and copper uptake by flax were high. The best relationship between extractable copper and copper uptake by flax was found when Na_2DP was used as an extractant. The r^2 values obtained for the various extractants decreased as follows: Na_2DP, DPTA at pH = 7.0, DPTA at pH =7.5, DPTA at pH = 8.0, DPTA at pH = 8.5, Conc. HNO_3 + 70% $HClO_4$, 0.67 M $(NH_4)_2CO_3$ + 0.01 M Na_2EDTA at pH = 8.65 (1:2), 1.0 M $(NH_4)_2CO_3$ + 0.01 M Na_2EDTA at pH = 8.8, 0.67 M $(NH_4)_2CO_3$ + 0.01 M Na_2EDTA at pH = 8.65 (1:10), 2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0, 1% Na_2EDTA, 0.1 N HCl.

The zinc content of flax and wheat was best reflected by the amounts of zinc extracted by a solution consisting of DPTA, $CaCl_2$, and TEA adjusted to pH=8.0 (Table VIII). The zinc content of the plants was also significantly related to amounts of zinc extracted by several other extractants. The r^2 values obtained for the above relationships, considering both crops, decreased in the order: DPTA at pH = 8.0, DPTA at pH = 7.0, DPTA at pH = 8.5, 1.0 M $(NH_4)_2CO_3$ + 0.01 M Na_2EDTA at pH = 8.8, DPTA at pH = 7.5, 2% Na_2EDTA + 1.0 NH_4OAc at pH = 7.0. The relationships between the zinc content of plants and extractable zinc using: conc. HNO_3 + 70% $HClO_4$, 0.1 N HCl, 1% Na_2EDTA, 0.67 M $(NH_4)_2CO_3$ + 0.01 M Na_2EDTA at pH = 8.65 (1:2), and 0.67 M $(NH_4)_2CO_3$ + 0.01 M Na_2EDTA at pH = 8.65 (1:10) as extractants had r^2 values which were low and not significant for either one or both crops.

In general, the r^2 values obtained for the relationships between extractable zinc and the zinc uptake by flax and wheat were lower than those found for the relationships between soil available zinc and the zinc content of flax and wheat. This may be due to deficiencies of other elements or other soil factors which reduced growth of the plant while not affecting the zinc content of the plant. As was found for plant zinc content, zinc uptake by the plants was more closely related to zinc extracted by a solution of DPTA, $CaCl_2$, and TEA adjusted to pH = 8.0 than to zinc extracted by other reagents. The r^2 values obtained for the significant relationships between zinc uptake and extractable zinc, considering both crops, decreased in the order: DPTA at pH = 8.0, DPTA at pH = 8.5, 0.1 N HCl, DPTA at pH = 7.5. Zinc extracted by other extractants such as: conc. HNO_3 + 70% $HClO_4$, 1% Na_2EDTA, 2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0, 0.67 $M(NH_4)_2CO_3$+ 0.01 M Na_2EDTA at pH = 8.65 (1:2), and 0.67 M $(NH_4)_2CO_3$ +0.01 M Na_2EDTA at pH = 8.65 (1:10) were not significantly related to the zinc uptake of flax and wheat.

The results of this study indicate that a solution of DPTA, $CaCl_2$, and TEA at pH = 8.0 would be the best extractant for measuring available zinc in Manitoba soils for both flax and wheat. The results also indicate that for both flax and wheat extractable soil zinc was more closely related to the zinc content than to zinc uptake. A solution of Na_2DP and NH_4OAc adjusted to pH = 7.0 was found to be the most useful extractant in assessing soil available copper for flax. A solution of DPTA, $CaCl_2$, and TEA at pH = 7.0 would also be a good extractant for measuring available copper in Manitoba soils. The results indicate that extractable soil copper was more closely related to the copper uptake than to the copper content of flax. None of the extractants proved useful in assessing the availability of soil copper for wheat.

(iv) The use of multiple regression analysis to predict the amounts of copper and zinc in flax and wheat.

Several workers (26, 62, 63) have found that soil properties such as pH and organic matter content when included along with extractable copper and zinc, aid in predicting the plant uptake and content of copper and zinc. Thus, the relationships between plant uptake and content of copper and zinc, and soil extractable copper and zinc, soil pH, and organic matter content were calculated (Appendicies 19A-26A). The two multiple regression equations used were:

(1) $Y=a_o + a_1x_1 + a_2x_1^2 + a_3x_2 + a_4x_2^2 + a_5x_1x_2$

(2) $Y=a_o + a_1x_1 + a_2x_1^2 + a_3x_2 + a_4x_2^2 + a_5x_3 + a_6x_3^2$

where Y = the content or uptake of copper or zinc for flax or wheat, x_1 = soil extractable copper or zinc, x_2 = soil pH, and x_3 = soil organic matter content. Tables IX to XII show the R^2 values obtained for the relationships between zinc and copper uptake and content for flax and wheat, and extractable copper and zinc in combination with the above mentioned soil properties. By comparing the above R^2 values with the r^2 values obtained using only extractable soil copper and zinc (Table VIII), a judgment can be made regarding the use of soil properties in combination with extractable copper and zinc as a criterion for assessing soil copper and zinc availability.

The R^2 values obtained for the relationships between the copper content of flax, and soil extractable copper and pH were highly significant (Table IX). The R^2 values for the relationships between copper content of flax and soil extractable copper, pH, and organic matter content were also highly significant. The R^2 values obtained with soil properties and extractable copper as independent variables were considerably higher than those obtained when only extractable copper was used as an independent variable (Table VIII). The R^2 values obtained using both soil properties (pH and organic matter content) along with available copper as independent variables

Table IX

Coefficients of Determination (R^2) for Multiple Regression Analysis Between Soil pH, Organic Matter Content, and Extractable Copper and the Copper Content of Flax and Wheat.

Extractant	Flax		Wheat	
	pH and extractable copper (equation 1)	pH, organic matter and extractable copper (equation 2)	pH and extractable copper (equation 1)	pH, organic matter and extractable copper (equation 2)
Conc. HNO_3 + 70% $HClO_4$	0.98^{xx}	0.97^{xx}	0.40	0.87
0.1 N HCl	0.64	0.97^{xx}	0.21	0.88
1% Na_2EDTA	0.85^{xx}	0.96^{xx}	0.33	0.74
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	0.98^{xx}	0.96^{xx}	0.36	0.91^{x}
0.01 M Na_2DP + 1.0 N NH_4OAc at pH = 7.0	0.98^{xx}	0.96^{xx}	0.39	0.87
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	0.95^{xx}	0.96^{xx}	0.48	0.88
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:2)	0.94^{xx}	0.96^{xx}	0.45	0.92^{x}
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	0.96^{xx}	0.97^{xx}	0.43	0.87
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	0.98^{xx}	0.97^{xx}	0.40	0.87
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	0.97^{xx}	0.96^{xx}	0.37	0.87
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	0.97^{xx}	0.97^{xx}	0.38	0.90
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	0.98^{xx}	0.97^{xx}	0.39	0.87

x Significant at 5% level of probability

xx Significant at 1% level of probability

were usually not higher than those obtained when soil pH and available copper were used as independent variables. For the majority of extractants, an equation including soil pH and soil extractable copper as independent variables would be the best equation to use to predict the copper content of flax plants. However, when 0.1 N HCl and 1% Na_2EDTA were used as extractants, the copper content of flax was best predicted when available soil copper, soil pH, and soil organic matter were used as independent variables.

The copper content of wheat was not significantly correlated with extractable soil copper (Table VIII). Significant R^2 values were obtained only when 2% Na_2EDTA + 1.0 N NH_4OAc and 0.01 M Na_2EDTA + 0.67 M $(NH_4)_2CO_3$ at pH = 8.65 (1:2) were used as extractants and both pH and organic matter included as independent variables (Table IX). Since little or no correlation existed between extractable soil copper and copper content of wheat, it is not surprising that the inclusion of soil pH and organic matter content as independent variables did not result in significant R^2 values.

The relationships between copper uptake by flax, and soil extractable copper and pH were highly significant except when 0.1 N HCl was used as an extractant (Table X). The relationships between copper uptake by flax and soil extractable copper, soil pH, and soil organic matter content were all highly significant. Generally, it was found that soil pH when combined with available soil copper best predicted the copper uptake of flax

Table X

Coefficients of Determination (R^2) for Multiple Regression Analysis Between Soil pH, Organic Matter Content, and Extractable Copper and Copper Uptake for Flax and Wheat.

	Flax		Wheat	
Extractant	pH and extractable copper (equation 1)	pH, organic matter and extractable copper (equation 2)	pH and extractable copper (equation 1)	pH, organic matter and extractable copper (equation 2)
Conc. HNO_3 + 70% $HClO_4$	0.88^{xx}	0.89^{x}	0.41	0.72
0.1 N HCl	0.69	0.91^{xx}	0.42	0.89
1% Na_2EDTA	0.85^{xx}	0.92^{xx}	0.35	0.76
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	0.96^{xx}	0.91^{xx}	0.34	0.90^{x}
0.01 M Na_2DP + 1.0 N NH_4OAc at pH = 7.0	0.96^{xx}	0.94^{xx}	0.40	0.82
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	0.95^{xx}	0.92^{xx}	0.44	0.90^{x}
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:2)	0.94^{xx}	0.92^{xx}	0.42	0.91^{x}
0.67M $(NH_4)_2CO_3$+0.01 Na_2EDTA at pH = 8.65 (1:10)	0.96^{xx}	0.91^{xx}	0.41	0.85
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	0.96^{xx}	0.94^{xx}	0.42	0.78
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	0.96^{xx}	0.93^{xx}	0.39	0.79
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	0.97^{xx}	0.94^{xx}	0.39	0.82
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	0.95^{xx}	0.90^{xx}	0.41	0.78

x Significant at the 5% probability level.

xx Significant at the 1% probability level.

plants. The R^2 values obtained when the above independent variables were used were 5 to 10% higher than those obtained when only soil available copper was used (Table VIII). The R^2 values, obtained when soil available copper, soil pH, and soil organic matter content were used to predict the copper uptake of flax plants, were lower than those obtained when soil available copper and soil pH were used to predict the copper uptake by flax except when: concentrated HNO_3 + 70% $HClO_4$, 0.1 N HCl, and 1% Na_2EDTA, were used as extractants.

Copper uptake by wheat was not significantly correlated with extractable soil copper (Table VIII) or extractable soil copper and soil properties (Table X). Significant R^2 values were obtained only when 2% Na_2EDTA + 1.0 N NH_4OAc, 0.01 M Na_2EDTA + 1.0 M $(NH_4)_2CO_3$ and 0.01 M Na_2EDTA + 0.67 M $(NH_4)_2CO_3$ at pH = 8.65 (1:2) were used as extractants and both soil pH and organic matter content included as independent variables. Since little or no correlation existed between extractable copper and copper uptake by wheat, it is not surprising that the inclusion of soil pH and organic matter content as independent variables greatly increased the R^2 values but did not result in significant R^2 values.

The relationships between zinc content of flax and extractable soil zinc plus soil pH were usually significant. The relationships between zinc content of flax and extractable soil zinc, soil pH, and soil organic matter were usually significant at the 5% level (Table XI). Generally, it was found

Table XI

Coefficients of Determination (R^2) for Multiple Regression Analysis Between Soil pH, Organic Matter Content, and Extractable Zinc and the Zinc Content of Flax and Wheat.

Extractant	Flax		Wheat	
	pH and extractable zinc (equation 1)	pH, organic matter and extractable zinc (equation 2)	pH and extractable zinc (equation 1)	pH, organic matter and extractable zinc (equation 2)
Conc. HNO_3 + 70% $HClO_4$	0.89^{xx}	0.90^{x}	0.79^{x}	0.86^{x}
0.1 N HCl	0.81^{x}	0.55	0.70^{x}	0.81^{x}
1% Na_2EDTA	0.73	0.60	0.69	0.80^{x}
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	0.88^{x}	0.87^{x}	0.66	0.78^{x}
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	0.87^{x}	0.89^{x}	0.70^{x}	0.82^{x}
0.67M $(NH_4)_2CO_3$+0.01M NaEDTA at pH = 8.65 (1:2)	0.86^{x}	0.84	0.71^{x}	0.84^{x}
0.67M $(NH_4)_2CO_3$+0.01M NaEDTA at pH = 8.65 (1:10)	0.59	0.55	0.69	0.88^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	0.91^{xx}	0.90^{x}	0.67	0.78^{x}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	0.93^{xx}	0.91^{x}	0.67	0.80^{x}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	0.88^{xx}	0.91^{x}	0.88^{xx}	0.93^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	0.88^{x}	0.88^{x}	0.71^{x}	0.81^{x}

x Significant at the 5% probability level.

xx Significant at the 1% probability level.

that soil pH when combined with extractable zinc best predicted the zinc content of flax plants. The R^2 values obtained when this combination was used were significantly larger than those obtained when only soil available zinc was used (Table VIII). The R^2 values obtained when soil available zinc, soil pH and soil organic matter content were used to predict the zinc content of flax were generally lower than the R^2 values obtained when soil available zinc and soil pH were used. Soil available zinc as measured by the use of 1% Na_2EDTA or 0.01 M Na_2EDTA + 0.67 M $(NH_4)_2CO_3$ at pH = 8.65 (1:10) combined with soil pH in a regression equation was not found to be significantly correlated with the zinc content of flax.

The relationships between zinc content of wheat and extractable soil zinc, pH, and organic matter content were found to be significant at the 5% level of probability (Table XI). A greater percentage of the variability in the zinc content of wheat was accounted for by the use of all three independent variables than when only extractable soil zinc was used as an independent variable (Table VIII). However, it should be noted that the r^2 value obtained when DPTA (pH = 8.0) extractable zinc was related to the zinc content of wheat, was higher than the R^2 values obtained when soil pH, organic matter content, and extractants other than concentracted NHO_3 +

70% $HClO_4$, 0.67 M $(NH_4)_2CO_3$ + 0.01 M Na_2EDTA (1:10) and 0.005 M DPTA + 0.01 M $CaCl_2$ + 0.1 M TEA at pH = 8.0 were used to predict the zinc content of wheat. The use of all three independent variables accounted for approximately 10% more of the variation in wheat zinc content than did the use of only soil pH and extractable zinc.

The relationships between zinc uptake by flax and soil extractable zinc and pH were significant only when concentrated HNO_3 + 70% $HClO_4$, 0.1 N HCl, 1% Na_2EDTA, 0.01 M Na_2EDTA + 0.67 M $(NH_4)_2CO_3$ at pH = 8.65 (1:2) and 0.005 M DPTA + 0.01 M $CaCl_2$ + 0.1 M TEA at pH=7.5 were used as extractants (Table XII). The relationships between zinc uptake by flax and all three independent variables were not significant. The significant R^2 values obtained when soil pH and extractable zinc were used to predict the zinc uptake by flax were considerably larger than the significant r^2 values obtained when only extractable soil zinc was used to predict the uptake of zinc by wheat. Therefore, an equation using soil pH and extractable soil zinc as independent variables was found to best predict the zinc uptake by flax.

The relationships between zinc uptake by wheat and soil pH and extractable zinc were found to be highly significant (Table XII). The relationships between zinc uptake by wheat and soil extractable zinc, pH,and organic matter content were all significant. The R^2 values obtained when all three factors

Table XII

Coefficients of Determination (R^2) for Multiple Regression Analysis Between Soil pH, Organic Matter Content, and Extractable Zinc and the Zinc Uptake of Flax and Wheat.

	Flax		Wheat	
Extractant	pH and extractable zinc (equation 1)	pH, organic matter and extractable zinc (equation 2)	pH and extractable zinc (equation 1)	pH, organic matter and extractable zinc (equation 2)
Conc. HNO_3 + 70% $HClO_4$	0.79^{x}	0.79	0.79^{x}	0.92^{xx}
0.1 N HCl	0.83^{x}	0.80	0.81^{xx}	0.87^{x}
1% Na_2EDTA	0.79^{x}	0.81	0.80^{x}	0.86^{x}
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	0.78	0.79	0.81^{xx}	0.86^{x}
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	0.75	0.80	0.81^{xx}	0.87^{x}
0.67M $(NH_4)_2CO_3$+0.01M NaEDTA at pH = 8.65 (1:2)	0.85^{x}	0.82	0.88^{xx}	0.89^{x}
0.67M $(NH_4)_2CO_3$+ 0.01M Na_2EDTA at pH = 8.65 (1:10)	0.74	0.80	0.80^{x}	0.91^{xx}
0.005M DPTA+0.01M $CaCl_2$ +1M TEA at pH = 7.0	0.75	0.79	0.85^{xx}	0.87^{x}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	0.79^{x}	0.83	0.85^{xx}	0.88^{x}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH= 8.0	0.76	0.80	0.88^{xx}	0.89^{x}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	0.77	0.77	0.85^{xx}	0.87^{x}

x Significant at the 5% probability level.
xx Significant at the 1% probability level.

were used as independent variables were higher than those obtained when only soil extractable zinc and pH were used. Therefore, zinc uptake of wheat was best predicted by an equation using soil extractable zinc, pH, and organic matter content as independent variables.

The relationships between the copper and zinc uptake and content of flax and wheat, and soil extractable copper and zinc were improved when soil pH was added along with extractable soil copper or zinc as a second independent variable. The relationships were further improved in some cases, when soil organic matter content was added to soil pH and extractable copper or zinc as a third independent variable. However, as more independent variables were inserted into the relationship, the effect of extractable soil copper or zinc on the coefficients of determination decreased since the values for pH and organic matter content are constant for all soils. It is advantageous to obtain the highest R^2 values and yet use the lowest number of independent variables since the significance of the relationship decreases with increasing number of variables. Also, the use of several variables results in having to do several laboratory determinations. Considering the above disadvantages of using several variables, it may be best to use only soil extractable copper or zinc and soil pH as criteria for assessing plant available copper or zinc in soil, except in cases whereby addition of the third independent variable (organic matter content) produced significant and considerably larger R^2 values than were produced by a regression equation using soil pH and extractable copper or zinc.

B. Field Experiments

Small plot field experiments were initiated on three soils in southern Manitoba. The soils selected were the Pine Ridge, Almasippi, and Plum Ridge located near Zhoda, Graysville, and Teulon, respectively. These soils are described in soil reports numbers 5, 4, and 12 (28, 29, 91). These soils were selected for study because of the low copper and/or zinc content of flax and wheat grown on these soils in the greenhouse.

Noralta flax was used as a test crop and seeding was performed with a six-row double disc type seeder with seven inch spacing. Each treatment consisted of an area of 3.5 feet by 20 feet.

The experiment was designed as a split plot experiment with one set of plots treated with 15 lb P_2O_5 (11-55-0) drilled in with the seed. The other set of plots received no phosphate. All plots were treated with 100 lb of N/acre as 34-0-0.

A factorial experiment, using $Na_2ZnEDTA$ or $Na_2CuEDTA$ at rates of 0.0, 0.5, 1.0, 2.0, and 4.0 ppm Zn or Cu was conducted on each split plot. The copper and zinc fertilizers were drilled in with the seed. Each treatment was replicated four times.

Emergence of flax on all plots except the check (no copper or zinc fertilizer) was poor and no yield measurements were made. Germination and/or emergence of the crop was related to the amounts of $Na_2CuEDTA$ and $Na_2ZnEDTA$ added. Both $Na_2CuEDTA$ and $Na_2ZnEDTA$ reduced germination at the lowest rates applied and completely inhibited germination at high rates of application. Germination and/or emergence reductions appeared to be greatest on the sandy acidic soil (Pine Ridge) and lowest, but still substantial, on the calcareous soil (Plum Ridge).

It would, therefore, appear that EDTA or copper and zinc inhibit some processes essential to germination of flax seed. It is also possible that flax may be more subject to seed injury than other crops. Therefore, copper or zinc EDTA should not be drilled in with flax seed.

C. Greenhouse Experiment

A greenhouse experiment was conducted to determine:

1) the yield of flax with and without copper and zinc fertilizers on four Manitoba soils.

2) the copper and zinc content of plants and soils below which the plant may respond to applications of copper or zinc.

Four soils, Pine Ridge, Stockton I, Plum Ridge, and Almasippi I, which had previously been shown to have low amounts of available copper and/or zinc (Table IV) were selected for study. A factorial design with rates of 0.0, 0.5, 1.0 and 2.0 ppm of zinc as $Na_2ZnEDTA$ and 0.0, 0.5, and 1.0 ppm of copper as $Na_2CuEDTA$ was used on each soil. Each treatment was replicated three times. The soils were kept in blocks on the greenhouse bench; the replicates of each treatment were randomized within each block.

Two kilograms of soil were added to one-half gallon glazed porcelain pots. One hundred ppm N as NH_4NO_3, 40 ppm S as K_2SO_4, 40 ppm P as KH_2PO_4, and 200 ppm K as KCl, KH_2PO_4, or K_2SO_4 were added to each pot in a band one-half inch below the seed. The appropriate amounts of $Na_2CuEDTA$ and $Na_2CuEDTA$ were also banded one-half inch below the seed. Sixteen flax seeds were sown one-half inch below the surface of the soil and the soils brought to field capacity with deionized water. The plants were thinned to eight plants per pot after emergence. The soils were kept at approximate field capacity by adding deionized water when needed. The pots within each block were periodically rotated on the greenhouse bench to insure uniform lighting for each pot. The plants were grown for eight weeks, harvested, washed, dried, weighed, and analyzed for zinc, copper, iron, and manganese.

1. Yield

Yield of flax was significantly increased by the application of copper or copper plus zinc to the Pine Ridge soil except when 1.0 ppm copper plus 2.0 ppm zinc was added (Table XIII). An application of 0.5 ppm copper resulted in a yield

Table XIII

Effects of Added $Na_2CuEDTA$ and $Na_2ZnEDTA$ on the Yield of Flax (g/pot)[1]

Treatment		Soil			
ppm Cu	ppm Zn	Pine Ridge	Stockton I	Plum Ridge	Almasippi I
0.0	0.0	3.57 abcd[2]	5.45	3.19 abc	3.00 abcde
0.5	0.0	4.77 efgh	5.25	3.01 ab	2.97 abcd
1.0	0.0	4.90 efgh	5.67	2.96 a	2.90 ab
0.0	0.5	3.05 a	5.04	3.92 e	2.93 abc
0.5	0.5	4.46 def	5.11	3.59 bcde	3.22 bcde
1.0	0.5	5.14 efgh	5.69	3.82 e	3.24 bcde
0.0	1.0	3.42 abc	5.13	3.47 abcde	3.37 e.
0.5	1.0	4.69 efg	5.01	3.66 cde	3.13 abcde
1.0	1.0	5.65 h	5.62	3.72 cde	3.15 abcde
0.0	2.0	3.16 ab	5.01	3.68 cde	2.81 a
0.5	2.0	4.74 efgh	5.47	3.65 cde	3.24 bcde
1.0	2.0	4.45 de	5.48	3.20 abcd	3.09 abcde
			N.S.		

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[1] Yields are average of 3 replicates

[2] Duncan's Multiple Range Test. Values followed by the same letter are not significantly different at the 5% probability level.

almost as high as that obtained with 1.0 ppm copper when zinc was not applied. However, in several instances yields obtained when both copper and zinc were applied were greater than those obtained when only copper was applied. An application of 1.0 ppm copper plus 1.0 ppm zinc produced the highest yield. This indicates that added zinc may have increased the physiological effect of copper in the flax plant since the zinc content of the flax plants was adequate and no zinc deficiency should have been noted (Table XIV)(90). The yield data obtained on the Pine Ridge soil showed that this soil did not supply adequate quantities of copper for the growth of flax.

Yields of flax on the Stockton I soil were not significantly affected by the application of zinc or copper (Table XIII). However, copper applied at the 1.0 ppm level slightly increased the yield of flax at all levels of applied zinc. Zinc applied alone slightly depressed the yield of flax. These results indicate that the Stockton I soil may be just adequate to meet the copper requirement of flax.

Yields of flax decreased slightly when copper was applied without zinc to a Plum Ridge soil (Table XIII). Application of 0.5 ppm zinc without copper significantly increased the yield of flax above that of the check yield. Applications of 1.0 and 2.0 ppm zinc without copper increased flax yields above that of the check treatment but the yield increases were not significant. Applications of copper did not significantly affect yields. Since the application of 0.5 ppm zinc significantly increased yields, the Plum Ridge soil can be classed as zinc deficient.

Yields of flax on the Almasippi I soil were not significantly increased by the application of copper or zinc (Table XIII). Applied zinc without copper increased yield slightly when 1.0 ppm zinc was added but slightly decreased yields when 2.0 ppm zinc was added. Applied copper without zinc decreased yields slightly. From the data, it would appear that the Almasippi soil supplied adequate amounts of copper for the growth of flax. The supply of zinc in the soil appeared to be just adequate to meet the zinc requirements of flax.

It was established earlier that Na_2DP and DPTA (pH = 8.0) would be good extractants to use in assessing copper and zinc availability in soils (Table VIII). Since yields on the Pine Ridge soil were increased when copper was applied and the soil contained 0.1 ppm Na_2DP extractable copper; soils containing 0.1 ppm Na_2DP extractable copper could be classified as copper deficient. The Stockton soil contained just adequate copper to meet the copper requirements of flax. Soils containing less than 1.3 ppm Na_2DP extractable copper may be suspect of being copper deficient.

Yields of flax were increased by the application of zinc to the Plum Ridge soil, thus, soils with a DPTA (pH=8.0) extractable zinc content of 0.8 or lower could be classified as being zinc deficient. The Almasippi I soil may be considered to slightly zinc deficient. Thus, soils with DPTA (pH=8.0) extractable zinc contents of less than 1.3 ppm may be suspect of being zinc deficient.

2. Copper and Zinc Content of Plants

Applications of copper usually increased the copper content of flax plants (Table XIV). Application of copper to a soil usually reduced the amount of zinc utilized by flax. Applications of zinc usually increased the zinc content of flax. The copper content of flax was usually reduced when zinc was added to the soil.

Flax grown without added copper or zinc on the Pine Ridge soil contained 2.0 ppm copper (Table XIV) and responded significantly to the application of $Na_2CuEDTA$ (Table XIII). Flax plants grown on the Stockton I soil were found to respond very slightly to applications of $Na_2CuEDTA$ and contained 2.7 ppm copper when not fertilized with trace elements. From this data it can be postulated that eight week old flax plants with copper contents lower than about 3.0 ppm may be suspected of being copper deficient and flax plants with copper contents lower than 2.0 ppm would be copper deficient.

The yield of flax containing 8.7 ppm zinc (Table XIV) and grown on the Plum Ridge soil was increased significantly when $Na_2ZnEDTA$ was applied (Table XIII). Flax plants grown

Table XIV

Effect of Added Copper and Zinc on the Copper and Zinc Content of Flax.

Treatment		Pine Ridge		Stockton I		Almasippi I		Plum Ridge	
Cu ppm	Zn ppm	Cu (ppm)	Zn (ppm)	Cu (ppm)	Zn (ppm)	Cu (ppm)	Zn (ppm)	Cu (ppm)	Zn (ppm)
0.0	0.0	2.0	37.5	2.7	39.2	5.8	13.3	6.0	8.7
0.5	0.0	3.0	28.3	3.2	35.0	7.5	11.7	7.7	10.8
1.0	0.0	4.8	25.8	3.2	33.3	7.8	10.8	8.2	8.3
0.0	0.5	2.7	58.3	2.3	36.7	5.3	12.8	6.3	13.3
0.5	0.5	3.0	31.0	2.8	35.8	8.3	15.8	7.2	10.0
1.0	0.5	3.2	30.8	4.0	33.3	7.5	14.2	8.3	10.0
0.0	1.0	1.7	55.8	2.7	37.5	6.3	18.3	6.7	11.7
0.5	1.0	2.3	36.7	3.0	36.7	6.3	20.0	7.6	16.7
1.0	1.0	2.8	29.2	3.5	34.2	8.7	20.0	7.2	17.3
0.0	2.0	1.7	64.2	2.8	40.8	5.3	25.8	5.7	2.0
0.5	2.0	2.3	45.0	2.8	41.6	6.0	28.3	5.3	--
1.0	2.0	3.0	37.5	3.3	33.3	8.0	25.0	6.3	18.3

on the Almasippi I soil contained 13.3 ppm zinc and responded only very slightly to applied zinc. Therefore, eight week old flax plants with zinc contents less than about 13.3 ppm may be slightly zinc deficient and flax plants with zinc contents less than about 8.7 ppm would be zinc deficient.

D. Solubilities of Copper and Zinc Compounds in Two Manitoba Soils

$Na_2CuEDTA$ and $Na_2ZnEDTA$ inhibited the germination of flax in the field experiments. Also, the cost of chelated fertilizers is extremely high. Therefore, studies were initiated to determine the suitability of several zinc and copper compounds as fertilizers. The compounds were added to the soil and the concentrations of copper and zinc in the soil extracts measured at intervals over a six-week period. It was assumed that if the compound increased the concentrations of zinc or copper in the soil solution it would also increase the amount of zinc or copper available to plants and, thus, act as a fertilizer. Two soils, Stockton I (non-calcareous) and Plum Ridge (calcareous) were selected for study. These soils were selected because of their similar texture, cation exchange capacity, organic matter content, and differing pH and carbonate content (Table XV).

The copper and zinc compounds selected for study included soluble inorganic salts, chelated compounds, and sparingly soluble salts. $CuSO_4$, $ZnSO_4$, $Na_2CuEDTA$, $Na_2ZnEDTA$, CuO, CuS,

Table XV

Characteristics of the Plum Ridge and Stockton I Soils

	Sand %	Silt %	Clay %	CEC (Meq/100g)	pH	Organic Matter(%)	%CO_3	Field Capacity Moisture Content (%)
Plum Ridge	56.39	15.70	27.91	17.16	8.1	3.4	19.0	29
Stockton	66.43	15.03	18.53	17.50	6.2	4.7	0.0	22

$Cu_3(PO_4)_2 \cdot 3H_2O$, $Cu_2P_2O_7$, ZnO, ZnS, $ZnNH_4PO_4$, $Zn_3(PO_4)_2 \cdot 4H_2O$, and ZnP_2O_7 were selected for study.

It has been shown that copper and zinc EDTA are about five to ten times more available to plants than other inorganic sources of copper or zinc (35, 101, 131, 132). Calculations indicated that the concentration of copper or zinc in a fertilizer band would be approximately 40 ppm copper or zinc when applied at 4 lb/acre copper or zinc to crops grown with 7 inch spacing between rows. Therefore, Na_2CuEDTA and Na_2ZnEDTA were applied at a rate of 40 ppm copper or zinc. Since inorganic salts have been shown to be about 10 times less effective than chelates, the inorganic salts were applied at a rate of 400 ppm copper or zinc. The soluble forms of copper and zinc were applied to the soil as a solution. Ten grams of soil were treated and stored in a plastic incubation tube. The sparingly soluble salts were finely ground and mixed with 50 g of soil. The 50 g of soil plus the incorporated sparingly soluble salt were then mixed with 1950 g of soil resulting in a soil containing 400 ppm of copper or zinc. Ten gram portions of the above soil were then placed in the incubation tubes. The soils were incubated for 1.5, 3, 7, 14, 21, 31, and 42 days at 20° C and field capacity moisture content. The samples were then shaken for one hour with 50 ml deionized water, filtered, and the copper and zinc content of the soil extracts determined.

Soil treated with Na_2CuEDTA or Na_2Zn EDTA and incubated over a six week period, contained more water extractable copper or zinc than soils treated with the other copper and zinc compounds (Tables XVI and XVII). The calcareous Plum Ridge soil treated with Na_2Cu EDTA or $Na_2ZnEDTA$ contained two to three times more water extractable copper or zinc than the similarily treated Stockton I soil. This maybe due to a rapid replacement of copper and zinc by iron on the EDTA complex in the Stockton I soil (Appendix 28A) and a slow replacement of copper and zinc by calcium on the EDTA complex in the calcareous Plum Ridge soil (46, 80).

The amounts of water soluble copper extracted from the treated soils were larger than the amounts of water soluble copper extracted from the untreated soils (Table XVI). The amounts of water soluble copper extracted from Stockton I and Plum Ridge soils treated with $CuSO_4$, CuO, $Cu_2P_2O_7$, or CuS were all approximately equal and only slightly higher than for the untreated soil. Other workers (18, 66, 109) have found $CuSO_4$, CuO, and $Cu_2P_2O_7$ to be almost equal in their ability to supply copper plants.

Soils treated with copper phosphate were found to contain approximately 20 to 30 times more water extractable copper than the soils treated with copper sulphate. The calcareous Plum Ridge soil contained slightly less extractable copper than the acid Stockton I soil when treated with 400 ppm copper as $Cu_3(PO_4)_2 \cdot 3H_2O$. The Stockton I soil treated with 40 ppm copper as $Na_2CuEDTA$ and incubated for 1.5 days con-

Table XVI

Copper

Extracted from Soils Treated with Various Compounds and Incubated for Various Periods of Time (Values Expressed as ppm-Soil Basis).

Stockton

Treatment	Amount Applied (ppm Cu)	Incubation time (days) $1\frac{1}{2}$	3	7	14	21	31	42
Control	0	0.2	0.1	0.05	0.05	0.05	0.1	0.05
$Na_2CuEDTA$	40	31.0	22.8	11.0	9.8	3.5	2.3	4.5
$CuSO_4$	400	0.3	0.2	0.1	0.1	0.4	0.2	0.1
CuO	400	0.1	0.1	0.1	0.1	0.2	0.1	0.2
$Cu_3(PO_4)_2$	400	7.9	4.9	2.1	2.3	3.4	0.8	1.2
$Cu_2P_2O_7$	400	0.2	0.1	0.1	0.1	0.2	0.1	0.1
CuS	400	0.2	0.2	0.1	0.3	0.2	0.2	0.1

Plum Ridge

Treatment	Amount Applied (ppm Cu)	$1\frac{1}{2}$	3	7	14	21	31	42
Control	0	0.05	0.05	0.05	0.05	0.05	0.05	0.2
$Na_2CuEDTA$	40	22.3	16.0	12.5	10.0	10.3	9.5	8.5
$CuSO_4$	400	0.4	0.4	0.2	0.2	0.3	0.2	0.5
CuO	400	0.05	0.1	0.1	0.05	0.1	0.3	0.1
$Cu_3(PO_4)_2$	400	2.3	2.0	1.9	2.3	1.8	3.4	0.4
$Cu_2P_2O_7$	400	0.2	0.2	0.1	0.1	0.1	0.2	0.1
CuS	400	0.1	0.1	0.1	0.05	0.1	0.1	0.1

Table XVII

Zinc

Extracted from Soils Treated with Various Zinc Compounds and Incubated for Various Periods of Time (Values Expressed as ppm-Soil Basis).

		Stockton						
		Incubation time (days)						
Treatment	Amount Applied (ppm Zn)	$1\frac{1}{2}$	3	7	14	21	31	42
Control	0	0.4	0.4	0.2	0.2	0.3	0.1	0.2
$Na_2ZnEDTA$	40	32.5	26.7	15.8	7.8	6.5	5.8	5.8
$ZnSO_4$	400	1.4	0.4	0.3	0.3	0.4	0.2	0.4
ZnO	400	0.9	2.0	0.7	0.7	1.6	1.4	0.3
$ZnNH_4PO_4$	400	0.8	0.8	1.0	1.5	1.9	1.6	3.4
$Zn_3(PO_4)_2$	400	0.3	0.3	0.3	0.8	0.6	0.2	1.4
$Zn_2P_2O_7$	400	0.5	0.4	0.3	0.5	1.1	0.7	0.2
ZnS	400	10.3	11.6	3.8	9.6	4.1	4.4	1.1
		Plum Ridge						
Control	0	0.0	0.05	0.1	0.2	0.3	0.0	0.3
$Na_2ZnEDTA$	40	32.8	32.8	25.3	24.5	18.3	23	21.3
$ZnSO_4$	400	0.2	0.1	0.1	0.1	0.1	0.1	0.1
ZnO	400	0.7	0.9	0.6	0.3	0.5	0.8	0.6
$ZnNH_4PO_4$	400	0.2	0.3	0.3	0.2	0.4	0.3	0.4
$Zn_3(PO_4)_2$	400	0.2	0.2	0.1	0.2	0.3	.2	0.2
$Zn_2P_2O_7$	400	0.2	0.2	0.3	0.2	0.3	0.3	0.1
ZnS	400	5.6	7.5	1.9	1.5	5.5	0.5	4.1

tained about 100 times more water soluble copper than when treated with 400 ppm copper as $CuSO_4$. However, when the samples were incubated for 4.5 weeks, samples treated with $Na_2CuEDTA$ contained only about 20 times more water extractable copper than samples treated with 400 ppm copper as $CuSO_4$. The calcareous Plum Ridge soil treated with 40 ppm copper as $Na_2CuEDTA$ contained approximately 40 times more water soluble copper than when treated with 400 ppm copper as $CuSO_4$. This appeared not to change with time of incubation.

It would appear that of the copper compounds studied other than $Na_2CuEDTA$, copper phosphate ($Cu_3(PO_4)_2 \cdot 3H_2O$) would make an excellent copper fertilizer. The amounts of copper supplied to the soil solution by the compound were relatively high and maintained throughout the duration of the experiment.

Lower concentrations of water extractable zinc were found in the calcareous soil than in the acid soil treated with an equal amount of inorganic zinc compound.

The concentrations of zinc extracted from both soils treated with any zinc compound were usually greater than those found for the untreated soils (Table XVII). The Plum Ridge soil , treated with $Zn_3(PO_4)_2 \cdot 4H_2O$, $ZnSO_4$, or $Zn_2P_2O_7$ contained about equal quantities of water extractable zinc.

ZnO and $ZnNH_4PO_4$ appear to be better zinc sources than $ZnSO_4$ when applied to the Stockton I soil. These two compounds were about twice as effective as $ZnSO_4$ in increasing the water soluble zinc content of the Stockton I soil. The Plum Ridge soil treated with ZnO also contained more water extractable zinc than when treated with $ZnSO_4$.

The Stockton I and Plum Ridge soils treated with ZnS contained approximately 20 fold more water extractable zinc than when the soils were treated with $ZnSO_4$. However, the Stockton I soil treated with 40 ppm zinc as $Na_2ZnEDTA$ contained approximately 5 fold more water extractable zinc than the same soil treated with 400 ppm zinc as ZnS throughout the incubation period. The calcareous Plum Ridge soil treated with 40 ppm zinc as $Na_2ZnEDTA$ contained about 15 times more extractable zinc than the same soil treated with 400 ppm ZnS.

Several of the inorganic zinc compounds in addition to $Na_2ZnEDTA$, would be useful as zinc fertilizers. ZnS would be a good zinc fertilizer as it increased the zinc concentrations in both soils;ZnO and $ZnNH_4PO_4$ also warrant attention as sources of zinc for plants.

V SUMMARY AND CONCLUSIONS

Some Manitoba soils have previously been shown to be copper and/or zinc deficient. Thus, methods of predicting deficiencies of copper and/or zinc in Manitoba soils were studied. Also, several copper and zinc compounds were evaluated as fertilizers and the amounts of copper and zinc required by flax studied.

A study was conducted using 14 soils in order to determine the effect of soil texture, pH, carbonate content, and organic matter content on the availability of soil copper and zinc to flax and wheat. The copper content of flax and wheat grown on fine textured soils was generally higher than the copper content of plants grown on coarse textured soils. The zinc content of flax and wheat grown on coarse textured soils was generally higher than the zinc content of plants grown on fine textured soils. The copper content of flax increased with increases in soil pH, carbonate content, and organic matter content. There were no significant relationships between the copper content of wheat and soil pH, carbonate content, or organic matter content. The zinc content of flax was negatively and significantly related to soil carbonate content or organic matter content. The zinc content of wheat was significantly and inversely related to soil pH, carbonate content, and organic matter content. The data indicated that wheat and flax may differ in their abilities to utilize native soil copper and zinc. Thus, results obtained using one crop would not be applicable to other crops.

DPTA at pH = 8.0 was found to be one of the best extractants to use to assess the zinc status of Manitoba soils. Eighty-four percent of variations in plant zinc content for both flax and wheat could be accounted for by variations in DPTA at pH = 8.0 extractable soil zinc. Zinc extracted by DPTA at pH = 8.0 was also closely related to plant zinc uptake of wheat and flax (r^2=0.77 and 0.60 respectively). None of the extractants studied were adequately related to the content or uptake of copper by wheat. Na_2DP was found to be the best extractant to use to assess the copper status of Manitoba soils when flax was grown. An r^2 value of 0.75 was obtained when Na_2DP extractable copper was related to the copper content of flax. An r^2 value of 0.93 was obtained when Na_2DP extractable copper was related to copper uptake by flax.

The relationships between the copper and zinc uptake and content of flax and wheat, and soil extractable copper and zinc were improved when soil pH was added along with extractable soil copper or zinc as a second independent variable. The relationships were further improved in some cases, when soil organic matter content was added to soil pH, and extractable copper or zinc as a third independent variable. There are several disadvantages to using several variables in multiple regression analysis. Therefore, it may be best to use only soil pH and extractable copper or zinc as independent variables except in cases whereby addition of organic matter content as a third independent variable produced significant and considerably larger R^2 values than were produced by a regression equation using soil pH and extractable copper or zinc as independent variables.

In field trials $Na_2CuEDTA$ and $Na_2ZnEDTA$ inhibited germination of flax when applied at rates of 0.5 to 4.0 ppm copper or zinc. Therefore, $Na_2CuEDTA$ and $Na_2ZnEDTA$ should not be banded with flax seeds.

Greenhouse studies were conducted in order to determine the effects of applied copper and zinc on the yield and the copper and zinc content of flax grown on Pine Ridge, Stockton I, Plum Ridge, and Almasippi I soils. The Pine Ridge soil did not supply adequate quantities of copper for the growth of flax plants. The Stockton I soil was found to supply quantities of copper which were just adequate to meet the copper requirements of flax. The Plum Ridge soil did not supply adequate quantities of zinc for the growth of flax while the Almasippi I soil was found to supply quantities of zinc which were barely adequate to meet the zinc requirements of flax.

Soils containing less than 1.3 ppm Na_2DP extractable copper may be suspected of being copper deficient; a soil containing 0.1 ppm Na_2DP extractable copper was found to be severely copper deficient. Soils containing less than 1.3 ppm DPTA (pH = 8.0) extractable zinc may be suspected of being zinc deficient; soil containing 0.8 ppm DPTA (pH = 8.0) extractable zinc was found to be moderately zinc deficient.

Eight week old flax plants containing less than 3.0 ppm copper may be suspected of being copper deficient while flax plants containing 2.0 ppm copper are severely deficient. Eight week old flax plants containing less than 13 ppm zinc may be suspected of being zinc deficient while flax plants containing 9.0 ppm zinc are moderately zinc deficient.

Incubation studies were conducted in order to evaluate various copper and zinc compounds as copper or zinc fertilizers. The compounds studied were $Na_2CuEDTA$, CuO, CuS, $Cu_2P_2O_7$, $Cu_3(PO_4)_2 \cdot 3H_2O$, $CuSO_4$, $Na_2ZnEDTA$, ZnO, ZnS, $Zn_2P_2O_7$, $Zn_3(PO_4)_2 \cdot 4H_2O$, $ZnNH_4PO_4$ and $ZnSO_4$. The amounts of copper or zinc extracted by water from a soil treated with copper or zinc were used as criteria for assessing the effectiveness of the compounds as suppliers of copper or zinc to a plant. $Na_2CuEDTA$ and $Na_2ZnEDTA$ proved to be the best sources of water extractable copper and zinc, respectively. Both $Na_2CuEDTA$ and $Na_2ZnEDTA$

were more soluble in calcareous soils than in noncalcareous soils. This was due to the more rapid replacement of copper or zinc by iron on the EDTA complex in Stockton soil as compared to the slower replacement of copper or zinc by calcium on the calcareous Plum Ridge soil. All the inorganic zinc compounds supplied about twice as much water extractable zinc on the noncalcareous soil as on the calcareous soil. Calcium carbonate content of the soil did not affect the copper supplying power of the inorganic copper compounds. Copper phosphate ($Cu_3(PO_4)_2 \cdot 3H_2O$) appeared to be the best inorganic copper fertilizer. Of the inorganic compounds studied, zinc sulphide (ZnS) appeared to be the best zinc fertilizer. Zinc oxide (ZnO) and zinc ammonium phosphate ($ZnNH_4PO_4$) also warrented attention as zinc fertilizers.

The studies reported in this manuscript indicate that some Manitoba soils do not supply sufficient quantities of zinc and/or copper for the growth of crops such as flax. Copper deficiencies appear to exist mainly on acidic very sandy soils, whereas zinc deficiencies appeared to occur on carbonated soils. Studies showed that the copper and zinc status of these soils can be assessed by the use of soil or plant analysis.

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VII APPENDIX

Table 1A. Iron and Manganese Content of Flax and Wheat.

Soil	Flax		Wheat	
	Fe (ppm)	Mn (ppm)	Fe (ppm)	Mn (ppm)
Tarno	63	160	47	25
Lakeland	64	192	64	68
Balmoral	74	67	39	33
Plum Ridge	70	73	50	23
Almasippi 1	97	156	40	38
Almasippi 2	56	178	83	63
Berlo	68	62	40	18
Red River	71	55	39	15
Newdale	69	100	53	65
Wellwood	78	102	45	45
Altona	86	93	50	37
Stockton 1	80	80	47	73
Stockton 2	63	160	47	28
Pine Ridge	81	167	48	83

Table 2A. Relationship Between Soil pH, Soil Carbonate Content, or Soil Organic Matter Content and the Copper or Zinc Content of Flax or Wheat.

Regression Equation	F	r^2
F.C.= $20.25 - 6.21X_2 + 0.59X_2^2$	5.33[1]	0.52^x
F.C.= $5.62 + 0.61X_3 - 0.023X_3^2$	5.98	0.55^x
F.C.= $6.40 - 0.68X_4 + 0.14X_4^2$	17.36	0.78^{xx}
W.C.= $118.41 + 34.41X_2 - 2.29X_2^2$	1.30	0.25
W.C.= $8.73 + 0.67X_3 + 0.035X_3^2$	0.94	0.19
W.C.= $20.07 - 4.80X_4 + 0.45X_4^2$	3.76	0.48
F.Z.= $120.30 + 53.41X_2 - 4.61X_2^2$	4.88	0.52^x
F.Z.= $28.64 - 3.50X_3 + 0.14X_3^2$	2.55	0.36
F.Z.= $1.38 + 11.38X_4 - 1.22X_4^2$	1.42	0.24
W.Z.= $174.57 + 62.83X_2 - 4.88X_2^2$	7.51	0.58^{xx}
W.Z.= $25.52 - 1.79X_3 + 0.065X_3^2$	5.82	0.51^x
W.Z.= $2.13 + 11.55X_4 - 1.17X_4^2$	6.72	0.55^x

F.C.= Copper content of flax
W.C.= Copper content of wheat
F.Z.= Zinc content of flax
W.Z.= Zinc content of wheat

X_2= Soil pH
X_3= Soil carbonate content
X_4= Soil organic matter content

x= Significant at the 5% level of probability

xx= Significant at the 1% level of probability

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[1] The F value is used as a measure of the significance of a relationship. It is the ratio of the variance due to regression to the variance due to error. The F value required for a significant relationship to exist varies with the size of the sample and with the number of parameters used in the regression equation.

Table 3A. Relationship Between Extractable Soil Copper and the Copper Content of Flax.

Extractant	Regression Equation	F	r^2
Conc. HNO_3 + 70% $HClO_4$	$Y=4.05+0.34X_1-0.0049X_1^2$	6.97	0.58^{x}
0.1 N HCl	$Y=11.78-17.76X_1+12.76X_1^2$	1.08	0.18
1% Na_2EDTA	$Y=5.68+0.81X_1-0.49X_1^2$	0.89	0.15
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	$Y=3.08+5.32X_1-1.14X_1^2$	4.18	0.45
0.01 M Na_2DP + 1.0 N NH_4OAc at pH = 7.0	$Y=3.99+2.28X_1-0.22X_1^2$	14.77	0.75^{xx}
1.0 M $(NH_4)_2CO_3$+0.01 M Na_2EDTA at pH = 7.8	$Y=2.25+4.25X_1-0.55X_1^2$	9.86	0.66^{xx}
0.67 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:2)	$Y=2.73+3.66X_1-0.46X_1^2$	11.32	0.68^{xx}
0.67 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=3.08+1.95X_1-0.15X_1^2$	5.36	0.52^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	$Y=3.03+7.07X_1-1.80X_1^2$	10.99	0.69^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y=3.22+6.94X_1-1.78X_1^2$	9.69	0.66^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y=3.17+6.77X_1-1.69X_1^2$	8.76	0.64^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=3.60+7.15X_1-2.02X_1^2$	8.69	0.63^{xx}

Y = Copper content of flax
X_1= Extractable soil copper

x Significant at the 5% level of probability

xx Significant at the 1% level of probability

Table 4A. Relationship Between Extractable Soil Copper and the Copper Content of Wheat.

Extractant	Regression Equation	F	r^2
Conc. HNO_3 + 70% $HClO_4$	$Y=9.81-0.055X_1+0.0023X_1^2$	0.02	0.01
0.1 N HCl	$Y=12.23-10.55X_1+7.84X_1^2$	0.14	0.03
1% Na_2EDTA	$Y=9.48-0.00081X_1+0.10X_1^2$	0.08	0.02
2% Na_2EDTA+1.0 N NH_4OAc at pH=7.0	$Y=9.91-0.69X_1+0.27X_1^2$	0.05	0.01
0.01 M Na_2DP + 1.0 N NH_4OAc at pH = 7.0	$Y=9.61-0.16X_1+0.45X_1^2$	0.06	0.02
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=9.72-0.27X_1+0.084X_1^2$	0.08	0.02
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:2)	$Y=9.30+0.11X_1+0.025X_1^2$	0.06	0.02
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=9.82-0.24X+0.043X_1^2$	0.07	0.02
0.005M DPTA+0.01M $CaCl_2$ 0.1M TEA at pH = 7.0	$Y=9.80-0.76X_1+0.43X_1^2$	0.06	0.02
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y=9.65-0.46X_1+0.32X_1^2$	0.05	0.01
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y = 10.10-1.33X_1+0.59_1^2$	0.09	0.02
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=10.14-1.68X_1+0.83X_1^2$	0.10	0.02

Y = Copper content of wheat
X_1=Extractable soil copper

Table 5A. Relationship Between Extractable Soil Copper and the Copper Uptake by Flax.

Extractant	Regression Equation	F	r^2
Conc. HNO_3 + 70% $HClO_4$	$Y=10.09+0.0043X_1+0.022X_1^2$	32.56	0.87^{xx}
0.1 N HCl	$Y=25.74-53.05X_1+47.73X_1^2$	7.13	0.59^{x}
1% Na_2EDTA	$Y=10.57+1.27X_1+0.046X_1^2$	9.84	0.66^{xx}
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	$Y=7.77+4.63X_1+0.65X_1^2$	17.50	0.78^{xx}
0.01 M Na_2DP + 1.0 N NH_4OAc at pH = 7.0	$Y=9.06+1.96X_1+0.18X_1^2$	61.82	0.93^{xx}
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=5.76+5.63X_1-0.17X_1^2$	25.05	0.83^{xx}
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:2)	$Y=7.11+3.88X_1+0.11X_1^2$	27.39	0.85^{xx}
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=8.04+1.49X_1+0.16X_1^2$	22.10	0.82^{xx}
0.005M DPTA+0.01M $CaCl_2$+ 0.1M TEA at pH = 7.0	$Y=8.01+5.99X_1+1.21X_1^2$	48.09	0.91^{xx}
0.005M DPTA+0.01M $CaCl_2$+ 0.1M TEA at pH = 7.5	$Y=7.83+6.84X_1+0.89X_1^2$	48.68	0.91^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y=7.28+7.65X_1+0.53X_1^2$	49.88	0.91^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=8.35+6.97X_1+1.15X_1^2$	43.32	0.90^{xx}

Y = Copper uptake by flax
X_1= Extractable soil copper
x Significant at 5% level of probability
xx Significant at 1% level of probability

Table 6A. Relationship Between Extractable Soil Copper and the Copper Uptake by Wheat.

Extractant	Regression Equation	F	r^2
Conc. HNO_3 + 70% $HClO_4$	$Y=29.16-0.66X_1+0.028X_1^2$	0.58	0.13
0.1 N HCl	$Y=30.25-20.38X_1+23.11X_1^2$	1.13	0.22
1% Na_2EDTA	$Y=25.31+0.44X_1+0.073X_1^2$	1.27	0.24
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	$Y=29.32-6.59X_1-2.92X_1^2$	1.15	0.22
0.01 M Na_2DP + 1.0 N NH_4OAc at pH = 7.0	$Y=28.46-2.65X_1+0.58X_1^2$	0.98	0.20
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=31.87-5.82X_1 1.30X_1^2$	1.37	0.25
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:2)	$Y=28.59-3.09X_1+0.92X_1^2$	1.07	0.21
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=30.11-2.93X_1+0.48X_1^2$	1.16	0.22
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	$Y=29.89-9.37X_1+4.90X_1^2$	1.03	0.20
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y=28.91-7.67X_1+4.39X_1^2$	0.99	0.20
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y=29.71-8.83X_1+4.60X_1^2$	1.12	0.22
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=29.81-10.62X_1+6.09X_1^2$	1.17	0.23

Y = Copper uptake of wheat
X_1= Extractable soil copper

Table 7A. Relationship Between Extractable Soil Zinc and the Zinc Content of Flax.

Extractant	Regression Equation	F	r^2
Conc. HNO_3 + 70% $HClO_4$	$Y=24.43-0.14X_1+0.0021X_1^2$	0.12	0.03
0.1 N HCl	$Y=12.69+4.75X_1-0.36X_1^2$	1.76	0.28
1% Na_2EDTA	$Y=10.11+4.64X_1-0.26X_1^2$	0.83	0.16
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	$Y=14.88-1.43X_1+1.92X_1^2$	7.52	0.63^{x}
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=14.94-1.47X_1-1.44X_1^2$	10.90	0.71^{xx}
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:2)	$Y=25.83-1.20X_1+0.091X_1^2$	1.97	0.30
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=21.59-6.11X_1+1.72X_1^2$	2.42	0.35
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	$Y=7.13+0.80X_1+0.0022X_1^2$	15.75	0.78^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y=10.05+0.60X_1+0.0038X_1^2$	14.09	0.76^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y=0.64+1.69X_1-0.018X_1^2$	23.53	0.84^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=5.27+1.51X_1-0.016X_1^2$	13.50	0.75^{xx}

Y = Zinc content of flax
X_1= Extractable soil zinc

x Significant at 5% level of probability
xx Significant at 1% level of probability

Table 8A. Relationship Between Extractable Soil Zinc and the Zinc Content of Wheat

Treatment	Regression Equation	F	r^2
Conc. HNO_3 + 70% $HClO_4$	$Y=14.34+0.29X_1-0.0026X_1^2$	0.13	0.05
0.1 N HCl	$Y=14.97+1.66X_1+0.018X_1^2$	9.75	0.64^{xx}
1% Na_2EDTA	$Y=12.10+2.68X_1+0.035X_1^2$	4.51	0.45^{x}
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	$Y=11.92+4.19X_1-0.072X_1^2$	4.04	0.42^{x}
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=18.17-2.90X_1+1.25X_1^2$	9.35	0.63^{xx}
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:2)	$Y=23.17-6.26X_1+1.81X_1^2$	4.90	0.47^{x}
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=18.22-1.92X_1+0.86X_1^2$	8.59	0.61^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	$Y=8.19+9.62X_1-1.09X_1^2$	8.70	0.61^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y=9.64+8.81X_1-1.03X_1^2$	6.74	0.55^{x}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y=1.26+17.42X_1-2.78X_1^2$	29.88	0.84^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=8.33+12.60X_1-2.02X_1^2$	8.40	0.60^{xx}

Y = Zinc content of flax
X_1= Extractable soil zinc
x Significant at the 5% level of probability
xx Significant at the 1% level of probability

Table 9A. Relationship Between Extractable Soil Zinc and the Zinc Uptake by Flax.

Extractant	Regression Equation	F	r^2
Conc. HNO_3 + 70% $HClO_4$	$Y=54.10-0.61X_1+0.010X_1^2$	0.63	0.12
0.1 N HCl	$Y=21.36+19.24X_1-1.68X_1^2$	6.05	0.57^x
1% Na_2EDTA	$Y=17.23+12.34X_1-0.31X_1^2$	2.28	0.34
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	$Y=17.37+14.28X_1+0.62X_1^2$	3.36	0.43
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=19.01+12.04X_1+0.36X_1^2$	4.29	0.49^x
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:2)	$Y=44.17-1.28X_1+1.83X_1^2$	0.81	0.15
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=23.65+9.42X_1+0.43X_1^2$	3.61	0.44
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	$Y=0.88+37.09X_1-3.94X_1^2$	5.45	0.55^x
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y=17.99+18.60X_1-0.13X_1^2$	5.44	0.55^x
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y=-3.97+39.81X_1-4.04X_1^2$	6.88	0.60^x
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=-7.76+63.59X_1-11.64X_1^2$	6.42	0.59^x

Y = Zinc uptake by flax
X_1 = Extractable soil zinc

x Significant at the 5% level of probability
xx Significant at the 1% level of probability

Table 10A. Relationship Between Extractable Soil Zinc and the Zinc Uptake by Wheat.

Extractant	Regression Equation	F	r^2
Conc. HNO_3 + 70% $HClO_4$	$Y=71.33-0.64X_1+0.079X_1^2$	0.19	0.03
0.1 N HCl	$Y=40.41+4.49X_1+0.29X_1^2$	7.74	0.58^{xx}
1% Na_2EDTA	$Y=48.66-5.27X_1+2.42X_1^2$	4.06	0.42^{x}
2% Na_2EDTA + 1.0 M NH_4OAc at pH = 7.0	$Y=28.73+15.92X_1-0.49X_1^2$	2.89	0.34
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=44.30-3.97X_1+3.43X_1^2$	7.51	0.58^{xx}
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:2)	$Y=79.04-31.86X_1+8.28X_1^2$	4.31	0.44^{x}
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=51.44-7.07X_1+3.19X_1^2$	6.59	0.55^{x}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	$Y=22.37+21.30X_1-0.25X_1^2$	9.92	0.64^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y=19.42+31.20X_1-3.26X_1^2$	6.60	0.55^{x}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y=19.20+75.70-13.30X_1^2$	18.61	0.77^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=15.76+43.34X_1-6.18X_1^2$	8.36	0.60^{xx}

Y = Zinc uptake by wheat
X_1 = Extractable soil zinc

x Significant at the 5% level of probability
xx Significant at the 1% level of probability

Table 11A. Relationship Between Extractable Soil Copper, Soil pH and the Copper Content of Flax.

Extractant	Regression Equation	F	R^2
Conc. HNO_3 + 70% $HClO_4$	$Y=18.42-1.04X_1-0.0073X_1^2-4.17X_2+0.30X_2^2+0.18X_1X_2$	87.33	0.98^{xx}
0.1 N HCl	$Y=137.77-22.78X_1-8.58X_1^2-39.38X_2+2.82X_2^2+5.24X_1X_2$	2.44	0.64
1% Na_2EDTA	$Y=102.94-6.24X_1-0.10X_1^2-28.43X_2+1.04X_2^2+1.05X_1X_2$	7.74	0.85^{xx}
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	$Y=22.77-19.57X_1-0.98X_1^2-4.45X_2+0.25X_2^2+3.26X_1X_2$	82.85	0.98^{xx}
0.01 M Na_2DP + 1.0 N NH_4OAc at pH = 7.0	$Y=-21.08-6.66X_1-0.16X_1^2+7.34X_2-0.52X_2^2+1.11X_1X_2$	73.06	0.98^{xx}
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=-25.34-14.09X_1-0.45X_1^2+9.68X_2-0.79X_2^2+2.35X_1X_2$	25.63	0.95^{xx}
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:2)	$Y=-34.91-12.81X_1-0.37X_1^2+12.32X_2-0.96X_2^2+2.11X_1X_2$	22.51	0.94^{xx}
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=-12.10-6.45X_1-8.15X_1^2+5.53X_2-0.46X_2^2+1.11X_1X_2$	31.52	0.96^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	$Y=-16.52-19.17X_1-1.38X_1^2+6.36X_2-o.48X_2^2+3.27X_1X_2$	71.52	0.98^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y=-14.68-18.33X_1-0.42X_1^2+5.68X_2-0.42X_2^2+3.14X_1X_2$	40.71	0.97^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y=-11.12-20.35X_1-1.52X_1^2+4.55X_2-0.33X_2^2+3.43X_1X_2$	90.54	0.98^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=-15.01-19.74X_1-1.21X_1^2+45.90X_2-0.44X_2^2+3.29X_1X_2$	71.52	0.97^{xx}

Y = Copper content of flax
X_1= Extractable soil copper
X_2= Soil pH

x Significant at the 5% level of probability
xx Significant at the 1% level of probability

Table 12A. Relationship Between Extractable Soil Copper, Soil pH and the Copper Content of Wheat.

Extractant	Regression Equation	F	R^2
Conc. HNO_3 + 70% $HClO_4$	$Y=-108.99+1.39X_1+0.013X_1^2+29.17X_2-1.72X_2^2-0.24X_1X_2$	0.66	0.40
0.1 N HCl	$Y=3.53+14.05X_1+1.87X_1^2-1.67X_2+0.32X_2^2-1.96X_1X_2$	0.27	0.21
1% Na_2EDTA	$Y=-150.46+7.52X_1+0.052X_1^2+41.51X_2-2.65X_2^2-1.09X_1X_2$	0.49	0.33
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	$Y=-105.01+20.00X_1+0.62X_1^2+27.73X_2-1.61X_2^2-3.01X_1X_2$	0.55	0.36
0.01 M Na_2DP + 1.0 N NH_4OAc at pH = 7.0	$Y=-54.57+9.07X_1+0.16X_1^2+13.99X_2-0.69X_2^2-1.36X_1X_2$	0.64	0.39
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=-48.40+19.55X_1+0.48X_1^2+10.22X_2-0.26X_2^2-3.02X_1X_2$	0.93	0.48
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:2)	$Y=52.95+15.88X_1+0.38X_1^2+12.00X_2-0.43_2^2-2.45X_1X_2$	0.81	0.45
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=-69.33+8.73X_1+0.14X_1^2+16.93X_2-0.79X_2^2-1.35X_1X_2$	0.76	0.43
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7:0	$Y=-75.74+23.10X_1+1.40X_1^2+19.45X_2-1.03X_2^2-3.61X_1X_2$	0.67	0.40
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y=-97.85+18.76X_1+1.03X_1^2+26.10X_2-1.53X_2^2-2.89X_1X_2$	0.59	0.37
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y=-100.51+19.78X_1+0.92X_1^2+26.68X_2-1.56X_2^2-3.00X_1X_2$	0.61	0.38
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=-92.38+21.91X_1+1.44X_1^2+24.53X_2-1.42X_2-3.41X_1X_2$	0.65	0.39

Y=Copper Content of Wheat X_1=Extractable Soil Copper X_2=Soil pH

Table 13A. Relationship Between Extractable Soil Copper, Soil pH and the Copper Uptake by flax.

Extractant	Regression Equation	F	R^2
Conc. HNO_3 + 70% $HClO_4$	$Y=-59.16-0.87X_1+0.019X_1^2+19.77X_2-1.39X_2^2+0.12X_1X_2$	10.11	0.88^{xx}
0.1 N HCl	$Y=343.89-157.0.X_1-0.72X_1^2-90.44X_2+5.99\ X_2^2+24.23X_1X_2$	3.17	0.69
1% Na_2EDTA	$Y=169.68-20.71X_1-0.094X_1^2-43.06X_2+2.84X_2^2+3.20X_1X_2$	8.18	0.85^{xx}
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	$Y=-4.54-69.28X_1+0.31X_1^2+10.76X_2-1.23X_2^2+10.06X_1X_2$	30.85	0.96^{xx}
0.01 M Na_2DP + 1.0 N NH_4OAc at pH = 7.0	$Y=-143.34-12.83X_1+0.12X_1^2+45.63X_2-3.36X_2^2+1.99X_1X_2$	30.43	0.96^{xx}
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=-195.96-45.88X_1-0.42X_1^2+65.77X_2-5.19X_2^2+7.06X_1X_2$	26.58	0.95^{xx}
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:2)	$Y=-217.13-38.59X_1-0.13X_1^2+70.82X_2-5.46X_2^2+5.84X_1X_2$	21.21	0.94^{xx}
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=-146.00-20.65X_1+0.02X_1^2+50.18X_2-3.97X_2^2+3.12X_1X_2$	34.07	0.96^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	$Y=-142.03-45.37X_1+0.70X_1^2+46.46X_2-3.51X_2^2+6.94X_1X_2$	30.34	0.96^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y=-146.35-45.23X_1+0.42X_1^2+47.53X_2-3.58X_2^2+7.01X_1X_2$	33.89	0.96^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y=-141.30-55.22X_1+0.43X_1^2+47.02X_2-3.60X_2^2+8.32X_1X_2$	50.09	0.97^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=-118.63-48.98X_1+0.91X_1^2+39.24X_2-2.96X_2^2+7.43X_1X_2$	27.01	0.95^{xx}

Y = Copper uptake by flax
X_1 = Extractable soil copper
X_2 = Soil pH

x Significant at the 5% level of probability
xx Significant at the 1% level of probability

Table 14A. Relationship Between Extractable Soil Copper, Soil pH and the Copper Uptake by Wheat.

Extractant	Regression Equations	F	R^2
Conc. HNO_3 + 70% $HClO_4$	$Y=-141.35+1.20X_1+0.017X_1^2+39.91X_2-2.58X_2^2-0.22X_1X_2$	0.70	0.41
0.1 N HCl	$Y=-271.13+21.79X_1+22.18X_1^2+78.16X_2-5.26X_2^2-7.06X_1X_2$	0.72	0.42
1% Na_2EDTA	$Y=-132.87+4.61X_1+0.049X_1^2+38.55X_2-2.59X_2^2-0.65X_1X_2$	0.54	0.35
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	$Y=-278.04+37.54X_1+2.88X_1^2+79.62X_2-5.08X_2^2-6.06X_1X_2$	0.51	0.34
0.01 M Na_2DP + 1.0 N NH_4OAc at pH = 7.0	$Y=-85.37+7.66X_1+0.19X_1^2+24.55X_2-1.55X_2^2-1.15X_1X_2$	0.68	0.40
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=-87.47+14.88X_1+0.43X_1^2+23.60X_2-1.38X_2^2-2.27X_1X_2$	0.78	0.44
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:2)	$Y=-262.94+33.23X_1+1.17X_1^2+73.09X_2-4.45X_2^2-5.16X_1X_2$	0.72	0.42
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=-305.62+17.78X_1+0.48X_1^2+85.90X_2-5.40X_2^2-2.81X_1X_2$	0.70	0.41
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	$Y=-305.50+56.31X_1+5.44X_1^2+86.13X_2-5.43X_2^2-9.09X_1X_2$	0.72	0.42
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y=-382.46+40.19X_1+4.06X_1^2+109.41X_2-7.20X_2^2-6.40X_1X_2$	0.63	0.39
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y=-376.41+42.47X_1+3.70X_1^2+107.30X_2-7.03X_2^2-6.64X_1X_2$	0.64	0.39
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=353.96+49.59X_1+5.55X_1^2+101.05X_2-6.59X_2^2-7.99X_1X_2$	0.70	0.41

Y = Copper uptake by wheat
X_1 = Extractable soil copper
X_2 = Soil pH

Table 15A. **Relationship Between Extractable Soil Zinc, Soil pH and the Zinc Content of Flax.**

Extractant	Regression Equation	F	R^2
Conc. HNO_3 + 70% $HClO_4$	$Y= -668.31+0.69X_1-0.00X_1^2+206.31X_2-15.26X_2^2-0.042X_1X_2$	9.26	0.89^{xx}
0.1 N HCl	$Y=-1226.81+52.24X_1-1.11X_1^2+353.23X_2-24.97X_2^2-6.47X_1X_2$	4.99	0.81^{x}
1% Na_2EDTA	$Y=-675.97+56.01X_1-2.92X_1^2+194.34X_2-13.71X_2^2-5.51X_1X_2$	3.03	0.73
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	$Y=-366.82+17.69X_1-0.92X_1^2+115.71X_2-8.64X_2^2-1.50X_1X_2$	8.56	0.88^{x}
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=-342.98+4.31X_1+0.77X_1^2+111.02X_2-8.30X_2^2-0.84X_1X_2$	8.22	0.87^{x}
0.67M $(NH_4)_2CO_3$+0.01M NaEDTA at pH = 8.65 (1:2)	$Y=-527.13+9.52X_1-1.24X_1^2+168.21X_1-12.76X_2^2-1.24X_1X_2$	7.39	0.86^{x}
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=-533.90+29.30X_1+0.45X_1^2+161.05X_2-11.45X_2^2-4.62X_1X_2$	1.74	0.59
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	$Y=-42.93-5.36X_1+0.048X_1^2+35.00X_2-3.47X_2^2+0.58X_1X_2$	12.11	0.91^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y=-3.68-3.82X_1+0.022X_1^2+1957X_2-2.26X_2^2+0.50X_1X_2$	16.42	0.93^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y=-307.98+2.04X_1-0.0070X_1^2+94.44X_2-6.88X_2^2-0.17X_1X_2$	8.93	0.88^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=-246.37-0.0073X_1^2+0.00074X_1^2+83.44X_2-6.45X_2^2+0.067X_1X_2$	8.41	0.88^{x}

Y = Zinc content of flax

X_1 = Extractable soil zinc

X_2 = Soil pH

x Significant at the 5% level of probability

xx Significant at the 1% level of probability

Table 16A. Relationship Between Extractable Soil Zinc, Soil pH and the Zinc Content of Wheat.

Extractant	Regression Equation	F	R^2
Conc. HNO_3 + 70% $HClO_4$	$Y=-99.25+0.53X_1-0.0066X_1^2+40.43X_2-3.49X_2^2+0.019X_1X_2$	5.97	0.79^x
0.1 N HCl	$Y=82.24+0.90X_1-0.013X_1^2-15.33X_2+0.85X_2^2+0.082X_1X_2$	3.72	0.70^x
1% Na_2EDTA	$Y=-123.16+12.27X_1-0.84X_1^2+42.28X_2-3.25X_2^2-0.80X_1X_2$	3.51	0.69
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	$Y=-88.97+12.15X_1-0.95X_1^2+32.96X_2-2.58X_2^2-0.81X_1X_2$	3.18	0.66
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=63.92-12.44X_1+1.44X_1^2-6.19X_2+0.057X_2^2+1.07X_1X_2$	3.80	0.70^x
0.67M $(NH_4)_2CO_3$+0.01M NaEDTA at pH = 8.65 (1:2)	$Y=-326.20+14.71X_1+0.75X_1^2+101.38X_2-7.23X_2^2-2.58X_1X_2$	3.95	0.71^x
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=10.06-4.59X_1+0.66X_1^2+7.46X_2-0.83X_2^2+0.40X_1X_2$	3.57	0.69
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	$Y=-19.55+17.65X_1-1.99X_1^2+10.62X_2-0.90X_2^2-0.91X_1X_2$	3.25	0.67
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y=131.89+7.15X_1-1.88X_1^2-28.93X_2+1.65X_2^2+0.71X_1X_2$	3.28	0.67
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y=331.60-14.08X_1-1.55X_1^2-86.68X_2+5.66X_2^2+3.91X_1X_2$	11.38	0.88^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=121.56+35.76X_1-5.53X_1^2-31.02X_2+2.02X_2^2-1.85X_1X_2$	3.84	0.71

Y = Zinc content of wheat
X_1= Extractable soil zinc
X_2= Soil pH

x Significant at the 5% level of probability
xx Significant at the 1% level of probability

Table 17A. Relationship Between Extractable Soil Zinc, Soil pH and the Zinc Uptake by Flax.

Extractant	Regression Equation	F	R^2
Conc. HNO_3 + 70% $HClO_4$	$Y=-1599.77+0.074X_1+0.0040X_1^2+477.23X_2-35.45X_2^2-0.036X_1X_2$	4.40	0.79^x
0.1 N HCl	$Y=-2659.25+68.97X_1-1.93X_1^2+782.18X_2-55.90X_2^2-7.96X_1X_2$	5.84	0.83^x
1% Na_2EDTA	$Y=-1949.75+58.94X_1-4.21X_1^2+582.48X_2-42.40X_2^2-4.58X_1X_2$	4.57	0.79^x
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	$Y=-1744.72+63.78X_1-7.92X_1^2+526.14X_2-38.67X_2^2-3.65X_1X_2$	4.24	0.78
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=-2253.04+70.56X_1-2.89X_1^2+667.02X_2-47.88X_2^2-8.01X_1X_2$	3.59	0.75
0.67M $(NH_4)_2CO_3$+0.01M NaEDTA at pH = 8.65 (1:2)	$Y=-5034.43+93.44X_1+2.46X_1^2+1438.72X_2-104.07X_2^2-17.82X_1X_2$	6.83	0.85^x
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=-1842.92+31.74X_1-1.05X_1^2+559.55X_2-40.49X_2^2-3.59X_1X_2$	3.43	0.74
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	$Y=-1492.25-10.65C_1+2.86X_1^2+465.17X_2-34.43X_2^2+0.57X_1X_2$	3.55	0.75
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y=-1004.16-104.95X_1+8.82X_1^2+337.65X_2-26.03X_2^2+11.08X_1X_2$	4.56	0.79^x
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y=-1443.25+43.72X_1-2.63X_1^2+434.82X_2-31.65X_2^2-3.53X_1X_2$	3.82	0.76
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=-1250.92+71.68X_1-8.89X_1^2+383.14X_2-28.29X_2^2-5.00X_1X_2$	3.67	0.77

Y = Zinc uptake by flax
X_1= Extractable soil zinc
X_2= Soil pH

x Significant at the 5% level of probability

Table 18A. Relationship Between Extractable Soil Zinc, Soil pH and the Zinc Uptake by Wheat.

Extractant			
Conc. HNO_3 + 70% $HClO_4$	$Y=-464.14+0.20X_1-0.0052X_1^2+185.87X_2-15.45X_2^2+0.025X_1X_2$	6.13	0.79^x
0.1 N HCl	$Y=-284.49-2.36X_1+0.39X_1^2+125.54X_2-10.65X_2^2+0.30X_1X_2$	6.73	0.81^{xx}
1% Na_2EDTA	$Y=-340.13+19.34X_1-1.43X_1^2+138.04X_2-11.60X_2^2-1.04X_1X_2$	6.57	0.80^x
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	$Y=-313.65+34.47X_1-5.28X_1^2+129.05X_2-11.04X_2^2-0.91X_1X_2$	7.04	0.81^{xx}
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=112.23-36.16X_1+3.24X_1^2+20.29X_2-3.63X_2+3.53X_1X_2$	6.84	0.81^{xx}
0.67M $(NH_4)_2CO_3$+0.01M NaEDTA at pH = 8.65 (1:2)	$Y=-2025.82+74.82X_1+3.27X_1^2+611.03X_2-43.50X_2^2-13.65X_1X_2$	12.18	0.88^{xx}
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=-87.14-16.89X_1+1.63X_1^2+73.46X_2-7.18X_2^2+1.64X_1X_2$	6.57	0.80^x
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	$Y=740.37-46.99X_1-0.18X_1^2-161.17X_2+8.86X_2^2+8.34X_1X_2$	8.73	0.85^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y=995.83+2.75X_1-8.44X_1^2-240.16X_2+14.39X_2^2+6.24X_1X_2$	9.38	0.85^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y=329.36+39.93X_1-10.95X_1^2-68.17X_2+3.25X_2^2+2.32X_1X_2$	11.92	0.88^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=619.84+98.10X_1-19.12X_1^2-148.71X_2+8.82X_2^2-3.15X_1X_2$	9.08	0.85^{xx}

Y = Zinc uptake by wheat
X_1 = Extractable soil zinc
X_2 = Soil pH

x Significant at the 5% level of probability
xx Significant at the 1% level of probability

Table 19A. Relationship Between Extractable Soil Copper, Soil pH, Soil Organic Matter Content and the Copper Content of Flax.

Extractant	Regression Equation	F	R^2
Conc. HNO_3 + 70% $HClO_4$	$Y=1.31+0.023X_1+0.00022X_1^2-5.33X_2+0.49X_2^2+0.26X_3+0.029X_3^2$	28.50	0.97^{xx}
0.1 N HCl	$Y=-15.21-4.27X_1+0.36X_1^2+4.27X_2-0.20X_2^2+0.57X_3+0.013X_3^2$	30.43	0.97^{xx}
1% Na_2EDTA	$Y=2.95-0.021X_1-0.00085X_1^2-1.20X_2+0.19X_2^2+0.26X_3+0.041X_3^2$	26.99	0.96^{xx}
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	$Y=12.00+0.59X_1-0.14X_1^2-3.76X_2+0.37X_2^2+0.13X_3+0.047X_3^2$	27.43	0.96^{xx}
0.01 M Na_2DP + 1.0 N NH_4OAc at pH = 7.0	$Y=10.50+0.092X_1-0.0086X_1^2-3.30X_2-10.34X_2^2+0.20X_3+0.042X_3^2$	26.40	0.96^{xx}
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=5.24-0.11X_1+0.0037X_1^2-1.89X_2+0.24X_2^2+0.29X_3+0.040X_3^2$	27.10	0.96^{xx}
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:2)	$Y=4.67-0.14X_1+0.0069X_1^2-1.75X_2+0.23X_2^2+0.31X_3+0.039X_3^2$	27.19	0.96^{xx}
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=5.66-0.15X_1+0.0077X_1^2-2.01X_2+0.25X_2^2+0.35X_3+0.037X_3^2$	27.69	0.97^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	$Y=11.72+0.94X_1-0.25X_1^2-3.60X_2+0.35X_2^2+0.09X_3+0.048X_3^2$	27.81	0.97^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y=10.42+0.71X_1-0.19X_1^2-3.28X_2+0.34X_2^2+0.14X_3+0.04X_3^2$	27.24	0.96^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y=10.98+1.00X_1-0.30X^2-3.42X_2+0.35X_2^2+0.10X_3+0.046X_3^2$	27.83	0.97^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=10.16+1.23X_1-0.33X_1^2-3.18X_2-10.33X_2^2+0.04X_3-0.050X_3^2$	29.31	0.97^{xx}

Y= Copper content of Flax
X_1= Extractable soil copper
X_2= Soil pH
X_3= Soil organic matter content

xx Significant at the 1% level of probability

Table 20A. Relationship Between Soil Copper, Soil pH, Soil Organic Matter Content and the Copper Content of Wheat.

Extractant	Regression Equation	F	R^2
Conc. HNO_3 + 70% $HClO_4$	$Y=12.12+0.96X_1-0.019X_1^2+0.45X_2+0.051X_2^2-5.96X_3+0.43X_3^2$	4.35	0.87
0.1 N HCl	$Y=11.86+32.99X_1-18.61X_1^2-2.21X_2+0.34X_2^2-6.24X_3+0.54X_3^2$	4.88	0.88
1% Na_2EDTA	$Y=59.15+1.86X_1-0.10X_1^2-13.13X_2+1.03X_2^2-4.86X_3+0.39X_3^2$	1.89	0.74
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	$Y=108.76+10.64X_1-1.83X_1^2-26.44X_2+1.92X_2^2-6.89X_3+0.51X_3^2$	6.86	0.91
0.01 M Na_2DP + 1.0 N NH_4OAc at pH = 7.0	$Y=-60.40+5.06X_1-0.48X_1^2+23.13X_2-1.64X_2^2-6.19X_3+0.43X_3^2$	4.35	0.87
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=-46.53+7.83X_1-0.96X_1^2+18.90X_2-1.35X_2^2-7.02X_3+0.54X_3^2$	4.67	0.88
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:2)	$Y=-51.12+6.83X_1-0.81X_1^2+20.52X_2-1.47X_2^2-6.91X_3+0.53X_3^2$	7.39	0.92
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=-91.28+4.50X_1-0.35X_1^2+30.58X_2-2.13X_2^2-6.15X_3+0.44X_3^2$	4.44	0.87
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	$Y=-76.95+12.64X_1-3.21X_1^2+26.66X_2-1.87X_2^2-6.13X_3+0.46X_3^2$	4.30	0.87
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y=-103.59+11.18X_1-2.88X_1^2+33.46X_2-2.28X_2^2-5.47X_3+0.40X_3^2$	4.39	0.87
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y=-111.84+12.46X_1-3.06X_1^2+35.69X_2-2.42X_2^2-5.95X_3+0.43X_3^2$	5.79	0.90
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=-112.04+13.80X_1-3.89X_1^2+35.82X_2-2.43X_2^2-5.71X_3+0.40X_3^2$	4.34	0.87

Y = Copper content of wheat

X_1 = Extractable soil copper

X_2 = Soil pH

X_3 = Soil organic matter content

x=Significant at the 5% level of probability

Table 21A. Relationship Between Extractable Soil Copper, Soil pH, Soil Organic Matter Content and the Uptake of Copper by Flax.

Extractant	Regression Equation	F	R^2
Conc. HNO_3 + 70% $HClO_4$	$Y=-87.85-0.41X_1+0.03X_1^2+26.67X_2-1.81X_2^2+0.87X_3-0.0083X_3^2$	7.80	0.89^x
0.1 N HCl	$Y=-103.69-39.80X_1+34.40X_1^2+35.01X_2-2.46X_2^2-0.52X_3+0.22X_3^2$	10.36	0.91^{xx}
1% Na_2EDTA	$Y=-43.95-0.68X_1+0.15X_1^2+15.26X_2-1.03X_2^2-1.21X_3+0.28X_3^2$	11.55	0.92^{xx}
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	$Y=55.91-1.67X_1+1.90X_1^2-12.45X_2+0.91X_2^2-2.16X_3+0.32X_3^2$	10.16	0.91^{xx}
0.01 M Na_2DP + 1.0 N NH_4OAc at pH = 7.0	$Y=-59.03+0.91X_1+0.25X_1^2+19.51X_2-1.36X_2-0.46X_3+-.10X_3^2$	14.42	0.94^{xx}
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=-63.81+1.28X_1+0.29X_1^2+21.56X_2-1.52X_2^2-1.95X_3+0.31X_3^2$	11.31	0.92^{xx}
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:2)	$Y=-67.34+0.59X_1+0.42X_1^2+21.33X_2-1.51X_2^2-1.85X_3+0.29X_3^2$	11.34	0.92^{xx}
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=-78.79-1.40X_1+0.34X_1^2+24.92X_2-1.69X_2^2-0.66X_3+0.20X_3^2$	10.64	0.91^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	$Y=-69.01+0.53X_1+2.28X_1^2+22.26X_2-1.54X_2^2-0.75X_3+0.20X_3^2$	14.60	0.94^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y=-73.46+1.68X_1+1.91X_1^2+23.34X_2-1.61X_2^2-0.67X_3+0.14X_3^2$	14.30	0.93^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y=-55.73+3.95X_1+1.17X_1^2+18.78X_2-1.30X_2^2-1.60X_3+0.22X_3^2$	16.57	0.94^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=-61.01-0.15X_1+2.84X_1^2+19.79X_2-1.35X_2^2-0.54X_3+0.15X_3^2$	25.69	0.90^{xx}

Y = Copper uptake by flax
X_1 = Extractable soil copper
X_2 = Soil organic matter content
X_3 = Soil organic matter content

x Significant at the 5% level of probability
xx Significant at the 1% level of probability

Table 22A. Relationship Between Extractable Soil Copper, Soil pH, Soil Organic Matter Content and the Copper Uptake by Wheat.

Extractant	Regression Equation	F	R^2
Conc. HNO_3 + 70% $HClO_4$	$Y=-46.60+0.68X_1-0.011X_1^2+18.41X_2-1.31X_2^2-5.34X_3+0.41X_3^2$	1.74	0.72
0.1 N HCl	$Y=50.20+27.49X_1-13.09X_1^2-11.39X_2+0.88X_2^2-6.49X_3+0.59X_3^2$	5.16	0.89
1% Na_2EDTA	$Y=34.00-4.35X_1-0.062X_1^2-4.93X_2+0.29X_2^2-4.93X_3+0.42X_3^2$	2.07	0.76
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	$Y=306.36+24.29X_1-3.04X_1^2-68.47X_2+4.68X_2^2-20.61X_3+1.61X_3^2$	6.29	0.90
0.01 M Na_2DP + 1.0 N NH_4OAc at pH = 7.0	$Y=-86.97+4.34X_1-0.36X_1^2+31.83X_2-2.35X_2^2-5.81X_3+0.42X_3^2$	3.06	0.82
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=118.92+9.72X_1-1.13X_1^3+40.32X_2-2.94X_2^2-7.57X_3+0.59X_3^2$	6.17	0.90
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:2)	$Y=-211.19+17.48X_1-1.76X_1^2+82.10X_2-6.17X_2^2-20.27X_3+1.63X_3^2$	7.10	0.91
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=-324.77+11.03X_1-0.71X_1^2+110.51X_2-8.01X_2^2-17.77X_3+1.38X_3^2$	3.90	0.85
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	$Y=-297.63+27.77X_1-5.79X_1^2+102.71X_2-7.41X_2^2-16.87X_3+1.34X_3^2$	2.36	0.78
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y=-373.12+24.89X_1-5.20X_1^2+122.16X_2-8.68X_2^2-15.36X_3+1.21X_3^2$	2.56	0.79
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y=-377.02+28.11X_1-5.73X_1^2+123.25X_2-8.73X_2^2-16.78X_3+1.31X_3^2$	3.22	0.82
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=-375.20+29.42X_1-6.81X_1^2+122.69X_2-8.69X_2^2-15.73X_3+1.21X_3^2$	2.33	0.78

Y = Copper uptake by wheat
X_1= Extractable soil copper
X_2= Soil pH
X_3 = Soil organic matter content
x Significant at the 5% level of probability

Table 23A. Relationship Between Extractable Soil Zinc, Soil pH, Soil Organic Matter Content and the Zinc Content of Flax.

Extractant	Regression Equation	F	R^2
Conc. HNO_3 + 70% $HClO_4$	$Y= 654.23+0.36X_1-0.0029X_1^2+200.07X_2-14.80X_2^2+3.78X_3-0.43X_3^2$	7.61	0.90^x
0.1 N HCl	$Y=195.92+4.27X_1-0.46X_1^2-36.79X_2+1.81X_2^2-3.47X_3+0.31X_3^2$	1.01	0.55
1% Na_2EDTA	$Y=-32.15+12.75X_1-1.90X_1^2+26.38X_2-2.80X_2^2-1.66X_3+0.11X_3^2$	1.25	0.60
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	$Y=-225.13+8.41X_1-0.99X_1^2+78.14X_2-6.17X_2^2-1.21X_3+0.091X_3^2$	5.78	0.87^x
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=-400.34-8.31X_1+1.86X_1^2+128.91X_2-9.71X_2^2+3.79X_3-0.30X_3^2$	6.67	0.89^x
0.67M $(NH_4)_2CO_3$+0.01M NaEDTA at pH = 8.65 (1:2)	$Y=-493.45+11.62X_1-1.65X_1^2+159.01X_2-12.14X_2^2-0.76X_3-0.036X_3^2$	4.43	0.84
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=56.47+3.23X_1-0.21X_1^2+0.98X_2-0.78X_2^2-2.63X_3+0.21X_3^2$	1.01	0.55
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	$Y=-430.65-0.70X_1+0.025X_1^2+135.73X_2-10.07X_2^2+2.56X_3-0.23X_3^2$	7.37	0.90^x
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y= -388.87-0.20X_1+0.013X_1^2+122.94X_2-9.15X_2^2+1.88X_3-0.17X_3^2$	8.51	0.91^x
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y= -916.46-4.48X_1+0.10X_1^2+282.87X_2-20.92X_2^2+16.03X_3-1.40X_3^2$	7.99	0.91^x
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=-239.47+0.75X_1-.0077X_1^2+79.69X_2-6.11X_2^2+0.51X_3-0.07X_3^2$	5.91	0.88

Y = Zinc content of flax
X_1= Extractable soil zinc
X_2= Soil pH
X_3= Soil organic matter content

x Significant at the 5% level of probability

Table 24A. RElationship Between Extractable Soil Zinc, Soil pH, Soil Organic Matter Content and the Zinc Content of Wheat.

Extractant	Regression Equation	F	R^2
Conc. HNO_3 + 70% $HClO_4$	$Y=-186.84+0.41X_1-0.0045X_1^2+60.16X_2-4.68X_2^2+7.00X_3-0.56X_3^2$	7.02	0.86^x
0.1 N HCl	$Y=-284.77-1.12X_1+0.19X_1^2+75.46X_2-5.54X_2^2+8.17X_3-0.81X_3^2$	3.73	0.81^x
1% Na_2EDTA	$Y=-203.73+3.91X_1-0.60X_1^2+63.09X_2-4.78X_2^2+7.99X_3-0.79X_3^2$	4.60	0.80^x
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	$Y=-178.06+4.12X_1-0.78X_1^2+55.48X_2-4.19X_2^2+7.55X_3-0.75X_3^2$	4.21	0.78^x
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=-178.24-3.88X_1+0.95X_1^2+56.20X_2-4.17X_2^2+7.19X_3-0.70X_3^2$	5.44	0.82^x
0.67M $(NH_4)_2CO_3$+0.01M NaEDTA at pH = 8.65 (1:2)	$Y=-42.89-0.62X_1+0.46X_1^2+16.77X_2-1.41X_2^2+7.52X_3-0.74X_3^2$	5.92	0.84^x
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=-256.91-9.82X_1+1.76X_1^2+78.47X_2-5.70X_2^2+9.66X_3-0.91X_3^2$	8.37	0.88^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	$Y=-179.69+1.25X_1-0.11X_1^2+55.95X_2-4.19X_2^2+7.62X_3-0.75X_3^2$	4.08	0.78
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y=-46.93+7.62X_1-1.45X_1^2+17.25X_2-1.47X_2^2+7.95X_3-0.70X_3^2$	4.53	0.80^x
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y=378.12+37.65X_1-6.84X_1^2-112.35X_2+8.14X_2^2-5.31X_3+0.40X_3^2$	14.55	0.93^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=98.10+16.14X_1-3.83X_1^2-25.44X_2+1.58X_2^2+5.95X_3-0.62X_3^2$	4.96	0.81^x

Y = Zinc content of wheat
X_1 = Extractable soil zinc
X_2 = Soil pH
X_3 = Soil organic matter content

x Significant at the 5% level of probability
xx Significant at the 1% level of probability

Table 25A. Relationship Between Extractable Soil Zinc, Soil pH, Soil Organic Matter Content and the Uptake of Zinc by Flax.

Extractant	Regression Equation	F	R^2
Conc. HNO_3 + 70% $HClO_4$	$Y=-1549.41-0.24X_1+0.0049X_1^2+380.45X_2-35.69X_2^2+4.75X_3-0.43X_3^2$	3.09	0.79
0.1 N HCl	$Y=-1494.57+4.46X_1-0.68X_1^2+469.74X_2-35.25X_2^2+5.93X_3-0.32X_3^2$	3.24	0.80
1% Na_2EDTA	$Y=-1595.18+28.67X_1-5.94X_1^2+493.70X_2-37.00X_2^2+0.28_3+0.14X_3^2$	3.10	0.79
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	$Y=-1869.28+15.71X_1-2.97X_1^2+569.41X_2-42.44X_2^2+12.71X_3-0.96X_3^2$	3.58	0.81
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=2186.24-29.07X_1+4.83X_1^2+671.51X_2-49.61X_2^2+11.57X_3-0.66X_3^2$	3.28	0.80
0.67M $(NH_4)_2CO_3$+0.01M NaEDTA at pH = 8.65 (1:2)	$Y=-2725.55-21.16X_1+2.58X_1^2+827.46X_2-60.49X_2^2+6.45X_3-0.37X_3^2$	3.80	0.82
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=-2056.58-47.09X_1+7.44X_1^2+685.53X_2-45.83X_2^2+23.30X_3-1.78X_3^2$	3.34	0.80
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	$Y=-2163.85-42.61X_1+9.60X_1^2+659.92X_2-48.42X_2^2+14.51X_3-1.10X_3^2$	3.18	0.79
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y=-2434.23-51.14X_1+11.69X_1^2+733.81X_2-53.27X_2^2+11.66X_3-0.78X_3^2$	4.16	0.83
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y=-1822.52-36.49X_1+9.18X_1^2+562.01X_2-41.60X_2^2+12.56X_3-0.82X_3^2$	3.75	0.80
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=-1855.00-14.33X_1+4.23X_1^2+569.87X_2-42.12X_2^2+6.27X_3-0.34X_3^2$	2.84	0.77

Y = Zinc uptake by flax

X_1= Extractable soil zinc

X_2= Soil pH

X_3= Soil organic matter content

x Significant at the 5% level of probability

Table 26A. Relationship Between Extractable Soil Zinc, Soil pH, Soil Organic Matter Content and the Uptake of Zinc by Wheat.

Extractant	Regression Equation	F	R^2
Conc. HNO_3 + 70% $HClO_4$	$Y=-569.64+0.74X_1-0.01X_1^2+204.32X_2-16.91X_2^2+16.64X_3-1.12X_3^2$	14.98	0.92^{xx}
0.1 N HCl	$Y=-1126.91-6.73X_1+0.80X_1^2+356.66X_2-27.05X_2^2+20.96X_3-1.88X_3^2$	8.00	0.87^{x}
1% Na_2EDTA	$Y=-881.11+3.37X_1-0.91X_1^2+287.40X_2-22.39X_2^2+21.53X_3-1.86X_3^2$	7.16	0.86^{x}
2% Na_2EDTA + 1.0 N NH_4OAc at pH = 7.0	$Y=-651.80+13.73X_1-3.04X_1^2+219.77X_2-17.49X_2^2+16.61X_3-1.47X_3^2$	6.98	0.86^{x}
1.0 M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.8	$Y=-885.18-17.00X_1+3.21X_1^2+293.33X_2-22.65X_2^2+16.43X_3-1.34X_3^2$	8.05	0.87^{x}
0.67M $(NH_4)_2CO_3$+0.01M NaEDTA at pH = 8.65 (1:2)	$Y=-405.83-12.50X_1+3.15X_1^2+152.65X_2-12.50X_2^2+13.91X_3-1.17X_3^2$	9.21	0.89^{x}
0.67M $(NH_4)_2CO_3$+0.01M Na_2EDTA at pH = 8.65 (1:10)	$Y=-1050.84-36.70X_1+6.03X_1^2+339.03X_2-25.67X_2^2+24.45X_3-2.06X_3^2$	11.43	0.91^{xx}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.0	$Y=-445.69+0.24X_1-0.00052X_1^2+162.98X_2-13.41X_2^2+17.12X_3-1.56X_3^2$	7.72	0.87^{x}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 7.5	$Y=49.32+34.28X_1-7.39X_1^2+18.53X_2-3.83X_2^2+13.65X_3-1.22X_3^2$	8.28	0.88^{x}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.0	$Y=166.74+56.91X_1-11.29X_1^2-24.65X_2+0.35X_2^2-0.65X_3+0.14X_3^2$	9.02	0.89^{x}
0.005M DPTA+0.01M $CaCl_2$ +0.1M TEA at pH = 8.5	$Y=143.17+45.00X_1-12.40X_1^2-10.05X_2-1.27X_2^2+13.08X_3-1.16X_3^2$	7.79	0.87^{x}

Y = Zinc uptake by wheat

X_1= Extractable soil zinc

X_2= Soil pH

X_3= Soil organic matter content

x Significant at the 5% level of probability

xx Significant at the 1% level of probability

Table 27A

Iron and Manganese Contents of Flax.

Treatment		Soil							
		Pine Ridge		Stockton I		Almasippi I		Plum Ridge	
ppm Cu	ppm Zn	Fe ppm	Mn ppm	Fe ppm	Mn ppm	Fe ppm	Mn ppm	Fe ppm	Mn ppm
0.0	0.0	122	477	98	366	27	47	37	193
0.5	0.0	73	513	90	260	44	53	37	220
1.0	0.0	77	393	67	180	34	60	34	210
0.0	0.5	90	556	68	203	24	43	34	163
0.5	0.5	68	430	72	200	43	57	30	143
1.0	0.5	67	313	67	157	33	53	30	210
0.0	1.0	82	430	78	207	26	47	31	157
0.5	1.0	123	430	63	180	35	53	35	200
1.0	1.0	98	380	62	163	31	63	29	197
0.0	2.0	115	438	70	170	37	70	29	143
0.5	2.0	97	390	72	167	26	53	29	160
1.0	2.0	98	270	57	123	25	63	31	167

Table 28 A

Solubility of Soil Iron Influenced by Additions of $Na_2CuEDTA$ and $Na_2ZnEDTA$ (ppm - Soil Basis)

	Incubation time						
Treatment	1½ day	3 days	7 days	14 days	21 days	31 days	42 days
				Stockton			
No Chelate Added	28.5	50.0	17.0	23.5	22.5	13.5	19.5
$Na_2CuEDTA$	26.0	57.0	40.0	52.0	39.5	36.5	45.0
$Na_2ZnEDTA$	26.0	50.0	43.0	50.0	49.0	41.0	42.0
				Plum Ridge			
No Chelate Added	5.6	1.0	1.8	0.5	2.6	1.6	0.2
$Na_2CuEDTA$	7.8	1.2	3.2	1.0	6.0	1.9	0.9
$Na_2CuEDTA$	8.0	1.4	5.3	2.0	0.5	5.5	0.4

Table 29 A

Solubility of Soil Mn as Influenced by
Additions of $Na_2CuEDTA$ and $Na_2ZnEDTA$
(ppm - Soil Basis)

	Stockton						
	Incubation time						
Treatment	1½ day	3 days	7 days	14 days	21 days	31 days	42 days
No Chelate Added	0.6	0.7	0.3	0.3	0.5	0.3	0.7
$Na_2CuEDTA$	2.4	1.5	0.5	0.1	0.4	0.4	0.1
$Na_2ZnEDTA$	1.5	0.9	0.1	0.1	1.0	0.6	0.1
	Plum Ridge						
No Chelate Added	0.2	0.1	0.4	0.4	0.2	0.2	0.4
$Na_2CuEDTA$	1.6	0.5	0.5	0.4	0.6	0.1	0.7
$Na_2ZnEDTA$	0.7	0.1	0.6	0.4	0.1	0.3	0.5