A STUDY OF THE MICRONUTRIENT STATUS AND REQUIREMENTS FOR CROP PRODUCTION ON SOME MANITOBA ORGANIC SOILS

By

Lawrence V. Gusta

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ABSTRACT

Field experiments were carried out for two years on organic soils to determine if certain micronutrients were in sufficient supply for field and vegetable crop production. Micronutrient elements under study were manganese, boron, copper and zinc. Application of copper alone or in combination with other micronutrients resulted in a significant response in yield of carrots, onion and wheat crops.

Application of 0.5 pounds of copper per acre at one location produced yields as high as those where higher rates of copper were used. Copper rates for optimun crop yield were not studied at other locations.

In a greenhouse experiment, using spinach as a test crop, a significant yield increase due to copper fertilization was obtained on three of the nine organic soils studied.

The application of 200 pounds per acre of sodium chloride gave a significant yield increase to sugar beets and appeared to have a beneficial effect on frost tolerance.

Potassium applied at a rate of 50 pounds per acre to wheat significantly reduced yields.

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INTRODUCTION

Manitoba has 160 million acres of land of which 37 million acres or approximately 23 percent can be arbitrarily classified as peat or organic soils (52). Most of these soils occur in the humid, wooded lowlands of central and northern Manitoba. Peat consists of the remains of a variety of plants that have accumulated in low, wet, poorly drained areas such as bogs, marshes or swamps.

At the present time most of these soils are unbroken bogs and a limited acreage is used as sources of low quality hay in dry seasons. Some areas are being utilized for the production of wheat, oats, barley, rye, timothy and cultivated hay and pasture. As a rule, the quality and yield of grain produced on organic soils in Manitoba are very poor. As a result of this, the resale value of organic deposits is very low, \$5.00 to \$10.00 per acre. This is in contrast to areas such as the Bradford Marsh, the peat deposits in Wisconsin and Michigan and the Florida Everglades. These deposits have been developed to such an extent for horticultural crops such as carrots, onions, mint, lettuce and celery that their resale value is \$300.00 to \$1,200.00 per acre depending on the depth of the deposit. These premium prices are paid for organic deposits because of their natural characteristics which make them ideal for horticultural crops. They have a very high water holding capacity, are very friable and do not compact as compared to mineral soils. This makes them ideally suited for root crops and those requiring a high amount of water during the growing season.

Investigation of organic soils for crop production is receiving increasing attention in Canada. Although Manitoba has some 250,000 acres (52) of potential arable organic soils, information on their chemical properties relating to nutrient supply is meagre. Field experiments were carried out at two different locations to determine some of the soils' chemical properties. Prime consideration was given to the micronutrients to determine if they were in sufficient supply.

REVIEW OF LITERATURE

The micronutrients copper, boron, zinc and manganese are required in trace amounts by plants. The majority of mineral soils are able to supply this need but in general organic soils have micronutrient deficiencies and response to their application have been reported by many workers.

Boron

Dregne and Powers (10) report that the availability of boron in soils is influenced by soil reaction, soil moisture, active calcium and organic matter. Mulvihill and McGregor (39) showed in a field study of Minnesota soils, that boron availability is also strongly influenced by colloid content, texture and a good correlation was obtained between boron and organic matter content. Dible and Berger (9) working with alfalfa showed that boron content dropped in the tissue from 30 to 20 ppm as soil moisture became limiting. According to Ouellette and Lachance (42) more boron is required in a heavy soil than a sandy soil. Stinson (53) showed that boron deficiency occurs for alfalfa when the water soluble boron drops below 0.5 ppm in heavy soils and 0.3 ppm in sandy soils. Boron is less available to plants at high pH although acid soils have been shown to be deficient. Wear and Patterson (60) working with a range of soils found that as pH was lowered from 7.4 to 5.2 boron content of plants increased. There was also a linear relationship between boron content of plants and water soluble boron in the soil. In the same study it was shown that boron content of plants increased with coarser type soils. Mackay, Langille and Chipman (36) working with a sphagnum peat soil deficient in boron, showed that borax should be applied initially for all crops at from 10 to 50 pounds per acre, the actual rate depending upon the relative requirements of the species. The range in application which prevented deficiency without causing toxicity was much less critical for organic soils as compared to inorganic soils (36).

Copper

The first credible evidence that copper was an essential element in the nutrition of lower plants was provided by Bortels in 1927 (44). Confirmation of his results were soon provided by other scientists. The functions of copper in the plant are quite complex. It is concentrated more in the rootlets of plants than in leaves or other tissue (44). Copper probably functions as an enzyme activator or as an integral part of enzyme molecules involved in certain reactions. Addition of copper where deficient will increase carotene content of carrots and increase onion bulb skin color (8).

Nelson et al (40) working with a copper deficient peat soil tested several crops for order of response to copper. Crops showing a high response and listed in order of decreasing response are wheat, barley, oats, corn, carrots, red beets, onions, spinach, alfalfa and cabbage. Those showing a medium response to copper are soybean, red clover, snap beans, potatoes and tomatoes.

General copper deficiency symptoms as delineated by Nelson et al (40) are reduced growth, a change in color to a grayish-green, blue green or olive green, die back of the leaves and shortened internodes. With wheat, oats and barley when the plants reach 3 to 5 inches in height they may develop a disease called "yellow tip". The tips of the youngest leaves become chlorotic, thin, twisted and shrivelled. The plants may either die or else survive to produce a few chaffy grains or none at all. Grain production may be reduced more than the vegetative growth (44). With spinach the leaves become a dark olive green with the tips of the youngest leaves becoming chlorotic. Onion tips tend to become necrotic (40).

Highly significant increases in yield of several copper-responsive crops growing on acid organic soils have been obtained from the application of various rates of copper. Davis and Lucas (8) make general recommendations for crops growing on deficient Michigan organic soils. Application of 5 pounds of copper per acre for low responsive crops and 10 for highly responsive crops are suggested. Younts (63) in a field experiment with wheat on high organic and low organic soils found 2.5 pounds per acre of copper resulted in either maximum or near maximum yields. Where soils were acutely deficient, application at planting gave results superior to later applications. In addition, he found the application of manganese tended to increase the copper content while zinc tended to decrease the level of copper in the plant. On the other hand Butler (6) found that high rates of manganese decreased copper uptake. Mackay et al (36) found that on a very acid sphagnum peat soil, limed to pH 6.0, addition of sodium increased the availability of copper and decreased zinc.

Organic matter and pH play decisive roles in copper availability. Broadbent and Ott (3) found that the amount of copper complexed by organic matter increased as pH increased. In slightly alkaline or slightly acid soil solutions the percent of copper complexed is directly proportional to the amount of organic matter but there is no direct relationship between total copper complexed and total organic carbon (56).

Apparently as soil pH is raised beyond a certain level soluble copper is precipitated as $Cu(OH)_2$. Also, increasing the pH of an organic soil results in more complexing of copper by phenolic and carboxylic groups. This view is supported by many workers (2, 37, 54, 62). Lewis and Broadbent (32) postulated that copper may be complexed by the acidic sites of the phenolic and/or carboxylic groups of the organic matter fraction. The form of the complexed ion is Cu^{++} or $CuOH^+$ depending on the stereochemistry of the ligand. $CuOH^+$ is thought to be retained on the more acidic sites in preference to Cu^{++}. Tobia and Hanna (56) using a clay soil found that the concentration of organic carbon, from Morgan's reagent extracts, was directly proportional to that of copper complexed. The complexing of copper at that pH was due to fulvic acid. A high content of lime will decrease the availability of copper to plants in the soil. This view has been supported by such workers as Byran (7), Young (62), Reuther and Smith (44).

Regardless of the total amount of copper present in a soil, its copper supplying capacity varies widely among different soils; thus total copper is no more than an inventory and does not indicate the amount of copper available to plants growing on that soil (17). Although analysis for total copper does not indicate whether a copper deficiency will occur, it does give some idea of the risk of this occurring (35).

Johnson, Van Eck and Shepherd (25) of Michigan reported that levels of copper in Missouri varied between 15 and 82 ppm; the mean values for low, medium and high soil groups being 21, 33 and 54 ppm, respectively. Lundblad, Svanberg and Ekman (35) reported 20 ppm as critical for Swedish peats.

Zinc

Although zinc deficiencies are not wide spread, several instances of deficiency symptoms in crops and yield increases through zinc fertilization have been reported.

Two factors govern the ability of a soil to provide enough zinc to a growing plant; the total supply of zinc in the soil and its availability to the plant (49). At pH greater than 7.0, available supplies of zinc are depleted by the precipitating action of hydroxides, phosphates and absorption of zinc to lime minerals (12). As pH increases, zinc availability decreases. Brown and Krantz (4) have shown that soils with less than 0.55 ppm dithizone extractable zinc respond to soil additions of $ZnSO_4$. Grunes, Boawn and Carlson (18) showed that corn and potatoes grown on a zinc deficient soil responded in yield to applications of 15 to 30 pounds of zinc sulfate. Their study showed that high pH and the presence of lime carbonate decreased zinc availability and that zinc chelates applied as foliar sprays are as effective as soil applications. Heavy applications of phosphate fertilizers, high organic matter, liming and land leveling have been known to cause a zinc deficiency (27).

Manganese

Although the total fraction of manganese may be adequate in a soil, the exchangeable and water soluble form of manganese, Mn^{++} ion, may be in short supply. The manganous ion is the only form available to the plant (50). The availability of manganese is influenced by the soil pH, soil organic matter, moisture level, temperature and biological activity. Soil conditions associated with manganese deficiency are: burned over areas, free marl or limestone, alkaline springs, high content of alkaline mineral oxides such as limonite and cold wet soils (8). Leeper (28) suggested that manganese exists in the soil in the water soluble form, exchangeable, available manganic oxides and insoluble higher oxides of manganese all of which are in equilibrium.

Wain, Silk and Wills (59) observed a rapid fixation of added manganese to an unexchangeable form by neutral or alkaline soils. As the pH is raised above 6, organic or mineral soils may become deficient in available manganese (14, 15, 20). Heintze and Mann (22) have suggested that organic soils, neutral or alkaline in reaction, may hold manganese complexed with organic matter. Mulder and Gerretsen (38) reported that in the Netherlands, the level of organic matter in soils with a pH of 6 or greater, is correlated with a manganese deficiency. Fujimoto and Sherman (16) stated that in the presence of water, manganese oxide and manganese dioxide form a hydrated complex that is insoluble and upon drying the manganous oxide is made available for plant growth. Willis (61) reported that manganese deficiency was most pronounced in wet seasons and on wet soils. Sanchez and Kamprath (48) stated that the addition of lime decreased the amount of exchangeable manganese. Leeper and Swaby (28) reported that manganese oxidizing microorganisms play an important role in the amount of available manganese.

According to Mulder and Gerretsen (38) soils with a pH of less than 5.5 may contain most of their manganese in the water soluble and/or exchangeable form. Increasing the pH of the soil favors the oxidation of manganous (Mn^{++}) to the less available manganic oxides (Mn^{3+} and Mn^{4+}) (15). Page (43) in a series of field experiments, found that the relationship of soil pH to water soluble manganese was incompatible with the theory that nonavailability of manganese is the result of the formation of insoluble higher oxides at high pH values. The formation of complexes with organic matter in the soil may account for the observed relationship of manganese and pH.

Deficiency of manganese can be corrected by the application of manganese salts and in the case of neutral or alkaline soils, by the addition of enough sulfur to acidify the soil (14). Manganese with the aid of iron assists in the synthesis of chlorophyll, since all chlorophyll tissue have the highest concentration of manganese (50).

Sodium

The yield response of some crops to sodium has been recognized by many workers. As early as 1865 Voelcker as cited by Lehr (30) obtained yield increases by treating mangels with sodium chloride. Holt and Volk (23) reported that for some plants sodium may be an essential nutrient for maximum growth and that sodium can substitute for potassium to a variable extent, depending on the plant species. Harmer and Benne (19) working with an organic soil in Michigan reported a six year average increase of 4.3 tons of sugar beets per acre from 500 pounds of sodium chloride where the average annual potash rate of application was 136 pounds per acre. Shepherd, Shickluna and Davis (51) working with a muck soil in Michigan reported that the yield increase of sugar beets due to salt decreased with increased rates of potash applied. Adams (1) reported that sodium is a nutrient for sugar beets and not a potassium substitute. He also reported that the majority of the sodium occurring within the plant, at harvest time, was in the lamina.

Chlorine

Chlorine was first proved to be an essential plant nutrient in 1954 by Broyer and his associates (5). From the same study it was shown that plants deficient in chlorine had leaves which displayed symptoms of wilt, chlorosis, necrosis and (on tomatoes) an unusual bronze color. Sugar beets, carrots, cabbage, lettuce, barley, wheat, cotton and subterranean clover were among the other species that were severely restricted in growth without supplementary chlorine. Johnson et al (24) grew sugar beets in cultural solutions with and without chlorine. It was noted that the sugar beets with minus chlorine tended to wilt more readily than those which were supplied with chlorine. Also the minus chlorine sugar beet plants had a club-like root morphology with many branched laterals as compared to the fibrous development of those plants supplied with chlorine. These authors estimate that plants require one pound of chlorine for each 10,000 pounds of dry matter produced. Ulrich and Ohki (57) reported that symptoms of chlorine deficiency appear first as a chlorosis on the leaf blades of the younger leaves of the sugar beet plant growing in cultural solutions. The main veins and the minor veins of these leaves remain green while the interveinal areas are a light green to yellow in color in the early stages of chlorosis. As the symptoms develop, the interveinal areas appear as smooth flat depressions, light green to yellow in color, which is in striking contrast to the green veins having a "raised" appearance. The roots are very stubby. From the same study it was shown that with high potassium levels there was an increase in the weights of the tops but there was no increase in the size of the storage root. When plants are high in potassium, a chlorine deficiency causes a decrease in the sucrose concentration of the beet roots, but when the plants are low in potassium, a chlorine deficiency increases the sucrose concentration of the beet roots.

MATERIALS AND METHODS

GENERAL METHODS

The crops were grown on organic soils which were acidic to slightly acidic in nature. Five field experiments and one greenhouse experiment were conducted. Records were kept of rainfall and ground and air temperatures at Vivian during the growing season (Appendix I).

FIELD EXPERIMENTS

Five field experiments were conducted during the growing seasons of 1963 and 1964. The two sites chosen for experimentation were SW4-11-8E and NE5-17-9E which are near the towns of Vivian and Stead, respectively. Vivian is located approximately 40 miles east of the city of Winnipeg while Stead is located 65 miles north east of Winnipeg. The site at Stead was chosen for investigation because it was reported that crops of low yield and quality were being produced.

The site at Vivian was chosen for investigation because of recent establishment of a commercial vegetable production in this area. These two sites shall be referred to as Vivian and Stead.

Both sites were fall worked and disked in the spring prior to fertilization and seeding. Prior to seeding, both sites received a broadcast fertilization of

200 pounds of 11-48-0 ($NH_4H_2PO_4$); Vivian received 200 pounds of 0-0-50 (K_2SO_4) while Stead received 100 pounds of 0-0-50 (K_2SO_4) on certain plots.

During the growing season of 1963, an additional 40 pounds of nitrogen and 50 pounds of potassium were side dressed next to the crop by means of a V-belt seeder. The rates of nitrogen, phosphorous and potassium used in 1963 were based on soil tests done by the Soil Science Department, Michigan State University, East Lansing. They used the Bray PI method for available phosphorous and the Spurway "reserve" method for potassium (14).

Soil tests in 1964 for all the organic soils under study were done by the Soil Science Department, University of Manitoba. The modified Harper Method (21) was employed to determine the quantity of nitrate nitrogen, Olsen's (41) 0.5M $NaHCO_3$ method was used to determine available phosphorous. Exchangeable potassium was determined with ammonium acetate at pH 7 using a flame photometer.

In both years the micronutrients boron, copper and zinc were applied at the following rates and in the following forms. Boron, 3.0 pounds per acre applied as borax. Copper 4.0 pounds per acre applied as copper sulfate. Zinc, 5.0 pounds per acre applied as zinc sulfate.

Manganese was applied at the rate of 20.0 pounds per acre in 1963 and 10.0 pounds per acre in 1964. It was applied as manganese sulfate in both years. The micronutrients in 1963 were broadcast and worked into the soil to a depth of 4 to 6 inches prior to seeding. In 1964 to insure greater accuracy of application, the micronutrients were applied by means of a V-belt seeder one week after the crop emerged, 1 to 2 inches to the sides of the row and 2 inches deep.

All crops were planted at their recommended rates of seeding. Sowing was done by means of a Planet Junior except for wheat which was sown with a seed drill. The varieties used were Great Lakes lettuce, a Nantes type carrot, Autumn Spice onion, Selkirk wheat and a monogerm type sugar beet.

The size of plots for Experiments I, II, IIIa and IV were 15 x 7.5 feet with 18 inch row spacings. There were five rows in each plot of which 10 feet of the three middle rows were harvested. The size of the main plots in Experiment IIIb were 50 x 7.5 feet; the subplots were 25 x 7.5 feet with 18 inch row spacings. There were 5 rows in each plot of which 20 feet of the three middle rows were harvested. In Experiment V the size of the main plots were 30 x 4 feet; the subplots were 15 x 4 feet with

1 foot row spacings. There were 4 rows in each plot of which 12 feet of the two middle rows were harvested. All crops were harvested manually.

EXPERIMENT I (Vivian, 1963)

Lettuce and carrots were used as test crops to evaluate their response in yield to the application of copper, manganese, boron and their combinations. Experimental design was a factorial with eight treatments replicated four times. Planting and harvest dates were June 7th and September 8th, respectively. Due to a combination of extreme heat and Aster Yellows, the lettuce crop deteriorated and was not harvested.

EXPERIMENT II (Vivian, 1963)

Onions were used as a test crop to evaluate their response in yield and skin color to the application of copper, manganese, zinc and their combinations. The experimental design, planting and harvest dates were the same as in Experiment I. Onion bulb samples from each plot were obtained and brought to the University where they were cured. After curing, the onions were evaluated visually for color of the onion bulb skins. A rating of 1 to 5 was used where 5 was the darkest brown color.

EXPERIMENT IIIa (Vivian, 1964)

Carrots and onions were used as test crops to evaluate the response in yield to the application of copper, manganese, boron, zinc and their combinations. Experimental design was a factorial, with sixteen treatments replicated four times. The onion data was not analyzed statistically for a level of significance due to the high variability between replications. Planting and harvest dates were May 28th and September 23rd, respectively.

EXPERIMENT IIIb (Vivian, 1964)

Sugar beets were used as a test crop to evaluate the response in yield and sugar content to the application of NaCl and the micronutrients copper, boron, zinc and manganese alone and in combination. A factorial split plot design was used with 32 treatments replicated four times. The subplots were used to evaluate the response in yield of sugar beets to copper, zinc, boron and manganese. The main plots were used to evaluate the response in yield to sodium, with one half of each replicate receiving 200 pounds per acre of sodium chloride, which was broadcast prior to seeding. Sugar was determined according to the Sachs-la Docte cold water digestion method (47).

EXPERIMENT IV (Vivian, 1964)

This experiment was conducted to more thoroughly evaluate the yield response to copper, observed in 1963. Onions and carrots were used as test crops. A randomized block design was used with six rates of copper replicated four times. The treatment rates were 0, 0.5, 1.0, 1.5, 2.0 and 2.5 pounds per acre of copper. Manganese, boron and zinc were applied to ensure that they would not be deficient. Planting and harvest dates were May 28th and September 23rd, respectively. Due to adverse growing conditions and variable stand, the data from the onion trial was not analyzed statistically.

EXPERIMENT V (Stead, 1964)

This was a factorial split plot design, with 32 treatments replicated four times. All four micronutrients under study and all of their possible combinations were used. Each replicate was divided longitudinally and to one half of the replicate was broadcast 100 pounds of 0-0-50 (K_2SO_4) per acre. The indicator crop was wheat which was sown and harvested May 26th and September 16th. Nitrogen was determined by the Kjeldhal method (26) which was then used to calculate percent protein.

EXPERIMENT VI

A greenhouse experiment was conducted in the late autumn and early winter of 1964. Nine different organic deposits were sampled in four different areas. One sample was from the experimental site at Vivian, two samples from the Stead area and one from a sphagnum peat deposit near the town of Julius. Five locations were sampled in the Riverton area. These different locations shall be referred to as locations 1 to 9 and are given in Table I. Some of the chemical and physical characteristics of these organic soils are given in Table II. Total copper, zinc and manganese was determined by means of a fluorescent x-ray spectophotometer. Ash was determined by means of dry ashing the soils in a muffle furnace at 550°C for 24 hours.

The test crop spinach was grown in glazed pots. Nitrogen, phosphorous and potassium were added to each organic soil as ammonium dihydrogen phosphate and potassium sulfate (chemically pure grades). Copper was added as copper sulfate at a rate of 0.75 pounds of actual copper at the time of seeding. After six weeks of growth, the plants were harvested, air dried and weighed. An unpaired "t" test (53) was used to analyze the yields statistically.

TABLE I THE CODING SYSTEM USED IN EXPERIMENT VI FOR THE ORGANIC SOILS SAMPLED AT NINE DIFFERENT SITES

Area	Legal Description	Site
Vivian	SW4-11-8E	I
Stead	NE5-17-9E	II
	NE18-17-9E	III
Riverton	SW2-24-3E	IV
	SE36-23-3E	V
	NW15-25-3E	VI
	SW23-24-3E	VII
	NW35-23-3E	VIII
Julius	NE3-12-10E	IX

TABLE II SOME CHARACTERISTICS OF THE PEAT SOILS (0 - 6") EMPLOYED IN THE GREENHOUSE EXPERIMENT. EXPERIMENT VI.

Site	pH	Cond. mmhos	O.M. %	Avail P ppm	NO_3-N ppm	Avail K ppm	Total Cu ppm	Total Zn ppm	Total Mn ppm
I	6.2	0.82	87	156	125	232	ND*	ND*	285
II	6.7	2.4	88	83	505	232	ND	0.80	892
III	6.3	0.40	87	16	57	240	0.64	ND	60
IV	5.4	1.0	70	36	170	252	23.6	14.8	480
V	6.6	2.9	37	14	205	140	15.7	32.7	740
VI	4.0	0.12	93	35	6	440	ND	ND	68
VII	6.5	0.70	84	28	186	300	0.47	0.78	54
VIII	6.5	0.55	98	7	75	40	ND	ND	Trace
IX	4.2	0.09	97	13	17	212	1.00	0.14	26

ND* - Not Detectible.

RESULTS AND DISCUSSION

EXPERIMENT I (Vivian, 1963)

The data in Table III shows the effects of the micronutrients boron, copper and manganese, alone and in combination, on the yield of carrots at Vivian in 1963.

TABLE III THE EFFECT OF MICRONUTRIENTS, APPLIED ALONE AND IN COMBINATION ON THE YIELD OF CARROTS AT VIVIAN IN 1963

Treatment	Mean Yield Tons/acre
B + Cu	23.74
Mn + Cu	23.50
Cu	23.01
Cu + B + Mn	22.61
Check	18.40
Mn + B	17.53
B	16.31
Mn	14.37

In this and all ensuing tables where Duncan's Multiple Range Test was used, there are no significant differences between yields within groups indicated by vertical lines. (P = 0.05)

The treatment means can be divided into three groups which differ significantly from each other. In the first group are the four treatments containing copper. Copper when applied at the rate of 0.75 pounds per acre significantly increased the yield of carrots. In the second group are the check and the Mn + B treatments. In the third group, significantly lower than group two, are the manganese and boron treatments. It would appear that manganese and boron when applied separately resulted in a detrimental effect and a yield reduction. This effect did not occur when boron and manganese were applied together.

The Cu + B + Mn interaction was significant. This interaction was not investigated to determine what caused it. Further work would have to be done to substantiate this finding.

EXPERIMENT II (Vivian, 1963)

The data in Table IV shows the effect of copper, manganese and zinc on yield of onions and onion bulb skin color. The individual treatment means are shown in Table IV.

TABLE IV EFFECT OF MICRONUTRIENTS, APPLIED ALONE AND IN COMBINATION, ON THE YIELD OF ONIONS AND ONION BULB SKIN COLOR AT VIVIAN IN 1963

Treatment	Mean Yield Tons/acre	Bulb Skin Color (a)
Mn + Cu	15.30	4.12
Cu	14.47	4.12
Cu + Zn	13.05	3.50
Cu + Zn + Mn	12.15	3.62
Zn	9.10	1.75
Check	9.06	1.90
Mn	6.19	1.75
Zn + Mn	5.56	1.50

(a) Onion color was rated from 1 to 5 (5 being the best).

The treatment means for both yield and skin color can be divided into two distinct groups which differ significantly from each other. In the first group are the four treatments which include copper. Copper applied at 0.75 pounds per acre significantly increased the yield of onion bulbs. Onion bulb skins had a darker brown color where copper was applied and the effect was significant. In the second group, the check and the three treatments not containing copper are significantly lower in yield. It appears that manganese and Mn + Zn treatments are lower in yield but they are not significantly lower in yield than the check. This indicates again, as in Experiment I, a detrimental effect from manganese.

Treatments had almost identical effects on yield and on bulb skin color. The correlation coefficients were 0.491 for error term and 0.948 for treatment components and are statistically significant (Appendix V). The treatments which gave the highest yields produced the most desirable skin color. The treatments which gave the lowest yields produced the least desirable skin color.

EXPERIMENT IIIa (Vivian, 1964)

The data in Table V shows the effect of the micronutrients copper, manganese, boron and zinc alone and in combination on the yield of carrots.

TABLE V THE EFFECT OF THE MICRONUTRIENTS COPPER, MANGANESE, BORON AND ZINC ALONE AND IN COMBINATION ON THE YIELD OF CARROTS AT VIVIAN IN 1964

Treatment	Mean Yield Tons/acre
Check	9.50
Mn	7.75
B	8.27
Cu	9.84
Zn	10.39
Mn + B	8.62
Mn + Cu	9.57
Mn + Zn	8.92
B + Cu	9.22
B + Zn	8.13
Cu + Zn	8.92
Mn + B + Cu	9.28
Mn + B + Zn	8.37
Mn + Cu + Zn	8.79
B + Cu + Zn	8.84
Mn + B + Cu + Zn	8.73
	N.S.

The applied micronutrients did not have a significant effect on the yield of carrots. The coefficient of variability for this experiment was very high (19.16%). The possible reason for the high variability in the experiment was due to the growing conditions which were not ideal. In the spring after planting there was a prolonged period (28 days) of no precipitation, resulting in poor germination and an uneven stand. In addition to cool temperatures during the growing season, there were 2 to 3 F. degrees of frost. On September 14th there were 12 F. degrees of frost that killed the carrot crop. Plants under such a stress grow slowly and thus require less nutrients generally, including micronutrients. Possibly for these reasons there was no yield response to copper as in 1963.

The same growing conditions affected the onion crop. As a result of this the onions did not mature and no marketable yield results could be obtained. However, the onions were harvested for total bulb yield, but the range of variability within treatments for onions (for example 12.6, 13.0, 9.7 and 5.6) exceeded variability between treatments (0.7, 3.1, 0.5 and 0.6) and it may be assumed that treatment means are not significant.

EXPERIMENT IIIb (Vivian, 1964)

The data in Table VI shows the effect of NaCl and the micronutrients copper, manganese, boron and zinc alone and in combination on the yield and percent sugar of sugar beets.

TABLE VI THE EFFECT OF NaCl AND THE MICRONUTRIENTS COPPER, BORON, ZINC AND MANGANESE ALONE AND IN COMBINATION ON THE YIELD OF SUGAR BEET ROOTS AND PERCENT SUGAR

Treatment	Plus NaCl Root Yield Tons/acre	Plus NaCl Sugar Percent	Minus NaCl Root Yield Tons/acre	Minus NaCl Sugar Percent
Check	4.64	11.9	3.78	10.4
Mn	4.05	11.1	3.98	10.2
B	3.78	11.9	4.01	9.9
Cu	4.90	11.2	3.65	9.9
Zn	4.33	11.8	3.72	10.5
Mn + B	4.83	11.1	3.98	11.1
Mn + Cu	4.55	10.8	4.88	10.3
Mn + Zn	4.78	11.5	4.16	10.6
B + Cu	4.99	10.8	4.61	10.4
B + Zn	4.34	12.2	4.25	10.9
Cu + Zn	5.19	11.4	4.54	10.0
Mn + B + Cu	5.08	11.7	4.55	11.0
Mn + B + Zn	4.95	10.9	4.14	10.6
Mn + Cu + Zn	4.75	11.4	4.38	10.4
B + Cu + Zn	4.47	10.9	4.15	10.3
Mn + B + Cu + Zn	4.95	11.1	4.36	10.5
	N.S.	N.S.	N.S.	N.S.

The applied micronutrients did not significantly affect the yield or percent sugar of sugar beets. The reasons for this are probably the same as given in Experiment IIIa. However, when the effect of NaCl on sugar beets was analyzed separately, a significant response in yield and in percent sugar was obtained. The yield of sugar beet roots was increased 0.41 tons per acre where NaCl was applied. This is a 11.0 percent increase in yield. Sugar was increased from 10.45 to 11.36 percent. This type of response is similar to reports from work done in other areas by other investigators (1, 19, 23, 51). The response in yield and sugar content to the applied NaCl may be attributed to a deficiency of sodium or chloride. Although sodium has not been proved to be an essential plant nutrient, there have been reports (23, 30) strongly indicating that it could be for sugar beets. Sodium can partially substitute for potassium when potassium is limiting (19, 57, 58) and the response may be due to a sparing action on potassium requirement if potassium was deficient in these muck soils. Chloride was proven to be an essential plant nutrient in 1954 (5) and it is possible that the observed response is due to the additional chloride. Sugar beets have been shown by Johnson et al (24) to be very responsive to chloride. Ulrich and Ohki (58) report that when plants are low in potassium, a chloride deficiency increases the sucrose concentration of the beet roots.

Figure I shows the effect of NaCl on reducing the damage due to frost. Several theories can be postulated for this beneficial effect of NaCl in increasing frost hardiness in these sugar beet plants.

(1) The application of 200 pounds per acre of NaCl could have resulted in a higher solute concentration in the plant as compared to those plants where no NaCl was applied. Adams (1) reported that increasing the concentration of sodium in the soil resulted in a greater sodium concentration in the plant. The majority of sodium was in the lamina. Levitt (31) reported there are two types of water binding - one by osmotically active the other by colloidal substances. He also reported that most of the results showing a correlation between bound water and hardiness have been due to osmotically bound water. The correlation with frost hardiness involves both an increase in solutes during hardening and a parallelism between the solute concentration and the hardiness of different varieties. Tullin (57) applied various rates of NaCl to sugar beets and he also measured the concentration of NaCl in the leaves. At the

Figure 1 - Resistance to frost damage of sugar beets due to application of 200 lbs. sodium chloride (right side) vs no sodium chloride (left side). Exp. IIIb (Site I, 1964).

maximum concentration of NaCl in the leaves there could only be a freezing point depression of 0.86° F. of the cell sap. Thus it is possible that NaCl could increase hardiness by increasing osmotically bound water but only to a limited degree.

(2) Vasil'yev (64) reported that potassium fertilizers, as a rule, strengthen frost resistance. Arland (64) believes that potassium is responsible for the better development of surface tissues and thereby intensifies hardiness. From the same report, Stoklasa reported that beets taken from soil lacking available potassium had a low rate of respiration. These plants were less hardy and more severely injured by all kinds of fungus infections. Sodium too had a beneficial effect on hardiness. Sodium has been shown to substitute for potassium within the plant when potassium is limiting. Thus it is possible that when sodium was added there was more potassium available for metabolic roles and the sugar beets were more hardy.

(3) It is possible that the increased frost resistance of the sugar beet plants was due to the addition of chloride. Johnson et al (24) have shown that chloride is essential for sugar beet growth. Although chloride has not been

shown to be limiting in these soils, it is possible that this observed effect is due to its application. This could have resulted in a healthier plant. Tullin (57) has shown that there is a competitive effect between chloride and nitrate ions. Thus if the uptake of the nitrate ions was reduced by the chloride ion in the plants, the plant could have been less succulent.

These actions of NaCl are, however, very speculative and no definite conclusions can be made without additional work.

EXPERIMENT IV (Vivian, 1964)

As shown by the data in Table VII the yield of carrots was increased significantly by the application of 0.50 pounds per acre of copper. However, increasing the rate of copper as high as 2.50 pounds per acre did not result in a significant yield increase over the 0.50 pound per acre rate.

TABLE VII THE EFFECT OF SIX RATES OF COPPER ON THE YIELD OF CARROTS AT VIVIAN IN 1964

Copper lbs/acre	Mean Yield tons/acre
0	9.15
0.50	13.91
1.00	15.06
1.50	14.50
2.00	14.00
2.50	15.41

EXPERIMENT V (Stead, 1964)

Potassium applied at a rate of 50 pounds K_2O/acre caused a significant reduction in the yield of wheat. The mean yield of all plots which received no potassium was 18.23 bushels/acre. The mean yield of all plots which received the application of 50 pounds K_2O/acre was 13.88 bushels/acre. This is a reduction of 4.35 bushels/acre. Potassium applied to organic matter does not revert to non-exchangeable forms; clay minerals differ in that potassium can revert to non-exchangeable forms (13). Certain elements such as potassium, calcium and magnesium need to be in a reasonable balance for proper plant utilization. It is possible that an overabundance of one of these elements could result in a deficiency of the others. A marked deficiency of magnesium has been observed by Lucas (33) in tomatoes grown in the greenhouse because of large potash application. It is possible that an overabundance of applied potassium resulted in an imbalance which could result in a suppression in yield. A second possible reason why potassium decreased yields could be due to the salt effect on the germinating seeds. This was not noticed however. This would result in a lower germination, which would subsequently reduce yields.

From the analysis of variance (Appendix IX) there is a significant effect on the yield of wheat of the following components: K, Cu, K x Cu, Zn x Mn, Zn x B and Cu x Zn x Mn. The effect of copper, manganese, zinc and boron on the yield of wheat, with and without potassium is shown in Table VIII.

TABLE VIII THE EFFECT OF COPPER, MANGANESE, ZINC AND BORON ON THE YIELD OF WHEAT IN BUSHELS/ACRE, WITH AND WITHOUT POTASSIUM AT STEAD IN 1964

Micronutrient Lbs/acre		Rate of K_2O Lbs/acre 0	50
Cu	0	19.94	12.50
Cu	4.0	18.43	15.14
Mn	0	17.78	13.70
Mn	10.0	19.24	13.94
Zn	0	18.10	14.18
Zn	5.0	18.27	13.46
B	0	17.62	14.18
B	3.0	18.67	13.46
Mean		18.23	13.88

Copper gave a significant increase in yield but only when potassium was applied. When copper was applied with potassium, there was an increase in yield of 2.64 bushels/acre. When copper was applied without potassium, there was little or no effect on yield.

The yield data for the two first order interactions, Zn x Mn and Zn x B, are presented in Tables IX and X.

TABLE IX THE EFFECT OF ZINC AT TWO LEVELS OF MANGANESE AND MANGANESE AT TWO LEVELS OF ZINC ON THE YIELD OF WHEAT AT STEAD IN 1964.

Rate of Manganese Lbs/acre	Rate of Zinc Lbs/acre	
	0	1.25
0	15.22	16.26
10.0	17.14	15.38

TABLE X THE EFFECT OF ZINC AT TWO LEVELS OF BORON AND BORON AT TWO LEVELS OF ZINC ON THE YIELD OF WHEAT AT STEAD IN 1964.

Rate of Boron Lbs/acre	Rate of Zinc Lbs/acre	
	0	1.25
0	16.74	15.06
3.0	15.54	16.58

Although these interactions are statistically significant, little reliance can be placed on the results. On examining the Mn x Zn interaction, it was found that when either micronutrient was applied alone yield was increased, but when they were applied together there was little or no effect on yield. On examining the B x Zn interaction, it was found that when either micronutrient was applied alone yield was reduced but when they were applied together, again there was little or no effect on yield.

The point is that in one case zinc alone increases yield, in the other case zinc alone decreases yield. This is because in the two interactions the means of the zinc treatments are obtained from different treatment means. To prove the validity of these first order interactions and the second order interactions Cu x Zn x Mn, further work would have to be done.

EXPERIMENT VI

The application of copper sulfate at 0.75 pounds per acre resulted in a significant increase in yield of spinach when applied to the organic soils sampled from Site I, Site VII and Site VIII (Table I). As indicated in Table II, these soils have a very low amount of total copper. This could explain the general response in plant growth when this element was added. Spinach could not be established on the organic soils sampled at Site VI and Site IX.

In the field experiment at Stead, there was a significant increase in the yield of wheat when copper was added with potassium (Table VIII). In the greenhouse experiment using the organic soil (Site II) sampled from the site at Stead, there was very little effect when copper was added. The lack of a significant increase in yield could be due to the fact that a different plant species was being used as a test crop or it could be due to a deficiency of one of the other micronutrients since zinc, boron and manganese were not applied to the soils in the greenhouse experiment. This is borne out by the fact that the spinach showed symptoms of a nutrient deficiency and by the fact that in the field experiment the Zn + B and Cu + Zn + B interactions were significant.

TABLE XI THE EFFECT OF 0.75 POUNDS/ACRE OF COPPER ON THE DRY WEIGHT OF SPINACH GROWN FOR SIX WEEKS IN THE GREENHOUSE ON ORGANIC SOILS FROM NINE DIFFERENT LOCATIONS

Site	Mean Yield Copper 0.75 Lbs/acre	Check
I	4.29**	3.49
II	4.29	4.11
III	3.62	3.15
IV	4.74*	4.02
V	3.95	2.90
VI	0	0
VII	4.47	3.20
VIII	4.29**	3.09
IX	0	0

** Significant at the 1% level of probability.

* Significant at the 5% level of probability.

SUMMARY

Investigation of the comparative effects of various micronutrients, as measured by yield and quality response were conducted on organic soils from nine different locations. The study consisted of five field experiments during the growing seasons of 1963 and 1964 and a greenhouse experiment during the winter of 1964/65.

Results of the field experiments at Vivian.

(1) The application of copper resulted in a significant increase in the yield of carrots and onions.

(2) The application of 0.50 pounds per acre of copper resulted in yields of carrots as high as those where higher rates of copper were used.

(3) The application of copper to onions resulted in a significant increase in the color of onion bulb skins.

(4) There were no significant increases in yield of the test crops where zinc, manganese and boron were applied.

(5) The application of 200 pounds per acre of sodium chloride caused a significant increase in the yield of sugar beet roots and percent sugar. There was also an apparent increase in frost hardiness of the sugar beets where sodium chloride was applied.

Results of the field experiment at Stead.

(1) When copper was applied with potassium there was a significant increase in the yield of wheat. When copper was applied alone this effect was not observed.

(2) Potassium applied as K_2SO_4 at 100 pounds per acre significantly reduced the yield of wheat at Stead.

Results of the greenhouse experiment.

(1) The application of copper caused a significant increase in the yield of spinach at three of the nine sites studied.

(2) These three locations where a response in yield was observed due to copper are low in total copper. This would explain the general response in plant growth when this element was added.

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APPENDIX I

MONTHLY MEAN TEMPERATURES OF AIR AND SOIL DURING THE GROWING SEASONS OF 1963 AND 1964

Month	Temperature Air	Temperature Soil
1963		
May	42.5	44
June	61.8	60
July	68.5	66
August	63.5	63
September	57.0	63
1964		
May	44.5	37
June	56.5	42
July	66.5	54
August	58.5	53
September	50.0	49

APPENDIX II

THE SOURCE AND PERCENTAGE OF MICRONUTRIENTS USED

Micronutrient	Source	Percentage
Boron	$Na_2B_4O_7.10H_2O$	11.0
Copper	$CuSO_4.5H_2O$	25.2
Zinc	$ZnSO_4.H_2O$	36.0
Manganese	$MnSO_4$	27.3

APPENDIX III

ANALYSIS OF VARIANCE FOR THE EFFECT OF THE MICRONUTRIENTS MANGANESE, BORON AND COPPER ALONE AND IN COMBINATION ON THE YIELD OF CARROTS AT VIVIAN IN 1963. EXPERIMENT I.

Source	d.f.	S.S.	M.S.	F
Reps.	3	32.1500	10.7167	
Treat.	7	1646.6450	235.2350	
Mn	1	24.1512	24.1512	
B	1	1.4450	1.4450	
Cu	1	1476.9612	1476.9612	82.66**
Mn + B	1	27.7513	27.7513	
Mn + Cu	1	10.5801	10.5801	
B + Cu	1	3.5113	3.5113	
Mn + B + Cu	1	102.2449	102.2449	5.72*
Error	21	375.2050	17.8669	
Total	31	2054.0000		

** Significant at P = 0.01

* Significant at P = 0.05

APPENDIX IV

AN ANALYSIS OF VARIANCE FOR THE EFFECT OF THE MICRONUTRIENTS MANGANESE, COPPER AND ZINC ALONE AND IN COMBINATION ON THE YIELD OF ONIONS AT VIVIAN IN 1963. EXPERIMENT II.

Source of Variance	d.f.	S.S.	M.S.	F
Reps.	3	190.2153	63.4051	
Treat.	7	1575.0088	225.0012	
Mn	1	98.0000	98.0000	
Cu	1	1308.1613	1308.1613	36.84**
Zn	1	50.5013	50.5013	
Mn + Cu	1	78.1250	78.1250	
Mn + Zn	1	9.6800	9.6800	
Cu + Zn	1	29.2612	29.2612	
Mn + Cu + Zn	1	1.2800	1.2800	
Error	21	745.7947	35.5140	
Total	31	2511.0188		

** Significant at P = 0.01

APPENDIX V

ANALYSIS OF VARIANCE FOR THE CORRELATION BETWEEN ONION YIELD (x) AND ONION BULB SKIN COLOR (y) DUE TO THE EFFECT OF THE MICRONUTRIENTS MANGANESE, COPPER AND ZINC ALONE AND IN COMBINATION.

Source	d.f.	x	xy	y	d.f.	r
Reps.	3	2.0560	0.3013	0.1609	2	+ 0.911
Treatment	7	4.6805	7.7243	1.7410	6	+ 0.948**
Error	21	3.3360	1.2399	0.7570	20	+ 0.491*
Variance + Error	28	5.7476	8.9642	1.8985	27	+ 0.822
Total	31	6.1051	9.2655	1.9053	30	+ 0.796

APPENDIX VI

ANALYSIS OF VARIANCE FOR THE EFFECT OF THE MICRONUTRIENTS BORON, COPPER, ZINC AND MANGANESE ALONE AND IN COMBINATION ON THE YIELD OF CARROTS AT VIVIAN IN 1964. EXPERIMENT IIIa.

Source	d.f.	S.S.	M.S.	F
Reps.	3	97.2537	32.4179	2.8049
Treatment	15	116.6275	7.7751	
Cu	1	11.2225	11.2225	0.8936
Zn	1	0.9506	0.9506	
Mn	1	10.0806	10.0806	
B	1	19.1406	19.1406	1.5242
Cu + Zn	1	19.5806	19.5806	1.6592
Cu + Mn	1	4.9506	4.9506	
Cu + B	1	4.7306	4.7306	
Zn + Mn	1	0.0225	0.0225	
Zn + B	1	3.0625	3.0625	
Mn + B	1	18.4901	18.4901	
Cu + Zn + Mn	1	0.0401	0.0401	
Cu + Zn + B	1	11.2226	11.2226	
Cu + Mn + B	1	12.6025	12.6025	
Zn + Mn + B	1	0.5256	0.5256	
Cu + Zn + Mn + B	1	0.0055	0.0055	
Error	33	414.3963	12.5574	
Total	63	628.2775		

C.V. = 19.16%

APPENDIX VII

ANALYSIS OF VARIANCE FOR THE EFFECT OF NaCl ON SUGAR BEET YIELD AT VIVIAN IN 1964. EXPERIMENT IIIb.

Source of Variance	d.f.	S.S.	M.S.	F
Treat.	1	248.227	248.227	16.978**
Reps.	3	121.360	40.45	
Error	123	1798.268	14.62	
Total	127	2167.855		

** Significant at P = 0.01

APPENDIX VIII

AN ANALYSIS OF VARIANCE OF THE EFFECT OF VARIOUS RATES OF COPPER ON THE YIELD OF CARROTS AT VIVIAN IN 1964.

EXPERIMENT IV

Source of Variance	d.f.	S.S.	M.S.	F
Treat.	5	524.7	104.9	3.73*
Reps.	3	8.22	2.74	
Error	15	421.33	28.08	
Total	23	954.15		

* Significant at P = 0.05

APPENDIX IX

ANALYSIS OF VARIANCE FOR THE EFFECT OF MICRONUTRIENTS AND POTASSIUM ON THE YIELD OF WHEAT AT STEAD IN 1964

EXPERIMENT V

Source of Variance	S.S.	d.f.	M.S.	F
Reps.	45,774.3984	3	15,258.1328	
K	94,015.3200	1	94,015.3200	19.68*
Error	14,329.7738	3	4,776.5913	
Total (a)	154,119.4922	7		
Cu	12,187.5080	1	12,187.5080	7.72**
Zn	508.0050	1	508.0050	
Mn	1,206.6300	1	1,206.6300	
B	118.2000	1	118.2000	
Cu + Zn	354.4020	1	354.4020	
Cu + Mn	973.5090	1	973.5090	
Cu + B	717.2520	1	717.2520	
Zn + Mn	9,852.5750	1	9,852.5750	6.24*
Zn + B	8,894.4450	1	8,894.4450	5.63*
Mn + B	679.8800	1	679.8800	
Cu + Zn + Mn	7,275.2360	1	7,275.2360	4.61*
Cu + Zn + B	3,773.6810	1	3,773.6810	
Cu + Mn + B	202.5110	1	202.5110	
Zn + Mn + B	1,006.8800	1	1,006.8800	
Cu + Zn + Mn + B	70.4590	1	70.4590	
K + Cu	6,370.3840	1	6,370.3840	4.04*
K + Zn	995.6900	1	995.6900	
K + Mn	381.5620	1	381.5620	
K + B	3,559.5650	1	3,559.5650	
K + Cu + Zn	8.5580	1	8.5580	
K + Cu + Mn	468.9510	1	468.9510	
K + Cu + B	82.7630	1	82.7630	
K + Zn + Mn	707.7420	1	707.7420	
K + Zn + B	3,601.8920	1	3,601.8920	
K + Mn + B	207.5820	1	207.5820	
K + Cu + Zn + Mn	122.0130	1	122.0130	
K + Cu + Zn + B	969.6130	1	969.6130	
K + Cu + Mn + B	4,085.0630	1	4,085.0630	
K + Zn + Mn + B	3,270.4500	1	3,270.4500	
Error	143,560.0615	91	1,577.5831	
Total (b)	370,332.5547	127		

C.V. (a) = 33%

C.V. (b) = 19.4%

** Significant at P = 0.01

* Significant at P = 0.05

APPENDIX X

ANALYSIS OF VARIANCE FOR THE COMBINED EFFECT OF MICRONUTRIENTS AND POTASSIUM ON WHEAT PROTEIN AT STEAD IN 1964. EXPERIMENT V

Source of Variance	d.f.	S.S.	M.S.	F
Treat.	15	12.3602	.8240	1.583
Reps.	3	2.489	.6829	
Error	45	23.4208	.5204	
Total	63	38.2700		

APPENDIX XI

ANALYSIS OF VARIANCE FOR THE EFFECT OF MICRONUTRIENTS ON WHEAT PROTEIN AT STEAD IN 1964.

EXPERIMENT V

Source of Variance	d.f.	S.S.	M.S.	F
Treat.	15	5.155	.343	.79
Reps.	3	2.235	.745	
Error	45	19.613	.43	
Total	63	27.002		