THE EFFECTS OF FERTILIZERS ON THE YIELD AND CHEMICAL COMPOSITION OF CROPS GROWN ON ORGANIC SOILS

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ABSTRACT

THE EFFECTS OF FERTILIZERS ON THE YIELD AND CHEMICAL COMPOSITION OF CROPS GROWN ON ORGANIC SOILS

by Lawrence N. Shepherd

Studies were initiated on Michigan organic soils to determine: (a) crop response to variable rates of sodium chloride and potash; (b) methods of control of magnesium deficiency associated with certain Pascal celery varieties; (c) the need for and methods of application of molybdenum for crop production; and (d) the effect of placement of phosphorus and manganese fertilizers on the availability of manganese.

A field experiment was carried out at the Michigan Muck Experimental Farm to determine the effects of rates of sodium chloride at varying rates of residual and applied potash on the yield and chemical composition of sugar beets.

A three-ton increase in the yield of sugar beet roots was obtained from plots treated with sodium chloride at low rates of potash, and no yield increase was obtained where the potash rate was 600 pounds per acre. A partial substitution of sodium for potassium occurred with the sugar beet

plant. Sodium and potassium were antagonistic to each other, as evidenced in plant uptake, and either or both suppressed the uptake of magnesium and calcium. The level of residual potassium in the soil was not maintained even at a 600-pound annual application of potash per acre.

Field experiments were conducted to determine the residual effect of hydrated magnesium sulphate (9.87% Mg) applied as high as 10,000 pounds per acre to the soil on the control of magnesium deficiency symptoms on the leaves of Utah 10B celery. A second field experiment was carried out to study the interaction of levels of potash and magnesium on the yield and chemical composition of celery.

Controlling the symptoms of magnesium deficiency on the leaves of Utah 10B celery did not significantly affect the yield of the crop. Magnesium sulphate applied at 10,000 pounds per acre to the soil was less effective in the control of the symptoms than 80 pounds of magnesium sulphate applied in eight applications of ten pounds each as a foliar spray.

The magnesium composition of the above-ground portion of celery did reflect the magnesium treatment to the soil. However, the magnesium content of the plant was not considered as a reliable index to the incidence of magnesium deficiency symptoms occurring on the leaves of the plant. Potash applied at 1,200 pounds per acre suppressed the yield of celery and the uptake of magnesium by the plant. This was not true, however, with calcium.

Field and greenhouse experiments were initiated to determine crop response from molybdenum. Molybdenum analyses of plant tissue were made to determine availability of the element to plants from various methods of application.

Significant increases in the yield of cauliflower, onions, lettuce and spinach were obtained from molybdenum applied to several Michigan organic soils.

In a field experiment of split-plot design, broadcast sodium-molybdate applications to the soil were ineffective in increasing the yield or molybdenum content of spinach. However, the split-plot treatment of Moly-Gro (38% Mo) applied on the seed significantly increased the yield of spinach. When molybdenum seed treatment was coupled with one-half pound of sodium molybdate per acre, mixed with the basic fertilizer and banded two inches below the seed of cauliflower, the molybdenum content of the oven-dry tissue was 9.5 parts per million.

The molybdenum seed treatment at one-half ounce per acre of Moly-Gro increased the molybdenum content of the tissue by .2 to .4 of a part per million in the oven-dry tissue.

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It was found that banding a phosphate carrier two inches to the side and two inches below the seed of soybeans increased the yield to about the same extent as a broadcast application of 20 pounds of manganese per acre. The data indicated that the increased yields from the band application of phosphorus were the result of enhanced availability of manganese rather than the phosphate uptake by the crop.

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This thesis is affectionately dedicated

to my wife and daughter.

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INTRODUCTION

Studies reported herein are related to four problem areas of crop production on Michigan organic soils. These are: (a) the response of some crops to sodium chloride; (b) the magnesium deficiency associated with certain varieties of celery; (c) crop response to molybdenum; and (d) the effect of phosphate and manganese placement on the availability of manganese to soybeans.

In general, sodium is not considered as an essential element for the growth of plants; however, the yield response of some crops to sodium has been known for nearly one hundred years. In Michigan sodium chloride is recommended on organic soils for the celery and beet crops. Reports from growers have indicated inconsistent results from the application of sodium chloride to organic soils where salt responsive crops were grown; however, the results obtained in Michigan studies over the years indicate the response from sodium to be related to the level of residual potassium in the soil or to the rate of potash fertilizer applied to the soil for the crop, with response to sodium chloride decreasing with increased available potassium. The sodium chloride study was initiated on existing plots at the Michigan Muck Experimental Farm to determine the yield response of sugar beets to sodium chloride at various soil levels of residual potassium and to determine the yield response of this crop where additional rates of potash were applied across soil varying in levels of potassium.

Some Pascal celery varieties show very serious magnesium deficiency symptoms when grown on the organic soils of Michigan. In fact, to the present, certain varieties of celery are the only crops grown on organic soils in Michigan on which a magnesium problem has been known to occur. In general, the problem is one of quality as indicated by marked yellowing of the foliage. Yield loss is usually caused by trimming the outer petioles to remove the yellow appearance of the celery stalk rather than a loss of dry matter produced per acre from inadequate magnesium for plant growth. Johnson (40) reported that the magnesium deficiency of celery grown on organic soil could be corrected by applying high rates of magnesium compounds to the soil; and he stated that for mature susceptible varieties when the magnesium content was raised to .144 percent or above in the above-ground portion of the plant no symptoms of deficiency developed. This magnesium work was carried out as a follow up to Johnson's studies to determine the residual value of high rates of magnesium sulphate in controlling the symptoms and to obtain additional data on the composition at the deficiency level in the plant.

The first indication that a molybdenum problem existed on organic soils in Michigan was recognized by Lucas (48) in comparing the chemical composition of onion leaves obtained from a problem area with leaves from an area where the onions were growing normally. Onion leaves from the problem area contained only .05 parts per million of molybdenum in the tissue, whereas the normal plants contained 0.7 parts per million of molybdenum. Hosner (38) demonstrated the first known response to this element on organic soil in this country in a greenhouse study using lettuce and cauliflower as indicator crops. To determine the need for this element in fertilizer recommendations for crop production on organic soils, studies were initiated both in the field and the greenhouse.

In fertilizer placement studies, response of some crops appeared to be greater than should be expected from the elements applied in the fertilizer band; also, many crops appear to suffer from inadequate manganese because of method of application, rate, or choice of the carrier used. The phosphate-manganese study was initiated to determine the effect of placement of phosphate and manganese fertilizers on the availability of manganese.

REVIEW OF LITERATURE

Sodium Chloride

In general, sodium is not considered at the present time to be an essential element for the growth of plants; however, the yield response of some crops to sodium has been known for nearly one hundred years. Voelcker, as cited by Lehr (47), obtained yield increases of mangels from soil treatments of sodium chloride as early as 1865.

The most common role of sodium in plant growth was attributed to the substitution of this element for potassium (66). The amount of sodium substitution for potassium was reported to be from two-thirds the total potassium requirement for a crop (30) to no response for some species of plants. Cope et al. (13) obtained yields of crops equal to potassium-treated plots where one-half the potassium requirement was substituted with sodium. Sayre (61) used sodium at four levels to replace one-fourth the potassium requirement of soybeans and table beets. He concluded that sodium chloride should be considered more as an important ingredient of the fertilizer mixture than as a substitute for part of the potassium.

Dorp-Petersen and Steenbjerg (22) concluded that sodium has some of the same functions as potassium in plants and can be substituted for it in part. Their pot experiments showed that sodium did not replace equivalent amounts of potassium in plant tissue and that two to three times as much sodium was required in the plant to produce the same effect in increasing yield as potassium. They obtained no response in plant growth from sodium when the level of potassium was adequate.

Harmer and Benne (33) showed an absence of response to sodium when the level of potassium in the soil was very low.

Aldrovandi (1), in studying potassium and sodium relationships on soils of Italy, found no response in beet yields from sodium where the soils were low enough in available potassium to obtain a response from potassium.

Decoux *et al*. (20) obtained the highest yield of sugar (6.243 kg. per ha.) where the plots received 60 kilograms of potash and 119 kilograms per hectare of sodium oxide equivalent, while the lowest yield of sugar (5.884 kg. per ha.) was obtained from plots receiving a soil treatment of 240 kilograms per hectare of potash.

Harmer and Benne (33) classified crops according to their degree of response to sodium. Harmer *et al*. (34) reported that not only were there differences among species in their response to sodium, but varieties of the same species were markedly different in their response.

Cope and co-workers (13) attributed yield increases of corn, sudangrass and alfalfa to increased potassium adsorption when sodium was applied to the soil. Yield increase of ladino was believed to be a combined effect from sodium substitution for potassium and from increased adsorption of potassium. When soils were fertilized with sodium and cropped by oats, the potassium content of the oat tissue was decreased and large amounts of sodium were adsorbed. The yield increase of oats was attributed to a sodium substitution for potassium. They found that the addition of sodium to a Mardin silt loam increased the release of nonexchangeable potassium by about 40 percent as measured by ladino clover and alfalfa uptake. On the other hand, the application of potassium decreased the release of nonexchangeable potassium. The application of potassium or sodium to the soil tended to reduce the content of calcium and magnesium in plants grown on it.

According to Bower and Wadleigh (10), increasing the percent saturation of the exchange complex with sodium tended to decrease the level of calcium, magnesium and potassium in plants.

Larson and Pierre (46) found the effectiveness of sodium to be 100, 40, 29 and 1 percent as effective as potassium on a Carrington loam with the growth of beet roots, flax grain, oat grain and corn, respectively. They suggested that the response of various crops to potassium or sodium might be estimated from the value of K + (X) (Na), where K = exchangeable potassium in me. per 100 grams, Na = exchangeable sodium in me. per 100 grams, and X = a factor specific for each crop. Their correlation coefficients of total (K + Na) contents versus yield of beets were 0.91 and 0.93 for two soils, compared with values of 0.24 and 0.46 respectively for K alone versus yield. They concluded that this information indicates that at low soil potassium levels, the amounts of exchangeable potassium may not be a reliable index to response of sodium-responsive crops to potassium fertilizers. The additions of sodium to the soil will generally depress the uptake of potassium by plants. In some cases it may have no effect, or may even slightly increase the uptake of potassium. Additions of either sodium or potassium will generally depress the uptake of calcium and magnesium, but additions of one may have little effect if calcium and magnesium have already been depressed by the other.

Several workers (11, 12, 37, 45), studying the effect of sodium on the yield response of the cotton plant at low levels of potassium, have demonstrated marked response of cotton to sodium on potassium-responsive soils. In general, the response to sodium decreases with increased rate of potash applied. In some cases, sodium from sodium nitrate was more effective in increasing the yield of cotton than an equivalent amount of potash (45). Marshall and Sturgis (51) decreased the yield of seed cotton with sodium chloride at a rate of 72 pounds of Na_2O equivalent but increased yields when sodium nitrate was used. This suggests that the cotton plant is very sensitive to chloride.

Bear (7) has described the tendency of plants to maintain a constant level of cations and anions in plant tissue per unit of dry matter. Additions of too much potassium may repress adsorption of calcium, or too much chlorine may lower nitrogen uptake by the crop.

Younts and Musgrave (76) have reported depressed corn growth from chlorine rates of 45 to 90 pounds per acre (60 to 120 pounds K_2O as KCl) when applied in the row. Teater et al. (69) found the yield of corn was not affected by chlorine rates up to 90 pounds in the row and 540 pounds broadcast. However, a chloride rate of 120 pounds per acre in the row did depress corn yield significantly in one year out of two. They stated the amount of chloride accumulating in the top soil after two years of heavy fertilization with ammonium chloride was relatively insignificant. Haas (32) has suggested that an application of 100 pounds or less of chlorides per acre may interfere with carbohydrate metabolism in tobacco plants, resulting in excessive starch accumulation in the leaves. Also associated with increased salts are decreased percentages of nitrate-nitrogen and protein nitrogen in plants.

In nutrient solution studies, Truog et al. (71) found that the amount of water required per gram of dry matter produced was considerably less with the addition of sodium to the nutrient solution than without it. The contents of sodium and potassium were high in the plants and proportional to the amounts in the nutrient solution.

Other workers (49, 57) have reported that increasing the salt concentration of the soil solution increases the osmotic pressure, and the rate of water adsorption in the plant is reduced. Timm (70) has emphasized the resistance of sugar beets to wilting at high temperatures in the greenhouse where sodium chloride was applied to the soil.

In studying the effect of salt on aerobic microorganisms, Franco (29) found no microorganisms developed on soils where the sodium chloride content was greater than 0.2 percent or where the sulfur content was over 0.06 percent.

Other factors affecting crop responses to sodium as suggested by Harmer et al. (34) are the composition of the fertilizer (content of sodium), composition and drainage of the soil and seasonal climate. Harmer and Benne (33) reported plants with a narrow potassium to sodium ratio indicated a probable sodium-responsive crop and a wide ratio a non-responsive crop.

Magnesium Deficiency of Pascal Celery

Some 1045 abstracts of recent compilation on magnesium research appear in a publication by International Minerals and Chemical Corporation (50).

The interest of this review was limited to the magnesium problem associated with certain Pascal celery varieties of which Utah 10B is one of the most susceptible to magnesium deficiency.

The work of Pope and Munger (56) showed a single gene controlled the utilization of magnesium as evidenced by a 3:1 Mendelian ratio of the first generation from crossing a non-susceptible variety with Utah 10B.

The magnesium deficiency as described by Davis and McCall (19) was "A foliar condition, appearing on celery as a definite pattern of mottling and yellowing on the tips of the older leaves, and then progressively spreading downward along the margins and inward between the veins of the leaflets."

Wittwer and McCall, as cited by Johnson (40), listed the green celery varieties as to their degree of susceptibility to magnesium deficiency as follows: (a) highly susceptible--Utah 10B, Utah Ten Grand, Utah Top Ten, Pascal Superb, Superior Pascal; (b) moderately susceptible--Utah 16; (c) slightly susceptible--Utah 52-70, Utah Special, Utah Jumbo, Emerson Pascal; (d) not susceptible--Utah 15 and Summer Pascal.

Davis and McCall (19), in studying methods of correcting the magnesium problem of celery at ten locations in Michigan, found that applications of 2000 pounds per acre of magnesium sulphate applied as a side-dressing proved ineffective (100 percent of plants contained symptoms); but symptoms were almost completely controlled and yields increased slightly by spraying ten pounds of magnesium sulphate per acre at 10-day intervals throughout the growing season.

Johnson et al. (42), in a two-year study with 19 celery varieties at four locations in Michigan on soils with exchangeable calcium to magnesium ratios ranging from 6:1 to 14:1 and the magnesium saturation as high as 23 percent, found that severe symptoms of magnesium deficiency occurred at all locations. The most susceptible varieties arranged in decreasing order were: Utah 10B, Utah 52-70, Emerson Pascal, Growers Pascal 49, and Summer Pascal (Waltham strain).

Johnson et al. (41) reported two to four tons of hydrated magnesium sulphate applied to the soil were required to control symptoms of magnesium deficiency. Symptoms were reduced to a minimum when the exchangeable calcium to magnesium ratio in the soil was less than 3:1 and when the magnesium saturation of the exchange complex was greater than 22 percent. Sodium chloride and high rates of potash tended to make the problem more serious (40); but, in general, the most effective means of control of the magnesium problem associated with certain Pascal Celery varieties were through foliar sprays of Magnesium (19, 56, 40, 41, 42).

Molybdenum

Arnon and Stout (4) were the first to establish molybdenum as an essential element for the growth of higher plants using the tomato as an indicator plant. Anderson (2), working on an Australian ironstone soil in pot tests, obtained yield increases of lucern almost double the check from sodium molybdate applied at two pounds per acre. Walker (73) was the first to demonstrate a plant response to molybdenum on soils of this country.

Rubins (60) cited areas of known molybdenum deficiencies in the United States as being along the Atlantic and Gulf Coasts, the Midwest and the Northwest. Robinson (58) reported molybdenum content of soils ranged from a trace to about 20 parts per million, and the average of 500 analyses from several countries as 2.5 parts per million of molybdenum in soil.

Evans (24), from a review of the role of molybdenum in plant growth, concluded that molybdenum is an essential element in the process of nitrogen fixation and nitrate reduction when the nitrate source of nitrogen is utilized. There is evidence that hydrogenase is associated with the nitrogen-fixation mechanism in microorganisms, and molybdenum is an essential constituent of this enzyme.

Mulder (52), working with organic soils in the Netherlands, obtained increased yields of white clover from the application of molybdenum to soils in 13 out of 17 cases. The pH of the soils ranged from 4.9 to 6.2. He worked with indicator crops of lucern, cauliflower, white cabbage, turnip, lettuce, spinach, radish, sugar beet, potato, tomato and cereals. In estimating available molybdenum by the *Aspergillus niger* assay method, some rather high values were obtained in acid soils on which cauliflower plants showed severe symptoms of molybdenum deficiency.

Several workers (52, 68, 3) report phosphate in most cases enhances molybdenum uptake. Stout *et al*. (68) stated under conditions of intensive cropping at high phosphate levels, recoveries of 10 to 50 percent of the applied molybdenum may be removed in a single crop. Stout (68) postulated that added phosphate might exchange for soil adsorbed molybdenum; this is analogous to the release of soil molybdenum upon making soils alkaline by exchange of soil adsorbed molybdate for hydroxyl ions (5).

Several workers (72, 38, 52, 3, 23, 6) and others have demonstrated that the availability of molybdenum to plants in general increases as the pH of the soil is increased. Although soil molybdate is fixed more strongly in acid reactions, it has been shown (68) in culture solution studies that adsorption of molybdates by the plant is greater from acid solutions than from solutions of neutral reactions.

Anderson (3) stated that the extent to which the application of lime corrects molybdenum deficiency depends upon the amount of unavailable molybdenum present in the soil. Good response from liming or molybdenum application was obtained from a soil containing ten parts per million of molybdenum, whereas very little response was obtained from lime where the soil contained only one part per million of molybdenum. Walker (73) obtained a response to molybdenum on serpentine soils of a pH as high as 6.8.

Barshad (6) found the molybdenum content of plants grown on the same soil varied from 1.3 parts per million in the leaves of cantaloupe to 141 parts per million in the dry tissue of cow peas. Stout _et al_. (68), in analysis of molybdenum deficient plants, found a range from .25 to .03 parts per million of molybdenum in the dry tissue and tentatively set .5 parts per million of molybdenum in the dry tissue as indicative of an adequate supply.

Barshad (6) observed that the amount of molybdenum in the plant was related to the amount of molybdenum in the soil, and that molybdenum in the plant may vary widely without any deleterious effect on the plant.

Many workers (14, 15, 25) in areas where the molybdenum content of pasture forage ranged from 4.6 to 20 parts per million or above have reported a disease of cattle or sheep caused by an excess of molybdenum. In the United States, the problem has been reported in California (5, 6), Florida (44, 31) and Oregon (60). Suggestions by workers to reduce the problem were: (a) feed cattle dry roughage (5); (b) utilize the peat and muck areas of Florida for hay production rather than pasture to prevent return of plant residue to the soil (31); and (c) injection of copper solution into the animal (16).

Mulder (52) found an antagonistic relationship between manganese and molybdenum. Mulder (52) and Stout <u>et al</u>. (68) reported that sulfates suppress the uptake of molybdenum. Stout <u>et al</u>. (68) demonstrated molybdenum adsorption by soil grown plants can be lowered by reducing soluble phosphate and increasing soil sulfate levels. He reduced the molybdenum content of peas from 16 to 2.75 parts per million in the tissue by the application of two tons of calcium sulfate per acre.

Robinson and Edgington (59) have suggested a connection between abundance of free hydrated iron oxides and molybdenum availability, and the possibility of iron concretions locking up molybdenum in an entirely unavailable form.

Davies (17) in reviewing literature concerning availability of molybdenum in soils discussed it in relation to four forms: (a) unavailable (held within the crystal lattice of primary and secondary minerals); (b) conditionally available (retained as the MoO_4 anion by clay minerals and available depending upon the pH and phosphate status); (c) in organic matter; (d) water soluble.

Kedrov-Zikhman <u>et al</u>. (43), working on podzolic and peat soils, found that supplying cobalt and molybdenum by side-dressing growing plants or by soaking the seed in solutions of cobalt and molybdenum salts were often more effective in increasing plant growth than broadcasting the materials.

Placement of Phosphate and Manganese

Manganese availability on organic soils decreases as the pH of the soil increases. At a pH of about 5.8 and above, it is advisable to apply supplementary manganese in order to meet requirements of many crops for this element (26).

Sherman and Harmer (64) were the first to study the need for manganese for crops in Michigan. They reported that to control manganese deficiency in oats grown on organic soil the most practical methods were the application of manganese sulfate or sulfur.

Shepherd et al. (62), in a study with several manganese carriers to determine the most effective method of application and the effectiveness of the various carriers, found the order of response in methods of application to be banding, broadcasting, and spraying, with no difference among carriers when the carriers were banded. They used the onion as an indicator crop. When Frit or oxide carriers of manganese were broadcast, they were much less effective in increasing crop yield than the sulfate carrier.

Hashimoto et al. (35) applied fused phosphate to the soil. The pH was increased, and the availability of manganese decreased. The resulting deficiency was corrected in barley by the application of manganese fertilizer. They reported fertilizing the crop with super phosphate on unlimed fields was not injurious.

Fiskel and Mourkides (28) in evaluating manganese carriers found, in general, an increase in the manganese content of tomato plants at the higher of two levels of super phosphate applied in pot experiments. They thought the increased response at the higher level may have been due to calcium or to localized acidity from the gypsum.

Hoff and Mederski (36) reported that banding 200 pounds per acre of 0-20-20 was as effective in increasing the yield of soybeans as a 30 pound per acre rate of manganese sulfate. The yields were 17, 30, and 31 bushels per acre for the control (no fertilizer or manganese), 30 pounds of manganese sulfate, and 200 pounds of 0-20-20 per acre, respectively.

EXPERIMENT I

THE EFFECTS OF SODIUM AND POTASSIUM ON THE YIELD AND CHEMICAL COMPOSITION OF SUGAR BEETS

Procedure

A study concerning the response of crops to salt at varying rates of potash was established on Houghton Muck located at the Michigan Muck Experimental Farm in 1951. The soil had a pH of 6.3 and contained 85 percent organic matter as determined by loss on ignition. The experimental design was a split plot containing four potash levels and two sodium chloride levels. The treatments, replicated four times, were: 100, 200, 300 and 600 pounds per acre of potash applied annually. The split treatment consisted of an annual application of 500 pounds of sodium chloride per acre on one-half of each plot. All polts received a basic application of 100 pounds per acre of phosphate along with minor elements appropriate for the crop grown. Table beets and celery were grown on the area from 1951 through 1954. All plots were sampled and tested in the spring of 1955. The test results indicated a uniform level of residual phosphorus across all plots in the experiment, and a uniform residual potassium level for each of the four rates of potash applied.

In 1955, the plots were split a second time--one-half of each plot received the regular treatment, and the other half was left untreated with phosphate or potash fertilizer. There were a total of 72 plots following the last split.

The potash source used was fertilizer grade potassium chloride, and the phosphorus was 0-45-0. The potassium carrier, sodium chloride and 40 pounds per acre equivalent of borax were weighed and broadcast on each plot as required according to plot diagrams then disced-in prior to planting. The 0-45-0, applied at the rate of 100 pounds per acre of P_2O_5, was banded two inches below the seed at time of planting on those plots which were to receive the treatment. The area was cropped with U.S. 400 sugar beets for two consecutive years, 1955, and 1956. Soil samples were taken each fall and spring, and tests for phosphorus and potassium were made by the Spurway Active method (67).

The planting dates were May 20 in 1955 and June 2 in 1956. At harvest time, fresh weights of the tops and roots were recorded, and samples for chemical analysis were taken.

The roots were washed, quartered vertically, and a few thin slices were cut from each piece. The field sample contained a minimum of ten roots or tops from each plot. The beet top sample was obtained by cutting the petioles at their base near the crown of a quartered root. The samples were weighed fresh, and again after having been dried in a forced-draft electrical oven at 174 degrees Fahrenheit.

Plant material was ground in a Wiley Mill through a 20-mesh screen and stored in 8-ounce wide-mouth sample jars. A further sample was prepared by bulking the replicates of each treatment for the tops and roots for chemical analyses.

The calcium and magnesium analyses of sugar beet tissue from plots in 1956 were determined with a Beckman DU flame spectrophotometer equipped with a photomultiplier. All other analyses for chemical constituents of the sugar beet samples taken in 1955 and 1956 were analyzed in accordance with methods as outlined in Official Methods of Analysis of the Association of Official Agricultural Chemists (54).

Results and Discussion

The data in Table 1 show the yield of tops were fairly uniform across all treatments with no significant differences in weight apparent. Likewise, no significant differences in the percent sucrose resulted from treatment. Potash, however, caused significant increases in the root yields. Yields from plots receiving 200 pounds of potash were significantly higher

Table 1. The effects of rates of application of sodium chloride and potash on the yield and sucrose content of sugar beets, 1955.

Pounds per acre			Fertilized 1951-1955				Fertilized 1951-1954			
			Tons per acre				Tons per acre			
P_2O_5	K_2O	NaCl	Tops	Roots	Mean (K levels)	Percent sucrose	Tops	Roots	Mean (K levels)	Percent sucrose
100	100	0	14.2	13.8	15.3	11.8	12.7	11.3	12.8	11.5
100	100	500	13.9	16.8		11.7	14.5	14.4		10.8
100	200	0	14.5	18.7	20.2	12.3	15.1	14.6	17.0	11.5
100	200	500	12.9	21.7		11.8	15.7	19.4		12.2
100	300	0	14.3	20.7	21.5	12.2	15.6	17.2	18.9	12.4
100	300	500	15.4	22.3		12.0	15.3	20.6		12.0
100	600	0	14.6	23.5	23.2	11.8	15.9	22.5	23.8	11.4
100	600	500	12.2	23.0		11.9	15.9	25.1		11.0
LSD (5% level)			N.S.		2.3	N.S.	N.S.		3.3	N.S.

than those from plots treated with 100 pounds. Also, the yields from the plots treated with 600 pounds of potash were significantly higher than those from plots treated at the 200-pound rate. The salt did not significantly increase yields of beets on the fertilized plots, but these data indicate a yield response from the salt where the two lowest levels of potash were applied.

The 1955 chemical composition data of the tops and roots are given in Tables 2 and 3. These data show a much higher value in the tops than in the roots for all elements reported. The nitrogen and phosphorus content of the plants appear to be high and rather uniform across all treatments. The manganese content of the tops appears to be well within a desirable range for plant growth, and the treatments apparently had no effect on the level of this element. The calcium and magnesium contents of the tops were consistently depressed from the sodium chloride treatment except at the lowest residual level of potash (Table 2). However, this fact is not apparent from the composition of the roots (Table 3). The potassium content of the tops, in general, increased with residual potassium level in the soil or potash applied. Also, the sodium content of the tops reflected the treatment to the soil. There was an inverse relationship between the percentages of sodium and potassium in the tissue.

Table 2. The effects of the rates of application of sodium chloride and potash on the chemical composition of sugar beet tops, 1955.

Pounds per acre			Percent of oven-dry tissues						
P_2O_5	K_2O	NaCl	N	P	K	Na	Ca	Mg	Mn
Part A. Fertilized 1951 - 1954									
100	100	0	4.55	.545	2.87	3.07	1.14	1.16	.0044
100	100	500	4.44	.439	4.04	2.25	1.15	1.29	.0057
100	200	0	3.89	.491	2.91	2.61	1.13	1.12	.0107
100	200	500	4.59	.502	3.81	2.80	.88	.94	.0065
100	300	0	4.20	.498	4.06	.98	1.10	1.10	.0049
100	300	500	4.06	.586	4.03	2.03	.73	.66	.0053
100	600	0	4.11	.432	4.77	1.88	1.08	1.09	.0064
100	600	500	4.50	.459	5.73	2.69	.70	.80	.0064
Part B. Fertilized 1951 - 1955									
100	100	0	4.35	.583	3.20	1.76	1.63	1.28	.0099
100	100	500	4.20	.488	2.28	3.09	1.00	.99	.0096
100	200	0	4.51	.504	4.72	1.62	1.15	.98	.0110
100	200	500	3.86	.433	5.16	2.12	1.07	.90	.0074
100	300	0	3.92	.491	5.39	1.32	1.34	1.07	.0070
100	300	500	4.06	.482	5.01	2.19	1.02	.97	.0069
100	600	0	4.26	.512	6.49	1.01	1.15	.83	.0065
100	600	500	3.49	.366	6.35	1.97	1.34	.81	.0096

Table 3. The effects of rates of application of sodium chloride and of potash on the chemical composition of sugar beet roots, 1955.

Pounds per acre			Percent of oven-dry tissue						
P_2O_5	K_2O	NaCl	N	P	K	Na	Ca	Mg	Mn
Part A. Fertilized 1951 - 1954									
100	100	0	2.10	.201	.79	.76	.110	.266	.0014
100	100	500	1.53	.225	.98	1.06	.088	.233	.0018
100	200	0	1.43	.202	1.49	.16	.133	.239	.0015
100	200	500	1.74	.212	.91	2.10	.135	.244	.0019
100	300	0	1.04	.169	2.28	.19	.089	.176	.0009
100	300	500	1.49	.246	2.27	1.28	.102	.213	.0019
100	600	0	1.89	.192	3.44	.53	.098	.285	.0010
100	600	500	1.86	.247	2.45	.65	.105	.323	.0023
Part B. Fertilized 1951 - 1955									
100	100	0	1.70	.286	1.21	.39	.125	.251	.0014
100	100	500	1.00	.185	1.01	.90	.087	.160	.0018
100	200	0	.92	.204	1.55	.44	.098	.158	.0025
100	200	500	1.50	.289	2.22	.63	.124	.225	.0019
100	300	0	1.02	.157	2.34	.38	.098	.165	.0013
100	300	500	1.48	.213	2.23	.60	.088	.206	.0019
100	600	0	1.36	.236	2.97	.24	.112	.174	.0020
100	600	500	1.19	.216	2.75	.31	.099	.214	.0018

The data in Table 4 show that 1956 yields and sugar percentages were considerably different from those of 1955. In 1956 the yields of roots from plots receiving the three highest rates of potash (200, 300 and 600) were significantly higher than the yields from plots receiving the 100-pound rate. Also, the plots where either 100 or 200 pounds of potash were applied and which received salt produced higher beet yields than did the corresponding plots which did not receive salt. By grouping the data from all plots that received potash, it was possible to show that salt caused significantly higher sucrose percentages.

In 1956 the yield of beets from the fertilized plots was considerably higher than from the unfertilized plots. In Table 4 the data from the unfertilized plots show that in every case where salt was applied sugar beet yields were increased. The percent of sucrose was not significantly affected by the plot treatments of salt or residual potassium level in the soil.

The data in Table 7 show the potassium level of the soil in the spring of 1955, and in the spring of 1957 following the two-years' cropping with sugar beets. The loss of potassium from the soil as a result of cropping is apparent on the plots that were unfertilized in 1955 and 1956. The highest soil test level dropped in a two-year period from about 300

Table 4. The effects of rates of application of sodium chloride and potash on the yield and sucrose content of sugar beets, 1956.

Pounds per acre			Fertilized 1951-1956				Fertilized 1951-1954			
			Tons per acre				Tons per acre			
P_2O_5	K_2O	NaCl	Tops	Roots	Mean (K levels)	Percent* sucrose	Tops**	Roots**	Mean (K levels)	Percent sucrose
100	100	0	10.8	9.2	9.9	14.1	8.2	5.8	7.2	14.1
100	100	500	13.1	10.6		14.9	13.5	8.6		14.0
100	200	0	13.3	11.1	11.6	15.2	9.1	6.3	7.1	14.3
100	200	500	13.3	12.2		15.3	13.0	8.0		13.9
100	300	0	13.4	11.5	11.7	15.1	11.1	7.4	8.0	14.4
100	300	500	11.8	11.8		16.5	11.0	8.7		14.5
100	600	0	12.5	12.5	12.1	14.4	10.0	7.6	8.7	13.6
100	600	500	11.1	11.8		16.0	11.4	9.9		13.9
LSD (5% level)			N.S		1.7				1.7	N.S.

*Significantly higher sugar content in favor of salt treatment (5% level).

**Significantly higher root and top yields in favor of salt treatment (5% level).

Table 5. The effects of rates of application of sodium chloride and potash on the chemical composition of sugar beet tops, 1956.

Pounds per acre			Percent of oven-dry tissue					
P_2O_5	K_2O	NaCl	N	P	K	Na	Ca	Mg
			Part A. Fertilized 1951 - 1954					
100	100	0	3.25	.458	2.71	1.53	.793	.926
100	100	500	2.82	.428	2.83	3.20	.727	.717
100	200	0	3.47	.480	2.54	1.50	.700	.807
100	200	500	3.12	.473	2.11	3.15	.600	.513
100	300	0	3.09	.463	3.07	1.32	.640	.627
100	300	500	2.56	.393	2.46	3.20	.380	.420
100	600	0	3.06	.395	4.31	.92	.466	.707
100	600	500	2.06	.418	4.04	1.68	.500	.607
			Part B. Fertilized 1951 - 1956					
100	100	0	2.93	.497	3.21	1.19	.547	.647
100	100	500	2.65	.458	2.78	2.97	.473	.507
100	200	0	3.04	.510	3.52	1.11	.507	.567
100	200	500	2.87	.477	3.98	1.81	.407	.393
100	300	0	2.82	.475	4.23	.79	.620	.420
100	300	500	3.13	.477	4.50	1.40	.283	.293
100	600	0	2.61	.477	4.71	.67	.473	.413
100	600	500	2.63	.442	4.99	.97	.440	.367

Table 6. The effects of rates of application of sodium chloride and potash on the chemical composition of sugar beet roots, 1956.

Pounds per acre			Percent of oven-dry tissue					
P_2O_5	K_2O	NaCl	N	P	K	Na	Ca	Mg
Part A. Fertilized 1951 - 1954								
100	100	0	1.12	.190	1.05	.590	.217	.340
100	100	500	.98	.160	1.08	.543	.162	.280
100	200	0	1.09	.213	.88	.346	.202	.265
100	200	500	.93	.197	.79	.750	.192	.308
100	300	0	.98	.140	.89	.250	.183	.238
100	300	500	.95	.170	1.07	.397	.197	.292
100	600	0	1.15	.157	1.85	.247	.192	.322
100	600	500	.93	.197	1.47	.283	.150	.263
Part B. Fertilized 1951 - 1956								
100	100	0	.93	.220	.96	.233	.202	.255
100	100	500	.86	.187	.94	.340	.167	.247
100	200	0	.85	.207	1.19	.173	.172	.237
100	200	500	.82	.223	1.18	.210	.177	.237
100	300	0	.88	.217	1.34	.130	.175	.237
100	300	500	.82	.203	1.29	.177	.152	.233
100	600	0	.81	.220	1.49	.113	.157	.233
100	600	500	.83	.263	1.61	.130	.147	.223

Table 7. The effect of sugar beets on potassium soil test values.*

Grade	0-10-10		0-10-20		0-10-30		0-10-60	
Spring** 1955	lbs./A. 90		lbs./A. 111		lbs./A. 152		lbs./A. 286	
Fertilized 1955-1956	None	1000 lb/A	None	1000 lb/A	None	1000 lb/A	None	1000 lb/A
Spring*** 1957	17	13	15	41	42	94	68	260

*.018 normal acetic acid extract.

**Soil test levels established by continuous treatment of the fertilizer grade as indicated and applied annually at 1,000 pounds per acre from 1951 through 1954.

***Soil test values following two years' consecutive cropping with U.S. 400 sugar beets.

pounds of potassium per acre to less than 50 pounds. Potash applied at the rate of 600 pounds per acre tended to lose residual potassium under the sugar beet cropping.

The data in Tables 5 and 6 show the chemical composition of tops and roots of sugar beets from the 1956 season. In general, the same trends are apparent from these data as were mentioned previously from the 1955 data. That is, the application of sodium chloride and the increased residual and/or applied potassium depressed the contents of magnesium and calcium in the tops. This is not apparent from the composition data obtained for the roots. An antagonistic relationship between potassium and sodium contents of the tops from the fertilized plots was demonstrated. However, the residual potassium level was so low in plots previously treated at the 100-, 200- and 300-pound levels that the sodium chloride treatment increased the percent of sodium in the tissue above that of the potassium.

The nitrogen content of the tissue from plots treated with salt was lower than that of the tissue from plots with the no-sodium chloride treatment. The lower nitrogen values were more consistent on the unfertilized plots where salt did not affect the percent sucrose; but on the fertilized half of the plot where salt did significantly increase the percent sucrose, the nitrogen level of the tissue was more inconsistent. A dry fall occurred in 1956, and it is possible that the water level in the soil coupled with the salt treatments may have slowed mineralization of nitrogen as mentioned by Franco (29). The phosphorus content of the tissue in 1956 was high and uniform on all plots including those receiving no phosphate or potash after 1954.

These data show a trend toward a slight reduction in the yield of tops and roots where the highest level of potash was applied with the sodium chloride. Decoux et al. (20) reported that a sodium carrier was more effective than potassium chloride in producing sugar per acre with sugar beets. In view of the depressing effects of chlorides on some crops as cited by others (51, 76, 69, 32), chlorine may have been the depressant where the highest rates of sodium chloride and potash were applied. The chlorine in both carriers applied annually at the highest rate was approximately 800 pounds per acre.

These data agree with the work of others (7, 10, 46) on the effects of potassium and sodium on the yields and composition of the crop. The two elements appear to be antagonistic to each other, and either or both tend to suppress the uptake of magnesium and calcium. These data further indicate that a partial substitution of sodium for potassium occurred in the sugar beet plant. The crop response from sodium decreased with an increased residual level of potassium in the soil or an increased rate of potash applied for the crop.

EXPERIMENT II

MAGNESIUM AND UTAH 10B CELERY

Procedure

A. The effect of magnesium sulphate on the chemical composition and control of magnesium deficiency of Utah 10B celery.

This experiment was established at the Michigan Muck Experimental Farm in 1955 to determine the residual effect of high rates of hydrated magnesium sulphate on the control of magnesium deficiency of Utah 10B celery. The magnesium sulphate treatments were applied in 1955 only. The plots were cropped with Utah 10B celery in 1955 and 1956.

The treatments consisted of hydrated magnesium sulphate (9.87% Mg) applied at the pounds per acre indicated: (a) none, (b) 1,000, (c) 2,000, (d) 3,000, (e) 4,000, (f) 6,000, (g) 8,000, (h) 10,000 and (i) 80 (ten pounds per acre in 150 gallons of water at ten-day intervals throughout the growing season). The experimental design was a randomized block with three replications. All plots received a basic fertilizer applied with the fertilizer attachment on the grain drill in 1955 and 1956 to give nutrients of 50-100-300-

40 pounds per acre of N, P_2O_5, K_2O, and borax, respectively. The magnesium sulphate was weighed for each plot, broadcast by hand and then disced-in prior to planting the celery in 1955. The celery seedlings were transplanted into the field in late June and harvested in early October each year.

The plants from each plot were harvested from a fixed area in size, the fresh untrimmed plants were weighed, and the weights were recorded. The yields were computed and reported in tons per acre of fresh weight.

A minimum of five plants per plot obtained at harvest time were quartered vertically, and one-quarter from each was saved for tissue analysis. Drying, grinding, preparation of the composite samples and chemical analyses were the same procedures as previously stated for sugar beet tissue.

B. The effects of magnesium and potassium application on the yield and chemical composition of Utah 10B celery.

The experiment was established at the Michigan Muck Experimental Farm in 1953. The area, a Houghton muck, was originally developed in 1941 and had been used for experimental plots continuously from 1941 through 1952. Standard grades and rates of fertilizer normally used throughout this period were 0-10-20 and 0-10-30 at 1,000 to 2,000 pounds per acre annually. Chemical characteristics of the plot area as reported by Johnson (40) from samples taken in 1953 were: (a) pH 5.9-6.2, (b) 80 percent organic matter, (c) cation exchange capacity 189 me. per 100 grams soil, (d) exchangeable magnesium 23 me. per 100 grams soil, (e) exchangeable calcium 130 me. per 100 grams soil, (f) exchangeable sodium 1.2 me. per 100 grams soil, and (g) base saturation 83.4 percent. Shickluna (65) has reported the results of soil test correlation studies of these plots for phosphorus and potassium carried out in 1955 and 1956.

The treatments consisted of four rates of potash: (a) none, (b) 400, (c) 800, and (d) 1,200 pounds per acre with three rates of magnesium sulphate (9.87% Mg) superimposed on each potash treatment. The three magnesium sulphate treatments were: (a) none, (b) 500 pounds per acre, and (c) 80 pounds per acre applied in eight foliar applications of ten pounds each in 150 gallons of water. The plots were replicated three times. All plots received a basic application of 200 pounds of P_2O_5 per acre along with 40 pounds of borax. The plots were cropped with Utah 10B celery in 1953 and then split in 1954 so that one-half of each plot received the regular treatment, and the other half of each plot received no potash or phosphate fertilizer. The data reported were obtained from the 1955 and 1956 crops.

The Utah 10B celery seedlings were transplanted late in June and harvested in early October each year.

Harvesting, plant sampling, sample preparation and methods of chemical analyses were the same as previously mentioned.

Results and Discussion

The data in Table 8 show the effect of magnesium sulphate (9.87% Mg) on the yield, chemical composition and deficiency rank of Utah 10B celery in the year of treatment. The residual effect of these treatments are reported in Table 9.

There is a great deal of difference in the severity of the magnesium deficiency symptoms occurring on the crop from one year to the next as indicated by the deficiency rank in the check treatments. The yield of celery was not significantly affected by treatment in either year. The percent of nitrogen, phosphorus, potassium and sodium in the tissue appears to be adequate and rather uniform across all treatments of the experiment (Table 8). The magnesium in the tissue increased as the rate of magnesium applied to the soil was increased. The 10,000 pounds per acre treatment of magnesium sulphate resulted in .256 percent magnesium in the tissue which was the highest of any treatment. On the other hand,

Table 8. The effect of magnesium on the yield, chemical composition and incidence of magnesium deficiency on the leaves of Utah 10B celery, 1955.

Pounds $MgSO_4$ $.7H_2O$ per acre	Tons per acre	Deficiency rank*	Percent of oven-dry weight					
			N	P	K	Na	Mg	Ca
None	31.1	2.7	2.67	.474	5.55	.715	.177	2.00
1000	36.4	2.0	2.54	.447	5.80	.723	.196	2.32
2000	35.4	2.3	2.58	.454	5.70	.952	.209	2.33
3000	36.7	1.7	2.66	.490	6.23	.649	.216	2.23
4000	37.2	2.3	2.63	.444	5.66	1.015	.234	2.60
6000	35.0	3.3	2.80	.493	6.18	.817	.239	2.25
8000	31.8	2.7	2.85	.499	5.88	.813	.249	2.06
10000	32.1	4.3	2.64	.437	5.55	.802	.256	2.13
Spray**	32.5	2.0	2.84	.544	5.74	.975	.193	2.02
LSD (5% level)	N.S.							

*Rank: 1 = no symptoms and 10 = 100 percent symptoms of magnesium deficiency.

**80 pounds of hydrated magnesium sulphate applied in 8 applications of 10 pounds each in 150 gallons of water.

Table 9. The effect of residual magnesium on the yield and incidence of magnesium deficiency on the leaves of Utah 10B celery, 1956.

Pounds $MgSO_4 \cdot 7H_2O$ per acre	Tons per acre	Deficiency rank*
None	39.6	7.0
1000	45.0	7.3
2000	43.3	7.7
3000	45.0	6.0
4000	46.3	8.8
6000	43.9	6.0
8000	44.8	4.3
10000	44.7	4.7
Spray**	47.0	1.0
LSD (5% level)	N.S.	

*Rank 1 = no symptoms 10 = 100 percent symptoms of magnesium deficiency.

**80 pounds per acre of hydrated magnesium sulphate applied in 8 applications of 10 pounds each in 150 gallons of water.

the check treatment contained the lowest level of magnesium in the tissue. In general, the magnesium content of a representative sample of the above-ground growth of Utah 10B celery reflected the magnesium treatment to the soil. However, there was no relationship between the magnesium content of the tissue in this method of sampling and the incidence of the deficiency symptoms appearing on the plants as indicated by rank.

Johnson (40) stated that for mature susceptible varieties when the percent magnesium of the above-ground portion was raised to 0.144 percent or above no symptoms developed. These data indicate that magnesium content of the Utah 10B celery in the above-ground portion of the plant reflect soil treatment, but must be considered as an unreliable guide as to the occurrence and control of the magnesium symptoms appearing on the plant.

In a later publication, Johnson et al. (42) reported that Utah 10B plants with a maximum of symptoms contained 0.247 to 0.257 percent magnesium. Values from 0.274 to 0.426 percent magnesium were found in plants with few-to-no symptoms of deficiency.

Several publications (19, 56, 41, 42) reported that the most effective method of control of magnesium deficiency on Utah 10B celery was by foliar application of magnesium compounds to the growing plants. A soil application of 10,000 pounds per acre of magnesium sulphate (9.87% Mg) was less effective in controlling the symptoms of magnesium deficiency in Utah 10B celery than 80 pounds per acre applied in eight applications of ten pounds each as a foliar spray. These data show that the foliar application was also the most effective means of control of the problem.

Johnson _et al_. (41) reported effective control of magnesium deficiency from the soil application of two or more tons of magnesium sulphate. The purpose of this experiment was to determine the residual value in succeeding years of such treatment on the control of the magnesium deficiency.

The data in Table 8 show that the 3,000 pound per acre treatment of magnesium sulphate was effective in 1955 in the control of the problem as indicated by the deficiency rank number, the lowest in the experiment. However, the data in Table 9 show very low residual effect in the control of the problem in 1956, one year after the treatments. The only effective control as dictated by economics was the spray treatment.

The data in Tables 10 and 11 show that the level of nitrogen, phosphorus, and calcium in the tissue was fairly uniform across all treatments with more variability in 1956 than in 1955. The calcium values obtained in 1956 were much

Table 10. The effects of magnesium and potassium levels on the yield and chemical composition of Utah 10B celery, 1955.

Pounds per acre			Tons per acre	Percent of oven-dry weight					
P_2O_5	K_2O	$MgSO_4 \cdot 7H_2O$		N	P	K	Na	Mg	Ca
Part A. Fertilized 1953 only									
200	0	0	24.7	2.52	.549	3.37	2.67	.223	2.45
200	400	0	25.5	2.68	.578	4.82	1.87	.215	2.22
200	800	0	28.8	2.50	.483	6.84	.84	.210	2.56
200	1200	0	27.4	2.45	.547	6.86	.67	.160	2.34
200	0	500	23.1	2.64	.537	2.97	2.76	.223	2.44
200	400	500	26.9	2.59	.613	5.45	2.01	.193	2.22
200	800	500	26.0	2.57	.538	6.94	.79	.191	2.55
200	1200	500	29.8	2.52	.536	6.81	.64	.159	2.32
200	0	80*	23.1	2.99	.648	3.74	2.68	.243	2.47
200	400	80*	25.8	2.79	.589	5.25	1.70	.249	2.44
200	800	80*	27.2	2.58	.586	6.96	.78	.187	2.24
200	1200	80*	22.6	2.92	.555	6.95	.57	.172	2.39
Part B. Fertilized 1953 - 1955									
200	0	0	22.8	2.71	.489	3.85	2.39	.214	2.46
200	400	0	26.6	2.53	.569	6.07	.98	.194	2.16
200	800	0	31.4	2.73	.622	7.46	.82	.210	2.48
200	1200	0	25.3	2.65	.604	7.98	.74	.167	2.39
200	0	500	24.8	2.63	.518	3.55	2.53	.215	2.37
200	400	500	26.3	2.44	.528	6.65	.88	.244	2.38
200	800	500	31.3	2.50	.593	6.53	.94	.227	2.60
200	1200	500	26.5	2.70	.572	7.53	.74	.191	2.48
200	0	80*	23.6	2.59	.491	3.03	3.01	.217	2.39
200	400	80*	26.2	2.58	.519	6.23	.81	.195	2.38
200	800	80*	27.1	2.62	.607	6.87	.69	.203	2.32
200	1200	80*	23.1	2.91	.616	7.45	.66	.196	2.36

*8 applications of 10 pounds each in 150 gallons of water per acre at 10-day intervals.

Table 11. The effects of magnesium and potassium levels on the yield and chemical composition of Utah 10B celery, 1956.

Pounds per acre			Tons per acre	Percent of oven-dry weight					
P_2O_5	K_2O	$MgSO_4 \cdot 7H_2O$		N	P	K	Na	Mg	Ca
Part A. Fertilized 1953 only									
200	0	0	34.0	2.45	.610	4.47	1.40	.187	.903
200	400	0	35.9	2.30	.563	4.70	1.21	.173	.913
200	800	0	39.1	2.20	.547	5.60	1.03	.217	1.013
200	1200	0	41.6	2.30	.600	7.07	.65	.257	.987
200	0	500	31.0	2.28	.533	4.33	1.28	.200	.973
200	400	500	34.9	2.18	.577	5.03	1.23	.197	.913
200	800	500	36.8	2.18	.587	6.37	.95	.190	1.033
200	1200	500	37.2	2.29	.590	6.27	.64	.173	.900
200	0	80*	33.1	2.54	.587	4.37	1.32	.167	.923
200	400	80*	36.2	2.16	.583	5.63	1.17	.197	.853
200	800	80*	34.5	2.06	.557	5.83	.76	.173	.830
200	1200	80*	37.0	2.25	.540	7.13	.85	.257	1.033
Part B. Fertilized 1953 - 1956									
200	0	0	39.8	2.18	.550	4.07	1.482	.200	.770
200	400	0	41.8	2.31	.573	6.13	.873	.218	1.100
200	800	0	44.3	2.04	.580	8.13	.475	.233	.840
200	1200	0	42.8	2.31	.627	7.40	.508	.210	.954
200	0	500	36.6	2.53	.380	3.80	1.375	.175	.970
200	400	500	43.2	2.00	.543	7.16	.600	.190	1.080
200	800	500	44.4	2.12	.597	8.06	.550	.240	1.100
200	1200	500	45.8	2.08	.567	7.75	.507	.230	.954
200	0	80*	36.0	2.25	.380	3.80	1.625	.175	.830
200	400	80*	41.1	2.05	.540	6.70	.733	.260	1.060
200	800	80*	42.9	2.05	.593	7.40	.500	.210	.904
200	1200	80*	44.4	2.13	.565	7.29	.475	.200	.860

*8 applications of 10 pounds each in 150 gallons of water per acre at 10-day intervals.

lower than those obtained in 1955. However, Johnson (40) obtained calcium values as low as 1.06 and as high as 3.44 percent in the oven-dry tissue in 1953 and 1954, respectively, from the same plots in the experiment. In spite of the low values for calcium obtained in 1956, these data show the same trend in both years; that is, the level of potassium did not appear to affect calcium level in the plant to any great extent. As the residual fertility level increased, or as the rate of potash applied was increased, the percent of potassium in the plant increased and the percent of sodium decreased. In 1955 as the level of available potassium in the soil increased, the percent of magnesium appears to have decreased (Table 10). The data in Table 11 show more variability in percent magnesium with no definite trend apparent for this element in 1956.

The 1956 data from the unfertilized plots represent the third consecutive celery crop without fertilizer applied; and on the zero potash level, the fourth consecutive year without potash. The only significant difference in yield from treatment that occurred in the four years of the experiment was on the fertilized half of the plots in 1956; the celery yields from the three highest levels of potash were significantly higher than from the no-potash treatment. The same trend was apparent from the unfertilized plots, but it was not significant. Another trend observed in data over the years was for depressed yields at the highest level of potash. This may have been an effect of chlorides as previously mentioned in the discussion of Experiment I. Root-knot nematodes were present on the roots of celery during the harvesting in 1956 which may have been the cause of some of the variability of these data and the lack of significance in celery yield from the unfertilized half of the plots in 1956.

Furthermore, the only effective control of the magnesium-deficiency symptoms of plants grown on these plots resulted from the magnesium foliar treatment.

EXPERIMENT III

THE EFFECTS OF METHODS OF APPLICATION OF MOLYBDENUM AND THE EFFECT OF LIME ON THE YIELD AND MOLYBDENUM CONTENT OF CROPS

Procedure

Molybdenum studies both in the greenhouse and field were initiated to determine the need for this element in fertilizer recommendations for crop production on the organic soils of Michigan. Hosner (38) reported the first known crop response from this element on organic soil in this country in a greenhouse study using lettuce and cauliflower as indicator crops.

A. Greenhouse Experiment

Four organic soils were obtained from problem areas in the State. The soils were in a pH range from 5.0 to 5.4; they were large deep deposits, high in organic matter, and all were problem areas in onion production.

Soil 1 was obtained from a large deposit of Carlisle muck. The sample obtained for greenhouse studies was from a localized area within the deposit containing visible concretions of iron and having a natural pH of 5.2. The area had been cropped continuously by onions for about 20 years; but crop failure had always occurred in the localized areas containing the iron.

Soil 2 was obtained from a deposit of Rifle peat in Mason County. This soil was located about 100 miles northwest of East Lansing. The pH of the soil was 5.4. The farmer had grown satisfactory crops of carrots, but the yields of onions were unsatisfactory.

Soil 3 was from a deposit of Spalding peat of recent development that had been limed with about ten tons of lime per acre to bring the pH to 5.0. The only crop grown on this soil was onions, and the yields were unsatisfactory.

Soil 4 was obtained from a large deposit of Spalding peat in Calhoun County that had been previously limed with about 20 tons of lime per acre to bring the pH to about 5.0. In some areas of this deposit, the pH was 4.7. This field had also been cropped by onions, carrots and potatoes for more than ten years. However, the onion yields were, in general, the most unsatisfactory of the crops grown.

These soils, referred to in Table 12 as 1, 2, 3 and 4, were partially air dried, screened and each thoroughly mixed. A uniform weight of each soil was placed in eight previously cleaned and weighed two-gallon glazed earthenware jars. A basic application of fertilizer equivalent to 3,000 pounds of 10-10-30 and 25 pounds of copper per acre compounded from analytical grade chemicals was applied to all pots.

The experiment consisted of two treatments: (a) no molybdenum, and (b) four pounds of $NaMoO_4 \cdot 2H_2O$ per acre. Each treatment was replicated four times with each soil. The fertilizer materials were thoroughly mixed throughout the entire soil volume. Snowball A cauliflower seedlings, started in a molybdenum-deficient Montcalm sandy loam, were transplanted on November 6, 1958. The greenhouse temperature was maintained at about 75 degrees Fahrenheit throughout the experiment. The plants were harvested January 1, 1959. The fresh and dry weights of the samples were recorded, and the plant material was prepared for chemical analyses.

B. Field Experiment

The next experiment in chronological order was a field experiment established in Calhoun County on Spalding peat at the location where the number 4 soil was obtained for the greenhouse study. The experimental design was a split plot with three treatments and four replications. The indicator crop used was spinach. The main treatments consisted of sodium molybdate applied at the rate per acre indicated: (a) none, (b) one-half pound, and (c) two pounds. The split consisted of (a) none, and (b) a Moly-Gro[1] seed treatment. The seed was treated at the rate of one-half ounce of Moly-Gro to four pounds of spinach seed. The treatment for the experimental area was 300 pounds of potassium chloride drilled-in. The sodium molybdate was weighed, dissolved in water, sprayed on the plots and then mixed in the soil by discing. Fertilizer of the grade 6-24-12 containing one percent copper was banded under the rows at the rate of 450 pounds per acre. The plots were seeded with a Planet Junior Garden Seeder in the rows previously marked by the fertilizer drill. The spinach was planted May 4 and harvested June 12, 1959. Samples of the above-ground portion of plants were saved at harvest time for molybdenum determination.

C. Greenhouse Experiment

A second greenhouse experiment was set up using soil 1, the most molybdenum-responsive soil of the first greenhouse experiment. The experiment was designed to measure the effects of methods of applying molybdenum and the effect of lime on the growth of several crops. The basic fertilizer was the same as described in the previous greenhouse experiment. This experiment consisted of five treatments:

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[1]Moly-Gro (38% Mo) trade name compound of Climax Molybdenum Company, New York.

(a) no molybdenum, (b) Mo seed treatment, (c) three tons of lime, (d) Mo (.2 pounds per acre) banded, and (e) Mo (.4 pounds per acre) banded. All treatments were replicated four times. The greenhouse temperatures were set for 75 degrees Fahrenheit in the daytime and reduced to 55 degrees Fahrenheit at night. The indicator crops were Snowball A cauliflower, Downing's Yellow Globe onions and Cornell 456 head lettuce. All crops were planted early in January and harvested in March. Fresh and dry weights were recorded, and the tissues prepared for molybdenum analysis. The seed treatments for the crops are listed on Tables 13, 14 and 15 in the Results and Discussion.

D. Field Experiment

A final experiment was established at the Michigan Muck Experimental Farm to determine the effects of seed treatment alone and a seed treatment in combination with molybdenum mixed in the banded portion of the fertilizer on the molybdenum content of the crop. The experimental design consisted of a randomized block with three treatments and three replications. The basic fertilizer was 5-10-30 containing one percent manganese and one-fourth percent boron applied at 800 pounds per acre two inches below the seed at the time of planting. The treatments were: (a) no molybdenum, (b) Mo seed treatment, and (c) Mo seed treatment + Mo (.2 pounds per acre) banded with the basic fertilizer. The indicator crop was Snowball A cauliflower. The crop was planted in June and harvested in September, 1960. The cauliflower heads were harvested, weighed and the yields reported in fresh weight of the cauliflower heads in hundred weights per acre. Plant tissue samples were taken at harvest time for molybdenum determinations.

Molybdenum determinations in composite plant samples were made in duplicate by the Thiocyanate method as outlined by Benne and Jerrim (8). This method is a modification of the original method by Dick and Bingley.

Results and Discussion

The data in Table 12 show a significant increase in the dry weights of cauliflower from the molybdenum treated pots on soils 1 and 2. On soils 3 and 4, the dry weights of the cauliflower from the molybdenum treated plots were higher than the check; but the differences were not significant. The molybdenum contents of the oven-dry cauliflower in Table 12 are all below the .5 parts per million of molybdenum that Stout (68) set as indicative of an adequate level in plant tissue. Interveinal yellowing of the leaves of all plants was observed in the experiment in the early stages of growth, but the plants in the molybdenum treated pots tended to grow

Table 12. The effect of molybdenum applied to several organic soils on the dry weight and molybdenum content of cauliflower grown in the greenhouse, 1959.

	Grams per pot				mmg Mo per gram of tissue			
Treatment	Soil 1	Soil 2	Soil 3	Soil 4	Soil 1	Soil 2	Soil 3	Soil 4
None	5.1	3.2	10.0	5.1	.2	.2	.3	.3
Mo (.4 lb/A.)	21.5	8.7	11.4	8.4	.2	.3	.2	.2
LSD (5% level)	3.5	2.7	N.S.	N.S.				

out of the condition before harvest. Hosner (38) observed the same trouble; he added additional molybdenum to the soil and then finally applied molybdenum to the foliage to correct the symptoms. This might indicate that insufficient molybdenum was applied to the soil or that soil applied molybdenum was slowly available to the plant. It was observed that the plant eventually grew out of the condition in the greenhouse where the temperature was relatively high. This may indicate a tie-up of molybdenum in an organic complex. With a relatively rapid decomposition rate occurring in the greenhouse, the molybdenum applied to the soil apparently became released to the plants through microbial activity. Mulder (52), in working on the effects of manganese and sulfates suggested a molybdenum tie-up problem on organic soil but concluded that both manganese and sulfates were suppressing the uptake of molybdenum. Kedrov-Zikhman et al. (43), working on peat soils, found that supplying molybdenum by side-dressing growing plants or by soaking seeds in solutions of molybdenum salts was more effective than broadcasting the material in increasing plant growth. The results of these workers tended to confirm a problem of availability of molybdenum to plants when the molybdenum had been applied to organic soil by mixing throughout the soil volume or by broadcasting.

The data in Table 13 show a lack of response in spinach yields from plots where the molybdenum was dissolved in water, sprayed on the plots and disced-in before planting at rates of .2 and .8 pounds per acre of molybdenum. The .4 mmg. of Mo per gram of dry tissue contained in plant material from the above treated plots and from the check plots indicate a critical level of molybdenum in the plant tissue. In every case where the seed treatment was used the molybdenum level in the tissue was adequate for plant growth. The yields of spinach obtained from plots with the seed treatment were significantly higher than the yields obtained from plots without the molybdenum seed treatment. These data from the field experiment point out the fact that molybdenum applied broadcast to organic soil was less available to the plant than where molybdenum was applied as a seed treatment. This was indicated by the yield increase of spinach and the level of molybdenum in the tissue.

The data in Tables 14, 15 and 16 were obtained by using additional soil 1 from the same location as previously described. Molybdenum availability to plants in this soil was so low that cauliflower plants did not grow beyond a three-to-four-leaf stage without a molybdenum treatment.

The data in Table 14 show a significant increase in the dry weight of cauliflower from pots receiving molybdenum

Table 13. The effects of broadcast and seed treatment applications of molybdenum on the yield and molybdenum content of spinach grown on Spalding peat, 1959.

Treatment	Tons per acre	mmg Mo per gram of tissue
None	6.1	.4
Mo seed treatment*	7.7	.6
Mo (.2 lb/A.)	6.4	.4
Mo (.2 lb/A. plus seed treatment)	8.6	.6
Mo (.8 lb/A.)	6.5	.4
Mo (.8 lb/A. plus seed treatment)	8.8	.6
LSD (5% level) method of application	Without seed treatment mean	Seed treatment mean
.6 ton	6.3	8.4

*Moly-Gro (38% Mo) seed treating compound 1/2 oz. to 4 pounds of seed.

Table 14. The effects of molybdenum and lime on the dry weight and molybdenum content of cauliflower grown on organic soil in the greenhouse, 1960.

Treatment	Grams per pot	mmg Mo per gram of tissue
None	.6	.2
Mo seed treatment*	19.4	.2
Lime (3 tons/A.)	.9	.2
Mo (.2 lb/A.) banded	15.7	.4
Mo (.4 lb/A.) banded	14.3	1.3
LSD (5% level)	2.11	

*Moly-Gro (38% Mo) seed treating compound 1/2 oz. to 2 pounds of seed.

Table 15. The effects of molybdenum and lime on the dry weight and molybdenum content of onions grown on organic soil in the greenhouse, 1960.

Treatment	Grams per pot	mmg Mo per gram of tissue
None	.8	-
Mo seed treatment*	8.6	.5
Lime (3 tons/A.)	3.5	.2
Mo. (.2 lb/A.) banded	1.2	.5
Mo. (.4 lb/A.) banded	3.6	.5
LSD (5% level)	1.5	

*Moly-Gro (38% Mo) seed treating compound 1/2 oz. to 4 pounds of seed.

Table 16. The effects of molybdenum and lime on the dry weight and molybdenum content of head lettuce grown on organic soil in the greenhouse, 1960.

Treatment	Grams per pot	mmg Mo per gram of tissue
None	5.2	.2
Mo seed treatment*	9.2	.3
Lime (3 tons/A.)	7.7	.4
Mo (.2 lb/A.) banded	4.0	.1
Mo (.4 lb/A.) banded	3.0	.4
LSD (5% level)	2.37	

*Moly-Gro (38% Mo) seed treating compound 1/2 oz. to 2 pounds of seed.

over that of the check. Lime did not significantly affect the yield. The dry weight of cauliflower from pots receiving the molybdenum seed treatment was significantly higher than the dry weight of plants from pots receiving the molybdenum banded in the soil. Even though the molybdenum at rates of .2 and .4 pounds per acre was banded two inches below the seed at planting time in this experiment (Tables 14, 15 and 16), the young emerging plants were seriously deficient in molybdenum before their roots extended sufficiently to obtain the element from the band. This treatment resulted in a growth lag for all three crops behind the growth rate of the crops with the seed treatment. In the greenhouse when harvesting plants in an immature stage of growth, a rate of growth was measured; whereas under field studies when plants are harvested at a certain stage of maturity, such a growth lag may not be apparent. The relative differences in cauliflower growth as caused by the treatments are apparent in Figure 1.

These data show similar results from the onions (Table 15) and lettuce (Table 16) which were used as indicator crops for response to the molybdenum and lime treatments.

Early growth differences of onions resulting between the check and seed treatment are shown in Figure 2. Figure 3 was a later photograph taken of the onions with the response from lime included.

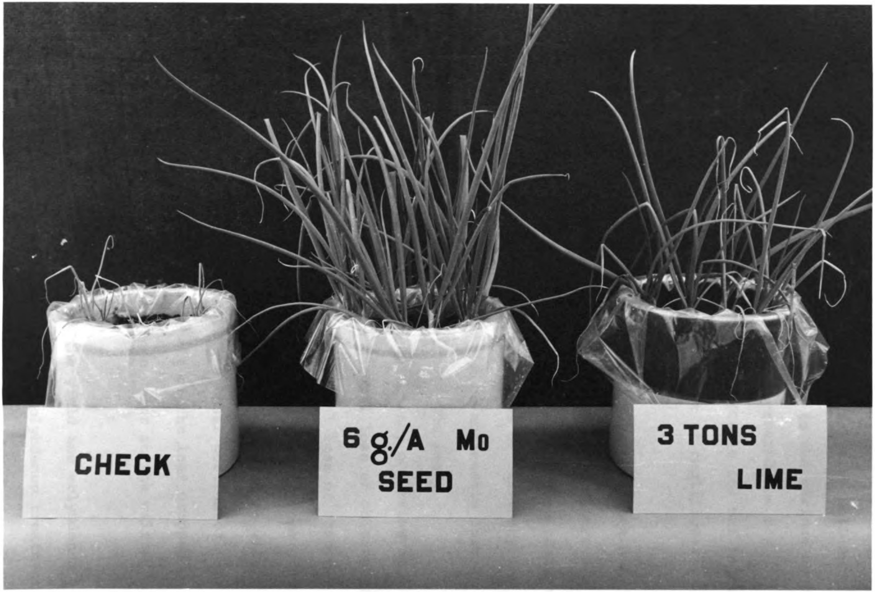
Figure 1. The effects of molybdenum and lime on the growth of cauliflower.


pH 5.2
CHECK
6 g./A Mo
SEED
3 TONS
LIME
.5 Lb/A Mo
SOIL

Figure 2. The effect of molybdenum seed treatment on the early growth of onions.


pH 5.2
CHECK
6 g./A Mo
SEED

Figure 3. The effects of molybdenum and lime on the growth of onions.


CHECK
6 g./A Mo
SEED
3 TONS
LIME

The data in these Tables show the relative influence of lime on the availability of molybdenum to the various crops. Lime applied to the soil significantly increased the dry weights of lettuce (Table 16) and onions (Table 15) but lacked effectiveness in increasing the dry weight of cauliflower (Table 14).

The growth differences of the head lettuce obtained between the check and seed treatment are shown in Figure 4.

The molybdenum deficiency symptom on the head lettuce plants of the check pots was a general loss of chlorophyll over most of the leaf surface with a more noticeable loss of chlorophyll from between the veins of the leaf.

The symptoms of molybdenum deficiency occurring on the onions were characterized by a general loss of chlorophyll over most of the leaf area, or by a general loss of chlorophyll in the tips of the older leaves. As the symptoms grew more severe, the tips of the older leaves appeared to wilt about one-half way down the leaf. The basal portion of the leaf remained erect, but the tip-half of the leaf dropped downward and tended to retain a green color in the wilted part of the leaf.

The data in Table 17 show the yield and molybdenum content of cauliflower as the result of molybdenum treatment. The soil had a pH of 6.0 and should be considered as a

Figure 4. The effect of molybdenum seed treatment on the growth of head lettuce.

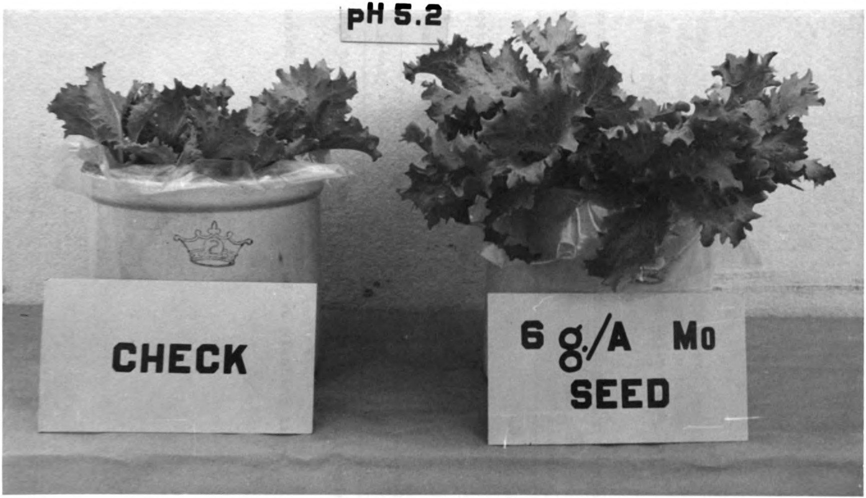

pH 5.2
CHECK
6 g./A Mo
SEED

Table 17. The effect of molybdenum on the yield and molybdenum content of cauliflower grown on Houghton muck - Michigan State University Muck Experimental Farm, 1960.

Treatment	Hundred weights per acre	mmg Mo per gram of tissue
None	204	.4
Mo seed treatment*	238	.8
Mo (.2 lb/A. plus seed treatment)**	210	9.5
LSD (5% level)	N.S.	

*Seed treatment 1/2 oz. Moly-Gro (38% Mo) to 2 pounds of seed.

**Banded 2 inches below the seed at planting time.

borderline responsive soil. Slight symptoms of molybdenum deficiency usually appear on the cauliflower crop early in the growth period, but the symptoms disappear as the season progresses. This was true of the cauliflower crop grown in 1960 and of the data reported in Table 17. These data show the lack of a significant increase in the yield of cauliflower from plots receiving the molybdenum treatments over the check. However, the composition data indicate a critical level of molybdenum in the cauliflower tissue from the check plot. The seed treatment for crops grown on this soil appears to be in adequate quantity and an excellent method for application because the level of molybdenum in the plant was in a desired range. When the seed treatment was coupled with molybdenum in the banded portion of the fertilizer, the level of molybdenum was increased to 9.5 mmg. Mo per gram of dry tissue which may be an undesirably high level.

The report of Cunningham (16) showed that molybdenum poisoning in cattle occurred where the average molybdenum content of pasture forage was as low as 4.6 parts per million.

Caution should be used in the application of this element if methods other than the recommended rate in seed treatment or parts of an ounce per acre are used in foliar application. Any management factor that would enhance microbial activity in subsequent years might increase the molybdenum level in plants grown beyond that desired.

EXPERIMENT IV

THE EFFECTS OF PLACEMENT OF PHOSPHATE AND MANGANESE FERTILIZERS ON THE YIELD AND CHEMICAL COMPOSITION OF SOYBEANS

Procedure

The experiment was initiated at the Michigan Muck Experimental Farm in 1961 to measure the effects of placement of phosphate and manganese on the yield and availability of manganese to plants. The indicator crop in the study was Acme soybeans. The experimental design was a randomized block with three replications. The treatments were: (a) 50 pounds of P_2O_5 per acre broadcast, (b) 100 pounds of P_2O_5 per acre broadcast, (c) 50 pounds of P_2O_5 per acre banded, (d) 100 pounds of P_2O_5 per acre banded, (e) 50 pounds of P_2O_5 and 20 pounds of manganese per acre broadcast, (f) 100 pounds of P_2O_5 and 20 pounds of manganese per acre broadcast, (g) 50 pounds of P_2O_5 and 20 pounds of manganese per acre banded, (h) 100 pounds of P_2O_5 and 20 pounds of manganese per acre banded, and (i) 100 pounds of P_2O_5, 20 pounds of manganese and 10 pounds of sulfur per acre banded. The fertilizer band was located two inches to the side of and two inches below the seed. The plot size was 11 feet (four

33-inch rows) by 52 feet. The basic fertilizer was 200 pounds of potash per acre drilled-in with the fertilizer attachment on the grain drill. The broadcast treatments were applied by hand, and the area was disced to mix the fertilizer in the soil before planting. The banded treatments were applied with the Muck Experimental Farm fertilizer placement drill at the time of seeding. The carriers used were 0-45-0, potassium chloride, NuManese (48% Mn) and sulfur. The plots were planted June 2, 1961; plant samples (above-ground portion) for chemical analyses were obtained July 15; and the plots were harvested late in September.

Plant material was prepared for chemical analyses as previously stated for other crops.

The analyses for potassium and nitrogen were determined as outlined in Official Methods of Analysis of the Association of Official Agricultural Chemists (54). All other chemical constituents in the soybean tissue were determined with a photoelectric spectrometer produced by Applied Research Laboratories, Incorporated, Glendale, California.

Results and Discussion

The data in Table 18 show that the highest yields of soybeans were obtained from plots where a combination of fertilizer materials was banded. There were no significant

Table 18. The effects of placement of phosphate and manganese fertilizer on the yield and chemical composition of soybeans, 1961.

Pounds per acre		Bushels per acre	Percent of oven-dry weight					Parts per million						
P_2O_5	Mn		N	P	K	Ca	Mg	Mn	Fe	Cu	B	Zn	Mo	Al
50	0*	23.4	4.08	.299	2.80	2.34	.550	16	200	13.7	63.8	41	8.6	176
100	0*	30.4	3.99	.452	2.94	2.12	.450	16	163	8.4	84.0	34	8.2	66
50	0**	31.7	4.00	.354	2.94	2.18	.500	16	140	14.7	69.6	30	8.4	154
100	0**	34.5	3.74	.432	2.54	2.08	.480	22	156	10.5	72.5	75	7.6	184
50	20*	37.5	3.76	.264	2.88	2.18	.550	16	186	12.9	61.0	26	8.4	62
100	20*	31.7	3.60	.282	2.54	2.34	.550	16	143	12.9	75.3	24	8.8	108
50	20**	37.6	3.69	.282	2.60	2.18	.550	38	143	7.6	58.0	24	8.4	54
100	20**	38.8	3.60	.336	2.80	2.23	.530	38	140	6.8	58.0	24	7.4	49
100	20***	40.2	3.80	.326	2.94	2.18	.500	38	124	7.6	65.2	26	7.6	49
LSD (5% level)		5.9												

*Broadcast and disced in.

**Banded 2 inches to the side and 2 inches below the seed.

***10 pounds of sulfur per acre included in this treatment.

differences between yields where different rates of phosphate were used when the manganese, or manganese and sulfur, were included in the banded fertilizer. With one exception the highest yields of soybeans were associated with manganese content of tissue of 22 parts per million or higher. The yield of soybeans from plots treated with 50 pounds of phosphate per acre broadcast was significantly lower than the yields of beans from all other treatments. It appears from the chemical composition of the tissue, that manganese and not phosphorus was associated with lower yields. These data show that the banding of the phosphate carrier was about as effective in increasing the yield as the broadcast application of 20 pounds of manganese. There was one exception to this where the "50-pound phosphate and 20-pound manganese" treatment was applied. The yield of soybeans from the plots treated at the 100-pound broadcast rate was significantly higher than the yields of beans from plots treated at the 50-pound rate of phosphate broadcast.

In general, chemical composition of nutrients in the plant other than manganese appears to be within desirable ranges; and these nutrients probably did not have a suppressing effect on the yield of soybeans.

SUMMARY AND CONCLUSIONS

EXPERIMENT I: THE EFFECTS OF RATES OF SODIUM CHLORIDE AND POTASH ON THE YIELD AND CHEMICAL COMPOSITION OF SUGAR BEETS

A field experiment was carried out at the Michigan Muck Experimental Farm to determine the effects of rates of sodium chloride at varying rates of residual and applied potash on the yield and chemical composition of sugar beets.

A three-ton increase in the yield of sugar beet roots was obtained from plots treated with sodium chloride at low rates of potash, but no yield increase was obtained from sodium chloride where the potash was applied at 600 pounds per acre.

A partial substitution of sodium for potassium occurred with the sugar beet plant.

Sodium and potassium were antagonistic to each other, as evidenced in plant uptake, and either or both suppressed the uptake of magnesium and calcium in the plant.

The level of residual potassium in the soil was not maintained even at a 600-pound annual application of potash per acre.

EXPERIMENT II: MAGNESIUM AND UTAH 10B CELERY

Field experiments were conducted to determine the residual effect of hydrated magnesium sulphate (9.87% Mg) applied as high as 10,000 pounds per acre to the soil on the control of magnesium deficiency symptoms on the leaves of Utah 10B celery. A second field experiment was carried out to study the interaction of levels of potash and magnesium on the yield and chemical composition of celery.

Controlling the symptoms of magnesium deficiency on the leaves of Utah 10B celery did not significantly affect the yield of the crop. Magnesium sulphate applied at 10,000 pounds per acre to the soil was less effective in the control of the symptoms than 80 pounds of magnesium sulphate per acre applied in eight applications of ten pounds each as a foliar spray.

The magnesium composition of the above-ground portion of celery did reflect the magnesium treatment to the soil. However, the magnesium content of the plant was not considered as a reliable index to the incidence of magnesium deficiency symptoms occurring on the leaves of the plant.

Potash applied at 1,200 pounds per acre suppressed the yield of celery and the uptake of magnesium by the plant. This was not true, however, with calcium.

EXPERIMENT III: THE EFFECT OF MOLYBDENUM ON THE YIELD AND MOLYBDENUM CONTENT OF CROPS

Field and greenhouse experiments were initiated to determine crop response from molybdenum and to formulate tentative recommendations for crop production on Michigan organic soils. Molybdenum analyses of plant tissue were made to determine availability of the element to plants from various methods of application.

Significant increases in the yields of cauliflower, onions, lettuce and spinach were obtained from molybdenum applied to several Michigan organic soils in field and greenhouse studies.

This is the first known report indicating the onion plant to be a molybdenum-responsive crop.

In a field experiment, sodium molybdate was applied to the soil at two pounds per acre and was ineffective in increasing the yield of spinach, whereas six grams of molybdenum per acre (Moly-Gro 38% Mo) applied as a seed treatment significantly increased the yield.

The molybdenum content of cauliflower was 9.5 parts per million when the molybdenum seed treatment was coupled with one-half pound of sodium molybdate per acre, mixed with the basic fertilizer and banded two inches below the seed.

The molybdenum seed treatment at one-half ounce per acre of Moly-Gro increased the molybdenum content of the tissue by .2 to .4 of a part per million in the oven-dry tissue.

The seed treatment is recommended for molybdenum responsive crops on soils where the pH is below 5.4. On the more acid soils, or soils containing visible concretions of iron, molybdenum in addition to the seed treatment may be advisable.

EXPERIMENT IV: THE EFFECTS OF PLACEMENT OF PHOSPHATE AND MANGANESE FERTILIZERS ON THE YIELD AND CHEMICAL COMPOSITION OF SOYBEANS

Banding phosphate fertilizer two inches to the side and two inches below the seed of soybeans increased the yield to about the same extent as a broadcast application of 20 pounds of manganese per acre.

The data indicated that the increased yields from the band application of the phosphorus were the result of enhanced availability of manganese rather than the phosphate uptake by the crop.

The highest yield of soybeans resulted where both manganese and phosphate were banded two inches to the side and two inches below the seed.

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