THE EFFECTS OF MOLYBDENUM AND LIME APPLICATIONS ON THE YIELD AND CHEMICAL COMPOSITION OF LETTUCE AND CAULIFLOWER GROWN ON TWO MICHIGAN ORGANIC SOILS

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ABSTRACT

THE EFFECTS OF MOLYBDENUM AND LIME APPLICATIONS ON THE YIELD AND CHEMICAL COMPOSITION OF LETTUCE AND CAULIFLOWER GROWN ON TWO MICHIGAN ORGANIC SOILS

by Albert W. Hosner

A greenhouse study was undertaken to determine the relationship between lime and molybdenum applied to two organic soils and the growth of lettuce and cauliflower.

Rifle peat (Soil 1) with a pH value of 4.0 and Rifle muck (Soil 2) with a pH value of 4.8 were the soils used. Lime consisting of several combinations of calcium carbonate and magnesium carbonate, was applied at 3 and 6 tons per acre. Applications of molybdenum plus 3 tons of lime, and molybdenum alone were used as additional soil treatments. A uniform fertilizer treatment was added to all jars. Each treatment was replicated four times with each crop.

The untreated soils were analyzed for calcium, magnesium, potassium, sodium, molybdenum, pH, exchangeable hydrogen, total exchange capacity, per cent organic matter, and ash.

The addition of 3 tons of lime per acre to soil 1 raised the pH value from 4.0 to approximately 4.8 and where 6 tons of lime was used, to 5.6. Similarly, the respective pH values for soil 2 increased from 4.8 to 6.1 and 6.8.

Molybdenum alone increased the yield of lettuce on soil 1. Slightly higher increases in yield were obtained

where lime alone was applied or applied in combination with molybdenum. There was no response of lettuce grown on soil 2 to molybdenum. In general, the yield of lettuce decreased as the amount of lime applied increased.

Yield of cauliflower growing on soil 1 was increased as much as seventeenfold where 6 tons of lime per acre was added. Lower yields were obtained where 3 tons of lime was added. A significant response to molybdenum was also obtained. This response amounted to approximately an eightfold increase. The addition of lime to soil 2 tended to increase yields of cauliflower. The response was much less than with the cauliflower growing on soil 1.

The uptake of molybdenum by lettuce was higher where lime was applied than where molybdenum alone was used. The reverse of this situation occurred with the cauliflower crop. Molybdenum did not influence the uptake or per cent of other ions.

In general, as the amount of calcium in the lime increased, the percentage of calcium in the plant tissue increased while the per cent magnesium decreased. Conversely, as the amount of magnesium in the lime increased, the percentage of calcium in the plant tissue decreased while the per cent of magnesium increased. In several cases, as the amount of lime applied increased, the amount of phosphorus taken up by the crops decreased. This was also accompanied by a decrease in the per cent of phosphorus in the tissue.

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The lime and molybdenum treatments had very little effect on the percentage composition of nitrogen, potassium, and sodium in the lettuce and cauliflower. However, the uptake of these three ions was related to the yield, with the highest uptakes obtained where the yield was the greatest.

The various ratios of magnesium and calcium carbonates in the lime applied did not have any definite effect on yield of lettuce. However, where magnesium carbonate alone was applied, the yields of cauliflower were, in general, lower than where a mixture of calcium carbonate and magnesium carbonate was used. There was no definite trend in the amount of molybdenum taken up by either the lettuce of cauliflower or the percentage of molybdenum in the lettuce and cauliflower associated with the ratios of magnesium and calcium carbonate used.

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INTRODUCTION

Lime is needed in the soil for many reasons. It supplies calcium to the growing plant, decreases soil acidity, and tends to regulate the availability of several nutrients required for plant growth. Lime may increase the availability of molybdenum to crops. It has been shown by various leaching experiments and actual plant growth that molybdenum becomes more available as the pH value rises. Hydroxyl ions may play a part in making molybdate ions more available by replacing them on the organic or clay complex.

A pH value of 5.0 for organic soils has been generally accepted as adequate to produce optimum plant growth. However, recent responses to lime by celery grown on organic soils having a pH value of 5.5 have been observed. This suggested the possibility that molybdenum deficiency might explain the differences in lime response.

Molybdenum is one of the essential elements for plant growth, and is required in very small quantities. The heaviest of all elements listed as needed by plants, it is the only element of the fifth period of the periodic table which has been determined essential for plant growth.

The objective of this research was to study the relationship of lime and molybdenum to yield and chemical composition of lettuce and cauliflower.

REVIEW OF LITERATURE

Wilson and Townsend (41), working on an experiment to increase productiveness of lettuce growing on low pH organic soils, reported that liming prevented the development of a chlorotic leaf condition, leaf curl, necrotic spots at the tips and on the margins of the leaves, and the death of the plant in early stages of growth. No organisms were isolated from the leaves or roots of affected plants, so the condition was termed nutritional and lime corrected the deficiency.

Stout and Johnson (36) stated that whiptail disease of broccoli and cauliflower was recognized by E. E. Clayton in 1924 in New York State. He believed the condition to be caused by the unavailability of some soil nutrient which could be controlled by liming.

Floyd (16) recognized yellow spots on citrus trees in Florida about 50 years ago. In 1952, Stewart and Leonard (34) showed that the trouble was caused by a molybdenum deficiency.

Arnon and Stout (2), utilizing water cultures, presented experimental proof that molybdenum is required by tomatoes. Piper (28), at approximately the same time, showed that this element is necessary for growth of oats. These workers stated that liming acid soils prevented or overcame the deficiency symptoms.

It was not until 1948, however, that Walker (38) demonstrated molybdenum deficiencies for soil-grown plants. He found that tomatoes growing in a greenhouse on California soils, derived from serpentine parent materials, developed deficiency symptoms that disappeared with molybdenum applications. He also found that Romaine lettuce responded to molybdenum treatments on one soil.

Weiss (40) stated that many plant growth abnormalities in this country were traceable to molybdenum deficiency. The whiptail disease of cauliflower is one such example.

Piper (28), Ulder (24), and Wilson, as cited by Evans (11) indicated that molybdenum is the one mineral element which is specifically and consistently associated with the mechanism of nitrogen fixation by root nodule bacteria.

Molybdenum is also necessary for nitrate reduction as shown by Mulder (24) and others (13) (18). The leaves of molybdenum deficient plants contained large amounts of nitrate nitrogen. Spraying the leaves with a solution of sodium molybdate resulted in a decrease of nitrate nitrogen to a normal level and recovery from chlorosis.

Agarwala (1) demonstrated that molybdenum undoubtedly plays a vital role in plant metabolism other than that associated with nitrate reduction and nitrogen fixation. Cauliflower plants grown with nitrogen from various sources, including urea and ammonium sulfate, developed characteristic molybdenum deficiency symptoms known as "whiptail" and contained reduced concentrations of ascorbic acid. This indicated that certain plant species, including citrus and cauliflower required molybdenum when grown where sources of nitrogen other than nitrates were used, and that a deficiency of the element resulted in profound chemical changes in tissues apparently not associated with nitrate metabolism.

Hewitt and McCready (17) reported molybdenum deficiencies in cauliflower, irrespective of whether the source of nitrogen was nitrate, nitrite, ammonium compounds, urea, or glutamic acid. The concentration of ascorbic acid and of some sugars was decreased in some cases. The chlorophyll content and total organic nitrogen of molybdenum deficient plants was lowest where nitrogen was supplied as nitrate.

Steinberg (32,33) reported the first evidence of a physiological role of molybdenum not associated with nitrogen fixation.

Stout (35) pointed out that the uptake of molybdenum by plants may be hindered by the presence of large amounts of sulfates since the two ions are of the same size and charge. Sulfates are not regarded as being adsorbed by soil colloidal materials; however, the uptake of molybdenum by plants, as pointed out by Stout (35) and also Barshad (4), is depressed in the presence of sulfates.

Arnon and Stout (2) and Piper (28) stated that molybdenum deficiencies in plants were overcome by liming. However, Stout (35), by using culture solutions, showed that absorption of molybdates by plants was greater from acid solutions than from solutions of neutral reactions. It must, therefore, be concluded that when lime is added to soils, the increased concentration of available soil molybdenum is more than sufficient to overcome the decreased absorption of molybdate by plants from increasingly alkaline media.

The first reported recognition of a soil deficiency of molybdenum, according to Rubins (31), was by van Niel in 1935. He found that some sandy, slightly alkaline soils from the Monterey Peninsula of California contained insufficient molybdenum to support nitrogen fixation by Azotobacter.

Plant (29) reported that dolomitic and calcitic limestone were equally effective in correcting molybdenum deficiencies and in producing normal yields of crops.

Barshad (4) reported that the differences in solubility between soil molybdenum and the molybdenum minerals indicated that the molybdenum in the soils studies was present not as a distinct mineral, but rather as a partly soluble molybdate salt, partly as a component of soil organic matter and partly as an adsorbed exchangeable anion $(MoO_4)^=$. Barshad further reported that the increase in adsorption of molybdate anion by clay, upon lowering the pH value of the suspension, and the increase in pH value of the solution resulting from the adsorption of molybdenum indicated that molydate anions

$(MoO_4)^=$ $(HMoO_4)^-$ exchanged with hydroxyl ions of the clays in the same manner as phosphate ions.

Davies (8) classified molybdenum under four headings: (1) unavailable (held within the crystal lattice of primary and secondary minerals; (2) conditionally available (retained as the $(MoO_4)^=$ anion by clay minerals and available to a greater or less degree depending on pH value and probably phosphate status); (3) in organic matter and (4) water soluble. He also stated that either heavy liming or a soil application of molybdenum frequently brought about the same improvement in yield.

Mulder (25) using Aspergillus niger showed molybdenum in soils to be more available at a pH value of 6.8 than at 5.0 or 2.0.

Kretschmer and Allen (21), working with organic soils of the Everglades in Florida, showed increases in soil molybdenum content up to a pH value of 6.8.

Evans, Purvis, and Bear (12) observed that as the pH value of the soil increased, the amount of available molybdenum increased. A soil with a pH value between 6.1 and 6.5 contained between 0.7 and 1.1 ppm molybdenum. A soil limed to a pH value between 6.9 and 7.6 contained between 1.6 and 3.0 ppm of molybdenum. The increased amount of soluble molybdenum was due to the increase in soil pH value rather than to the molybdenum supplied by the liming material. They concluded that molybdenum was present in acid soils in an unavailable form and that its availability to plants was increased by liming to near neutrality. The molybdenum content was very low in some naturally neutral or slightly alkaline soils in New Jersey. This was due to leaching that occurred at high pH values during the soil forming process. They also observed that a small application of molybdenum to a soil limed to a pH value of 5.5 might significantly increase the yield of certain crops. Crop responses to molybdenum at higher pH values were less pronounced.

Stout (35), working with phosphates and molybdenum found that as phosphate levels of the soil were increased, the molybdenum absorption was enhanced, sometimes by as much as tenfold. Under conditions of intensive cropping and at high phosphate levels, added molybdenum was rapidly removed, resulting in recoveries of 10 to 50 per cent of the molybdenum applied to a single crop. Molybdenum absorption by plants grown on soil was decreased where the content of soluble soil phosphates was lowered and the soil sulfate levels increased.

In 1948, Warington (39) working with lettuce and red clover, found that the amount of calcium present did not alter the need of either plant for molybdenum. However, with clover, the appearance of molybdenum deficiency symptoms was hastened when nitrogen was scarce, whereas, with lettuce it was retarded.

Kline (20) reported that an excess of molybdenum occurred in organic soils and poorly drained alkaline soils, especially in valley floors in the West. He postulated that the active molybdenum fraction in soils consisted of various molybdate ions and organic molybdenum complexes. Higher oxides were readily converted to these forms. Lower oxides and the disulfide forms were inactive until oxidized. The total molybdenum content of soils depended on the parent materials from which they were derived, and the accumulation of molybdenum from drainage waters and organic matter.

Deficiencies of total molybdenum in the soil as reported by Kline (20) were relatively few. However, deficiencies of available molybdenum were quite common in acid-soil regions. There are many cases of plant deficiencies, unexplained in earlier years, that were probably due to lack of molybdenum. Crops chiefly affected are legumes, tomatoes, lettuce, beets, spinach, crucifers, and cucurbits.

Most mineral soils in this country as stated by Robinson and Alexander (30) contained an average of about 2 ppm of molybdenum with some reaching as high as 31.5 ppm. Some soils in France and the Hawaiian Islands contained as much as 73.8 ppm.

Weiss (40) pointed out that an excess of molybdenum can be created by overliming. This might result in a deficiency of copper in the herbage, which in turn might cause a deficiency disease of grazing animals.

Kretschmer and Allen (21) found a lack of copper in diets which were high in molybdenum. Copper content of forage was found to decrease in the fall and increase in the spring, giving an unfavorable copper-molybdenum balance. Suitable forage contained about 10 ppm of copper and less than 3 ppm of molybdenum.

Evidence of a critical effect of pH on molybdenum uptake at the toxicity level was observed by Lewis (23) on the "teart" soils of Somerset. If the pH value was below 7.0, pasture was nontoxic to grazing animals, even though the soil might contain as much as 33 ppm of total molybdenum.

The first observations of toxic effects by excess molybdenum in forage consumed by animals was reported by Ferguson, Lewis, and Watson (14) in certain areas of Great Britain. Similar toxic effects in cattle grazing on pastures of high molybdenum content (15 to 30 ppm dry weight) have since been reported from America by Barshad (5), and by Dick (9) in Canada, New Zeland, and Sweden.

Lewis (23) reported that the molybdenum content of the "teart" pastures of Somerset contained from 20 to 200 ppm of molybdenum. The consumption of forage growing on soils in that area which were neutral or alkaline in reaction resulted in severe molybdenum toxicity to cattle. On the other hand, forages growing on soils which were acid in reaction, did not produce the disease when eaten by livestock.

Ketschmer and Allen (21) found that various forages have large differences in molybdenum accumulative powers. They also found that molybdenum contents may reach toxic levels in forages, even when the soil pH value is below 6.0. The molybdenum content of plants grown on older soils was considerably higher in every instance. Since length of cultivation of these organic soils resulted in an increased ash percentage, it was believed that the per cent ash (eliminating the forage variety and pH effect) might be positively correlated with the molybdenum contents of plants growing on a particular soil type. Pasture grasses sampled in the fall had higher molybdenum contents than those sampled in late spring. As growth rate slowed down, molybdenum content of forage crops increased.

Barshad (5) showed cattle toxicity from excessive molybdenum when the plants contained 20 or more ppm. When the molybdenum content of plants was less than 10 ppm, no toxicity resulted.

Lewis (23) showed, however, that certain plants, particularly legumes, absorbed sufficient molybdenum to be harmful to cattle from soils that contained as little as 1.5 to 5.0 ppm total molybdenum.

PROCEDURE

Samples of two organic soils (top 12 inches) were obtained from separate farms. The first soil, which was classified as Rifle peat, was obtained from the Anderson and Schonfeld Farms, Lapeer County. The second soil (Soil 2) which was classified as Rifle muck, was obtained from the Fisher Brothers Farm, Muskegon County. The pH value of this soil was 4.8. Portions of the soil from the Anderson and Schonfeld farms were mixed in a proportion of one part Anderson soil to two parts Schonfeld soil in order to obtain a composite (Soil 1) with a pH value of 4.0.

The soils were sieved through a one-half inch screen and a ten-gram sample of each was dried overnight at 105°C for determining the moisture content.

The original soils were analyzed for pH value, total cation exchange capacity, exchangeable calcium, magnesium, potassium, sodium, hydrogen, and total organic matter.

The materials representing the various treatments (Table 1) were thoroughly mixed with the soil, and the mixture placed in 2-gallon jars. Each treatment was replicated four times with each crop.

The basic fertilizer treatments for the soil in all jars was as follows: (1) 3,000 pounds of a 10-10-30 fertilizer per acre, with an additional 1,000 pounds for the second crop; (2) 25 pounds of copper per acre for the first crop, with no additional treatment for the second crop; (3) 5 pounds of boron per acre for each crop except treatments 1 and 2, which received only the initial application; (4) 100 pounds of manganese per acre for each crop except treatments 1 and 2 for the lettuce crop. The salts used to supply the minor elements were copper sulfate, borax, and manganese sulfate.

Table 1. Soil treatments.

Treatment Number	Tons Lime/A	Per Cent $CaCO_3$[a]	Per Cent $MgCO_3$	Pounds $Na_2MoO_4 \cdot 2H_2O$/A
1	0	0	0	0
2	0	0	0	0.5[b]
3	3	100	0	0
4	3	60	40	0
5	3	40	60	0
6	3	0	100	0
7	6	100	0	0
8	6	60	40	0
9	6	40	60	0
10	6	0	100	0
11	3	60	40	0.5[b]

[a]Amount added based on the neutralizing value of $CaCO_3$ as being 100.

[b]Additional amounts of $Na_2MoO_4 \cdot 2H_2O$ added to second crop to bring the total application of molybdenum to 3/4 pound per acre.

The minor elements, including sodium molybdate, were dissolved in distilled water and applied with a pipette.

Distilled water was added to bring the moisture content of the soil to field capacity. This moisture content, which was considered optimum, was maintained by periodically bringing the jars up to weight with distilled water.

Head lettuce plants of the "Cornell 456" variety, which had previously been grown on a molybdenum deficient mineral soil, were transplanted (two plants per jar) on April 29, 1958. In a few cases plants had to be replaced with others from the starting flat.

The lettuce plants were harvested June 13, 45 days after transplanting, placed in paper bags, and dried in a forced draft electrical oven at $174^{o}F$.

The dried plant material was then ground in a Wiley Mill, sived through a 20-mesh screen and stored in glass sample bottles for chemical analysis.

After the lettuce was harvested, the soil in the jars was screened to remove roots, and then refertilized as previously described.

Cauliflower of the "Early Snowball A" variety, treated in a similar manner as the lettuce, was transplanted June 30. Signs of molybdenum deficiency, on those plants receiving molybdenum treatments, appeared on July 23. An additional two and one-half ounces of $Na_2 MoO_4 \cdot 2H_2O$ was added to these jars. On August 7, signs of molybdenum deficiency were still apparent so another application of molybdenum was used. One-half of the molybdenum treated jars received a molybdenum spray (1/4# Mo/100 gal. H_2O) three times in consecutive days. This spray was applied with a hand operated fly sprayer until the leaves were dripping wet. Additional soil applications of molybdenum were made to the remaining molybdenum treated jars to make a total of 3/4 pound of actual molybdenum per acre.

The cauliflower was harvested on August 23, 54 days after transplanting, and samples prepared as described for lettuce.

The plant tissue was analyzed for molybdenum, nitrogen, phosphorus, potassium, magnesium, calcium, and sodium.

METHODS OF CHEMICAL ANALYSIS

Plants

Molybdenum determinations on the plant samples were made by the method of Dick and Bingley (10), as modified by Benne and Jerrim (6,7). Referee samples furnished by Dr. E. J. Benne of the Agricultural Chemistry Department were first analyzed to insure accuracy of results.

Known weights of plant tissue (0.5 to 5.0 grams) were placed in 250-milliliter pyrex beakers and digested with nitric acid, and a 2:1 mixture of 70 per cent perchloric acid and concentrated sulphuric acid. When cooled, the beaker was rinsed with distilled water. Two drops of a 0.1 per cent methyl orange solution was then added and the total solution neutralized with concentrated ammonium hydroxide. Enough 0.6N HCl was then added dropwise, while stirring, to make the solution just acid. Then 8.2 ml excess HCl was added to give a final concentration of approximately 3 per cent HCl.

To the acid solution, 2.0 ml of a 5 per cent sodium fluoride solution, and 1 ml of iron standard solution were added, after which it was thoroughly mixed. The mixture was then transferred to a 125 ml separatory funnel with distilled water. The solution was diluted to 50 ml volume with distilled water and then 4 ml of a 20 per cent potassium thiocynate solution, and 1.5 ml of a 20 per cent stannous chloride solution were added, mixing thoroughly after each addition.

From a pipette, 15 ml of iso-amyl alcohol were added and the mixture shaken vigorously for 1 minute. The alcohol-aqueous phase was allowed to separate and the aqueous portion drawn off and discarded. To the remaining portion, 25 ml of freshly prepared 0.8 per cent stannous chloride wash solution was added and shaken gently for 15 seconds. The phases were again allowed to separate and the aqueous portion drawn off and discarded. The remaining iso-amyl alcohol solution was transferred to a test tube and centrifuged 5 minutes at 2000 rpm to remove the water droplets.

The unknown samples were compared with an iso-amyl alcohol standard using a Cenco-Sheard-Sanford Photelometer. The photelometer was equipped with a Corning glass light filter No. 502 with maximum transmittance at 440-460 mu and 1 cm absorption cells of 10 ml capacity.

Nitrogen determinations were made by the Kjeldahl method as outlined by the Association of Official Agricultural Chemists (3).

Phosphorus was determined by first wet ashing a 1-gram plant sample by the perchloric acid method of Piper (27). A colorimetric determination was then made as described by Fiske-Subbarow (15) using a Coleman spectrophotometer with a red filter (650 mu).

Samples for determining calcium, magnesium, sodium, and potassium were prepared by the method of Piper (27). Determinations were made with the Beckman DU Flame Spectrophotometer, equipped with a photomultiplier. The source of fuel for the flame was hydrogen burned in the presence of oxygen. The instrumental conditions used for the determinations are listed below.

Conditions	Elements Determined			
	Calcium	Magnesium	Sodium	Potassium
Wave length	4227 A^o	3710 A^o	5893 A^o	7665 A^o
Phototube resistor	No. 2	No. 2	No. 2	No. 1
Phototube	Blue	Blue	Blue	Red
Selector	0.1	0.1	0.1	0.1
Slit	0.01	0.06	0.01	0.04
Sensitivity				
A. Instrument panel	Variable	Variable	Variable	Variable
B. Photomultiplier	No. 4	Full	No. 2	Off
Zero suppression	1.0	1.0	1.0	Off

Soils

The two soils used in this study were analyzed for pH, organic matter, exchange capacity, exchangeable calcium, magnesium, potassium, sodium, hydrogen, and total molybdenum.

Soil reaction was determined by the glass electrode, using a 1 to 2 soil to water ratio.

Exchange capacity was determined by the neutral normal ammonium acetate method as described by Peech (26).

Exchangeable potassium, calcium, magnesium, and sodium were determined on the leachates from the ammonium acetate extractions of the soils, using the Beckman DU Flame Spectrophotometer as outlined by Toth, Prince, Wallace, and Mikkelsen (37).

Per cent organic matter was determined by the combustion method as outlined by Piper (37).

The exchangeable hydrogen was determined by Woodruff's solution as described by Jackson (19).

The molybdenum determination, because of the high organic matter content of the two soils, was made in a similar way as was used for the plant tissue. A 5-gram sample was wet digested. One-half of the samples were then run through the test for molybdenum. The remaining samples were filtered to remove the residue that still remained. They were then placed in platinum crucibles and gradually heated in an electric muffle furnace to 500 to 600°C and allowed to remain at this temperature overnight. The residue was then washed with hydro-floric acid to remove the silica.

$$SiO_2 + 4HF \text{ ----------} \underset{\text{gas}}{SiF_4} + 2H_2O$$

The solution was then tested for molybdenum, using the method outlined for the plant tissue. Since no molybdenum was detected in the residue, the method as described for plant residue was assumed reliable.

EXPERIMENTAL RESULTS AND DISCUSSION

The organic matter content of the two soils used in this experiment varied from 92.9 per cent to 42.7 per cent (Table 2), due to the high amount of wind-blown-sand in the upper portion of soil 2. This would, at least, partially explain the lower total exchange capacity of soil 2 (Table 3).

Soil 1 contained approximately 20 per cent more total molybdenum than soil 2. Both soils ranged slightly higher in molybdenum content than the average of 2 ppm for mineral soils, as stated by Robinson and Alexander (30).

Table 2. Some chemical and physical characteristics of two acid organic soils used in this investigation.

Soil	pH Value	Per Cent Organic Matter	Per Cent Ash	Molybdenum ug
1	4.0	92.9	7.1	3.0
2	4.8	42.6	57.3	2.4

Hydrogen was found to be the predominant exchangeable cation in soil 1, but was just slightly lower than calcium in soil 2 (Table 3). Magnesium, sodium, and potassium followed in decreasing order of magnitude in soil 2, while in soil 1 the potassium content was slightly higher than sodium.

Table 3. Total exchange capacity and exchangeable cations of two acid organic soils.

Soil	Total Exchange Capacity	Milliequivalents per 100 grams of air dried soil				
		H	Ca	Mg	K	Na
1	72.4	50.3	11.8	9.8	.256	.250
2	50.3	20.0	20.8	9.0	.128	.163

The effect of lime applications on the pH value of the two organic soils is shown in Table 4. All values seemed to be raised in a consistent manner except where 3 tons of 40-60 lime was applied to soil 1. No explanation for the unusually high reading can be given.

I. Crop yields as affected by treatments

The data for yield and uptake of nutrients per jar was analyzed by analysis of variance. The treatment differences were evaluated by using Duncan's Studentized Range Table, and the significant differences between means indicated by letters.

Lettuce, Soil 1.--The lettuce showed a definite response to molybdenum applications (Table 5 and Figure 1). In the check soil, the lettuce did not develop normally. The leaves were light yellowish-green in color, slender, and stunted in growth. The edges of the older leaves became very light in color and then turned brown. An application of molybdenum corrected this deficiency.

Table 4. The effect of lime on the pH value of two organic soils.

Treatment Number	Tons lime/A	Per Cent		Pounds	pH	
		$CaCO_3$	$MgCO_3$[a]	$Na_2MoO_4 \cdot 2H_2O$/A	Soil 1	Soil 2
1	0	0	0	0	4.0	4.8
2	0	0	0	0.5[b]	4.0	5.0
3	3	100	0	0	4.7	6.1
4	3	60	40	0	4.9	6.2
5	3	40	60	0	5.4	6.1
6	3	0	100	0	4.6	6.0
7	6	100	0	0	5.7	6.7
8	6	60	40	0	5.5	7.0
9	6	40	60	0	5.6	6.7
10	6	0	100	0	5.6	6.7
11	3	60	40	0.5[b]	4.9	6.2

[a]Amount added based on neutralizing of $CaCO_3$ as 100.

[b]Additional amounts of $Na_2MoO_4 . 2H_2O$ added to second crop to bring the total application of molybdenum to 3/4 pound per acre.

Jars treated at the rate of 3 tons of lime, which raised the pH value to approximately 4.9, produced higher yields that were significantly different from those receiving molybdenum alone. The benefit from the lime is understandable, as stated by Evans, Purvis, Bear (12) and others, that as the pH value rises the availability of molybdenum increases. Barshad (4) reported that the molybdenum present in the soil can be tied up as a component of soil organic matter, which might have been the case with such a low pH value. However, with the lime application increased to 6 tons, resulting in a pH value of about 5.6, no further significant difference in growth response was obtained.

No significant difference in lettuce yields were obtained where molybdenum plus lime was used over those where lime alone was used indicating that there was molybdenum in the soil. Enough molybdenum was released for normal plant growth where the lime was applied. The color, however, was darker where molybdenum was applied.

No significant difference in yields were obtained from the different types of lime.

Lettuce, Soil 2.--No response by lettuce from molybdenum applications was apparent on this soil (Table 5). However, as the amount of lime increased, the growth decreased. The lowest yields were obtained where 6 tons of lime were applied, indicating that a pH value of 4.8 was more ideal for growing lettuce than where the pH value was increased by use of lime.

No significant difference in yields due to the type of lime was evident.

Cauliflower, Soil 1.--Cauliflower grown in the check jars was very light yellowish-green in color, the leaves curled upward, dried at the edges and eventually fell off (Figure 2).

The cauliflower plants growing on the molybdenum treated soil showed symptoms of molybdenum deficiency the first 3 weeks after transplanting. To overcome this, additional molybdenum was added in two separate applications as outlined in the procedure. The cauliflower responded in both cases with no visible advantage to either foliar or soil applied molybdenum.

The yield from the molybdenum treated soil was approximately 700 per cent higher than that of the check (Table 6). A further increase in yield of over 400 per cent was obtained where 3 tons of lime plus molybdenum was used.

The response to molybdenum applied alone was similar to that obtained from an application of 3 tons of 40-60 lime per acre, but was higher than where 100 per cent magnesium carbonate was used. Where molybdenum plus 3 tons of lime was applied, the yield was about equal to that obtained where 6 tons of 100 per cent magnesium carbonate lime was added. However, all of the jars receiving 6 tons of lime per acre produced a higher yield than those receiving molybdenum plus 3 tons of lime.

Yields were lowest at both rates of application where 100 per cent magnesium carbonate lime was used. The mean yield for treatment 6 was lower than those of treatments 3 and 5, and significantly lower than treatment 4. Similarly the mean yield of treatment 10 was significantly lower than those of treatments 7, 8, or 9 (Table 6).

Cauliflower, Soil 2.--Table 6 also shows no significant differences in yield response by cauliflower from a molybdenum application to this soil. The lowest yield was obtained from the soil receiving molybdenum alone. Yields where molybdenum plus 3 tons of lime was applied were higher than the check and significantly higher than the molybdenum alone treated soils.

Mean yields of treatments 4 and 11 were not significantly different. The lowest yield was obtained where the molybdenum was applied.

Yields again were lower at both rates of application where 100 per cent magnesium carbonate lime was used, but being most evident where the lower rate of lime was applied.

Table 5. The effect of lime and molybdenum on the yield of lettuce grown on soil 1 and 2.

		Soil 1		Soil 2	
Number	Treatments[1]	Grams dry tissue per jar[2]	Test for sig.dif.[3]	Grams dry tissue per jar[2]	Test for sig.dif.[3]
			5%		5%
1	0-0-0-0	10.6	a	19.0	d
2	0-0-0-.5[4]	14.0	b	18.9	d
3	3-100-0-0	16.0	c	16.1	bc
4	3-60-40-0	16.8	c	15.6	bc
5	3-40-60-0	16.8	c	15.1	bc
6	3-0-100-0	15.4	c	15.2	bc
7	6-100-0-0	16.2	c	11.9	a
8	6-60-40-0	15.5	c	13.4	ab
9	6-40-60-0	15.8	c	14.0	abc
10	6-0-100-0	16.0	c	13.4	ab
11	3-60-40-.5[4]	15.8	c	16.4	cd

[1]Tons of lime/A, per cent calcium carbonate, per cent magnesium carbonate, and pounds of molybdenum carrier per acre, respectively.

[2]Average of four replications.

[3]Values with the same literal postscript are not significantly different at the probability level shown.

[4]Additional amounts of $Na_2MoO_4 \cdot 2H_2O$ added to second crop to bring the total application of molybdenum to 3/4 pound per acre.

Table 6. The effect of lime and molybdenum on the yield of cauliflower grown on soil 1 and 2.

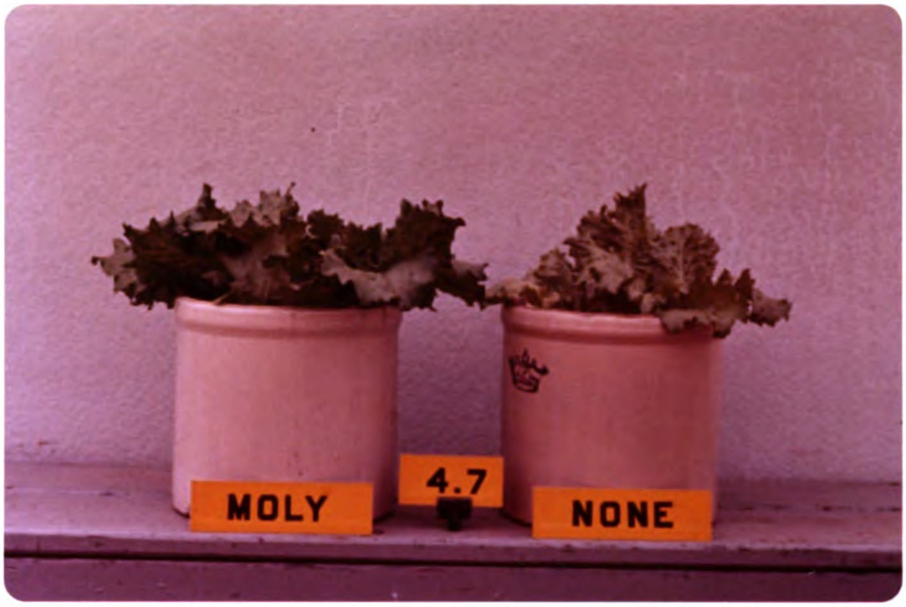
		Soil 1		Soil 2	
Number	Treatments[1]	Grams dry tissue per jar[2]	Test for sig.dif.[3]	Grams dry tissue per jar[2]	Test for sig.dif.[3]
			5%		5%
1	0-0-0-0	2.2	a	32.3	ab
2	0-0-0-.5[4]	17.4	bc	30.7	a
3	3-100-0-0	18.2	bc	39.0	cd
4	3-60-40-0	20.7	c	40.0	d
5	3-40-60-0	17.9	bc	36.4	bcd
6	3-0-100-0	12.7	b	33.8	abc
7	6-100-0-0	37.3	e	36.6	bcd
8	6-60-40-0	36.6	e	37.1	bcd
9	6-40-60-0	36.6	e	39.4	d
10	6-0-100-0	29.1	d	36.3	bcd
11	3-60-40-.5[4]	28.0	d	35.7	bcd

[1]Tons of lime/A, per cent calcium carbonate, per cent magnesium carbonate, and pounds of molybdenum carrier per acre, respectively.

[2]Average of four replications.

[3]Values with the same literal postscript are not significantly different at the probability level shown.

[4]Additional amounts of $Na_2MoO_4 \cdot 2H_2O$ added to second crop to bring the total application of molybdenum to 3/4 pound per acre.



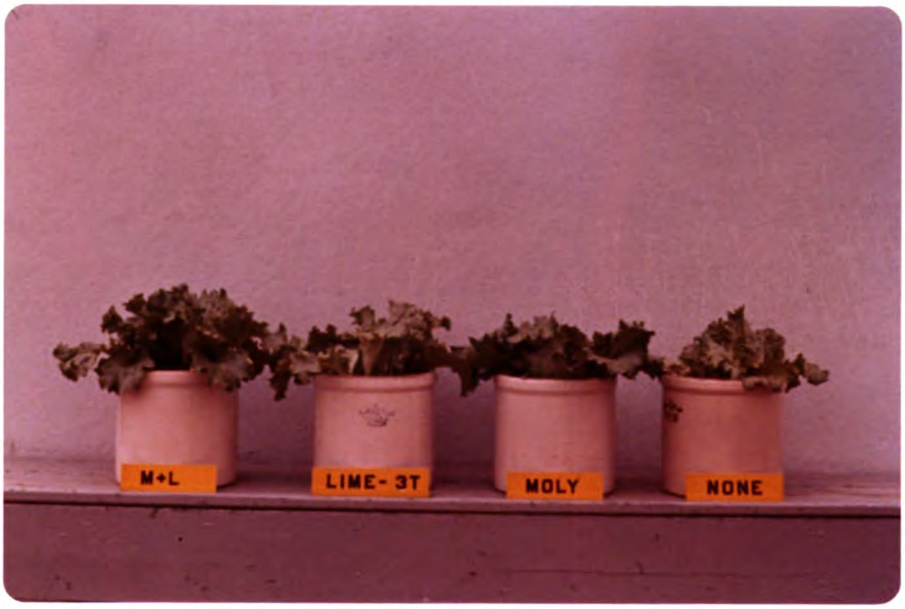


Figure 1. The effect of lime and molybdenum on the growth of lettuce on soil 1, five weeks after transplanting.

Figure 2. The effect of lime and molybdenum alone on the growth of cauliflower on soil 1, four weeks after transplanting.

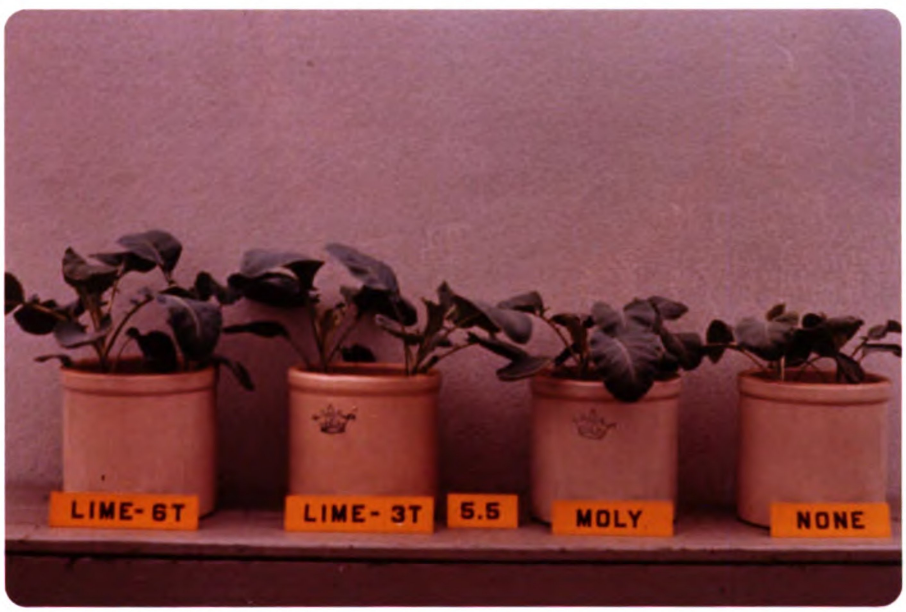


Figure 3. The effect of lime and molybdenum on the growth of cauliflower on soil 2, four weeks after transplanting.

Figure 4. Molybdenum-deficient cauliflower leaf grown on an acid organic soil.

II. Molybdenum uptake as affected by treatments

Lettuce, Soil 1.--Less molybdenum was taken up by lettuce where molybdenum was applied alone or with 3 tons of lime than where lime alone was applied (Table 7). This was the reverse of results obtained from lettuce growing on soil 2 and cauliflower growing on both soils (Tables 7 and 8). There was, however, a significant increase in yield where molybdenum alone was applied, over the check. The molybdenum uptake in most of these treatments did not follow a trend.

No significant differences in molybdenum uptake were obtained due to type or amount of lime applied.

Lettuce, Soil 2.--Molybdenum applications to this soil increased the uptake of molybdenum, by lettuce, 100 per cent over that of the check. A further increase in molybdenum taken up was obtained where 3 tons of lime plus molybdenum was applied (Table 7).

The total amount of molybdenum in the tissue increased as the amount of lime applied increased, with the highest molybdenum uptake being obtained where 100 per cent magnesium carbonate lime was used at both rates of lime. This was a complete reversal of the results obtained with cauliflower.

Cauliflower, Soil 1.--No detectable amount of molybdenum was obtained from the plant tissue harvested from the check jars of cauliflower as the plants did not grow large enough to provide an adequate testing sample (Table 8).

The molybdenum uptake by cauliflower rose sharply from no detectable amount to .58 micro-grams per gram of dry tissue where molybdenum alone was added to the soil. The molybdenum per gram of dry tissue was .48 micro-grams where 3 tons of lime plus molybdenum was added, which was an increase of over 100 per cent in molybdenum per gram of dry tissue and over 200 per cent of total molybdenum over that obtained where the equivalent application of lime alone was used.

Molybdenum applications alone resulted in nearly equal or greater uptakes of molybdenum than applications of 6 tons of lime, as shown by a comparison of data from treatment 2 with that of treatments 7, 8, and 10. The highest molybdenum uptake resulted where 3 tons of lime plus molybdenum was used.

No significant difference in molybdenum taken up due to types of lime was obtained, but a noticeable decrease in molybdenum uptake occurred with the highest rate of magnesium carbonate lime.

<u>Cauliflower, Soil 2</u>.--Nearly the same pattern was obtained with cauliflower growing on this soil as was obtained from soil 1. The highest molybdenum uptake occurred where molybdenum was applied, whether alone or with the lower rate of lime.

Table 7. The effect of lime and molybdenum on the molybdenum composition of lettuce grown on soil 1 and 2.

		Soil 1			Soil 2		
		Micro-grams Mo in oven dry tissue			Micro-grams Mo in oven dry tissue		
Number	Treatments[1]	per gram[2]	per treatment[2]	5% sig.[3]	per gram[2]	per treatment[2]	5% sig.[3]
1	0-0-0-0	.13	1.4	ab	.15	2.5	a
2	0-0-0-.5[4]	.03	.4	a	.30	5.6	b
3	3-100-0-0	.21	3.4	abc	.48	7.5	b
4	3-60-40-0	.27	4.6	c	.49	7.6	b
6	3-0-100-0	.15	2.3	abc	.64	9.7	c
7	6-100-0-0	.17	2.7	abc	.87	10.3	cd
8	6-60-40-0	.33	5.0	c	.92	11.9	d
10	6-0-100-0	.24	3.9	bc	1.19	15.6	e
11	3-60-40-.5[4]	.09	1.5	ab	.61	9.7	c

[1]Tons of lime/A, per cent calcium carbonate, per cent magnesium carbonate, and pounds of molybdenum carrier per acre, respectively.

[2]Average of four replications.

[3]Values with the same literal postscript are not significantly different at the probability level shown.

[4]Additional amounts of $Na_2MoO_4 \cdot 2H_2O$ added to second crop to bring the total application of molybdenum to 3/4 pound per acre.

Table 8. The effect of lime and molybdenum on the molybdenum composition of cauliflower grown on soil 1 and 2.

		Soil 1			Soil 2		
		Micro-grams Mo in oven dry tissue			Micro-grams Mo in oven dry tissue		
Number	Treatments[1]	per gram[2]	per treatment[2]	5% sig.[4]	per gram[2]	per treatment[2]	5% sig.[4]
1	0-0-0-0	----[3]	----[3]	a	.59	19.9	ab
2	0-0-0-.5[4]	.58	9.8	bc	1.37	41.2	cd
3	3-100-0-0	.23	3.4	ab	.35	13.6	a
4	3-60-40-0	.21	3.7	ab	.29	11.7	a
6	3-0-100-0	.13	6.0	abc	.30	10.4	a
7	6-100-0-0	.29	10.8	bc	.97	35.7	c
8	6-60-40-0	.26	9.6	bc	1.04	38.6	cd
10	6-0-100-0	.18	5.5	abc	.90	33.0	bc
11	3-60-40-.5[5]	.48	12.0	c	1.49	52.6	d

[1]Tons of lime/A, per cent calcium carbonate, per cent magnesium carbonate, and pounds of molybdenum carrier per acre, respectively.

[2]Average of four replications. [3]Insufficient size sample available for testing.

[4]Values with the same literal postscript are not significantly different at the probability level shown.

[5]Additional amounts of $Na_2MoO_4 \cdot 2H_2O$ added to second crop to bring the total application of molybdenum to 3/4 pound per acre.

No significant difference in molybdenum uptake was obtained due to the type of lime applied. However, at the higher rate of lime application, a lower plant content and total uptake resulted where 100 per cent magnesium carbonate lime was used.

III. Calcium uptake as affected by treatments

Lettuce, Soil 1.--No significant differences in calcium uptake was obtained where molybdenum applications alone were used. However, where applied with 3 tons of lime, it resulted in lower calcium uptake than was obtained with lime alone (Table 9). The greatest uptake was obtained where 3 tons of a 60-40 lime was applied. As the amount of calcium content of the lime applied increased, there was a trend for the calcium uptake to increase.

Lettuce, Soil 2.--No significant differences in calcium uptake due to applications of molybdenum was obtained from lettuce growing on this soil. The per cent of calcium in the lettuce grown on soil 1 generally decreased as the amount of magnesium applied increased. This trend was not apparent with lettuce grown on soil 2.

Cauliflower, Soil 1.--No significant differences were obtained in calcium uptake by cauliflower due to molybdenum plus lime over lime alone (Table 11). A significant difference in calcium uptake was obtained, however, between the check and where molybdenum alone was used. As the calcium content of the lime increased, there was a corresponding increase in the amount of calcium taken up.

Cauliflower, Soil 2.--The greatest calcium uptake by cauliflower was obtained where molybdenum alone was applied (Table 12). An application of molybdenum plus lime resulted in greater calcium uptake, though not significantly so, than where lime alone was applied.

Again, where the calcium content of the lime increased, there was a corresponding increase in calcium uptake.

IV. Magnesium uptake as affected by treatments

Lettuce, Soil 1.--No significant differences were obtained in the amount of magnesium taken up by lettuce due to applications of molybdenum alone (Table 9).

There was a corresponding increase in the magnesium uptake by lettuce as the magnesium content of the lime increased.

Lettuce, Soil 2.--No significant differences were obtained in magnesium uptake by lettuce due to applications of molybdenum or to the type or amount of lime applied. However, the magnesium taken up by lettuce increased as the magnesium content of the lime increased.

Cauliflower, Soils 1 and 2.--No significant differences were obtained in magnesium uptake due to applications of molybdenum to cauliflower growing on either soil (Tables 11 and 12).

The uptake of magnesium by cauliflower growing on both soils, increased in all cases as the magnesium content of the lime increased.

V. Nitrogen uptake as affected by treatments

Lettuce, Soil 1.--No significant differences were found in nitrogen uptake by lettuce due to additions of molybdenum alone, type or amount of lime (Table 9). However, a significantly lower amount of nitrogen was taken up where molybdenum plus lime was used as compared to lime alone.

Lettuce, Soil 2.--No significant differences were obtained in nitrogen uptake by lettuce due to additions of molybdenum or type of lime. However, the uptake on the average was less where 6 tons of lime was applied as compared to the lower rate of applications, and significantly so where 100 per cent calcium carbonate lime was used (Table 10).

Cauliflower, Soil 1.--The nitrogen uptake of cauliflower receiving applications of molybdenum alone was significantly higher than the check (Table 11). Where molybdenum plus lime was applied, the nitrogen uptake was significantly greater than where lime alone was used. No significant differences in nitrogen uptake was obtained due to the type of lime applied, but a significant increase in nitrogen was observed due to the rate. Where the 6 ton rates were used, higher nitrogen uptake occurred in all cases.

Cauliflower, Soil 2.--No significant differences in nitrogen taken up by cauliflower were obtained from additions of molybdenum, whether applied alone or with the lime (Table 12). Where 3 tons of calcium carbonate lime was applied, a significantly higher nitrogen uptake resulted than from other equivalent lime applications. Where the higher rate of 40-60 lime was applied a significantly higher nitrogen uptake was obtained than from all other equivalent applications, except where the 60-40 lime was used. This type of lime resulted in lower nitrogen uptake, but not significantly lower.

Greater uptake of nitrogen occurred where the larger amounts of lime were applied.

VI. Phosphorus uptake as affected by treatments

Lettuce, Soil 1.--Applications of molybdenum alone had relatively no effect on the amount of phosphorus removed by lettuce (Table 9). Molybdenum plus lime, as compared with lime alone, actually decreased the amount of phosphorus taken up though this decrease was not great enough to be significantly different.

Applications of the higher rate of lime decreased the phosphorus taken up by lettuce. This is in agreement with the results Lawton and Davis (22) obtained working with corn, field beans, and sudan grass. There also seemed to be a trend toward higher phosphorus uptake where the magnesium content of the lime increased and the calcium content decreased.

Lettuce, Soil 2.--Molybdenum plus lime did not effect the phosphorus uptake of lettuce growing on this soil. However, there was a decrease in phosphorus uptake where molybdenum alone was applied as compared with the check (Table 10). In agreement with the results obtained from soil 1, the higher rate of lime application lowered the phosphorus uptake in all cases except where 100 per cent magnesium carbonate lime was used; here a slight increase was observed.

Cauliflower, Soil 1.--Applications of molybdenum alone actually lowered the phosphorus uptake of cauliflower, but not enough to be significantly different from the check (Table 11). Applications of molybdenum plus 3 tons of lime, however, resulted in a greater phosphorus uptake than was obtained from 3 tons of lime alone, though it too was not significantly different.

The lowest phosphorus uptake with both rates of lime occurred where 100 per cent magnesium carbonate was used. With lettuce growing on this same soil, the magnesium carbonate tended to increase the amount of phosphorus taken up. A lower phosphorus uptake was also obtained where the lower rate of lime was applied. This is in contrast to results obtained with lettuce, where the higher lime applications resulted in lower phosphorus content, and is not in agreement with the results of Lawton and Davis (22).

Cauliflower, Soil 2.--Molybdenum applications to cauliflower did not effect the amount of phosphorus taken up by the plants enough to be significantly different. However, a higher uptake was obtained where molybdenum was applied alone and with 3 tons of lime, as compared to the check and lime alone (Table 12).

No significant differences in phosphorus uptake were obtained due to type or amount of lime applied. Nevertheless, a lower phosphorus uptake was evident where the higher rates of lime were used. This is in agreement with the results obtained with lettuce on both soils.

VII. Potassium uptake as affected by treatments

Lettuce, Soil 1.--The potassium uptake of lettuce was significantly increased where a molybdenum application alone was used. However, an application of lime plus molybdenum resulted in a lower potassium uptake than where lime alone was used (Table 9). Though significant differences were obtained in potassium uptake due to type of lime, no trend seemed to be apparent. Lower potassium content was obtained where 3 tons per acre of 100 per cent magnesium carbonate was used. At the higher rate of lime, the lowest potassium uptake was obtained where the 60-40 lime was applied, though it was not significantly lower.

Lettuce, Soil 2.--Decreased potassium uptake by lettuce resulted where molybdenum was added alone and with lime, as compared to the check and where lime alone was used. The decrease in potassium uptake was only slight and appeared to be of little importance (Table 10). No significant differences in the amount of potassium taken up was obtained due to the type of lime used. Where the higher rate of lime was applied, however, a significantly lower potassium uptake was obtained in all cases except where the 40-60 lime was applied; here a lower result occurred, but it was not significantly lower.

Cauliflower, Soil 1.--The amount of potassium taken up by cauliflower increased significantly where molybdenum was applied both alone and with 3 tons of lime, as compared to the check and lime alone (Table 11). The type of lime seemed to have little effect on amount of potassium taken up except where 100 per cent magnesium carbonate lime was used. Where this type of lime was applied, at both rates, a lower potassium uptake was obtained, but it was not significantly lower than the other equivalent applications.

Where the higher rate of lime was applied, as compared to its equivalent lower rate, significantly more potassium was taken up.

Cauliflower, Soil 2.--No significant differences were obtained in potassium uptake by cauliflower between any of the treatments used on this soil.

VII. Sodium uptake as affected by treatments

Lettuce, Soil 1.--An addition of molybdenum alone to this soil seemed to have little effect on sodium uptake by lettuce, though a slight increase in sodium taken up was obtained where molybdenum alone was used (Table 9). Where molybdenum plus lime was added, significantly less sodium was taken up as compared to where lime alone was applied. Since the sodium content of lettuce increased slightly in one instance where molybdenum was added and significantly decreased in another, no conclusion could be drawn.

The amount of lime used seemed to have little effect on sodium uptake of lettuce (Table 9). However, where the lower rate of lime was applied, the sodium taken up by lettuce significantly increased where the 60-40 lime was used. It also increased where the higher rate was used, but not significantly so. This could indicate that the 60-40 lime produces conditions more favorable to sodium uptake than the other types of lime used.

Lettuce, Soil 2.--No significant differences were obtained between any of the treatments used where lettuce was growing on this soil (Table 10).

Cauliflower, Soil 1.--An addition of molybdenum alone to cauliflower resulted in a significantly higher sodium uptake as compared to the check (Table 11). Where molybdenum plus lime was used, a greater amount of sodium was taken up than where lime alone was used. However it was not significantly different.

The type of lime applied to cauliflower had little effect on sodium uptake. The higher rate of application, however, seemed to enhance the amount of sodium taken up, and resulted in significantly greater sodium uptake where the 40-60 and the 100 per cent mganesium carbonate lime was used as compared to their equivalents at the lower rate (Table 11).

Cauliflower, Soil 2.--No significant differences in sodium uptake were obtained between any of the treatments (Table 12).

Table 9. The effect of lime and molybdenum on the total uptake of calcium, magnesium, nitrogen, phosphorus, potassium, and sodium by lettuce grown on soil 1.

		Grams per jar[2]											
Number	Treatments[1]	Ca	5%	Mg	5%	N	5%	P	5%	K	5%	Na	5%
1	0-0-0-0	.068	a	.075	a	.41	a	.059	a	.69	a	.00040	a
2	0-0-0-.5[3]	.080	ab	.079	a	.46	ab	.060	a	.95	b	.00047	ab
3	3-100-0-0	.132	d	.074	a	.51	bc	.061	a	1.28	de	.00062	abc
4	3-60-40-0	.142	d	.087	abc	.55	c	.086	abc	1.29	e	.00090	d
5	3-40-60-0	.109	c	.106	bcd	.52	bc	.123	c	1.27	de	.00052	ab
6	3-0-100-0	.088	abc	.117	d	.48	abc	.104	bc	1.16	cd	.00062	abc
7	6-100-0-0	.130	d	.069	a	.53	bc	.049	a	1.24	cde	.00057	abc
8	6-60-40-0	.107	c	.082	ab	.49	abc	.056	a	1.13	c	.00075	cd
9	6-40-60-0	.091	bc	.112	cd	.50	bc	.080	ab	1.20	cde	.00065	bc
10	6-0-100-0	.081	ab	.167	e	.48	abc	.080	ab	1.23	cde	.00050	ab
11	3-60-40-.5[3]	.099	bc	.107	bcd	.45	ab	.049	a	1.22	cde	.00060	abc

[1]Tons of lime per acre, per cent calcium carbonate, per cent magnesium carbonate, and pounds of molybdenum carrier per acre, respectively.

[2]Values with the same literal postscript are not significantly different at the probability level shown.

[3]Additional amounts of $Na_2MoO_4 \cdot 2H_2O$ added to second crop to bring the total application of molybdenum to 3/4 pound per acre.

Table 10. The effect of lime and molybdenum on the total uptake of calcium, magnesium, nitrogen, phosphorus, potassium, and sodium by lettuce grown on soil 2.

		Grams per jar[2]											
Number	Treatments[1]	Ca	5%	Mg	5%	N	5%	P	5%	K	5%	Na	5%
1	0-0-0-0	.147	c	.074		.570	d	.084	c	1.54	e	.00038	
2	0-0-0-.5[3]	.128	bc	.082		.565	cd	.060	bc	1.47	de	.00043	
3	3-100-0-0	.131	bc	.082	not significant	.510	bdc	.047	ab	1.33	cde	.00037	not significant
4	3-60-40-0	.122	bc	.076		.490	bcd	.051	ab	1.32	cde	.00039	
5	3-40-60-0	.126	bc	.081		.482	abc	.049	ab	1.25	abcd	.00048	
6	3-0-100-0	.118	bc	.092		.480	abc	.031	ab	1.35	cde	.00046	
7	6-100-0-0	.103	b	.060		.400	a	.025	a	1.02	a	.00036	
8	6-60-40-0	.103	b	.072		.450	ab	.028	ab	1.06	ab	.00034	
9	6-40-60-0	.109	b	.090		.482	abc	.035	ab	1.14	abc	.00042	
10	6-0-100-0	.074	a	.102		.460	ab	.034	ab	1.07	ab	.00030	
11	3-60-40-.5[3]	.116	b	.077		.507	bcd	.029	ab	1.26	bcd	.00037	

[1]Tons of lime per acre, per cent calcium carbonate, per cent magnesium carbonate, and pounds of molybdenum carrier per acre, respectively.

[2]Values with the same literal postscript are not significantly different at the probability level shown.

[3]Additional amounts of $Na_2MoO_4 \cdot 2H_2O$ added to second crop to bring the total application of molybdenum to 3/4 pound per acre.

Table 11. The effect of lime and molybdenum on the total uptake of calcium, magnesium, nitrogen, phosphorus, potassium, and sodium by cauliflower grown on soil 1.

		Grams per jar[2]											
Number	Treatments[1]	Ca	5%	Mg	5%	N	5%	P	5%	K	5%	Na	5%
1	0-0-0-0	.03	a	.018	a	.09	a	.113	b	.16	a	.0003	a
2	0-0-0-.5[3]	.44	bc	.090	ab	.70	cd	.107	b	1.26	b	.0023	bcd
3	3-100-0-0	.66	c	.116	b	.61	bc	.094	b	1.27	b	.0018	bc
4	3-60-40-0	.43	bc	.167	bc	.60	bc	.126	bc	1.37	bc	.0022	bcd
5	3-40-60-0	.50	bc	.220	c	.54	bc	.108	b	1.24	b	.0014	ab
6	3-0-100-0	.34	b	.220	c	.40	b	.071	a	.89	b	.0011	ab
7	6-100-0-0	.99	d	.100	ab	.87	de	.155	bc	1.88	d	.0027	bcde
8	6-60-40-0	.65	c	.215	c	.92	de	.158	bc	2.11	d	.0034	de
9	6-40-60-0	.61	bc	.325	d	.97	e	.190	c	1.99	d	.0039	e
10	6-0-100-0	.40	bc	.442	e	.97	e	.140	bc	1.75	cd	.0033	cde
11	3-60-40-.5[3]	.53	bc	.180	bc	.85	de	.157	bc	1.85	d	.0026	bcde

[1]Tons of lime per acre, per cent calcium carbonate, per cent magnesium carbonate, and pounds of molybdenum carrier per acre, respectively.

[2]Values with the same literal postscript are not significantly different at the probability level shown.

[3]Additional amounts of $Na_2MoO_4 \cdot 2H_2O$ added to second crop to bring the total application of molybdenum to 3/4 pound per acre.

Table 12. The effect of lime and molybdenum on the total uptake of calcium, magnesium, nitrogen, phosphorus, potassium, and sodium by cauliflower grown on soil 2.

		Grams per jar[2]											
Number	Treatments[1]	Ca	5%	Mg	5%	N	5%	P	5%	K	5%	Na	5%
1	0-0-0-0	.69	ab	.162	abc	1.08	cd	.106		1.97		.0025	
2	0-0-0-.5[3]	1.09	c	.136	ab	1.00	bcd	.123		1.83		.0036	
3	3-100-0-0	.73	ab	.113	a	1.08	cd	.113	not significant	2.02	not significant	.0041	not significant
4	3-60-40-0	.53	a	.130	ab	.84	a	.114		2.09		.0034	
5	3-40-60-0	.67	ab	.190	cd	.92	ab	.100		2.06		.0035	
6	3-0-100-0	.47	a	.250	e	.95	abc	.104		2.11		.0022	
7	6-100-0-0	.88	bc	.127	ab	1.10	cd	.076		2.30		.0044	
8	6-60-40-0	.72	ab	.174	bc	1.15	de	.097		2.26		.0041	
9	6-40-60-0	.68	ab	.235	de	1.25	e	.097		2.09		.0051	
10	6-0-100-0	.47	a	.436	f	1.01	bcd	.097		2.24		.0024	
11	3-60-40-.5[3]	.71	ab	.110	a	.98	abc	.118		1.91		.0025	

[1]Tons of lime per acre, per cent calcium carbonate, per cent magnesium carbonate, and pounds of molybdenum carrier per acre, respectively.

[2]Values with the same literal postscript are not significantly different at the probability level shown.

[3]Additional amounts of $Na_2MoO_4 \cdot 2H_2O$ added to second crop to bring the total application of molybdenum to 3/4 pound per acre.

VIII. The chemical composition of lettuce and cauliflower as affected by treatments

As the amount of calcium in the lime increased, the percentage of calcium increased in lettuce growing on soil 1 and cauliflower growing on both soils (Tables 13, 15, 16). Where lettuce was growing on soil 2, the results were somewhat inconsistent (Table 14).

As the amount of magnesium in the lime increased, the per cent of magnesium increased in both crops growing on both soils (Tables 13, 14, 15, 16).

In general, as the amount of calcium in the lime increased, there was a corresponding decrease in the per cent of magnesium in both lettuce and cauliflower. Conversely, as the amount of magnesium in the lime increased, there was a corresponding decrease in the per cent of calcium in the plant tissue.

In most cases as the amount of lime applied increased, the percentage of phosphorus in lettuce and cauliflower decreased. Also, where 100 per cent calcium carbonate was used, the percentage of phosphorus tended to be lower (Tables 13, 14, 15, 16).

The lime and molybdenum treatments had very little effect on the percentage of nitrogen, potassium, and sodium in the lettuce and cauliflower.

Table 13. The effect of lime and molybdenum on the per cent of calcium, magnesium, nitrogen, phosphorus, potassium, and sodium obtained from lettuce grown on soil 1.

		Per Cent (oven dry tissue)					
Number	Treatments[1]	Ca	Mg	N	P	K	Na
1	0-0-0-0	.62	.70	3.8	.53	6.5	.0034
2	0-0-0-.5[2]	.57	.57	3.3	.43	6.8	.0035
3	3-100-0-0	.83	.46	3.2	.39	8.0	.0039
4	3-60-40-0	.85	.52	3.3	.51	7.7	.0050
5	3-40-60-0	.65	.64	3.1	.67	7.6	.0038
6	3-0-100-0	.57	.76	3.1	.67	7.5	.0040
7	6-100-0-0	.80	.43	3.3	.31	7.6	.0039
8	6-60-40-0	.69	.53	3.1	.36	7.3	.0048
9	6-40-60-0	.58	.70	3.2	.50	7.6	.0041
10	6-0-100-0	.51	1.05	3.0	.51	7.7	.0021
11	3-60-40-.5[2]	.62	.68	2.8	.31	7.7	.0040

[1]Tons of lime per acre, per cent calcium carbonate, per cent magnesium carbonate, and pounds of molybdenum carrier per acre, respectively.

[2]Additional amounts of $Na_2MoO_4 \cdot 2H_2O$ added to second crop to bring the total application of molybdenum to 3/4 pound per acre.

Table 14. The effect of lime and molybdenum on the per cent of calcium, magnesium, nitrogen, phosphorus, potassium, and sodium obtained from lettuce grown on soil 2.

		Per Cent (oven dry tissue)					
Number	Treatments[1]	Ca	Mg	N	P	K	Na
1	0-0-0-0	.77	.39	3.0	.44	8.1	.0021
2	0-0-0-.5[2]	.68	.44	3.0	.31	7.8	.0023
3	3-100-0-0	.82	.51	3.2	.29	8.3	.0029
4	3-60-40-0	.78	.48	3.1	.32	8.5	.0029
5	3-40-60-0	.85	.56	3.2	.30	8.3	.0035
6	3-0-100-0	.77	.61	3.2	.20	9.0	.0033
7	6-100-0-0	.87	.50	3.4	.26	8.6	.0034
8	6-60-40-0	.77	.53	3.4	.22	8.0	.0031
9	6-40-60-0	.77	.64	3.5	.25	8.1	.0032
10	6-0-100-0	.55	.77	3.5	.26	8.0	.0028
11	3-60-40-.5[2]	.71	.47	3.1	.17	7.7	.0028

[1]Tons of lime per acre, per cent calcium carbonate, per cent magnesium carbonate, and pounds of molybdenum carrier per acre, respectively.

[2]Additional amounts of $Na_2MoO_4 \cdot 2H_2O$ added to second crop to bring the total application of molybdenum to 3/4 pound per acre.

Table 15. The effect of lime and molybdenum on the per cent of calcium, magnesium, nitrogen, phosphorus, potassium, and sodium obtained from cauliflower grown on soil 1.

		Per Cent (oven dry tissue)					
Number	Treatments[1]	Ca	Mg	N	P	K	Na
1	0-0-0-0	1.0	.80	4.1	.54	3.9	.0135
2	0-0-0-.5[2]	2.4	.51	4.1	.59	7.1	.0125
3	3-100-0-0	2.7	.62	3.4	.52	7.0	.0100
4	3-60-40-0	2.1	.84	3.0	.62	6.6	.0067
5	3-40-60-0	2.6	1.29	3.1	.62	7.0	.0085
6	3-0-100-0	2.7	1.74	3.2	.55	7.1	.0093
7	6-100-0-0	2.7	.27	2.3	.41	5.0	.0074
8	6-60-40-0	1.8	.59	2.5	.43	5.8	.0097
9	6-40-60-0	1.7	.89	2.7	.52	5.5	.0109
10	6-0-100-0	1.0	1.52	3.4	.48	6.1	.0111
11	3-60-40-.5[2]	1.9	.65	3.1	.56	6.6	.0096

[1]Tons of lime per acre, per cent calcium carbonate, per cent magnesium carbonate, and pounds of molybdenum carrier per acre, respectively.

[2]Additional amounts of $Na_2MoO_4 \cdot 2H_2O$ added to second crop to bring the total application of molybdenum to 3/4 pound per acre.

Table 16. The effect of lime and molybdenum on the per cent of calcium, magnesium, nitrogen, phosphorus, potassium, and sodium obtained from cauliflower grown on soil 2.

		Per Cent (oven dry tissue)					
Number	Treatments[1]	Ca	Mg	N	P	K	Na
1	0-0-0-0	2.2	.51	3.4	.34	6.1	.0080
2	0-0-0-.5[2]	3.0	.44	3.3	.39	6.1	.0118
3	3-100-0-0	1.9	.29	2.8	.29	5.2	.0104
4	3-60-40-0	1.4	.75	2.1	.28	5.2	.0089
5	3-40-60-0	1.8	.50	2.6	.27	5.7	.0100
6	3-0-100-0	1.4	.74	2.8	.31	6.4	.0068
7	6-100-0-0	2.4	.35	3.0	.21	6.3	.0120
8	6-60-40-0	2.0	.47	3.1	.26	6.1	.0110
9	6-40-60-0	1.7	.60	3.2	.24	5.3	.0130
10	6-0-100-0	1.3	1.21	2.8	.28	6.2	.0065
11	3-60-40-.5[2]	2.0	.31	2.7	.33	5.4	.0068

[1] Tons of lime per acre, per cent calcium carbonate, per cent magnesium carbonate, and pounds of molybdenum carrier per acre, respectively.

[2] Additional amounts of $Na_2MoO_4 \cdot 2H_2O$ added to second crop to bring the total application of molybdenum to 3/4 pound per acre.

SUMMARY AND CONCLUSIONS

Molybdenum alone increased the yield of lettuce grown on soil 1. Slightly higher increases in yield were obtained where lime alone was applied, and also where lime was applied in combination with molybdenum. There was no response by lettuce grown on soil 2 to molybdenum. In general, the yield of lettuce decreased on this soil when the pH value reached approximately 6.0, and further decreased as more lime was applied.

Yields of cauliflower growing on soil 1 were increased as much as seventeen fold where 6 tons of lime per acre was added. Lower yields were obtained where 3 tons of lime was used. A significant response to molybdenum was also obtained. This response amounted to approximately an eight-fold increase. The addition of lime to soil 2 tended to increase yields of cauliflower. The response was much less than with the cauliflower growing on soil 1.

All cauliflower plants showed molybdenum deficiencies for several weeks after planting. This may have been due to a possible tie-up of molybdenum with the organic matter. Additional molybdenum was added to the soil in some cases, and as a foliar spray in others. The deficiency symptoms disappeared, in both cases, as the plants matured, with no apparent advantage to either method.

The uptake of molybdenum by lettuce was higher where lime was applied than where molybdenum alone was used. The reverse of this situation occurred with the cauliflower crop. Molybdenum did not influence the uptake or per cent of other ions. No relationship was obtained between the amounts of molybdenum taken up by lettuce or cauliflower and yield.

In general, as the amount of calcium in the lime increased, the percentage of calcium in the plant tissue increased while the per cent magnesium decreased. Conversely, as the amount of magnesium in the lime increased, the percentage of calcium in the plant tissue decreased while the per cent of magnesium increased.

In several cases, as the amount of lime applied increased, the amount of phosphorus taken up by the crops decreased. This was also accompanied by a decrease in the per cent of phosphorus in the tissue.

The lime and molybdenum treatments had little effect on the percentage composition of nitrogen, potassium, and sodium in the lettuce and cauliflower. However, the uptake of these three ions was related to the yield, with the highest uptakes obtained where the yield was the greatest.

The various ratios of magnesium and calcium carbonates in the lime applied did not have any definite effect on yield of lettuce. However, where magnesium carbonate alone was applied the yields of cauliflower were, in general, lower than where a mixture of calcium carbonate and magnesium carbonate was used. There was no definite trend in the amount of molybdenum taken up by either the lettuce or cauliflower or the percentage of molybdenum in the lettuce and cauliflower associated with the ratios of magnesium and calcium carbonate used.

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