THE EVALUATION OF VARIOUS MAGNESIUM CARRIERS WHEN APPLIED WITH MIXED FERTILIZERS

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ABSTRACT

THE EVALUATION OF VARIOUS MAGNESIUM CARRIERS WHEN APPLIED WITH MIXED FERTILIZERS

by Lawrence Alton Rudgers

The interaction of six Mg carriers and two P sources was evaluated in a greenhouse study with oats and in three field experiments with potatoes. Yield of oat plants or potato tubers, plant content, and total uptake of Mg, Ca, and K, and available soil P, K, Ca, and Mg were determined.

Calcined magnesite was more effective when coated on monocalcium phosphate (MCP) (initially acidic) than when coated on diammonium phosphate (DAP) (initially basic). The results for calcined brucite were more variable but followed the same trend. The P sources had no effect on the availability of Mg from uncalcined magnesite and serpentine coated on the P fertilizers, or on $MgSO_4 \cdot 7H_2O$ mixed with the P fertilizers. Sulfate of potash magnesia ("Sul-Po-Mag"), when dry blended with a fertilizer containing both MCP and DAP, was as effective as $MgSO_4 \cdot 7H_2O$.

The order of availability of the Mg carriers when applied with MCP was: calcined magnesite $\cong$ calcined brucite $>$ or $\cong$ $MgSO_4 \cdot 7H_2O$ $>$ uncalcined magnesite $\cong$ serpentine, and

when applied with DAP the order was: $MgSO_4 \cdot 7H_2O$ > or $\cong$ calcined magnesite $\cong$ calcined brucite > uncalcined magnesite $\cong$ serpentine.

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By

Lawrence Alton Rudgers

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INTRODUCTION

The world population is expanding at an exponential rate. The burden of producing adequate quantity and quality of food for this expanding population is shared by agricultural specialists, including those in soil fertility and fertilizer research. By applying new technology, such as the increased use of fertilizers, agriculturalists have increased yields and improved crop quality. But, only in certain countries have they been able to keep pace with the population explosion. And, the situation promises to worsen unless the rate of development of new technological methods increases.

Higher yields produced because of new improved methods and technology may increase the need for elements that were formerly in sufficient supply in soils. For example, Mg ranks seventh in abundance in the earth's crust; consequently, in the past, most soils contained adequate levels of Mg. Now, however, Mg deficiencies are commonly found on many acid, sandy soils. This necessitates a critical evaluation of sources of fertilizer Mg that may prove to be economical.

The objective of this investigation was to evaluate the effectiveness of various carriers of Mg when coated on granules of mixed fertilizer made with either monocalcium phosphate (initially acidic) or diammonium phosphate (initially basic) as a source of P.

LITERATURE REVIEW

Loew(59), in 1892, was probably the first person to realize that magnesium (Mg) is important in plant growth. But, he and many other early workers were more concerned with Mg as a toxic element rather than an essential nutrient (25, 29,52,58,59,60,62). Loew believed that an excess of either lime or magnesia is toxic to plants and that either substance will neutralize the deleterious effects of the other. Thus, a favorable lime-magnesia ratio must be established in both the soil and in the plant (58). However, it is now known that Mg or calcium (Ca) toxicity as described in the early literature was potassium (K) deficiency.

Loew also introduced the hypothesis that Mg acts as a carrier of phosphorus (P) in the plant (59,61,111). Until recently, much of the research in Mg plant nutrition was designed to test this hypothesis.

Until the past 10 years, Mg was seldom found to be deficient. As late as 1963, Tobin and Lawton (109,110), reported that in Michigan with 14 crops grown on 37 soil types from 1956 to 1958, there was little or no yield response to applications of Mg. Now, however, Mg deficiency symptoms are commonly found in potatoes, oats, and rye grown on loamy sands or sandy loams in Michigan (22). Magnesium deficiencies are also prevalent in various vegetable crops grown on the sandy soils of the Atlantic Coastal Plain (12,13). Because higher rates of more refined, higher analysis fertilizer are resulting in higher yields, greater amounts of Mg are being removed from the soil. Consequently, some soils which contained adequate levels of Mg are now deficient (41,63).

As a result, more research is now being devoted to the development of economical sources of fertilizer Mg.

Magnesium in Plants

Function of Magnesium in Plants

Magnesium is present in the plant in at least three forms. It is present in combined form in the protoplasm, comprises 2.7 percent of the chlorophyll molecules and occurs as an inorganic salt in the cell sap (18,103,125). Since Mg is the only mineral in the chlorophyll molecule, it is not surprising that the most obvious Mg deficiency symptom is chlorosis. Since Mg is mobile in the plant, chlorosis first appears on the lower leaves. Yellowing first occurs as patches between the veins and around the leaf edges. The younger leaves at the top of the plant then begin to curl. Later, the yellow areas become necrotic and the tissue may eventually disintegrate leaving holes in the leaf. The veins then appear as prominent green areas (18,22,103,125).

Magnesium plays a predominant role in the activity of various enzymes concerned with carbohydrate metabolism.

It serves as an activator for at least 14 enzymes which catalyze those reactions involving transfer of phosphate groups. Below is an example of a reaction for which the metal activator is Mg (103).

$$\text{Glucose + Adenosine Triphosphate} \xrightarrow[\text{Glucokinase}]{\text{Mg}^{++}}$$

$$\text{Glucose-6-Phosphate + Adenosine Diphosphate}$$

It is known that Mg functions in photosynthesis, but the exact mode of action is not well understood. It also is probably involved in protein synthesis, since it is found in ribosome organelles which are specific sites for protein synthesis. It is thought that Mg^{+2} ions hold together molecules of ribonucleic acid (RNA) by combining with the phosphate radicals of RNA (103).

Because both Mg and P accumulate in the seed, it was postulated 60 years ago by Loew (55) that Mg serves as a carrier for phosphoric acid (H_3PO_4) in the plant. Most workers in this area believed that Mg acts as a carrier of P by forming Mg-phosphates which are more soluble than Ca-phosphates. Calcium phosphates may precipitate in plants which contain a much higher concentration of Ca than Mg, thus slowing the translocation of P (5,20). As mentioned earlier, much Mg research has been designed to refute or substantiate this theory.

Some early workers (35,49,79,81,108) found that many crops responded to P fertilization only when Mg was also applied. They maintained that this was sufficient evidence in support of the theory. However, other researchers (28) reported that the influence of Mg on the effect of P increasing yields was small. They were not convinced that Mg is a carrier of P.

Many workers (3,6,21,35,53,98,114,121) obtained positive correlations between content of Mg and P in the whole plant and thought that this was strong evidence in support of the theory. But, just as many researchers (27,36,39,43, 44,77,87,115,122) were unable to obtain positive correlations.

In recent years, Truog (111) and Webb (118) have postulated that by comparing the Mg and P contents of the vegetative and reproductive organs, they can distinguish between the effect of Mg upon the absorption and its effect upon the translocation of P in plants. Working with soybeans in nutrient solution, Webb (118) found that although the content of P in a whole plant was not increased by greater Mg uptake, the translocation of P from the vegetative portions to the seed was increased. Therefore, although Mg may not enhance the absorption of P, it may aid in the translocation of P by acting as a carrier.

Recently, some plant physiologists (103) have been theorizing that the role of Mg as a carrier is due to the great importance of this element as an activator in many of the enzyme systems involved in P metabolism. It is thought that the response to P might be limited, if the enzymatic systems involved in its metabolism are limited by the supply of Mg. If the Mg supply to a particular portion of the plant were to increase, the need for P would increase and P would move to this site.

Principles of Foliar Analysis

When researchers first began analyzing plants for nutrient content, they analyzed the plant as a unit. There are, however, certain disadvantages to this technique. According to Thomas (105), a gross analysis of heterogeneous organs, all having different sensitive functions, does not give a "sufficiently comparative index in reflecting the responses of the plant to differences in its environment." The ideal plant sampling would consist of leaves of the same metabolic age (taken from the same position on the plant) taken at the same time from a sufficient number of plants in each plot. In order to provide a sample representative of a 4-row plot the leaves should be selected from the center two rows (105,112). In addition, ideally, the experiment should be conducted in a homogeneous growing medium and there should be several sampling dates. At each sampling date, leaves of the same age as were taken in the previous samplings should be selected (105,112). If this procedure is followed, the effects of the environment (such as varying fertilizer rates), and not effects due to senescence or differing plant parts, will be reflected in the nutrient content of the leaves (105, 112). It is true that foliar analyses can not be used to obtain total nutrient uptake data. In such cases, it is necessary to base the analyses on whole plants. But, when a comparative study on the effects of varying fertilizer rates or sources throughout the growing season is desired, foliar analysis is the more sensitive method.

When conducting foliar analysis of potatoes, Tyler and Lorenz (112) and others (101) recommend taking 40 to 50 petioles from the fourth leaf below the growing tip of the plant (usually the youngest fully expanded leaf on the plant) in the center two rows of a 4-row plot. The first sampling should not be taken before three to four weeks after emergence.

Content of Magnesium and Other Nutrients in the Plant

It is generally agreed that as the supply of available Mg in the growing medium increases, the content of Mg in the plant increases (7,8,21,31,54,57,71,72,83,84,90,94,95, 98,99,101,106,114). However, plant species differ in their ability to absorb Mg and other plant nutrients (8,17,110, 125). Legumes, for example, have larger Ca requirements and can more easily remove Ca from the soil than grass and cereal crops (17). Cucumbers and potatoes have higher Mg requirements than oats and barley (110). This is reflected in the content of Mg in these crops. Tobin and Lawton (109, 110) on a sandy soil in Michigan found that oats and barley had an average Mg content of 0.16 percent, whereas, the content of potatoes was 0.40 percent.

There are several explanations for plant species differing in their abilities to absorb cations. One theory is that plants which require large amounts of cations, produce more carbon dioxide (or carbonic acid). The hydrogen ions produced can then move onto the exchange complex freeing cations for uptake by the plants. Another theory is that plants which have a higher root cation exchange capacity are better able to absorb cations. As of yet, it is not known whether either of these theories is valid (17).

Using leaf chambers and a carbon dioxide infrared gas analyzer, Peasler and Moss (82) have found that the critical level of K in maize leaves is 2 milligrams per gram on a fresh weight basis and for Mg, 200 micrograms per gram. Normal appearing, but K stressed leaves, showed a reduction in photosynthesis, but Mg affected photosynthesis only after chlorosis appeared. They theorize that in the case of Mg, the reduction in the photosynthetic rate is due to a breakdown of chlorophyll, whereas K deficiency causes a decrease in the net assimilation rate by decreasing the stomatal aperatures.

For most crops, the total content of Mg, Ca and K when expressed in milliequivalents per 100 grams of oven dry whole plant material remains rather constant (4,64,113). This is known as Ehrenberg's potash-lime law, because he first saw a relationship between Ca and K in plants (25,64). Usually the relative intensity of removal of cations from the soil is $K^{+1} > Ca^{+2} > Mg^{+2}$ (19,125). Even though the relative content of these cations in the plant varies, the total content of cations must remain rather constant in order to buffer cell sap, neutralize organic acids and regulate salt concentration (64).

Also, because many of the properties and functions of K^{+1}, Ca^{+2} and Mg^{+2} are not interchangeable, the relative content of these cations in the plant should not greatly deviate from a theoretical balance (64).

It follows that in order to obtain the correct amount and balance of K^{+1}, Ca^{+2}, and Mg^{+2} in the plant, the soil in which the plant grows must also have the proper balance and adequate levels of available K^{+1}, Ca^{+2} and Mg^{+2}.

Magnesium in Soil

Magnesium occurs in the soil in primary and secondary minerals such as micas, chlorites, and vermiculites, from which Mg is released slowly to the exchange complex and into the soil solution where it is available for plants (18,88). In humid regions, the most abundant basic cations are Ca^{+2} and Mg^{+2}. As a soil is leached, the percent base saturation decreases and the percent hydrogen ion saturation (or aluminum complexes) increases along with a reduction in soil pH (18, 22). As a consequence, acid sandy soils with low cation exchange capacities are often deficient in Mg and Ca (9,12, 13,15,16,17,18,21,22,50,57,66,72,76,83,84,90,96,102,108,124). Although the figures do not agree exactly, most workers suggest that if the Mg saturation on the exchange complex falls below 10 percent and/or when the level of available Mg falls below 75 pounds of elemental Mg per acre furrow slice (2,000,000 pounds per acre), Mg will be deficient (5,22,31, 50,71,90,96,98,100,102).

However, it is actually more difficult to predict when Mg will become deficient than is implied in the preceding paragraph. The problem is often one of obtaining good correlations between Mg soil test results and crop yields. This difficulty stems at least in part from the variation among soils in the types and relative amounts of different silicate clays present. The silicate clays differ in their abilities to fix and release Mg. Caillere, Menin and Mering (11) and Grim (32) indicate that Mg^{+2} can be fixed as magnesium hydroxide ($Mg(OH)_2$) in the interlayer spaces of montmorillonite, resulting in a chlorite type structure. Magnesium ions can also be fixed by "degraded chlorite" in a manner similar to K^{+1} fixation by "degraded illite" (32). Magnesium ions are apparently very readily fixed by vermiculite (11). Vermiculite is composed of silicate layers bound together by Mg^{+2} and Ca^{+2} which are probably exchangeable. Potassium and ammonium (NH_4^{+1}) ions are capable of collapsing this mineral and preventing expansion upon hydration (11).

Thus, after K addition, the Mg^{+2} and Ca^{+2} are no longer as readily available to plants. Kaolinite, on the other hand, does not fix Mg.

In soil testing laboratories, 1 N ammonium acetate (NH_4Ac) is often used as the extracting solution for estimating available Mg. If a soil is high in vermiculite, the high concentration of NH_4^+ in the extracting solution can collapse the clay trapping Mg^{+2} and giving an available Mg estimate which is lower than the amount of Mg available to plants in the field. To a lesser extent this probably can happen for soils which contain "degraded chlorite" and montmorillonite (11). This may partly explain why some soils testing low in Mg will not respond to Mg fertilization. Although there is not complete agreement, many researchers indicate that the Mg in the brucite layer of chlorite type clays is easily released and available to plants (41). But, the NH_4Ac extracting solution will not remove this Mg (41). This may also help explain why there is often poor correlation between Mg soil test results and crop yields.

Thus, it becomes apparent that when estimating available Mg, the types and relative amounts of clay in the soil must be considered.

An unbalanced soil nutrient status can also lead to a Mg deficiency. For example, if calcic limestone is applied to a very acid soil, the ratio of Ca to Mg and K become so great that a deficiency in these elements results.

Or, excessive applications of K may result in a high ratio of K to Mg and subsequently, a deficiency in Mg (17,18,22,40). Because the subject of cationic balance has received so much attention over the past 60 years, it will be discussed here in more detail.

Potassium-Magnesium Antagonism

Numerous researchers, working with water, sand, and especially soil cultures, have found that if K is applied in excess and/or the ratio of K to Mg on the exchange complex is above 4 to 1, then Mg deficiency often develops (13,17,22, 23,33,42,46,48,51,64,73,74,75,83,84,86,91,92,93,104,107,113, 116,117,119). Although this usually occurs in acid sandy soils low in Mg, Mg deficiency symptoms sometimes develop on soils which have abundant available Mg, but, which have excessive amounts of exchangeable K (42). Hovland (42) reports that Mg deficiencies developed in potatoes and sugar beets grown on soils of calcareous lacustrine origin with ample Mg, when K was applied at a rate of only 100 pounds elemental K per acre. Unless sufficient Mg is available, crops with high Mg requirements may not respond well to K fertilization.

In water and sand cultures high K-Mg ratios do not induce Mg deficiencies as easily as in soil cultures. This may indicate that the center of the K-Mg antagonism is on the soil exchange complex, rather than the plant roots (17, 52).

Calcium-Magnesium Antagonism

Around the turn of the century, Loew and others (58, 59,60,62) developed the famous lime-magnesia ratio hypothesis. They hypothesized that excesses of either lime or magnesia are toxic to plants and that either substance will neutralize wholly or in part the deleterious effects of the other. They stated that each crop requires a rather definite ratio of Ca to Mg in the soil. For oats this was placed at a 1 to 1 ratio of CaO to MgO, for barley 2 to 1, and for buckwheat 3 to 1. But, other researchers (29,58,80) criticized this hypothesis, stating that the ratios can vary considerably more than Loew allowed. They also suggested that many of the favorable effects which follow the adjustment of the ratio "can easily be explained on many other grounds which do not call at all for the introduction of the hypothesis of the lime-magnesia ratio" (58).

It is probably true that a crop does not require a rigid lime-magnesia ratio, but Loew was correct in postulating that an antagonism exists between Ca and Mg. Many researchers (13,25,64,66,67,69,76,89,106) have since reported this phenomenom for a variety of crops on many different soils.

Calcium-Magnesium-Potassium Antagonism in Terms of Soil Cation Exchange Equilibria and Cationic Fixation by Clays

As mentioned before, the fact that many of these antagonisms are not easily produced in water and sand cultures, indicates that the interactions between Ca, Mg and K are controlled largely by cation exchange equilibria. If (K^{+1}ad.) and (Mg^{+2}ad.) are the activities respectively of K^{+1} and Mg^{+2} on the exchange complex, and (K^{+1}sol.) and (Mg^{+2}sol.) are the activities of these ions in solution, then the following equilibrium and mass action expression can be formulated (17).

$$2K^{+1}\text{sol.} + Mg^{+2}\text{ad.} \rightleftharpoons 2K^{+1}\text{ad.} + Mg^{+2}\text{sol.}$$

$$K = \frac{(K^{+1}\text{ad.})^2 (Mg^{+2}\text{sol.})}{(K^{+1}\text{sol.})^2 (Mg^{+2}\text{ad.})}$$

When an excess of K is added to the soil, the activity of K^{+1} in the soil solution (K^{+1}sol.) is increased and the equilibrium disturbed. In an attempt to reestablish the equilibrium, the reaction moves to the right with K^{+} replacing Mg^{+2} on the exchange complex. This increases the activity of Mg^{+2} in solution (Mg^{+2}sol.) and therefore, initially, its availability to plants. However, later, much of the Mg^{++} and K^{+} in solution is leached from the soil. The reaction continues to move closer to equilibrium, but the equilibrium activity of Mg^{+2} on the exchange complex (Mg^{+2}ad.) will be lower than it was before the K was added to the soil. As the reaction moves toward equilibrium, the

(Mg^{+2}sol.) decreases and approaches equality with the (Mg^{+2}ad.). Consequently, the (Mg^{+2}sol.), and therefore the availability of Mg to plants, will be lower than they were before K was applied to the soil.

As mentioned earlier, montmorillonite "degraded illite" and especially vermiculite can fix Mg (11,30,32). Since K^{+1} ions bring about the collapse of these clays and trap Mg and Ca between the silicate layers, it can be seen that excesses of K in a soil could enhance this fixation and decrease the supply of available Ca and Mg.

Sources of Fertilizer Magnesium

Dolomite ($CaCO_3 \cdot MgCO_3$): Dolomite and limestone which contains dolomite (dolomitic limestone) are, when compared to the other fertilizer sources of Mg, moderately soluble (14,41,65,120). Since they are more soluble in acid soils (30) and can be used to raise soil pH, they are often applied to these soils in order to gradually build up the supply of available Mg.

Magnesite ($MgCO_3$): Magnesite is also a moderately soluble form of fertilizer magnesium. Some researchers suggest that magnesite and dolomite are equally available to plants (63,134). Others (65) state that magnesite is more available than dolomite, while still others (41,63) suggest that it is less available. However, since the differences in their availabilities are so small, it can be safely stated that plants fertilized with these minerals can utilize about the same amount of Mg from each.

<u>Brucite</u> ($Mg(OH)_2$): Brucite contains principally Mg-hydroxide ($Mg(OH)_2$). The mineral consists of two sheets of hydroxyl groups arranged in a hexagonal closely packed structure with Mg^{++} between the sheets (10,38,123). $Mg(OH)_2$ is more soluble than MgO. However, in brucite the Mg^{+2} and OH^- ions are organized in a crystal lattice structure. Consequently, the solubility of brucite may be less than precipitated $Mg(OH)_2$ and MgO.

<u>Serpentine</u> ($3MgO \cdot 2SiO_2 \cdot 2H_2O$): Serpentine is a greenish silicate mineral which has $Si_4O_{11}^{-6}$ groups arranged in chains. These chains are held together by $Mg(OH)_2$ groups. But, because these bonds are weaker than the silicon (Si^{+4}) to oxygen (O^{-2}) bonds, the mineral is usually fibrous. It is commonly a constituent of asbestos. Because serpentine is a silicate, it is one of the more insoluble fertilizer sources of Mg (10,38,120,123). During the first 2 years after application, it is often less available than dolomite. However, by the third year it probably supplies as much Mg as does dolomite (16). Since it is more expensive than dolomitic limestone, and does not have as much neutralizing power, it is not usually applied to acid soils to gradually build up the supply of available Mg. However, it is occasionally mixed with supersphosphate and 15 percent water, then allowed to cure for 2 to 3 weeks. In this way the superphosphate becomes less acidic and the Mg is placed in a more available

form. The resulting serpentine-superphosphate has a better consistency and is easier to handle than superphosphate (1, 2,26,37,68,78).

Olivine $(Mg,Fe)_2SiO_4$: Olivine is also a greenish silicate mineral, but has iron (Fe) substituting for Mg in the crystal lattice. Its structure also differs from serpentine in that it contains separate SiO_4^{-4} groups which are not arranged in chains. The O^{-2} ions are shared by Mg^{+2} and Si^{+4}. As a consequence, olivine is often granular and massive (10, 38,123). However, it has about the same solubility as serpentine (97,120) and is sometimes mixed with superphosphate (24,37,56,68,107).

Epsom Salts $(MgSO_4 \cdot 7H_2O)$: Epsom salts is one of the most soluble forms of fertilizer Mg commonly used. It is applied to correct a severe Mg deficiency during the year of application. It is often applied to less acidic soils that do not require liming. Dolomitic limestone would not release Mg rapidly enough on less acidic soils (10,22,38,123).

Sulfate of Potash Magnesia (Sul-Po-Mag) $(K_2SO_4 \cdot 2MgSO_4)$: This is a double salt of K and Mg and is probably as effective in correcting Mg deficiencies as $MgSO_4 \cdot 7H_2O$. It is also used to quickly correct Mg deficiencies (14,15,22).

In addition to the fertilizer sources listed, dolomite, brucite, magnesite, serpentine and olivine are often calcined, heated at temperatures ranging from 600°C to

1100°C. This converts the Mg from more insoluble forms to MgO, which increases the availability of Mg (34,68,120).

Below are listed some of the fertilizer sources of Mg in a probable order of decreasing ability to supply Mg to plants:

Epsom Salts $\cong$ Sul-Po-Mag > MgO > calcined brucite $\cong$ calcined dolomite $\cong$ calcined serpentine $\cong$ calcined olivine $\cong$ calcined magnesite > brucite > dolomite $\cong$ magnesite > serpentine $\cong$ olivine > hornblend $\cong$ talc.

MATERIALS AND METHODS

Locations of the Field Experiments

Three field experiments with potatoes as the test crop were conducted at the following locations in Michigan where Mg deficiency had been identified (see Figure 1):

1. Otsego County - on the Edwin Estelle Farm in the S.W. one quarter of section 6 in T.30N. and R.4W.

2. Houghton County - on the Paul Mustonen Farm in the S.E. one quarter of section 24 in T.53N. and R.34W.

3. Montcalm County - on the Arville Perkins Farm in the S.W. one quarter of section 12 in T.10N. and R.5W.

Climatological and weather information for United States Weather Bureau stations located near each of the three field experiments is summarized in Table 1. Because of variation in elevation and distance to Lake Michigan between the weather stations and the Edwin Estelle farm, the average length of the growing season at this location could only be roughly estimated at 60 to 90 days. The climatological data shows that precipitation for the 1965 growing season was below normal at all three locations.

Brief descriptions of the soil series for the three field locations are given below. More detailed descriptions are given in the Appendix.

Figure 1. Map of Michigan showing location of field experiments and weather stations.

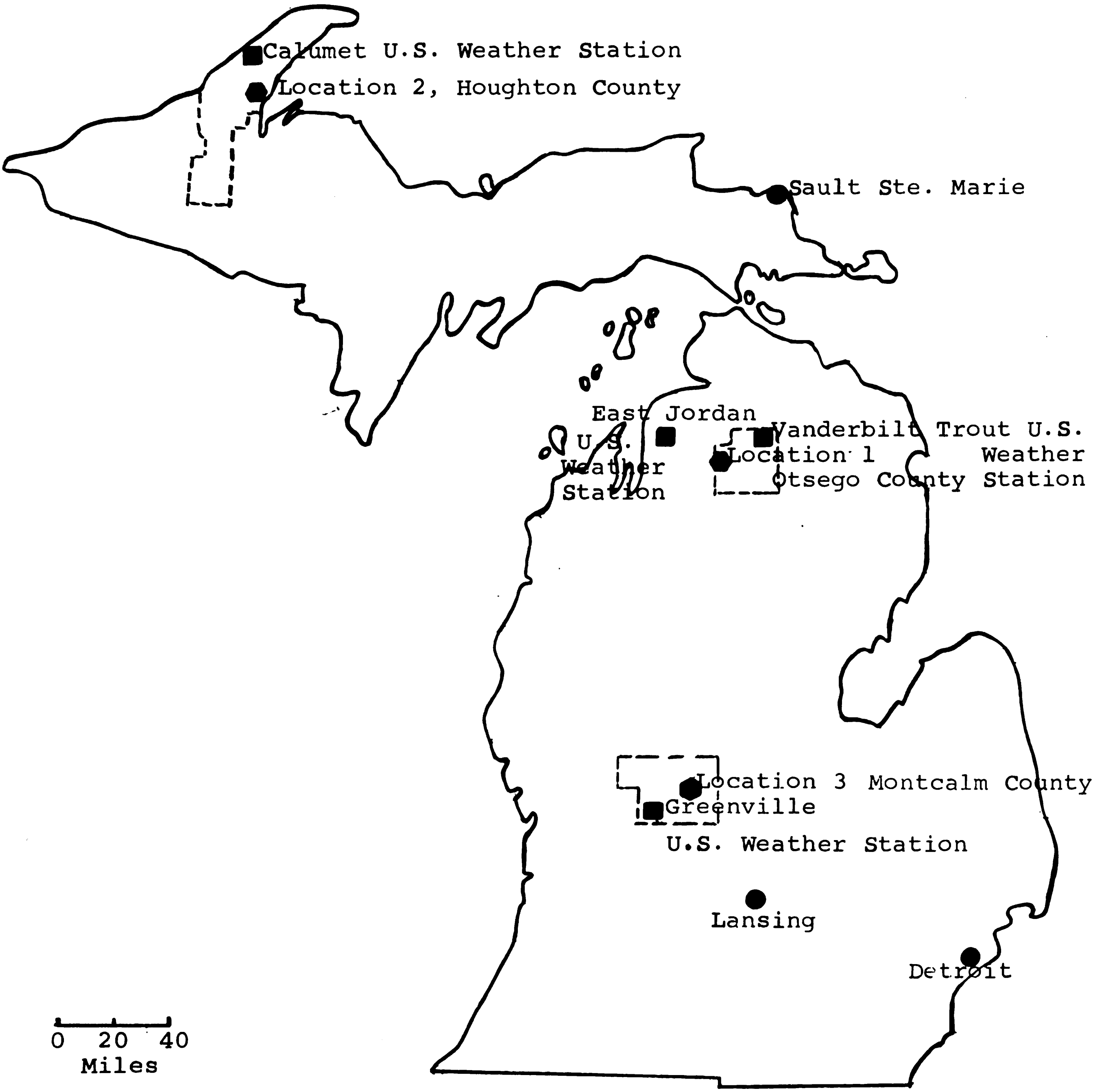

Table 1. Climatological information for United States Weather Bureau stations near each of the field experiments.

Experiment	Location of Weather Station	Distance Between Experiment and Weather Station (Miles)	Mean Precipitation (1930-1959) (inches)		Precipitation in 1965 (inches)		Mean Temperatures (F^{O}) (1930-1959)			Mean Number of Days Between Last Freezing Temperature in Spring and First in Fall
			Year	June-Aug.	Year	June-Aug.	Year	June-Aug.	Dec.-Mar.	
Otsego County (Elevation, 1410 ft.)	East Jordan, Michigan (Elevation, 590 ft.)	18	32	9	30	5	45	67	24	120
	Verderbilt Trout Station, Michigan (Elevation, 925 ft.)	21	29	8.5	31	6.5	42	63	21	60
Houghton County (Elevation, 900 ft.)	Calumet, Michigan (Elevation, 1241 ft.)	18	35	10	31	6	40	63	18	130
Montcalm County (Elevation, 780 ft.	Greenville, Michigan (Elevation, 837 ft.	15	31	9	36	7	48	70	27	150

1. Karlin series (Otsego County):

The Karlin soils are well-drained, slightly to medium acid Podzols which have developed in loamy fine sand to fine sandy loam, 15 to 42 inches thick, overlying sand. Because they are sandy with low cation exchange capacities and have developed from acid parent materials, these soils are often deficient in Ca and Mg.

2. Mancelona series (Montcalm County):

The Mancelona soils are well to moderately well drained, slightly to medium acid Podzols which have developed in either stratified gravelly and sandy outwash or in unassorted gravelly sand or loamy sand. Because these soils have better developed textural B horizons than the Karlin soils, they have higher cation exchange capacities. Also, since the parent materials for the Mancelona soils were more calcareous than those for the Karlin soils, they are probably less apt to become deficient in Ca and Mg.

3. Munising series (Houghton County):

The Munising soils are well drained Podzols with fragipans, which have developed in strongly acid, reddish sandy loam glacial till derived from red sandstone. Because they have developed in strongly acid parent material, they are probably more often deficient in Ca and Mg than soils in the other two series.

The topography of the plot areas in Otsego and Montcalm Counties was nearly level. But, the plot area in

Houghton County was rolling containing some ridges that were nearly 10 feet in height.

Treatments in the Field and Greenhouse

In Table 2 are listed the 20 treatments which were used in both the field and in the greenhouse. Four carriers of Mg, calcined brucite, calcined magnesite, uncalcined magnesite and serpentine were coated on the granules of two sources of P, monocalcium phosphate (MCP), and a mixture of diammonium phosphate and superphosphate (DAP). These made up treatments one through four and six through nine, respectively. Treatments five and ten served as checks, with MCP and DAP, respectively, being used alone. Two sources of P were evaluated, because it was expected that calcined brucite and calcined magnesite, which both contain large amounts of MgO, would be more soluble in the acidic solution diffusing from dissolving MCP than in the more basic solution around dissolving DAP. The P in most wet-mixed fertilizers sold in Michigan is supplied as MCP, but that in the dry-mixed, or bulk-blended fertilizers is largely DAP.

Since sulfate of potash magnesia ($K_2SO_4 \cdot 2MgSO_4$) is a common source of fertilizer Mg, marketed as Sul-Po-Mag, treatment 11 was designed to test the effectiveness of a fertilizer formulated in the same manner as Sul-Po-Mag. Treatment 12 was included to serve as a check for treatment 11.

Table 2. Summary of treatments in the field and in the greenhouse.

Treatment Number	Source of Mg[1] Name	Source of Mg[1] Chemical Formula	Rate of Mg lbs./acre	Source of P[2]	Analyses of Fertilizers Percent by Weight N	P_2O_5	K_2O	Mg
1	Calcined Brucite-Cm	MgO	20	MCP	4.9	24.0	19.2	3.00
2	Calcined Magnesite-Cm	MgO	20	MCP	4.9	24.0	19.2	3.00
3	Uncalcined Magnesite-Cm	$MgCO_3$	20	MCP	4.9	24.0	19.2	3.00
4	Serpentine-Cm	$3MgO \cdot 2SiO_2 \cdot 2H_2O$	20	MCP	4.7	23.1	18.5	2.89
5	None	---	0	MCP	5.0	2.46	19.7	0
6	Calcined Brucite-Cm	$3MgO \cdot H_2O$	20	DAP	4.9	24.0	19.2	3.00
7	Calcined Magnesite-Cm	MgO	20	DAP	4.9	24.0	19.2	3.00
8	Uncalcined Magnesite-Cm	$MgCO_3$	20	DAP	4.9	24.0	19.2	3.00
9	Serpentine-Cm	$3MgO \cdot 2SiO_2 \cdot 2H_2O$	20	DAP	4.8	23.6	18.9	3.00
10	None	---	0	DAP	4.9	24.0	19.2	0

11	Sulfate of Potash Magnesia-Cm	$K_2SO_4 \cdot 2MgSO_4$	20	**DAP**	4.8	23.5	18.8	2.94
12	None	---	0	**DAP**	4.9	24.0	19.2	0
13	Epsom salts-Hm	$MgSO_4 \cdot 7H_2O$	10	**MCP**				
14	Epsom salts-Hm	$MgSO_4 \cdot 7H_2O$	20	**MCP**				
15	Epsom salts-Hm	$MgSO_4 \cdot 7H_2O$	30	**MCP**				
16	Epsom salts-Hm	$MgSO_4 \cdot 7H_2O$	40	**MCP**				
17	Epsom salts-Hm	$MgSO_4 \cdot 7H_2O$	10	**DAP**				
18	Epsom salts-Hm	$MgSO_4 \cdot 7H_2O$	20	**DAP**				
19	Epsom salts-Hm	$MgSO_4 \cdot 7H_2O$	30	**DAP**				
20	Epsom salts-Hm	$MgSO_4 \cdot 7H_2O$	40	**DAP**				

[1] Cm - coated on **DAP** or **MCP**; Hm- Handmixed with **DAP** or **MCP**; Cn- Dry blended.

[2] **MCP** - Commercial 6-24-24, Monocalcium phosphate; **DAP** - Diammonium phosphate, and Triple Superphosphate.

Mg response curves were constructed for Mg at rates of 0, 10, 20, 30, and 40 pounds per acre with treatments 5 and 13 through 16 having MCP as the P carrier and treatments 10 and 17 through 20 having DAP as the P carrier.

Methods of Preparation and Properties of the Treatment Fertilizers

The P carrier containing primarily MCP $Ca(H_2PO_4)_2$ was commercial granular 6-24-24. The superphosphate and triple superphosphate in this fertilizer were prepared by acidulating rock phosphate with sulfuric acid (H_2SO_4) and phosphoric acid (H_3PO_4), respectively. These two fertilizers were then mixed with KCl and $(NH_4)_2SO_4$, then ammoniated and granulated. Granulated DAP ($(NH_4)_2HPO_4$) was prepared by ammoniating H_3PO_4 by the Dorr Slurry process. This DAP was mixed with red granular KCl and granular triple superphosphate in about a 1:1:1 weight ratio.

The calcined brucite (MgO) was prepared by calcination of brucite limestone at about 2100°F followed by hydration of the lime to a fine powder which was removed from the unchanged magnesia granules by air separation. The calcined magnesite (MgO) consisted of the reactive grade of synthetic MgO. The uncalcined magnesite was weathered flue dust recovered from the precipitators in the caustic calcination of natural carbonate rock to produce calcined magnesite (MgO). The serpentine was serpentine rock that had been crushed, dried, and screened. The Mg content of these carriers were 40, 56, 27, and 22 percent, respectively.

The two granular base fertilizer materials were dry blended with the powdered Mg sources for one minute in an enclosed mixer. Then warm (100°-$120^{\circ}F$) "used" motor oil was sprayed into the rotating mixer and mixing continued for another two minutes.

In preparing the fertilizer for treatment 11, magnesium potassium sulfate ($K_2SO_4 \cdot 2MgSO_4$) (11 percent Mg) was dry-blended with granular potassium chloride, DAP and granular triple superphosphate. The fertilizer for check treatment 12 contained K_2SO_4 in the place of $K_2SO_4 \cdot 2MgSO_4$.[1]

Experimental Design and Cultural Practices in the Field

In the field, the 20 treatments were replicated four times in a randomized block design. In Montcalm and Houghton Counties, each of the 80 plots was 50 feet by 11-1/3 feet (four (34 inch) rows). In Otsego County, the plot size was 50 feet by 8½ feet (three (34 inch) rows). In Montcalm and Houghton Counties, 100 pounds of N per acre as ammonium sulfate ($(NH_4)_2SO_4$), and 500 pounds of K per acre as KCl were plowed down before planting. In Houghton County these fertilizers were spread on the soil surface after planting.

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[1]The treatment fertilizers were prepared by the Division of Chemical Development, Tennessee Valley Authority, Muscle Shoals, Alabama.

Sebago potatoes were planted on May 15th in Montcalm County, May 22nd in Otsego County and May 31st in Houghton County. A two-row planter spaced the seed potatoes 11 to 14 inches apart in the row at a depth of about six inches. The fertilizer was placed in two bands on either side of the row about two inches below the seed and two inches to the side. A rotating solid cone mounted on the planter above each row was geared to make one rotation in 50 feet, so as to deliver a preweighed quantity of fertilizer uniformly along the row. The fertilizer was placed in a cylindrical bottomless container positioned over the apex of the cone. When the cylinder was lifted, the fertilizer flowed evenly down the surface of the cone into a circular trough, attached to the base of the cone, where it was scraped off into a hose leading to the potato row.

Throughout the growing season, hilling, cultivation, other weed control measures, insect control and disease control were carried out by the cooperating farmers. In Otsego County the potatoes suffered moderate damage from a potato bug infestation. The severity of the damage varied considerably among the plots. The potatoes in Montcalm County were irrigated.

Experimental Design and Cultural Practices in the Greenhouse

In the greenhouse, the 20 treatments were replicated 6 times in a randomized block design with pots periodically rotated by one replication.

The soil used in the greenhouse was Karlin loamy sand obtained from the Edwin Estelle Farm. The air dried soil was thoroughly mixed and then sieved to remove all stones above approximately eight millimeters in diameter. At that time a soil sample was taken to be analyzed at the Michigan State University Soil Testing Laboratory.

Three thousand, five hundred grams of soil was placed in a number 10 can lined with a plastic bag. Enough $(NH_4)_2SO_4$ and KCl to provide 100 pounds of N and 500 pounds of K per 2,000,000 pounds of air dried soil (acre furrow slice) were thoroughly mixed with the soil. Nitrogen as $(NH_4)_2SO_4$ was added as needed during the growing season.

The treatment fertilizer was placed in a circular band three inches in diameter at a depth of about 1½ inches. Twenty oat seeds were planted July 19-20, 1965 at a depth of about ½ inch in a four inch diameter circular band. After emergence the oats were thinned to 15 plants per pot. When the oats needed water the same amount was applied to each pot and periodically the pots were brought to a 15 percent moisture level.

On October 12, when the oats had reached the milk stage, they were cut at the soil level, dried in an oven at $65^{\circ}C$, weighed, and ground to pass a 40 mesh screen.

On December 20, 1965, a second crop of oats was planted at a depth of about ½ inch without disturbing the fertilizer band established at the first planting. With the exception of N, this crop was given no additional fertilizer. This crop was harvested on March 20, 1966 just as the oats began to ripen.

Yield Determinations in the Field

In Montcalm County, potato vines were harvested on September 10, in order to determine the total dry weight yield of vines.

The potatoes were harvested and yield determinations made on September 28, September 29, and September 23 in Otsego, Houghton and Montcalm Counties respectively.

At all three locations, about ten pounds of number one potatoes were selected at random from each plot. A few weeks later, the specific gravities of these potatoes were determined using the hydrometer method.

Laboratory Analyses

Soil Tests

Two soil samples per plot were taken in the field, one a few weeks after planting and the other just before harvest. Each sample consisted of 40 to 50 cores taken to a depth of about seven inches from between the potato rows. These samples and the sample from the greenhouse were air dried, ground, mixed, split with a soil splitter, and sent to the Soil Testing Laboratory at Michigan State University. In this laboratory, Bray's P_1 method (45) was used to extract the P, and P was determined colormetrically by the molybdenum blue method. After extraction from the soil with 1 N NH_4Ac solution, K was determined with a Coleman model 21 flame photometer, Ca with a Beckman model DU quartz spectrophotometer and Mg with a Perkin-Elmer model 290 atomic absorption spectrophotometer. The soil pH, of a 1:1 soil to water suspension, was determined using a glass electrode with a calomel electrode as a reference.

In order to obtain an estimate of the amount of Mg trapped between the layers of the soil clays by the NH_4^+ ions from the NH_4Ac extracting solution, two soil samples from each field location were extracted with 0.1 N NaCl, which contains the expanding Na^+ ion.

Fertilizer Analyses

In order to verify its formulations, the Tennessee Valley Authority determined the total N, P, K, and Mg in the treatment fertilizers. In addition, total Mg was determined at Michigan State University. For the first Mg determination at Michigan State University, each sample was taken from near the top of the fertilizer bag. For the second set of determinations, each sample was taken to the bottom of the bag with a sampling probe. The samples were digested at $180^{\circ}C$ in a mixture of concentrated HNO_3 and HCl at a ratio of 1:1. Magnesium was determined by the use of the Perkin-Elmer model 303 absorption spectrophotometer.

Plant Analyses

In Otsego and Montcalm Counties, two petiole samplings were taken from each plot. In Otsego County, the samplings were made on July 22 and August 16, 9 and 12 weeks after planting. In Montcalm County, the samples were taken on July 21 and August 26, 9½ and 15 weeks after planting. Each petiole was taken from the youngest fully expanded leaf on the potato plant, usually the fourth or fifth leaf below the growing tip. Approximately 40 of these petioles were selected at random from the center two rows of each four row plot in Montcalm County and from the center row of each three row plot in Otsego County. In Houghton County, one petiole sampling was made on August 8, about 10 weeks after planting, using the same method as in Montcalm County.

The petiole samples were then dried at 65°C and ground to pass a 40 mesh screen. These samples, the oats from the greenhouse, and the potato vines from Montcalm County were wet digested with nitric and perchloric acid, as described by Jackson (45).

Mg and Ca were then determined by use of a Perkin-Elmer model 303 absorption spectrophotometer using 285 and 212 mμ wavelengths, respectively. K was determined by use of a Coleman model 21 flame photometer.

RESULTS AND DISCUSSION

Soil Test Results

The soil test results are given in Table 3. Since the first samplings in the field were taken from between the potato rows after KCl and $(NH_4)_2SO_4$ had been broadcasted, the available K values were higher than they were prior to establishing the experiment. However, the available P, Ca, and Mg values should reflect their respective levels before the fertilizer in 1965 was applied.

The measured available nutrient levels at each location varied substantially between individual plots. Variation in available nutrient levels may have contributed to non-treatment variation in yields and the Mg content of the potato plants.

The soil test results indicate that the amount of available P in the Otsego County soil was lower than the greenhouse soil or the soils in Houghton and Montcalm Counties. Therefore, there should have been a greater response to P fertilization in Otsego County.

The available soil K values in the field were lower at the end of the growing season than at the beginning. This was probably the result of leaching and K uptake by the

Table 3. Average pH and available P, K, Ca and Mg per acre for the three soils in the field and the soil in the greenhouse.[1]

Location	Soil Type	Date of Sampling	Soil Reaction	Available P	Available K	Available Ca	Available Mg
			pH	---------------	pounds/acre[2]	---------------	
Otsego County, Michigan	Karlin loamy sand	6/21/65	5.0	45	419	1230	43
		9/7/65	5.5	53	264	1054	43
Houghton County, Michigan	Munising fine sandy loam	7/3/65	4.3	168	563	656	27
		9/10/65	4.9	167	500	575	25
Montcalm County, Michigan	Mancelona loamy sand	6/14/65	4.9	216	460	634	39
		9/10/65	5.5	210	213	420	48
Green-house	Karlin loamy sand	Composite sample taken be-fore planting	5.0	171	239	659	16

[1]Available P determined by Brays P_1 method; K, Ca and Mg were NH_4Ac extractable.

[2]One acre or acre furrow slice = 2,000,000 pounds of soil.

potato plants. Since the greenhouse soil sample was taken from before KCl had been applied, it tested lower in K than did the first field samples.

There were no differences between the amounts of soil Mg extracted by 1 N NH_4Ac as compared to 0.1 N NaCl. This does not necessarily indicate that only a small portion of the clay fraction of each soil consisted of collapsing vermiculite and montmorillonite clay types. Because the soils contained abundant K, large amounts of Mg may have been trapped between the clay layers before the soils were extracted. Since this Mg was unavailable to plants, the 1 N NH_4Ac method probably accurately measured the amounts of available soil Mg.

The available Mg values were below 75 pounds per acre. This along with the high available K levels should have resulted in responses to Mg fertilization, especially in the greenhouses and at the location in Houghton County.

Fertilizer Analysis

In general, for total N and K_2O, there was good agreement between Tennessee Valley Authority's (T.V.A.) formulated analyses and chemical analyses. But, the values for total P_2O_5 and Mg did not agree as well (see Table 4). Calculations for the fertilizer rates were based on the formulated analyses. According to the chemical analyses, the P rates were about 160 pounds of P_2O_5 per acre for the

Table 4. Analyses of the experimental fertilizers.

Fertilizer (Treatment) Number	Fertilizer Description[1]	Formulated Analyses[2]				Chemical Analyses				Analyses Conducted at M.S.U.	
		N	P_2O_5	K_2O	Mg	N	P_2O_5	K_2O	Mg	First run Mg	Second run Mg
		%				%				%	
1	Calcined Brucite with MCP	4.9	24.0	19.2	3.00	4.9	19.9	19.7	2.9	1.5	2.7
2	Calcined Magnesite with MCP	4.9	24.0	19.2	3.00	4.9	19.1	19.2	3.3	2.7	2.8
3	Uncalcined Magnesite with MCP	4.9	24.0	19.2	3.00	4.9	19.7	20.0	2.8	2.6	2.6
4	Serpentine with MCP	4.7	23.1	18.5	2.89	5.0	19.6	19.0	2.4	1.3	2.3
5	MCP	5.0	24.6	19.7	0	Not analyzed				0.19	0.15
6	Calcined Brucite with DAP	4.9	24.0	19.2	3.00	5.1	24.5	19.6	2.7	2.3	2.6
7	Calcined Magnesite with DAP	4.9	24.0	19.2	3.00	5.3	27.1	17.4	3.1	2.9	2.8
8	Uncalcined Magnesite with DAP	4.9	24.0	19.2	3.00	4.9	25.2	19.6	2.9	2.5	2.4

9	Serpentine with DAP	4.8	23.6	18.9	3.00	4.9	24.7	18.7	3.5	2.4	3.2
10	DAP	4.9	24.0	19.2	0	Not analyzed				0.22	0.21
11	Sulfate of Potash-magnesia with DAP	4.8	23.5	18.8	2.94	4.8	25.0	17.5	3.4	1.6	3.1
12	K_2SO_4 with DAP	4.9	24.0	19.2	0	Not analyzed				0.37	0.46

[1] MCP - Monocalcium phosphate; DAP - Diammonium phosphate and MCP; $MgSO_4 \cdot 7H_2O$ - Epsom salts.

[2] All analyses in percent by weight.

treatments which included DAP (6-10 and 17-20) and 130 pounds of P_2O_5 per acre for the MCP treatments (1-5 and 13-16).

Calculations for the 20 pound per acre Mg rates were also based on the formulated analyses. The chemical analyses indicated that the actual Mg rates ranged from 17 pounds per acre, for treatments four and six, to 22 pounds per acre, for treatment nine.

In general, for the analyses conducted at Michigan State University, the total Mg values for the first set of determinations were much lower than for the second set. Since each sample for the first set of determinations was taken from the top of the fertilizer bag, whereas each sample for the second set was taken to the bottom of the bag with a sampling probe, the analyses probably indicate that there was segregation of the powered Mg sources. This could have resulted in Mg rates generally lower than 20 pounds per acre and quite variable.

Greenhouse Studies

Application of Mg fertilizer increased dry matter yield, Mg content and Mg uptake of the first crop of oats (see Figures 2, 3, and 4 and Table 1A in the Appendix).

For those 10 treatments which included the five Mg sources--$MgSO_4 \cdot 7H_2O$, calcined brucite, calcined and uncalcined magnesite and serpentine applied with two P sources MCP

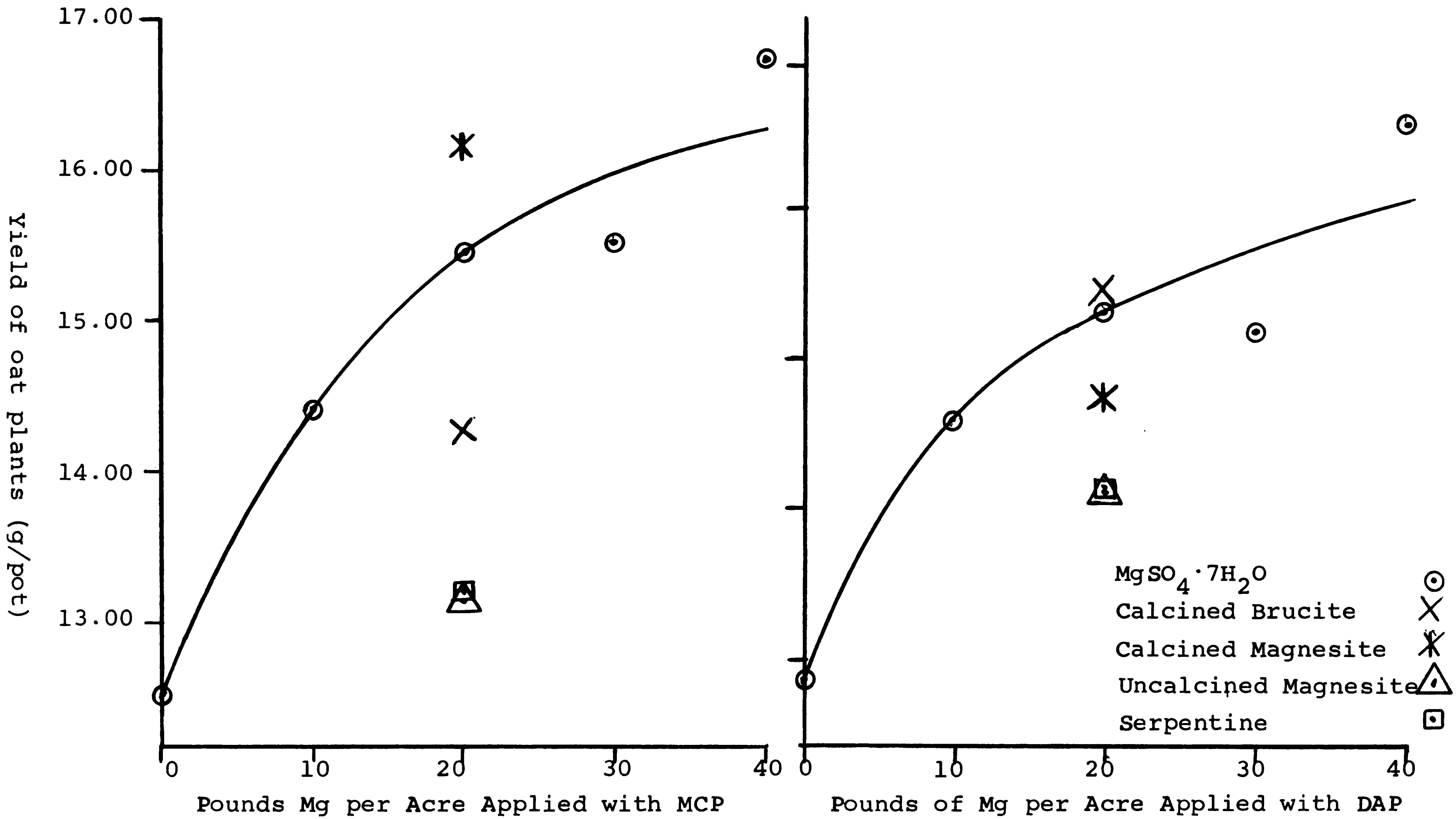

Figure 2. Yield of oat plants as a function of rate and carrier of Mg and carrier of P--first crop.

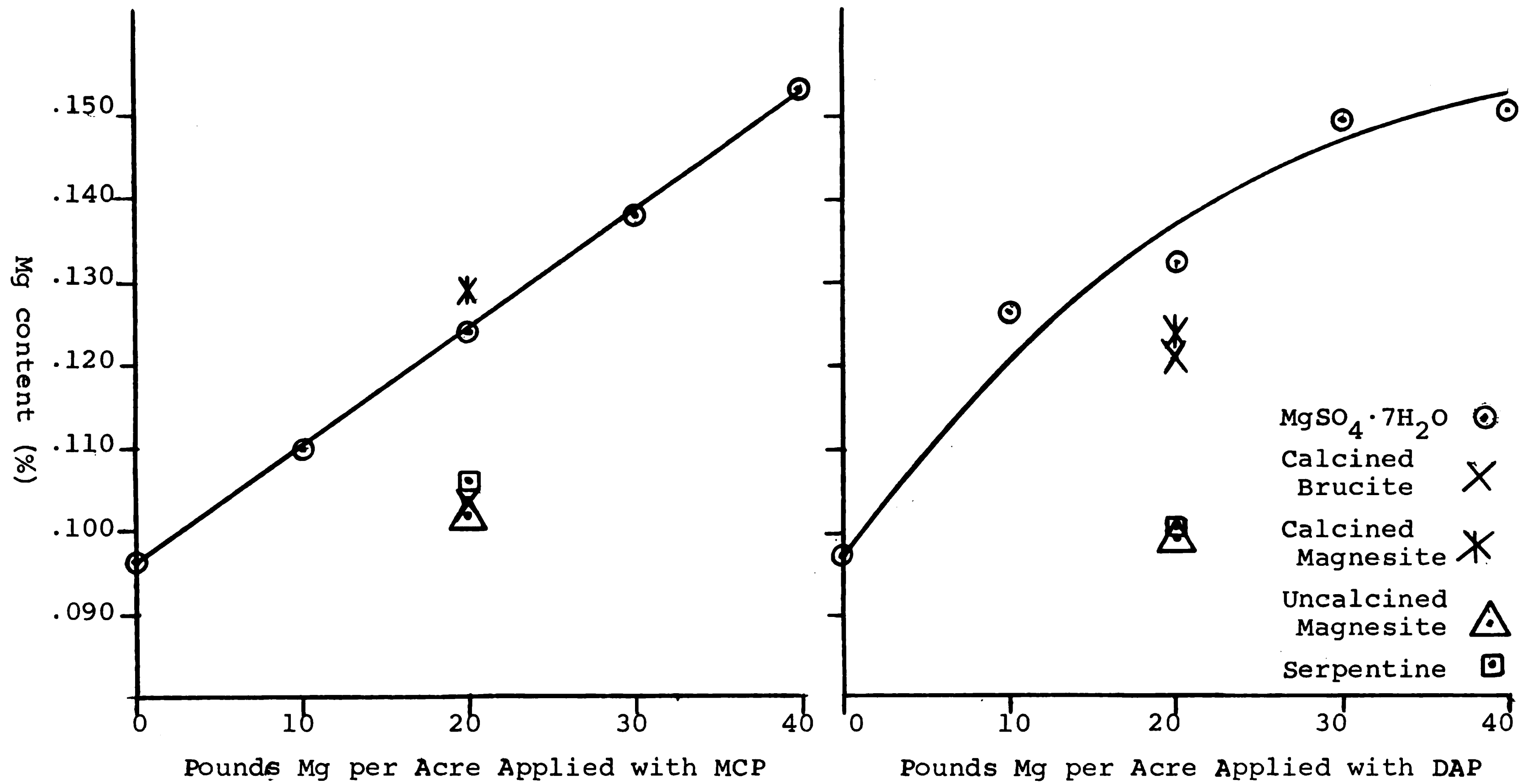

Figure 3. Mg content of oat plants as a function of rate and carrier of Mg and carrier of P--first crop.

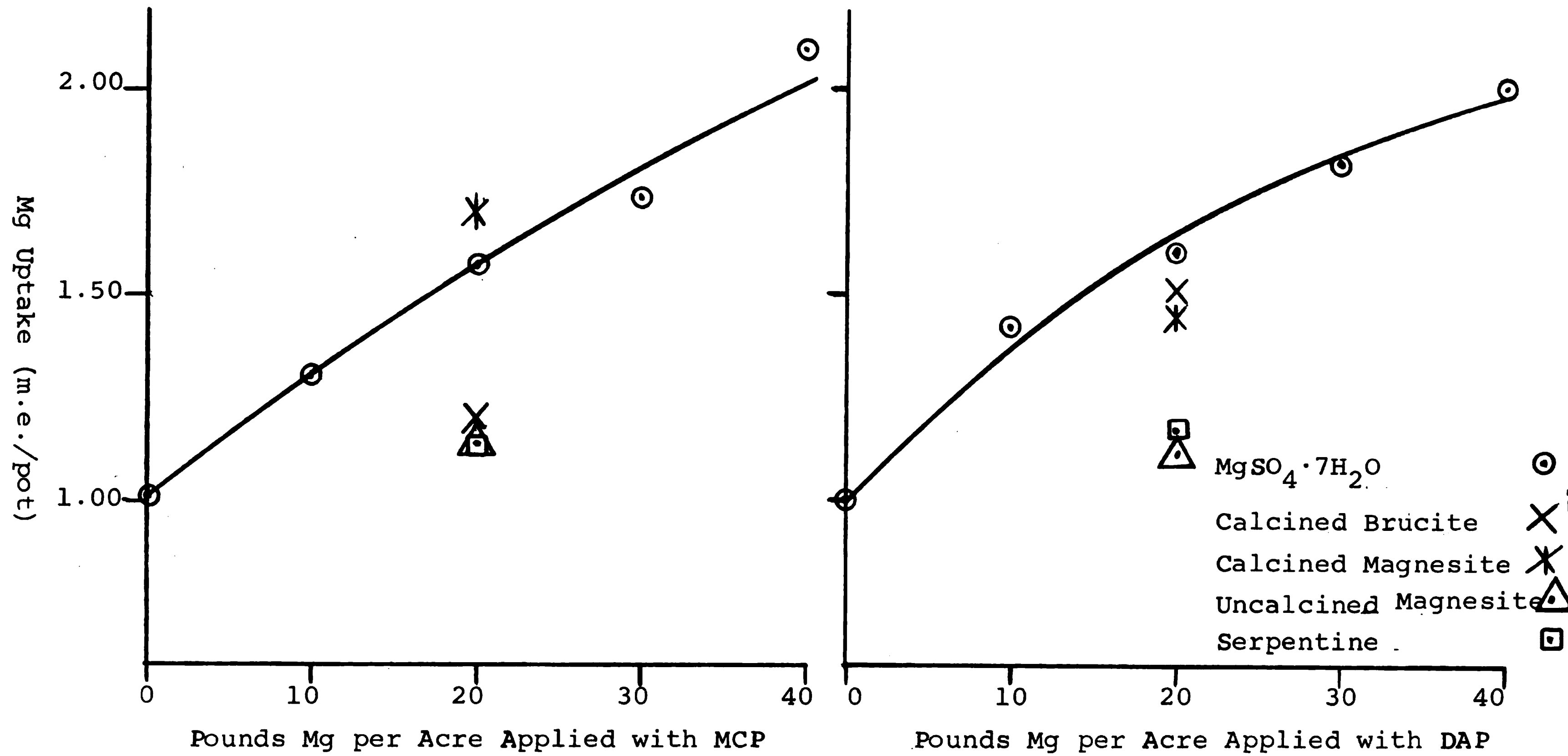

Figure 4. Uptake of Mg as a function of rate and carrier of Mg and carrier of P--first crop.

and DAP at a Mg rate of 20 pounds per acre (treatments 1-4, 6-9, 14 and 18), the differences in dry weight yield of oat plants were statistically significant at the one percent level (see Table 5). This primarily reflects the variation in the availability of Mg from the five Mg sources, rather than influences of the two different P sources. Although the differences in dry weight yield between the various Mg source treatments were not always larger than the honestly significant differences[1] (see Table 5), definite trends are evident. When the Mg sources were applied with MCP, calcined magnesite and $MgSO_4 \cdot 7H_2O$ resulted in the highest dry weight yields, calcined brucite in moderate yields and serpentine and uncalcined magnesite in the lowest yields. When the Mg sources were applied with DAP, calcined brucite and $MgSO_4 \cdot 7H_2O$ resulted in the highest yields, calcined magnesite in moderate yields and uncalcined magnesite and serpentine in the lowest yields.

The sulfate of potash-magnesia treatment (number 11) resulted in a dry weight yield which was only surpassed by the calcined magnesite with MCP treatment. (Table 1A in the

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[1]H.S.D., or the honestly significant difference is part of Tukey's test and is calculated from the following equation:

$$H.S.D. = q_\alpha S\bar{x},$$

where q_α is a constant which has been compiled in table form for α = .01 or .05, similar to the way in which the constant t is tabulated for the L.S.D. test, and $S\bar{x}$ is the standard error of the difference between two means. The H.S.D. test is similar to the L.S.D. test, but is more severe and probably gives a more accurate estimate of the significant difference when there are more than a few treatments in an experiment.

Table 5. Results for analyses of variance[1] of data from the greenhouse experiment. This includes sets of data that are in graph form.

Source of Variance		Yield of Oat Plants First Crop	Yield of Oat Plants Second Crop	Mg Content First Crop	Mg Content Second Crop	Mg Uptake First Crop	Mg Uptake Second Crop
Treatment	Level of Significance	.01	.05	.01	.01	.01	.01
	H.S.D. at .05 level of significance	1.85[2]	1.31[2]	.017[3]	.018[3]	.15[4]	.14[4]
	H.S.D. at .01 level of significance	2.18[2]	---	.020[3]	.021[3]	.18[4]	.17[4]
P Source	Level of Significance	>.10	>.10	>.10	>.10	>.10	>.10
Mg Source	Level of Significance	.01	.01	.01	.01	.01	.01
Interaction of Mg and P Sources	Level of Significance	.05	.05	.01	.05	.01	.01

[1]Analyses of variance were conducted for data from those treatments which included all of the Mg sources, except sulfate of potash-magnesia, at a Mg rate of 20 lbs./acre. These treatments were 1-4, 14, 6-9, and 18.

[2]g/pot.

[3]Percent.

[4]m.e./pot.

Appendix.) However, the check treatment (number 12) resulted in a yield which was substantially higher than for the other two check treatments (numbers 5 and 10).

Magnesium content and total Mg uptake were closely related to dry matter production (see Figures 3 and 4, Table 5, and Table 1A in the Appendix). This data indicates that the order of availability of the Mg sources when applied with MCP was calcined magnesite $\cong$ $MgSO_4 \cdot 7H_2O$ > calcined brucite $\cong$ uncalcined magnesite $\cong$ serpentine. When the Mg sources were applied with DAP, the order was $MgSO_4 \cdot 7H_2O$ $\cong$ calcined magnesite $\cong$ calcined brucite > serpentine $\cong$ uncalcined magnesite. From the Mg content and uptake data, it appears that sulfate of potash-magnesia released as much or more Mg than did the other five Mg carriers.

For the second crop of oats, there were no significant treatment differences in dry weight yield (see Table 5 and Figure 5). Although there were not as many significant differences as for the first crop, the Mg content and Mg uptake data for the second crop indicate that there were residual effects from the Mg sources. The trends in Mg content and uptake also support the conclusions drawn from the first crop data. Probably there were no responses in dry matter production, to Mg fertilization, because other environmental factors were more limiting to growth than the supply of available Mg.

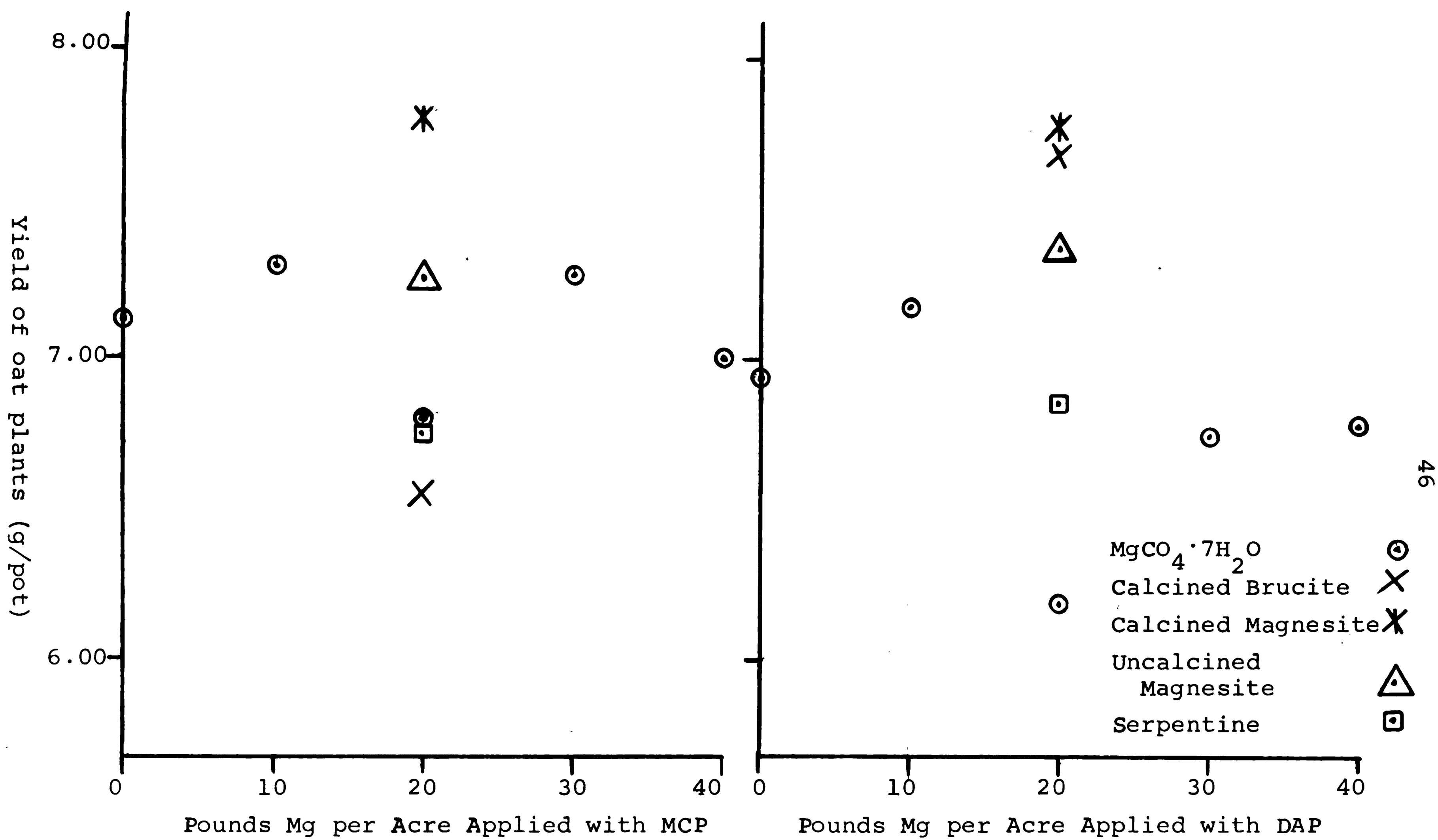

Figure 5. Yield of oat plants as a function of rate and carrier of Mg and carrier of P--second crop.

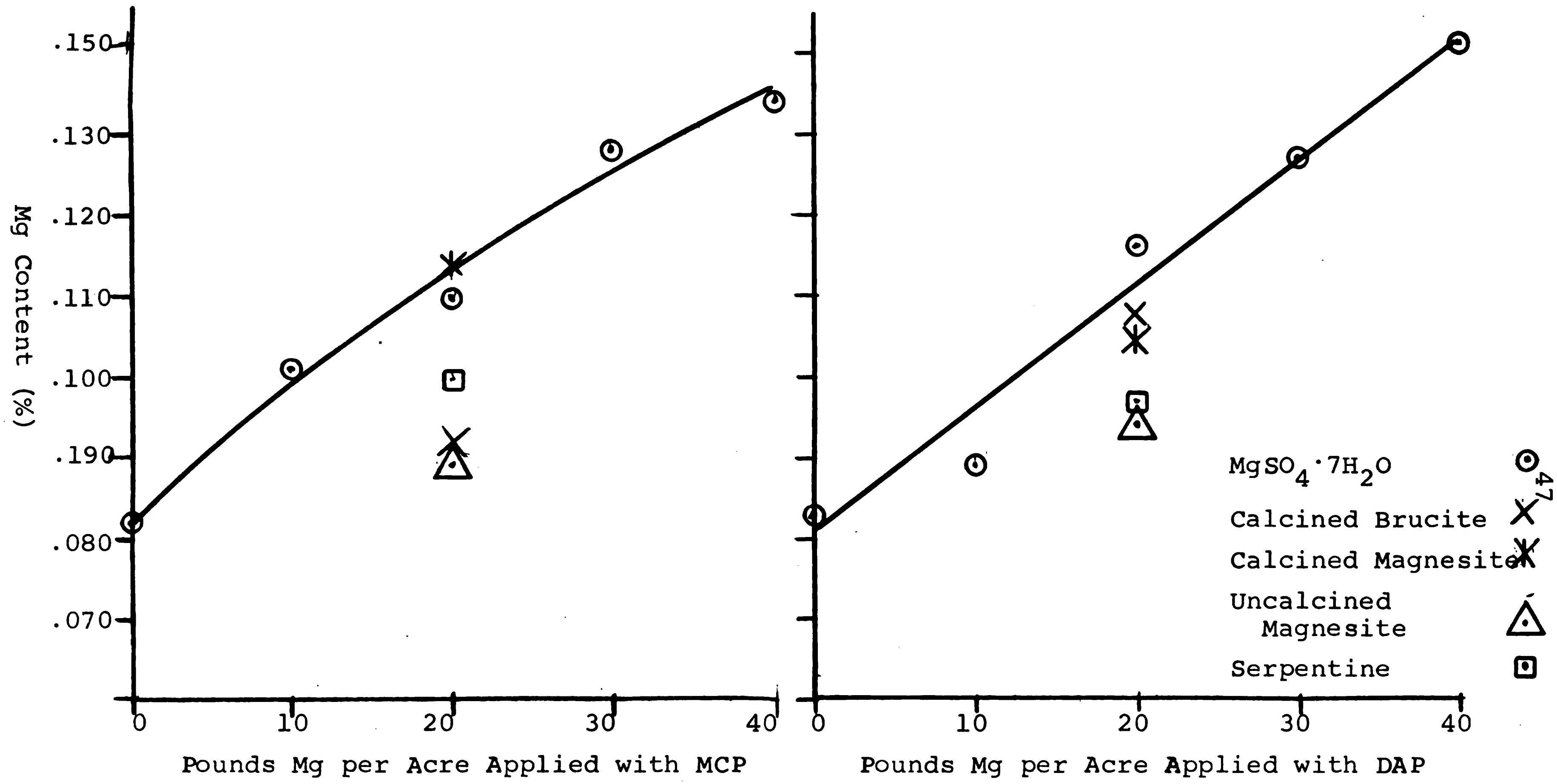

Figure 6. Mg content of oat plants as a function of rate and carrier of Mg and carrier of P--second crop.

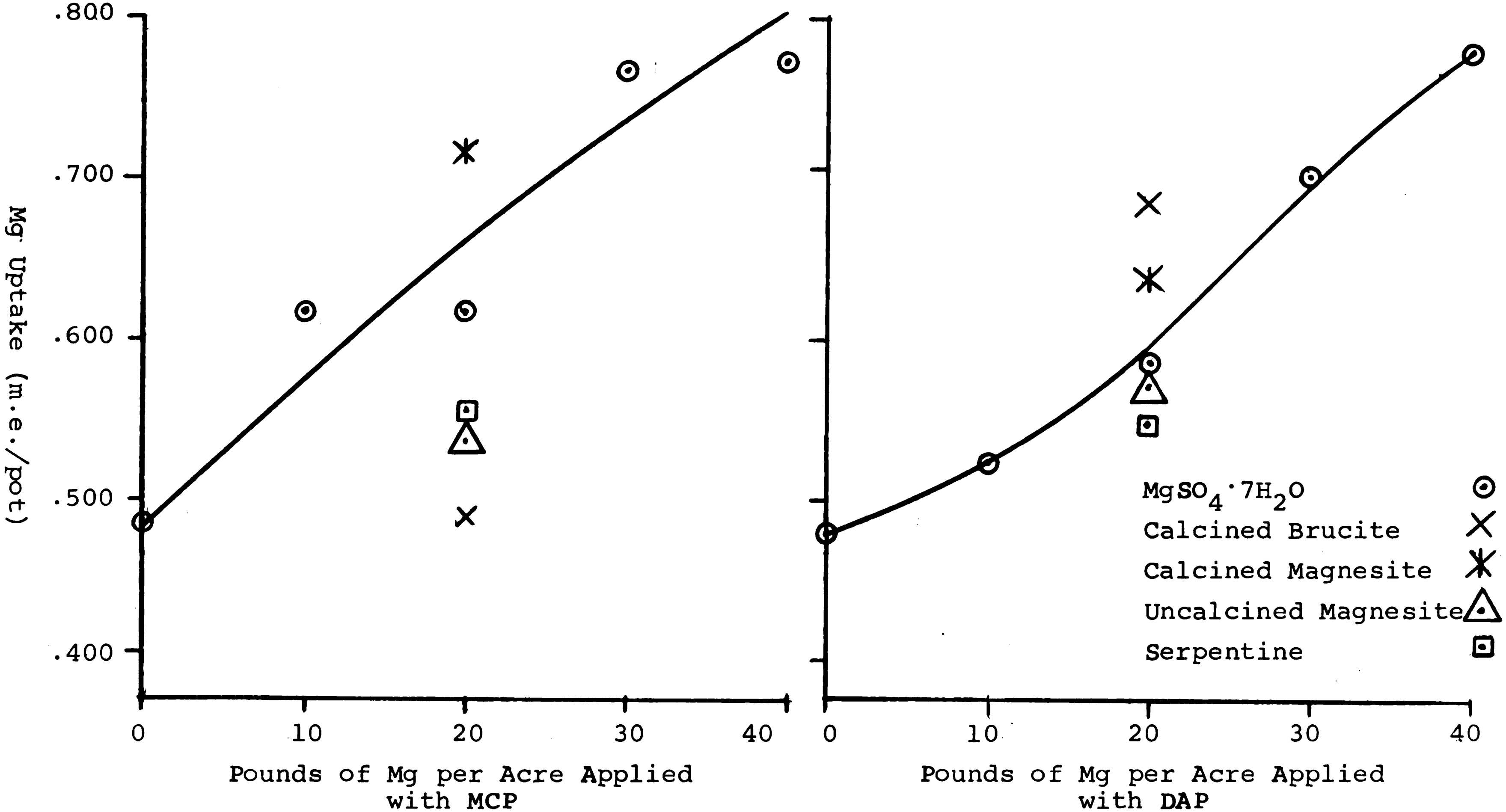

Figure 7. Uptake of Mg as a function of rate and carrier of Mg and carrier of P--second crop.

It should be noted that when applied with MCP, calcined brucite resulted in much lower dry weight yield, Mg content, and Mg uptake values, than when it was applied with DAP. For calcined magnesite, however, these values were somewhat higher when it was applied with MCP. This is difficult to explain, since both of these minerals should have contained largely MgO.

Field Studies

A summary of the field data for the three field locations is given in Table 6. Dry weight yield, Mg content, and Mg uptake data for potato vines were taken only in Montcalm County. The average yield of potatoes for the three locations and the dry weight vine yields show that there were small responses to Mg fertilization. Check treatments 5 and 10 resulted in somewhat lower potato yields. Check treatment 12, which included K_2SO_4 in the mixed fertilizer instead of the KCl used for treatments 5 and 10, resulted in the second highest potato yield, but produced one of the lowest vine yields. The differences were not great enough or the trends definite enough to draw any conclusions from the yield data concerning the order of availability of the Mg sources. In general, the average Mg content of the petioles for the first samplings and the Mg content of the potato vines were not closely related to the average potato yield and vine yield, respectively. Also, from the Mg content and

Table 6. Summary of field data for all three locations.

Treatments: Number	Treatments: Fertilizer Description[1]	Rate of Mg	Average Yield of Potatoes for the Three Locations	Average Mg Content of Petioles, First Sampling for the Three Locations	Dry Weight Yield Potato vines, Montcalm County	Mg Content of Vines, Montcalm County	Uptake Mg by Vines, Montcalm County
		lbs./A.	c.w.t./A.	%	lbs./A.	%	lbs./A.
1	Calcined Brucite with MCP	20	214	.149	3690	.319	12.1
2	Calcined Magnesite with MCP	20	222	.169	3380	.349	11.7
3	Uncalcined Magnesite with MCP	20	219	.141	3000	.268	8.0
4	Serpentine with MCP	20	213	.139	3500	.321	11.3
14	$MgSO_4 \cdot 7H_2O$ with MCP	20	221	.153	3330	.310	10.3
5	MCP	0	206	.145	3040	.330	10.0
6	Calcined Brucite with DAP	20	232	.147	3100	.279	8.6
7	Calcined Magnesite with DAP	20	217	.149	3990	.309	12.3

8	Uncalcined Magnesite with DAP	20	224	.131	3430	.278	9.7
9	Serpentine with DAP	20	223	.142	3230	.330	10.9
18	$MgSO_4 \cdot 7H_2O$ with DAP	20	222	.156	3370	.323	10.1
10	DAP	0	219	.137	3530	.286	9.9
11	Sulfate of Potash-Magnesia with DAP	20	222	.165	3550	.319	11.3
12	K_2SO_4 with DAP	0	226	.131	3060	.273	8.2

[1] MCP - Monocalcium Phosphate; DAP - Diammonium Phosphate and MCP.

uptake of potato vines, it is difficult to draw any conclusions for the order of availability of the Mg sources. But, the average Mg content values for the first petiole samplings indicate that when applied with MCP the order of availability of the Mg sources was calcined magnesite > $MgSO_4 \cdot 7H_2O$ > or $\cong$ calcined brucite > uncalcined magnesite $\cong$ serpentine and when applied with DAP, $MgSO_4 \cdot 7H_2O$ > calcined magnesite $\cong$ calcined brucite > serpentine > uncalcined magnesite.

Otsego County

In Otsego County, the treatment differences in yields were significant only at the 10 percent level (Table 3A in the Appendix). The Mg sources did not contribute significantly to these treatment differences. However, the influence of the two P sources on yield was statistically significant at the 5 percent level. The average yield for the MCP treatments (1-5 and 13-16) was 207 c.w.t. per acre and for the DAP treatments (6-10 and 17-20) it was 234 c.w.t. per acre. The soil test results indicate that the supply of available soil P was relatively low at the location in Otsego County. Since on the basis of the chemical analyses of the fertilizers the DAP treatments received 160 pounds of P_2O_5 per acre and the MCP treatments 130 pounds of P_2O_5 per acre, there was apparently a response to P fertilization at this location.

Table 7. Results for analyses of variance of data from the field experiment in Otsego County. This includes sets of data that are in graph form.[1]

Source of Variance		Mg Content of Petioles First Sampling[2]	Mg Content of Petioles Second Sampling[3]
Treatment	Level of Significance	$> .10$	.10
	H.S.D. at .05 Level of Significance	---	---
	H.S.D. at .01 Level of Significance	---	---
P Source	Level of Significance	$> .10$	$> .10$
Mg Source	Level of Significance	$> .10$	$> .10$
Interaction of Mg and P Sources	Level of Significance	$> .10$	.05

[1]Analyses of variance were conducted for data from those treatments which included all the Mg sources, except sulfate of potash-magnesia, at a Mg rate of 20 pounds/acre. These treatments were 1-4, 14, 6-9, and 18.

[2]First sampling made on July 21, 1965, 9½ weeks after planting.

[3]Second sampling made on August 26, 1965, 15 weeks after planting.

For the first petiole sampling, although the effects of the P sources were not statistically significant (see Table 7), the Mg content of the petioles was generally higher for MCP than for DAP (see Figure 8). Since the potato yields were higher for DAP, perhaps the lower Mg content for the DAP treatments was the result of a dilution effect. This effect was less pronounced by the time of the second petiole sampling.

On the basis of the Mg content of the petioles, there were no consistent differences between the effects of the two P carriers on the order of availability of the five Mg sources.

Although there were no significant differences in the Mg content of the petioles between the five Mg sources (Table 5 and Figures 8 and 9), it probably can be said that the $MgSO_4 \cdot 7H_2O$, calcined brucite and calcined magnesite treatments resulted in higher Mg contents than the uncalcined magnesite or serpentine treatments.

It should be noted that in the case of the calcined magnesite with DAP treatment, the Mg content of the petioles for the second sampling was very low. It is difficult to attribute this to experimental error since the same treatment resulted in a relatively higher value for the first petiole sampling.

When calcined brucite was applied with MCP, the resulting Mg content was slightly higher than the value for

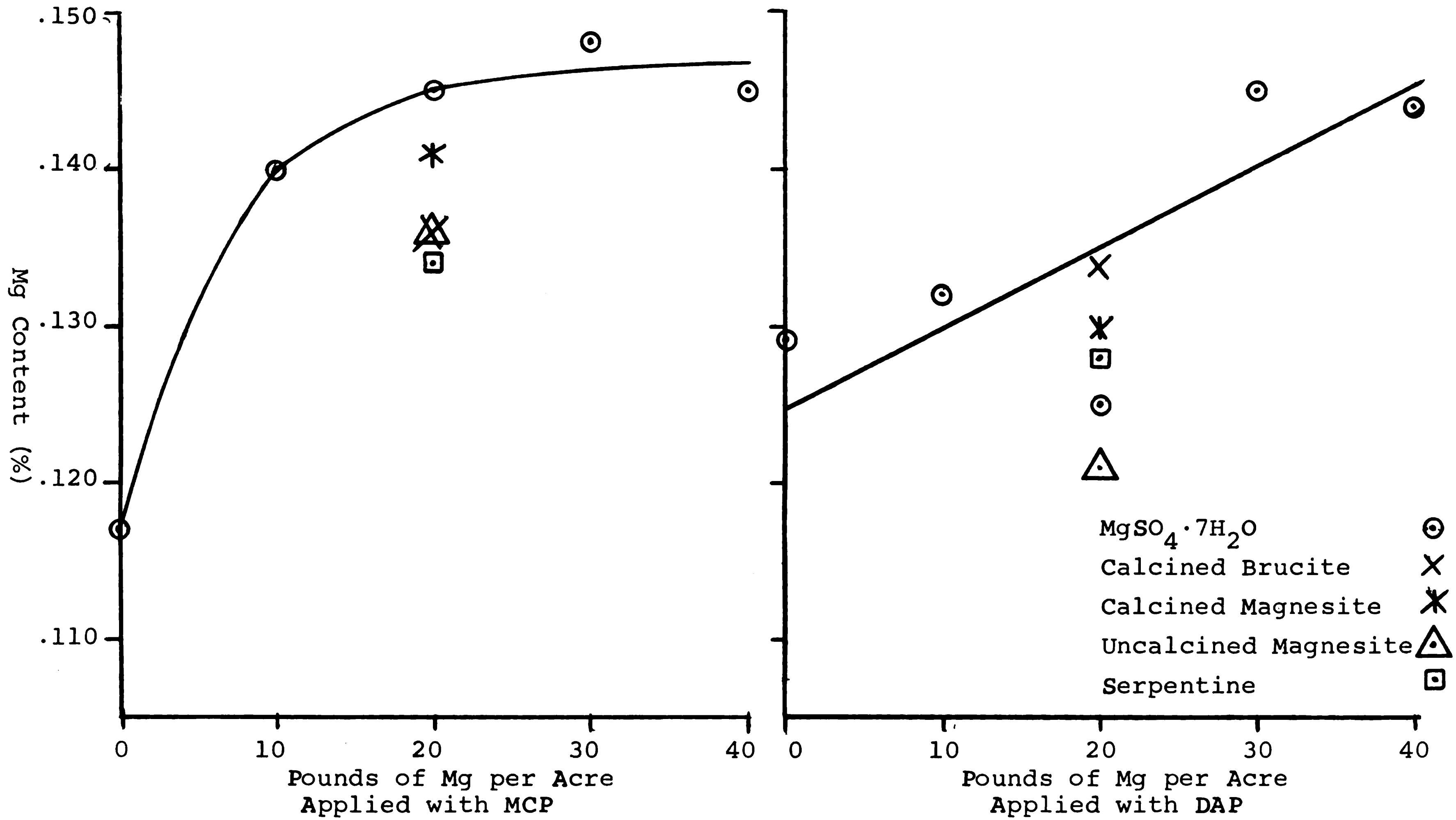

Figure 8. Mg content of potato petioles, July 22, 1965 (9 weeks after planting) as a function of rate and carrier of Mg and carrier of P--Otsego County.

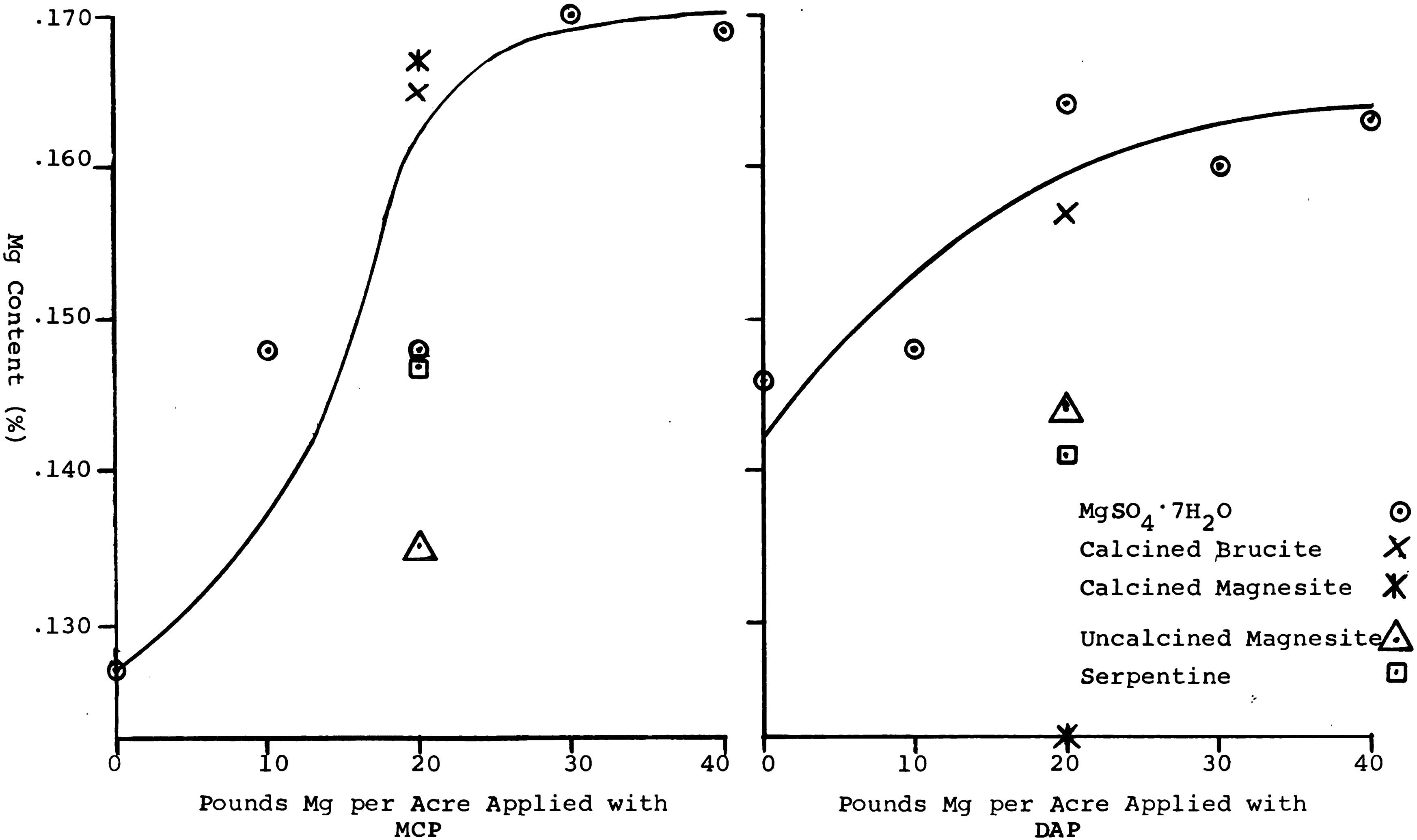

Figure 9. Mg content of potato petioles, August 16, 1965 (12 weeks after planting) as a function of rate and carrier of Mg and carrier of P--Otsego County.

calcined brucite with DAP. Although this did not agree with the data from the greenhouse study, it is the expected result.

The Mg content of the petioles for the sulfate of potash-magnesia treatment (number 11) were not significantly different from those for the other five Mg sources or treatment 12, the check for the sulfate of potash-magnesia treatment (see Table 3A in the Appendix).

Houghton County

The response to Mg fertilization in yield and Mg content of the petioles was greater in this county than at the other two locations. This is evident when the yields for the zero and ten pounds per acre Mg rates are compared (see Figure 10). However, there were no consistent trends in yield for the five Mg sources. Apparently, for those treatments above ten pounds of Mg per acre, there were other factors limiting growth.

The differences in Mg content of the petioles due to treatment were statistically significant and greater than the differences at the other two locations (see Table 8 and Table 4A in the Appendix). The Mg content of the petioles indicated that the two P sources had no significant effect on the average availability (see Table 8) or the order of availability of the Mg sources (see Figure 11). But it should be noted that calcined magnesite when applied with DAP resulted in a lower Mg content than when applied with

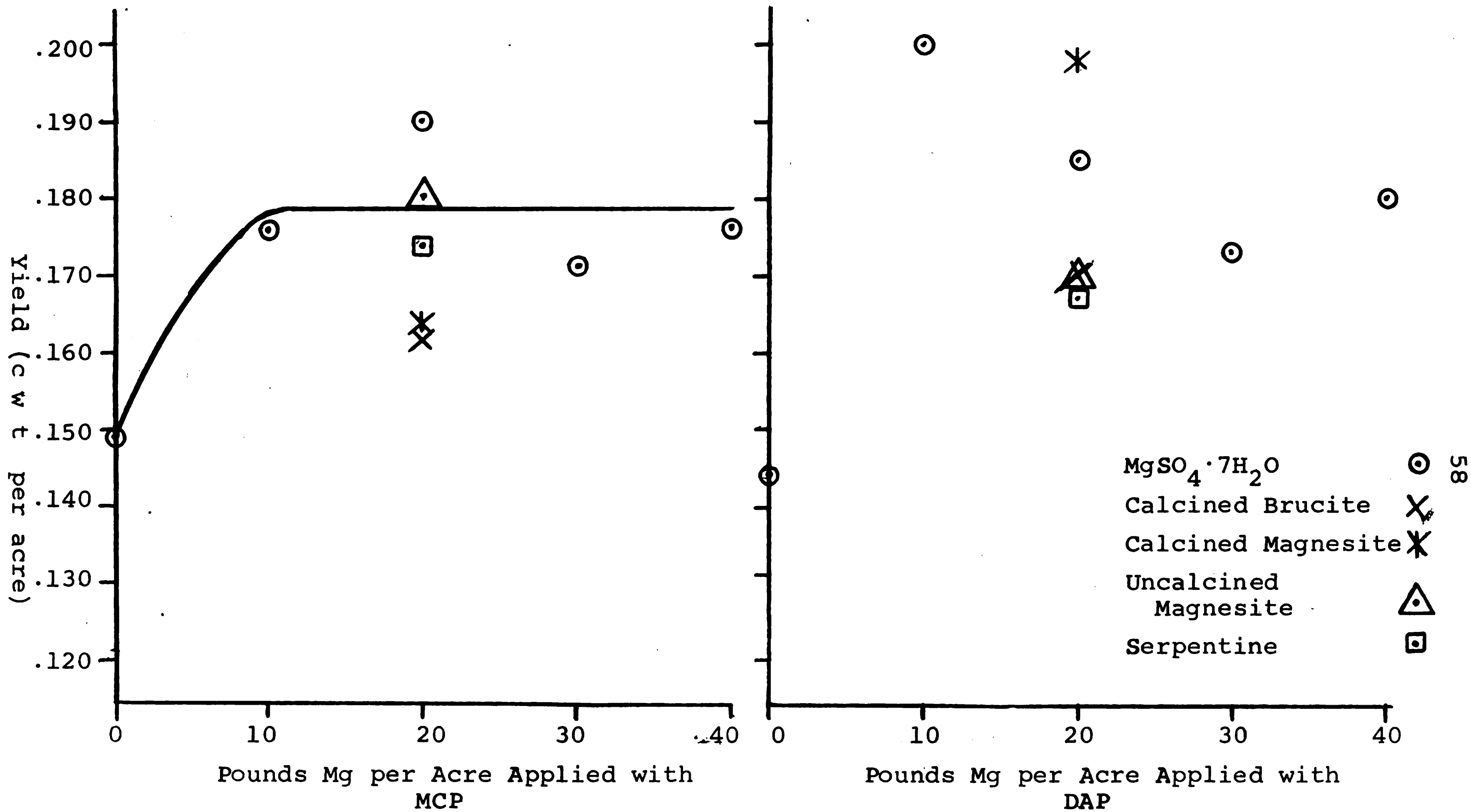

Figure 10. Yield of potato tubers as a function of rate and carrier of Mg and carrier of P--Houghton County.

Table 8. Results for analyses of variance of data from the field experiment in Houghton County. This includes sets of data that are in graph form.[1]

Source of Variance		Yield of Potatoes	Mg Content of Petioles[2]
Treatment	Level of Significance	> .10	.01
	H.S.D. at .05 Level of Significance	---	.041[3]
	H.S.D. at .01 Level of Significance	---	.049[3]
P Source	Level of Significance	> .10	> .10
Mg Source	Level of Significance	> .10	.01
Interaction of Mg and P Sources	Level of Significance	> .10	.05

[1]Analyses of variance were conducted for data from those treatments which included all of the Mg sources, except sulfate of potash-magnesia, at a Mg rate of 20 lbs./acre. These treatments were 1-4, 14, 6-9, and 18.

[2]Sampling made August 8, 1965, 10 weeks after planting.

[3]Percent.

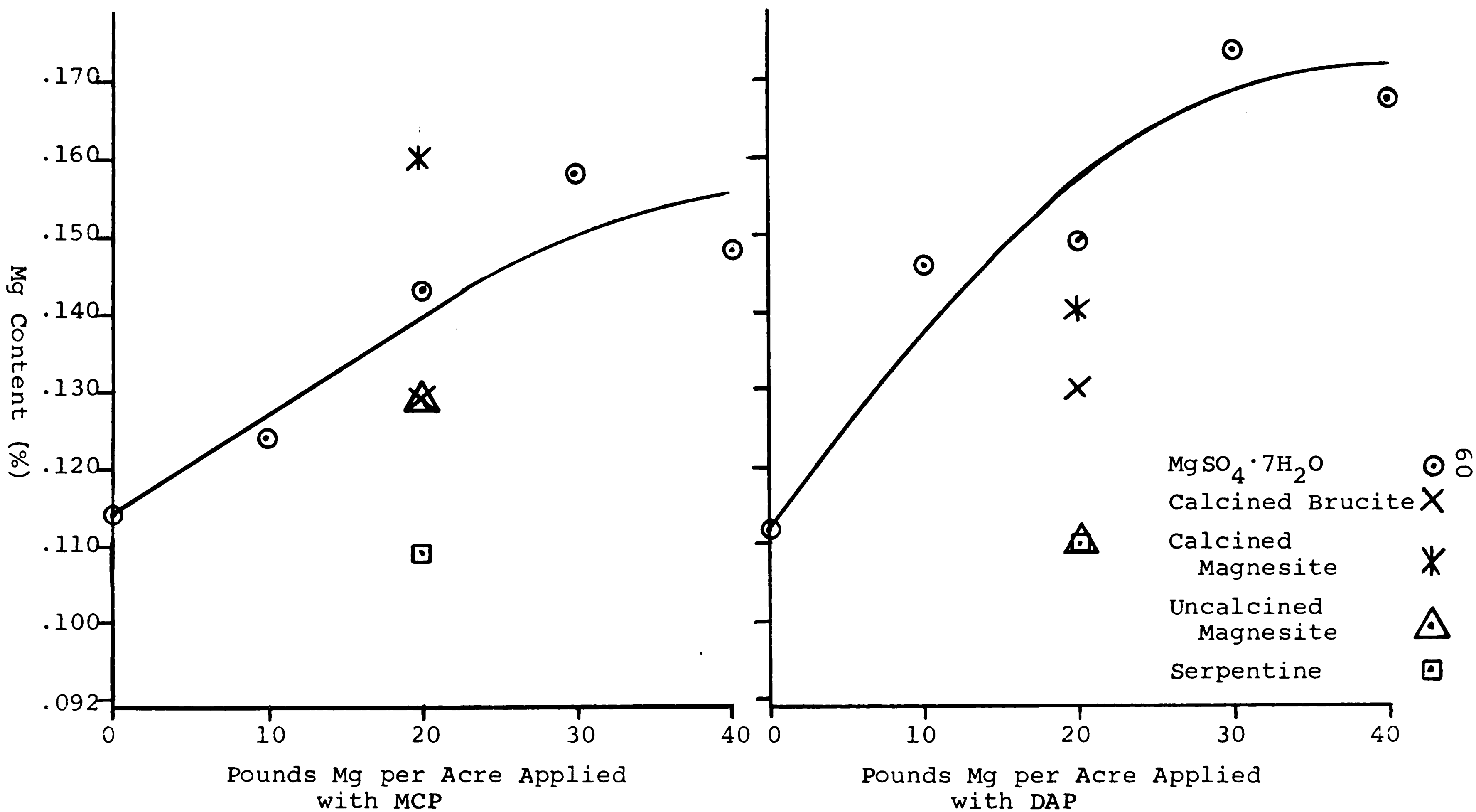

Figure 11. Mg content of potato perioles, August 8, 1965 (10 weeks after planting) as a function of rate and carrier of Mg and carrier of P--Houghton County.

MCP. There was no difference for calcined brucite between the two P sources.

The Mg content of the petioles for the sulfate of potash-magnesia treatment was as high or higher than for any other Mg carrier (see Table 4A in the Appendix).

Montcalm County

At this location there were no significant differences or trends in yield (see Table 5A in the Appendix), nor was the Mg content of the petioles closely related to the yield. For the second petiole sampling there were no significant differences due to the Mg sources or the P sources (see Table 9). However, according to the statistical analyses in Table 9, the variation in the Mg content of the petioles from the first sampling was due primarily to variation in the availability of the various Mg sources. The trends in Mg content for the first petiole sampling were not as evident as for the other two locations (see Figure 12). It can be seen, however, that when applied with MCP, calcined magnesite supplied more Mg than the other Mg carriers. But the availability of calcined magnesite was lower when it was applied with DAP. The P sources had no apparent effect on the availability of calcined brucite. Uncalcined magnesite supplied the smallest amounts of Mg.

The sulfate of potash-magnesia treatment resulted in the highest Mg content of the petioles from the first sampling (see Table 5A in the Appendix).

Table 9. Results for analyses of variance of data from the field experiment in Montcalm County. This includes sets of data that are in graph form.[1]

Source of Variance		Mg Content of Petioles		Mg Content of Vines
		First Sampling[2]	Second Sampling[3]	
Treatment	Level of Significance	.01	$>$ .10	.10
	H.S.D. at .05 Level of Significance	.040[4]	---	---
	H.S.D. at .01 Level of Significance	.044	---	---
P Source	Level of Significance	$>$ .10	$>$ .10	$>$ .10
Mg Source	Level of Significance	.01	$>$ .10	$>$ .10
Interaction of Mg and P Sources	Level of Significance	.05	$>$ .10	$>$ .10

[1]Analyses of variance were conducted for data from those treatments which included all the Mg sources, except sulfate of magnesia, at a Mg rate of 20 pounds/acre. These treatments were 1-4, 14, 6-9, and 18.

[2]First sampling made July 21, 1965, 9½ weeks after planting.

[3]Second sampling made on August 26, 1965, 15 weeks after planting.

[4]Percent.

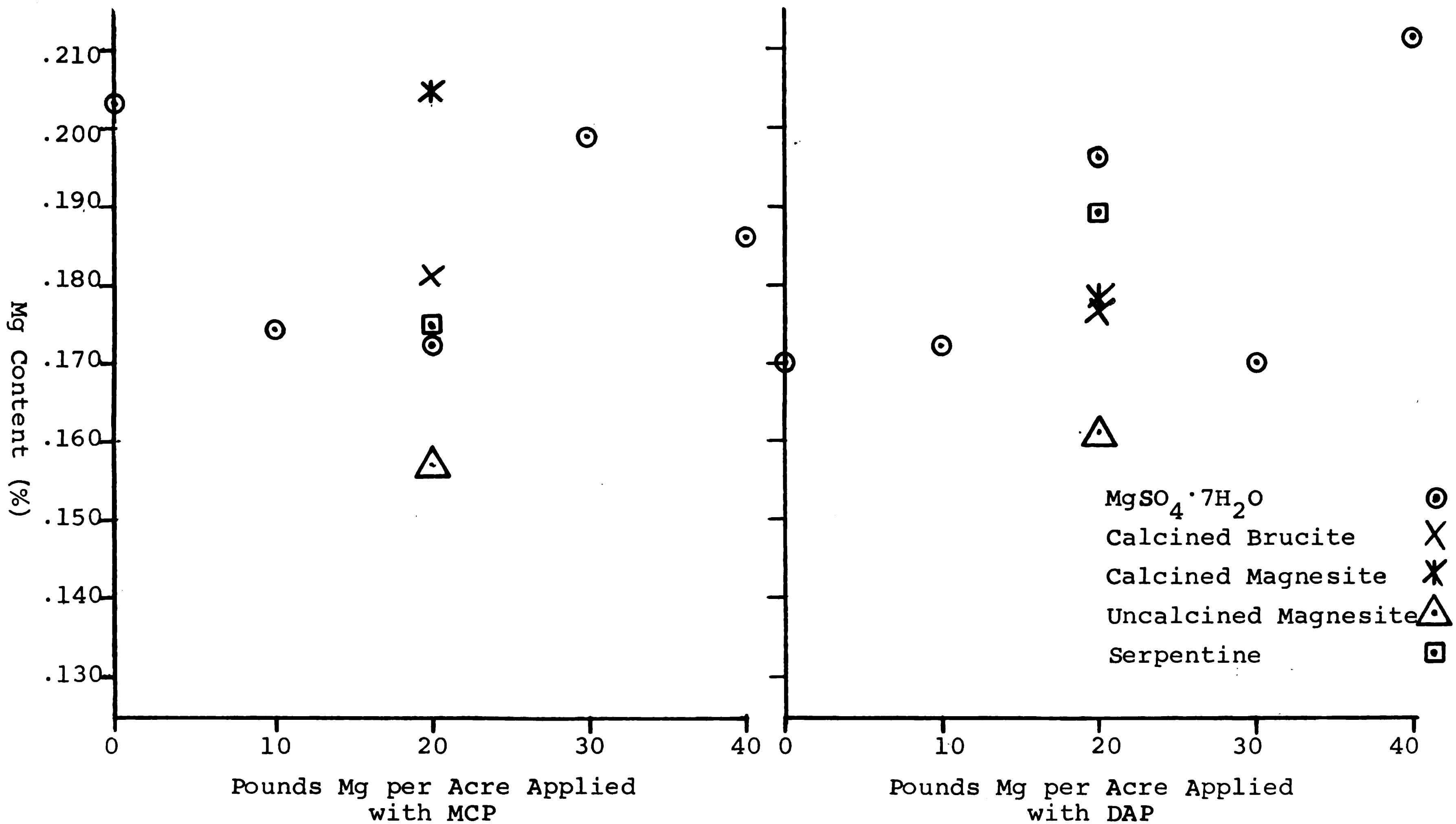

Figure 12. Mg content of potato petioles, July 5, 1965 (9½ weeks after planting) as a function of rate and carrier of Mg and carrier of P--Montcalm County.

As mentioned earlier, there were no significant treatment differences in dry weight vine yields or Mg uptake by the vines in Montcalm County (see Table 6A in the Appendix). The differences in Mg content of the vines were significant only at the 10 percent level (see Table 6A in the Appendix). The Mg content of the vines indicated that both calcined magnesite and calcined brucite were considerably more available when applied with MCP than when applied with DAP (see Figure 13). This is not consistent with the greenhouse data, but is the expected result.

There were no significant treatment differences in specific gravity of potato tubers for any of the field locations. But, in Houghton County the specific gravity readings were substantially higher than the other two locations. The average specific gravity in Houghton County was 1.077, whereas the average reading was 1.058 for Otsego and Montcalm Counties (see Tables 3A, 4A, and 5A in the Appendix).

Comparison of the Mg, Ca and K Contents of the Oat and Potato Plants

The average Mg contents of the greenhouse oats and potato vines in Montcalm County were .11 percent and .32 percent respectively. These values are somewhat lower than those obtained by Tobin and Lawton (110) who on a sandy soil in Michigan found that oats and barley had an average Mg content of .16 percent, whereas the average Mg content of potato vines was found to be .40 percent. Since the soil in Tobin

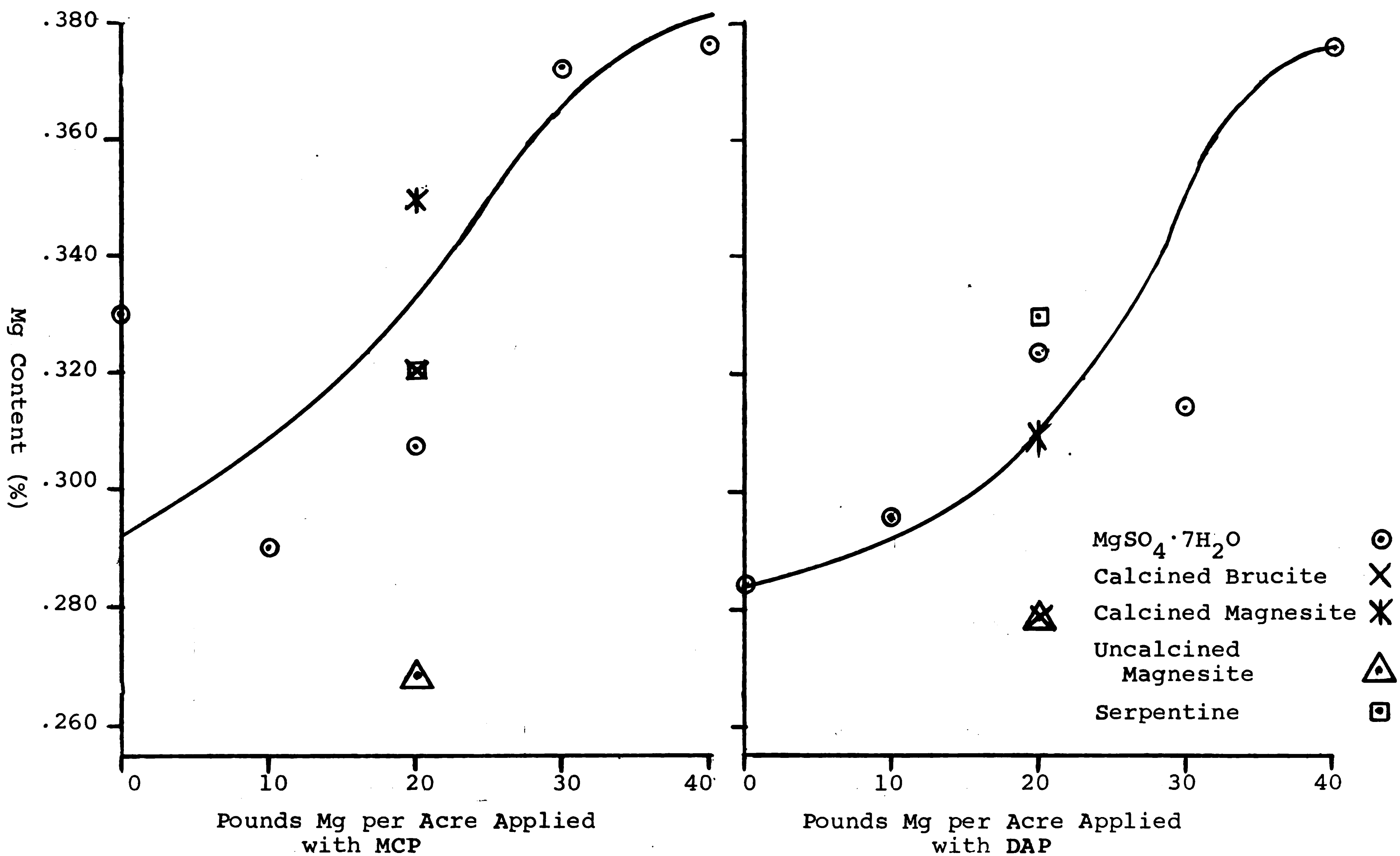

Figure 13. Mg content of potato vines as a function of rate and carrier of Mg and carrier of P--Montcalm County.

and Lawton's investigation was not deficient in Mg, it is easy to understand why the Mg contents in the experiment were higher.

It has been found that there are often reciprocal relationships between the contents of Mg, Ca, and K. Using the data for the first crop of oats in the greenhouse, simple correlations were calculated for all possible pairs of dry weight yield, and content and uptake of Mg, Ca, and K. For the data at all three field locations, all possible correlations between potato yield, and content of Mg, Ca, and K in the petioles were calculated. In Montcalm County, simple correlations were calculated for all possible pairs of dry weight vine yields, and content of Mg, Ca, and K in the potato vines. The results for these calculations appear in Table 10 and Tables 7A, 8A, 10A, 12A and 14A in the Appendix.

Only in the greenhouse under more controlled conditions were there definite reciprocal relationships between percent content of Mg, Ca, and K (see Table 10). There were statistically significant negative correlations between the Mg and Ca contents and Mg and K contents. However, there was a positive correlation between the Ca and K contents. In addition, it should be noted that dry weight yield was positively correlated with Mg content but negatively correlated with the Ca and K contents. Since the supply of Mg was limiting to growth, decreases in Mg supply resulted in

Table 10. Simple correlation analysis,[1] dry weight yield and nutrient content of first crop of oats in the greenhouse.

	Dry Weight Yield of Oat Plants		Mg Content		Uptake of Mg		Ca Content		Uptake of Ca		K Content		Uptake of K	
	r[2]	P[3]	r	P	r	P	r	P	r	P	r	P	r	P
Dry Weight Yield	1.000	--		--										
Mg Content	.315	.01	1.000	.01										
Uptake Mg	.682	.01	.895	.01	1.000	--								
Ca Content	-.697	.01	-.364	.01	-.612	.01	1.000	--						
Uptake Ca	-.073	>.10	-.125	>.10	-.180	.05	.644	.01	1.000	--				
K Content	-.647	.01	-.338	.01	-.576	.01	.652	.01	.369	.01	1.000	--		
Uptake K	.700	.01	.076	>.10	.337	.01	-.301	.01	.241	.01	--	--	1.000	--

[1]Degree of freedom = 120-2 = 118.

[2]r = correlation coefficient.

[3]P = level of significance of correlation coefficient (r).

decreased yields. Because of the reciprocal relationships between Mg and Ca contents and Mg and K contents, the Ca and K contents were higher when the supply of Mg was lower. This probably explains the negative correlations between yield and Ca and K contents.

Simple Correlations Between Potato Yield or Mg Content and Available Soil Nutrient Levels

Simple correlations between potato yield or Mg content and available soil P, K, Ca and Mg were calculated to aid in determining which nutrients were limiting growth and the degree to which variation in available soil nutrient levels resulted in non-treatment variation. However, few conclusions could be drawn from these correlations. The results to these calculations are presented in Tables 9A, 11A, 13A and 15A in the Appendix. In general, there were no significant positive correlations between potato yield and available soil P, K, Ca or Mg. In Otsego County, since there was a response to P fertilization, it is reasonable to assume that the supply of P was limiting to growth. However, there was not a significant positive correlation between potato yield and available soil P (see Table iA in the Appendix). In Montcalm County, where the response to Mg fertilization was the smallest, there were significant positive correlations between Mg content of petioles or vines and available soil Mg (see Tables 13A and 15A). In this county, variation in available Mg may have contributed to non-treatment variation in Mg content. But, since there were no significant positive correlations between yield and available soil Mg, factors other than the supply of soil Mg probably were more limiting to potato and vine yields.

Multiple Correlations Between Yield or Plant Mg Content and Plant and Soil Nutrient Content

Multiple correlations were calculated for potato yield as a function of Mg, Ca, and K content of potato petioles and plants and amounts of available soil P, K, Ca and Mg. They were also calculated for Mg content of petioles or plants as a function of Ca, K content of potato petioles and plants and the amounts of available soil P, K, Ca and Mg. As for the simple correlation analyses, these calculations were made primarily to aid in determining which nutrients were limiting yield and the degree to which variation in available soil nutrient levels contributed to non-treatment variation of yield and plant Mg content. However, no conclusions could be drawn from the results to the calculations.

General Discussion and Summary

In both the greenhouse and the field, there were responses to Mg fertilization. Yield, Mg content, and Mg uptake data for oats in the greenhouse and potatoes in the field showed that the order of availability of the Mg sources when applied with MCP was: Calcined magnesite $\cong$ (calcined brucite) $>$ or $\cong$ $MgSO_4 \cdot 7H_2O$ $>$ uncalcined magnesite $\cong$ serpentine, and when applied with DAP the order was: $MgSO_4 \cdot 7H_2O$ $>$ $\cong$ calcined magnesite $\cong$ calcined brucite $>$ uncalcined magnesite $\cong$ serpentine. The availability of Mg from sulfate of potash-magnesia (Sul-Po-Mag) was about equal to that for $MgSO_4 \cdot 7H_2O$.

Greater responses were obtained in the greenhouse than the field because the soil used in the greenhouse contained a lower level of available Mg initially and there was less environmental variability. At one location in the field, the responses to Mg fertilization were small because the supply of available P was more limiting than the supply of available Mg.

Field results were quite variable due to soil differences, lower than average rainfall, and insect damage in one county. However, simple and multiple correlation analyses, including soil test results for P, K, Ca and Mg on individual plots did not explain much of this variation.

Calcined magnesite was more effective when applied with MCP as compared to DAP. Since both the calcined magnesite and calcined brucite contained largely MgO, it was thought that they would release more Mg in the acidic solution around dissolving MCP than in the more basic solution around dissolving DAP. However, in the greenhouse, the yield and Mg content were lower for the calcined brucite with MCP treatment than for the calcined brucite with DAP treatment. In the field, these values were approximately equal for the two treatments. The chemical analyses of the treatment fertilizers indicated that there may have been more segregation of calcined brucite when it was coated on MCP than when it was coated on DAP. This may explain why the yield and Mg content were lower than expected when calcined brucite was applied with MCP. The P sources had no effect on the availability of Mg from $MgSO_4 \cdot 7H_2O$, uncalcined magnesite, and serpentine.

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APPENDIX

APPENDIX

Descriptions of the Soil Series at the Three Field Locations

I. Karlin Series:

The Karlin soils are well-drained Podzols which have developed in loamy fine sand to fine sandy loam, 15 to 42 inches thick, overlying sand. Below 36 inches, weak, thin textural B horizons are often present.

Karlin fine sandy loam

Horizon	Depth (inches)	Description
Ap	0-8	FINE SANDY LOAM; very dark grayish brown (10YR3/2); very weak, fine granular structure; very friable; moderate in organic matter; slightly to medium acid; abrupt smooth boundary. 6 to 11 inches thick.
A2	8-9	SANDY LOAM; pinkish gray (7.5YR6/2-7/2); very weak, coarse, granular structure; very friable; medium to strongly acid; abrupt wavy boundary. 1 to 3 inches thick.
B2ir	9-23	COARSE, SANDY LOAM; dark brown (10YR4/3-7,5YR4/4); very weak, medium subangular blocky structure; very friable; medium to strongly acid; gradual wavy boundary. 9 to 20 inches thick.
11B2	23-30	SAND; yellowish brown (10YR5/4-5/6); single grain structure; loose; medium acid; gradual wavy boundary. 8 to 15 inches thick.
11B3	30+	SAND; light yellowish brown (10YR6/4); single grain structure; loose; medium to slightly acid.

2. Munising Series:

The munising soils are moderately well to well-drained Podzols with fragipans, which have developed in strongly acid, reddish sandy loam glacial till derived from red sandstone. The parent material is more acid than either that for the Karlin or Mancelona series.

Munising sandy loam

Horizon	Depth (inches)	Description
Ap	0-5	SANDY LOAM; dark brown (7.5YR4/2) to dark reddish brown (5YR3/3); weak, fine to medium, granular structure; friable; strongly acid; abrupt smooth boundary. 4 to 10 inches thick.
A2	5-6	FINE SANDY LOAM; reddish gray (5YR5/2) to pinkish gray (5YR6/2); weak, thin platy structure breaking down into very weak, fine, granular structure; very friable, strongly to very strongly acid; abrupt wavy boundary. 0 to 5 inches thick.
B2hir	6-10	SANDY LOAM; dark reddish brown (5YR3/3-3/2); weak, fine to coarse, subangular blocky structure; friable; strongly to very strongly acid; gradual wavy boundary. 3 to 5 inches thick.
B2ir	10-16	SANDY LOAM; reddish brown (5YR4/3-4/4); weak, medium to coarse, subangular blocky structure; friable; strongly to very strongly acid. 4 to 9 inches thick.
A2x	16-25	SANDY LOAM; reddish brown (5YR5/3) to light reddish brown (5YR6/3) grading downward to reddish brown (5YR4/4-5/4) in lower part; weak, thick, platy to weak, coarse, subangular blocky structure; vesicular; hard; brittle; strongly cemented when dry and firm when moist; strongly acid; gradual wavy boundary. 6 to 11 inches thick.

B2t	25-40	**SANDY CLAY LOAM**; reddish brown (2.5YR4/4-5/4) with some streaks and coatings of pale red (2.5YR6/2-6/3) on ped surfaces in the upper part; moderate, medium to coarse, subangular blocky structure; firm; strongly to very strongly acid; clear wavy boundary. 10 to 20 inches thick.
C1	40+	**SANDY LOAM**; reddish brown (2.5YR4/4), red (2.5YR4/6) to light reddish brown (2.5YR6/4); some whitish loamy sand and sand lenses; weak coarse, subangular blocky to massive structure; friable; strongly acid.

3. Mancelona Series:

The Mancelona soils are well to moderately well drained Podzols which have developed in either stratified gravelly and sand outwash or in unsaturated gravelly sand or loamy sand. They have a Podzol upper sequum and Gray Wooded lower sequum. The parent material of these soils is more calcareous than that for either of the other two series.

Mancelona loamy sand

Mancelona	Depth (inches)	Description
Ap	0-7	**LOAMY SAND**; very dark grayish brown (10YR3/2) or dark grayish brown (10YR 4/2); very weak, fine, granular structure; moderately high organic content; very friable when moist; slightly to medium acid; abrupt smooth boundary. 6 to 12 inches thick.
A2	7-10	**SAND OR LOAMY SAND**; gray (10YR6/1) or light brownish gray (10YR6/12); very weak fine, granular structure; very friable when moist; slightly to medium acid; clear wavy boundary. 0 to 6 inches thick.
B21hir	10-15	**LOAMY SAND OR SAND**; dark reddish brown (5YR3/4) or dark brown (7.5YR3/2-4/4); very weak, medium, subangular blocky structure; very friable when moist;

		medium acid to neutral; clear wavy boundary. 4 to 12 inches thick.
A′2	15-33	**SAND OR LOAMY SAND**; yellowish brown (10YR5/6), pale brown (10YR6/3), or brown (10YR5/3); very weak, fine, subangular blocky to single grain structure; very friable when moist; medium acid to neutral; clear wavy boundary. 6 to 9 inches thick.
B′2t	33-36	**SANDY LOAM OR SANDY CLAY LOAM**; brown (7.5YR5/4) or dark brown (7.5YR3/2-4/4); weak, medium, subangular blocky structure; friable when moist; neutral to slightly acid; abrupt irregular boundary. 2 to 8 inches thick.
IICl	36	**SAND AND GRAVEL**; light yellowish brown (10YR6/4) or light gray (10YR7/2); loose; calcareous.

Table 1A. Data from the greenhouse experiment; first crop of oats.

Number	Treatments: Fertilizer Description[1]	Rate of Mg	Oven Dry Weight Yield	Mg Content	Uptake Mg	Ca Content	Uptake Ca	K Content	Uptake K
		lbs./A.	g./pot	%	m.e./pot	%	m.e./pot	%	m.e./pot
1	Calcined Brucite with MCP	20	14.29	.103	1.21	.382	1.35	4.94	18.0
2	Calcined Magnesite with MCP	20	16.15	.129	1.71	.310	1.25	4.56	18.8
3	Uncalcined Magnesite with MCP	20	13.14	.102	1.15	.369	1.30	4.97	16.8
4	Serpentine with MCP	20	13.23	.106	1.16	.331	1.34	4.95	17.0
5	MCP	0	12.49	.096	1.01	.408	1.27	5.26	16.8
6	Calcined Brucite with DAP	20	15.20	.121	1.52	.371	1.40	4.71	18.3
7	Calcined Magnesite with DAP	20	14.47	.124	1.46	.367	1.30	4.88	18.1
8	Uncalcined Magnesite with DAP	20	13.84	.099	1.12	.406	1.40	5.10	18.0
9	Serpentine with DAP	20	13.83	.100	1.18	.381	1.32	4.67	16.5

10	**DAP**	0	12.61	.097	1.00	.438	1.37	5.10	16.4
11	Sulfate of potash-magnesia with **DAP**	20	15.82	.146	1.89	.302	1.19	4.54	18.3
12	K_2SO_4 with **DAP**	0	14.37	.109	1.12	.370	1.32	5.01	18.4
13	**MCP** and $MgSO_4 \cdot 7H_2O$	10	14.41	.110	1.31	.372	1.34	4.70	17.4
14	**MCP** and $MgSO_4 \cdot 7H_2O$	20	15.45	.124	1.58	.347	1.36	4.69	18.5
15	**MCP** and $MgSO_4 \cdot 7H_2O$	30	15.52	.138	1.74	.307	1.22	4.44	17.5
16	**MCP** and $MgSO_4 \cdot 7H_2O$	40	16.75	.153	2.10	.317	1.31	4.36	18.6
17	**DAP** and $MgSO_4 \cdot 7H_2O$	10	14.33	.126	1.43	.362	1.35	4.74	17.3
18	**DAP** and $MgSO_4 \cdot 7H_2O$	20	15.05	.132	1.61	.373	1.38	4.51	17.8
19	**DAP** and $MgSO_4 \cdot 7H_2O$	30	14.92	.149	1.82	.338	1.24	4.52	17.2
20.	**DAP** and $MgSO_4 \cdot 7H_2O$	40	16.28	.150	2.01	.300	1.22	4.43	18.4
Level of Significance			.01	.01	.01	.01	.10	.01	.05
H.S.D. at .05 Level of Significance			2.12	.026	.20	.081	--	.6	2.4
H.S.D. at .01 Level of Significance			2.41	.030	.23	.092	--	.7	--

[1]MCP - Monocalcium phosphate; **DAP** - Diammonium phosphate and **MCP**; $MgSO_4 \cdot 7H_2O$ - Epsom salts.

Table 2A. Data from the greenhouse experiment; second crop of oats.

Number	Treatments Fertilizer Description[1]	Rate of Mg	Oven Dry Weight Yield	Mg Content	Uptake Mg	Ca Content	Uptake Ca	K Content	Uptake K
		lbs./A.	g./pot	%	m.e./pot	%	m.e./pot	%	m.e./pot
1	Calcined Brucite with MCP	20	6.55	.091	.488	.356	1.17	3.38	5.68
2	Calcined Magnesite with MCP	20	7.80	.114	.717	.344	1.32	3.52	7.00
3	Uncalcined Magnesite with MCP	20	7.36	.089	.536	.350	1.27	3.49	6.51
4	Serpentine with MCP	20	6.77	.100	.554	.396	1.33	3.60	6.22
5	MCP	0	7.12	.082	.484	.372	1.33	3.42	6.22
6	Calcined Brucite with DAP	20	7.68	.108	.685	.371	1.43	3.45	6.78
7	Calcined Magnesite with DAP	20	7.76	.105	.637	.329	1.14	3.40	6.82
8	Uncalcined Magnesite with DAP	20	7.37	.094	.570	.366	1.34	3.49	6.56
9	Serpentine with DAP	20	6.85	.097	.547	.369	1.26	3.72	6.52

10	DAP	0	6.93	.083	.478	.355	1.25	3.57	6.22
11	Sulfate of potash-magnesia with DAP	20	7.20	.127	.752	.337	1.20	3.51	6.44
12	K_2SO_4 with DAP	0	7.40	.088	.534	.335	1.23	3.49	6.60
13	MCP and $MgSO_4 \cdot 7H_2O$	10	7.26	.101	.616	.353	1.31	3.39	6.46
14	MCP and $MgSO_4 \cdot 7H_2O$	20	6.79	.110	.616	.365	1.24	3.32	5.74
15	MCP and $MgSO_4 \cdot 7H_2O$	30	7.28	.128	.766	.392	1.42	3.40	6.34
16	MCP and $MgSO_4 \cdot 7H_2O$	40	7.00	.134	.772	.360	1.26	3.48	6.22
17	DAP and $MgSO_4 \cdot 7H_2O$	10	7.17	.089	.524	.342	1.21	3.37	6.17
18	DAP and $MgSO_4 \cdot 7H_2O$	20	6.18	.116	.587	.392	1.21	3.55	5.61
19	DAP and $MgSO_4 \cdot 7H_2O$	30	6.74	.127	.701	.377	1.26	3.42	5.90
20.	DAP and $MgSO_4 \cdot 7H_2O$	40	6.78	.141	.777	.373	1.25	3.35	5.46
Level of Significance			.01	.01	.01	>.10	>.10	>.10	.10
H.S.D. at .05 Level of Significance			1.40	.020	.160	--	--	--	1.4
H.S.D. at .01 Level of Significance			1.59	.023	.180	--	--	--	1.6

[1]MCP - Monocalcium phosphate; DAP - Daimmonium phosphate and MCP; $MgSO_4 \cdot 7H_2O$ - Epsom salts.

Table 3A. Data for potatoes in the field; Otsego County.

Treatments		Rate of Mg	Yield of Tubers	Specific Gravity of Tubers	Mg Content of Petioles		Ca Content of Petioles		K Content of Petioles	
Number	Fertilizer Description[1]				First Sampling[2]	Second Sampling[3]	First Sampling[2]	Second Sampling[3]	First Sampling[2]	Second Sampling[3]
		lbs./A.	c.w.t/A.		------%	------	-----%	-------	------%	------
1	Calcined Brucite with MCP	20	216	1.059	.136	.165	.972	.862	13.3	12.5
2	Calcined Magnesite with MCP	20	230	1.062	.141	.167	.891	.804	13.5	12.5
3	Uncalcined Magnesite with MCP	20	216	1.057	.136	.135	.860	.900	13.7	11.9
4	Serpentine with MCP	20	192	1.060	.134	.147	.895	.784	14.0	11.5
5	MCP	0	200	1.059	.117	.127	.868	.821	14.4	12.7
6	Calcined Brucite with DAP	20	251	1.058	.134	.157	.829	.805	14.9	12.1
7	Calcined Brucite with DAP	20	223	1.057	.130	.121	.859	.645	14.4	12.4
8	Uncalcined Magnesite with DAP	20	230	1.058	.121	.144	.859	.766	14.0	13.0
9	Serpentine with DAP	20	222	1.057	.128	.141	.793	.757	14.3	11.7

10	DAP	0	233	1.057	.128	.146	.916	.804	13.8	11.7
11	Sulfate of potash-magnesia with DAP	20	222	1.059	.130	.148	.882	.751	13.0	11.9
12	K_2SO_4 with DAP	0	212	1.057	.127	.142	.824	.822	13.8	11.6
13	MCP and $MgSO_4 \cdot 7H_2O$	10	205	1.059	.140	.148	.847	.879	13.4	11.3
14	MCP and $MgSO_4 \cdot 7H_2O$	20	198	1.059	.145	.148	.959	.765	13.9	11.2
15	MCP and $MgSO_4 \cdot 7H_2O$	30	190	1.058	.148	.170	.946	.766	13.4	11.7
16	MCP and $MgSO_4 \cdot 7H_2O$	40	212	1.057	.145	.169	.784	.740	13.3	12.7
17	DAP and $MgSO_4 \cdot 7H_2O$	10	239	1.058	.132	.148	.875	.907	14.3	11.8
18	DAP and $MgSO_4 \cdot 7H_2O$	20	234	1.057	.125	.164	.861	.790	13.6	12.4
19	DAP and $MgSO_4 \cdot 7H_2O$	30	240	1.057	.145	.160	.869	.726	14.3	12.2
20	DAP and $MgSO_4 \cdot 7H_2O$	40	231	1.058	.144	.163	.810	.730	13.3	12.1
Level of Significance			.10	---	>.10	.05	>.10	>.10	>.10	>.10
H.S.D. at .05 Level of Significance			---	---	---	.053	---	---	---	---
H.S.D. at .01 Level of Significance			---	---	---	---	---	---	---	---

[1]MCP - Monocalcium phosphate; DAP - Diammonium phosphate and MCP; $MgSO_4 \cdot 7H_2O$ - Epsom salts.

[2]First Sampling made on July 22, 1965, 9 weeks after planting.

[3]Second sampling made on August 16, 1965, 12 weeks after planting.

Table 4A. Data for potatoes in the field; Houghton County.

Number	Treatments Fertilizer Description[1]	Rate of Mg	Yield of Tubers	Specific Gravity of Tubers	Mg[2] Content of Petioles	Ca[2] Content of Petioles	K[2] Content of Petioles
		lbs./A.	c.w.t./A.		---%----	---%----	---%----
1	Calcined Brucite with MCP	20	162	1.076	.129	.836	10.3
2	Calcined Magnesite with MCP	20	164	1.078	.160	.744	10.1
3	Uncalcined Magnesite with MCP	20	180	1.079	.129	.982	9.9
4	Serpentine with MCP	20	174	1.077	.109	.855	9.8
5	MCP	0	149	1.078	.114	.976	10.1
6	Calcined Brucite with DAP	20	170	1.077	.130	.798	9.9
7	Calcined Magnesite with DAP	20	198	1.076	.140	.894	9.8
8	Uncalcined Magnesite with DAP	20	170	1.077	.110	.811	9.9
9	Serpentine with DAP	20	167	1.077	.110	.811	9.9

10	**DAP**	0	144	1.076	.113	.818	9.8
11	Sulfate of potash-magnesia with **DAP**	20	186	1.078	.148	.786	10.0
12	K_2SO_4 with **DAP**	0	186	1.077	.109	.932	9.8
13	**MCP** and $MgSO_4 \cdot 7H_2O$	10	176	1.077	.124	.768	10.2
14	**MCP** and $MgSO_4 \cdot 7H_2O$	20	190	1.078	.143	.802	10.3
15	**MCP** and $MgSO_4 \cdot 7H_2O$	30	171	1.076	.158	.799	9.6
16	**MCP** and $MgSO_4 \cdot 7H_2O$	40	176	1.075	.148	.815	10.2
17	**DAP** and $MgSO_4 \cdot 7H_2O$	10	200	1.076	.146	.893	10.4
18	**DAP** and $MgSO_4 \cdot 7H_2O$	20	180	1.075	.149	.878	10.1
19	**DAP** and $MgSO_4 \cdot 7H_2O$	30	173	1.076	.174	.785	10.0
20	**DAP** and $MgSO_4 \cdot 7H_2O$	40	180	1.077	.167	.825	10.2
Level of Significance			$>.10$	--	.01	.05	$>.10$
H.S.D. at .05 Level of Significance			--	--	.037	.244	--
H.S.D. at .01 Level of Significance			--	--	.042	--	--

[1]**MCP** - Monocalcium phosphate; **DAP** - Diammonium phosphate and **MCP**; $MgSO_4 \cdot 7H_2O$ - Epsom salts.

[2]Sampling made August 8, 1965, 10 weeks after planting.

Table 5A. Data for potatoes in the field; Montcalm County.

Number	Treatment: Fertilizer Description[1]	Rate of Mg	Yield of Tubers	Specific Gravity of Tubers	Mg Content of Petioles: First Sampling[2]	Mg Content of Petioles: Second Sampling[3]	Ca Content of Petioles: First Sampling[2]	Ca Content of Petioles: Second Sampling[3]	K Content of Petioles: First Sampling[2]	K Content of Petioles: Second Sampling[3]
		lbs./A.	c.w.t/A.		%	%	%	%	%	%
1	Calcined Brucite with MCP	20	264	1.056	.181	.168	.481	.549	12.0	11.6
2	Calcined Magnesite with MCP	20	273	1.058	.205	.159	.499	.542	11.0	11.8
3	Uncalcined Magnesite with MCP	20	260	1.057	.157	.156	.464	.598	11.1	11.5
4	Serpentine with MCP	20	272	1.059	.175	.178	.555	.586	12.3	11.5
5	MCP	0	271	1.058	.203	.182	.556	.582	12.3	11.5
6	Calcined Brucite with DAP	20	274	1.058	.177	.178	.552	.675	13.3	11.5
7	Calcined Brucite with DAP	20	229	1.057	.178	.180	.512	.569	12.6	11.8
8	Uncalcined Magnesite with DAP	20	273	1.058	.161	.160	.514	.583	11.5	11.8
9	Serpentine with DAP	20	281	1.057	.189	.206	.529	.616	12.4	10.9

10	DAP	0	279	1.058	.170	.175	.493	.577	12.7	13.2
11	Sulfate of potash-magnesia with DAP	20	259	1.057	.218	.168	.625	.570	12.4	10.8
12	K_2SO_4 with DAP	0	282	1.058	.156	.169	.515	.589	12.4	11.4
13	MCP and $MgSO_4 \cdot 7H_2O$	10	272	1.058	.174	.194	.495	.650	12.4	11.3
14	MCP and $MgSO_4 \cdot 7H_2O$	20	275	1.058	.172	.164	.484	.565	11.7	11.4
15	MCP and $MgSO_4 \cdot 7H_2O$	30	275	1.059	.199	.195	.472	.549	12.2	12.0
16	MCP and $MgSO_4 \cdot 7H_2O$	40	255	1.059	.186	.178	.468	.579	12.2	12.0
17	DAP and $MgSO_4 \cdot 7H_2O$	10	250	1.057	.172	.180	.489	.536	12.8	11.9
18	DAP and $MgSO_4 \cdot 7H_2O$	20	248	1.057	.196	.168	.602	.584	12.8	11.4
19	DAP and $MgSO_4 \cdot 7H_2O$	30	265	1.059	.170	.189	.479	.558	12.4	11.0
20	DAP and $MgSO_4 \cdot 7H_2O$	40	241	1.059	.211	.211	.519	.566	12.4	11.1
Level of Significance			$>.10$	--	.10	$>.10$	.05	.05	$>.10$	.05
H.S.D. at .05 Level of Significance			--	--	--	--	.155	.122	--	1.9
H.S.D. at .01 Level of Significance			--	--	--	--	--	--	--	--

[1]MCP - Monocalcium phosphate; DAP - Daimmonium phosphate and MCP; $MgSO_4 \cdot 7H_2O$ - Epsom salts.

[2]First sampling made on July 21, 1965, 9½ weeks after planting.

[3]Second sampling made on August 26, 1965, 15 weeks after planting.

Table 6A. Data for potatoes in the field; Montcalm County, nutrient content of potato vines.

Number	Treatments: Fertilizer Description[1]	Rate of Mg	Oven Dry Weight Yield of Vines	Mg Content	Uptake Mg	Ca Content	Uptake Ca	K Content	Uptake K
		lbs/A.	lbs/A.	%	lbs/A.	%	lbs/A	%	lbs/A
1	Calcined Brucite with MCP	20	3690	.319	12.1	.742	28.0	6.37	236
2	Calcined Magnesite with MCP	20	3380	.349	11.7	.721	24.4	5.30	176
3	Uncalcined Magnesite with MCP	20	3000	.268	8.0	.690	20.6	4.80	145
4	Serpentine with MCP	20	3500	.321	11.3	.795	27.9	5.38	188
5	MCP	0	3040	.330	10.0	.824	24.6	4.95	150
6	Calcined Brucite with DAP	20	3100	.279	8.6	.736	23.3	5.16	163
7	Calcined Brucite with DAP	20	3990	.309	12.3	.705	27.8	4.99	198
8	Uncalcined Magnesite with DAP	20	3430	.278	9.7	.786	27.7	5.28	180
9	Serpentine with DAP	20	3230	.330	10.9	.865	28.7	5.42	174

10	DAP	0	3530	.286	9.9	.711	24.8	5.26	180
11	Sulfate of potash-magnesia with DAP	20	3550	.319	11.3	.700	24.9	5.29	188
12	K_2SO_4 with DAP	0	3060	.273	8.2	.757	22.9	5.89	183
13	MCP and $MgSO_4 \cdot 7H_2O$	10	3020	.290	8.6	.713	21.4	5.46	165
14	MCP and $MgSO_4 \cdot 7H_2O$	20	3330	.310	10.3	.693	23.8	5.17	172
15	MCP and $MgSO_4 \cdot 7H_2O$	30	2860	.370	10.6	.714	20.6	5.40	152
16	MCP and $MgSO_4 \cdot 7H_2O$	40	2870	.376	11.8	.776	24.4	5.63	176
17	DAP and $MgSO_4 \cdot 7H_2O$	10	3440	.295	10.1	.694	23.9	4.95	170
18	DAP and $MgSO_4 \cdot 7H_2O$	20	3370	.323	10.9	.714	24.1	4.80	168
19	DAP and $MgSO_4 \cdot 7H_2O$	30	3170	.314	9.9	.687	21.9	5.48	173
20	DAP and $MgSO_4 \cdot 7H_2O$	40	2710	.377	10.0	.719	19.0	5.44	147
Level of Significance			$>.10$	.05	$>.10$	$>.10$	$>.10$	$>.10$	$>.10$
H.S.D. at .05 Level of Significance			--	.121	--	--	--	--	--
H.S.D. at .01 Level of Significance			--	--	--	--	--	--	--

[1]MCP - Monocalcium phosphate; DAP - Diammonium phosphate and MCP; $MgSO_4 \cdot 7H_2O$ - Epsom salts.

Table 7A. Simple correlation analysis,[1] dry weight yield and nutrient content of second crop of oats in the greenhouse.

	Dry Weight Yield of Oat Plants		Mg Content		Uptake Mg		Ca Content		Uptake Ca		K Content		Total Uptake K	
	r[2]	P[3]	r	P	r	P	r	P	r	P	r	P	r	P
Dry Weight Yield	1.000	--												
Mg Content	-.077	>.10	1.000	--										
Uptake Mg	.055	>.10	-.041	>.10	1.000	--								
Ca Content	-.111	>.10	.116	>.10	.087	>.10	1.000	--						
Uptake Ca	.178	.10	-.159	.10	.152	.10	.084	>.10	1.000	--				
K Content	-.177	.10	.004	>.10	.075	>.10	.155	.10	-.081	>.10	1.000	--		
Uptake K	.226	.05	.140	>.10	-.110	>.10	.080	>.10	-.053	>.10	.033	>.10	1.000	

[1]Degrees of freedom = 120 - 2 = 118.

[2]r = correlation coefficient.

[3]P = level of significance of correlation coefficient (r).

Table 8A. Simple correlation analysis;[1] yield and nutrient content of potato petioles; Otsego County.

	Yield of Potatoes		Mg Content of Petioles				Ca Content of Petioles				K Content of Petioles			
			First Sampling		Second Sampling		First Sampling		Second Sampling		First Sampling		Second Sampling	
	r[2]	P[3]	r	P	r	P	r	P	r	P	r	P	r	P
Yield of Potatoes	1.000	--												
Mg Content of Petioles														
First Sampling	.114	>.10	1.000	--										
Second Sampling	.341	.01	.407	.01	1.000	--								
Ca Content of Petioles														
First Sampling	.158	>.10	.496	.01	.364	.01	1.000	--						
Second Sampling	.317	.01	.214	.10	.418	.01	.290	.02	1.000	--				
K Content of Petioles														
First Sampling	.167	>.10	-.106	>.10	.041	>.10	.009	>.10	.032	>.10	1.000	--		
Second Sampling	.084	>.10	-.107	>.10	.092	>.10	.026	>.10	-.155	>.10	-.102	>.10	1.000	--

[1] Degrees of freedom = 80 - 2 = 78.

[2] r = correlation coefficient.

[3] P = level of significance of correlation coefficient (r).

Table 9A. Simple correlation analysis;[1] yield, nutrient content of potato petiole and soil test results; Otsego County.

	Soil Test Results, First Sampling[4]								Soil Test Results, Second Sampling							
	P		K		Ca		Mg		P		K		Ca		Mg	
	r[2]	P[3]	r	P	r	P	r	P	r	P	r	P	r	P	r	P
Yield of Potatoes	.098	>.10	.038	>.10	-.137	>.10	.200	.10	.063	>.10	.132	>.10	.045	>.10	.065	>.10
Mg Content of Petioles																
First Sampling	.002	>.10	.265	.02	-.057	>.10	.128	>.10	-.148	>.10	-.030	>.10	.177	>.10	.196	.10
Second Sampling	.015	>.10	-.033	>.10	.121	>.10	.188	.10	.062	>.10	.225	.05	.143	>.10	.119	>.10
Ca Content of Petioles																
First Sampling	-.070	>.10	.219	.10	-.123	>.10	.228	.05	-.033	>.10	-.149	>.10	.032	>.10	.097	>.10
Second Sampling	-.175	>.10	-.057	>.10	-.118	>.10	.008	>.10	.178	>.10	.049	>.10	.080	>.10	.013	>.10
K Content of Petioles																
First Sampling	-.071	>.10	-.111	>.10	.080	>.10	.066	>.10	-.148	>.10	-.126	>.10	.077	>.10	.054	>.10
Second Sampling	.227	.05	-.086	>.10	-.040	>.10	.243	.05	-.014	>.10	-.037	>.10	0	>.10	.066	>.10

[1] Degrees of freedom = 80 - 2 = 78.

[2] r = correlation coefficient.

[3] P = level of significance of correlation coefficient (r).

[4] P was determined by Bray's P_1 method and K, Ca and Mg by the NH_4Ac method at the Michigan State University Soil Testing Laboratory. Acre=2,000,000 lbs. air dried soil.

Table 10A. Simple correlation analysis;[1] yield and nutrient content of potato petioles; Houghton County.

	Yield of		Mg Content		Ca Content		K Content	
	r[2]	P[3]	r	P	r	P	r	P
Yield of Potatoes	1.000	--						
Mg Content of Petioles	.210	.10	1.000	--				
Ca Content of Petioles	.185	>.10	-.133	>.10	1.000	--		
K Content of Perioles	.113	>.10	.065	>.10	-.130	>.10	1.000	--

[1]Degree of freedom = 80 - 2 = 78.

[2]r = correlation coefficient.

[3]P = level of significance of correlation coefficient (r).

Table 11A. Simple correlation analysis;[1] yield, nutrient content potato petioles and soil test results; Houghton County.

	Soil Test Results, First Sampling[4]								Soil Test Results, Second Sampling							
	P		K		Ca		Mg		P		K		Ca		Mg	
	r[2]	P[3]	r	P	r	P	r	P	r	P	r	P	r	P	r	P
Yield of Potaotes	-.078	>.10	-.184	>.10	.276	.02	.133	>.10	.030	>.10	-.091	>.10	.196	.10	.055	>.10
Mg Content of Petioles	.075	>.10	-.198	.10	.045	>.10	.157	>.10	.051	>.10	-.062	>.10	.358	.01	.286	.01
Ca Content of Petioles	-.014	>.10	.094	>.10	.233	.05	-.013	>.10	-.002	>.10	.079	>.10	.277	.02	-.064	>.10
K Content of Petioles	.226	.05	-.009	>.10	.006	>.10	.041	>.10	.113	>.10	-.038	>.10	.126	>.10	.059	>.10

[1] Degrees of freedom = 80 - 2 = 78.

[2] r = correlation coefficient.

[3] P = level of significance of correlation coefficient (r).

[4] P was determined by Bray's P_1 method and K, Ca and Mg by the NH_4Ac method at the Michigan State University Soil Testing Laboratory. Acre = 2,000,000 pounds air dried soil.

Table 12A. Simple correlations analysis;[1] yield and nutrient content of potato petioles; Montcalm County.

	Yield of Potatoes		Mg Content of Petioles				Ca Content of Petioles				K Content of Petioles			
			First Sampling		Second Sampling		First Sampling		Second Sampling		First Sampling		Second Sampling	
	r[2]	P[3]	r	P	r	P	r	P	r	P	r	P	r	P
Yield of Potatoes	1.000	--												
Mg Content of Petioles														
First Sampling	.0916	>.10	1.000	--										
Second Sampling	.031	>.10	.341	.01	1.000	--								
Ca Content of Petioles														
First Sampling	.079	>.10	.614	.01	.264	.02	1.000	--						
Second Sampling	-.342	.01	.014	>.10	.250	.05	.163	>.10	1.000	--				
K Content of Perioles														
First Sampling	-.298	.02	.033	>.10	.072	>.10	.055	>.10	-.020	>.10	1.000	--		
Second Sampling	-.091	>.10	-.237	.05	-.141	>.10	-.339	.01	-.213	.10	.199	.10	1.000	--

[1] Degree of freedom = 80 - 2 = 78.

[2] r = correlation coefficient.

[3] P = level of significance of correlation coefficient (r).

Table 13A. Simple correlation analysis;[1] yield, nutrient content of potato petiole and soil test results; Montcalm County.

	Soil Test Results, First Sampling[4]								Soil Test Results, Second Sampling							
	P		K		Ca		Mg		P		K		Ca		Mg	
	r[2]	P[3]	r	P	r	P	r	P	r	P	r	P	r	P	r	P
Yield of Potatoes	-.055	>.10	-.179	>.10	.130	>.10	.130	>.10	-.232	.05	-.051	>.10	.121	>.10	.168	>.10
Mg Content of Petioles																
First Sampling	-.326	.01	.037	>.10	.364	.01	.561	.01	.021	>.10	-.014	>.10	.064	>.10	.136	>.10
Second Sampling	-.237	.05	-.006	>.10	.147	>.10	.308	.01	.037	>.10	-.220	.05	-.007	>.10	.019	>.10
Ca Content of Petioles																
First Sampling	-.233	.05	.082	>.10	.115	>.10	.181	>.10	-.087	>.10	-.077	>.10	.243	.05	.176	>.10
Second Sampling	.058	>.10	-.113	>.10	-.060	>.10	.084	>.10	.070	>.10	-.117	>.10	-.013	>.10	.215	.10
K Content of Petioles																
First Sampling	.047	>.10	.149	>.10	-.019	>.10	-.084	>.10	.048	>.10	.121	>.10	-.108	>.10	-.136	>.10
Second Sampling	.235	.05	.136	>.10	.012	>.10	.023	>.10	.169	>.10	.183	>.10	-.254	.05	-.197	.10

[1]Degree of freedom = 80 - 2 = 78.

[2]r = correlation coefficient.

[3]P = level of significance of correlation coefficient (r).

[4]P was determined by Bray's P_1 method and K, Ca and Mg by the NH_4Ac method at the Michigan State University Soil Testing Laboratory. Acre = 2,000,000 lbs. air dried soil.

Table 14A. Simple correlation analysis;[1] dry weight yield and nutrient content of potato vines; Montcalm County.

	Dry Weight Yield of Potato Vine		Mg Content		Uptake Mg		Ca Content		Uptake Ca		K Content		Uptake K	
	r[2]	P[3]	r	P	r	P	r	P	r	P	r	P	r	P
Dry Weight Yield of Potato Vine	1.000	--												
Mg Content	-.075	>.10	1.000	--										
Uptake Mg	.734	.01	.603	.01	1.000	--								
Ca Content	.128	>.10	.526	.01	.454	.01	1.000	--						
Uptake Ca	.788	.01	.262	.02	.809	.01	.699	.01	1.000	--				
K Content	-.027	.02	.028	>.10	-.008	>.10	.019	>.10	.002	>.10	1.000	--		
Uptake K	.801	.01	.045	>.10	.601	.01	.129	>.10	.657	.01	.567	.01	.1000	--

[1] Degree of freedom = 80 - 2 = 78.

[2] r = correlation coefficient.

[3] P = level of significance of correlation coefficient (r).

Table 15A. Simple correlation analysis;[1] dry weight yield and nutrient content of potato vines and soil test results; Montcalm County.

	Soil Test Results, First Sampling[4]								Soil Test Results, Second Sampling							
	P		K		Ca		Mg		P		K		Ca		Mg	
	r[2]	P[3]	r	P	r	P	r	P	r	P	r	P	r	P	r	P
Dry Weight Yield of Potato Vines	.247	.05	.042	>.10	-.024	>.10	-.017	>.10	.307	.01	.162	>.10	-.010	>.10	-.070	>.10
Mg Content	-.159	>.10	.019	>.10	.319	.01	.366	.01	.108	>.10	-.067	>.10	-.098	>.10	-.059	>.10
Uptake Mg	.083	>.10	.045	>.10	.176	>.10	.325	.10	.325	.01	.074	>.10	-.073	>.10	-.116	>.10
Ca Content	-.104	>.10	.020	>.10	.142	>.10	.068	>.10	.045	>.10	-.022	>.10	.025	>.10	.086	>.10
Uptake Ca	.115	>.10	.050	>.10	.064	>.10	-.005	>.10	.255	.05	.105	>.10	.010	>.10	-.015	>.10
K Content	.071	>.10	0	>.10	.024	>.10	.082	>.10	.027	>.10	.185	>.10	-.082	>.10	-.074	>.10
Uptake K	.264	.02	.049	>.10	-.028	>.10	.008	>.10	.277	.02	.248	.05	-.069	>.10	-.108	>.10

[1] Degrees of freedom = 80 - 2 = 78.

[2] r = correlation coefficient.

[3] P = level of significance of correlation coefficient (r).

[4] P was determined by Bray's P_1 method and K, Ca and Mg by the NH_4Ac method at the Michigan State University Soil Testing Laboratory. Acre = 2,000,000 pounds air dried soil.

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