DEVELOPMENT AND USE OF A SHORT-TERM NUTRIENT
ABSORPTION TECHNIQUE FOR EVALUATING
SOIL MAGNESIUM STATUS

by

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ABSTRACT OF THESIS

DEVELOPMENT AND USE OF A SHORT-TERM NUTRIENT ABSORPTION TECHNIQUE FOR EVALUATING SOIL MAGNESIUM STATUS

A greenhouse investigation was undertaken to study and evaluate the use of a short-term nutrient absorption technique for evaluating soil magnesium status. Barley (Hordeum vulgare), variety Arivat, was used as the test plant.

The investigation included four experiments with the following objectives: (1) to determine the need for base applications of nitrogen and phosphorus in a soil magnesium study using a short-term nutrient absorption technique; (2) to study the effect of base applications of nitrogen and phosphorus on magnesium uptake by plants under three time periods of root-soil contact; (3) to study the effect of increasing soil moisture from 75 percent to 100 percent of the soil moisture equivalent on the plant uptake of magnesium, and (4) to evaluate the short-term nutrient absorption technique in determining the magnesium status in six different soils: Gila silt loam, Tours silty clay loam, Cajon clay loam, La Palma fine sandy loam, Yavapai sandy clay loam, and Casa Grande loam. Magnesium was applied in the form of MgSO_4 and

Sul-Po-Mag in the first three experiments and in the form of Sul-Po-Mag in the fourth experiment.

Plant growth (on dry weight basis), potassium, calcium, and magnesium uptake were increased by the base application of nitrogen and phosphorus using a 7-day period of root-soil contact.

Plant growth (on dry weight basis) was not affected by soil moisture level. Potassium and calcium concentrations in the plant were decreased with increasing soil moisture, but the total plant uptake of these nutrients was not affected. Total plant uptake and concentration of magnesium were increased by increasing soil moisture level.

Among the soils used in this investigation, only Yavapai sandy clay loam may need supplemental applications of magnesium to support intensive plant growth.

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INTRODUCTION

Magnesium is an essential nutrient element for the growth and reproduction of all plants. It ranks third to fifth in abundance among the nutrient elements in plant ash. In the earth's crust, magnesium occupies the eighth position among its elemental components.

Magnesium plays an important role in a number of metabolic processes in the plant such as cell division, phosphorus assimilation and translocation, oil formation, enzyme activation, lipid metabolism, nitrogen metabolism, phosphorylation, and photosynthesis, as a constituent of chlorophyll. It also aids in nitrogen fixation by legumes through stimulation of microbial activity.

Being so important, magnesium was subjected to intensive studies for a long time, particularly with regard to its function in the plant and in soil-plant relationships. However, according to many investigators, it appears that the major problems of magnesium assay in soils, lie in the lack of a suitable method for measuring the soil supplying power of magnesium. Such a method should take into account that the ability of the plant to obtain sufficient magnesium from the soil is a function of a number of environmental factors and the interaction between those factors. Jacob (31) stated

...an investigation of the soil in Germany could not offer an explanation of the problem of the magnesium status of soils owing to the absence of a suitable method for determining their content of magnesium available to plants.... Already, the application of the methods that have been devised has shown that the number of soils requiring magnesium in Germany has been greatly underestimated.

The results of a magnesium survey of Arizona soils (36) are in agreement with the earlier opinion that additional magnesium may be needed on Arizona soils in order to support intensive crop production.

On this premise, a series of investigations have been conducted by Maier and co-workers (36, 37) to evaluate the magnesium status of Arizona soils.

The present investigation is an attempt to apply the short-term nutrient absorption technique suggested by Stanford and DeMent (54) for soil magnesium evaluation and, if satisfactory, to use this method for the study of the magnesium status of some of the important agricultural soils in Arizona.

LITERATURE REVIEW

Soil Magnesium Conditions and Magnesium Supply to Plants

Formerly, the tendency was to believe that, in general, soils had sufficient magnesium to support the growth of plants. This was based on the fact that the earth's crust contains 2.07 percent magnesium on the average (33), while its phosphorus content is only 0.12 percent, and its potassium content is 2.58 percent. This idea of magnesium sufficiency cannot be regarded as correct for all soils, owing to the great variations in soil magnesium content which resulted from their different geological origin and the different conditions operative in their formation.

According to the present ideas, magnesium exists in the soil in one or more of several forms: (1) as a constituent of the primary or secondary minerals, (2) as an exchangeable cation on clay or organic matter, (3) as a constituent of the organic matter in the soil, and (4) as a free ion in the soil solution. Under normal conditions the amount of magnesium in the soil solution does not probably meet the demands for normal plant growth. Therefore, it seems necessary that the plant utilize other forms of soil magnesium.

Beeson (4) stated that soils developed on sandstones, granite, and possibly limestone could normally be low in magnesium because of the low content of magnesium in these rocks. However, those soils containing a mixture of the important basic magnesium silicates, the dolomites, or the dolomitic limestones in their parent material, should have greater supplies of magnesium.

Magnesium deficiency is most prevalent on the acid sandy soils of the coastal plains or on sandy alluvial soils naturally low in exchange capacity and subject to extensive leaching (13). Also, many soils which are unusually high in potassium or calcium may increase the possibility of magnesium deficiency.

In Florida (14), magnesium (both total and exchangeable plus soluble) has always been deficient in calcareous and sandy soils. The calcareous soils usually contain a higher content of magnesium than sandy soils, but this is largely offset by the antagonistic effect of the extremely high exchangeable and soluble calcium.

MacIntire, Shaw, and Robinson (34) postulated two types of acid complexes in the soil. One of these quickly adsorbed magnesium and held it in a readily exchangeable condition. The other type reacted over a more extended period to form a complex, from which the magnesium was not released by conventional methods, although it could be extracted by successive shakings with 0.02 N nitric acid. They concluded that a

considerable amount of this cation was withdrawn from the soil solution and fixed by the soil.

Haas and Gruppe (26) reported that for the growth of apple trees light soils should contain the following amounts of potassium and magnesium (mg./100 gm. soil): 15-20 K_2O and 6-10 MgO ; for medium soils: 20-30 K_2O and 10-15 MgO ; and for heavy soils: > 30 K_2O and 15 MgO .

The influence of soil chemical and physical conditions on the extent of magnesium leaching is considerable. Jacob (31) indicated that besides soil permeability, the soil reaction also plays a part, since magnesium goes into solution to a greater degree in acid soils and can be leached readily, especially under high rainfall. Also, manuring with farmyard manure, as well as the application of calcium and mineral fertilizers, has an effect on magnesium losses from soil by leaching.

In Holland (43) magnesium deficiencies occurred in agricultural and vegetable crops as well as in fruit trees on both sandy and clay soils. After testing those soils, it was found that the soils had a rather low content of magnesium and a high content of potassium in the surface layer.

Evidence shown by Bower and Turk (6) indicates that calcium and magnesium deficiencies may occur in noncalcareous soils under conditions of a high percentage of sodium saturation (40% or more). In the case of calcareous soils, a high pH value (above 9 or 9.5) seems to be an additional prerequisite.

Bear et al. (2) studied the magnesium relationship in plant and soil, and they concluded that approximately 10 percent of the exchange complex of an "ideal soil" should be occupied by magnesium. Magnesium deficiency symptoms are likely to develop when this percentage falls below 6 percent, or when the K:Mg ratio in the exchange complex exceeds 1:2. In one of their experiments, different sources of magnesium, including Sul-Po-Mag,¹ Actomag,² epsom salt,³ and finely pulverized dolomitic limestone, were compared on sweet potatoes, Irish potatoes, snap beans, and okra in a soil deficient in magnesium. Yields of all crops were greatly increased by magnesium applications. The soluble forms of magnesium tended to be more effective the first year of the test on soil that had been limed to pH 6.5 with CaCO_3 . The magnesium of both dolomitic limestone and Actomag was immediately useful for the Irish potato and sweet potato crops grown on the soil at pH 5.5.

During a study of cotton growth on Superstition sand, Maier (36) obtained some evidence indicating that some "fixation" occurred in the soil for potassium and magnesium. Plant chemical analysis showed that for potassium this "fixation" did not generally reduce the plant uptake of potassium. The "fixation" of soil magnesium as indicated by soil analysis

¹ A double sulfate of potassium and magnesium containing 18.8 percent MgO.

² A selectively calcined dolomite containing 21.3 percent MgO.

³ Containing 16.8 percent MgO.

did appear to be related to the nonincrease in plant magnesium as a function of adding magnesium to the soil.

Boynton (7) found that when the magnesium content of apple leaves was between 0.40 and 0.25 percent magnesium, leaf blotch symptoms may appear if other conditions favor their appearance. When the magnesium content falls below 0.15 percent magnesium, leaf symptoms of magnesium are likely to appear in some orchards, regardless of other conditions. The application of different magnesium carriers to the soil to control magnesium deficiency in apple trees did not result in complete recovery even after three years of rather heavy magnesium applications. This was attributed to the failure of the roots to absorb enough magnesium to restore normal function.

McMurtery (39) showed that the magnesium content of tobacco leaves varies with degree of magnesium deficiency. The most severe symptoms becoming evident with the lowest percentage (0.08-0.19%) and well-defined symptoms at a higher percentage (0.15%). He also related magnesium deficiency to magnesium content of the soil. According to his view, soils of different series varying in the acid-soluble magnesium content from 0.024 percent to ten times this figure have been found to manifest magnesium deficiency. Such a deficiency was corrected by an application of 12 pounds of magnesium as sulfate or chloride.

Adams and Henderson (1) showed that a yield response to magnesium was obtained on soils that had < 4 percent of its cation exchange

capacity as magnesium. They stated that the ratio of exchangeable Mg/K was not a better indicator of available magnesium than percent magnesium saturation. Neither was absolute exchangeable magnesium a satisfactory indicator. They added that magnesium deficient plants (Sudangrass and Ladino clover) contained 0.25 meq. or less of magnesium per gram of dry material.

No correlation was found by Perkins and Stelly (48) between calcium and magnesium composition of the plant and milliequivalents or percentage saturation of exchangeable calcium and magnesium of the soil. Also, Nearpass and Drosdoff (45) found that magnesium in tung leaves was not significantly correlated with soil-magnesium expressed as milliequivalents or percent saturation, but for the leaf samples containing less than 29 meq./100 gm. of magnesium, a highly significant correlation was found with the degree of magnesium saturation of the soil. Also, leaf-magnesium was negatively correlated to a highly significant degree with the percentage saturation of potassium in the soil.

Seo (53) indicated that magnesium deficiency symptoms appeared when the MgO content of plants was < 0.15-0.20% in tobacco, 0.15% in citrus, 0.27-0.28% in grapes, 0.25% in tomatoes, and 0.15% in oats. In each case, the leaves of magnesium-deficient plants contained more total CaO and K₂O than the leaves of normal plants. Also, magnesium deficiency symptoms appeared when the exchangeable magnesium content in the soil was < 6 mg./100 gm. soil.

In citrus, it was found (38) that deficiency symptoms were associated with leaf-magnesium concentrations of 0.20 percent or less. The ratio of exchangeable K/Mg in the soil (particularly the 18-30 inch depth) was highly correlated with the percent magnesium in the leaves. The addition of magnesium fertilizer resulted in a marked increase in leaf magnesium and a disappearance of deficiency symptoms.

Cooper and others (19) stated that magnesium, being exceeded by potassium and calcium in the metallic composition of plants in humid climates, should be the next metallic nutrient included in a mixed fertilizer where heavy applications of fertilizers are common and relatively heavy yields of vegetative crops are expected. They added that crops containing relatively large quantities of magnesium such as potatoes, cotton, tobacco, tomatoes, and other vegetables often give a marked yield response to applications of mixed fertilizers containing magnesium.

The availability of magnesium in MgCO_3 as compared to that of MgSO_4 was found (49) to depend upon the pH of the soil. The effect of MgCO_3 is, in general, slower but longer lasting and offers some correction of acidity, especially when applied with CaCO_3 in dolomite.

Hester and others (27) reported that magnesium deficiency in New Jersey was observed on sandy soils that contained less than 100 pounds of replaceable magnesium per acre and did not occur on those that averaged 132 or more pounds per acre. They added that MgSO_4 , applied at the rate of 200 pounds per acre, prevented the deficiency

from developing, and in another case, alleviated the deficiency even after it became prevalent in the field.

Carolus (15) suggested that on all soils with a reaction below pH 5.0, the addition, several months before planting, of a finely divided dolomite lime at a rate sufficient to bring the soil up to a reaction of pH 5.2 or 5.3 should prove beneficial. On soils in which the pH is too high to allow any additions of MgO to be made through liming, fertilizer containing magnesium from a soluble source in a sufficient quantity to allow an addition of 20-30 pounds per acre of MgO should be used. If neither of these methods can be utilized, a row application of 100-200 pounds of Epsom salts (MgSO_4 containing 9 percent magnesium) per acre immediately before planting will add sufficient magnesium to care for the needs of an average crop.

Factors Affecting Magnesium Absorption

Moore, Overstreet, and Jacobson (42) showed that magnesium absorption was sensitive to both low temperature and dinitrophenol treatment. Excess magnesium absorption was found to be related to organic acid production in the root, which established the metabolic nature of magnesium absorption. In their studies, they observed a lag phase in the time curves for magnesium uptake, which could be eliminated by a 30-minute pretreatment of the roots in a dilute acid solution. This was explained on the basis that there is a "labile" fraction of the

initial magnesium content which can be easily lost from the root, even to a solution which contains magnesium.

Cain (12) used apple trees growing in nutrient solutions to obtain information about the mechanism of potassium and magnesium absorption. He showed that magnesium absorption was governed almost exclusively by the magnesium supply. He also indicated that there was a slight negative absorption of magnesium in the low magnesium cultures during the first half of the period (118 days). This was attributed to an excretion of magnesium from the roots into the low magnesium solution.

Felbeck (23) summarized the factors that affect the magnesium uptake by the plant in the following: (1) the solubility of the various forms of magnesium in the soil, (2) the effect of pH on the absorption of magnesium by the plant, (3) the effect of the relative levels of other nutrient ions in the soil, (4) the structure of the lower horizons of the soil, (5) the variation among various plant species in their need for magnesium, and (6) the effect of limiting levels of other nutrients.

Beeson (4) emphasized the influence of rainfall and subsequent leaching in the variations in magnesium content of different soils. He stated that the concentration of magnesium is inversely correlated with the rainfall. In support of this is the apparent variation of the magnesium content between the horizons in the soil profiles of different types of soils. As shown in Beeson's data, percentage total and colloidal magnesium in the A2 horizon was 0.08, while it was 0.39 in the C

horizon of a Podzol soil. In a Chernozem, it was 0.55 in A horizon and 1.43 in C horizon. In a Sierozem and Desert soil, it was 0.89 in the 0-3 inches depth, while it was 2.06 in the 15-36 inch depth.

Soil pH value was found (1) not to affect the magnesium content of Sudangrass, whereas the magnesium content of Ladino clover grown at pH 6.5 was considerably less than at pH 5.5 on certain soils. However, it was found that this effect was dependent on the soil-magnesium status. Total magnesium uptake tended to be less at pH 6.5 than at pH 5.5 on magnesium-deficient soils, but greater at pH 6.5 on magnesium-sufficient soils.

Jacob (31) indicated that the lower the pH value, the more hydrogen ions are to be found in the presence of magnesium ions, and according to their greater mobility they can displace Mg^{++} ions from the vicinity of the plant roots. By liming, the excess of H^{+} ions over Mg^{++} ions is removed. In addition, the liberation of Mg^{++} ions in exchange for Ca^{++} ions can also be a favorable effect.

The variation among plant species and the effect of its genetic make-up on the behavior of the different species in magnesium absorption and the interrelationships with other nutrients have been reported by several investigators. Perkins and Stelly (48) found that applications of potassium or sodium, or mixtures of potassium and sodium, on a soil containing a very low exchangeable potassium and nitrogen supply reduced the percentage of calcium and magnesium in oats. The same

treatments failed to cause any changes in the percentage of calcium in crimson clover, but magnesium percentage was significantly reduced by potassium only.

Peel (47) showed that many inbred lines of corn growing in solution culture responded to magnesium application. Other inbreds neither responded to magnesium application nor showed magnesium chlorosis even at the lowest level (2 ppm) of magnesium used. The influence of magnesium on P^{32} uptake varied also with the different inbreds.

Beaumont and Snell (3) showed that there was almost a perfect agreement between rainfall in Massachusetts and extent of magnesium chlorosis in corn. They added that the beneficial effects of magnesium were enhanced by the addition of lime. They also emphasized the difference in the response of different plant species to a deficiency of magnesium in the soil.

According to Cooper (18) the soluble compounds of magnesium such as the acetate, chloride, bromide, iodide, nitrate, and sulfate, appear to be readily removed from certain soils by drainage water, and this may result in a deficiency of magnesium for certain crops. When ammonium phosphate was used, only 2.7 percent of the leaves of certain crops showed magnesium deficiency. This was attributed to the formation of magnesium-ammonium phosphate which is only slightly water-soluble and prevents the leaching of magnesium from the soil.

Prince and others (50) concluded that the most important single factor influencing the magnesium uptake of plants is the quantity of potassium available for plant use. If there is an abundance of potassium, the plant content of magnesium will be relatively low. As the potassium supply decreased with repeated harvest of alfalfa, the magnesium content of the plant increased, even where the plant was growing in a soil that was very deficient in magnesium.

Collander (17) indicated that some of the cations transported with the transpiration stream to the shoot are probably sent back along the sieve tubes to the roots where they can impede any further absorption of cations of the same kind, while other cations are retained in the shoot, and thus no repressing effect is exercised on the uptake of cations of their own kind. He also stressed the role of the differential behavior of plant species in ion absorption.

One of the problems associated with plant growth and nutrition studies is that of deciding upon the percentage of available water required for optimum plant growth, and its relationship to the mineral nutrition of plants. Brown (9) found that the amounts of the cations--calcium, magnesium, sodium, and potassium exchanged--increased sharply as the soil moisture increased. Also, the suite of cations on the exchange complex were significantly altered with increases in moisture in a way that the percentages of calcium and magnesium increased in the suite of

cations, while that of potassium and sodium decreased correspondingly with an increase in soil moisture.

Mederski and Wilson (40) studied the relation of soil moisture to ion absorption by corn plants using a split-root technique. They obtained the following results: (1) the dry weights of both tops and roots that developed in the soil showed a significant linear increase with increasing soil moisture at the two levels of atmospheric humidity used (50% and 98%), (2) under conditions of low humidity, the percent of phosphorus and potassium increased with increasing soil moisture, but under high humidity conditions, the differences in both phosphorus and potassium percentages were not statistically significant, and (3) soil moisture significantly affected magnesium uptake under both humidity levels, being increased by the increase in moisture level.

Bear et al. (2) introduced another factor which affects magnesium availability in the soil, and that is the type of clay mineral existing in the finer fractions of the soil. They noted that the relative rate of removal of the cations from soils by electrodialysis is $K > Ca > Mg$, and the plants tend to absorb these ions in this order. Also, the availability of the magnesium adsorbed on kaolinite, montmorillonite, and illite is likely to vary considerably.

Interrelationships of Magnesium with Other Nutrients

Soil-plant literature contains many examples of the depressing effect of high concentrations of calcium and potassium on plant uptake of magnesium.

Cain (13) reported that extra potassium in the nutrient solution caused an increase in the growth, but greatly decreased the translocation of magnesium from roots to leaves. Under such conditions magnesium accumulated in the roots and ultimately magnesium absorption stopped. In another experiment, Cain (11) studied the interrelationships between calcium, magnesium, and potassium in one-year-old McIntosh apple trees grown in sand culture. He found that each cation increased in concentration in the leaves as its respective supply was increased in the nutrient solution. Both calcium and magnesium decreased with increasing potassium, but not in exact chemically equivalent amounts. Conversely, the potassium content of the leaves was decreased by increasing the magnesium supply. Increasing the calcium supply decreased the magnesium and potassium content of the foliage, only at the high calcium levels, these values increasing slightly at the lower calcium levels. With increasing magnesium, both calcium and potassium were decreased in the leaves.

Overstreet (46) showed that, for a given plant tissue and nutrient environment, cations and anions will be absorbed in such proportions

and amounts as to form the most stable structure. Thus, competition between ions of like sign and mutual effects between ions of unlike sign in absorption are logically expected. Accordingly, K^+ is less rapidly absorbed when Na^+ is present, or that K^+ is more rapidly absorbed from KCl solution than from a K_2SO_4 solution of the same equivalent concentration.

Using a split-root technique, it has been shown (32) that impaired magnesium uptake by citrus seedlings at a Mg/Ca ratio of 0.05 in the medium is not due to its low magnesium content, but rather to an excess of calcium. In a pot experiment, leaf analysis showed positive correlations between Mg/Ca ratios in the medium and magnesium contents and Mg/Ca ratio in the leaves.

Moore and others (42) found that a large fraction of the magnesium absorption was blocked very effectively by small amounts of calcium. The blocking action was quite pronounced even at calcium concentrations where there was a net loss of calcium from the root. They explained that, on the basis that calcium acts by altering the permselective properties of the cell surface region.

The behavior of potassium and magnesium with each other was found to be dependent on soil type (1). Added potassium actually increased total magnesium uptake along with an increase in plant growth. However, potassium level tended to result in less of a change in the magnesium content of plants on magnesium-deficient soil than on

magnesium-sufficient soil. Two explanations were suggested for this behavior: first, that less of the available magnesium was absorbed by plants moderately deficient in potassium because of less vigorous plant growth; second, that magnesium availability was increased by added potassium, displacing exchangeable magnesium into solution.

Cain (12) obtained some evidence indicating that neither potassium nor magnesium influence the rate of absorption of the other; however, a high level of supply of either may result in a lower tissue concentration of the other. When used in equivalent concentrations, the effect of potassium in reducing the leaf concentration of magnesium was much greater than that of magnesium in reducing leaf concentration of potassium.

The ratios Ca/Mg and K/Mg were used rather extensively as indicators to measure the availability of those three nutrients to plants. Mehlich (41) found that the ratio Ca/Mg in the soil divided by this ratio in the plant or HCl extract of the soil was increased with an increase in the cation adsorption capacity; increased with increasing degree of calcium saturation accompanied by an increase in the cation ratios of the soil; and these ratios were also somewhat greater for the soils representing the 2:1 lattice type than for those representing the 1:1 lattice type.

Hunter (29) found that alfalfa plants grown on soils with a constant level of magnesium showed an increase in magnesium percentage with

increasing Mg:K ratios. Magnesium uptake by the plant also increased with increasing Ca:K ratios in the exchange complex.

Maier (36) found that a soil application of 80 pounds K per acre did not suppress the amount of magnesium in the stem or in the entire aerial portion of the cotton plant. With respect to tomatoes, there was an increased amount of total magnesium in the leaves with a soil application of 80 pounds potassium per acre. This indicates that added potassium may have increased plant uptake and translocation of magnesium.

One of the functions ascribed to magnesium in plant nutrition is as a carrier of phosphorus used by the plant. Truog and others (56) found an appreciable and consistent increase in phosphorus content with increasing supplies of available magnesium. They stated that increasing supplies of available soil magnesium increased the phosphorus content of peas much more than did increasing supplies of available phosphorus.

Growing soybean plants in sand culture, Webb and others (59) obtained a positive relationship between the magnesium and phosphorus contents of the seed, and a negative relationship between the content of these two elements in the leaflets.

A parallel relationship was observed by Mulder (44) between the phosphate and magnesium contents in leaves of apple trees. He also found that in apple trees a low potassium content is associated with high phosphorus and high magnesium contents.

Ammonium was reported (31) to have a strongly antagonistic effect towards the magnesium ion. In other words, there is an inhibitory influence of ammonium ions on magnesium uptake. This antagonistic effect contributes therefore to the unfavorable action of ammonia nitrogen on soils exhibiting magnesium deficiency, while nitrate nitrogen shows a beneficial effect.

Pfaff and Buchner (49) stated that fertilization with nitrate promotes the uptake of magnesium much more than ammonia, and usually more than a small addition of magnesium alone. Also, heavy applications of calcium stimulated the uptake of magnesium.

Along with the effect of nitrogen on the availability of magnesium, Boynton (7) showed that nitrogen fertilization seems to some degree to decrease the prevalence and severity of magnesium deficiency in apple orchards. He also showed that liberal potassium fertilization of trees on soils that are low in calcium and magnesium has been found to induce magnesium deficiency and/or increase its severity. Two reasons were given: first, it inhibits the absorption of magnesium by apple tree roots, and over a period of years, it decreased the amounts of replaceable calcium and magnesium in the soil exchange mechanism.

Relatively few reports have appeared on the influence of elements other than calcium and potassium on magnesium uptake by plants. Walsh and Clarke (58) recorded that a low level of sulfur nutrition retarded the

development of magnesium deficiency chlorosis by enhancing magnesium uptake.

The Short-Term Nutrient Absorption Technique

In 1957, Stanford and DeMent (54) developed a method to study the absorption of phosphorus by plants during relatively short periods of root-soil contact. This method consists of growing plants in bottomless cardboard cartons, containing quartz sand, for two to three weeks. During this time a root mat develops at the bottom of the container. The bottomless carton containing the exposed root mat with plants intact is then placed in another carton containing the soil to be tested, allowing root contact with the soil. They stated that the method can be used in further studies of phosphorus absorption as well as other nutrients. Later, this technique was developed for potassium and nitrogen absorption studies (20, 21).

In 1961, this short-term nutrient absorption technique was used by Maier (37) to evaluate the magnesium status of some calcareous and alkaline soils in Arizona. Two soils--Pima silty clay loam and Mohave loam--were used. The investigation was more concerned with the establishment of some experimentally accepted basis for using the Stanford and DeMent technique for magnesium absorption studies. With respect to the contact period, it was found that a 7-day contact period was the most suitable for potassium, calcium, and magnesium uptake studies.

The dry weight of plant tops and potassium and calcium uptake were not influenced by soil treatment with magnesium alone or magnesium plus potassium or potassium alone. Magnesium uptake by barley plants was not consistently influenced by soil treatment on the Pima soil. On Mohave loam, the application of potassium decreased the uptake of magnesium at the 4-day contact period, while the reverse was found at the 10-day contact period. On the basis of the information obtained, it was concluded that both soils studied were not deficient in available supplies of magnesium.

MATERIALS AND METHODS

Soil Sampling

Six different calcareous soils, known to be agriculturally important, were collected from various locations in the state of Arizona. The locations of these soils are shown in Figure 1. The soil samples were taken to a depth of 0-12 inches. Table 1 shows the legal description of the soil sampling sites in Arizona.

The collected soil samples were thoroughly air dried, then crushed with a wooden roller and passed through a polyethylene screen having a hole size of 10 mm.². A subsample of each soil was allowed to pass through a 12-mesh screen and kept in paper containers for chemical analysis.

Analytical Procedures

Soil Analysis

Subsamples of the original collected soils were chemically analyzed for:

1. Ammonium acetate-soluble calcium and magnesium (35): Ten gms. of air-dry soil were accurately weighed, placed on top of a folded Whatman No. 42 filter paper in a Fisher Filterator funnel, and covered

Figure 1:- Soils collected from Arizona.

Table 1. Legal description of soil sampling sites in Arizona.

Map No.	Soil	Legal Description
1	Gila silt loam	Sec. 17, T9S, R8E, cotton field
2	Tours silty clay loam	Sec. 34, T13N, R21E.
3	Cajon clay loam	Sec. 22, T7S, R26E.
4	La Palma fine sandy loam	Sec. 27, T6S, R8E.
5	Yavapai sandy clay loam	Sec. 9, R16N, R2W.
6	Casa Grande loam	Sec. 5, T6S, R6E.

with another circle of filter paper. One hundred milliliters of 1 N NH_4Ac , pH 7.0 were added to the sample in 10 increments, allowing the soil to be sucked dry after each increment. The leachate was collected in a 200 ml. beaker and evaporated to dryness on a hot plate. To the residue, 10 ml. deionized H_2O and 10 ml. concentrated HNO_3 (69-71%) were added, followed by washing the sides of the beaker with a polyethylene policeman and deionized H_2O ; then 10 ml. of HClO_4 (70-72%) were added. The mixture was then evaporated to dryness over medium to low heat. To the white residue in the beaker, 10 ml. of 0.01 N HNO_3 were added and the residue was brought into solution with heat. The colorless solution was then transferred to a 50 ml. volumetric flask and diluted to the mark with 0.1 N HNO_3 . After mixing, two suitable aliquots were withdrawn from the flask and each passed through an anion-exchange column (15 by 70 mm., Dowex 1 x 8, 50-100 mesh, NO_3^- -form) to remove phosphate. The column was then washed with 30 ml. deionized H_2O in two increments. The sample with its H_2O washings were received in a 150 ml. beaker. The column was usually recharged with 0.1 N HNO_3 after every two aliquots. One of the aliquots was used for calcium titration and the other for calcium plus magnesium titration. Duplicate titrations were made with 0.01 N EDTA solution (16). Calcium titrations were made using 0.1 percent Erichrome Blue SE and 0.1 percent Naphtol Green indicators to an end-point at which the solution color changed from "dirty" red to blue. Erichrome Black T

indicator was used for calcium plus magnesium titration to an end-point at which the solution color changed from wine red to deep blue.

The EDTA (disodium dihydrogen ethylenediamine tetraacetate dihydrate) solution was standardized with a calcium standard solution containing 0.2 mg. Ca per ml., also with a magnesium standard solution containing 1.0 mg. Mg per ml. Magnesium was obtained by subtracting the volume of EDTA solution used for the calcium determination alone, from the volume of EDTA solution used for the combined Ca and Mg determination.

2. Ammonium acetate-soluble potassium determination: A standard solution of potassium (as KCl) was prepared, containing 1.0 mg. K per ml. and used in obtaining a standard curve for potassium by means of a Beckman Spectrophotometer-flame attachment, Model DU (30). Potassium concentration, in soil sample solutions, in a suitable dilution, was measured by the same apparatus and under the exact conditions under which the standard curve was made.

3. Cation exchange capacity (51): Ten gms. of the air dried soil were accurately weighed, placed in a medium porosity fritted glass filter funnel containing a Whatman No. 42 filter paper and covered with another circle of filter paper. The sample was then washed with 30 ml. of neutral 60 percent methanol in three increments to remove the soluble salts. Fifty milliliters of neutral NH_4Ac solution were used in washing the sample in ten portions allowing the soil sample to be sucked dry after

each portion. After sucking the sample dry, it was washed twice with 60 percent methanol and again sucked dry. The sample was then transferred to a Kjeldahl flask and attached to the Kjeldahl distillation system. The distilled ammonia was received in 60 ml. saturated H_3BO_3 , then titrated with 0.1 N HCl solution using the double indicator--methyl red-methylene blue.

4. pH values were measured in both soil paste and 1:5 soil, water extract, using a Beckman pH meter Model N-1 (30).

5. Total soluble salts were measured in the saturation extracts of soil, using the conductivity method (57).

6. Moisture equivalent was determined by the centrifugal method (8).

Plant Tissue Analysis

The wet combustion method (35) was used as follows: Plant samples dried at 70° C. for three days were accurately weighed and each placed in 200 ml. beakers. Thirty milliliters of concentrated HNO_3 (69-71%) were added to each sample, then left overnight. Then the sides of the beakers were washed with deionized water using a polyethylene policeman and 10 ml. of 70-72 percent HClO_4 were added to each sample. The beakers were covered with watch glasses and placed over low to medium heat for about three to four hours until the sample was thoroughly oxidized and evaporated to dryness. The white residue was then

solubilized with 10 ml. of 0.01 N HNO_3 and filtered through a Whatman No. 42 filter paper. The filtrate was collected in a 100 ml. volumetric flask and diluted to the mark with 0.01 N HNO_3 . After mixing the sample solution in the flask, two suitable aliquots were withdrawn for the determination of calcium and magnesium previously described in "Soil Analysis."

Potassium determinations were conducted as described previously in "Soil Analysis."

General Procedure for the Short-term Nutrient Absorption Technique

The method used was a slight modification of the original technique developed by Stanford and DeMent (54) and is summarized below:

Germination of Seeds and Growth of Plants in Minus Magnesium Nutrient Solution

Fifty seeds of barley (Hordeum vulgare), variety Arivat, were germinated in a bottomless cardboard carton, slipped in another carton with bottom intact, containing 680 gms. acid-water-washed quartz sand.¹ The procedure of acid washing the sand is described later. It was found necessary to make a triangle cut in the bottom of the intact carton and place a piece of nylon cloth² on top of the cut before putting in the sand.

¹ Flint Slot Grade from Ottawa Silica Co., Ottawa, Illinois.

² Having a hole size of 0.01 mm². from The National Filter Media Corp., Salt Lake City, Utah.

This was principally made to improve aeration conditions in the root zone. The seeds were germinated at the half-inch depth. Fifty milliliters of a minus-magnesium nutrient solution-Hoagland No. 2 (28), plus 40 ml. of deionized water were added to each pot at the start of germination. The average weight of 10 pots (after addition of the nutrient solution plus deionized H_2O) was obtained and was used thereafter as a standard weight to which the pot weights were adjusted by adding deionized water one to three times a day. The pots were covered with sheets of brown paper followed by sheets of aluminum foil to keep temperature constant and retain moisture. After emergence of the seedlings, the pots were uncovered. Another 50 ml. of the minus-magnesium nutrient solution were added to each pot one week after the first addition. At the end of 14 days, a sufficient root mat had developed at the bottom of the carton. As shown in Plate 1, usually a uniform plant growth was obtained in most of the pots during the period before root-soil contact.

Sand Washing Procedure

White quartz sand was first submerged in 1 N HCl solution for one hour, after which it was sucked dry, washed with six liters of deionized water, and again sucked dry. Again the sand was submerged in 1 N HCl solution for another hour, after which it was sucked dry and washed with 16 liters of deionized water. Care was taken to test the washings for Cl^- to be sure that no traces of chloride remained. The washed sand was then air dried.

Plate 1. Barley plants grown in a minus-magnesium sand culture and before soil contact.

Plate 2. Physical arrangement of pots in a single experiment.

Contact Period

The pots were first watered with deionized water to the standard weight as usual. Then the bottomless carton containing the growing plants with its developed root mat was transferred to another carton containing 200 gm. of the soil or soil plus fertilizer to be tested. The soil was first adjusted to 100 percent of its moisture equivalent with deionized H_2O and the contact was made by placing the plant's root mat in the bottomless carton on the top of the soil. The carton, containing the soil media, was usually prepared by making a triangle cut in the bottom, covered by a piece of nylon cloth as previously described. Later, it was found necessary to make additional holes in the carton wall near the bottom to further increase aeration. Fertilizer additions were made by mixing the specified amount of fertilizers with the soil sample, using a Twin Shell Dry Blender¹, prior to placing the soil in the carton. The average weights of 10 pots after the contact was made was determined in order to be used as a standard weight for replenishing moisture losses by adding deionized water one to three times daily. At the end of the 7-day contact period, the plant tops of each pot were harvested, placed in a paper bag, and dried in an oven at 70° C for three days.

¹ L B 1715 plastic blender manufactured by Patterson-Kelly Co., East Stroudsburg, Pennsylvania.

Before contact, soil samples were taken from each treatment and held at 100 percent of their moisture equivalent for four days. They were analyzed for (1) pH in paste and in 1:5 soil water extract, (2) total soluble salts in the saturation extract, and (3) ammonium acetate-soluble potassium, calcium, and magnesium, following the same procedures used in the analysis of the original untreated soils as described previously.

Experimental Designs

The investigation included four separate experiments; the first three were concerned with establishing some basic information on the conditions under which the short-term nutrient absorption technique could be used for soil magnesium studies.

Experiment I

The principle of this experiment was to determine the need for base applications of nitrogen and phosphorus in a soil magnesium study using the short-term nutrient absorption technique. Two different soils--Gila silt loam and La Palma fine sandy loam--were chosen for this experiment. Table 2 shows the treatments used for each soil. Nitrogen and phosphorus were applied as NH_4NO_3 and $\text{NH}_4\text{H}_2\text{PO}_4$. Potassium and magnesium were added in two forms--as sulfate and Sul-Po-Mag.¹

¹ Available from International Minerals and Chemical Co., Skokie, Ill., and composed of a mixture of magnesium and potassium sulfates, containing 18.5 percent MgO and 22 percent K_2O .

Table 2. Explanation of the treatments used in Experiment I.

Treatment No.	Amount and source of elements added in pounds per acre			
	N*	P*	K	Mg
1	0	0	0	0
2	0	0	84 (K_2SO_4)	50 ($MgSO_4$)
3	0	0	84 (Sul-Po-Mag)	50 (Sul-Po-Mag)
4	0	0	84 (K_2SO_4)	0
5	0	0	0	50 ($MgSO_4$)
6	220	50	0	0
7	220	50	84 (K_2SO_4)	50 ($MgSO_4$)
8	220	50	84 (Sul-Po-Mag)	50 (Sul-Po-Mag)
9	220	50	84 (K_2SO_4)	0
10	220	50	0	50 ($MgSO_4$)

* Sources of nitrogen and phosphorus were: NH_4NO_3 and $NH_4H_2PO_4$.

The experiment was started by planting barley in the greenhouse, following the exact procedure described previously. Tops of plants were harvested, dried in an oven at 70° C. for three days, and placed in paper bags for subsequent chemical analysis. Four replications were used for each treatment. For each soil, the experimental design was as follows:

Two NP treatments x five Mg treatments x four replications
+ (ten pots as control-harvested without soil contact)

Experiment II

This experiment was designed to further study three periods of root-soil contact--7-, 10-, and 12-day periods. One soil--Gila silt loam--was chosen for this experiment. The same treatments as in Experiment I were used for each contact period (Table 2). The experiment was initiated by planting barley following the same procedure used in Experiment I. Tops of plants were harvested at the end of the three periods of root-soil contact: 7-, 10-, and 12-day periods. Plant samples were dried as before and placed in paper bags for subsequent chemical analysis. Experimental design was as follows:

Two NP treatments x five Mg treatments x three periods of
contact x four replications + (eight pots as control-
harvested without contact)

Experiment III

This experiment was conducted to study the effect of soil moisture on plant uptake of magnesium and determine the optimum moisture level for magnesium uptake using the short-term nutrient absorption technique. Gila silt loam was chosen for this study. Two soil moisture levels were used--100 percent and 75 percent of the moisture equivalent of the soil. Extreme care was taken in adjusting the levels of soil moisture daily. The explanation of treatments applied is shown in Table 3. Sources of nitrogen and phosphorus were the same as in Experiments I and II. The experiment was started in the greenhouse following the same procedure as in Experiments I and II. Tops of plants were harvested, dried at 70° C. for three days, then kept in paper bags for chemical analysis. Experimental design was as follows:

Five Mg treatments x two levels of moisture x four replications
+ (eight pots as control harvested without contact)

Experiment IV

This study was designed to use the results obtained from Experiments I, II, and III for conducting an experiment to evaluate the magnesium status of some of the calcareous soils in Arizona, using the short-term nutrient absorption technique. Five soils were used: (1) Tours silty clay loam, (2) Cajon clay loam, (3) La Palma fine sandy loam, (4) Yavapai sandy clay loam, and (5) Casa Grande loam. Soil moisture

Table 3. Explanation of treatments applied in Experiment III.

Treatment No.	Amount and source of elements added in pounds per acre			
	N	P	K	Mg
1	220	50	0	0
2	220	50	84 (K_2SO_4)	50 ($MgSO_4$)
3	220	50	84 (Sul-Po-Mag)	50 (Sul-Po-Mag)
4	220	50	84 (K_2SO_4)	0
5	220	50	0	50 (Sul-Po-Mag)

level was maintained at 100 percent moisture equivalent. Two treatments were applied for each soil as follows:

Treatment No. 1: 220 lbs. N/A. + 50 lbs. P/A. + 0 K + 0 Mg.

Treatment No. 2: 220 lbs. N/A. + 50 lbs. P/A. + 84 lbs. K/A.
+ 50 lbs. Mg/A.

Sul-Po-Mag was used as the source for magnesium and potassium.

Sources of nitrogen and phosphorus were the same as previously stated.

The experiment was started in the greenhouse following the same scheme as in the previous experiments. Tops of plants were harvested and treated in the same way as before. The experimental design was as follows:

Two Mg treatments x four replications x five soils
+ (ten pots as control harvested without contact)

The arrangement of this experiment is shown in Plate 2.

Statistical Procedures

The results of each experiment were analyzed statistically by analysis of variance (55). The means were separated by the Duncan Multiple Range Test (22).

RESULTS AND DISCUSSION

Soil Analysis

The collected soil samples (original from the field) were analyzed chemically and the results are shown in Table 4. The soils varied from calcareous to highly calcareous, with percent calcium saturation ranging from 51.1 to 110.7. The percent saturation of potassium and magnesium indicates that the soils analyzed were fairly high in magnesium and low in potassium contents except in La Palma fine sandy loam. The pH values shown indicate that Casa Grande loam may have a high content of sodium which may account for the relatively low percent saturation of calcium. The total soluble salts, expressed as mmhos per cm., indicate that most of the soils contained low amounts of total soluble salts with the exception of Cajon clay loam and Casa Grande loam. Casa Grande loam had the lowest moisture equivalent, and also the lowest cation exchange capacity among all soils analyzed.

Table 4. Chemical and physical characterization of the collected soil samples (original from the field).

Soil	pH		T.S.S. mmhos. per cm.	Mois- ture equiv. %	C.E.C. meq./ 100 gm	Ammonium acetate soluble mg./gm. soil			Percent saturation		
	paste	1:5 water extract				K	Ca	Mg	K	Ca	Mg
1-Gila silt loam	7.70	8.50	0.64	25.27	20.24	0.39	4.48	0.31	4.9	110.7	12.9
2-Tours silty clay loam	7.75	8.20	0.44	30.64	23.80	0.72	3.89	0.61	7.8	81.7	21.9
3-Cajon clay loam	7.95	8.90	5.20	32.43	29.78	0.62	4.61	0.76	5.3	77.4	21.2
4-La Palma fine sandy loam	8.10	8.70	0.48	27.27	16.60	0.98	3.33	0.69	15.0	100.3	34.8
5-Yavapai sandy clay loam	7.70	8.30	0.91	26.59	24.87	0.42	3.94	1.06	4.3	79.2	35.5
6-Casa Grande loam	8.20	9.45	2.65	14.83	9.98	0.34	1.02	0.20	8.6	51.1	16.3

Experiment I

The first experiment was conducted to determine the need for base applications of nitrogen and phosphorus for studying magnesium uptake using the short-term nutrient absorption technique. The soils chosen for this study were: Gila silt loam and La Palma fine sandy loam, representing two extreme limits of magnesium content (12.90-34.81 percent saturation, respectively). A description of treatments applied are shown in Table 2.

Table 5 shows the dry weight, total uptake and concentration of potassium, calcium, and magnesium in the plants of the control treatments. These data were used in obtaining the percent gains in plant dry weight and total uptake of the nutrients during the period of root-soil contact. These gains were expressed in a range representing the upper and lower limits.

The dry weights of plants in the treated series are shown in Table 6 and in Figure 2. These data indicate a highly significant increase in dry weight of plants as a result of NP treatments in both soils. In La Palma fine sandy loam the plants gained an increase of 31-43 percent during the 7-day contact with the soil. In Gila silt loam this gain in dry weight was 32-42 percent. Tables 7 and 8 show the total uptake and concentration of potassium as affected by NP and Mg treatments in La Palma fine sandy loam and Gila silt loam, respectively. Figures 3 and 4 present the same data for both soils. NP additions produced a significant

Table 5. Dry weight, total uptake and concentration of potassium, calcium, and magnesium in plants from control treatments.

Repli- ca- tions	Dry weight gm./pot	Total uptake--mg./pot			Concentration--mg./gm. dry matter		
		K	Ca	Mg	K	Ca	Mg
1	0.84	46.00	7.60	2.12	54.63	9.03	2.52
2	0.75	45.00	5.40	2.00	59.86	7.18	2.66
3	0.84	45.00	8.00	1.56	53.66	9.54	1.86
4	0.75	44.00	6.50	0.93	58.98	8.71	1.25
5	0.80	46.50	7.00	1.25	58.12	8.75	1.56
6	0.74	44.00	6.60	1.25	59.20	8.88	1.68
7	0.84	44.00	7.40	1.43	52.58	8.84	1.71
8	0.75	44.00	6.40	1.12	58.57	8.52	1.49
9	0.89	46.00	8.70	2.12	51.77	9.79	2.39
10	0.89	44.00	9.20	1.31	49.38	10.33	1.47
Mean	0.81	44.85	7.28	1.51	55.68	8.96	1.86

Table 6. Dry weight (tops of plants) as affected by NP and Mg treatments (gm./pot).

Treatment	La Palma fine sandy loam						Gila silt loam					
	Replications				Mean		Replications				Mean	
	1	2	3	4			1	2	3	4		
1	1.11	1.18	1.14	1.20	1.16	a	1.18	1.28	1.17	1.16	1.20	a
2	1.22	1.03	1.15	1.17	1.14	a	1.18	1.17	1.20	1.19	1.19	a
3	1.31	1.12	1.24	1.22	1.22	ab	1.19	1.28	1.25	1.25	1.24	ab
4	1.15	1.19	1.28	1.22	1.21	ab	1.20	1.22	1.25	1.17	1.21	a
5	1.19	1.11	1.19	1.22	1.18	ab	1.17	1.19	1.24	1.18	1.19	a
6	1.38	1.36	1.21	1.12	1.27	bc	1.43	1.43	1.39	1.38	1.41	e
7	1.38	1.23	1.35	1.39	1.34	cd	1.37	1.41	1.27	1.40	1.36	d
8	1.38	1.35	1.43	1.36	1.37	d	1.35	1.37	1.35	1.32	1.35	cde
9	1.36	1.40	1.45	1.32	1.38	d	1.34	1.30	1.36	1.23	1.31	cd
10	1.40	1.45	1.46	1.38	1.42	d	1.31	1.31	1.29	1.24	1.29	bc
"F" value					8.85**						15.88**	

** Significant at the 1% level.

Note: All means with the same symbols are from the same population.

Figure 2:- Average dry weight of barley plants in four replications as affected by NP and Mg treatments.

Table 7. Total uptake and concentration of potassium, as affected by NP and Mg treatments (La Palma fine sandy loam).

Treat- ment	Total uptake--mg./pot						Concentration--mg./gm.dry matter					
	Replications				Mean		Replications				Mean	
	1	2	3	4			1	2	3	4		
1	61.00	70.00	68.50	71.00	67.63	a	54.00	59.10	60.19	59.07	58.32	abc
2	73.50	70.00	70.00	67.00	70.13	ab	60.54	67.79	61.09	57.07	61.60	c
3	77.50	70.00	61.00	70.00	69.63	ab	59.04	62.52	49.32	57.45	57.08	abc
4	74.50	71.00	68.50	73.00	71.75	abc	64.84	59.79	53.73	59.92	59.57	bc
5	69.50	69.00	70.50	68.50	69.25	ab	58.31	62.25	59.14	55.96	58.92	bc
6	75.00	79.00	64.00	67.00	71.25	ab	54.39	58.05	52.89	59.75	56.27	abc
7	82.00	74.50	77.50	79.00	78.25	c	59.27	60.66	57.55	56.99	58.62	bc
8	75.50	79.50	74.00	72.50	75.38	bc	55.64	58.85	51.79	53.43	54.93	ab
9	79.50	76.00	78.00	69.50	75.75	bc	58.67	54.13	53.90	52.50	54.80	ab
10	72.00	72.00	78.50	76.50	74.75	bc	51.47	49.58	53.70	55.93	52.67	a
"F" value					2.64*						2.36*	

* Significant at the 5% level.

Note: All means with the same symbols are from the same population.

Figure 3: - Average total uptake and concentration of potassium in four replications of barley (tops of plants) grown on La Palma fine sandy loam as affected by NP and Mg treatments.

Table 8. Total uptake and concentration of potassium, as affected by NP and Mg treatments (Gila silt loam).

Treat- ment	Total uptake--mg./pot					Concentration--mg./gm. dry matter						
	Replications				Mean	Replications				Mean		
	1	2	3	4		1	2	3	4			
1	64.00	58.50	61.50	61.00	61.25	a	54.13	45.87	52.58	52.71	51.32	
2	60.00	68.00	63.00	65.50	64.13	ab	50.79	58.28	52.62	54.87	54.14	
3	69.00	64.50	69.50	60.50	65.88	abc	57.94	50.40	55.77	48.24	53.09	
4	61.00	67.00	60.00	68.00	64.00	ab	50.83	54.95	48.12	58.03	52.98	
5	66.00	59.50	68.50	58.50	63.38	ab	56.60	50.11	55.17	49.17	52.87	
6	66.00	76.00	72.00	72.00	71.50	cd	46.22	53.31	52.00	52.06	50.90	
7	68.50	71.00	66.50	72.00	69.50	bcd	50.10	50.29	52.28	51.53	51.05	
8	72.00	60.50	73.50	58.50	66.13	abc	53.45	44.09	54.49	44.47	49.12	
9	74.00	74.00	69.00	71.50	72.13	cd	55.08	57.05	50.60	58.28	55.25	
10	75.00	77.00	73.00	68.00	73.25	d	57.23	58.88	56.40	54.74	56.81	
"F" value					3.91*							1.55 ^{ns}

^{ns} Not significant.

* Significant at the 5% level.

Note: All means with the same symbols are from the same population.

Figure 4:—Average total uptake and concentration of potassium in four replications of barley (tops of plants) grown on Gila silt loam as affected by NP and Mg treatments.

increase in total plant uptake of potassium. In La Palma fine sandy loam, treatment 7 showed a more pronounced increase over treatment 2. Treatments 6, 9, and 10 gave a more pronounced increase over treatments 1, 4, and 5, respectively, in Gila silt loam. With respect to potassium concentration, there was a decrease in potassium concentration with NP additions in the case of La Palma only. This may be explained on the basis that the increase in growth caused by NP additions resulted in dilution in potassium content which was not corrected by an increase in potassium absorption, probably due to the short period of contact used (7 days). The concentration of potassium in Gila silt loam was not affected by NP treatments. Within the period of soil contact, the total uptake of potassium increased by 34-43 percent in La Palma fine sandy loam and 27-39 percent in Gila silt loam.

Tables 9 and 10 show the total uptake and concentration of calcium as affected by NP and Mg treatments for La Palma fine sandy loam and Gila silt loam, respectively. The same data are shown in Figures 5 and 6. The data indicate that a significant increase in calcium uptake was associated with the addition of nitrogen and phosphorus in both soils. Treatment 10 showed a more pronounced increase over treatment 5 in the case of La Palma. In the case of Gila silt loam, both treatments 9 and 10 gave a more pronounced response to NP addition compared to treatments 4 and 5. Plant calcium concentration was not affected by nitrogen and phosphorus addition, probably because of the dilution effect

Table 9. Total uptake and concentration of calcium as affected by NP and Mg treatments (La Palma fine sandy loam).

Treat- ment	Total uptake--mg./pot						Concentration--mg./gm. dry matter					
	Replications				Mean		Replications				Mean	
	1	2	3	4			1	2	3	4		
1	9.60	11.20	10.40	12.10	10.83	ab	8.64	9.46	9.14	10.07	9.33	
2	11.00	9.40	10.90	11.40	10.68	a	9.05	9.10	9.51	9.71	9.34	
3	11.10	11.10	9.00	12.10	10.83	ab	8.46	9.91	7.28	9.93	8.89	
4	12.00	11.50	10.80	11.40	11.43	abc	10.44	9.68	8.47	9.36	9.49	
5	10.90	11.00	10.90	10.40	10.80	ab	9.15	9.92	9.14	8.50	9.18	
6	12.20	12.70	10.80	10.60	11.58	abc	8.85	9.33	8.93	9.45	9.14	
7	11.50	9.80	10.80	12.60	11.18	ab	8.31	7.93	8.02	9.09	8.35	
8	11.80	10.80	11.90	11.80	11.58	abc	8.70	8.00	8.33	8.70	8.43	
9	13.00	10.80	12.30	12.50	12.15	bc	9.59	7.69	8.50	9.44	8.81	
10	13.10	12.30	12.90	12.60	12.73	c	9.36	8.47	8.82	9.21	8.97	
"F" value					2.30*						1.29 ^{ns}	

^{ns} Not significant.

* Significant at the 5% level.

Note: All means with the same symbols are from the same population.

Figure 5:- Average total uptake and concentration of calcium in four replications of barley (tops of plants) grown on La Palma fine sandy loam as affected by NP and Mg treatments.

Table 10. Total uptake and concentration of calcium as affected by NP and Mg treatments (Gila silt loam).

Treat- ment	Total uptake--mg./pot						Concentration--mg./gm. dry matter					
	Replications				Mean		Replications				Mean	
	1	2	3	4			1	2	3	4		
1	13.60	11.10	11.00	11.40	11.78	ab	11.50	8.70	9.40	9.85	9.87	
2	11.00	12.20	11.60	13.30	12.03	ab	9.31	10.45	9.69	11.14	10.15	
3	12.40	12.40	10.80	10.20	11.45	a	10.41	9.69	8.67	8.13	9.23	
4	8.10	8.80	9.70	13.80	10.10	a	6.75	7.22	7.78	11.78	8.38	
5	13.30	10.00	12.40	8.60	11.08	a	11.39	11.42	9.99	7.31	10.03	
6	16.60	11.00	14.10	15.40	14.28	bc	11.62	7.72	10.18	11.13	10.16	
7	14.40	14.20	13.40	14.40	14.10	bc	10.53	10.06	10.53	10.31	10.36	
8	13.10	12.10	12.40	11.70	12.33	abc	9.72	8.82	9.19	8.89	9.16	
9	15.50	15.20	13.60	14.30	14.65	c	11.45	11.72	9.97	11.66	11.22	
10	13.60	12.20	14.60	15.50	13.98	bc	10.38	9.33	11.28	12.48	10.87	
"F" value					4.09**						1.57 ^{ns}	

^{ns} Not significant.

** Significant at the 1% level.

Note: All means with same symbols are from the same population.

Figure 6:—Average total uptake and concentration of calcium in four replications of barley (tops of plants) grown on Gila silt loam as affected by NP and Mg treatments.

which resulted from the increase in growth with NP application. Total uptake of calcium was increased by 32-43 percent during the contact period (7-days) in La Palma fine sandy loam and 28-50 percent in Gila silt loam.

The total uptake and concentration of magnesium are presented in Table 11 and Figure 7 for La Palma fine sandy loam. The same data are presented in Table 12 and Figure 8 for Gila silt loam. There was no significant increase in either the total uptake or the concentration of magnesium in the plants with NP addition on both soils. Such a result may be attributed to the short period of contact used, which did not permit enough time for the slow absorption of magnesium to be influenced by NP treatments. Consequently, NP additions were not effective in producing an increase in total uptake of magnesium. This phenomenon of the slow absorption of magnesium by plants has been reported by other investigators (13, 17, 18). However, in a 7-day period of contact, the plant uptake of magnesium was increased by 22-53 percent in La Palma fine sandy loam and 13-49 percent in Gila silt loam.

As a consequence of the results obtained, it was decided to conduct another experiment with the same objectives, in which the contact period was extended to more than a 7-day period in order to study the effect of NP additions on magnesium absorption by barley plants.

Table 11. Total uptake and concentration of magnesium as affected by NP and Mg treatments (La Palma fine sandy loam).

Treat- ment	Total uptake--mg./pot					Concentration--mg./gm. dry matter				
	Replications				Mean	Replications				Mean
	1	2	3	4		1	2	3	4	
1	1.43	2.23	1.93	2.12	1.93	2.90	1.74	1.08	2.11	1.96
2	1.81	1.93	2.18	2.06	1.99	1.63	2.49	1.67	1.57	1.84
3	2.81	2.12	2.62	2.75	2.58	1.79	1.85	1.75	2.12	1.88
4	1.87	1.75	2.50	1.87	2.00	1.93	2.67	3.02	1.65	2.32
5	2.43	2.00	2.96	2.62	2.50	1.65	1.66	1.79	1.73	1.71
6	4.00	2.37	1.31	2.37	2.51	1.29	1.88	1.70	1.76	1.66
7	2.25	3.06	2.25	2.18	2.44	1.49	1.87	1.90	1.76	1.75
8	2.43	2.50	2.50	2.87	2.58	2.14	1.89	2.12	2.26	2.10
9	2.62	3.75	4.37	2.18	3.23	1.63	1.47	1.96	1.54	1.65
10	2.31	2.41	2.62	2.37	2.43	2.04	1.80	2.48	2.14	2.12
"F" value	1.96 ^{ns}					0.90 ^{ns}				

^{ns} Not significant.

Figure 7 :- Average total uptake and concentration of magnesium in four replications of barley (tops of plants) grown on La Palma fine sandy loam as affected by NP and Mg treatments.

Table 12. Total uptake and concentration of magnesium as affected by NP and Mg treatments (Gila silt loam).

Treat- ment	Total uptake--mg./pot					Concentration--mg./gm. dry matter				
	Replications				Mean	Replications				Mean
	1	2	3	4		1	2	3	4	
1	1.57	1.68	1.87	1.81	1.73	1.33	1.32	1.60	1.58	1.45
2	1.87	2.00	2.12	2.25	2.06	1.58	1.71	1.77	1.89	1.74
3	1.50	1.87	3.12	1.75	2.06	1.26	1.46	2.50	1.40	1.66
4	3.31	4.56	2.12	1.75	2.94	2.76	3.74	1.70	1.49	2.43
5	2.25	1.87	1.25	2.06	1.86	1.93	1.58	1.01	1.75	1.56
6	2.18	5.12	2.18	1.87	2.84	1.53	3.59	1.57	1.35	2.01
7	2.37	2.50	2.50	2.93	2.58	1.73	1.77	1.97	2.10	1.89
8	3.43	1.75	3.06	1.56	2.45	2.55	1.28	2.27	1.19	1.82
9	2.37	2.12	2.25	1.68	2.11	1.76	1.63	1.65	1.37	1.60
10	2.93	3.06	1.76	1.93	2.42	2.24	2.34	1.36	1.55	1.87
"F" value	1.07 ^{ns}					0.88 ^{ns}				

^{ns} Not significant.

Figure 8:-Average total uptake and concentration of magnesium in four replications of barley (tops of plants) grown on Gila silt loam as affected by NP and Mg treatments.

Tables 13 and 14 show data on the chemical analysis of soil samples taken after fertilizer application and after both soils had been held at 100 percent soil moisture equivalent for four days. From these data, it can be seen that there were no appreciable changes in pH values as a result of nitrogen and phosphorus applications to both soils. Soluble salts were increased with NP addition owing to an increase in concentration of certain anions like phosphate and nitrate, but there was no change in total soluble salts associated with magnesium treatments. In both soils, percent saturation of potassium did not show any change with NP application. However, percent saturation of calcium was increased by NP additions, especially in treatments 6, 7, and 10 compared to treatments 1, 2, and 5, respectively, in the case of La Palma fine sandy loam, and in treatment 6 compared to treatment 1 in Gila silt loam. Percent saturation of magnesium was increased with magnesium applications in treatments 8 and 10 over treatments 3 and 5, respectively, in La Palma fine sandy loam. In Gila silt loam treatments 6, 8, and 10 showed an increase in percent saturation of magnesium over treatments 1, 3, and 5, respectively. Generally, the results obtained from the chemical analysis of the soils after fertilization and constant moisture level could not be correlated with the results obtained from the plant tissue analysis.

Table 13. Chemical analysis of soil samples (after fertilizer application and held at 100 percent moisture equivalent for four days), La Palma fine sandy loam.

Treatment	pH values		T.S.S. mmhos. per cm.	Ammonium acetate soluble mg./gm. soil			Percent saturation		
	Soil paste	1:5		K	Ca	Mg	K	Ca	Mg
1	8.15	8.75	0.48	4.20	2.40	0.45	12.7	72.3	22.6
2	8.50	8.85	0.60	4.80	3.69	0.56	14.5	111.4	28.1
3	8.18	8.80	0.57	4.60	3.83	0.62	13.9	115.7	31.1
4	8.10	8.70	0.48	4.35	2.39	0.55	13.3	72.3	27.6
5	8.10	8.70	0.57	4.40	3.28	0.52	13.3	98.8	26.1
6	8.05	8.70	0.70	4.00	5.74	0.46	12.1	172.9	23.1
7	8.05	8.75	0.95	4.40	4.27	0.54	12.1	128.3	27.1
8	7.98	8.70	0.90	4.60	3.64	0.86	13.9	109.6	43.2
9	8.15	8.80	1.35	4.20	2.28	0.56	12.7	68.7	28.1
10	8.10	8.80	1.30	4.80	4.16	0.60	14.5	125.3	30.1

Table 14. Chemical analysis of soil samples (after fertilizer application and held at 100 percent moisture equivalent for four days), Gila silt loam.

Treat- ment	pH values		T.S.S. mmhos. per cm.	Ammonium acetate soluble mg./gm. soil			Percent saturation		
	Soil paste	1:5		K	Ca	Mg	K	Ca	Mg
1	7.70	8.50	0.75	2.25	4.34	0.11	5.6	107.2	4.5
2	7.75	8.70	1.85	2.40	5.94	0.27	5.9	146.7	11.1
3	7.75	8.65	1.80	2.70	5.97	0.28	6.7	147.7	11.5
4	7.75	8.75	1.45	2.60	4.48	0.28	6.4	110.7	11.5
5	7.80	8.80	1.40	2.70	5.69	0.25	6.7	140.8	10.3
6	7.50	8.60	1.90	2.70	5.68	0.21	6.7	140.3	8.7
7	7.45	8.40	2.00	2.70	6.01	0.26	6.7	148.2	10.7
8	7.40	8.35	2.10	2.70	5.55	0.39	6.7	137.4	16.1
9	7.45	8.40	2.20	2.70	3.58	0.20	6.7	88.4	8.3
10	7.45	8.45	1.90	2.70	5.82	0.36	6.7	143.7	14.8

Experiment II

The objective of this experiment was based on the hypothesis that the effect of NP additions on plant uptake of magnesium may be more pronounced if the period of root-soil contact was extended to more than one week. Gila silt loam was chosen for this study as it showed some promise in the first experiment. Three periods of contact were used--7-, 10-, and 12-day periods. The treatments applied for each period were identical to those used in Experiment I and are shown in Table 2. After the first week of contact, the plants began to show increasing wilting and yellowing of the leaves which was probably a result of inadequate drainage in the root zone. This condition probably accounts for most of the unexpected results obtained.

Table 15 shows the dry weight, total uptake and concentration of potassium, calcium, and magnesium in the plants of the control treatments. These data were used in obtaining the percent gains in plant dry weight and total uptake of the nutrients during the period of root-soil contact. These gains were expressed in a range representing the upper and lower limits.

The dry weights of plant tops in each pot as affected by NP and Mg treatments for the three periods of contact are shown in Table 16 and in Figure 9. The results indicate that dry weights were significantly increased by NP additions which confirm the results obtained in Experiment I. All treatments showed this increase except treatment 7

Table 15. Dry weight, total uptake, and concentration of potassium, calcium, and magnesium in plants from control treatments.

Repli- ca- tions	Dry weight gm./pot	Total uptake--mg./pot			Concentration--mg./gm. dry matter		
		K	Ca	Mg	K	Ca	Mg
1	0.88	41.00	6.41	1.25	46.86	7.32	1.43
2	0.82	39.00	6.51	1.13	47.46	7.92	1.37
3	0.84	39.00	7.09	1.13	46.39	8.43	1.34
4	0.82	35.50	6.60	1.75	43.22	8.04	2.13
5	0.82	37.00	6.70	1.06	44.89	8.13	1.29
6	0.86	40.00	7.09	0.94	46.74	8.28	1.10
7	0.87	37.50	7.48	1.06	43.36	8.64	1.23
8	0.85	38.50	6.99	1.31	45.40	8.24	1.55
Mean	0.85	38.44	6.86	1.20	45.54	8.13	1.43

Table 16. Dry weight (tops of plants) as affected by NP and Mg treatments (gm./pot).

Treat- ment	7-day contact period						10-day contact period						12-day contact period					
	Replications				Mean		Replications				Mean		Replications				Mean	
	1	2	3	4			1	2	3	4			1	2	3	4		
1	1.09	1.03	1.00	1.00	1.02	ab	1.05	1.14	1.17	0.99	1.09	c	0.86	0.96	0.92	0.93	0.92	ab
2	0.99	0.97	1.00	1.04	1.00	a	1.01	0.96	1.01	0.94	0.98	abc	0.79	0.89	0.88	0.88	0.86	a
3	0.98	1.01	1.00	1.00	1.00	a	0.95	0.99	0.91	0.96	0.96	ab	0.85	0.91	0.90	0.86	0.88	a
4	1.02	1.00	1.00	0.96	0.99	a	0.95	1.00	0.91	0.98	0.96	ab	0.99	0.78	0.86	0.85	0.87	a
5	1.02	0.97	0.96	1.02	0.99	a	0.96	1.00	1.04	0.97	0.99	abc	0.83	0.83	0.90	0.91	0.87	a
6	1.14	1.15	1.12	1.03	1.11	cd	0.96	0.95	0.97	1.00	0.97	abc	0.97	0.97	0.97	1.03	0.99	bcd
7	1.05	1.04	0.12	1.11	1.06	abc	1.00	1.00	0.95	1.05	1.00	bc	1.07	1.10	1.07	1.02	1.07	de
8	1.21	1.12	1.20	1.10	1.16	d	1.05	1.04	0.97	0.99	1.01	be	1.15	1.00	1.14	1.10	1.10	e
9	1.15	1.11	1.11	1.03	1.10	cd	0.93	0.96	0.90	0.91	0.93	a	1.08	0.91	0.95	0.96	0.97	bc
10	1.03	1.04	1.16	1.10	1.08	bc	1.08	1.04	1.03	1.01	1.04	cd	0.98	1.02	1.02	1.13	1.03	cd
"F" value					10.91**						4.74**						9.99**	

** Significant at the 1% level.

Note: All means with the same symbols are from the same population.

Figure 9:— Average dry weight of barley plants in four replications as affected by NP and Mg treatments and root-soil contact time.

which was not significantly different from treatment 2 in the 7-day contact period. The significance of this increase was not clear in the second group (10-day contact period), which might be due to the initiation of the aeration problem. In the third group (12-day contact period), all treatments showed significant increase with addition of nitrogen and phosphorus, except treatment 6 which did not show any significant increase over treatment 1. During the 7-day period of contact, the plants gained 14-27 percent in dry weight, while this gain was 9-22 percent in the 10-day period. In the 12-day period, the increase in dry matter was 1-23 percent. Actually, there was no increase in growth after the first week of the contact period, which is attributed to the effects of poor aeration on plant growth.

Potassium total uptake and concentration as affected by NP and Mg treatments for the three periods of contact are shown in Tables 17, 18, and 19 and in Figures 10, 11, and 12, respectively. As the data in these three tables indicate, there was a general decrease in both total uptake and concentration of potassium with the addition of nitrogen and phosphorus in all periods of contact. A possible explanation for reduced potassium uptake is that the inadequate aeration in the root media resulted in the subsequent impaired ion absorption due to the disturbance in the physiological function of the plant (5, 52). The gains in total uptake of potassium by plants during the three periods of contact were as follows: 15-27 percent in the first group (7-day period), 4-16 percent in the

Table 17. Total uptake and concentration of potassium as affected by NP and Mg treatments (7-day contact period).

Treat- ment	Total uptake--mg./pot						Concentration--mg./gm. dry matter					
	Replications				Mean		Replications				Mean	
	1	2	3	4			1	2	3	4		
1	55.0	55.0	52.5	48.0	52.6	c	50.6	53.5	53.7	48.2	51.5	e
2	54.0	46.0	54.0	53.0	51.8	c	54.5	47.4	54.1	51.1	51.8	e
3	48.5	50.5	49.0	51.0	49.8	bc	49.6	50.3	49.0	51.0	50.0	de
4	46.5	49.0	49.0	49.0	48.4	ab	45.8	48.8	49.2	51.0	48.7	cd
5	49.0	45.5	45.0	47.0	46.6	ab	48.0	46.7	47.0	46.0	46.9	bcd
6	52.0	52.0	54.5	49.0	51.6	c	45.8	45.4	48.7	47.7	46.9	bcd
7	50.0	45.5	45.0	51.0	47.9	ab	47.7	43.7	44.0	45.8	45.3	bc
8	54.0	51.5	55.0	46.0	51.6	c	44.6	45.9	45.9	42.0	44.6	ab
9	55.0	50.5	51.0	42.5	49.8	bc	47.8	45.3	46.0	41.2	45.1	abc
10	42.5	44.0	47.5	46.0	45.0	a	41.1	42.4	41.1	42.0	41.6	a
"F" value					2.89*						8.70**	

* Significant at the 5% level.

** Significant at the 1% level.

Note: All means with the same symbols are from the same population.

Figure 10:-Average total uptake and concentration of potassium in four replications of barley (tops of plants) as affected by NP and Mg treatments (7-days root-soil contact).

Table 18. Total uptake and concentration of potassium as affected by NP and Mg treatments (10-day contact period).

Treat- ment	Total uptake--mg./pot						Concentration--mg./gm. dry matter					
	Replications				Mean		Replications				Mean	
	1	2	3	4			1	2	3	4		
1	41.5	46.0	43.5	42.0	43.3	b	39.5	40.2	37.2	42.6	39.9	a
2	43.0	43.5	46.0	44.0	44.1	bc	42.4	45.5	45.5	46.7	45.0	c
3	44.0	45.5	41.0	45.0	43.9	bc	46.2	45.8	44.9	46.8	45.9	c
4	44.0	47.0	42.5	45.0	44.6	bc	46.5	46.9	46.6	46.1	46.5	c
5	45.0	46.0	46.0	43.5	45.1	bc	46.9	46.2	44.4	44.9	45.6	c
6	41.0	42.0	42.0	41.0	41.5	ab	42.8	44.2	43.5	41.0	42.9	b
7	43.0	42.5	41.0	46.0	43.1	b	43.2	42.5	43.5	43.6	43.2	b
8	44.0	46.0	43.0	41.0	43.5	bc	41.9	44.4	44.4	41.4	43.0	b
9	40.0	41.0	39.5	39.5	40.0	a	42.9	42.7	44.0	43.3	43.2	b
10	46.0	48.0	44.0	46.0	46.0	c	42.8	46.1	42.9	45.7	44.4	bc
"F" value					4.46**						8.31**	

** Significant at the 1% level.

Note: All means with the same symbols are from the same population.

Figure II:- Average total uptake and concentration of potassium in four replications of barley (tops of plants) as affected by NP and Mg treatments (10-days root-soil contact).

Table 19. Total uptake and concentration of potassium as affected by NP and Mg treatments (12-day contact period).

Treat- ment	Total uptake--mg./pot					Concentration--mg./gm. dry matter				
	Replications				Mean	Replications				Mean
	1	2	3	4		1	2	3	4	
1	44.0	44.0	45.5	45.5	44.8	50.9	46.1	49.5	48.7	48.8 d
2	40.0	42.0	38.0	42.5	40.6	50.8	47.5	43.5	49.2	47.7 cd
3	38.5	47.0	44.0	41.0	42.6	45.4	51.8	48.9	47.5	48.4 cd
4	48.5	36.0	41.0	41.0	41.6	48.9	46.0	47.9	48.0	47.7 cd
5	38.0	37.5	41.0	41.0	39.4	46.0	45.5	45.4	45.0	45.4 bc
6	43.5	40.0	45.0	44.0	43.1	44.9	41.4	45.4	42.7	43.6 ab
7	44.0	48.5	42.0	42.0	44.1	41.2	44.0	39.2	41.3	41.4 a
8	50.5	41.5	46.0	44.5	45.6	43.8	41.7	40.4	40.4	41.6 a
9	44.5	40.0	40.5	41.5	41.6	41.1	44.1	42.6	44.0	42.9 ab
10	40.5	47.0	42.0	47.5	44.3	41.5	46.3	41.4	42.2	42.9 ab
"F" value					1.66 ^{ns}	8.44 ^{**}				

^{ns} Not significant.

^{**} Significant at the 1% level.

Note: All means with the same symbols are from the same population.

Figure 12:-Average total uptake and concentration of potassium in four replications of barley (tops of plants) as affected by NP and Mg treatments (12-days root-soil contact).

second group (10-day period), and 2-16 percent in the third group (12-day period). By comparing these gains in the three periods, it is obvious how serious were the effects of the inadequate aeration on potassium absorption.

Tables 20, 21, and 22 show the total uptake and concentration of calcium as affected by NP and Mg treatments for the 7-, 10-, and 12-day periods of contact, respectively. The same data are shown in Figures 13, 14, and 15. Generally, there was a significant increase in total plant uptake of calcium with the NP addition in all periods of contact. The increases were more pronounced with all treatments except treatment 6 compared to treatment 1 in the 7-day period and the 12-day period. In the second group (10-day period of contact) the differences were not as clear as in the other two groups. With respect to calcium concentration, a significant increase was obtained as a result of NP additions, particularly in treatment 9 compared to treatment 4 in both the first group (7-day period) and the second group (10-day period). In the case of the 12-day contact period, the increase was more pronounced with all treatments except treatments 6 and 7 which did not show an increase over treatments 1 and 2, respectively. It is worthy to note that by comparing treatment 4 with treatment 1, in the 7-day and 12-day periods, it was found that calcium total uptake and concentration were decreased by the potassium addition. However, by comparing treatment 6 with treatment 9 in all the periods, there was no decrease in both

Table 20. Total uptake and concentration of calcium as affected by NP and Mg treatments (7-day contact period).

Treatment	Total uptake--mg./pot						Concentration--mg./gm. dry matter					
	Replications				Mean		Replications				Mean	
	1	2	3	4			1	2	3	4		
1	10.49	10.49	10.19	9.90	10.27	bcd	9.65	10.19	10.43	9.95	10.06	bc
2	9.81	10.19	10.68	10.78	10.36	bcd	9.89	10.50	10.69	10.40	10.37	c
3	9.42	9.32	10.19	9.90	9.71	abc	9.64	9.27	10.20	9.90	9.75	bc
4	8.45	9.90	8.84	7.48	8.67	a	8.32	9.86	8.88	7.79	8.71	a
5	9.42	9.13	9.32	10.10	9.49	ab	9.23	9.37	9.73	9.88	9.55	b
6	11.17	11.26	11.46	10.58	11.12	de	9.84	9.83	10.23	10.29	10.05	bc
7	11.07	10.19	11.26	11.65	11.04	e	10.56	9.79	11.02	10.47	10.46	c
8	13.11	10.78	11.46	11.07	11.60	de	10.83	9.60	9.56	10.10	10.02	bc
9	12.33	12.04	11.07	10.10	11.38	de	10.71	10.81	9.98	9.78	10.32	bc
10	9.90	10.10	11.85	11.46	10.83	cde	9.59	9.72	10.25	10.45	10.00	bc
"F" value					6.68**		6.52**					

** Significant at the 1% level.

Note: All means with the same symbols are from the same population.

Figure 13:- Average total uptake and concentration of calcium in four replications of barley (tops of plants) as affected by NP and Mg treatments (7-days root-soil contact).

Table 21. Total uptake and concentration of calcium as affected by NP and Mg treatments (10-day contact period).

Treat- ment	Total uptake--mg./pot						Concentration--mg./gm. dry matter					
	Replications				Mean		Replications				Mean	
	1	2	3	4			1	2	3	4		
1	10.49	11.75	10.87	9.81	10.73	cd	9.97	10.27	9.30	9.95	9.87	abc
2	10.10	9.61	10.39	10.19	10.07	bcd	9.97	10.06	10.27	10.81	10.28	bc
3	10.29	9.90	9.90	10.49	10.15	bcd	10.80	9.96	10.84	10.90	10.63	bc
4	9.81	6.41	9.03	8.54	8.45	a	10.37	6.39	9.90	8.74	8.83	a
5	9.71	10.10	8.84	8.93	9.39	abc	10.11	10.15	8.53	9.21	9.50	abc
6	9.13	7.96	8.35	10.39	8.96	ab	9.52	8.38	8.66	10.38	9.23	ab
7	10.87	10.87	9.22	11.46	10.61	cd	10.93	10.88	9.78	10.87	10.61	bc
8	10.49	11.46	11.07	10.29	10.83	c	9.98	11.05	11.42	10.39	10.71	c
9	9.71	10.10	9.81	8.93	9.64	abcd	10.42	10.52	10.92	9.79	10.41	bc
10	12.14	9.61	10.29	10.49	10.63	cd	11.30	9.22	10.04	10.41	10.24	bc
"F" value					3.73**						2.49*	

* Significant at the 5% level.

** Significant at the 1% level.

Note: All means with the same symbols are from the same population.

Figure 14:—Average total uptake and concentration of calcium in four replications of barley (tops of plants) as affected by NP and Mg treatments (10-days root-soil contact).

Table 22. Total uptake and concentration of calcium as affected by NP and Mg treatments (12-day contact period).

Treat- ment	Total uptake--mg./pot						Concentration--mg./gm. dry matter					
	Replications				Mean		Replications				Mean	
	1	2	3	4			1	2	3	4		
1	10.10	10.68	9.81	9.61	10.05	cd	11.69	11.19	10.66	10.30	10.96	c
2	7.67	8.64	8.35	8.45	8.28	a	9.74	9.76	9.55	9.57	9.65	a
3	8.25	8.45	8.74	8.84	8.57	ab	9.73	9.30	9.71	10.23	9.74	a
4	10.00	7.48	7.77	8.74	8.50	ab	10.09	9.55	9.08	10.23	9.74	a
5	8.64	9.03	10.10	10.00	9.44	bc	10.45	10.94	11.17	10.98	10.89	c
6	9.32	9.81	11.36	10.29	10.10	cd	9.61	10.16	11.45	9.98	10.30	abc
7	10.68	10.68	10.78	11.36	10.87	de	10.00	9.69	10.07	11.17	10.23	abc
8	12.43	10.68	11.46	11.75	11.58	e	10.78	10.74	10.05	10.67	10.56	bc
9	11.46	10.39	10.39	10.29	10.63	ee	10.58	11.44	10.92	10.92	10.97	c
10	10.10	10.68	10.39	10.97	10.53	d	10.36	10.14	10.24	9.74	10.09	ab
"F" value					12.29**						4.66**	

** Significant at the 1% level.

Note: All means with the same symbols are from the same population.

Figure 15:- Average total uptake and concentration of calcium in four replications of barley (tops of plants) as affected by NP and Mg treatments (12-days root-soil contact).

calcium uptake and concentration when nitrogen and phosphorus were applied with potassium. Such a result emphasizes the necessity for a base application of NP, for better absorption of calcium, in using the short-term nutrient absorption technique. It also indicates that potassium has no antagonistic effect on calcium when applied with nitrogen and phosphorus. The gains in total uptake of calcium by plants during contact periods were as follows: 21-41 percent for the 7-day contact period, 19-37 percent for the 10-day contact period, and 17-41 percent for the 12-day contact period. These results indicate that calcium absorption was not affected as much as potassium by limited aeration in the root media. This can be accepted on the basis that potassium is more involved than calcium in the respiration processes which depend to a great extent on the oxygen supply to the roots (5, 24).

The data on magnesium uptake and concentration as affected by NP and Mg treatments are shown in Tables 23, 24, and 25 for the 7-day, the 10-day, and the 12-day periods of contact, respectively. Figures 16, 17, and 18 present the same data for the three periods of root-soil contact. Total uptake and concentration of magnesium were significantly increased by NP additions in the first group (7-day contact period). It seems that the potassium addition (presented in treatment 9 compared to treatment 4) increased magnesium content more than did the NP additions. This indicates that potassium did not suppress magnesium uptake by plants under the conditions of the experiment. Such a result supports

Table 23. Total uptake and concentration of magnesium as affected by NP and Mg treatments (7-day contact period).

Treat- ment	Total uptake--mg./pot						Concentration--mg./gm. dry matter					
	Replications				Mean		Replications				Mean	
	1	2	3	4			1	2	3	4		
1	2.31	1.50	1.56	1.56	1.74	ab	2.13	1.46	1.60	1.57	1.69	a
2	1.69	1.69	1.19	1.25	1.46	a	1.70	1.74	1.19	1.21	1.46	a
3	1.69	2.00	2.00	1.88	1.89	ab	1.73	1.99	2.00	1.88	1.90	a
4	2.88	2.00	2.19	3.13	2.55	c	2.83	1.99	2.20	3.21	2.56	b
5	2.00	1.31	1.81	1.44	1.64	ab	1.96	1.35	1.89	1.41	1.65	a
6	2.56	2.38	1.94	1.75	2.16	bc	2.26	2.07	1.73	1.70	1.94	a
7	2.00	1.94	1.50	1.50	1.74	ab	1.91	1.86	1.47	1.35	1.65	a
8	1.75	2.06	2.63	2.00	2.11	bc	1.45	1.84	2.19	1.83	1.83	a
9	1.94	1.50	2.13	2.13	1.92	ab	1.68	1.35	1.92	2.06	1.75	
10	2.00	2.18	1.50	2.19	1.97	ab	1.94	2.10	1.30	2.00	1.83	a
"F" value					3.21**						3.17**	

** Significant at the 1% level.

Note: All means with the same symbols are from the same population.

Figure 16:—Average total uptake and concentration of magnesium in four replications of barley (tops of plants) as affected by NP and Mg treatments (7-days root-soil contact).

Table 24. Total uptake and concentration of magnesium as affected by NP and Mg treatments (10-day contact period).

Treat- ment	Total uptake--mg./pot					Concentration--mg./gm. dry matter				
	Replications				Mean	Replications				Mean
	1	2	3	4		1	2	3	4	
1	2.44	1.94	2.13	2.19	2.17	2.32	1.69	1.82	2.22	2.01
2	2.44	1.81	2.25	1.81	2.08	2.41	1.90	2.22	1.92	2.11
3	1.76	2.25	1.75	2.13	1.97	1.84	2.26	1.92	2.21	2.06
4	2.19	1.13	2.06	2.56	1.99	2.31	1.12	2.26	2.62	2.08
5	2.13	1.88	3.06	2.25	2.33	2.21	1.88	2.96	2.32	2.34
6	2.13	2.88	2.25	2.25	2.38	2.22	3.03	2.33	2.25	2.46
7	1.69	1.75	1.88	2.25	1.89	1.70	1.75	1.99	2.13	1.89
8	2.25	1.75	2.38	2.06	2.11	2.14	1.69	2.45	2.08	2.09
9	2.00	2.00	2.06	1.88	1.99	2.22	2.08	2.30	2.06	2.16
10	1.63	2.94	2.38	2.00	2.24	1.51	2.82	2.32	1.99	2.16
"F" value					0.74 ^{ns}	0.73 ^{ns}				

ns Not significant.

Figure 17 :- Average total uptake and concentration of magnesium in four replications of barley (tops of plants) as affected by NP and Mg treatments (10-days root-soil contact).

Table 25. Total uptake and concentration of magnesium as affected by NP and Mg treatments (12-day contact period).

Treat- ment	Total uptake--mg./pot					Concentration--mg./gm. dry matter				
	Replications				Mean	Replications				Mean
	1	2	3	4		1	2	3	4	
1	1.69	1.86	2.44	2.00	2.00	1.95	1.96	2.65	2.14	2.18 ab
2	1.88	1.84	2.13	1.88	1.93	2.38	2.08	2.43	2.13	2.25 b
3	2.13	1.94	2.63	1.75	2.11	2.51	2.13	2.92	2.03	2.40 b
4	1.94	1.81	1.72	1.69	1.79	1.95	2.32	2.01	1.98	2.06 ab
5	1.94	1.75	2.06	2.44	2.05	2.34	2.12	2.28	2.68	2.36 b
6	1.88	1.94	1.44	1.94	1.80	1.93	2.01	1.45	1.88	1.82 a
7	2.19	2.06	2.50	1.94	2.17	2.05	1.88	2.34	1.90	2.04 ab
8	2.19	1.93	2.25	1.63	2.00	1.90	1.94	1.97	1.48	1.82 a
9	1.94	2.25	2.06	1.75	2.00	1.79	2.48	2.17	1.86	2.07 ab
10	1.94	1.69	1.75	2.06	1.86	1.99	1.66	1.72	1.83	1.80 a
"F" value	0.92 ^{ns}					2.87*				

^{ns} Not significant

* Significant at the 5% level.

Note: All means with the same symbols are from the same population.

Figure 18:-Average total uptake and concentration of magnesium in four replications of barley (tops of plants) as affected by NP and Mg treatments (12-days root-soil contact).

the findings reported by Adams and Henderson (1) and that found by Maier (37) and can be explained on the ground that the added K^+ ions displaced Mg^{++} ions into solution, thus making the latter more available to plants. In the other two groups: the 10-day and the 12-day periods of contact, there was no significant increase in the magnesium uptake as a result of NP additions. It was expected that absorption of magnesium might be affected by NP additions if the contact period was extended beyond 7 days; especially when it was observed that some positive results were obtained in the first period of contact (7-day period) in this experiment. But owing to the poor conditions of aeration, the mechanism of magnesium absorption was probably not proceeding in a normal manner. In the third group (12-day contact period) there was a slight decrease in magnesium concentration with NP addition, due to the dilution factor resulting from the slight increase in plant growth with NP additions. The gains in magnesium uptake during the contact periods were as follows: 18-54 percent for the 7-day period of contact, 37-50 percent for the 10-day period, and 33-44 percent for the 12-day period. These figures indicate that the total uptake of magnesium was slightly increased by increasing the time of root-soil contact.

Table 26 shows the chemical analysis of the Gila silt loam samples taken after fertilizer application and after the soil had been held at 100 percent moisture equivalent for four days without root contact. These data show that the pH values were slightly decreased with NP application,

Table 26. Chemical analysis of soil samples (after fertilizer application and held at 100 percent moisture equivalent for four days), Experiment II--Gila silt loam.

Treat- ment	pH values		T.S.S. mmhos. per cm.	Ammonium acetate soluble mg./gm. soil			Percent saturation		
	Soil paste	1:5 water extract		K	Ca	Mg	K	Ca	Mg
1	7.70	8.50	0.98	0.60	4.24	0.16	7.6	104.7	6.7
2	7.75	8.60	1.95	0.82	4.60	0.16	10.4	113.6	6.7
3	7.80	8.65	1.25	0.70	3.52	0.16	8.8	87.0	6.7
4	7.75	8.75	1.30	0.85	3.32	0.18	10.8	82.0	7.2
5	7.75	8.75	1.40	0.80	4.94	0.23	10.1	122.0	9.4
6	7.45	8.50	2.40	0.70	4.84	0.19	8.9	119.5	7.8
7	7.40	8.35	2.30	0.80	4.07	0.22	10.8	100.8	9.0
8	7.25	8.30	2.40	0.80	4.68	0.24	10.8	115.6	9.8
9	7.45	8.40	2.00	0.75	4.73	0.22	9.5	117.1	5.4
10	7.40	8.35	1.90	0.75	4.28	0.30	9.5	105.7	12.4

while the total soluble salts were slightly increased with all treatments and especially with NP application. This increase in soluble salts and the decrease in pH values with NP additions, suggests that the anions in the fertilizers added displaced some other anions such as SO_4^{--} on the soil particles and thus the latter were transferred into the soil solution.

It appears that NP applications generally increased the magnesium percent saturation except in treatment 9 in which no magnesium was added. Also, by comparing treatments 5 by 1 and 10 by 6, it is clear that magnesium addition to the soil increased the magnesium saturation on the soil exchange complex. The data show no considerable changes in percent saturation of potassium with NP addition. Only treatments 8 and 9 showed an increase in calcium saturation percentage over treatments 3 and 4 as a result of NP application. However, by comparing treatment 5 versus treatment 1, it seems that potassium application increased potassium, calcium, and magnesium saturation percentages. Generally, the results of the "treated soil" analysis could not be correlated with the results obtained from plant tissue analysis.

Experiment III

This experiment was conducted to study the effect of soil moisture on the uptake of magnesium, using the short-term nutrient absorption technique. Gila silt loam was chosen for this study, with the application of five treatments shown in Table 3. Two soil moisture levels were used--100 and 75 percent of the soil moisture equivalent. According to the results obtained in Experiment II, which indicated the extreme importance of furnishing the plant roots with an adequate supply of oxygen, it was decided to cut holes in the carton wall near the bottom to aid, together with the triangle cut in the bottom, in improving the aeration conditions in the root media.

Table 27 shows the dry weight, total uptake, and concentration of potassium, calcium, and magnesium in the plants of the control treatments. These data were used in obtaining the percent gains in plant dry weight and total uptake of the nutrients during the period of root-soil contact. These gains were expressed in a range representing the upper and lower limits.

Table 28 shows the dry weight of plants (tops) as affected by magnesium treatments and soil moisture level. The same data are shown in Figure 19. There was no significant difference in plant dry weight as a function of soil moisture level. This result might be accepted if one realized that the two soil moisture levels used provided an adequate level of moisture for the plants as far as amount of growth is concerned. The

Table 27. Dry weight, total uptake, and concentration of potassium, calcium, and magnesium in plants from control treatments.

Repli- ca- tions	Dry weight gm./pot	Total uptake--mg./pot			Concentration--mg./gm. dry matter		
		K	Ca	Mg	K	Ca	Mg
1	0.87	35.0	7.4	1.3	40.5	8.6	1.5
2	0.96	36.5	7.7	1.3	38.1	8.0	1.3
3	0.97	36.0	7.9	1.5	37.1	8.2	1.6
4	0.94	40.0	8.1	1.5	42.5	8.6	1.6
5	1.00	35.0	8.8	1.3	34.9	8.8	1.3
6	1.04	39.5	9.1	1.3	38.0	8.8	1.3
7	0.90	35.0	7.0	1.5	38.8	7.8	1.6
8	0.92	35.5	8.2	1.3	38.6	8.9	1.4
Mean	0.95	36.7	8.0	1.4	38.6	8.5	1.5

Table 28. Dry weight (tops of plants) as affected by magnesium treatments and soil moisture level (gm./pot).

Treat- ment	Replications				Mean
	1	2	3	4	
<u>100 percent moisture equivalent</u>					
1	1.44	1.31	1.43	1.32	1.38
2	1.46	1.41	1.37	1.38	1.41
3	1.42	1.36	1.50	1.31	1.40
4	1.42	1.36	1.50	1.31	1.40
5	1.41	1.33	1.55	1.33	1.40
<u>75 percent moisture equivalent</u>					
6	1.45	1.21	1.45	1.41	1.38
7	1.27	1.39	1.39	1.28	1.34
8	1.28	1.29	1.35	1.40	1.33
9	1.38	1.39	1.38	1.21	1.34
10	1.31	1.32	1.23	1.39	1.31
"F" value					0.72 ^{ns}

^{ns} Not significant.

Figure 19:- Average dry weight of barley plants in four replications as affected by Mg treatments and soil moisture level.

increase in dry weight of plants during the 7-day period of contact ranged between 28 and 33 percent.

Total uptake and concentration of potassium as affected by magnesium treatments and moisture level are shown in Table 29 and Figure 20. The total uptake of potassium was not significantly affected by either soil moisture level or by magnesium treatments. Potassium concentration, however, was significantly decreased by raising the soil moisture level. The decrease was more pronounced in treatments 8 and 9 compared to treatments 3 and 4. From the data shown in the table, it can be concluded that there was no significant effect of magnesium application on potassium uptake or concentration. During the 7-day period of contact, the growing plants gained the following in total uptake of potassium: 38-41 percent under the 100 percent moisture level and 40-44 percent under the 75 percent moisture level.

Table 30 and Figure 21 show the total uptake and concentration of calcium as affected by magnesium treatments and soil moisture levels. Total plant uptake of calcium was not significantly affected by soil moisture level or by magnesium treatments. However, calcium concentration showed the same trend as potassium, decreasing with increasing soil moisture level, particularly in treatment 9 compared to treatment 4. Again, like potassium, calcium concentration was not affected by magnesium addition. The total uptake of calcium was increased during the 7-day period of contact by the following amounts: 41-44 percent for

Table 29. Total uptake and concentration of potassium as affected by magnesium treatments and soil moisture level.

Treat- ment	Total uptake--mg./pot					Concentration--mg./gm. dry matter					
	Replications				Mean	Replications				Mean	
	1	2	3	4		1	2	3	4		
100 percent moisture equivalent											
1	62.5	52.2	63.5	56.5	58.8	43.5	39.8	44.3	42.7	42.6	a
2	65.0	60.0	54.0	60.2	59.8	44.5	42.5	39.5	43.5	42.5	a
3	61.0	53.0	61.0	64.5	59.9	42.9	38.9	40.8	49.3	43.0	ab
4	49.5	59.0	64.5	62.0	58.8	37.8	44.8	42.8	43.8	42.3	a
5	60.2	58.0	71.5	57.5	61.8	42.7	43.8	46.1	43.2	44.0	abc
75 percent moisture equivalent											
6	70.0	55.5	64.5	62.5	63.1	48.1	46.0	44.4	44.3	45.7	abcd
7	58.5	63.5	65.5	57.5	61.3	46.0	45.6	47.2	44.8	45.9	abcd
8	66.0	63.5	63.5	68.0	65.3	51.6	49.1	47.2	48.6	49.1	c
9	65.5	66.0	66.0	57.0	63.6	47.4	47.5	47.7	47.3	47.5	cd
10	64.0	64.0	53.5	63.5	61.3	49.1	48.5	43.6	45.6	46.7	bcd
"F" value					0.75 ^{ns}						4.20**

^{ns} Not significant

** Significant at 1% level.

Note: All means with the same symbols are from the same population.

Figure 20 :- Average total uptake and concentration of potassium in four replications of barley (tops of plants) as affected by magnesium treatments and soil moisture level.

Table 30. Total uptake and concentration of calcium as affected by magnesium treatments and soil moisture level.

Treat- ment	Total uptake--mg./pot					Concentration--mg./gm. dry matter					
	Replications				Mean	Replications				Mean	
	1	2	3	4		1	2	3	4		
<u>100 percent moisture equivalent</u>											
1	14.8	12.1	15.3	13.1	13.8	10.3	9.2	10.7	9.9	10.0	abc
2	15.1	14.7	13.6	13.5	14.2	10.3	10.4	9.6	9.8	10.1	abc
3	13.6	13.3	15.4	13.2	13.9	9.6	9.8	10.3	10.1	9.9	ab
4	11.8	12.9	15.0	14.7	13.6	9.0	9.8	10.0	10.4	9.8	a
5	14.3	12.8	17.4	13.1	14.4	10.1	9.7	11.2	9.9	10.2	abcd
<u>75 percent moisture equivalent</u>											
6	14.4	12.9	14.3	15.0	14.2	9.9	10.7	9.8	10.6	10.3	abcd
7	12.7	15.3	15.7	13.4	14.3	10.0	11.0	11.3	10.4	10.7	bcd
8	13.9	14.0	14.2	14.8	14.2	10.9	10.8	10.6	10.6	10.7	bcd
9	15.3	15.0	14.9	13.7	14.7	11.1	10.8	10.8	11.4	11.0	c
10	14.1	13.4	12.9	16.5	14.2	10.8	10.2	10.5	11.9	10.8	cd
"F" value					0.24 ^{ns}						2.70*

^{ns} Not significant.

* Significant at the 5% level.

Note: All treatments with the same symbols are from the same population.

Figure 21:-Average total uptake and concentration of calcium in four replications of barley (tops of plants) as affected by magnesium treatments and soil moisture level.

the 100 percent moisture equivalent and 44-46 percent for the 75 percent moisture equivalent.

With respect to magnesium, Table 31 and Figure 22 present the data for the total uptake and concentration of magnesium as affected by soil moisture level and magnesium applications. The data indicate that both the total plant uptake and the concentration of magnesium were significantly increased with an increase in soil moisture. The increase was particularly pronounced with treatments 6 and 8 compared to treatments 1 and 3, respectively. With respect to the response of plants to magnesium addition in terms of magnesium uptake and concentration, treatment 3 was superior to treatments 2 and 5 under the 100 percent moisture equivalent. Other than that, no differences were obtained. During the 7-day contact period, the total plant uptake of magnesium increased by the following: 33-48 percent for the 100 percent moisture equivalent level and 22-36 percent for the 75 percent level. It is quite clear that magnesium uptake was greater with the 100 percent moisture equivalent level than with the 75 percent level.

The results obtained in this experiment indicate a differential behavior for the three ions--potassium, calcium, and magnesium--with respect to plant response as a consequence of soil moisture level. While magnesium was increased by the increase in soil moisture level both in the total uptake and concentration, potassium and calcium were decreased in concentration, and the total uptake was not affected. These results are

Table 31. Total uptake and concentration of magnesium as affected by magnesium treatment and soil moisture level.

Treat- ment	Total uptake--mg./pot					Concentration--mg./gm. dry matter					
	Replications				Mean	Replications				Mean	
	1	2	3	4		1	2	3	4		
100 percent moisture equivalent											
1	2.5	2.5	2.7	2.2	2.5 bc	1.8	1.9	1.9	1.6	1.8 bc	
2	2.0	1.8	1.9	2.6	2.1 ab	1.3	1.3	1.4	1.9	1.5 ab	
3	3.3	2.2	2.5	2.8	2.7 c	2.3	1.6	1.7	2.2	1.9 c	
4	2.3	2.1	2.4	2.2	2.2 abc	1.7	1.6	1.6	1.5	1.6 abc	
5	2.1	2.4	2.2	2.9	2.1 ab	1.5	1.8	1.4	1.4	1.5 ab	
75 percent moisture equivalent											
6	2.0	1.8	2.0	1.9	1.9 a	1.4	1.5	1.4	1.4	1.4 a	
7	1.9	2.4	2.0	2.6	2.2 ab	1.5	1.7	1.4	2.0	1.7 abc	
8	1.7	2.2	1.8	2.3	2.0 ab	1.3	1.7	1.3	1.7	1.5 ab	
9	1.9	2.0	2.5	1.6	2.0 ab	1.4	1.5	1.8	1.3	1.5 ab	
10	1.5	2.3	1.7	1.8	1.8 a	1.2	1.7	1.4	1.3	1.4 a	
"F" value	3.31**					2.6 *					

* Significant at 5% level.

** Significant at 1% level.

Note: All means with the same symbols are from the same population

Figure 22:—Average total uptake and concentration of magnesium in four replications of barley (tops of plants) as affected by magnesium treatments and soil moisture level.

in partial agreement with the results found by Mederski and Wilson (40) which showed that magnesium was linearly increased with increasing soil moisture up to field capacity under high humidity conditions. Potassium did not show the same linear increase under the same levels of humidity. Calcium did not show any differences under all levels of humidity.

The results obtained may possibly be explained in two ways. The first is based upon the dilution effect and the strength with which cations are adsorbed on the soil-exchange complex. Ca^{++} is known (60) to have a stronger adsorption capacity on the exchange complex than Mg^{++} and K^+ . In other words, Ca^{++} is more strongly held on the exchange sites than Mg^{++} and K^+ . By dilution, Mg^{++} ions can be readily exchanged by H^+ ions and thus brought into solution to be more available for root absorption. If this were the true picture, then K^+ ions would be expected to be more easily exchanged by H^+ ions resulting from dilution, and thus be more readily absorbed by the plant roots, but it might be that potassium was fixed in some way on or in the soil-exchange complex; consequently, such a behavior did not occur.

The second explanation is based upon the physiological function of each cation in the plant. Magnesium is known to be more involved in most of the respiratory reactions in the plant than potassium and calcium (5). Aeration and oxygen supply for plant roots are influenced by soil moisture level and therefore the plant respiration processes are

influenced by soil moisture. Under the conditions of the two moisture levels used in this study, an adequate supply of oxygen was assumed, and thus the moisture level was effective in influencing the ion uptake by plants in the manner of increasing the absorption of those ions that are more involved in the respiration reactions and other physiological processes. However, this explanation does not account for the decrease in potassium and calcium concentration by increasing soil moisture level.

Table 32 shows the chemical analysis of the soil samples taken after fertilizer application and after the soil had been held at 100 and 75 percent of the moisture equivalent for four days without root contact. These data indicate that there were no considerable differences in the pH values and total soluble salts between the various treatments as a function of soil moisture levels or magnesium applications. With respect to percent saturation of potassium and calcium, there were no differences associated with the soil moisture level or with magnesium applications. Also, there were no appreciable differences in percent saturation of magnesium except in treatments 2 and 5 in which percent saturation of magnesium was increased with magnesium and potassium additions under the 100 percent moisture equivalent, but under the 75 percent moisture equivalent level, the same treatments (treatments 7 and 10) did not show this increase. This indicates that magnesium availability increased with increasing soil moisture level. This result agrees with the results obtained from the plant tissue analysis and established the

Table 32. Chemical analysis of soil samples (after fertilizer application and held at 100 percent and 75 percent moisture equivalent for four days), Experiment III--Gila silt loam.

Treat- ment	pH values		T.S.S. mmhos. per cm.	Ammonium Acetate Soluble mg./gm. soil			Percent Saturation		
	Soil paste	1:5 water extract		K	Ca	Mg	K	Ca	Mg
1	7.15	8.20	2.45	0.32	5.40	0.18	4.0	133.4	7.2
2	7.20	8.25	2.20	0.32	5.27	0.44	4.0	130.4	18.3
3	7.10	8.30	2.55	0.35	5.24	0.20	4.5	129.5	8.3
4	7.15	8.40	2.15	0.32	5.38	0.22	4.0	132.9	9.0
5	7.20	8.40	1.90	0.35	5.34	0.28	4.5	131.9	11.3
6	7.35	8.45	2.40	0.32	4.89	0.20	4.1	121.1	8.3
7	7.20	8.30	2.20	0.32	4.92	0.23	4.0	121.5	9.3
8	7.30	8.30	2.50	0.32	5.26	0.19	4.1	129.9	7.8
9	7.20	8.50	2.20	0.32	5.17	0.15	4.1	128.0	6.2
10	7.20	8.30	2.00	0.32	5.12	0.21	4.1	126.5	8.8

fact that magnesium absorption by plants increases with increasing soil moisture level from 75 to 100 percent of the soil moisture equivalent.

Experiment IV

The results obtained in Experiments I, II, and III were utilized in this experiment to evaluate the magnesium status of some alkaline and calcareous soils in Arizona using the short-term nutrient absorption technique. According to the results obtained in Experiments I and II, a base application of nitrogen and phosphorus was applied, and the contact period was 7 days. Based on the results obtained in Experiment III, the moisture level was adjusted to 100 percent moisture equivalent, and the source of magnesium used was Sul-Po-Mag. The following two treatments were applied for each soil tested:

1. 220 lbs. N/A. + 50 lbs. P/A. + 0 K + 0 Mg.
2. 220 lbs. N/A. + 50 lbs. P/A. + 84 lbs. K/A. + 50 lbs. Mg/A.

The soils tested in this experiment were: (1) Tours silty clay loam, (2) Cajon clay loam, (3) La Palma fine sandy loam, (4) Yavapai sandy clay loam, and (5) Casa Grande loam. Two comparisons were made for the data of plant dry weight and for each nutrient: one to test the response of each soil to magnesium applications, and the other to evaluate the differences between the soils used. The latter was separated in two tests: one for treatments receiving magnesium, and the other for those not receiving magnesium.

Table 33 shows the dry weight, total uptake, and concentration of potassium, calcium, and magnesium in the plants of the control treatments. These data were used in obtaining the percent gains in

Table 33. Dry weight, total uptake, and concentration of potassium, calcium, and magnesium in plants from control treatments.

Repli- ca- tions	Dry weight gm./pot	Total uptake--mg./pot			Concentration--mg./gm. dry matter		
		K	Ca	Mg	K	Ca	Mg
1	1.02	33.5	8.7	1.8	32.9	8.5	1.7
2	0.95	33.0	9.0	0.9	34.6	9.4	0.9
3	0.99	34.0	8.7	1.8	34.5	8.8	1.8
4	0.98	35.5	8.6	1.6	36.2	8.8	1.7
5	1.06	38.0	8.5	1.9	35.9	8.1	1.8
6	1.00	35.0	8.6	1.8	35.2	8.7	1.8
7	1.02	35.5	8.7	2.3	34.8	7.9	2.3
8	0.98	32.0	8.0	2.2	32.7	8.5	2.2
9	0.99	34.5	8.3	2.3	34.8	8.3	2.3
10	1.08	37.5	8.2	1.4	34.9	7.9	1.3
Mean	1.07	34.85	8.53	1.8	34.65	8.49	1.78

plant dry weight, and the total uptake of the nutrients during the period of root-soil contact. These gains were expressed in a range representing the upper and lower limits.

Data on the dry weights (tops of plants) are shown in Table 34 and in Figure 23. The data indicate that all soils did not show any significant response to magnesium addition in terms of the dry weights except Yavapai sandy clay loam. It also showed that there were no significant differences in dry weight of plants between the soils used in both cases--with and without magnesium addition. During the 7-day contact period the plant dry weight increased by 20-31 percent when no magnesium was added and 25-32 percent with magnesium addition.

Tables 35 and 36 and Figure 24 present the total uptake and concentration of potassium as affected by magnesium treatments and soil type. No significant response, in terms of potassium uptake and concentration, could be detected in any of the soils used except Yavapai sandy clay loam, which showed a significant increase in both potassium uptake and concentration. Also, there were significant differences between the soils used in terms of the total uptake and concentration of potassium with both no magnesium and magnesium treatments. In total potassium uptake, La Palma fine sandy loam gave the maximum response when no magnesium was added, followed by Yavapai sandy clay loam. When magnesium was added, Yavapai sandy clay loam gave the maximum response followed by La Palma fine sandy loam, and Casa Grande loam

Table 34. Dry weight (tops of plants) as affected by Mg treatments and type of soil (gm./pot).

Soil	Mg treat- ment	Replications				Means of treat- ments without Mg	Means of treat- ments with Mg	"F" value for Mg treat- ments within each soil
		1	2	3	4			
Tours silty clay loam	0	1.33	1.38	1.31	1.30	1.33		2.85 ^{ns}
	+	1.35	1.36	1.32	1.47		1.43	
Cajon clay loam	0	1.31	1.49	1.54	1.35	1.42		0.84 ^{ns}
	+	1.33	1.41	1.86	1.27		1.47	
La Palma fine sandy loam	0	1.46	1.70	1.41	1.43	1.50		0.84 ^{ns}
	+	1.52	1.56	1.56	1.62		1.57	
Yavapai sandy clay loam	0	1.58	1.54	1.55	1.59	1.56		22.49 ^{**}
	+	1.51	1.47	1.49	1.45		1.48	
Casa Grande loam	0	1.94	1.53	1.32	1.30	1.52		0.40 ^{ns}
	+	1.23	1.40	1.57	1.57		1.42	
"F" value for analysis between soils without Mg						1.38 ^{ns}		
"F" value for analysis between soils with Mg							0.64 ^{ns}	

^{ns} Not significant.

^{**} Significant at the 1% level.

Figure 23:-Average dry weight of barley plants in four replications as affected by magnesium application and soil type.

Table 35. Total plant uptake of potassium as affected by Mg treatments and soil type (mg./pot).

Soil	Mg treat- ment	Replications				Means	Means	"F"
						of	of	value
						treat- ments without Mg	treat- ments with Mg	for Mg treat- ments within each soil
		1	2	3	4			
Tours silty clay loam	0	46.5	47.0	44.0	47.0	46.1 ab		1.49 ^{ns}
	+	44.5	52.0	50.0	46.5		48.3 b	
Cajon clay loam	0	41.5	50.5	39.0	41.0	43.0 a		0.27 ^{ns}
	+	43.0	47.0	49.5	39.5		44.8 ab	
La Palma fine sandy loam	0	49.5	61.5	51.5	51.5	53.5 c		0.77 ^{ns}
	+	52.0	55.5	58.5	51.5		54.4 c	
Yavapai sandy clay loam	0	49.5	55.0	50.0	52.0	51.6 bc		6.20*
	+	55.0	56.0	58.0	58.0		56.8 c	
Casa Grande loam	0	44.5	44.0	39.0	43.0	42.6 a		0.38 ^{ns}
	+	40.5	41.0	43.5	42.0		41.8 a	
"F" value for analysis between soils without Mg						7.06**		
"F" value for analysis between soils with Mg							17.56**	

ns Not significant.

* Significant at the 5% level.

** Significant at the 1% level.

Note: All means with the same symbols are from the same population.

Table 36. Potassium concentration in plants as affected by Mg treatments and soil type (mg./gm. dry matter).

Soil	Mg treat- ment	Replications				Means of treat- ments without Mg	Means of treat- ments with Mg	"F" value for Mg treat- ments within each soil
		1	2	3	4			
Tours silty clay loam	0	35.1	34.1	33.5	36.1	34.7 bc		0.29 ^{ns}
	+	33.0	33.4	37.8	31.5		33.9 ab	
Cajon clay loam	0	31.6	33.8	25.3	30.4	30.2 ab		0.06 ^{ns}
	+	32.4	33.4	26.7	31.1		30.9 ab	
La Palma fine sandy loam	0	33.9	36.2	36.7	35.9	35.7 c		0.41 ^{ns}
	+	34.1	35.6	37.6	31.8		34.8 bc	
Yavapai sandy clay loam	0	31.3	35.8	32.3	32.7	33.0 abc		19.33**
	+	36.5	38.1	38.9	40.0		38.4 c	
Casa Grande loam	0	23.0	38.7	29.5	33.0	28.6 a		0.19 ^{ns}
	+	33.1	29.4	27.8	28.2		29.6 a	
"F" value for analysis between soils without Mg						4.84*		
"F" value for analysis between soils with Mg							7.90**	

ns Not significant.

* Significant at the 5% level.

** Significant at the 1% level.

Note: All means with the same symbols are from the same population.

Figure 24:-Average total uptake and concentration of potassium in four replications of barley (tops of plants) as affected by Mg application and soil type.

was the lowest. During the 7-day period of contact, the plants gained the following in total uptake of potassium: 18-35 percent when no magnesium was added and 17-39 percent with magnesium applied.

The data presented in Tables 37 and 38 and Figure 25 show the total uptake and concentration of calcium as affected by magnesium treatments and soil type. No significant response to magnesium addition in terms of calcium total uptake and concentration was shown by any soil. Also, there were no significant differences between soils in both total uptake and concentration of calcium when magnesium was not added. When magnesium was applied, Yavapai sandy clay loam was significantly higher than all other soils in terms of total uptake and concentration of calcium. The increases in calcium uptake during the period of contact (7 days) were: 11-38 percent without addition of magnesium and 10-46 percent with magnesium applied.

Magnesium uptake by plants and concentration data are presented in Tables 39 and 40 and Figure 26. With respect to total plant uptake of magnesium, all soils did not show any response to magnesium applications. Casa Grande loam showed some decrease in total plant uptake of magnesium with magnesium addition. This was probably due to the fixation of magnesium that might have occurred after fertilizer application. In terms of magnesium concentration in plants, Yavapai sandy clay loam was the only soil that gave a significant response to magnesium. The differences between soils expressed as total plant uptake of magnesium

Table 37. Total plant uptake of calcium as affected by Mg treatments and soil type (mg./pot).

Soil	Mg treat- ment	Replications				Means of treat- ments without Mg	Means of treat- ments with Mg	"F" value for Mg treat- ments within each soil
		1	2	3	4			
Tours silty clay loam	0	10.6	10.2	11.4	7.4	9.9		
	+	9.0	13.8	12.5	12.1		11.9 a	2.13 ^{ns}
Cajon clay loam	0	9.8	11.4	11.1	7.8	10.0		
	+	9.7	11.5	11.6	9.2		10.5 a	0.22 ^{ns}
La Palma fine sandy loam	0	10.4	11.5	12.2	11.2	11.3		
	+	12.2	12.4	8.2	9.9		10.7 a	0.37 ^{ns}
Yavapai sandy clay loam	0	14.6	9.6	15.6	16.2	13.9		
	+	14.6	16.0	15.2	17.3		15.8 b	1.21 ^{ns}
Casa Grande loam	0	10.6	11.4	9.5	6.9	9.6		
	+	8.8	11.8	8.4	9.0		9.5 a	0.01 ^{ns}
"F" value for analysis between soils without Mg						2.91 ^{ns}		
"F" value for analysis between soils with Mg							8.94**	

ns Not significant.

** Significant at the 1% level.

Note: All means with the same symbols are from the same population.

Table 38. Calcium concentration in plants as affected by Mg treatments and soil type (mg./gm. dry matter).

Soil	Mg treatment	Replications				Means of treatments without Mg	Means of treatments with Mg	"F" value for Mg treatments within each soil
		1	2	3	4			
Tours silty clay loam	0	8.0	7.4	8.7	5.5	7.4		1.70 ^{ns}
	+	6.7	8.9	9.5	8.2		8.3 a	
Cajon clay loam	0	7.5	7.6	7.2	5.2	7.0		0.02 ^{ns}
	+	7.3	8.2	6.3	7.3		7.2 a	
La Palma fine sandy loam	0	7.1	6.8	8.7	7.8	7.6		1.13 ^{ns}
	+	8.0	8.0	5.3	6.1		6.8 a	
Yavapai sandy clay loam	0	9.2	5.9	10.1	10.2	8.8		2.63 ^{ns}
	+	9.7	10.9	10.2	11.9		10.7 b	
Casa Grande loam	0	5.5	7.5	7.2	5.3	6.4		0.02 ^{ns}
	+	7.2	8.5	5.4	6.1		6.8 a	
"F" value for analysis between soils without Mg						1.93 ^{ns}		
"F" value for analysis between soils with Mg							7.97**	

^{ns} Not significant.

** Significant at the 1% level.

Note: All means with the same symbols are from the same population.

Figure 25:-Average total uptake and concentration of calcium in four replications of barley (tops of plants) as affected by Mg application and soil type.

Table 39. Total plant uptake of magnesium as affected by Mg treatments and soil type (mg./pot).

Soil	Mg treat- ment	Replications				Means of treat- ments without Mg	Means of treat- ments with Mg	"F" value for Mg treat- ments within each soil
		1	2	3	4			
Tours silty clay loam	0	2.3	2.6	2.6	1.6	2.3 b		0.23 ^{ns}
	+	2.1	2.0	2.1	2.5		2.2 ab	
Cajon clay loam	0	1.8	1.6	0.9	1.3	1.4 a		3.50 ^{ns}
	+	1.9	1.6	2.3	1.6		1.8 ab	
La Palma fine sandy loam	0	2.3	3.7	2.4	1.8	2.5 b		0.01 ^{ns}
	+	1.9	2.6	2.8	2.8		2.4 bc	
Yavapai sandy clay loam	0	3.0	1.9	2.3	2.1	2.3 b		5.09 ^{ns}
	+	3.2	3.0	3.2	2.5		3.0 c	
Casa Grande loam	0	2.5	2.5	2.4	1.9	2.3 b		8.68*
	+	1.6	1.8	2.0	1.1		1.6 a	
"F" value for analysis between soils without Mg						3.89**		
"F" value for analysis between soils with Mg							9.87**	

^{ns} Not significant.

* Significant at the 5% level.

** Significant at the 1% level.

Note: All means with the same symbol are from the same population.

Table 40. Magnesium concentration in plants as affected by Mg treatments and soil type (mg./gm. dry matter).

Soil	Mg treat- ment	Replications				Means of treat- ments without Mg	Means of treat- ments with Mg	"F" value for Mg treat- ments within each soil
		1	2	3	4			
Tours silty clay loam	0	1.8	1.9	2.0	1.3	1.7 b		
	+	1.6	1.3	1.6	1.7		1.5 ab	1.09 ^{ns}
Cajon clay loam	0	1.3	1.1	0.6	1.0	1.0 a		
	+	1.4	1.2	1.2	1.3		1.2 ab	2.70 ^{ns}
La Palma fine sandy loam	0	1.5	2.2	1.7	1.2	1.7 b		
	+	1.2	1.7	1.8	1.5		1.6 b	0.22 ^{ns}
Yavapai sandy clay loam	0	1.9	1.3	1.5	1.3	1.5 ab		
	+	2.1	2.0	2.1	1.7		2.0 c	9.14*
Casa Grande loam	0	1.3	1.6	1.9	1.5	1.6 b		
	+	1.3	1.3	1.3	0.7		1.2 a	4.79 ^{ns}
"F" value for analysis between soils without Mg						3.35*		
"F" value for analysis between soils with Mg							9.73**	

^{ns} Not significant.

* Significant at the 5% level.

** Significant at the 1% level.

Note: All means with the same symbols are from the same population.

Figure 26:-Average total uptake and concentration of magnesium in four replications of barley (tops of plants) as affected by Mg application and soil type.

and as magnesium concentration indicate that Cajon clay loam was the lowest, the others being almost equal, under conditions of no magnesium added. When magnesium was applied, Yavapai sandy clay loam gave the maximum response in total uptake and concentration of magnesium, followed by La Palma fine sandy loam. During the 7-day contact period, the change in total uptake of magnesium was: -22 to +29 percent when magnesium was not added and -9 to +39 percent when magnesium was added. These figures indicate some losses in the magnesium content of plants during the contact period. If we compare the magnesium content determined in the soil samples taken after fertilizer application and held at 100 percent moisture equivalent for four days (Table 41) with the magnesium content in the original soils (Table 4), we find a decrease in magnesium content in these soils. This decrease may be due to some fixation within the soil exchange complex. This might be the reasonable explanation for the losses that occurred in plant uptake of magnesium.

From these results, it is seen that although Yavapai sandy clay loam had the highest percent saturation of magnesium among all soils tested, it responded to magnesium application in terms of potassium total uptake and concentration and magnesium concentration in plants. These results agree with the fact (1, 10, 31) that soil response to magnesium does not depend upon the amount of exchangeable magnesium. However, as shown in the present data, Casa Grande loam which has

Table 41. Chemical analysis of soil samples (after fertilizer application and held at 100 percent moisture equivalent for four days), Experiment IV.

Soil	Mg treat- ment	pH value		T.S.S. mmhos. per ml.	Ammonium acetate soluble mg./gm. soil			Percent saturation		
		Soil paste	1:5 water extract		K	Ca	Mg	K	Ca	Mg
Tours silty clay loam	0	7.45	9.30	1.40	0.80	4.42	0.62	8.6	92.9	21.7
	+	7.40	8.25	1.85	0.80	4.54	0.62	8.6	95.4	21.7
Cajon clay loam	0	7.80	8.95	3.90	0.63	5.56	0.55	5.4	93.4	15.4
	+	7.85	9.00	4.00	0.63	5.56	0.57	5.4	93.4	15.9
La Palma fine sandy loam	0	7.85	8.75	1.80	0.95	4.48	0.21	14.7	134.9	10.4
	+	7.75	8.50	2.25	0.95	4.33	0.48	14.7	130.7	24.2
Yavapai sandy clay loam	0	7.50	8.45	1.90	0.35	4.80	0.64	3.6	96.5	21.4
	+	7.50	8.45	2.10	0.35	4.70	0.78	3.6	94.5	26.2
Casa Grande loam	0	7.95	9.60	5.10	0.35	1.38	0.16	9.0	69.1	13.6
	+	7.95	9.50	5.20	0.35	1.16	0.18	9.0	58.1	15.2

the lowest percent saturation of magnesium did not show any response to magnesium application as indicated by total plant uptake of magnesium. Generally, it seems that some other factor that could not be revealed under the conditions of this study is involved in determining the soil response to magnesium.

By using the short-term nutrient absorption technique in evaluating the magnesium content in different soils, measured by total uptake and concentration of magnesium, it was possible under the conditions used, to detect differences among the five soils used. Cajon clay loam showed the lowest total uptake and concentration of magnesium under conditions of no magnesium added, and the other soils seem to be equal. With addition of magnesium, Yavapai sandy clay loam showed the highest and Casa Grande loam the lowest responses to magnesium addition.

According to these results, it can be concluded that Yavapai sandy clay loam may need magnesium applications to support intensive plant growth.

Table 41 shows the chemical analysis of soil samples taken after fertilizer application and after the soil had been held at 100 percent moisture equivalent for four days without root contact. The data show that pH values and total soluble salts were not changed by magnesium addition in all soils analyzed. Percent potassium saturation was not changed by magnesium application. However, percent saturation

of calcium was decreased by the addition of magnesium only in Casa Grande loam and no change occurred in any other soil. Percent saturation of magnesium was increased in three soils: La Palma fine sandy loam, Yavapai sandy clay loam, and Casa Grande loam, being more pronounced in both La Palma and Yavapai soil, which confirms the results stated previously.

SUMMARY

This investigation was undertaken to study and evaluate the use of a short-term nutrient absorption technique for evaluating soil magnesium status. This technique was then used in the evaluation of the magnesium status of some of the calcareous soils in Arizona. The investigation included four greenhouse experiments of which the first three were concerned with establishing basic information on the conditions under which the short-term nutrient absorption technique could be used for soil magnesium studies. The fourth experiment was concerned with the evaluation of the soil magnesium status.

Samples representing six soils were collected from different locations in Arizona. They were chemically analyzed for pH value, soluble salts, cation exchange capacity, and NH_4Ac soluble-potassium, calcium, and magnesium. The moisture equivalent of the soils was also determined.

The first experiment was established to determine the need for base applications of nitrogen and phosphorus in a soil magnesium study using the short-term nutrient absorption technique. For this purpose, two different soils, Gila silt loam and La Palma fine sandy loam, were

used and fertilizer applications were added at the rate of 220 pounds of nitrogen per acre and 50 pounds of phosphorus per acre. Magnesium was applied at the rate of 50 pounds of magnesium per acre, in the forms of MgSO_4 and Sul-Po-Mag (available from International Mineral and Chemical Co., Skokie, Illinois, and containing 18.5 percent MgO and 22 percent K_2O). Barley (Hordeum vulgare) variety Arivat, was used as the test plant. The plants were grown in a minus magnesium sand culture for two weeks after which they were transferred to soil or soil and fertilizer media in which the plant roots were allowed to be in contact with the soil. At the end of a 7-day period of root-soil contact, the plant tops were harvested, dried, and analyzed for potassium, calcium, and magnesium. The results showed that plant growth (on dry weight basis) and potassium and calcium uptake were significantly increased by the application of nitrogen and phosphorus. However, there was no significant increase in magnesium uptake as a function of nitrogen and phosphorus applications. This was attributed to the short-period of root-soil contact used.

The second experiment was an extension of Experiment I, using three periods of root-soil contact: 7-day, 10-day, and 12-day periods. One soil--Gila silt loam--was chosen for this experiment with the application of the same treatments as used in Experiment I. The total dry weight of plants was increased significantly with the application of nitrogen and phosphorus, but the results obtained for potassium, calcium,

and magnesium were not definite due to lack of proper aeration conditions. However, there was a significant increase in magnesium uptake by plants as a function of nitrogen and phosphorus applications, only in the 7-day period of root-soil contact. The results of this experiment showed the extreme importance of assuring adequate and proper aeration conditions in the root zone.

The third experiment was concerned with the study of the effect of soil moisture on the uptake of magnesium, using the short-term nutrient absorption technique. For this purpose, Gila silt loam was the soil chosen with nitrogen and phosphorus applied at the same rates as in Experiments I and II. Magnesium was added at the same rate and in the same forms as in Experiments I and II, and two soil moisture levels--100 percent and 75 percent of the soil moisture equivalent--were used. The results showed that plant growth (on dry weight basis) was not affected by soil moisture levels. Potassium, calcium, and magnesium showed a differential behavior towards soil moisture treatments. Potassium and calcium concentrations in the plant tissue were decreased with increasing soil moisture, while the total uptake and concentration of magnesium were increased with an increase in soil moisture. Total plant uptake of potassium and calcium were not significantly affected by soil moisture level. Possible suggestions for these observations include the differential effect of dilution on the above mentioned ions in the soil,

and the different ways in which those ions are involved in the physiological functions of the plant.

In the fourth experiment, five different soils--Tours silty clay loam, Cajon clay loam, La Palma fine sandy loam, Yavapai sandy clay loam, and Casa Grande loam--were evaluated for their magnesium status using the short-term nutrient absorption technique, utilizing the conclusions from the first three experiments. Each soil was tested for its response to magnesium application (in the form of Sul-Po-Mag). The five soils were also tested for their variation in magnesium supplying power to the plant. Yavapai sandy clay loam was the only soil that showed significant response to magnesium application as indicated by the magnesium concentration in the plant tissue. However, Casa Grande loam showed also a significant response to magnesium application in terms of the total plant uptake of magnesium. The variation between the magnesium supplying powers of the soils used, expressed as magnesium total uptake by plants and magnesium concentrations, showed that with no magnesium applications, Cajon clay loam gave the lowest values, the other soils being equal. With magnesium applied, Yavapai sandy clay loam gave the highest magnesium uptake values followed by La Palma fine sandy loam, while the other soils were almost equal. It was concluded that among the six soils tested in this investigation, Yavapai sandy clay loam was the only soil which may need supplemental application of magnesium to support intensive plant growth.

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