NUTRIENT AVAILABILITY IN RELATION TO PLANT RESPONSE IN THE GREENHOUSE ON TEN SOILS OF THE MIDDLE EAST

By

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NUTRIENT STATUS OF SOILS

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AN ABSTRACT OF THE THESIS OF

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Title: Nutrient availability in relation to plant response in the greenhouse on ten soils of the Middle East.

A greenhouse pot experiment was conducted on ten soils of the Middle East growing corn and ryegrass with N, P, K, and Mg as variables applied at the respective rates of 300, 30, 200, and 50 mg per 1.5 kg of soil. A factorial experiment with N, P, K, and Mg each at five levels from 27 to 440 mg per 1.5 kg pot was conducted on two of the ten soils. Addition of N resulted in high yields of dry matter and indicated a severe N deficiency. Decreases in yield caused by omitting P varied between 10 and 40 percent with one soil that had no decrease. Responses to K or Mg were slight averaging about five percent for nine of the soils. The one soil from Turkey had considerable response to both K and Mg. Soil test values for P, K, and Mg correlated very closely with plant uptake, plant contents and response in yield of dry matter. Exchangeable K was reduced by cropping by about one half to two thirds. This indicated that continued heavy cropping might result in considerable K deficiency. Under the heavy cropping regime imposed in this study, available P of the soil was reduced to very low levels. Extractable Mg (N NH_4Ac) was slightly reduced by cropping and a release from non-extractable sources was indicated. The reciprocals of the soil test values for K and Mg correlated higher with plant response than the soil test values and indicated an improved fit with the curvilinear relationship.

Tentative critical levels, below which response to application might be expected were placed at 0.5 meq per 100 g of soil for K and 1.5 meq per 100 g for Mg when extracted with N NH_4Ac. The critical level for P was estimated to be about 10 ppm as determined by the Olsen method and about 20 ppm when determined by the Al-Abbas method. Further work was recommended.

The results obtained in the factorial experiment on two of the soils confirmed the responses obtained in the first experiment and indicated that at high levels of application of P, K, and Mg, positive interactions of nutrients had more influence on crop yields than the direct effects of added nutrients. The positive K-Mg and P-K interactions and the P-K-Mg three-way interaction implied the presence of a necessary balance of these three nutrients with regard to applying fertilizers to these soils.

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I. INTRODUCTION

The arable lands of the Middle East have been under a relatively intensive system of cultivation and the practice of the local farmers to remove all the above-ground portion of crops has probably lead to a depletion of the soil supply of nutrients. The calcareous nature of these soils results in a need for experimentation to assess nutrient availabilities or deficiencies under such conditions. Soil and plant analyses are being used but are limited to areas where the necessary studies of correlation by well-planned and well-conducted experiments are completed. The principal criterion for assessing the efficiency of testing soil for available nutrients is the degree of correlation of the analytical values with the data concerning plant growth, plant response to fertilizers, and nutrient uptake from the soil by the plant. Information on the effectiveness of the various methods of testing Middle East soils for P, K, and Mg is limited. Reports regarding the extent and degree of nutrient deficiencies under local conditions are conflicting. The need to investigate nutrient availability in the Middle Eastern soils, and the necessity of finding more reliable soil testing methods are of paramount importance for profitable farming.

To achieve these objectives a greenhouse pot experiment was conducted at the American University of Beirut, on ten soils from Jordan, Syria, Turkey, and Lebanon using the vertical split root technique (soil over sand). Maize and ryegrass were grown simultaneously in every pot to test the effect of exhaustive cropping on the availability of N, P, K, and Mg. Interactions of these nutrients were studied on two of the soils using a four-variable, rotatable, central composite design with two methods of placement of nutrients compared.

II. REVIEW OF LITERATURE

The importance of nutrient availability in soils has held the attention of research workers for a long time. Some of the data pertaining to K, P, Mg, and N availability in soils are reviewed here.

Soil Potassium

Hagin (1966) studied the effects of potassic fertilizers on peanuts in twelve commercial fields in Israel and used Woodruff's method (1955) to measure the energy of replacement of Ca by K (Δ F) as an indication of the K status of the soil. He found that K deficiency may be expected at -4000 calories per mole. Energies of -3400 calories or less corresponded to percentage K in the plants of 1.8 or more and indicated a satisfactory supply. This result on Middle East soils confirmed the data presented by Woodruff (1955) on acidic soils. He found that K deficiency was associated with (Δ F) values between -3500 to -4000 calories and excessive K as related to soil Ca when (Δ F) falls below -2500 calories.

De Freitas _et al_. (1966), trying to determine K deficient areas in Brazil where cotton was cropped, found that yield responses to potassic fertilizers would not be expected in soils containing 0.3 meq per 100 g or more of K determined by 0.05 _N_ HNO_3 which was reported equivalent to _N_ NH_4Ac in extraction power. Potassium saturation greater than 4 percent indicated an adequate supply of K.

In a study on coastal bermudagrass, Jordan (1966) found that response to applications of K on sandy loams and loamy sands occurred at K soil test values below 40 ppm (0.05 N HCl plus 0.025 N H_2SO_4 extract). In solution cultures maintained at constant K concentration, Asher and Ozanne (1967) found that at 1 μM K concentration, all of the twelve species studied were K deficient. Maximum yield in eight species was reached at 24 μM and above 95 μM, K concentration had little effect on yield, K content, dry matter percentage or root/top ratio of the plants.

In a field experiment in Israel with soils similar to those studied, Dovrat (1966) studied the response of rhodesgrass in legume mixtures to K fertilizers and to the availability of soil K expressed in terms of energies of replacement $[\Delta F(-1)]$. He found that ΔF decreased proportionally with N application and at approximately 4250 calories per mole overseeded legumes were K deficient. The grass was still able to extract sufficient K from the soil. Dwight and Caldwell (1960) studied, in a field experiment, the relationships of K and Mg in humic clay soils using sugar beets and potatoes. They found that the ½ pMg - pK values which reflected the ease of replacement of Mg by K in the saturated extract increased with K fertilization in three of four soils. This increase coincided with a reduction of Mg in the crop.

Van Diest (1963) correlated exchangeable soil K (N NH_4Ac) with that extracted by ammonium lactate-acetic acid and found a high correlation ($r = 0.98$). Schulte and Corey (1965) extracted K from soils with sodiumtetraphenylboron and using ryegrass as a test crop, found that there was a high correlation (r = 0.991) with plant available K. Scott and Bates (1967) studied K reversion by rewetting and found that rewetting with water was less effective than adding n-octanol with water and then drying. Hanway and Ozus (1966) found very high correlations of soil test values for K with percentage K contents of corn and ryegrass leaves grown on 24 soils in a greenhouse experiment.

Adams and Sayegh (1955) studied 31 soils from Lebanon in a greenhouse pot experiment and found that none of the soils appeared to respond to K fertilization.

Plant Potassium

Jourbitzky and Strausberg (1966) made foliar diagnosis of the tea plant. They found that the level of K nutrition does not affect the N and P concentrations in the leaves. Optimal concentration of leaf tips was placed at 2 percent K and a decline of 0.2 to 0.3 below this indicated a need for K fertilizers. In a field experiment on rhodesgrass grown with berseem or vetch, in Israel, Dovrat (1966) found that a K content of 0.65 and 0.74 percent was associated with starved plants for berseem and vetch, respectively. Concentrations of K, 1.63 percent for berseem and 1.75 percent for vetch, were associated with healthy plants. When K was applied its percentage in leaves rose to 2. A 1.2 percent or more K in cotton leaves at the onset of flowering indicated adequate K status according to de Freitas *et al*. (1966) working on Brazilian soils. Hagin (1966) found that a 1.8 percent K in peanut leaves indicated a satisfactory

K supply in soils of Israel. Bermudagrass was found to be adequately supplied with K when the plant content was 1 percent or more as described by Jordan et al. (1966) working with loamy sands and sandy loam soils.

In olives, Prevot and Buchmann (1960) proposed critical levels of K concentrations in vegetative leaves at 1.2 percent based on correlations with yield on calcareous soils of Tunisia. They reported critical levels in France at 0.74 percent and described a general K deficiency and low yields which might have resulted in underestimation of the critical level. The correlation between K content of leaves and olive yield was high.

Freeman (1967) studied the effect of K concentration on growth and mineral composition of vegetable seedlings in sand cultures and found that in red beets, cabbage, and ryegrass, changes in K concentration were balanced by changes in Na with relative constancy of Ca and Mg. In lettuce, Ca and Mg functioned in maintaining the balance.

Soil Phosphorus

Yield response to P application was observed on bermudagrass by Jordan et al. (1966) at P soil test values below 25 ppm in 0.05 N HCl plus 0.025 N H_2SO_4 extract. Plant contents above 0.16 percent P were adequate for maximum production on the sandy loams studied.

Loneragan and Asher (1967) studied the response of eight pasture species to P concentration in nutrient solution maintained at constant P over the range 0.04 to 24 uM. They found that increasing the rate of phosphate absorption from 1 to 10 μg atoms per g of fresh roots per day increased the growth of all species. Higher rates caused P toxicity in some species at P plant contents greater than 0.9 percent as evidenced by necrotic symptoms.

Van Diest (1963) compared seven methods for measuring labile inorganic soil P on ten soils from New Jersey using tomatoes as the greenhouse test crop. He found that water extraction gave the highest correlation with yield of P ($r = 0.99$). The ammonium lactate-acetic acid method ranked second ($r = 0.94$) but could give an estimate of exchangeable cations as well.

Gunary and Sutton (1967) studied soil factors affecting ryegrass uptake of P in greenhouse pots and found that short and long term uptake of P were well correlated with the logarithms of P concentration in solution and with a capacity factor (L-value) representing labile P. Olsen and Watanabe (1963) used differences in diffusion coefficients of P between sandy and clay soils to explain variations in rates of P uptake by corn seedlings from equal initial concentrations of P in the soil solutions. An equation predicted P uptake from sandy soils as being one third as much as from clay soils. Actual measurements on corn seedlings agreed closely with predicted values for P concentrations less than 0.2 ppm.

Peaslee (1967) studied indexes of available K, Ca, Mg, and P in six soils using tomatoes in a greenhouse experiment. He found that plant indexes for P were related to available P as extracted by sodium acetate plus acetic acid and to total organic P.

The critical level for P in vegetative olive leaves was found by Prevot and Buchmann (1960) to be 0.10 percent in Tunisia and agreed with levels found in France. The leaf content of P and olive yields were highly correlated.

Soil Magnesium

The reciprocal effects of Mg and K were studied by McLean (1949) in four clays. It was found that as K saturation increased, the activity of Mg dropped lower in montmorillonite than in other clays. Dwight and Caldwell (1960) studied Mg and K relationships in soils and plants using potatoes and sugar beets in a field experiment. Magnesium content was found lower in plants grown on soils treated with K than in plants from untreated soil. The ½ pMg - pK values reflecting ease of exchange of Mg by K increased in three of four soils. This increase in values coincided with a reduction of Mg in crops.

In a pot experiment on acidic soils, applying $CaCO_3$, $MgSO_4.7H_2O$ and $Ca(NO_3)_2$ increased percent Mg and total Mg uptake of oats according to Alston (1966). At Mg contents lower than 0.1 percent deficiency symptoms occurred widely. Mehlich and Reed (1948) studied the effects of exchange properties of soils on cation content of plants in a pot experiment using soybeans, oats, and turnips. They found that increasing K or Mg in soil increased K or Mg uptake by plants. If the ratio Ca to Mg or Ca to K increased in soil it increased in the plant and in the soil extract.

Indexes of available Mg in six soils ranging from alluvial schists to limestones were established by Peaslee (1967) through measurement of the uptake of Mg by tomatoes in the greenhouse. Laboratory indexes were determined by extracting with 0.73 M sodium acetate plus 0.53 M acetic acid, cation exchange resins, N NH_4Ac or 0.03 N NH_4F plus 0.025 N HCl. Plant indexes were closely related to laboratory indexes and laboratory indexes were highly correlated with each other.

Soil Nitrogen

In a greenhouse experiment with thirty-one soils from Lebanon, Adams and Sayegh (1955) used barley and lettuce as test crops. They found that only three of the soils did not show high response to applied N.

Koukoulakis (1967), studying the Zn-P-N interrelationships in a greenhouse experiment with maize grown on two calcareous soils from Lebanon, found large effect of N on yield and P and Zn plant composition for the two soils. Soil tests for NH_4^+ and NO_3^- nitrogen were correlated by Hanway and Ozus (1966) with plant uptake using corn and ryegrass in a pot experiment on twenty-four soils. Significantly high correlations were obtained.

III. MATERIALS AND METHODS

A greenhouse pot experiment was conducted to study the nutrient availability in ten soils from the Middle East. Exhaustive cropping was obtained by planting corn, together with ryegrass, and allowing to grow until two cuttings of the ryegrass were made. The effects of N, P, K, and Mg and their interactions were studied in two of these soils by use of a four-variable, central composite, factorial design.

Greenhouse Procedure

Ten soils (Table 1) were screened through a 0.6 cm plastic sieve. Clean, white mountain sand was collected from a mountain near Beirut. The sand was soaked in commercial hydrochloric acid for two weeks, then washed thoroughly with tap water to eliminate the calcium carbonate and other impurities.

Preparation of Cans

Cans of 15.5 cm diameter and 24.5 cm height lined with polyethylene bags were used. Clean sand was placed in each can to make the weight of can plus sand equal 2000 g. A 22 cm section of plastic hose (1.25 cm in diameter) was placed in the center of each can extending to a depth of about 1 cm from the bottom of the can. Field moist soil equivalent to 1500 g of oven-dry soil was placed on top of the sand in each can. Nutrients were added to the sand layer through the plastic hose in four aliquots (Table 2).

Table 1. Description and location of the ten soils used in the greenhouse study.

Soil	Location	Description	Crops
1	Abdeh, N.Lebanon	Calcareous, dark brown, clay	Corn
2[a]	Daudieh, S.Lebanon	Calcareous, brown to dark brown, clay	Wheat
3	Antalya, Turkey	Very calcareous, light brown, loam	Cotton, vegetables
4	Mreibet, Syria	Calcareous, greyish brown, clay loam	Cotton
5	Shweifat, Lebanon	Calcareous, yellowish brown, sandy loam	Olives
6	Arka, N.Lebanon	Very calcareous, greyish brown, clay loam	Olives
7	Massoudieh,N.Lebanon	Calcareous, dark brown, clay loam	Tomatoes
8	Abboudieh, N.Lebanon	Calcareous, black, clay	Vegetables
9	Rakka, Jordan	Calcareous, greyish brown clay to clay loam	Wheat
10[b]	Bazurieh, S.Lebanon	Very calcareous, light greyish brown, clay to clay loam.	Wheat, corn

a and b
Soils were used in a four-variable, central composite experiment.

Table 2. Form and total amount of nutrients added to the sand layer below the soil.

Nutrient	Form	Amount mg/pot	Stock solution ppm
N	$Ca(NO_3)_2$	300	3000
P	$Ca(H_2PO_4)_2$	30	300
K	K_2SO_4	200	2000
Mg	$MgSO_4$	50	500

Treatments consisted of:

1. NPMg or -K
2. NKMg or -P
3. PKMg or -N
4. NPK or -Mg
5. NPKMg or +All
6. Check or -All

The six treatments were replicated four times making a total of 240 pots. The cans were arranged in a split plot design with treatments as main plots and soils as the subplots. In the greenhouse, pots were frequently rotated within subplots, plots were rotated within replicates and replicates rotated in the greenhouse.

Experimental Design

Two soils, 2 and 10 (Daudieh and Bazurieh, Table 1), were subjected to a more comprehensive study using a central composite, rotatable, factorial design as described by Cochran and Cox (pp 370, 1957). This design allows the study of the yield response for the four variables, N, P, K, and Mg, at five levels each and allows the study of interactions among the variables. The levels of variables studied were coded as -2, -1, 0, +1, and +2 and were varied according to a logarithmic scale (Table 3). The design requires sixteen treatment combinations of the -1 and +1 coded levels, eight combinations of the very low or very high levels, -2 and +2 coded levels, and one treatment combination with all variables at the coded "0" level which is repeated seven times to provide a means of estimating the experimental error (Table 4).

Table 3. Applied N, P, K, and Mg and their levels in central composite, rotatable, factorial experiment.

Levels (log scale)	Coded values	N	P	K	Mg
		mg/pot			
1	-2	27.5	27.5	27.5	27.5
2	-1	55.0	55.0	55.0	55.0
3	0	110.0	110.0	110.0	110.0
4	+1	220.0	220.0	220.0	220.0
5	+2	440.0	440.0	440.0	440.0

Table 4. Treatment combinations (coded levels) applied to each can as required by the central composite, rotatable, factorial design.

Treatments	Variables			
	N	P	K	Mg
	Coded levels			
1	-1	-1	-1	-1
2	+1	-1	-1	-1
3	-1	+1	-1	-1
4	+1	+1	-1	-1
5	-1	-1	+1	-1
6	+1	-1	+1	-1
7	-1	+1	+1	-1
8	+1	+1	+1	-1
9	-1	-1	-1	+1
10	+1	-1	-1	+1
11	-1	+1	-1	+1
12	+1	+1	-1	+1
13	-1	-1	+1	+1
14	+1	-1	+1	+1
15	-1	+1	+1	+1
16	+1	+1	+1	+1
17	+2	0	0	0
18	-2	0	0	0
19	0	+2	0	0
20	0	-2	0	0
21	0	0	+2	0
22	0	0	-2	0
23	0	0	0	+2
24	0	0	0	-2
25 - 31	0	0	0	0

Two methods of placement of nutrients were studied, mixing with the soil and adding nutrients into the sand layer below the soil. In the latter method the amount of P added was cut down to half that reported in Table 3 because of less expected P fixation in the sand. Nitrogen was added as NH_4NO_3 when mixed with the soil. The total number of pots used in this experimental design was 124. Each group of 31 pots was randomly arranged in a block and rotated every week to eliminate microclimate differences in the greenhouse.

Nutrient Balance

Sulfur was balanced in all pots by use of $CaSO_4$ where nutrients were mixed with the soil or by use of a saturated $CaSO_4$ solution added to the sand layer below the soil in the other case. A micronutrient solution was prepared according to Hoagland and Arnon (1950) and added frequently to eliminate the effects of micronutrient deficiencies. Iron was added as the iron ethylenediaminetetraaceticacid chelate.

Seeding

On January 27, 1967, six seeds of corn and one gram of common ryegrass (Lolium multiflorum) seed were sown in each can. After seeding, 400 g of the clean sand were added on top of seeds in each can. According to Hanway and Ozus (1966), this layer provided a cover for the seeds, a slow and even loss of water which prevented drying of the soil, and a basis for cutting the ryegrass so that all plants would be cut to the same height. Distilled water was added to each can until a moisture content of 25 percent for the soil and 10 percent for the sand was reached. This corresponded to a total weight of 4500 g for each can. Every can is a closed system where excess water causes water logging, so the amount of water applied at each irrigation was that needed to bring the weight of each can back to 4500 g.

Ten days after planting, corn was thinned to four plants in each can. The first aliquot of nutrients was added through the plastic hose. Micronutrients and $CaSO_4$ were also added at this time. Another aliquot of nutrients was added on February 28.

Harvesting

Corn was harvested on March 14, 1967. Ryegrass was harvested on March 28, 1967. A third aliquot of nutrients was added together with micronutrients and $CaSO_4$. All plants were sprayed with metasystox to control an infestation of aphids. Only treatments containing N were harvested on April 25, 1967. The last aliquot of nutrients, micronutrients and $CaSO_4$ was added and another metasystox spray applied. All pots were harvested on May 25. The data of April 25 and May 25 were combined in order to equalize the total growth period for all treatments. Plants were oven-dried at 70^{o}C, weighed, ground through a 40 mesh sieve and stored for analysis.

Plant Analyses

Total K and Mg

Total K and Mg of plants were determined by digesting 0.5 g of dry matter in a nitric-perchloric acid system as suggested by Johnson and Ulrich (1959). A Beckman DU flame photometer was used to determine K and Mg in the digest.

Total P

Total P of plants was determined on the nitric-perchloric acid digest by color development with ammonium vanadate in a nitric acid system, Jackson (pp 153, 1958). A Fisher spectrophotometer was used to determine absorption by the yellow color.

Total N

Total N of plants was determined by the Kjeldahl method as reported by Jackson (pp 183, 1958).

Soil Analyses

Available P

Available P of soil was extracted with 0.5 M $NaHCO_3$, pH 8.5, and activated charcoal and the color was developed with ammonium molybdate-stannous chloride in HCl system (old Olsen method), Jackson, (pp 144, 1958). Another method consisted of shaking 1 g of soil with 20 ml of solution made up from 17 ml of 0.3 N NaOH and 3 ml of 0.5 N $Na_2C_2O_4$ (Al-Abbas and Barber, 1964). The color was developed with stannous chloride in ammonium molybdate HCl system. The new method of Watanabe and Olsen (1965) consisted of extracting with 0.5 N $NaHCO_3$, pH 8.5, and color development was made in ammonium molybdate and antimony K-tartrate in an ascorbic acid medium acidified with sulfuric acid to pH 5 (new Olsen method). Absorption of colored solutions was measured on a Klett-Summerson spectrophotometer.

Soil K

Total soil K was determined by decomposing 1 g of soil in H_2SO_4, $HClO_4$ and HF. The residue was dissolved in HCl (Jackson, pp 319, 1958). Fixed K was determined by extraction with HNO_3 (Pratt, 1951). Fixed K was also determined by shaking a 2 g sample of soil in 10 ml of 0.3 N Na-tetraphenylboron for either 15 minutes or 16 hours. Five ml of N NH_4Ac were added and the K salt dissolved in 50 ml of 95 percent acetone. The solution was evaporated to dryness at 60°C on a water bath and the residue dissolved in N NH_4Ac, according to Schulte and Corey (1965). Exchangeable K and Mg were determined by extraction with N NH_4Ac (Richards, 1954). However, Mg from $MgCO_3$ soluble in NH_4Ac was included. Therefore, the terms "extractable" and "exchangeable" will be used interchangeably. Exchangeable K on rewetted soil was determined by rewetting a 10 g sample with 7 ml of water mixed with 7 ml of n-octanol and dried for 48 hours at 110°C in a gravity draft oven. Exchangeable K was extracted with N NH_4Ac as described by Scott and Bates (1967). Potassium potential was determined by shaking 10 g of soil in 50 ml of 0.01 N $CaCl_2$ solution for 15 minutes. Calcium and Mg were determined by versene titration according to Davidescu et al. (1966). The energies of replacement of Ca or Mg by K were determined by saturating the soil for one hour and using suction for 15 minutes (Woodruff, 1955). The concentrations of Ca, K, or Mg were determined in extracts and digests by using a Perkin Elmer 303 atomic absorption spectrophotometer.

Soil Organic Matter

Soil organic matter was determined by oxidizing a 2 g sample with 10 ml of N $K_2Cr_2O_7$ and 20 ml of concentrated sulfuric acid for 30 minutes. The solution was back-titrated with ferrous ammonium sulfate (Jackson, pp 220, 1958).

Soil Nitrates

Soil nitrates were determined by extraction of 50 g of soil in 250 ml of phenoldisulphonic acid (Jackson, pp 198, 1958). The yellow color was developed with 6 N NH_4OH and absorption measured on a Klett-Summerson spectrophotometer.

Alkaline Earth Carbonates

Alkaline earth carbonates were determined by acid neutralization of 5 g sample with 50 ml of 0.5 N HCl and titrating excess acid with 0.25 N NaOH according to Richards (pp 105, 1954).

pH

pH was determined on a 1/2.5 soil to water ratio using a glass electrode.

Soil Particle-Size Analysis

Soil particle-size analysis was done according to the hydrometer method of Bouyoucos (1936).

IV. RESULTS AND DISCUSSION

The arable soils of the Middle East have been subjected to intensive cropping for centuries. Information on the effectiveness of the various methods of testing these soils for P, K, and Mg is limited. Conflicting reports regarding the extent and degree of nutrient deficiencies under local conditions resulted in the carrying out of this experiment.

To choose soils that might respond in the greenhouse to the various nutrients tested, a leaf and soil survey of twenty-eight fields in different parts of Lebanon was made in the summer of 1966. The soils had a range in exchangeable K content of 0.38 to 2.00 meq per 100 g of soil (Table 5) with five fields containing less than 0.50, fifteen fields between 0.50 and 0.99, and eight between 1.00 and 2.00 (N NH_4Ac extract). In general, 0.30 meq per 100 g of exchangeable K in the soil has been considered as the point below which K application would probably be profitable for most crops, (de Freitas, et al., 1966; Ulrich and Ohki, 1966). On the basis of this none of the twenty-eight fields would be considered K deficient. However, the calcareous nature of the soils and the generally high levels of cation exchange capacity indicate that 0.30 meq per 100 g may be too low for K sensitive or very high yielding crops. The soils with exchangeable K levels below 0.5 and possibly below 0.75 meq per 100 g might show response to K fertilization, especially under intensive cropping conditions. Leaf analysis indicated a K range of 0.97 to 1.43 percent

Table 5. Analysis of soil and leaf samples from twenty-eight fields in various parts of Lebanon.

Sample	Place	Soil[1]	Extractable (NH_4Ac) K	Na	Ca	Mg	Leaf Analysis[2] K, Petiole	K, Blade	Mg, Petiole	Mg, Blade
			meq per 100 g				Percent			
Potato 1	Beqa'a		0.56	0.52	76.3	5.7	5.55		1.19	1.01
Potato 2	Beqa'a		0.64	0.64	52.0	7.7				
Potato 3	Beqa'a		0.45	0.19	12.4	2.5	4.69	2.66	1.41	1.15
Potato 4	Beqa'a		0.76	0.17	24.3	3.7	5.24		1.34	
Potato 5	Beqa'a		0.63	0.08	22.5	3.5				
Potato 6	Beqa'a		0.64	0.74	83.5	7.0				
Tomato 1	Akkar		0.87	0.54	55.5	14.8	6.30	1.92		1.08
Tomato 2	Akkar	7	0.41	0.76	47.2	19.0	6.23	2.27	0.87	0.57
Tomato 3	Akkar	8	0.38	1.26	72.5	6.8	5.29	1.91	1.19	0.77
Tomato 10	Amchit		1.82	0.44	25.2	5.0	6.00	6.17	0.50	0.47
Tomato 11	Jbeil		2.00	0.21	30.2	6.0	5.05		1.06	
Tomato 12	Jbeil		1.66	0.22	61.1	4.0	5.97	2.69	0.71	0.46
Tomato 13	Halat		0.63	0.37	63.5	3.9	2.77	1.62	0.34	0.48
Tomato 14	Bo ar		1.76	0.36	62.3	5.1	5.76	2.94	0.56	0.46
							Vegetative leaves	Reproductive leaves	Vegetative leaves	Reproductive leaves
Olive I	Akkar		0.40	0.34	59.3	5.7	1.06	0.58	0.17	0.25
Olive II	Akkar		0.55	0.34	64.2	3.2	1.01	0.62	0.17	0.28
Olive III	Akkar	6	0.84	0.27	51.6	2.6	1.43	1.07	0.10	0.14
Olive 1	Shweifat		0.52	0.28	32.6	3.3	0.97	0.63	0.15	0.17
Olive 2	Shweifat		0.80	0.21	22.3	3.3	1.07	0.55	0.20	0.24
Olive 3	Shweifat	5	0.40	0.24	44.2	2.5	1.05	0.56	0.13	0.15
Olive 4	Shweifat		1.14	0.14	43.2	3.2	1.38	0.93	0.12	0.16
Olive 5	Shweifat		1.04	0.29	54.7	3.3	1.25	1.05	0.18	0.19
Olive 6	Shweifat		1.00	0.15	31.0	2.2	1.21	0.93	0.13	0.16
Olive 10	Koura		0.72	0.12	45.2	2.5	1.04	1.21	0.15	0.13
Olive 11	Koura		0.66	0.20	48.8	3.7	0.97	0.67	0.17	0.25
Olive 12	Koura		0.89	0.18	28.8	2.5	1.06	0.68	0.17	0.19
Olive 13	Koura		0.51	0.18	17.5	2.9	0.97	0.65	0.14	0.16
Olive 14	Koura		0.74	0.23	16.3	3.4	1.08	0.73	0.18	0.16

1. Soil number in greenhouse experiment.

2. K and Mg in leaves as percent dry matter basis 2 percent acetic acid extract.

in vegetative leaves of olives and 0.55 to 1.21 percent in the reproductive leaves. Prevot and Buchmann (1960) reported critical values for vegetative leaves in France at 0.74 percent and in Tunisia at 1.2 percent K. The much lower general yield level in France probably accounted for the difference. Since soil conditions here are closer to those for Tunisia than for France, it is possible that most of these samples have levels of K below the critical point. Two thirds of the leaf samples in this study had less than 1.2 percent K. A mean value of 1.09 percent K in vegetative leaves, ranging from 0.72 to 1.46 percent K was found by Fox et al.[1] in Turkey and is in good agreement with these values from Lebanon. Fox et al. found that yields were increasing up to the 1.5 percent level of leaf K under high lime conditions. Thus, they suggest that the value of 1.2 percent K reported for Tunisia may be too low. Leaf K of olives in Lebanon correlated significantly with exchangeable soil K for vegetative leaves ($r = 0.753^{xx}$) and for reproductive leaves ($r = 0.675^{x}$) indicating possible response to K application on olive trees.

The levels of extractable Mg include the exchangeable plus any $MgCO_3$ that dissolves in N NH_4Ac. This Mg ranged between 2.0 and 19.0 meq per 100 g of soil for the twenty-eight fields surveyed. A level of exchangeable Mg of 1.0 meq per 100 g or above is usually considered adequate at moderate K (Yamashaki et al., 1956). on this basis all of the twenty-eight soils would be expected to give little

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1. Fox, R.L., A. Aydeniz, and B. Kacar. 1960. Soil and tissue tests for predicting olive yields in Turkey.

response to Mg application. However, the calcareous nature of the soils and a fairly high level of soil K might result in response to Mg under some conditions or if excess K fertilizers are applied. Magnesium soil test values did not correlate significantly with the leaf content of Mg although there was a trend of increased leaf contents as the soil content increased.

Of the twenty-eight fields studied, soils from three of the lowest and one medium level K which varied in content of Mg from 2.5 to 19.0 meq per 100 g of soil were used in a greenhouse experiment together with three supposedly K deficient soils from Turkey, Syria, and Abdeh, Lebanon. A soil from Jordan and two soils from South Lebanon, one of which showed some previous response to K, made a total of ten soils. These soils were heavily cropped with corn and ryegrass in relation to the application of N, P, K, and Mg in a three-layer pot system. One harvest of corn and two harvests of ryegrass were made. Results of soil and plant analyses and their relationships will be discussed in the following sections.

Soil Test Relationships

The soil samples used in this study varied markedly in properties (Table 6). All soils were calcareous with pH values between 7.8 and 8.5. Three of the soils were very calcareous (over 60 percent $CaCO_3$) and one only slightly calcareous (3 percent). Soil texture varied from a sandy loam to a clay with a range from 21 to 69 percent clay. Initial nitrate-N varied from 9 to 42 ppm. Total N varied from 0.05 to 0.10 percent. Organic matter was generally low

Table 6. Characteristics of the soil samples at the time of potting for the greenhouse study.

Soil	1	2	3	4	5	6	7	8	9	10
pH	8.5	7.8	8.5	8.0	8.3	8.2	8.4	7.8	8.0	8.4
$CaCO_3$ equivalent, %	17.4	14.8	68.8	22.2	17.0	64.2	25.5	3.2	36.0	69.6
Sand, %	16	15	45	13	61	31	27	12	33	9
Clay, %	62	67	21	37	23	33	37	69	41	57
Cation exchange capacity, meq/100 g	48.5	59.0	7.5	14.3	10.8	20.4	34.8	80.5	15.1	18.8
Organic matter, %	1.9	1.5	2.4	1.2	1.3	2.0	1.2	1.3	1.3	1.7
Total N, %	0.101	0.070	0.087	0.051	0.052	0.080	0.064	0.064	0.055	0.078
Initial nitrate N, ppm	12	12	28	13	12	12	9	32	42	10
P (Old Olsen method) ppm	6.8	2.3	5.5	4.4	4.3	54.3	4.0	3.0	4.0	9.6
P (New Olsen method) ppm	5.8	2.2	4.8	4.1	4.1	35.0	3.3	3.8	4.3	9.5
P (Al Abbas method) ppm	29.6	4.7	7.5	18.7	19.6	50.8	21.3	19.4	18.5	18.3
K, Total, meq/100 g	9.4	15.3	1.8	32.5	9.0	9.2	16.3	7.6	22.4	4.6
K, NH_4Ac, meq/100 g	0.75	0.60	0.08	1.59	0.26	0.84	0.42	0.34	1.01	0.22
K, n-octanol rewetting, meq/100 g	0.31	0.30	0.05	0.94	0.19	0.57	0.26	0.26	0.69	0.12
K, HNO_3, meq/100 g	1.18	1.20	0.20	3.84	1.05	1.08	0.79	0.63	3.72	0.28
K, Na-tetraphenylboron, meq/100 g	0.56	0.57	0.38	4.24	0.94	1.20	0.60	0.26	2.28	0.40
K, $\lvert \Delta F \rvert = 1364 \log \frac{a_k}{\sqrt{a_{Ca}}}$	3125	3423	2765	1778	2666	2376	2924	3328	2140	3153
K, $pK - \frac{1}{2}p$ (Ca + Mg)	2.53	2.64	2.80	1.67	2.16	1.90	2.47	2.80	1.86	2.49
Mg, Total, meq/100 g	34.0	36.5	13.2	128.1	35.0	29.4	138.6	52.1	65.8	32.3
Mg, NH_4Ac, meq/100 g	6.7	3.4	1.2	5.7	1.3	1.4	6.4	21.7	4.8	1.9

ranging from 1.2 to 2.0 percent. Cation exchange capacity varied from 10.8 to 80.5 meq per 100 g of soil. Phosphorus and Mg were determined by several methods (Table 6) and there was a wide variation. Magnesium extracted with N NH_4Ac varied from 1.2 to 21.7 meq per 100 g of soil.

Samples of the soils were collected from some of the greenhouse treatments at the end of the cropping period. The P soil test values were reduced more by cropping where no P was added to the sand layer below the soil than when P was added (Figure 1). The slope of the regression line relating P soil tests before and after cropping was somewhat steeper where P was added indicating a lesser rate of extraction of soil P. Even where P was added in the nutrient solution the crops reduced the available P of the soil to a very low level under the heavy cropping regime imposed.

Exchangeable K was reduced in all soils by cropping. The decrease was related to the amount present before cropping (Figure 1). Stronger retention at low levels resulted in lower percentage reduction. This reduction of about one half to two thirds indicates that continued heavy cropping might result in considerable K deficiency. Potassium added to the sand layer below the soil resulted in higher soil test values after cropping than when it was not added. This effect is evident to a greater extent at high soil test values since at low K soil test levels reduction by cropping is not very appreciable. It is probable that part of the exchangeable K after cropping comes from the residues of the roots.

Extractable Mg was only slightly reduced by cropping

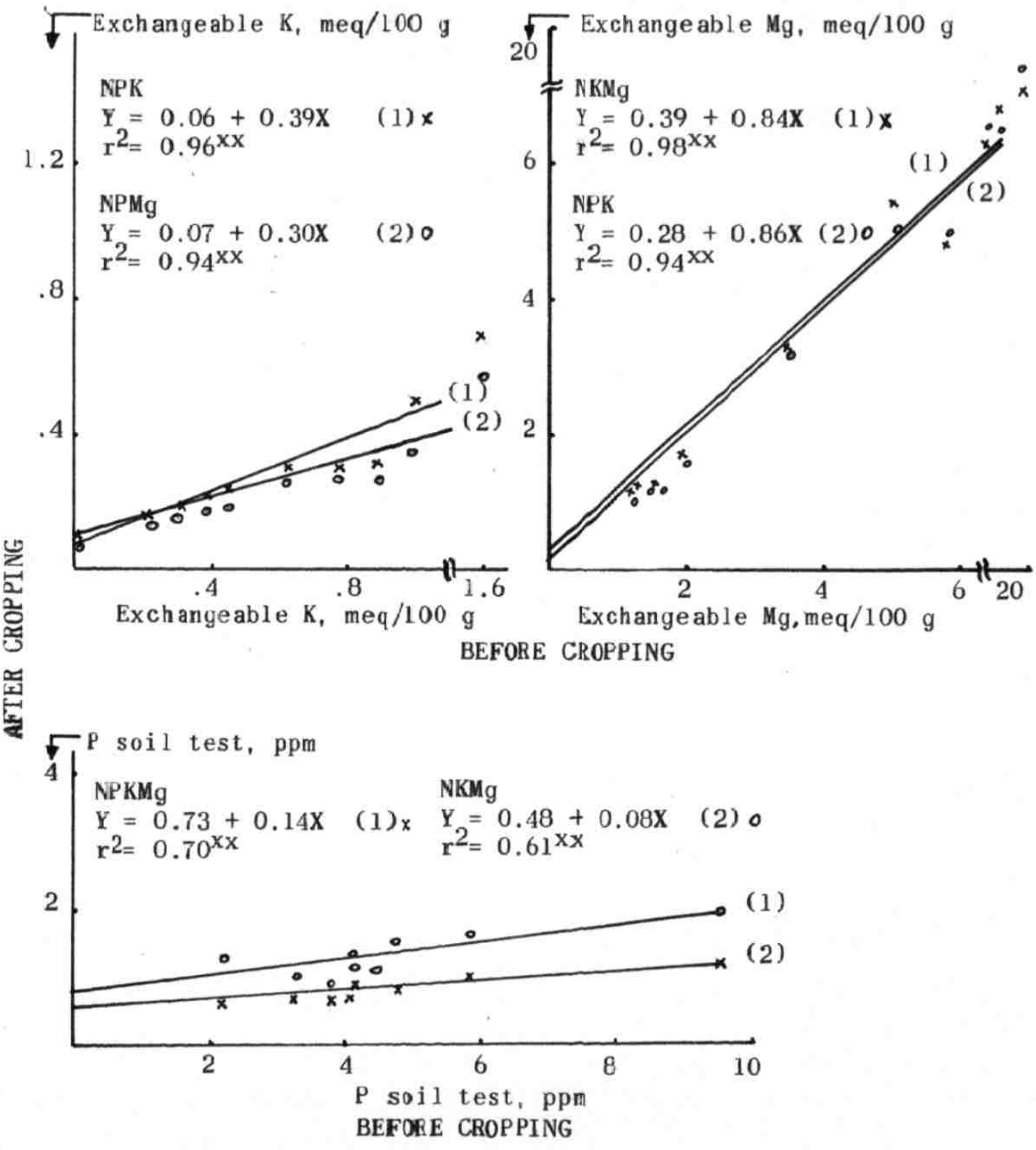

Figure 1. The influence of nutrient additions to the sand layer below the soil on P soil test values (Olsen method) and exchangeable K and Mg values ($\underline{N}$ NH_4Ac extract) in the soil samples after cropping in relation to values before cropping. (Soil 6 had high P and was not included in the regression).

(Figure 1). Regression lines are almost parallel with steep slopes equal to 0.86 and 0.84 for the NPK and NKMg treatments, respectively. The steep slopes of the regression lines are an indication of Mg release from non-exchangeable forms during cropping.

Effects of Nutrient Additions on Plant Growth, Composition and Nutrient Uptake

Periodic additions of P and Mg to the sand layer below the soil exceeded average removal, so it is assumed that there were adequate amounts of these nutrients available for plant use (Figure 2). However, average removal of K when N was added exceeded the amounts of added K. Similar results for P and K were obtained by Hanway and Ozus (1966) who used the same experimental technique.

Absence of P, K, or Mg resulted in decreased uptake of the nutrient omitted (Figure 3). When N was omitted, plant growth and P, K, and Mg uptake were depressed indicating a very severe N deficiency. The interference of K with Mg in plant nutrition showed in the higher uptake of Mg in the absence of K. Hovland and Caldwell (1960) reported three generalizations on this effect: 1. Addition of K to soils may decrease ease of replacement of soil Mg and result in less Mg being available for plants. 2. Increased K may provide more competition with Mg for exchange sites on plant roots and thus decrease the rate of Mg uptake. 3. High amounts of K in plants may in some way prevent Mg from performing its functions. The soil was presumably not involved here because added nutrients were placed in the sand layer below, but still the last two generalizations might apply.

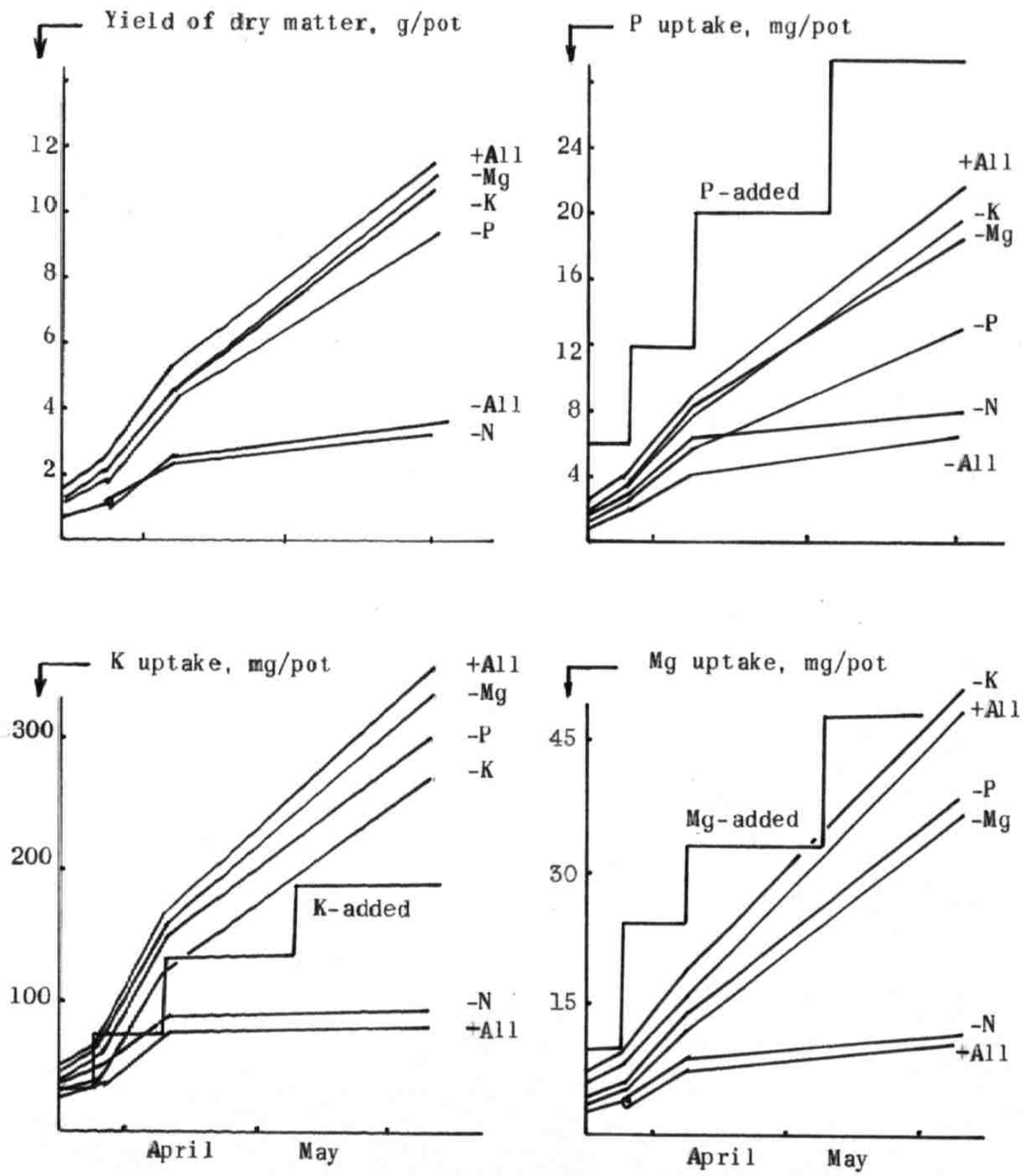

Figure 2. Amounts of P, K, and Mg added to the sand layer below the soil in relation to yield of dry matter and P, K, and Mg accumulation in the above-ground parts of the corn and ryegrass plants in the greenhouse. (Average of 10 soils).

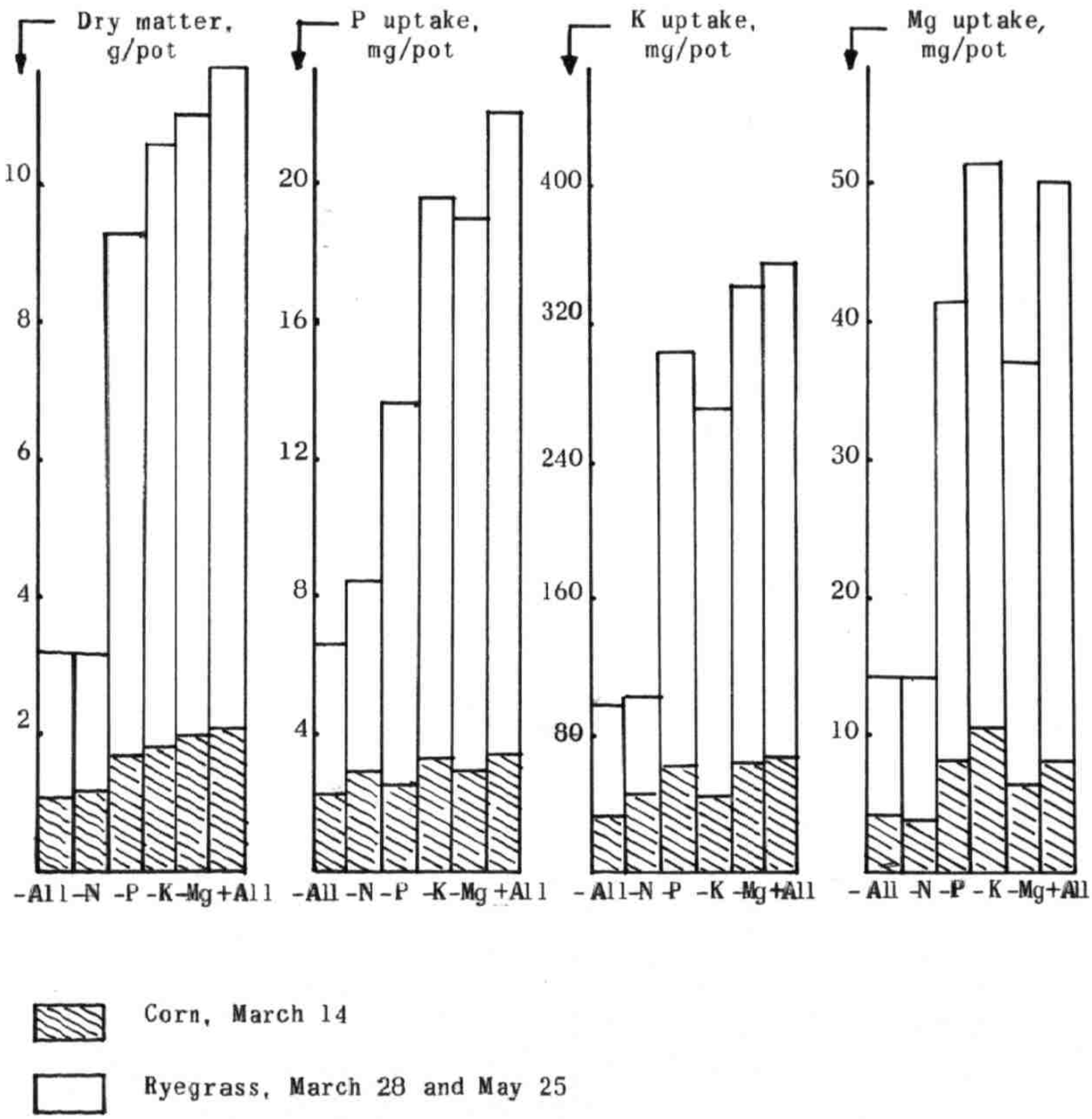

Figure 3. Yield of dry matter and P, K, and Mg uptake in the above-ground parts of the corn and ryegrass as influenced by the nutrient additions. (Average of 10 soils).

Omitting P resulted in lower uptake of P, K, and Mg most probably due to the decrease in yield caused by absence of P. Absence of N resulted in significantly lower yields throughout the growing season and in higher P concentrations in the corn and ryegrass (Table 7). The K concentrations were increased in corn harvested forty days after emergence while Mg concentrations were decreased. In the ryegrass plants harvested at later dates, absence of N resulted in lower K concentrations but higher Mg levels. Absence of P caused decreases in yield and in P concentrations but resulted in increased K and Mg concentrations. Omitting K resulted in very high Mg levels while omitting Mg had no significant effects on K or P levels nor on yield.

Relationships Between Laboratory and Greenhouse Test Results

Yield of Dry Matter

Total yield of dry matter varied widely between the treatments but not as much between the soils (Table 8). All soils showed severe N deficiency 67 to 80 percent decrease in yield when N was omitted. Nine of the soils had a 10 to 40 percent decrease in total yield when P was omitted with soil 6 showing no decrease and having a comparatively high soil test for P (Table 6). Only one soil (Soil 3) had a severe K deficiency. The other nine gave less than 11 percent decrease when K was omitted. Five of the soils had greater than 6 percent decrease in yield when Mg was omitted with soil 3 having 14 percent decrease. If soil 3 is left out the response to K and Mg is about equal and less than 5 percent on the average for

Table 7. Average dry matter yields and percent P, K, and Mg in the corn and ryegrass plants at different harvests from the different treatments in the greenhouse (comparisons were made with the + All treatment).

Treatment		Yield	P	K	Mg
		g/pot		Percent	
Corn March 14	-K	1.85^{x}	0.167	2.24^{xx}	0.509^{xx}
	-P	1.73^{xx}	0.131^{x}	3.47^{xx}	0.412^{xx}
	-Mg	1.93	0.145	3.25	0.277^{xx}
	+All	2.01	0.158	3.06	0.358
	-N	1.16^{xx}	0.237^{xx}	3.79^{xx}	0.312^{xx}
	-All	1.06^{xx}	0.188^{xx}	3.15	0.356
Ryegrass March 28	-K	2.95^{x}	0.176	3.12^{xx}	0.350^{xx}
	-P	2.61^{xx}	0.134^{xx}	3.54^{x}	0.328
	-Mg	2.99	0.182	3.52	0.271^{xx}
	+All	3.15	0.181	3.34	0.312
	-N	1.41^{xx}	0.244^{xx}	3.14^{x}	0.361^{xx}
	-All	1.48	0.196	3.17	0.348^{xx}
Ryegrass May 25	-K	5.88^{xx}	0.175	1.67^{xx}	0.620
	-P	5.00^{xx}	0.140	2.72^{xx}	0.501
	-Mg	6.08	0.164	2.45	0.412
	+All	6.12	0.168	2.48	0.543
	-N	0.57^{xx}	0.389^{xx}	2.03^{xx}	0.768^{xx}
	-All	0.69^{xx}	0.309^{xx}	1.88^{xx}	0.688

x Significant at 5% level.

xx Significant at 1% level.

Table 8. Total yield of dry matter for one harvest of corn and two harvests of ryegrass, average of four pots. N, P, K, and Mg were applied at the rates of 300, 30, 200, and 50 mg/pot, respectively. Nutrients were added to the sand layer below the soil in four applications.

Soil	Treatments						
	+All	-N	-P	-K	-Mg	-All	Average
				g/pot			
1 Abdeh	11.67	2.82	10.20	11.31	11.42	2.82	8.38
% Decrease		75.8	12.6	3.1	2.1	75.8	
2 Daudieh	12.01	3.05	7.26	11.10	11.18	3.56	8.07
% Decrease		74.6	39.6	7.60	6.9	70.4	
3 Turkey	11.59	4.10	7.95	6.27	9.93	4.15	7.34
% Decrease		64.6	31.4	45.9	14.3	64.2	
4 Syria	12.80	3.95	9.18	12.60	12.31	3.81	9.11
% Decrease		69.1	28.3	1.6	3.8	70.2	
5 Shweifat	11.31	2.84	8.85	10.57	9.76	2.77	7.68
% Decrease		74.9	21.7	6.5	13.7	75.5	
6 Arka	11.49	2.50	11.43	11.36	10.61	2.68	8.30
% Decrease		78.2	0.5	1.1	7.7	76.6	
7 Massoudieh	11.32	2.67	9.63	10.84	10.63	2.64	7.95
% Decrease		70.3	14.9	4.2	6.1	76.6	
8 Abboudieh	12.00	3.69	10.80	11.24	12.21	3.59	8.88
% Decrease		69.2	10.0	6.3	-1.7	70.1	
9 Jordan	11.61	2.33	8.77	11.76	11.41	3.21	8.18
% Decrease		79.9	24.5	-1.3	1.7	72.3	
10 Bazurieh	10.94	3.45	9.35	9.78	10.57	7.83	7.87
% Decrease		68.5	14.5	10.6	3.4	71.6	
Average	11.67	3.14	9.34	10.68	11.00	3.23	8.18
		73.1	20.0	8.5	5.7	72.3	

L.S.D.	.05	.01
Between two treatment means	0.430	0.545
Between two soils means	0.333	0.428
Between two soils for one treatment	0.815	1.045
Between two treatments for one soil	0.892	1.218

the nine other soils. Seven of the soils were chosen as being likely to show response either to K or Mg application. The heavy cropping imposed in this experiment has resulted in only slight K or Mg response. Analyses of the soils after cropping have shown that exchangeable K (N NH_4Ac) was reduced by cropping but most of the soils were over the critical limit of 0.30 meq per 100 g of soil reported and confirmed by de Freitas et al. (1966). The slight response to K and the relatively high exchangeable K even after intensive cropping indicate an adequate supply in most of the soils studied. Soil analysis for extractable Mg (N NH_4Ac) indicated a slight decrease after cropping. The response in yield to Mg application was slight indicating a good supply of Mg. All soils on which the plants responded to P application had P soil test values lower than 10 ppm (New Olsen method) and lower than 30 ppm (Al-Abbas method). Data reported by Bingham (1966) center around 10 ppm P as the medium level for many soils using the $NaHCO_3$ extraction (Olsen method). This, and the response to P indicate that the supply of P in the soils studied is not high.

Nitrogen

The nitrate-N in the soils at the time of potting had a controlling influence on the growth and N uptake by the plants during the early period of cropping when the plants were becoming established. However, the soils were severely N deficient (Tables 6 and 7) and the addition of P, K, and Mg without N had little effect on plant growth. Yields from the check and minus N treatments were similar. When initial nitrate-N in soils was correlated with decrease in yield (early harvest of corn, March 14, 1967) caused by absence of N, the correlation coefficient was significant ($r = -0.64^{x}$). Results from later harvests did not correlate significantly. There was little relation between total soil N and plant uptake ($r = +0.20$).

Phosphorus

The treatment in which P was not added to the sand layer below the soil is assumed to provide an estimate of the availability of soil P to plants. Dry weights of the plants, percent P in the plants and P uptake by the plants correlated significantly with the two P soil testing methods (Figure 4). This indicated that the laboratory soil tests provided a good estimate of P availability in these soils. Hanway and Ozus (1966) found similar correlations on soils from Iowa and by use of two modifications of the Bray method of testing. However, the two methods of soil testing used here did not extract similar amounts of P. The Al-Abbas method (Na-oxalate plus NaOH extraction) tested on soils of Indiana was recommended for soils of high pH. This method gave higher soil test values than the Olsen method ($NaHCO_3$ extraction) which is widely used for calcareous soils. Dry weight of the plants correlated more significantly with the Al-Abbas P soil test values ($r = 0.87^{xx}$) than with values obtained by the Olsen method ($r = 0.62^{x}$). The average weighted percentage of P in plants correlated higher with the Olsen soil test values ($r = 0.97^{xx}$) than with those of Al-Abbas ($r = 0.69^{x}$). Total P uptake correlated highly significantly with soil test values obtained by the two methods. Soil test values for P obtained by use of the Al-Abbas method correlated higher with decrease in yield

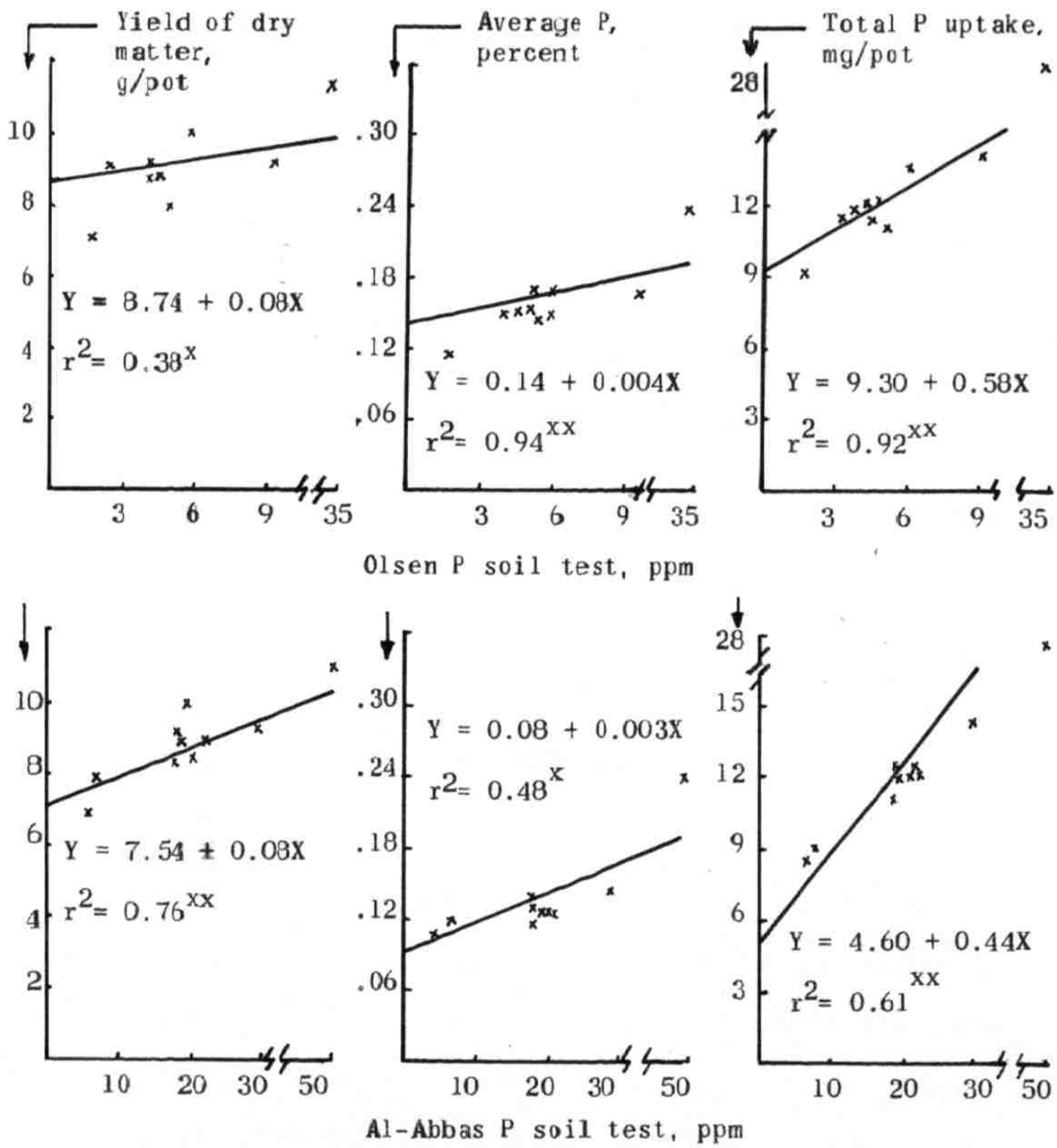

Figure 4. Combined data for all harvests for yield of dry matter, percentage P and P uptake in the above-ground parts of corn and ryegrass in relation to laboratory soil tests for P in different soils.

caused by omitting P ($r = -0.856^{xx}$) than those obtained by the old ($r = -0.62^{x}$) or new ($r = -0.70^{x}$) Olsen methods. The Al-Abbas method tended to be more accurate than the Olsen method for predicting responses in yield and further work should be carried out. However, the better correlation of the Olsen method for P concentration indicates that tissue levels and yields were not very closely related. The decrease in yield from omission of P did not give as high a correlation with P concentration in the plants ($r = 0.695^{x}$) as the correlation with the Al-Abbas soil test method ($r = -0.856$). It is possible that the Al-Abbas method tends to integrate all factors involving P, including indirect effects on micronutrients, to a greater extent than the Olsen method. However, further study is required with regard to these relationships.

Potassium

The K supplying power of a soil is a resultant of two factors, an intensity factor represented by water soluble and exchangeable K and a capacity factor represented by moderately available K and the rate at which it is released when the available forms are depleted. In the ten soils used in this study, total K (HF digestion) and fixed K (HNO_3 extract) correlated very closely ($r = 0.97^{xx}$) and ($r = 0.85^{xx}$), respectively, with the exchangeable K determined by neutral ammonium acetate extraction. This indicated that the rate of release from non-exchangeable to exchangeable forms was proportional to total amounts present. Zero to 90 percent of total K taken up by crops during intensive cropping came from moderately available sources as reported by Gholston and Hoover (1948) and Stewart and Volk (1946).

The rate of release varied from soil to soil. Arnold and Close (1961), reported extreme values ranging from no release to more than 2000 pp2m released to ryegrass in 590 days. In the study reported here, the K removal by corn and ryegrass exceeded depletion of soil exchangeable K ($\underline{N}$ NH_4Ac) in nine of the ten soils studied indicating release of K from non-exchangeable sources. This did not occur in one soil that was relatively high in exchangeable K. Plant uptake of K correlated very closely ($r = 0.98^{xx}$) with soil exchangeable K ($\underline{N}$ NH_4Ac) before cropping and with the decrease in exchangeable K ($r = 0.91^{xx}$) caused by cropping.

Correlations were made between the K soil test values as determined by different methods (Table 9) and the percent decrease in yield of dry matter caused by omitting K. Significant correlations were obtained when the reciprocal of soil K level was considered as the independent variable and the decrease in yield caused by absence of K as the dependent variable. The correlation coefficients for n-octanol rewetting and NH_4Ac extraction were 0.980^{xx} and 0.977^{xx} respectively. Inverting the soil test values gave more weight to soils of low exchangeable K and this has probably resulted in higher correlations. Total K, fixed K (HNO_3 extract) and percent K saturation did not correlate significantly with the decrease in yield caused by absence of K. Potassium extracted with sodium tetraphenylboron, K potential and energies of replacement of Ca by K did not give high correlations with decreases in yield caused by omitting K. This indicated that these methods may not apply on these soils, but more work is required. The more elaborate tests for soil K involving

Table 9. Coefficients of correlation of K soil test values and percent decrease in yield of dry matter caused by absence of K.

Soil test	r
Total K determined by HF digestion	-0.547
Exchangeable K, N NH_4Ac extract	-0.550
1/exchangeable K, N NH_4Ac extract	0.977[xx]
Exchangeable K, n-octanol rewetting	-0.592
1/exchangeable K, n-octanol rewetting	0.980[xx]
Percent K saturation, N NH_4Ac extract	-0.367
1/percent K saturation, N NH_4Ac extract	0.224
Fixed K, HNO_3 extract, before cropping	-0.257
Fixed K, HNO_3 extract, after cropping	-0.466
Plant available K, HNO_3, before cropping minus after cropping	-0.122
Plant available K, Na-tetraphenylboron extract, before minus after cropping	-0.484
1/plant available, Na-tetraphenylboron	0.600
Magnesium/potassium, N NH_4Ac extract	0.097
Potassium potential, $pK - \frac{1}{2}\,p(Ca + Mg)$	0.560
Energies of replacement, $\Delta F = 1364 \log \frac{a_k}{\sqrt{a_{ca}}}$	0.550
Solution K plus log (1 + exchangeable K, N NH_4Ac)	-0.330

the more strongly held K or the relative energies of retention did not improve correlation with response under the conditions of this experiment.

Attoe (1946), Luebs et al. (1956) and Scott and Hanway (1960) have shown that drying the soil sample before analysis changed the exchangeable K level in the sample and affected the availability to plants. Rewetting the soil with n-octanol, according to Scott and Bates (1967) reverted soil K to approximately that of field moist conditions. Extraction with N NH_4Ac was closely related to rewetting with n-octanol Y (n-octanol) = 0.004 + 0.598 X (NH_4Ac), $r^2 = 0.94^{xx}$ indicating about 40 percent reversion. This indicated that the scale of values in relation to probable response should be approximately 40 percent lower for field moist soils or n-octanol treated soils than for air dry soils.

Percentage K in corn and ryegrass correlated significantly with K soil test values determined by N NH_4Ac extraction (Figure 5). These results indicate that N NH_4Ac extraction may be used to estimate the availability of K in soils of the Middle East which are similar to those studied. Of the ten soils studied four were relatively high in K, 0.7 to 1.6 meq per 100 g in N NH_4Ac, and gave 1.2 percent response to K; three soils were medium, 0.3 to 0.6 , and gave 6 percent response; and three were low, 0.08 to 0.26 meq per 100 g, and gave 21 percent average response.

A tentative K soil test value (N NH_4Ac extract of air dry soil) below which maintenance amounts of K fertilizers should be applied under heavy cropping conditions might be placed at 0.5 meq per 100 g.

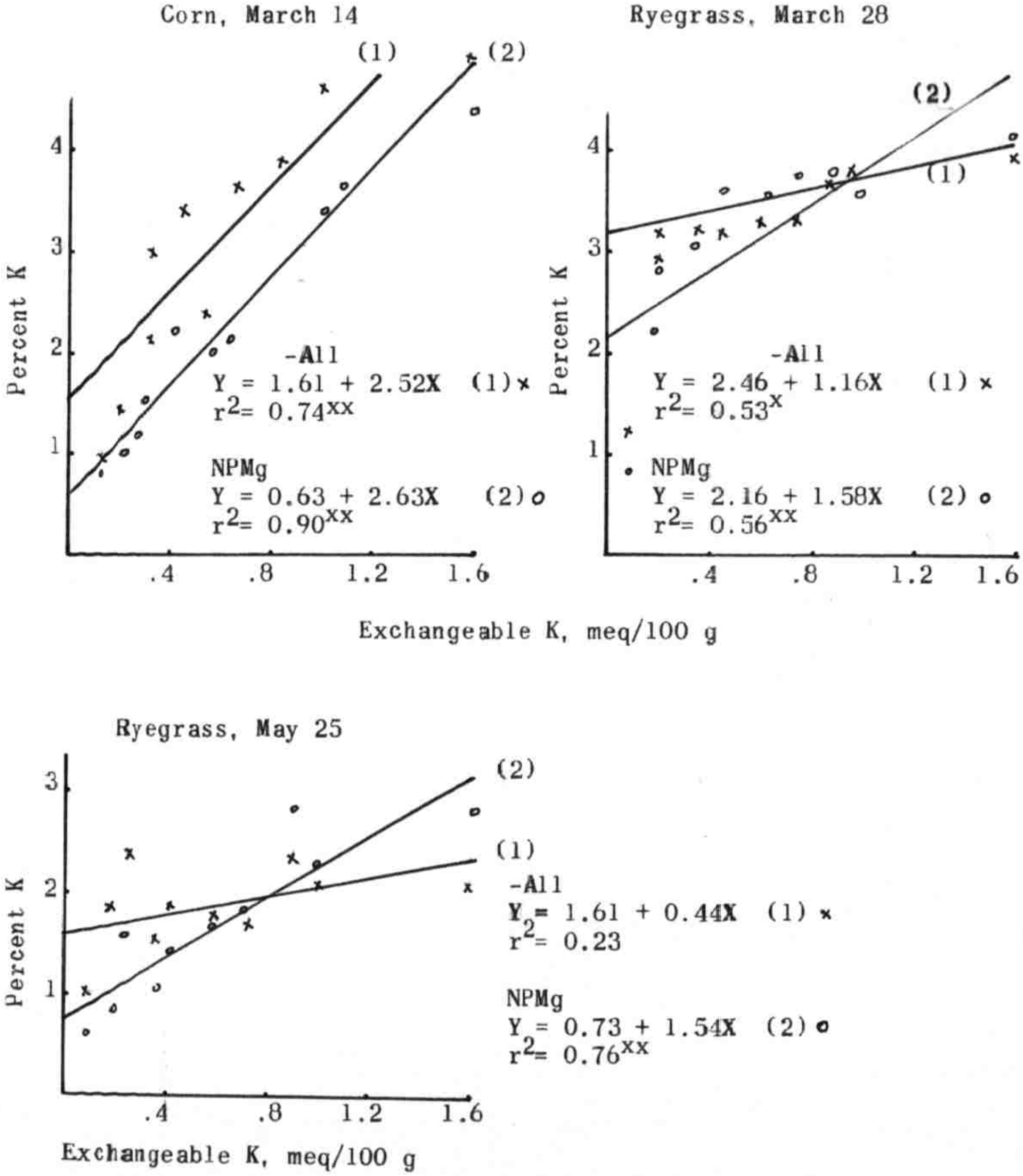

Figure 5. Relation between exchangeable K in soils ($\underline{N}$ NH_4Ac) and the percentage of K in plants.

The literature critical value of 0.3 meq per 100 g probably indicates the point below which definite response to K application would be expected. It appears that air dry samples are more practical for testing and are easier to standardize and handle. However, the data are limited and more information is needed with regard to actual response in the field for various crops.

Magnesium

Percentage decrease in yields caused by omitting Mg were relatively small in the presence of large amounts of applied K (Table 8) which decreased Mg uptake (Figure 3). However, these decreases were correlated with soil levels of Mg (Table 10). Soil Mg

Table 10. Coefficients of correlation of Mg soil test values and the percent decrease in corn and ryegrass yields caused by omitting Mg.

1. Percent Mg saturation	-0.477
2. Mg/K in N NH_4Ac extract	-0.629^{x}
3. 1/Mg/K in N NH_4Ac extract	-0.081
4. Mg in N NH_4Ac extract	-0.691^{x}
5. 1/Mg in N NH_4Ac extract	$+0.849^{xx}$
6. ½ p Mg − pK	-0.222

extractable with N NH_4Ac correlated significantly with the decrease in yield that occurred when Mg was omitted. However, a higher correlation was obtained when the reciprocal of NH_4Ac-extractable Mg was considered ($r = 0.849^{xx}$). This was probably due to the increased weight given to lower soil Mg values. The Mg/K ratio gave a significant correlation but the relations with soil K are complexed by the K added in the nutrient solutions. Mg extracted with N NH_4Ac is not strictly exchangeable but includes Mg dissolved from $MgCO_3$. However, the foregoing results indicate that the NH_4Ac extractable Mg may be used as a criterion for the availability of Mg in the soils used in this study and most probably in similar soils. Extractable Mg (N NH_4Ac) gave low correlation ($r = 0.214$) with total Mg of the soil determined by decomposition with hydrogen fluoride (Table 6). Of the ten soils, one was very high in extractable Mg (21 meq per 100 g) and gave no response in yield to applied Mg. Six soils had medium levels of extractable Mg (1.9 to 6.7 meq per 100 g) and gave an average response of 6 percent, and three were low (1.2 to 1.4 meq per 100 g) and averaged an 11.3 percent decrease in yield when Mg was omitted. A tentative critical value may be placed at 1.5 meq per 100 g below which an increase in yield from Mg application may be expected when K fertilizers are also applied. A critical level on acid soils expressed by Adams and Henderson (1962) is 4 percent Mg saturation. In general, soils with less than 10 percent Mg saturation responded to additions of Mg according to Graham et al. (1956). Yamashaki et al. (1956) found that plants growing on soils with exchangeable Mg levels between 0.5 and 1 meq per 100 g showed Mg deficiency symptoms at excessive available K but not when K was moderate. Of the ten soils studied, only two soils were less than 10 percent Mg saturated and all soils had over 1 meq per 100 g of extractable Mg. Percent saturation with Mg was considerably less correlated with response to Mg than the extractable Mg values. Response to Mg application may be obtained under some conditions at Mg levels over 1 meq exchangeable Mg per 100 g especially at high levels of applied K. Further work is needed to set critical soil levels under local conditions.

Interrelationships of N, P, K, and Mg

Finding the nutrient requirements for maximum dry matter yields is one of the main objectives of soil fertility trials. The effects of N, P, K, and Mg application at five levels each, on corn and ryegrass growth were studied on two calcareous soils with two methods of placement of nutrients. A greenhouse experiment was conducted on the Daudieh and Bazurieh soils (Soils 2 and 10, Tables 1 and 6). The same experimental technique (soil over sand) as used in the first part of the report was applied, but nutrients were added either to the sand layer below the soil as nutrient solution in five applications or mixed with the soil before planting (Table 3). The experimental design used was a central composite, rotatable, factorial which allowed the study of interactions of variables as contrasted to the previously reported experiment where only one level of each nutrient was applied and no interactions could be assessed. The predicted values were calculated from a regression equation (Cochran and Cox, 1957, pp 350) modified to include three-way interactions as follows:

$$Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + b_{44}x_4^2 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + b_{23}x_2x_3 + b_{24}x_2x_4 + b_{34}x_3x_4 + b_{123}x_1x_2x_3 + b_{124}x_1x_2x_4 + b_{134}x_1x_3x_4 + b_{234}x_2x_3x_4$$

Where Y = predicted values

b_0 = mean with all variables applied at coded "0" levels,

b_1, b_2, etc. = regression coefficients,

x_1, x_2, x_3, and x_4 = coded levels of N, P, K, and Mg, respectively.

A positive first order regression coefficient indicated that the slope of the response curve was positive at the "0" coded level of all variables. As the level increased there was a corresponding increase in the property measured. A negative first order coefficient indicated the reverse. A positive squared effect indicated a positive, or less negative, change of the slope of the response curve in the direction of increasing application rate of the element concerned, while a negative squared sign indicated the reverse. A positive two-way interaction indicated that at a high level of one variable, as compared to a low level, the response to the other variable was more positive or less negative. The three-way interaction effect depended on the combination of the levels of the variables. The net effect of any one variable depended on the combination of levels for the variables involved and the magnitude of their regression coefficients.

For the Daudieh soil, the first order regression coefficients for the effects of application of N on yield and nutrient uptake were significantly positive for both methods of nutrient application

(Tables 11 and 12). When nutrients were mixed with the soil, the first order effect of P on yield of dry matter was significantly positive and was intensified at high levels of K and Mg by the large positive P-K and P-K-Mg interactions (Table 11). While the first order effect of K tended to be negative, this effect was counteracted at high P levels by the positive P-K interaction. The net effect of applied Mg tended to be negative although counteracted by probably real and positive K-Mg and P-K-Mg interactions when P and K were applied at high levels. Where nutrients were added in solution, the first order effects of P, K, or Mg on yield of dry matter were insignificant at the levels studied but the large positive interactions of N-Mg, K-Mg, P-Mg and N-P-K resulted in increased yields when all variables were applied at high levels (Table 11). This was partly counteracted by the large negative N-P-Mg interaction. Although the amounts of P added in solution were half of those added when P was mixed in the soil, the uptake of P was at a greater rate from solution and consequently the higher levels were greater than needed as shown by the reduced yield response. The first order effects of the added P or Mg on their respective uptakes were significantly positive and resulted in larger uptake by the plants from solution than from nutrients mixed in the soil (Tables 11 and 12). Significant interactions affecting nutrient uptake were rare when the nutrients were mixed with the soil and indicated a capacity in the soil to buffer the activities of nutrients. Addition of P increased P concentration in the latest harvest of ryegrass while addition of K decreased Mg concentrations (Figure 6). Addition of Mg resulted in higher Mg

Table 11. Regression coefficients for total yield and P uptake of corn and ryegrass grown on Daudieh soil, as affected by application of N, P, K, and Mg. Nutrients were mixed with soil (m) or added in solution (S).

Terms	Daudieh m	Daudieh S	Daudieh m	Daudieh S
	Yield, g/pot		P, mg/pot	
Mean	6.950	6.542	11.743	13.129
N	$+2.330^{xx}$	$+1.901^{x}$	$+2.058^{xx}$	$+2.000^{xx}$
P	$+2.242^{xx}$	+0.010	$+2.042^{xx}$	$+2.875^{xx}$
K	-0.090	-0.100^{e}	-0.258	$+0.358^{e}$
Mg	-0.137^{e}	-0.110^{e}	+0.008	+0.183
<u>Sb</u>	±0.098	±0.050	±0.348	±0.189
N^2	$+0.580^{xx}$	$+0.400^{xx}$	-0.215	$+0.188^{e}$
P^2	-0.044	-0.065^{e}	-0.165	$+0.301^{e}$
K^2	+0.031	+0.006	+0.235	-0.099
Mg^2	-0.104^{e}	+0.002	-0.390^{e}	-0.074
<u>Sb</u>	±0.089	±0.047	±0.316	±0.172
NP	+0.080	-0.008	+0.225	$+0.612^{x}$
NK	-0.034	$+0.065^{e}$	-0.450^{e}	+0.088
NMg	-0.194^{e}	$+0.207^{x}$	-0.325	$+0.950^{xx}$
PK	$+0.308^{x}$	+0.128	+0.275	-0.312^{e}
PMg	+0.066	$+0.354^{xx}$	$+0.525^{e}$	$+0.475^{e}$
KMg	$+0.132^{e}$	$+0.146^{e}$	$+0.475^{e}$	+0.050
NPK	+0.074	$+0.243^{xx}$	-0.100	$+0.562^{e}$
NPMg	-0.073	-0.278^{xx}	+0.150	-0.350^{e}
NKMg	-0.057	+0.046	-0.100	+0.125
PKMg	$+0.131^{e}$	-0.012	+0.275	+0.075
<u>Sb</u>	±0.120	±0.060	±0.426	±0.232
R^1	0.972	0.993	0.928	0.984
$C.V.^2$, %	6.900	3.900	14.500	7.000

e. Probably real because greater than the standard error.

x. Significant at 5% level.

xx. Significant at 1% level.

1. Multiple correlation coefficient.

2. Coefficient of variation.

Table 12. Regression coefficients for total K and Mg uptake by corn and ryegrass on Daudieh soil, as affected by application of N, P, K, and Mg. Nutrients were mixed with soil (m) or added in solution (S).

Terms	Daudieh m	Daudieh S	Daudieh m	Daudieh S
	K, mg/pot		Mg, mg/pot	
Mean	188.75	144.88	20.943	26.786
N	+46.40xx	+39.36xx	+9.738xx	+8.758xx
P	-2.37	-1.94e	+0.754e	+0.250
K	+13.11x	+6.73xx	-1.088e	-1.175x
Mg	-7.34e	-2.58e	+0.496e	+2.167xx
Sb	±4.50	±1.45	±0.492	±0.386
N^2	+2.72	+9.45xx	+4.067xx	+1.712x
P^2	-3.51	-1.48e	+0.329	-0.526e
K^2	+4.60e	+4.45x	+0.217	-0.538e
Mg^2	+0.30	+0.65	-0.508e	+0.312
Sb	±4.08	±1.32	±0.447	±0.350
NP	-0.12	-3.26e	-0.081	+0.262
NK	+0.46	+2.16	-0.156	-0.238
NMg	-13.87x	+5.12x	+0.144	+1.300x
PK	+8.41e	+0.32	+0.756e	+0.212
PMg	+0.71	+6.73xx	+0.356	+2.000x
KMg	-6.68	+0.44	+1.931x	+0.550e
NPK	+2.64	+3.40e	+0.194	+0.512e
NPMg	-4.78	-5.01x	+0.244	-0.950e
NKMg	-7.07e	+1.11	+0.519	+0.225
PKMg	+3.53	+1.28	+0.706e	-0.700e
Sb	±5.51	±1.78	±0.604	±0.473
R[1]	0.945	0.989	0.979	0.988
C.V.[2] %	11.700	4.908	17.500	7.100

e. Probably real because greater than the standard error.

x. Significant at 5% level.

xx. Significant at 1% level.

1. Multiple correlation coefficient.

2. Coefficient of variation.

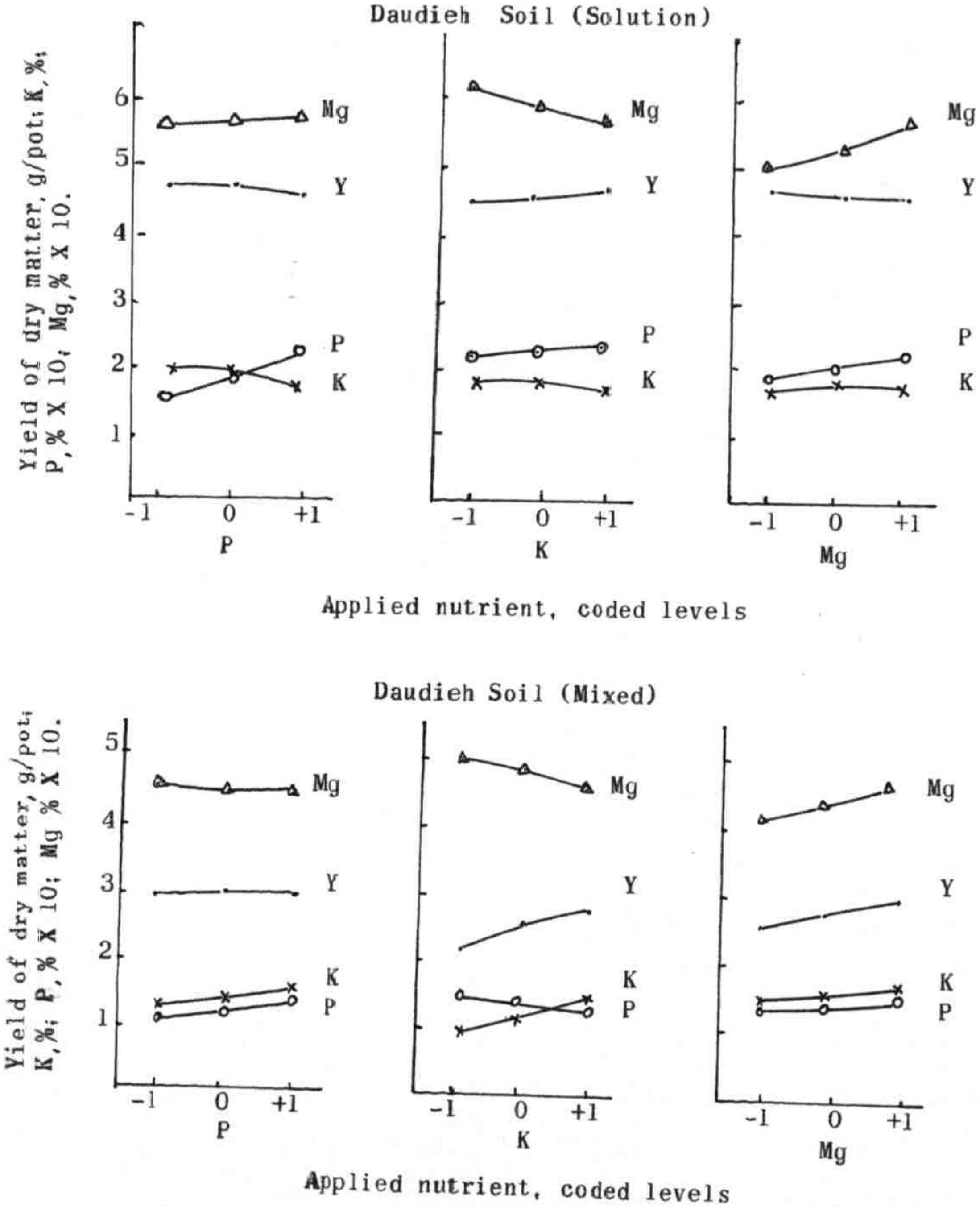

Figure 6. Predicted yields of dry matter (Y), and P, K, and Mg concentrations of the ryegrass grown on the Daudieh soil and harvested on May 25, 1967 as affected by increasing applications of P, K, or Mg at constant levels for other nutrients. When not varied, N, P, K, and Mg were kept at the +1 coded level.

concentrations in the ryegrass but there was little effect on the concentration of K.

When nutrients were added to the soil before planting, the supply of N and probably other nutrients was exhausted by early growth of corn and ryegrass. This resulted in lower dry matter yields and P, K, and Mg concentrations of the ryegrass harvested late than when nutrients were added in solution in the course of the growing season (Figure 6). In the latter case, nutrients were not added fast enough to obtain maximum rate of growth as that obtained when all nutrients were added into the soil before planting. The lack of response to P application at the last harvest of ryegrass was probably due to the exhaustion of available soil N during the earlier harvests.

The Daudieh soil gave respectively, 40, 8, and 7 percent decrease in yield when P, K, or Mg was omitted in the previous experiment. When the regression equation obtained in the second experiment was used to calculate predicted yields for the treatment combinations used in the first experiment, a significant correlation ($R = 0.797$) was obtained between predicted and actual yields, indicating a fairly close fit of the regression equation to the actual. Because of the logarithmic scale used for rates of nutrients in the factorial experiment, it was necessary to choose an arbitrary level, -2 in this case, in order to apply the equation for treatments in the first experiment. The relative small yield of dry matter responses to K and Mg by the Daudieh soil were shown to be due mainly to the positive K-Mg and P-K-Mg interactions. These results confirmed the responses obtained in the previous experiment and indicated the advantage of the factorial in explaining the response through nutrient interactions.

For the Bazurieh soil, the first order regression coefficients for the effects of application of N on yield and nutrient uptake were significantly positive for both methods of nutrient application (Tables 13 and 14). When nutrients were mixed with the soil, the first order effect of P on yield of dry matter was not high but large positive N-P-K, N-P-Mg and P-K-Mg interactions, at high levels of application of all variables, resulted in considerable net response to P (Table 13). The first order effects of K and Mg were small but positive and probably real interactions for K-Mg, N-P-K, N-P-Mg, and P-K-Mg at high levels for all variables, resulted in net positive effects on yield response. When nutrients were added into the sand layer below the soil, the first order effect of K on yield of dry matter was significantly positive while the effect of P was probably real and negative (Table 13). The uptake of P from solution was at a greater rate than from the soil although the amount applied in the soil was double that applied in solution. It appeared that the high levels were greater than needed as was shown by the reduced yield response. The first order effects of the added P or Mg on their respective uptakes were significantly positive and resulted in larger uptake by the plants from solution than from nutrients mixed in the soil (Tables 13 and 14). Significant interactions affecting the uptake of P or Mg were rare. The N-K interaction was positive and significant and enhanced the positive effects of applied N and K on K

Table 13. Regression coefficients for total yield and total P uptake of corn and ryegrass grown on Bazurieh soil, as affected by application of N, P, K, and Mg. Nutrients were mixed with soil (m) or added in solution (S).

Terms	Bazurieh (m)	Bazurieh (S)	Bazurieh (m)	Bazurieh (S)
	Yield, g/pot		P, mg/pot	
Mean	6.806	5.503	13.229	13.958
N	+1.880[xx]	+2.094[xx]	+1.877[xx]	+2.229[xx]
P	+0.155[e]	-0.044[e]	+1.171[xx]	+2.196[xx]
K	+0.125	+0.137[xx]	+0.096	+0.262[e]
Mg	+0.050	+0.021	+0.321[e]	+0.529[x]
<u>Sb</u>	±0.128	±0.022	±0.312	±0.159
N^2	+0.389[x]	+0.599[xx]	+0.181	+0.447[x]
P^2	-0.081	+0.073[x]	+0.294[e]	+0.184[e]
K^2	+0.014	+0.040	+0.131	-0.140
Mg^2	-0.162[e]	+0.102[xx]	-0.181	+0.097
<u>Sb</u>	±0.116	±0.020	±0.283	±0.144
NP	+0.132	-0.083[x]	+0.394[e]	+0.016
NK	+0.107	+0.055[e]	-0.081	+0.281[e]
NMg	-0.038	+0.052[e]	+0.044	+0.369[e]
PK	-0.028	-0.042[e]	+0.556[e]	-0.056
PMg	+0.012	-0.116[xx]	-0.069	+0.156
KMg	+0.272[e]	-0.122[xx]	+0.456[e]	+0.581[x]
NPK	+0.177[e]	+0.011	+0.619[e]	-0.081
NPMg	+0.197[e]	+0.001	+0.544[e]	+0.131
NKMg	+0.114	-0.024	+0.544[e]	+0.406[e]
PKMg	+0.247[e]	+0.131[xx]	+0.731[e]	+0.119
<u>Sb</u>	±0.157	±0.028	±0.383	±0.195
R[1]	0.966	0.993	0.921	0.928
C.V.[2], %	9.200	2.000	11.500	5.600

e. Probably real because greater than standard error.

x. Significant at 5% level.

xx. Significant at 1% level.

1. Multiple correlation coefficient.

2. Coefficient of variation.

Table 14. Regression coefficients for total K and Mg uptake by corn and ryegrass grown on Bazurieh soil, as affected by application of N, P, K, and Mg. Nutrients were mixed with soil (m) or added in solution (S).

Terms	Bazurieh (m)	Bazurieh (S)	Bazurieh (m)	Bazurieh (S)
	K mg/pot		Mg mg/pot	
Mean	125.85	96.00	29.115	26.744
N	+33.09[xx]	+24.72[xx]	+ 9.967[xx]	+10.292[xx]
P	- 0.53	- 1.96[e]	+ 0.025	+ 0.108
K	+37.27[xx]	+12.88[xx]	- 3.125[xx]	- 1.025[e]
Mg	+ 2.97[e]	- 0.13	+ 2.083[xx]	+ 3.150[xx]
<u>Sb</u>	± 2.15	± 1.14	± 0.575	± 0.559
N^2	+14.45[xx]	+ 5.07[xx]	+ 2.223[xx]	+ 3.008[xx]
P^2	+ 5.95[x]	+ 2.06[e]	- 0.614[e]	- 0.467
K^2	+ 5.40[x]	+ 1.86[e]	+ 0.336	- 0.330
Mg^2	- 1.10	+ 2.16[e]	+ 0.585[e]	+ 0.683[e]
<u>Sb</u>	± 1.95	± 1.03	± 0.522	± 0.507
NP	+ 1.72	- 1.24	+ 0.925	+ 0.375
NK	+19.85[xx]	+ 3.98[x]	- 1.100[e]	- 0.538
NMg	+ 6.28[e]	+ 0.52	- 0.087	+ 1.338[e]
PK	+ 0.81	- 2.10[e]	- 0.625	- 0.037
PMg	+ 1.16	- 0.85	- 0.362	- 0.588
KMg	+ 6.84[x]	+ 0.11	+ 0.837[e]	- 1.000[e]
NPK	+ 4.71[e]	- 1.11	+ 1.175[e]	+ 0.362
NPMg	+ 5.69[e]	- 0.94	+ 1.062[e]	+ 0.238
NKMg	+ 6.36[e]	- 0.38	- 0.712[e]	- 0.925
PKMg	+ 3.62[e]	+ 2.30[e]	- 0.188	+ 0.325
<u>Sb</u>	± 2.63	± 1.39	± 0.705	± 0.685
R[1]	0.969	0.990	0.984	0.974
C.V.[2], %	8.600	5.800	10.600	10.200

e. Probably real because greater than standard error.

x. Significant at 5% level.

xx. Significant at 1% level.

1. Multiple correlation coefficient.

2. Coefficient of variation.

uptake. Addition of P increased P concentration in the latest harvest of ryegrass. Addition of K decreased Mg concentrations (Figure 7). Addition of Mg resulted in higher Mg concentrations but had little effect on the concentration of K. Lower yield of dry matter and lower P, K, and Mg concentrations were obtained from the ryegrass growing on pots with nutrients mixed in the soil before planting than from plants in pots that received nutrients in solution in the course of growing season (Figure 7). This was caused by the rapid growth and early exhastion of the soil nutrient supply by the previously harvested corn and ryegrass where nutrients were all added before planting.

The Bazurieh soil gave respectively 14, 11, and 3 percent decrease in yield when P, K, or Mg were omitted in the previous experiment. Solving the regression equation in this experiment for the nutrient levels used in the previous experiment, with absence of a nutrient taken arbitrarily as the -2 coded level, gave a highly significant correlation ($r = .863$) between predicted and actual yields. The slight response to K and Mg was mainly due to K-Mg, N-P-K, N-P-Mg and P-K-Mg positive interactions. These results confirmed the responses obtained in the previous experiment. The advantage of the factorial in explaining the response through nutrient interactions was evident on the Bazurieh soil as well as that of the Daudieh.

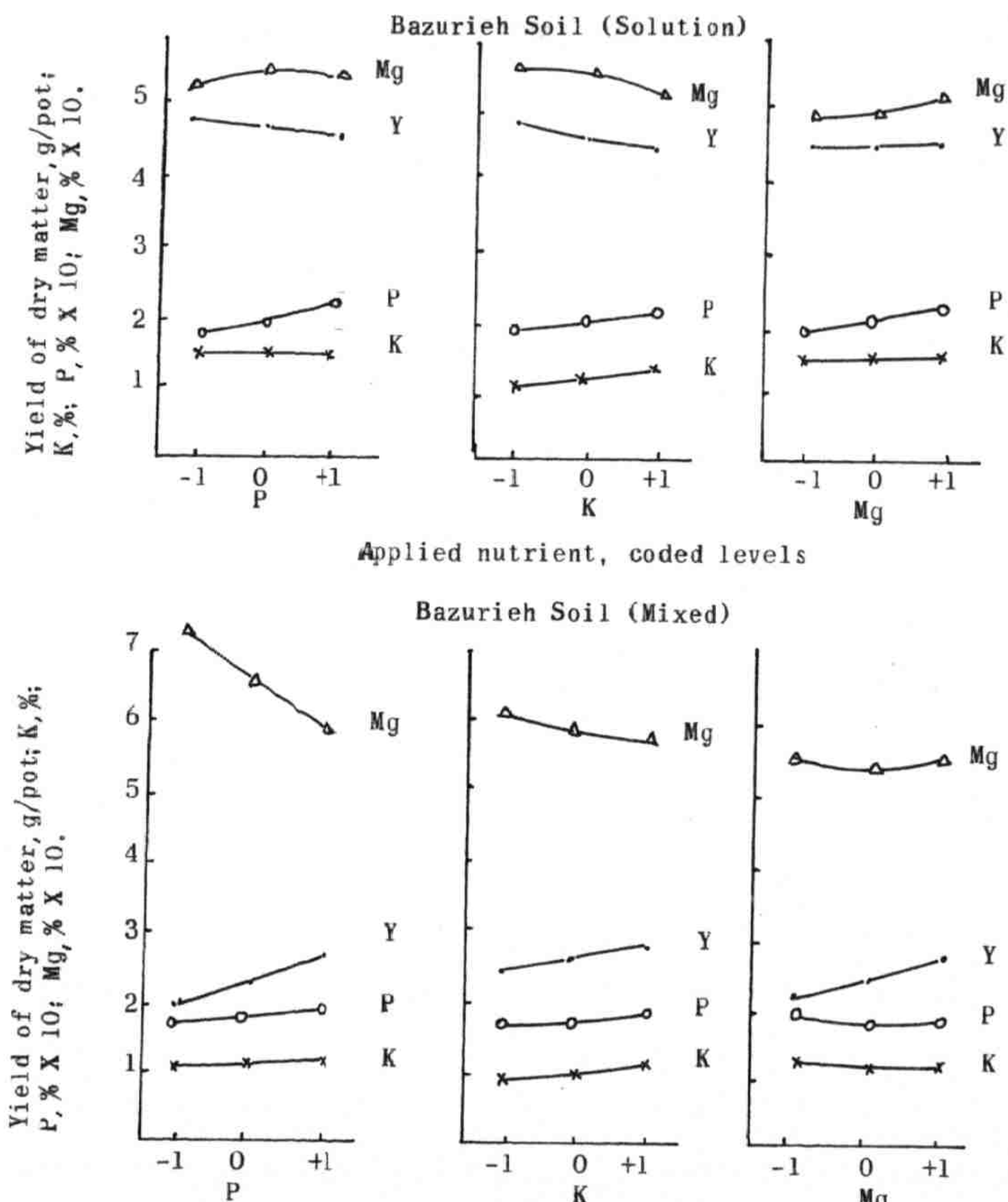

Figure 7. Predicted yields of dry matter (Y), and P, K, and Mg concentrations of the ryegrass grown on the Bazurieh soil and harvested on May 25, 1967 as affected by increasing applications of P, K, or Mg at constant levels for other nutrients. When not varied, N, P, K, and Mg were kept at the +1 level.

Effects of Added N, P, K, and Mg on Residual Soil P

Available soil P was measured after cropping the Daudieh and Bazurieh soils in the pots where N, P, K, and Mg were mixed with the soil. Two methods of extraction were used, the new Olsen method and the Al-Abbas method. The Al-Abbas method gave higher soil test values than the Olsen method (mean terms, Table 15). The first order regression coefficients for the effects of addition of N, K, and Mg on residual soil P were significantly negative on the Daudieh soil for the two methods of soil testing. While on the Bazurieh soil, these coefficients were positive. The Bazurieh soil contained higher available P before cropping than the Daudieh soil. It had 9.5 ppm and 18.3 ppm as tested by the Olsen and Al-Abbas methods, respectively, while the Daudieh soil had 2.2 and 4.7 ppm for the two methods, respectively. Two and three-way interactions were significant at the high levels of application for the two soil tests. On the Daudieh soil, negative interactions overbalanced positive interactions, while on the Bazurieh soil the reverse occurred.

The Olsen and Al-Abbas methods appeared to be equally effective in measuring the effect of applied nutrients on residual available P (R values, Table 15, all greater than 0.9). However, the reasons for the generally negative first order effects of N, K, and Mg on residual available P as determined by both methods in the Daudieh soil are unknown. The reasons are also unknown for the general positive effects of applied N, K, and Mg on residual available P as determined by both methods in the very calcareous Bazurieh soil.

Table 15. Regression coefficients for residual soil P as affected by N, P, K, and Mg addition into Bazurieh and Daudieh soils. Two methods of extracting P were used.

Terms	Daudieh, Olsen	Daudieh, Al-Abbas	Bazurieh, Olsen	Bazurieh, Al-Abbas
	ppm		ppm	
Mean	3.107	21.686	3.871	21.072
N	-0.464^{xx}	-3.375^{xx}	+0.061	+1.625^{x}
P	+2.168^{xx}	+14.750^{xx}	+2.070^{xx}	+10.916^{xx}
K	-0.314^{xx}	-1.792^{xx}	+0.248^{e}	-0.375
Mg	-0.318^{xx}	-2.500^{xx}	+0.292^{x}	+3.166^{xx}
<u>Sb</u>	±0.058	±0.412	±0.106	±0.515
N^2	-0.065	-2.765^{xx}	+0.153^{e}	-0.278
P^2	+0.778^{xx}	+7.984^{xx}	+0.707^{xx}	+5.158^{xx}
K^2	-0.414^{xx}	-1.453^{xx}	+0.059	-0.966^{e}
Mg^2	+0.559^{xx}	+1.297^{x}	+0.028	+0.034
<u>Sb</u>	±0.052	±0.373	±0.096	±0.467
NP	-0.570^{xx}	-5.375^{xx}	+0.440^{x}	+3.500^{xx}
NK	-0.223^{x}	+1.000^{e}	+0.247^{e}	-0.187
NMg	+0.289^{xx}	+1.937^{xx}	-0.530^{xx}	+1.125^{e}
PK	-0.489^{xx}	-1.937^{xx}	+0.565^{xx}	+0.187
PMg	-0.132^{e}	-2.750^{xx}	+0.092	+4.750^{xx}
KMg	-0.129^{e}	-2.125^{xx}	-0.280^{e}	+2.562^{xx}
NPK	-0.262^{x}	-1.375^{x}	+0.096	-0.250
NPMg	+0.696^{xx}	+1.687^{x}	-0.376^{x}	+0.937
NKMg	+0.106^{e}	-1.062^{e}	-0.374^{x}	+3.250^{xx}
PKMg	+0.177^{e}	-1.875^{xx}	-0.188^{e}	+2.125^{x}
<u>Sb</u>	±0.071	±0.505	±0.130	±0.631
R^1	0.976	0.934	0.919	0.944
C.V.^{2}, %	9.120	9.300	13.400	12.000

e. Probably real because greater than standard error.

x. Significant at 5% level.

xx. Significant at 1% level.

1. Multiple correlation coefficient.

2. Coefficient of variation.

Where applied N, K, or Mg increased yields it might be expected that the available P of the soil would be reduced to a lower level but this does not explain the effect in the Bazurieh soil. It is recommended that further work be conducted to explore the significance and reasons for these phenomena.

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A greenhouse pot experiment was conducted in 1967 at the American University of Beirut with maize and ryegrass grown simultaneously on ten soils from the Middle East to study the availability of N, P, K, and Mg using a three-layer split-root technique. Seven of the soils were from Lebanon and one soil each was obtained from Syria, Turkey, and Jordan. Some of the soils were chosen as being likely to show response to K or Mg applications. Each of N, P, K, and Mg were applied in nutrient solution to the sand layer below the soil at the rate of 300, 30, 200, and 50 mg per 1.5 kg of soil, respectively. Two of the soils Bazurieh and Daudieh, were subjected to a more comprehensive factorial study with N, P, K, and Mg as variables, each at five levels from 27 to 440 mg per 1.5 kg of soil. These were applied either as nutrient solution in the sand layer below the soil or were directly mixed with the soil.

Plants grown on all soils had severe N deficiency (67 to 80 percent decrease in yield when N was omitted). In nine of the soils a 10 to 40 percent decrease in total yield occurred when P was omitted with one soil showing no decrease. Only one soil, from Turkey, had a severe K deficiency. With the other nine soils, less than 11 percent decrease in yield occurred when K was omitted. Five of the soils had greater than 6 percent decrease in yield where Mg was omitted with the soil from Turkey showing a 14 percent decrease. One soil, originally high in Mg gave a slight decrease in yield from added

Mg. Excluding the soil from Turkey, response to K and Mg is about equal and less than 5 percent on the average.

Addition of P, K, or Mg resulted in greater respective uptakes and lead to higher concentrations in the plants. Addition of N resulted in high yields of dry matter and thus tended to decrease the concentration of other nutrients in the plants although it resulted in a much higher uptake.

Soil test values before cropping correlated very closely with values for after cropping. Exchangeable K (N NH_4Ac) was reduced by cropping by about one half to two thirds. This indicated that continued heavy cropping might result in considerable K deficiency. The crops reduced available P of the soil (Olsen test) to a very low level under the heavy cropping regime imposed. Extractable Mg (N NH_4Ac) was only slightly reduced by cropping and indicated a release of Mg from non-extractable sources. Soil test values for K (N NH_4Ac extract) correlated closely with plant contents and total K uptake when the application of K was omitted. The Al-Abbas soil test for available P correlated somewhat higher with response in yield than the Olsen test. Both tests were closely related to plant uptake and plant content of P. The soil test for Mg (N NH_4Ac extract) correlated significantly with decrease in yield caused by omitting Mg. The reciprocals of the soil test values for K and Mg correlated higher with plant response than the soil test values and indicated an improved fit with the curvilinear relationship thus obtained.

Tentative critical levels, below which response to application might be expected, were placed at 0.5 meq per 100 g of soil for K and

1.5 meq per 100 g for Mg when extracted with N NH_4Ac. The critical level for P was estimated to be about 10 ppm as determined by the Olsen method and about 20 ppm when determined by the Al-Abbas method. Compared with critical values found in other parts of the world, the critical levels for K and Mg estimated for these soils were somewhat higher. This may be related to the high lime content of the soils studied.

The results obtained in the factorial experiment on two of the soils essentially confirmed the responses obtained in the first experiment. The positive yield response to applied N was highly significant throughout. In both soils, the first order effects of K and Mg on total yield of dry matter were relatively small. However, the interactions involving P, K, and Mg tended to be positive resulting in net positive effects for each of the three when the other two were present at high levels of application. Thus, it is implied, and the conclusion can be made, that an overall balance of nutrients is involved. Recommendations for fertilizer application for crops grown on these soils must be made such that soil nutrient levels are kept in reasonable balance. The central composite design proved to be efficient in separating out the various interrelationships involved but more work is needed considering their nature.

It is recommended that further study be made to correlate the soil tests under local field conditions. It is important to establish soil test and plant concentration levels for various crops below which application of fertilizers will probably be profitable. Nitrogen was the most limiting nutrient and its application is very essential at rates commensurate with probable crop removal. The response to the application of P was generally high for most of the soils studied. Application of P may be necessary on those soils which test below 10 ppm (Olsen test) especially under intensive cropping conditions. For soils low in exchangeable K, it is recommended that applications be coupled with applications of Mg where the Mg test is also low. Indiscriminant application of K may result in K-induced Mg deficiency.

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APPENDIX

Table 16. Dry matter yield of corn, March 14 harvest, ryegrass, March 28 harvest and ryegrass May 25 harvest, on ten soils in the greenhouse. (Figures are averages of four replicates).

Soil number	Treatment						
	NPMg	NKMg	PKMg	NPK	NPKMg	-All	Average
			Corn, March 14 harvest, g/pot				
1	1.61	1.53	1.09	1.76	1.83	0.85	1.45
2	1.57	1.45	0.98	1.71	1.69	1.03	1.41
3	1.22	1.67	1.69	2.03	2.11	1.18	1.65
4	2.37	1.87	1.51	2.24	2.08	1.29	1.89
5	1.99	1.45	1.05	1.83	2.30	0.98	1.68
6	2.58	2.80	0.90	1.93	2.17	0.92	1.90
7	1.69	1.71	0.90	1.76	1.77	0.83	1.45
8	1.61	1.66	1.38	1.56	1.63	1.21	1.51
9	2.23	1.68	0.88	2.56	2.55	1.29	1.87
10	1.61	1.45	1.19	1.94	1.95	0.95	1.52
Average	1.85	1.73	1.16	1.94	2.01	1.05	1.62
			Ryegrass, March 28 harvest, g/pot				
1	3.04	2.46	1.32	3.31	3.00	1.41	2.43
2	3.09	2.28	1.51	3.21	3.15	1.70	2.49
3	2.46	2.31	1.75	2.53	3.28	1.97	2.38
4	3.64	3.05	1.76	3.29	3.81	1.86	2.91
5	2.65	1.95	1.17	2.64	2.87	1.09	2.07
6	2.69	2.51	0.94	2.59	2.90	1.08	2.12
7	3.01	2.82	1.34	2.99	3.12	1.18	2.42
8	3.43	3.34	1.71	3.81	3.78	1.90	3.00
9	2.81	2.64	0.97	2.59	2.79	1.28	2.18
10	2.67	2.70	1.56	2.85	2.71	1.31	2.30
Average	2.95	2.60	1.41	2.98	3.15	1.48	2.43
			Ryegrass, May 25 harvest, g/pot				
1	6.65	6.20	0.40	6.34	6.82	0.55	4.49
2	6.43	3.52	0.55	6.25	7.16	0.82	4.12
3	2.58	3.95	0.66	5.36	6.19	0.99	3.29
4	6.57	4.26	0.67	6.76	6.90	0.65	4.30
5	5.91	4.45	0.60	5.42	6.12	0.70	3.88
6	6.08	6.11	0.65	5.36	6.41	0.67	4.21
7	6.12	5.09	0.42	5.86	6.42	0.61	4.09
8	6.19	5.79	0.60	6.84	6.58	0.47	4.41
9	6.71	4.44	0.47	6.25	6.27	0.63	4.13
10	5.49	5.18	0.69	5.77	6.27	0.83	4.04
Average	5.87	4.90	0.57	6.02	6.51	0.69	4.10

Table 17. Phosphorus, potassium, and magnesium composition of corn tops grown on ten soils in the greenhouse and harvested on March 14, 1967. (Figures are averages of four replicates).

Soil number	Treatment						
	NPMg	NKMg	PKMg	NPK	NPKMg	-All	Average
				Phosphorus, percent			
1	0.118	0.137	0.204	0.153	0.118	0.178	0.151
2	0.126	0.124	0.197	0.108	0.124	0.176	0.142
3	0.349	0.128	0.182	0.142	0.187	0.180	0.194
4	0.140	0.118	0.164	0.129	0.124	0.165	0.140
5	0.139	0.123	0.270	0.141	0.144	0.184	0.167
6	0.187	0.160	0.377	0.212	0.209	0.302	0.241
7	0.131	0.115	0.242	0.132	0.173	0.183	0.163
8	0.150	0.127	0.196	0.131	0.158	0.139	0.150
9	0.134	0.133	0.290	0.153	0.177	0.171	0.176
10	0.198	0.142	0.246	0.152	0.176	0.201	0.186
Average	0.167	0.131	0.237	0.145	0.158	0.188	0.171
				Potassium, percent			
1	2.321	4.277	4.169	3.433	3.153	3.787	3.523
2	2.109	2.109	3.399	2.713	3.092	2.736	2.924
3	0.558	1.718	1.740	1.649	1.413	0.866	1.324
4	4.387	4.896	4.611	5.201	4.840	4.853	4.798
5	1.170	3.479	3.806	2.927	1.998	3.089	2.745
6	3.348	3.788	5.000	4.493	4.223	4.310	4.193
7	2.418	3.430	4.380	3.130	3.218	3.512	3.348
8	1.694	2.601	3.072	2.700	2.718	2.192	2.496
9	3.642	4.774	5.220	4.578	4.446	4.630	4.548
10	0.715	2.217	2.518	1.704	1.538	1.506	1.699
Average	2.236	3.468	3.791	3.253	3.064	3.148	3.160
				Magnesium, percent			
1	0.311	0.419	0.236	0.215	0.258	0.214	0.275
2	0.428	0.403	0.270	0.216	0.319	0.321	0.326
3	1.335	0.677	0.530	0.522	0.671	0.907	0.773
4	0.255	0.271	0.214	0.206	0.239	0.217	0.234
5	0.515	0.362	0.275	0.228	0.350	0.280	0.335
6	0.187	0.246	0.194	0.114	0.170	0.140	0.175
7	0.384	0.367	0.270	0.252	0.325	0.282	0.313
8	0.622	0.481	0.433	0.454	0.488	0.500	0.496
9	0.345	0.393	0.304	0.228	0.306	0.235	0.202
10	0.710	0.506	0.392	0.337	0.453	0.460	0.476
Average	0.509	0.412	0.312	0.277	0.358	0.356	0.371

Table 18. Phosphorus, potassium, and magnesium composition of ryegrass tops grown on ten soils in the greenhouse and harvested on March 28, 1967. (Figures are averages of four replicates).

Soil number	Treatment						
	NPMg	NKMg	PKMg	NPK	NPKMg	-All	Average
				Phosphorus, percent			
1	0.160	0.120	0.245	0.165	0.176	0.152	0.169
2	0.125	0.092	0.184	0.130	0.126	0.110	0.128
3	0.163	0.102	0.200	0.178	0.148	0.145	0.156
4	0.130	0.092	0.206	0.166	0.151	0.152	0.149
5	0.159	0.120	0.249	0.158	0.168	0.187	0.174
6	0.352	0.352	0.355	0.360	0.345	0.382	0.353
7	0.151	0.107	0.272	0.151	0.155	0.195	0.172
8	0.139	0.101	0.202	0.146	0.143	0.154	0.147
9	0.172	0.138	0.263	0.192	0.196	0.252	0.202
10	0.207	0.138	0.263	0.178	0.200	0.226	0.202
Average	0.176	0.134	0.244	0.182	0.181	0.195	0.185
				Potassium, percent			
1	3.802	3.970	3.572	4.055	3.818	3.348	3.761
2	3.490	3.682	3.205	3.798	3.512	3.220	3.484
3	0.848	1.988	1.755	1.902	1.455	1.378	1.544
4	4.040	4.300	3.685	4.555	4.062	3.900	4.090
5	2.852	3.775	3.158	3.505	3.302	3.195	3.297
6	3.808	3.970	3.382	4.055	3.910	3.608	3.788
7	3.562	3.780	3.328	3.775	3.610	3.212	3.544
8	3.095	3.205	3.020	3.600	3.325	3.218	3.244
9	3.585	3.972	3.412	3.270	3.328	3.810	3.563
10	2.068	2.732	2.848	2.720	3.092	2.850	2.718
Average	3.115	3.537	3.136	3.523	3.341	3.174	3.305
				Magnesium, percent			
1	0.325	0.296	0.354	0.249	0.295	0.301	0.303
2	0.288	0.266	0.294	0.204	0.237	0.264	0.259
3	0.522	0.430	0.362	0.345	0.351	0.394	0.401
4	0.299	0.287	0.344	0.252	0.310	0.331	0.304
5	0.359	0.320	0.349	0.246	0.317	0.326	0.320
6	0.283	0.264	0.314	0.243	0.280	0.289	0.279
7	0.327	0.324	0.400	0.284	0.320	0.402	0.343
8	0.335	0.332	0.394	0.300	0.329	0.402	0.349
9	0.374	0.382	0.438	0.310	0.336	0.405	0.374
10	0.382	0.378	0.360	0.280	0.352	0.370	0.353
Average	0.349	0.328	0.361	0.271	0.312	0.348	0.328

Table 19. Phosphorus, potassium, and magnesium composition of ryegrass tops grown on ten soils in the greenhouse and harvested on May 25, 1967. (Figures are averages of four replicates).

Soil number	Treatment						
	NPMg	NKMg	PKMg	NPK	NPKMg	-All	Average
				Phosphorus, percent			
1	0.134	0.129	0.314	0.147	0.142	0.214	0.180
2	0.130	0.108	0.271	0.130	0.132	0.166	0.156
3	0.190	0.120	0.352	0.143	0.150	0.227	0.197
4	0.154	0.126	0.399	0.141	0.157	0.332	0.217
5	0.180	0.137	0.422	0.154	0.185	0.406	0.247
6	0.294	0.150	0.578	0.283	0.279	0.522	0.368
7	0.163	0.128	0.408	0.169	0.147	0.336	0.225
8	0.178	0.135	0.349	0.140	0.159	0.225	0.198
9	0.140	0.135	0.400	0.160	0.171	0.346	0.225
10	0.187	0.127	0.398	0.166	0.161	0.325	0.227
Average	0.175	0.139	0.389	0.163	0.168	0.309	0.224
				Potassium, percent			
1	1.660	2.316	2.019	2.303	2.444	1.571	2.052
2	1.688	3.135	1.815	2.499	2.362	1.743	2.207
3	0.520	2.727	1.928	2.029	1.755	1.022	1.663
4	2.755	3.383	2.315	2.828	2.944	2.105	2.722
5	1.521	2.536	2.386	2.520	2.605	2.443	2.335
6	2.949	3.386	2.432	3.538	3.295	2.423	3.004
7	1.332	2.473	1.820	2.229	2.391	1.944	2.031
8	1.045	2.121	1.655	1.727	2.014	1.542	1.684
9	2.417	2.769	2.134	2.584	2.953	2.076	2.489
10	0.775	2.300	1.850	2.232	1.983	1.920	1.843
Average	1.666	2.715	2.035	2.449	2.475	1.879	2.203
				Magnesium, percent			
1	0.597	0.468	0.820	0.402	0.516	0.729	0.589
2	0.542	0.380	0.667	0.323	0.480	0.594	0.498
3	0.819	0.504	0.718	0.416	0.522	0.554	0.589
4	0.468	0.437	0.782	0.336	0.476	0.752	0.542
5	0.599	0.546	0.768	0.384	0.582	0.664	0.590
6	0.668	0.564	0.710	0.449	0.561	0.634	0.598
7	0.652	0.476	0.833	0.435	0.578	0.736	0.618
8	0.654	0.492	0.706	0.444	0.580	0.709	0.597
9	0.518	0.558	0.941	0.500	0.579	0.798	0.649
10	0.683	0.584	0.738	0.435	0.561	0.709	0.618
Average	0.620	0.500	0.768	0.412	0.543	0.688	0.589

Table 20. Total phosphorus, potassium and magnesium uptake by corn and ryegrass grown on the ten soils in the greenhouse. (Figures are averages of four replicates).

Soil number	Treatment						
	NPMg	NKMg	PKMg	NPK	NPKMg	-All	Average
				Phosphorus, mg/pot			
1	17.82	14.10	6.50	18.90	18.82	4.68	13.47
2	15.67	8.28	6.25	14.02	18.92	4.80	11.32
3	15.35	9.85	8.82	16.58	19.98	7.15	12.95
4	19.58	11.05	8.85	19.42	20.70	7.02	14.44
5	18.50	12.22	8.25	16.92	20.28	6.48	13.77
6	34.52	29.70	10.60	29.58	37.32	9.95	25.28
7	17.75	12.32	7.48	17.05	19.47	5.60	13.28
8	18.90	14.02	9.65	18.45	19.68	5.78	14.41
9	19.18	12.68	6.98	19.70	24.42	7.55	15.08
10	20.62	13.30	9.30	18.60	21.42	7.25	15.08
Average	19.79	13.75	8.26	18.92	22.10	6.62	14.91
				Potassium, mg/pot			
1	304.8	340.4	102.0	373.6	398.0	89.8	268.0
2	288.9	255.8	93.1	342.6	365.8	99.7	240.9
3	42.7	178.6	72.9	189.7	185.2	50.4	119.9
4	464.5	381.4	150.2	493.1	484.5	148.4	353.7
5	200.0	283.8	93.1	299.1	325.3	79.7	213.5
6	386.0	420.0	93.4	418.2	434.9	91.6	307.4
7	262.2	315.1	92.3	308.6	352.0	76.9	234.5
8	224.0	291.3	102.4	324.2	317.9	96.6	226.0
9	371.4	321.6	89.8	406.5	417.8	119.3	287.7
10	122.8	232.6	84.8	238.4	262.6	67.5	168.1
Average	266.7	302.0	97.4	339.4	354.4	91.9	242.0
				Magnesium, mg/pot			
1	51.05	43.18	11.78	35.70	47.02	10.05	33.13
2	46.88	30.52	10.72	27.48	43.48	12.08	28.52
3	49.65	43.28	20.10	40.20	55.00	21.65	38.31
4	47.65	33.75	14.55	35.58	47.70	13.87	32.18
5	54.45	41.58	11.62	32.30	49.50	10.78	33.37
6	48.15	46.08	9.28	32.95	44.32	8.48	31.54
7	55.15	40.32	11.30	35.15	50.20	11.45	33.93
8	60.90	48.52	16.90	45.65	56.32	17.02	40.89
9	53.88	42.02	11.32	43.88	51.32	13.18	35.93
10	56.92	47.48	15.30	38.95	51.82	14.35	37.47
Average	52.47	41.67	13.29	36.78	49.67	13.29	34.53

Table 21. Analysis of variance of dry matter yield, P, K, and Mg composition of corn as affected by application of N, P, K, and Mg on ten soils and harvested on March 14, 1967.

		d.f.	Yield g/pot	P percent	K percent	Mg percent
S.S.	Replicates	3	0.637	0.00752	4.518	0.0586
	Treatments	5	33.975	0.28271	54.597	1.3442
	Error "a"	15	1.486	0.02493	5.003	0.0382
	Soils	9	8.082	0.20177	288.443	6.3975
	Soils x treatments	45	14.298	0.24752	19.776	1.6300
	Soils x replicates	27	2.566	0.03424	5.892	0.0832
	Error "b"	135	10.673	0.12321	21.700	0.5988
	Total	239	71.719	0.92193	399.390	10.1509
M.S.	Replicates	3	0.212	0.00251	1.506^{x}	0.0195^{xx}
	Treatments	5	6.795^{xx}	0.05653^{xx}	10.919^{xx}	26.8840^{xx}
	Error "a"	15	0.099	0.00175	0.333	0.0025
	Soils	9	0.898^{xx}	0.02240^{xx}	32.049^{xx}	0.7108^{xx}
	Soils x treatments	45	0.317^{xx}	0.00550^{xx}	0.439^{xx}	0.0362^{xx}
	Soils x replicates	27	0.095	0.00012	0.218	0.0031
	Error "b"	135	0.079	0.00091	0.161	0.0044
L.S.D.	Two treatment	.05	0.150	0.019	0.272	0.024
	means	.01	0.208	0.027	0.376	0.033
	Two soil	.05	0.158	0.017	0.225	0.037
	means	.01	0.202	0.022	0.289	0.048
	Two soils,	.05	0.388	0.042	0.548	0.092
	one treatment	.01	0.498	0.054	0.702	0.117
	Two treatments,	.05	0.420	0.045	0.610	0.094
	one soil	.01	0.574	0.062	0.834	0.129

x. Significant at 5% level.

xx. Significant at 1% level.

Table 22. Analysis of variance of dry matter yield, P, K, and Mg composition of ryegrass as affected by application of N, P, K, and Mg on ten soils and harvested on March 28, 1967.

	d.f.		Yield g/pot	P percent	K percent	Mg percent
S.S.	Replicates	3	1.611	0.05884	1.111	0.01502
	Treatments	5	122.923	0.25332	7.393	0.21651
	Error "a"	15	2.118	0.02490	6.655	0.04583
	Soils	9	20.671	0.86867	111.077	0.41103
	Soils x treatments	45	9.483	0.06081	9.671	0.13480
	Soils x replicates	27	2.738	0.02672	3.663	0.02121
	Error "b"	135	12.797	0.11371	16.092	0.08193
	Total	239	172.343	1.40710	155.665	0.92640
M.S.	Replicates	3	0.537^{x}	0.01963^{xx}	0.370	0.00500
	Treatments	5	24.585^{xx}	0.05070^{xx}	1.478^{x}	0.04335^{xx}
	Error "a"	15	0.141	0.00173	0.443	0.00300
	Soils	9	2.297^{xx}	0.09652^{xx}	12.342^{xx}	0.04571^{xx}
	Soils x treatments	45	2.223^{xx}	0.00012	0.214^{xx}	0.00303^{xx}
	Soils x replicates	27	1.070	0.00103	0.135	0.00082
	Error "b"	135	0.094	0.00081	0.119	0.00063
L.S.D.	Two treatment	.05	0.179	0.019	0.317	0.025
	means	.01	0.248	0.027	0.438	0.036
	Two soil	.05	0.173	0.016	0.610	0.014
	means	.01	0.222	0.021	0.782	0.018
	Two soils,	.05	0.423	0.040	1.502	0.034
	one treatment	.01	0.542	0.051	1.925	0.044
	Two treatments,	.05	0.453	0.044	0.559	0.042
	one soil	.01	0.619	0.059	0.763	0.057

x. Significant at 5% level.

xx. Significant at 1% level.

Table 23. Analysis of variance of dry matter yield, P, K, and Mg composition of ryegrass as affected by application of N, P, K, and Mg on ten soils and harvested on May 25, 1967.

d.f.		Yield g/pot	P percent	K percent	Mg percent
S. S. Replicates	3	8.265	0.0091	4.283	0.1138
Treatments	5	258.656	2.0339	32.692	3.3594
Error "a"	15	7.470	0.0563	1.707	0.1094
Soils	9	7.281	0.7025	42.028	0.3849
Soils x treatments	45	27.355	0.2096	15.961	0.7197
Soils x replicates	27	2.959	0.0372	1.835	0.1092
Error "b"	135	15.088	0.2061	12.987	0.5150
Total	239	327.075	3.2550	110.496	5.3117
M.S. Replicates	3	2.755^{xx}	0.0030	1.427^{xx}	0.0380^{x}
Treatments	5	51.731^{xx}	0.4067^{xx}	6.538^{xx}	0.6719^{xx}
Error "a"	15	0.498	0.0038	0.113	0.0073
Soils	9	0.809^{xx}	0.0780^{xx}	4.669^{xx}	0.0428^{xx}
Soils x treatments	45	0.607^{xx}	0.0047^{xx}	0.354^{xx}	0.0160^{xx}
Soils x replicates	27	0.109	0.0014	0.068	0.0040
Error "b"	135	0.112	0.0015	0.096	0.0038
L.S.D. Two treatment	.05	0.336	0.029	0.161	0.195
means	.01	0.464	0.040	0.222	0.270
Two soil	.05	0.556	0.022	0.174	0.033
means	.01	0.712	0.028	0.224	0.042
Two soils,	.05	0.460	0.054	0.425	0.085
one treatment	.01	0.590	0.069	0.545	0.109
Two treatments,	.05	0.562	0.055	0.451	0.090
one soil	.01	0.767	0.076	0.619	0.123

x. Significant at 5% level.

xx. Significant at 1% level.

Table 24. Analysis of variance of total dry matter yield, P. K, and Mg uptake by corn and ryegrass as affected by application of N, P, K, and Mg on ten soils.

		d.f.	Yield g/pot	P mg/pot	K mg/pot	Mg mg/pot
S.S.	Replicates	3	10.84	97.08	2560	183.6
	Treatments	5	3116.19	8229.93	2790102	60377.3
	Error "a"	15	12.58	66.72	17650	555.1
	Soils	9	60.69	3138.31	984140	2868.1
	Soils x treatments	45	160.97	1066.63	369570	1699.7
	Soils x replicates	27	9.89	40.14	13190	302.10
	Error "b"	135	47.22	348.74	60720	4797.1
	Total	239	3418.46	12987.61	4237960	67915.4
M.S.	Replicates	3	3.61	32.36xx	850	61.2
	Treatments	5	623.23xx	1645.99xx	558020xx	12075.5xx
	Error "a"	15	0.83	4.44	1170	37.0
	Soils	9	6.74xx	348.70xx	109380xx	318.6x
	Soils x treatments	45	3.57xx	237.02xx	8212xx	37.7
	Soils x replicates	27	0.36	1.48	480	11.2
	Error "b"	135	0.34	2.58	440	142.8
L.S.D.	Two treatment	.05	0.430	1.004	16.49	2.898
	means	.01	0.595	1.388	22.81	4.008
	Two soil	.05	0.333	0.907	11.95	6.727
	means	.01	0.428	1.162	15.32	8.625
	Two soils,	.05	0.815	2.204	29.25	16.477
	one treatment	.01	1.045	2.825	37.50	21.25
	Two treatments,	.05	0.892	2.419	33.21	5.863
	one soil	.01	1.218	3.304	45.36	8.008

x. Significant at 5% level.

xx. Significant at 1% level.

Table 25. Dry matter yield of corn harvested on March 14, 1968, from Daudieh and Bazurieh soils as affected by application of N, P, K, and Mg. Nutrients were mixed with soil (m) or added in solution (S).

Level N	P	K	Mg	Daudieh (S)	Bazurieh (S)	Daudieh (m)	Bazurieh (m)
				g/pot			
2	2	2	2	1.41	0.99	2.02	1.27
4	2	2	2	2.13	1.73	1.96	2.06
2	4	2	2	1.37	1.18	1.99	2.53
4	4	2	2	1.61	1.76	2.11	1.92
2	2	4	2	1.66	1.13	1.49	2.23
4	2	4	2	1.53	1.87	1.97	2.37
2	4	4	2	0.99	1.12	1.65	2.58
4	4	4	2	1.97	0.92	1.38	2.60
2	2	2	4	1.28	1.12	1.64	1.70
4	2	2	4	2.08	1.73	1.44	2.49
2	4	2	4	1.11	1.11	1.89	1.79
4	4	2	4	2.04	1.51	1.88	1.94
2	2	4	4	1.14	1.09	1.53	2.54
4	2	4	4	1.86	1.73	1.61	2.59
2	4	4	4	1.73	1.24	2.03	2.08
4	4	4	4	1.72	1.78	2.00	2.54
5	3	3	3	1.75	1.80	1.43	2.27
1	3	3	3	1.32	1.21	1.24	1.45
3	5	3	3	1.79	1.41	3.01	2.18
3	1	3	3	1.45	1.82	2.40	2.64
3	3	5	3	1.60	1.70	1.68	2.51
3	3	1	3	2.16	1.24	3.22	3.04
3	3	3	5	1.44	1.51	2.29	2.63
3	3	3	1	2.23	1.56	2.55	2.07
3	3	3	3	1.69	1.32	1.99	2.59
3	3	3	3	1.33	1.28	1.58	3.13
3	3	3	3	1.87	1.28	2.06	1.54
3	3	3	3	1.96	1.60	2.49	2.52
3	3	3	3	1.56	1.06	2.15	2.50
3	3	3	3	1.53	1.31	2.15	2.43
3	3	3	3	1.71	1.41	2.37	2.37

Table 26. Dry matter yield of ryegrass, harvested on March 28, 1967, from Bazurieh and Daudieh soils as affected by application of N, P, K, and Mg. Nutrients were mixed with soil (m) or added in solution (S).

Level N	P	K	Mg	Daudieh (S)	Bazurieh (S)	Daudieh (m)	Bazurieh (m)
					g/pot		
2	2	2	2	1.54	1.23	2.67	1.80
4	2	2	2	2.23	1.54	4.51	4.01
2	4	2	2	2.08	1.61	2.37	2.16
4	4	2	2	2.57	1.73	5.47	4.93
2	2	4	2	2.07	1.55	2.74	2.06
4	2	4	2	2.35	1.90	4.77	4.22
2	4	4	2	1.84	1.47	2.91	1.73
4	4	4	2	2.39	2.98	6.59	4.08
2	2	2	4	1.35	1.53	2.47	1.95
4	2	2	4	2.37	1.82	5.35	3.37
2	4	2	4	1.68	1.49	2.41	2.06
4	4	2	4	2.13	1.55	4.93	3.80
2	2	4	4	1.18	1.53	2.69	2.20
4	2	4	4	2.37	2.04	3.97	4.20
2	4	4	4	1.89	1.35	2.99	2.10
4	4	4	4	3.30	1.89	5.45	5.28
5	3	3	3	2.96	3.04	6.28	5.60
1	3	3	3	1.57	1.17	2.02	1.64
3	5	3	3	2.10	1.72	3.27	3.14
3	1	3	3	1.89	1.50	2.87	2.57
3	3	5	3	2.13	1.88	3.79	2.95
3	3	1	3	2.17	1.18	3.24	3.04
3	3	3	5	1.90	1.77	3.50	2.69
3	3	3	1	2.20	1.70	2.82	2.79
3	3	3	3	2.05	1.54	4.27	3.06
3	3	3	3	2.24	1.63	3.85	3.23
3	3	3	3	2.05	1.72	3.67	2.73
3	3	3	3	2.17	1.27	3.65	3.14
3	3	3	3	2.08	1.71	2.98	3.02
3	3	3	3	2.11	1.56	3.13	3.33
3	3	3	3	2.13	1.67	2.69	2.85

Table 27. Dry matter yield of ryegrass, harvested on May 25, 1967 from Bazurieh and Daudieh soils as affected by application of N, P, K, and Mg. Nutrients were mixed with soil (m) or added in solution (S).

Level N	P	K	Mg	Daudieh (S)	Bazurieh (S)	Daudieh (m)	Bazurieh (m)
				g/pot			
2	2	2	2	3.13	1.64	0.89	1.36
4	2	2	2	4.81	4.42	3.34	2.04
2	4	2	2	1.39	1.68	0.87	0.88
4	4	2	2	4.06	4.57	2.66	2.10
2	2	4	2	1.95	1.69	0.63	0.83
4	2	4	2	4.22	4.83	2.60	2.14
2	4	4	2	1.42	1.80	0.82	0.82
4	4	4	2	4.14	4.29	2.35	1.83
2	2	2	4	1.44	1.72	0.80	1.12
4	2	2	4	4.68	5.08	2.56	1.87
2	4	2	4	2.83	1.53	0.75	1.02
4	4	2	4	4.17	4.81	1.95	2.02
2	2	4	4	2.02	1.48	0.67	1.04
4	2	4	4	4.43	4.52	2.63	1.44
2	4	4	4	1.54	1.44	1.00	1.18
4	4	4	4	4.51	4.42	2.68	2.69
5	3	3	3	7.50	7.90	7.00	5.10
1	3	3	3	1.22	1.08	0.63	1.07
3	5	3	3	2.64	2.78	0.93	1.35
3	1	3	3	2.71	2.77	1.14	1.49
3	3	5	3	2.57	2.88	1.04	1.06
3	3	1	3	2.53	2.87	1.25	1.55
3	3	3	5	2.56	2.99	0.88	1.23
3	3	3	1	2.81	2.71	1.10	1.32
3	3	3	3	2.58	2.65	1.23	1.33
3	3	3	3	3.22	2.70	1.40	1.45
3	3	3	3	2.69	2.62	1.18	1.42
3	3	3	3	2.77	2.42	1.18	1.10
3	3	3	3	2.56	2.68	1.28	1.31
3	3	3	3	2.90	2.54	0.98	1.14
3	3	3	3	2.49	2.47	2.29	1.34

Table 28. Total yield of dry matter from Bazurieh and Daudieh soils as affected by application of N, P, K, and Mg. Nutrients were mixed with soil (m) or added in solution (S).

Level N	P	K	Mg	Daudieh (S)	Bazurieh (S)	Daudieh (m)	Bazurieh (m)
				g/pot			
2	2	2	2	6.09	3.87	5.58	4.43
4	2	2	2	9.18	7.70	9.82	8.11
2	4	2	2	4.84	4.49	5.24	5.58
4	4	2	2	8.26	8.07	10.25	8.96
2	2	4	2	5.70	4.38	4.86	5.12
4	2	4	2	8.11	8.61	9.35	8.74
2	4	4	2	4.26	4.39	5.39	5.14
4	4	4	2	8.51	8.20	10.34	8.52
2	2	2	4	4.08	4.38	4.92	4.78
4	2	2	4	9.14	8.63	9.36	7.74
2	4	2	4	5.63	4.14	5.05	4.88
4	4	2	4	8.35	7.88	8.77	7.76
2	2	4	4	4.35	4.11	4.89	5.78
4	2	4	4	8.67	8.30	8.21	8.23
2	4	4	4	5.17	4.03	6.04	5.37
4	4	4	4	9.53	8.09	10.14	10.53
5	3	3	3	12.22	12.75	14.72	12.98
1	3	3	3	4.12	3.47	3.91	4.18
3	5	3	3	6.54	5.91	7.22	6.67
3	1	3	3	6.06	6.10	6.42	6.71
3	3	5	3	6.31	6.46	6.52	6.52
3	3	1	3	6.86	5.29	7.72	7.63
3	3	3	5	5.91	6.29	6.67	6.56
3	3	3	1	7.24	5.97	6.48	6.19
3	3	3	3	6.33	5.51	7.49	6.99
3	3	3	3	6.79	5.62	6.84	7.82
3	3	3	3	6.61	5.62	6.91	5.70
3	3	3	3	6.91	5.30	7.34	6.77
3	3	3	3	6.21	5.46	6.42	6.84
3	3	3	3	6.55	5.42	6.27	6.91
3	3	3	3	6.34	5.56	7.35	6.51

Table 29. Phosphorus in corn harvested on March 14, 1967 from Bazurieh and Daudieh soils as affected by application of N, P, K, and Mg. Nutrients were mixed with soil (m) or added in solution (S).

Level N	P	K	Mg	Daudieh (S)	Bazurieh (S)	Daudieh (m)	Bazurieh (m)
					Percent		
2	2	2	2	0.151	0.250	0.074	0.099
4	2	2	2	0.120	0.151	0.098	0.146
2	4	2	2	0.331	0.413	0.081	0.127
4	4	2	2	0.270	0.240	0.097	0.116
2	2	4	2	0.146	0.222	0.095	0.115
4	2	4	2	0.120	0.146	0.118	0.098
2	4	4	2	0.414	0.412	0.117	0.129
4	4	4	2	0.270	0.189	0.120	0.120
2	2	2	4	0.100	0.182	0.099	0.117
4	2	2	4	0.150	0.177	0.080	0.129
2	4	2	4	0.399	0.399	0.119	0.119
4	4	2	4	0.240	0.270	0.119	0.148
2	2	4	4	0.188	0.188	0.129	0.100
4	2	4	4	0.080	0.171	0.099	0.097
2	4	4	4	0.258	0.374	0.118	0.127
4	4	4	4	0.236	0.319	0.129	0.118
5	3	3	3	0.166	0.151	0.116	0.118
1	3	3	3	0.269	0.360	0.101	0.145
3	5	3	3	0.373	0.399	0.145	0.120
3	1	3	3	0.142	0.151	0.099	0.120
3	3	5	3	0.240	0.225	0.100	0.100
3	3	1	3	0.177	0.406	0.116	0.144
3	3	3	5	0.177	0.280	0.079	0.128
3	3	3	1	0.224	0.290	0.151	0.099
3	3	3	3	0.239	0.324	0.079	0.126
3	3	3	3	0.225	0.224	0.081	0.117
3	3	3	3	0.151	0.281	0.124	0.119
3	3	3	3	0.224	0.242	0.100	0.119
3	3	3	3	0.200	0.291	0.100	0.098
3	3	3	3	0.151	0.220	0.100	0.128
3	3	3	3	0.240	0.280	0.100	0.119

Table 30. Phosphorus in ryegrass harvested on March 28, 1967 from Daudieh and Bazurieh soils as affected by N, P, K, and Mg application. Nutrients were mixed with soil (m) or added in solution (S).

Level N	P	K	Mg	Daudieh (S)	Bazurieh (S)	Daudieh (m)	Bazurieh (m)
				Percent			
2	2	2	2	0.178	0.297	0.177	0.247
4	2	2	2	0.149	0.268	0.148	0.198
2	4	2	2	0.248	0.293	0.249	0.310
4	4	2	2	0.202	0.277	0.161	0.222
2	2	4	2	0.298	0.241	0.162	0.280
4	2	4	2	0.176	0.211	0.122	0.174
2	4	4	2	0.278	0.268	0.212	0.382
4	4	4	2	0.221	0.245	0.146	0.223
2	2	2	4	0.224	0.244	0.176	0.340
4	2	2	4	0.178	0.222	0.122	0.222
2	4	2	4	0.276	0.296	0.248	0.320
4	4	2	4	0.271	0.311	0.197	0.221
2	2	4	4	0.224	0.243	0.174	0.291
4	2	4	4	0.219	0.272	0.123	0.198
2	4	4	4	0.195	0.294	0.276	0.334
4	4	4	4	0.246	0.308	0.172	0.271
5	3	3	3	0.210	0.253	0.124	0.164
1	3	3	3	0.211	0.294	0.212	0.346
3	5	3	3	0.272	0.338	0.310	0.319
3	1	3	3	0.158	0.275	0.123	0.250
3	3	5	3	0.207	0.273	0.245	0.245
3	3	1	3	0.195	0.295	0.276	0.246
3	3	3	5	0.211	0.305	0.212	0.222
3	3	3	1	0.173	0.277	0.209	0.279
3	3	3	3	0.222	0.296	0.213	0.245
3	3	3	3	0.198	0.271	0.208	0.195
3	3	3	3	0.198	0.304	0.210	0.211
3	3	3	3	0.196	0.278	0.245	0.247
3	3	3	3	0.210	0.278	0.211	0.219
3	3	3	3	0.220	0.294	0.210	0.293
3	3	3	3	0.220	0.277	0.247	0.275

Table 31. **Phosphorus in ryegrass harvested on May 25, 1967 from Daudieh and Bazurieh soils as affected by application of N, P, K, and Mg. Nutrients were mixed with soil (m) or added in solution (S).**

Level N	P	K	Mg	Daudieh (S)	Bazurieh (S)	Daudieh (m)	Bazurieh (m)
				Percent			
2	2	2	2	0.149	0.211	0.148	0.177
4	2	2	2	0.093	0.148	0.106	0.176
2	4	2	2	0.280	0.272	0.248	0.281
4	4	2	2	0.176	0.177	0.163	0.160
2	2	4	2	0.161	0.212	0.138	0.263
4	2	4	2	0.117	0.125	0.094	0.148
2	4	4	2	0.248	0.279	0.165	0.329
4	4	4	2	0.162	0.162	0.106	0.199
2	2	2	4	0.176	0.248	0.124	0.279
4	2	2	4	0.124	0.105	0.100	0.177
2	4	2	4	0.198	0.320	0.198	0.271
4	4	2	4	0.200	0.176	0.149	0.177
2	2	4	4	0.211	0.274	0.141	0.279
4	2	4	4	0.148	0.162	0.093	0.174
2	4	4	4	0.312	0.415	0.210	0.309
4	4	4	4	0.199	0.200	0.125	0.176
5	3	3	3	0.124	0.163	0.106	0.106
1	3	3	3	0.249	0.322	0.115	0.298
3	5	3	3	0.324	0.342	0.263	0.274
3	1	3	3	0.116	0.162	0.125	0.223
3	3	5	3	0.212	0.223	0.162	0.272
3	3	1	3	0.167	0.210	0.177	0.223
3	3	3	5	0.225	0.249	0.167	0.223
3	3	3	1	0.177	0.204	0.177	0.248
3	3	3	3	0.178	0.210	0.177	0.223
3	3	3	3	0.176	0.210	0.163	0.223
3	3	3	3	0.186	0.210	0.166	0.223
3	3	3	3	0.198	0.223	0.176	0.247
3	3	3	3	0.200	0.240	0.167	0.223
3	3	3	3	0.198	0.249	0.177	0.247
3	3	3	3	0.200	0.249	0.164	0.223

Table 32. Total P uptake from Daudieh and Bazurieh soils as affected by application of N, P, K_2 and Mg. Nutrients were mixed with soil (m) or added in solution (S).

Level N	P	K	Mg	Daudieh (S)	Bazurieh (S)	Daudieh (m)	Bazurieh (m)
				mg/pot			
2	2	2	2	9.5	9.7	7.5	8.2
4	2	2	2	10.4	13.2	12.1	14.5
2	4	2	2	13.6	14.2	9.7	12.4
4	4	2	2	16.8	17.1	15.2	16.6
2	2	4	2	11.7	9.8	6.7	10.6
4	2	4	2	10.9	12.7	10.5	12.9
2	4	4	2	12.7	13.5	9.5	12.6
4	4	4	2	17.3	16.0	13.0	15.8
2	2	2	4	6.8	10.0	7.0	11.7
4	2	2	4	13.1	12.4	10.3	14.8
2	4	2	4	14.6	13.7	9.8	11.5
4	4	2	4	19.0	17.4	14.8	14.9
2	2	4	4	9.1	9.9	7.6	11.8
4	2	4	4	13.3	15.8	8.9	13.3
2	4	4	4	13.0	14.6	12.8	13.3
4	4	4	4	21.2	20.3	15.4	22.0
5	3	3	3	18.4	23.3	16.9	17.3
1	3	3	3	9.9	11.3	7.0	11.0
3	5	3	3	21.0	21.1	17.0	16.3
3	1	3	3	8.2	11.4	7.3	12.9
3	3	5	3	13.8	15.3	12.7	12.6
3	3	1	3	12.2	14.6	14.8	15.3
3	3	3	5	12.4	17.1	10.7	12.2
3	3	3	1	13.8	14.7	11.8	13.2
3	3	3	3	13.2	14.5	12.9	13.8
3	3	3	3	13.1	13.0	11.6	13.2
3	3	3	3	11.8	14.3	12.3	10.8
3	3	3	3	14.1	12.8	13.6	13.5
3	3	3	3	12.6	14.6	8.6	12.0
3	3	3	3	12.6	13.8	10.5	15.7
3	3	3	3	14.5	14.7	12.7	13.6

Table 33. Potassium in corn harvested on March 14, 1967 from Daudieh and Bazurieh soils as affected by application of N, P, K, and Mg. Nutrients were mixed with soil (m) or added in solution (S).

Level N	P	K	Mg	Daudieh (S)	Bazurieh (S)	Daudieh (m)	Bazurieh (m)
				Percent			
2	2	2	2	2.597	1.548	2.323	1.588
4	2	2	2	2.096	1.178	2.874	1.197
2	4	2	2	2.634	1.300	2.023	1.176
4	4	2	2	2.197	1.397	2.095	1.369
2	2	4	2	3.309	2.854	4.084	2.845
4	2	4	2	3.079	1.740	4.164	2.776
2	4	4	2	3.641	2.323	3.215	2.709
4	4	4	2	2.479	0.876	3.481	2.394
2	2	2	4	2.882	1.347	2.517	1.560
4	2	2	4	2.476	0.998	2.277	1.255
2	4	2	4	3.166	1.248	2.257	1.132
4	4	2	4	2.300	0.939	2.177	1.508
2	2	4	4	3.534	2.665	2.995	2.594
4	2	4	4	2.920	2.000	3.952	2.826
2	4	4	4	3.100	2.743	3.553	2.230
4	4	4	4	2.912	1.777	2.890	2.008
5	3	3	3	2.133	0.739	2.636	1.531
1	3	3	3	2.713	1.992	3.097	2.190
3	5	3	3	2.308	1.572	2.305	1.176
3	1	3	3	2.804	1.499	3.171	1.820
3	3	5	3	4.396	2.538	3.350	3.023
3	3	1	3	2.276	0.800	1.943	0.930
3	3	3	5	3.084	1.598	2.444	1.322
3	3	3	1	2.433	1.519	2.162	1.590
3	3	3	3	2.634	1.770	2.424	1.454
3	3	3	3	2.717	1.535	2.311	0.994
3	3	3	3	2.476	1.771	2.600	1.992
3	3	3	3	2.513	1.616	2.369	1.387
3	3	3	3	2.197	1.747	2.192	1.368
3	3	3	3	2.196	1.640	2.488	1.315
3	3	3	3	2.593	1.582	3.016	1.688

Table 34. Potassium in ryegrass harvested on March 28, 1967 from Daudieh and Bazurieh soils as affected by application of N, P, K, and Mg. Nutrients were mixed with soil (m) or added in solution (S).

Level N	P	K	Mg	Daudieh (S)	Bazurieh (S)	Daudieh (m)	Bazurieh (m)
					Percent		
2	2	2	2	2.401	2.723	2.991	2.720
4	2	2	2	2.780	2.444	3.311	1.734
2	4	2	2	2.775	2.441	3.040	2.785
4	4	2	2	2.470	2.222	3.030	1.261
2	2	4	2	2.901	2.465	3.605	3.378
4	2	4	2	3.145	2.378	3.776	3.035
2	4	4	2	3.140	2.266	3.170	3.448
4	4	4	2	2.950	2.281	3.660	3.016
2	2	2	4	2.791	2.338	3.515	2.718
4	2	2	4	2.610	2.340	3.178	1.798
2	4	2	4	2.630	2.368	3.030	2.710
4	4	2	4	2.631	2.394	2.830	1.521
2	2	4	4	2.993	2.530	3.333	3.302
4	2	4	4	2.917	2.350	3.011	3.712
2	4	4	4	2.603	2.450	3.116	3.450
4	4	4	4	2.555	2.340	2.521	3.843
5	3	3	3	3.020	1.773	2.071	3.515
1	3	3	3	2.579	2.500	3.241	3.422
3	5	3	3	2.721	2.333	2.061	3.561
3	1	3	3	2.913	2.542	2.950	3.501
3	3	5	3	2.921	2.485	3.681	3.632
3	3	1	3	2.731	2.222	3.122	3.041
3	3	3	5	2.741	2.320	3.488	2.641
3	3	3	1	2.531	2.291	3.440	2.901
3	3	3	3	2.841	2.371	2.931	2.635
3	3	3	3	2.646	2.036	3.333	2.101
3	3	3	3	2.650	2.311	3.351	2.350
3	3	3	3	2.871	2.377	3.921	2.468
3	3	3	3	2.880	2.521	3.151	2.193
3	3	3	3	2.691	2.450	3.070	2.622
3	3	3	3	2.681	2.365	3.951	2.853

Table 35. Potassium in ryegrass harvested on May 25, 1967 from Daudieh and Bazurieh soils as affected by application of N, P, K, and Mg. Nutrients were mixed with soil (m) or added in solution (S).

N	Level P	K	Mg	Daudieh (S)	Bazurieh (S)	Daudieh (m)	Bazurieh (m)
					Percent		
2	2	2	2	1.844	1.564	1.238	1.367
4	2	2	2	1.792	1.288	1.420	1.137
2	4	2	2	1.516	1.409	1.686	1.519
4	4	2	2	1.835	1.246	1.143	0.984
2	2	4	2	1.632	1.518	1.365	1.511
4	2	4	2	1.940	1.620	1.150	1.260
2	4	4	2	1.612	1.416	1.318	1.512
4	4	4	2	1.694	1.520	1.319	1.319
2	2	2	4	1.464	1.511	1.312	1.439
4	2	2	4	1.790	1.236	1.240	1.143
2	4	2	4	1.608	1.353	1.188	1.353
4	4	2	4	1.747	1.290	1.145	0.991
2	2	4	4	1.568	1.444	1.524	1.313
4	2	4	4	1.828	1.616	1.246	1.082
2	4	4	4	1.472	1.560	1.412	1.287
4	4	4	4	1.614	1.472	1.373	1.191
5	3	3	3	1.984	1.197	1.375	0.822
1	3	3	3	1.419	1.290	1.519	1.617
3	5	3	3	1.643	1.419	1.512	1.040
3	1	3	3	1.626	1.366	1.422	1.438
3	3	5	3	1.892	1.512	1.622	1.509
3	3	1	3	1.568	1.192	1.296	1.139
3	3	3	5	1.744	1.295	1.268	1.134
3	3	3	1	1.695	1.444	1.444	1.314
3	3	3	3	1.621	1.441	1.420	1.234
3	3	3	3	1.689	1.316	1.300	1.238
3	3	3	3	1.616	1.371	1.364	1.241
3	3	3	3	1.636	1.408	1.610	1.259
3	3	3	3	1.615	1.613	1.517	1.292
3	3	3	3	1.634	1.446	1.443	1.236
3	3	3	3	1.699	1.324	1.304	1.288

Table 36. Total K uptake from Daudieh and Bazurieh soils as affected by application of N, P, K, and Mg. Nutrients were mixed with soil (m) or added in solution (S).

Level				Daudieh (S)	Bazurieh (S)	Daudieh (m)	Bazurieh (m)
N	P	K	Mg				
				mg/pot			
2	2	2	2	131.4	74.7	137.8	87.9
4	2	2	2	193.1	115.0	253.4	117.3
2	4	2	2	114.9	78.6	127.3	103.4
4	4	2	2	173.7	120.1	240.4	109.3
2	2	4	2	147.1	96.3	168.5	145.7
4	2	4	2	203.1	156.4	292.1	221.4
2	4	4	2	116.9	85.0	155.4	142.3
4	4	4	2	189.8	141.5	320.7	209.8
2	2	2	4	95.9	77.1	139.0	95.9
4	2	2	4	197.4	122.7	235.0	113.4
2	4	2	4	125.1	70.1	124.4	90.0
4	4	2	4	176.2	113.5	203.1	107.1
2	2	4	4	107.5	89.4	145.6	152.3
4	2	4	4	204.8	155.9	216.1	244.6
2	4	4	4	125.8	89.7	180.1	134.1
4	4	4	4	207.3	141.0	231.0	286.1
5	3	3	3	275.8	161.7	264.1	273.9
1	3	3	3	93.9	67.7	114.0	105.5
3	5	3	3	142.1	102.9	151.1	151.6
3	1	3	3	140.1	102.4	177.2	159.8
3	3	5	3	181.6	133.3	213.1	199.1
3	3	1	3	148.1	70.4	180.1	107.9
3	3	3	5	141.7	104.3	190.6	123.7
3	3	3	1	157.6	101.8	168.2	131.3
3	3	3	3	145.0	98.1	190.9	134.9
3	3	3	3	150.0	88.5	183.3	117.2
3	3	3	3	144.3	98.5	192.7	111.7
3	3	3	3	157.0	90.3	222.0	126.5
3	3	3	3	135.8	105.2	160.8	117.5
3	3	3	3	138.0	96.8	163.8	134.4
3	3	3	3	144.0	94.6	207.7	138.7

Table 37. Magnesium in corn harvested on March 14, 1967 from Daudieh and Bazurieh soils as affected by application of N, P, K, and Mg. Nutrients were mixed with soil (m) or added in solution (S).

Level				Daudieh (S)	Bazurieh (S)	Daudieh (m)	Bazurieh (m)
N	P	K	Mg				
				Percent			
2	2	2	2	0.300	0.493	0.280	0.610
4	2	2	2	0.309	0.454	0.423	0.833
2	4	2	2	0.264	0.469	0.318	0.460
4	4	2	2	0.344	0.349	0.417	0.690
2	2	4	2	0.244	0.307	0.196	0.274
4	2	4	2	0.195	0.320	0.265	0.460
2	4	4	2	0.212	0.325	0.219	0.199
4	4	4	2	0.230	0.582	0.315	0.454
2	2	2	4	0.360	0.624	0.258	0.527
4	2	2	4	0.374	0.809	0.464	0.762
2	4	2	4	0.405	0.612	0.267	0.571
4	4	2	4	0.500	0.904	0.425	0.906
2	2	4	4	0.268	0.585	0.205	0.239
4	2	4	4	0.360	0.470	0.321	0.605
2	4	4	4	0.422	0.468	0.212	0.279
4	4	4	4	0.419	0.624	0.349	0.551
5	3	3	3	0..392	0.609	0.363	0.687
1	3	3	3	0.269	0.423	0.192	0.289
3	5	3	3	0.308	0.412	0.243	0.508
3	1	3	3	0.302	0.505	0.282	0.370
3	3	5	3	0.210	0.395	0.239	0.262
3	3	1	3	0.270	0.656	0.330	0.584
3	3	3	5	0.486	0.674	0.242	0.548
3	3	3	1	0.294	0.345	0.215	0.398
3	3	3	3	0.244	0.542	0.278	0.407
3	3	3	3	0.354	0.468	0.338	0.508
3	3	3	3	0.350	0.468	0.234	0.510
3	3	3	3	0.324	0.505	0.216	0.416
3	3	3	3	0.350	0.487	0.254	0.498
3	3	3	3	0.284	0.410	0.257	0.461
3	3	3	3	0.339	0.521	0.317	0.417

Table 38. Magnesium in ryegrass harvested on March 28, 1967 from Daudieh and Bazurieh soils as affected by application of N, P, K, and Mg. Nutrients were mixed with soil (m) or added in solution (S).

Level N	P	K	Mg	Daudieh (S)	Bazurieh (S)	Daudieh (m)	Bazurieh (m)
					Percent		
2	2	2	2	0.282	0.285	0.268	0.370
4	2	2	2	0.229	0.280	0.296	0.372
2	4	2	2	0.260	0.360	0.287	0.322
4	4	2	2	0.249	0.277	0.263	0.345
2	2	4	2	0.271	0.326	0.218	0.310
4	2	4	2	0.222	0.291	0.260	0.300
2	4	4	2	0.228	0.311	0.231	0.308
4	4	4	2	0.227	0.306	0.232	0.315
2	2	2	4	0.319	0.360	0.254	0.408
4	2	2	4	0.263	0.345	0.257	0.444
2	4	2	4	0.288	0.351	0.267	0.369
4	4	2	4	0.295	0.373	0.283	0.441
2	2	4	4	0.286	0.358	0.324	0.243
4	2	4	4	0.274	0.322	0.364	0.241
2	4	4	4	0.249	0.312	0.319	0.225
4	4	4	4	0.264	0.327	0.370	0.252
5	3	3	3	0.266	0.281	0.454	0.289
1	3	3	3	0.267	0.312	0.318	0.214
3	5	3	3	0.253	0.326	0.297	0.264
3	1	3	3	0.261	0.313	0.307	0.231
3	3	5	3	0.225	0.304	0.227	0.307
3	3	1	3	0.262	0.351	0.276	0.345
3	3	3	5	0.336	0.426	0.237	0.426
3	3	3	1	0.243	0.308	0.270	0.323
3	3	3	3	0.265	0.302	0.276	0.300
3	3	3	3	0.285	0.338	0.226	0.292
3	3	3	3	0.279	0.323	0.228	0.328
3	3	3	3	0.263	0.303	0.232	0.303
3	3	3	3	0.265	0.315	0.273	0.329
3	3	3	3	0.306	0.318	0.222	0.354
3	3	3	3	0.280	0.338	0.247	0.329

Table 39. Magnesium in ryegrass harvested on May 25, 1967 from Daudieh and Bazurieh soils as affected by application of N, P, K, and Mg. Nutrients were mixed with soil (m) or added in solution (S).

Level N	P	K	Mg	Daudieh (S)	Bazurieh (S)	Daudieh (m)	Bazurieh (m)
				Percent			
2	2	2	2	0.461	0.534	0.439	0.567
4	2	2	2	0.509	0.471	0.404	0.574
2	4	2	2	0.484	0.554	0.598	0.726
4	4	2	2	0.507	0.517	0.490	0.588
2	2	4	2	0.458	0.526	0.609	0.706
4	2	4	2	0.491	0.428	0.450	0.531
2	4	4	2	0.533	0.491	0.609	0.672
4	4	4	2	0.486	0.474	0.423	0.595
2	2	2	4	0.609	0.624	0.624	0.700
4	2	2	4	0.552	0.506	0.490	0.634
2	4	2	4	0.586	0.594	0.635	0.603
4	4	2	4	0.619	0.551	0.516	0.632
2	2	4	4	0.586	0.601	0.605	0.736
4	2	4	4	0.548	0.499	0.480	0.769
2	4	4	4	0.619	0.656	0.614	0.730
4	4	4	4	0.556	0.486	0.469	0.507
5	3	3	3	0.507	0.587	0.398	0.560
1	3	3	3	0.548	0.593	0.710	0.711
3	5	3	3	0.560	0.517	0.624	0.650
3	1	3	3	0.537	0.484	0.579	0.615
3	3	5	3	0.595	0.507	0.486	0.649
3	3	1	3	0.569	0.525	0.548	0.632
3	3	3	5	0.642	0.699	0.609	0.850
3	3	3	1	0.517	0.485	0.543	0.676
3	3	3	3	0.549	0.508	0.578	0.546
3	3	3	3	0.546	0.633	0.501	0.638
3	3	3	3	0.568	0.543	0.541	0.593
3	3	3	3	0.545	0.581	0.490	0.647
3	3	3	3	0.569	0.633	0.526	0.614
3	3	3	3	0.562	0.517	0.535	0.672
3	3	3	3	0.562	0.550	0.426	0.681

Table 40. Total Mg uptake from Daudieh and Bazurieh soils as affected by application of N, P, K, and Mg. Nutrients were mixed with soil (m) or added in solution (S).

Level N	P	K	Mg	Daudieh (S)	Bazurieh (S)	Daudieh (m)	Bazurieh (m)
				mg/pot			
2	2	2	2	23.1	17.2	16.8	22.2
4	2	2	2	36.2	33.0	35.2	43.8
2	4	2	2	15.7	20.8	18.3	25.1
4	4	2	2	32.6	34.5	36.3	42.7
2	2	4	2	18.7	17.5	12.7	18.4
4	2	4	2	28.9	32.2	29.3	35.0
2	4	4	2	13.9	17.0	15.3	16.1
4	4	4	2	30.0	34.9	29.7	35.6
2	2	2	4	17.7	23.3	15.5	24.8
4	2	2	4	39.9	46.0	33.1	45.9
2	4	2	4	25.9	21.1	16.3	24.0
4	4	2	4	42.3	46.0	32.1	47.1
2	2	4	4	18.4	20.8	15.9	29.2
4	2	4	4	37.5	37.4	32.5	37.1
2	4	4	4	21.6	19.5	20.1	19.2
4	4	4	4	41.0	38.8	39.8	41.0
5	3	3	3	52.9	65.9	61.6	60.4
1	3	3	3	14.5	15.2	13.3	15.4
3	5	3	3	25.6	26.0	22.8	28.1
3	1	3	3	23.9	27.3	22.2	25.0
3	3	5	3	23.5	27.0	47.2	49.8
3	3	1	3	25.9	27.4	50.6	62.8
3	3	3	5	29.8	38.7	45.9	46.1
3	3	3	1	26.4	23.8	42.3	56.6
3	3	3	3	23.7	25.3	49.4	83.2
3	3	3	3	28.7	32.3	46.7	50.3
3	3	3	3	27.4	25.8	55.9	50.0
3	3	3	3	29.1	26.0	57.0	62.5
3	3	3	3	25.6	27.6	51.0	51.1
3	3	3	3	27.2	23.6	39.0	56.4
3	3	3	3	25.8	26.6	55.4	56.0

Table 41. Residual soil phosphorus in Daudieh and Bazurieh soils as affected by application of N, P, K, and Mg, and determined by the Olsen and Al-Abbas methods.

Level N	P	K	Mg	Daudieh Olsen	Daudieh Al-Abbas	Bazurieh Olsen	Bazurieh Al-Abbas
					ppm		
2	2	2	2	1.15	15.5	2.75	15.5
4	2	2	2	1.65	14.5	2.75	14.5
2	4	2	2	8.00	61.0	5.50	17.5
4	4	2	2	6.00	24.5	5.50	39.0
2	2	4	2	1.25	12.0	3.00	15.5
4	2	4	2	3.00	12.0	2.25	13.0
2	4	4	2	8.00	50.0	5.50	22.0
4	4	4	2	2.12	29.0	11.25	17.5
2	2	2	4	2.15	14.0	4.75	16.5
4	2	2	4	2.15	16.5	2.75	14.5
2	4	2	4	6.50	47.5	7.25	36.5
4	4	2	4	6.50	31.5	8.00	42.0
2	2	4	4	2.12	12.0	3.25	16.5
4	2	4	4	1.15	10.5	3.25	16.5
2	4	4	4	4.75	26.5	9.75	35.5
4	4	4	4	4.75	14.0	7.50	63.5
5	3	3	3	2.00	16.5	3.50	19.0
1	3	3	3	4.25	14.0	3.50	22.0
3	5	3	3	11.50	102.5	9.25	70.0
3	1	3	3	1.50	14.0	2.18	14.5
3	3	5	3	1.58	24.5	3.00	14.5
3	3	1	3	1.88	16.5	3.25	21.0
3	3	3	5	4.00	28.0	2.75	19.0
3	3	3	1	7.25	35.0	3.25	24.5
3	3	3	3	3.25	22.5	3.25	19.0
3	3	3	3	3.50	23.0	3.75	19.0
3	3	3	3	3.25	20.0	3.75	19.0
3	3	3	3	2.75	20.0	4.00	20.0
3	3	3	3	2.75	25.5	3.75	22.0
3	3	3	3	3.25	21.0	4.75	25.5
3	3	3	3	3.00	20.0	4.25	23.0

Table 42. Soil characteristics after cropping with corn and ryegrass in various treatments.

Treatment	NPKMg	NPMg				NKMg	NPK	
Soil	P, Olsen	K, HNO_3 extract	K, Na tetra-phenylboron	K, NH_4Ac extract	Mg, NH_4Ac extract	P, Olsen	Mg, NH_4Ac extract	K, NH_4Ac extract
	ppm	meq/100 g	meq/100 g	meq/100 g	meq/100 g	ppm	meq/100 g	meq/100 g
1	1.66	1.00	0.28	0.28	6.82	1.12	6.58	0.31
2	1.29	1.24	0.28	0.29	3.12	0.68	3.13	0.31
3	1.58	0.12	0.26	0.06	0.99	0.92	0.95	0.05
4	1.31	3.73	3.24	0.57	4.67	0.75	4.85	0.69
5	1.27	1.20	0.61	0.19	1.14	1.00	1.20	0.18
6	9.20	0.59	0.65	0.27	1.22	7.86	1.24	0.32
7	1.00	0.66	0.33	0.19	6.43	0.76	6.53	0.22
8	0.97	0.61	0.16	0.20	18.10	0.68	18.60	0.23
9	1.12	3.20	1.61	0.38	5.54	0.65	4.96	0.51
10	2.00	0.21	0.23	0.14	1.69	1.28	1.63	0.16

Table 43. Regression coefficients for dry matter yield of corn and ryegrass grown on Daudieh and Bazurieh soils as affected by application of N, P, K, and Mg. Nutrients were added in solution.

Terms	Daudieh soil			Bazurieh soil		
	Corn March, 14	Ryegrass March, 28	Ryegrass May, 25	Corn March, 14	Ryegrass March, 28	Ryegrass May, 25
			g/pot			
Mean	1.6685	2.1219	2.7500	1.3280	1.5889	2.5886
N	+0.2145^{xx}	+0.3689^{xx}	+1.3267^{xx}	+0.2179^{xx}	+0.3090^{xx}	+1.5664^{xx}
P	+0.0059	+0.1179^{xx}	-0.1150^{e}	-0.0669^{e}	+0.0573^{e}	-0.0346^{e}
K	-0.0642^{e}	+0.0571^{x}	-0.0917^{e}	+0.0269	+0.1506^{xx}	-0.0401^{e}
Mg	-0.0527	+0.0579^{x}	-0.0002	+0.0217	-0.0275	+0.0269^{e}
Sb	±0.0435	±0.0138	±0.0509	±0.0334	±0.0319	±0.0218
N^2	-0.0518^{e}	+0.0310	+0.4219^{xx}	+0.0196	+0.1228^{xx}	+0.4555^{xx}
P^2	-0.0292	+0.0361^{x}	-0.0002	+0.0467^{e}	-0.0018	+0.0272^{e}
K^2	+0.0345	+0.0026	-0.0315	+0.0103	-0.0218	+0.0511^{x}
Mg^2	+0.0235	-0.0219^{e}	+0.0012	+0.0267	+0.0304^{e}	+0.0451^{e}
Sb	±0.0394	±0.0126	±0.0461	±0.0303	±0.0290	±0.0198
NP	+0.0028	-0.0173^{e}	+0.0062	-0.0892^{x}	+0.0487^{e}	-0.0421^{e}
NK	-0.0712^{e}	+0.0485^{x}	+0.0886^{e}	-0.0373	+0.1332^{x}	-0.0395^{e}
NMg	+0.0401	+0.1283^{xx}	+0.0377	+0.0212	-0.0563^{e}	+0.0855^{x}
PK	+0.0609^{e}	+0.0294^{e}	+0.0384	-0.0473^{e}	+0.0248	-0.0200
PMg	+0.0644	+0.0659^{xx}	+0.2230^{x}	+0.0442^{e}	-0.1387^{x}	-0.0220
KMg	+0.0197	+0.0596^{x}	+0.0658^{e}	+0.0621^{e}	-0.0854^{e}	-0.0991^{xx}
NPK	+0.0471	+0.0772^{xx}	+0.1194^{e}	-0.0421^{e}	+0.1008^{x}	-0.0470^{e}
NPMg	-0.0777^{e}	-0.0266	-0.1740^{x}	+0.0507^{e}	-0.0737^{e}	+0.0247
NKMg	-0.0562^{e}	+0.0926^{xx}	+0.0101	+0.0591^{e}	-0.0459^{e}	-0.0366^{e}
PKMg	+0.0204	+0.1642^{xx}	-0.1973^{x}	+0.1008^{x}	-0.0291	+0.0588^{e}
Sb	+0.0533	+0.0170	±0.0624	±0.0409	±0.0391	±0.0262
R^1	+0.774	+0.984	+0.981	+0.888	+0.943	+0.996

e. Greater than standard error.

x. Significant at 5% level.

xx. Significant at 1% level.

1. Multiple correlation coefficient.

Table 44. Regression coefficients for dry matter yield of corn and ryegrass grown on Daudieh and Bazurieh soils as affected by application of N, P, K, and Mg. Nutrients were mixed with soil.

Terms	Daudieh soil			Bazurieh soil		
	Corn March, 14	Ryegrass March, 28	Ryegrass May, 25	Corn March, 14	Ryegrass March, 28	Ryegrass May, 25
	g/pot					
Mean	2.1153	3.4684	1.3669	2.4456	3.0569	1.3024
N	+0.0207	$+1.1797^{xx}$	$+1.1281^{xx}$	$+0.1430^{e}$	$+1.0725^{xx}$	$+0.6638^{xx}$
P	$+0.1044^{e}$	$+0.1985^{e}$	-0.0610	-0.0084	$+0.1439^{x}$	+0.0191
K	-0.1811^{x}	$+0.1262^{e}$	-0.0363	$+0.1154^{e}$	$+0.0669^{e}$	-0.0584^{e}
Mg	-0.0443	-0.0168	-0.0661	+0.0515	-0.0101	+0.0088
Sb	±0.0597	±0.1127	±0.0872	±0.0959	±0.0428	±0.0271
N^2	-0.2667^{xx}	$+0.2416^{e}$	+0.6048	-0.1703^{e}	$+0.1533^{x}$	$+0.4062^{xx}$
P^2	$+0.0743^{e}$	-0.0284	-0.0895^{e}	-0.0326	-0.0375	-0.0109
K^2	+0.0115	+0.0831	-0.0629	-0.0585	-0.0036	-0.0403^{e}
Mg^2	+0.0035	-0.0074	-0.1100^{e}	-0.0468	-0.0673^{e}	-0.0471^{e}
Sb	±0.0542	±0.1022	±0.0791	±0.0870	±0.0388	±0.0246
NP	-0.0308	$+0.2316^{e}$	-0.1218^{e}	-0.1085	$+0.1404^{x}$	$+0.0994^{x}$
NK	+0.0261	-0.0557	-0.0045	-0.0273	$+0.0976^{e}$	$+0.0364^{e}$
NMg	-0.0276	-0.0939	-0.0722	+0.0694	-0.0717^{e}	-0.0350^{e}
PK	-0.0216	$+0.2255^{e}$	+0.1050	-0.0373	-0.0808^{e}	$+0.0698^{x}$
PMg	$+0.1191^{e}$	-0.0851	+0.0295	-0.1665^{e}	+0.0430	$+0.1361^{xx}$
KMg	$+0.1186^{e}$	-0.1287	$+0.1428^{e}$	-0.0100	$+0.2120^{xx}$	$+0.0680^{e}$
NPK	-0.0778^{e}	+0.1204	+0.0315	$+0.1456^{e}$	+0.0298	+0.0013
NPMg	+0.0406	-0.1300	+0.0157	+0.0811	+0.0472	$+0.0693^{e}$
NKMg	+0.0066	-0.1521^{e}	+0.0881	-0.0254	$+0.1550^{x}$	-0.0157
PKMg	+0.0464	+0.0581	+0.0266	+0.0316	$+0.1380^{x}$	$+0.0779^{e}$
Sb	±0.0732	±0.1381	±0.1068	±0.1175	±0.0526	±0.0332
R[1]	+0.814	+0.958	+0.960	+0.748	+0.991	+0.942

e. Greater than standard error.

x. Significant at 5% level.

xx. Significant at 1% level.

1. Multiple correlation coefficient.

Table 45. Regression coefficients for P in corn and ryegrass grown on Daudieh and Bazurieh soils, as affected by application of N, P, K, and Mg. Nutrients were added in solution.

Terms	Daudieh soil			Bazurieh soil		
	Corn March, 14	Ryegrass March, 28	Ryegrass May, 25	Corn March, 14	Ryegrass March, 28	Ryegrass May, 25
			Percent			
Mean	0.2043	0.2091	0.1909	0.2671	0.2854	0.2281
N	-0.0295[xx]	-0.0109[xx]	-0.0319[xx]	-0.0498[xx]	-0.0060[e]	-0.0539[xx]
P	+0.0760[xx]	+0.0216[xx]	+0.0422[xx]	+0.0677[xx]	+0.0175[x]	+0.0365[xx]
K	+0.0032	+0.0065[x]	+0.0105[x]	-0.0176[e]	-0.0071[x]	+0.0083[e]
Mg	-0.0110[e]	+0.0066[xx]	+0.0116[xx]	+0.0015	-0.0061[e]	+0.0168[xx]
Sb	±0.0079	±0.0024	±0.0022	±0.0080	±0.0025	±0.0036
N^2	+0.0026	+0.0036[e]	-0.0035[e]	-0.0073	-0.0064[x]	+0.0008
P^2	+0.0126[e]	+0.0047[e]	+0.0048[x]	-0.0024	+0.0018	+0.0032
K^2	+0.0004	+0.0012	-0.0028[e]	-0.0077[e]	-0.0038[e]	-0.0057[e]
Mg^2	-0.0016	-0.0011	+0.0001	-0.0001	-0.0020	-0.0032
Sb	±0.0072	±0.0022	±0.0020	±0.0073	±0.0023	±0.0032
NP	-0.0169[e]	+0.0091[x]	-0.0054[e]	-0.0239[e]	+0.0026	-0.0104[e]
NK	-0.0062	-0.0004	-0.0060[e]	+0.0022	+0.0026	-0.0054[e]
NMg	+0.0014	+0.0156[xx]	+0.0040	+0.0228[e]	+0.0084[x]	-0.0158[x]
PK	-0.0047	-0.0153[xx]	-0.0018	+0.0003	+0.0001	+0.0031
PMg	-0.0083	-0.0003	-0.0060[e]	+0.0099[e]	+0.0101[x]	+0.0080[e]
KMg	-0.0128[e]	-0.0163	+0.0114[xx]	+0.0068	+0.0134[xx]	+0.0145[x]
NPK	-0.0129[e]	+0.0061[e]	-0.0061[e]	+0.0008	-0.0036[e]	-0.0063[e]
NPMg	+0.0016	+0.0031[e]	+0.0059[e]	+0.0037	+0.0001	-0.0026
NKMg	+0.0036	+0.0126[xx]	-0.0098[x]	+0.0056	+0.0036[e]	+0.0004
PKMg	-0.0157[e]	-0.0031[e]	+0.0085[x]	+0.0027	-0.0069[e]	+0.0014
Sb	±0.0097	±0.0029	±0.0026	±0.0098	±0.0031	±0.0044
R[1]	0.940	0.930	0.978	0.684	0.924	0.941

e. Greater than standard error

x. Significant at 5% level.

xx. Significant at 1% level.

1. Multiple correlation coefficient.

Table 46. Regression coefficients for P in corn and ryegrass grown on Daudieh and Bazurieh soils as affected by application of N, P, K, and Mg. Nutrients were mixed with soil.

Terms	Daudieh soil			Bazurieh soil		
	Corn March, 14	Ryegrass March, 28	Ryegrass May, 25	Corn March, 14	Ryegrass March, 28	Ryegrass May, 25
			Percent			
Mean	0.0977	0.2206	0.1700	0.1180	0.2407	0.2299
N	+0.0024	-0.0275[xx]	-0.0189[xx]	-0.0006	-0.0475[xx]	-0.0494[xx]
P	+0.0083[x]	+0.0346[xx]	+0.0290[xx]	+0.0043[e]	+0.0196[xx]	+0.0138[xx]
K	+0.0056[e]	-0.0064[e]	-0.0081[xx]	-0.0077[xx]	+0.0030	+0.0115[xx]
Mg	-0.0022	+0.0049[e]	-0.0020[e]	+0.0026[e]	+0.0020	+0.0025[e]
Sb	±0.0030	±0.0036	±0.0013	±0.0020	±0.0062	±0.0024
N^2	-0.0014	-0.0189[xx]	-0.0178[xx]	+0.0029[e]	+0.0045	-0.0086[xx]
P^2	+0.0048[e]	-0.0068[e]	+0.0031[x]	+0.0001	+0.0119[e]	+0.0030[e]
K^2	+0.0013	+0.0042[e]	-0.0030[x]	+0.0006	+0.0021	+0.0028
Mg^2	+0.0030[e]	-0.0083[x]	-0.0024[e]	-0.0016	+0.0034	-0.0002
Sb	±0.0028	±0.0032	±0.0012	±0.0018	±0.0056	±0.0022
NP	+0.0020	-0.0084[e]	-0.0075[xx]	-0.0024	-0.0027	-0.0097[x]
NK	-0.0009	-0.0024	-0.0023[e]	-0.0072[x]	-0.0042	-0.0103[x]
NMg	-0.0065[e]	-0.0023	+0.0015	+0.0012	+0.0018	-0.0042[e]
PK	-0.0014	-0.0004	-0.0088[xx]	+0.0041[e]	+0.0126[x]	+0.0043[e]
PMg	+0.0030	+0.0087[e]	+0.0018	+0.0022	-0.0089[e]	-0.0113[xx]
KMg	-0.0026	+0.0059[e]	+0.0100[xx]	-0.0028	-0.0057	-0.0069[e]
NPK	-0.0006	-0.0014	+0.0010	+0.0027	-0.0002	+0.0043[e]
NPMg	+0.0055	+0.0022	-0.0003	+0.0038	+0.0088[e]	+0.0072[x]
NKMg	+0.0009	-0.0038	-0.0053[x]	+0.0006	+0.0118[x]	+0.0051[e]
PKMg	-0.0036	+0.0009	+0.0060[x]	-0.0007	+0.0046	+0.0007
Sb	±0.0037	±0.0044	±0.0016	±0.0024	±0.0076	±0.0029
R[1]	0.684	0.924	0.941	0.812	0.935	0.978

e. Greater than standard error.

x. Significant at 5% level.

xx. Significant at 1% level.

1. Multiple correlation coefficient.

Table 47. Regression coefficients for K in corn and ryegrass grown in Daudieh and Bazurieh soils, as affected by application of N, P, K, and Mg. Nutrients were added in solution.

Terms	Daudieh soil			Bazurieh soil		
	Corn March, 14	Ryegrass March, 28	Ryegrass May, 25	Corn March, 14	Ryegrass March, 28	Ryegrass May, 25
			Percent			
Mean	2.4572	2.7515	1.6443	1.6659	2.3472	1.4170
N	-0.2318[xx]	+0.0296[e]	+0.1106[xx]	-0.3179[xx]	-0.0958[x]	-0.0288[e]
P	-0.0607[e]	-0.0488[e]	-0.0303[xx]	-0.0659[x]	-0.0508[e]	-0.0177
K	+0.3694[xx]	+0.1038[xx]	+0.0172[e]	+0.4375[xx]	+0.0133	+0.0795[xx]
Mg	+0.1067[x]	-0.0171	-0.0282[xx]	+0.0275[e]	-0.0017	-0.0165
Sb	±0.0420	±0.0247	±0.0071	±0.0197	±0.0309	±0.0205
N^2	-0.0024	+0.0118	+0.0123[e]	-0.0499[x]	-0.0383[e]	-0.0264[e]
P^2	+0.0309	+0.0155	-0.0044	-0.0074	+0.0307[e]	+0.0109
K^2	+0.2259[xx]	+0.0180	+0.0195[x]	+0.0259[e]	+0.0155	+0.0007
Mg^2	+0.0815[x]	-0.0295[e]	+0.0168[x]	-0.0017	+0.0042	+0.0051
Sb	±0.0381	±0.0197	±0.0065	±0.0178	±0.0280	±0.0186
NP	-0.0564[e]	-0.0569[e]	-0.0100[e]	-0.0079	+0.0150	+0.0042
NK	+0.0010	+0.0019	+0.0038	-0.2038[xx]	+0.0075[e]	+0.0667[x]
NMg	+0.0160	-0.0269[e]	+0.0131[e]	+0.0341[e]	+0.0188	-0.0013
PK	-0.0598[e]	-0.0394[e]	-0.0245[x]	-0.0846[x]	+0.0025	+0.0044
PMg	-0.0128	-0.0631[e]	+0.0214[e]	+0.0701[x]	+0.0488[e]	+0.0167
KMg	-0.0839[e]	-0.0819[x]	-0.0011	+0.1427[xx]	+0.0413[e]	+0.0084
NPK	-0.0069	+0.0056	-0.0330[xx]	-0.0713[x]	+0.0050	-0.0364[e]
NPMg	+0.0521	+0.0819[x]	-0.0281[x]	-0.0247	-0.0038	-0.0102
NKMg	+0.0578[e]	+0.0056	-0.0116[e]	+0.0822[x]	-0.0463[e]	-0.0139
NPK	-0.0090	-0.0381[e]	-0.0269[x]	+0.0862[x]	-0.0238	+0.0051
Sb	±0.0515	±0.0266	±0.0088	±0.0241	±0.0379	±0.0252
R[1]	0.935	0.870	0.876	0.985	0.790	0.831

e. Greater than standard error.

x. Significant at 5% level.

xx. Significant at 1% level.

1. Multiple correlation coefficient.

Table 48. Regression coefficients for K in corn and ryegrass grown on Daudieh and Bazurieh soils, as affected by application of N, P, K, and Mg. Nutrients were mixed with soil.

Terms	Daudieh soil			Bazurieh soil		
	Corn March, 14	Ryegrass March, 28	Ryegrass May, 25	Corn March, 14	Ryegrass March, 28	Ryegrass May, 25
	Percent					
Mean	2.4858	3.3858	1.4226	1.4569	2.4586	1.2555
N	+0.0009	-0.1183[e]	-0.0540[e]	-0.0758[e]	-0.1829[x]	-0.1577[xx]
P	-0.2178[xx]	-0.1708[e]	+0.0112	-0.1418[x]	-0.0104	-0.0372[xx]
K	+0.5252[xx]	+0.0992[e]	+0.0411[e]	+0.5743[xx]	+0.5471[xx]	+0.0534[xx]
Mg	-0.0449	-0.0808	-0.0230	-0.0615	+0.0479	-0.0488[xx]
Sb	±0.0545	±0.0821	±0.0231	±0.0638	±0.0540	±0.0051
N^2	+0.1437[x]	-0.1513[x]	-0.0130	+0.1426[x]	+0.1904[x]	-0.0050
P^2	+0.1116[e]	-0.1888[x]	-0.0080	+0.0520	+0.2054[xx]	-0.0001
K^2	+0.0887[e]	+0.0349	-0.0100	+0.1716	+0.0317	-0.0211[xx]
Mg^2	+0.0028	+0.0512	-0.0358[e]	+0.0415	+0.0154	-0.0039
Sb	±0.0494	±0.0744	±0.0210	±0.0579	±0.0490	±0.0046
NP	-0.1096[e]	-0.0088	-0.0151	+0.0353	-0.0569	-0.0111[e]
NK	+0.0211	-0.0025	-0.0034	-0.0154	+0.2906[xx]	+0.0408[xx]
NMg	-0.0622[e]	-0.1513[e]	+0.0089	+0.0414	+0.1231[e]	+0.0140[e]
PK	-0.0386	-0.0113	+0.0116	-0.0803[e]	+0.0644	+0.0239[xx]
PMg	+0.1104[e]	-0.0475	-0.0311[e]	-0.0374	+0.0219	-0.0134
KMg	-0.0917[e]	-0.1513[e]	+0.0628[e]	-0.0744[e]	+0.0719[e]	-0.0405[xx]
NPK	-0.0697[e]	+0.0150	+0.0719[x]	-0.1228[e]	+0.0431	+0.0353[xx]
NPMg	-0.0729[e]	-0.0088	+0.0486[e]	-0.0069	+0.0206	+0.0198[x]
NKMg	+0.0557[e]	-0.0450	-0.0218	+0.0078	+0.0731[e]	+0.0006
NPK	+0.0206	+0.0288	+0.0177	-0.0456	+0.0069	+0.0163[x]
Sb	±0.0668	±0.1006	±0.0283	±0.0782	±0.0662	±0.0062
R[1]	0.912	0.836	0.804	0.953	0.922	0.950

e. Greater than standard error.

x. Significant at 5% level.

xx. Significant at 1% level.

1. Multiple correlation coefficient.

Table 49. Regression coefficients for Mg in corn and ryegrass, grown on Daudieh and Bazurieh soils as affected by application of N, P, K, and Mg. Nutrients were added in solution.

Terms	Daudieh soil			Bazurieh soil		
	Corn March, 14	Ryegrass March, 28	Ryegrass May, 25	Corn March, 14	Ryegrass March, 28	Ryegrass May, 25
			Percent			
Mean	0.3207	0.2776	0.5573	0.4859	0.3196	0.5664
N	+0.0204^{x}	-0.0068^{x}	-0.0062^{x}	+0.0417^{xx}	-0.0085^{x}	-0.0275^{x}
P	+0.0161^{e}	-0.0042^{e}	+0.0092^{xx}	+0.0035	+0.0032^{x}	+0.0083
K	-0.0256^{xx}	-0.0099^{xx}	+0.0001	-0.0650^{xx}	-0.0072^{x}	-0.0094
Mg	+0.0586^{xx}	+0.0190^{xx}	+0.0415^{e}	+0.1023^{xx}	+0.0228^{xx}	+0.0396^{xx}
Sb	±0.0085	±0.0028	±0.0021	±0.0088	±0.0030	±0.0103
N^2	+0.0041	-0.0029^{e}	-0.0110^{xx}	+0.0112^{e}	-0.0064^{e}	+0.0029
P^2	-0.0023	-0.0054^{e}	-0.0058^{x}	-0.0032	-0.0006	-0.0194^{e}
K^2	-0.0185^{x}	-0.0087^{x}	+0.0025^{e}	+0.0139^{e}	+0.0014	-0.0155^{e}
Mg^2	+0.0189^{x}	+0.0028	+0.0019^{e}	+0.0095^{e}	+0.0112^{xx}	+0.0034
Sb	±0.0077	±0.0026	±0.0019	±0.0080	±0.0027	±0.0094
NP	+0.0085	+0.0112^{xx}	-0.0025	+0.0338^{x}	+0.0025	+0.0071
NK	-0.0095	+0.0041^{e}	-0.0101^{xx}	-0.0004	+0.0012	-0.0079
NMg	+0.0080	+0.0042^{e}	-0.0114^{xx}	+0.0254^{e}	+0.0071^{e}	-0.0136^{e}
PK	+0.0021	-0.0052^{e}	+0.0029^{e}	+0.0226^{e}	-0.0082^{e}	-0.0017
PMg	+0.0231^{x}	-0.0004	-0.0004	-0.0019	-0.0059	-0.0012
KMg	+0.0111	-0.0012	-0.0040^{e}	-0.0357^{x}	-0.0089^{e}	+0.0077
NPK	-0.0105^{e}	-0.0019	-0.0106^{xx}	+0.0306^{x}	+0.0076^{e}	-0.0055
NPMg	-0.0097	+0.0000	+0.0106^{xx}	+0.0134^{e}	+0.0085^{e}	-0.0062
NKMg	+0.0055	+0.0024	+0.0005	-0.0541^{xx}	-0.0047^{e}	-0.0060
PKMg	+0.0016	-0.0008	-0.0033^{e}	-0.0284^{x}	+0.0007	+0.0051
Sb	±0.0104	±0.0035	±0.0026	±0.0108	±0.0037	±0.0126
R[1]	0.944	0.945	0.955	0.974	0.954	0.859

e. Greater than standard error.

x. Significant at 5% level.

xx. Significant at 1% level.

1. Multiple correlation coefficient.

Table 50. Regression coefficients for percent Mg in corn and ryegrass grown on Daudieh and Bazurieh soils as affected by application of N, P, K, and Mg. Nutrients were mixed with soil.

Terms	Daudieh soil			Bazurieh soil		
	Corn March, 14	Ryegrass March, 28	Ryegrass May, 25	Corn March, 14	Ryegrass March, 28	Ryegrass May, 25
			Percent			
Mean	0.2706	0.2434	0.5138	0.4596	0.3193	0.6273
N	$+0.0568^{xx}$	$+0.0179^{xx}$	-0.0681^{xx}	$+0.1208^{xx}$	$+0.0127^{x}$	-0.0380^{xx}
P	+0.0015	-0.0004	$+0.0143^{e}$	+0.0032	-0.0019	-0.0039
K	-0.0396^{xx}	+0.0019	-0.0025	-0.1225^{xx}	-0.0397^{x}	$+0.0107^{e}$
Mg	+0.0049	$+0.0132^{x}$	$+0.0226^{x}$	$+0.0317^{x}$	$+0.0078^{e}$	$+0.0292^{x}$
Sb	±0.0089	±0.0046	±0.0092	±0.0094	±0.0044	±0.0096
N^2	$+0.0092^{e}$	$+0.0327^{xx}$	+0.0044	$+0.0188^{e}$	-0.0121^{x}	-0.0023
P^2	+0.0055	$+0.0117^{x}$	$+0.0163^{e}$	+0.0066	-0.0131^{e}	-0.0030
K^2	$+0.0109^{e}$	-0.0009	-0.0048	+0.0026	$+0.0065^{e}$	-0.0010
Mg^2	-0.0030	-0.0004	$+0.0099^{e}$	+0.0151	$+0.0187^{xx}$	$+0.0296^{x}$
Sb	±0.0081	±0.0042	±0.0083	±0.0086	±0.0040	±0.0087
NP	-0.0026	-0.0043	-0.0066	+0.0051	$+0.0064^{e}$	-0.0130^{e}
NK	-0.0115^{e}	$+0.0069^{e}$	-0.0137^{e}	+0.0035	-0.0069^{e}	-0.0171^{e}
NMg	$+0.0130^{e}$	+0.0039	-0.0022	$+0.0196^{e}$	$+0.0069^{e}$	+0.0099
PK	+0.0064	-0.0024	-0.0194^{e}	+0.0006	$+0.0077^{e}$	$+0.0195^{e}$
PMg	-0.0061	+0.0043	-0.0114^{e}	$+0.0342^{x}$	+0.0008	-0.0356^{x}
KMg	+0.0075	$+0.0306^{xx}$	-0.0161^{e}	+0.0071	-0.0328^{xx}	+0.0079
NPK	+0.0086	+0.0005	+0.0007	-0.0082	-0.0006	-0.0058
NPMg	-0.0004	$+0.0073^{e}$	+0.0059	-0.0044	+0.0017	-0.0071
NKMg	-0.0020	+0.0021	$+0.0116^{e}$	-0.0050	-0.0034	-0.0020
PKMg	+0.0014	-0.0023	$+0.0146^{e}$	-0.0259^{e}	-0.0033	-0.0016
Sb	±0.0110	±0.0057	±0.0112	±0.0116	±0.0054	±0.0118
R[1]	0.903	0.895	0.933	0.952	0.886	0.859

e. Greater than standard error.

x. Significant at 5% level.

xx. Significant at 1% level.

1. Multiple correlation coefficient.