INTERRELATIONSHIPS OF VARIOUS MICRO AND MACRO NUTRIENTS ON THE GROWTH AND COMPOSITION OF CORN

by

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CORN NUTRIENT RELATIONSHIPS

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ABSTRACT

A field study was conducted on a calcareous soil to explore the interrelationships of micro (Zn, B, Fe, Mn, Cu) and macro (N, P, K, Mg, S) nutrients on growth and composition of corn using a central composite, rotatable, factorial design involving 5 variables, each at 5 levels, for each set. Quadratic regression equations were developed for characterization of the response surfaces for grain yield, dry forage yield and chemical composition of corn leaves. In general, corn grain production was adversely affected by all micronutrient additions. The Zn-Mn interaction was antagonistic and the toxicity of one was partially counteracted by increasing the level of the other. It was found that the Zn requirement of corn was much higher for forage than for grain production. The critical level of Zn for grain was less than 20 ppm. while the highest dry forage yields were obtained at more than 150 ppm. Zn in corn leaves. The B-Mn interaction was complementary while the B-Cu interaction was antagonistic in regard to dry forage yields. The highest dry forage yields were obtained at approximately the following concentrations in corn leaves: B, 30 ppm. ; Fe, 50-70 ppm. ; Mn, 100 ppm. and Cu, 20 ppm.

The macronutrient requirements for dry forage differed considerably from that for grain production. High rates of N, P, K and S with a low rate of Mg gave maximum dry forage yield. However, only N was required for grain yield. The Mg-S interaction had an antagonistic effect on grain yield. The K-S, P-S, N-K, N-S and P-K interactions had an antagonistic effect on dry forage yield while the N-Mg, P-Mg and Mg-S interactions were complementary in regard to dry forage yield. The highest dry forage yields were obtained at approximately the following concentrations in corn leaves: N, 2.0 % ; P, 0.25 % ; K, 5 % ; S, 0.2 % and Ca, 1.6 % .

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INTRODUCTION

Corn, _Zea mays, L.,_ is one of the most important agricultural crops of the world with a total annual acreage of about 220 millions. The United States, which produces over 50 per cent of the world's crop plants annually over 80 million acres. As might be expected with a crop of such great economic importance, a tremendous research effort has been expended and a large body of scientific literature has been accumulated. Reports in the literature indicate that in some cases corn yields are of limited nature even under supposedly high fertility conditions. Apparently this limitation is controlled by certain unknown factors which require further investigation.

The reason for "lime-induced" chlorosis of corn has long been investigated by various workers and some have related it to Fe deficiency, while others have shown it to be due Zn deficiency. However, the present information is inadequate and further research is needed. It has also been shown that the corn plant has a high degree of sensitivity to nutrient deficiencies indicating the importance of an adequate nutrient supply.

An exploratory field experiment related to the mineral nutrition of corn was carried out in 1960 at the American University of Beirut Farm located in the Beka'a plain. The object was to investigate and evaluate the presence and magnitude of possible interaction effects of micronutrients (Zn, B, Fe, Mn and Cu) and macronutrients (N,P, K, Mg and S) on vegetative growth, grain yield of corn and chemical composition of corn leaves. The existence and nature of such interactions have been reported to some extent but no studies have been reported in which all the nutrients included in the present study were investigated at one time.

The central composite, rotatable, incomplete factorial design developed by Box and Hunter (6) was used in this study to evaluate and characterize the response surfaces witha a reasonable number of treatments. This study included five different variables Zn, B, Fe, Mn and Cu as one set for micronutrients and five variables N, P, K, Mg and S as a second set for macronutrients. Each variable was varied at five different concentrations ranging from very high to very low rates of applications. There were twenty seven treatments under each set, with one treatment replicated six times to make possible the estimation of experimental error.

REVIEW OF LITERATURE

Investigation on the mineral nutrition of corn originated with Hornberger of Germany (1882) and was probably one of the most comprehensive studies ever published on the subject. His investigation initiated a line of research that has been pursued to the present. Nelson (34) has reviewed and made an extensive study of literature. It is the purpose of the following review to bring together and examine the pertinant literature dealing with the field of mineral nutrition and growth of corn.

Micronutrients

Zinc. Carlson *et al.* (11) reported that Zn is the trace element most likely to be deficient for corn and this becomes more serious especially when the top soil has been removed during leveling. According to Rhoades and Chesnin (41) Zn deficiency usually results in a chlorosis of the older leaves. Lower leaves of corn plants lacking Zn develop a pale yellow stripe on each side of the mid rib and latter the chlorotic area may develop a bronze color. Viets *et al.* (55) found that leaves of corn plants showing Zn deficiency were much more lower in Zn than the normal leaves. They also suggested that the leaf tissue was a better index of Zn status of corn plant than the total plant tops. Zinc sulfate application to soil did not increase yields although large and significant increases in Zn concentration were observed and judged by leaf analysis. They also reported that Zn deficient plants were high in P, Cu and frequently Mn. No evidence of a specific effect of Zn deficiency on the absorption of the above elements was obtained.

Scharrer and Jung (43) in their experiment on _Zea mays_ and _V. faba_ found that in the absence of Zn maize showed reduced growth, shortened internodes, chlorophyll deficiencies and pigmentation changes. At 0.25 mgm. Zn (in culture solution of 5 liters) growth was normal and higher concentrations had no adverse effect on growth. They also found that increasing Zn concentration resulted in a linear increase in Zn concentration in the plant and uptake of other elements appeared to be related to the Zn concentration of the solution. Hiatt and Massey (23) found that maize plants grown in a greenhouse in Zn free culture showed very severe deficiency symptoms and there was a linear relationship between Zn in solution and uptake by corn plants. However, Nearpass (33) found a logarithmic relation between Zn concentration in the substrate and Zn concentration in the aerial portion of plants.

Interaction between Zn and other elements has been reported by various workers. Chapman _et al._ (12) in their studies with lemon and orange plants reported that excess Zn brought on Fe chlorosis and found that high amounts of P may lead to Fe and Zn deficiencies. However, Boawn _et al._ (5) in their field studies reported that phosphate application did not produce or accentuate Zn deficiency symptoms. Bingham et al. (4) later reported that this was probably due to Zn contamination in the phosphate fertilizer. Wear (59) concluded that reduction in Zn uptake by the plant is a pH effect. Fuehring (16) in a sand culture study with maize found that maximum yields would be obtained at 7.73 ppm. of Zn. It was shown that a change in level of any one nutrient resulted in changes in the requirement of other nutrients. The above level of Zn in culture solution resulted in a concentration of 308 ppm. Zn in corn tops. Zinc paired with B, Fe, Mn, or Cu had a complementary effect on one another in regard to yield of maize tops. The critical level for Zn in maize plant was about 110 ppm. and maize appeared to have a high requirement for Zn.

Boron. Parks et al. (36) working with tomatoes found that B supply influenced the accumulation or utilization of other elements in leaflets and this has led certain investigators to postulate the regulatory role of B in this respect. Parks et al. concluded from the above study that as B supply was increased the concentration of this element in leaflet material was significantly increased. There were also large differences between treatments with respect to concentration of most of the other elements examined except Ca and S as the B supply was increased. They also suggested that B may be a component of one or more complex interactions involving more than two elements and reported the toxic effect of excess B supply on plant growth.

Scripture and McHargue (45) suggested the possibility of B being involved in protein metabolism. Bingham et al. (4) working in California found that excessive quantities of superphosphate reduced B availability to citrus plants. They also found that B and Cu deficiency symptoms were masked by Zn deficiency. Reeve and Shive (38) established the existence of a real relationship between B and Ca in that high rates of Ca enabled the plants to tolerate toxic amounts of B. Berger et al. (2) in a greenhouse study with corn with varying B concentrations from 0-0.25 ppm. found that all treatments receiving less than 0.25 ppm. B produced blank stalks or barren ears and fully developed ears were developed at 0.25 ppm. concentration. In their field study, a side dressing of 15 lb. sodium borate per acre, significantly increased yields. They also suggested that the supply of available B must be continuous and that the critical level of B in the upper leaves appeared to be between 11 and 13 ppm. Chapman et al. (12) pointed out that accumulation of excess B was sometimes a result of K deficiency. Scharrer and Jung (43) in their study with corn in culture solution obtained highest yields of dry matter at B levels of 0.25 and 0.5 ppm. The B concentrations in the corn plants were 8 and 11 ppm. respectively.

Berger and Truog (3) have reported the availability of B in relation to soil reaction and organic matter. A direct positive correlation existed between available B and percentage of organic matter in acid soils and a highly significant negative partial correlation existed between pH and available B in alkaline soils indicating that pH exerted a greater influence on the availability of B in alkaline soils than did organic matter while in acid soils the reverse was true. Eaton (15) reported that B deficient plants matured more slowly than those in the plus-boron cultures.

McIlrath and DeBruyn (29) working with Siberian millet found that high B application generally resulted in decreased dry weight of tops and roots and increased percentage ash of tops. McIlrath _et al_. (30) investigated the influence of twelve levels of B ranging from 0-200 ppm. in nutrient solution on the uptake of B, Cu, Fe, Mn and Mo by setaria shoots and found that at non-toxic levels of B the total dry weight and ash composition showed no difference but at highly toxic levels the dry weight was reduced while the percentage ash content was greater.

Fuehring (16) reported a complementary effect between B and Fe and between B and Zn in regard to yield of maize tops while the B-Mn and B-Cu interactions were antagonistic. He suggested that the critical level of B in the maize plant varied between 10 and 20 ppm.

Iron. It was reported in the literature that chlorosis of plants cultivated in calcareous soils was related to Fe nutrition. Iron is the limiting element in chlorosis which develops in plants grown on some naturally calcareous soils. This chlorosis is caused by the failure of the susceptable plant to absorb Fe from the soil or in some cases to utilize the Fe which is absorbed (22).

Bennet (1) and Wadleigh and Shive (57) also reported that causative factors which act in the soil and the plant to inactivate Fe are not clearly understood. Somers and Shive (50) found that pathological symptoms produced by excessive Fe were identical with those produced when Mn was deficient and symptoms produced with excessive Mn were similar to those produced when Fe was deficient. They suggested the optimum ratio of Fe/Mn as 2.0, above this chlorosis appeared. High concentration of soluble Mn in the plant tissue was invariably associated with low concentration of soluble Fe and vice versa. This suggested the inactivation or precipitation of Fe as ferric organic complex in the presence of active Mn. Brown _et al_. (9) reported that Cu deficiency affected Fe metabolism in corn in a different manner than in soybeans or wheat. Brown (7) found that plant species differ considerably in their ability to extract Fe from growth media. Brown and Holmes (8) in their experiment with corn found that Cu and P affected the absorption of Fe but had no effect with other plant species. Results reported in their paper showed that Fe metabolism differed between plant species and varieties and that these differences were dependant on growth media. This indicated that Cu had a regulatory function on Fe in corn.

Wallihan (58) reported in his work on citrus that leaf chemical analysis can be useful tool in the studies of Fe nutrition. He also concluded that macroelements are not considered significant in their relations with Fe function in the plant. Chapman _et al_. (12) reported that excessive rates of P, Zn or Cu caused deficiency of Fe in citrus. Hewitt (22) pointed out that Mn is not unique in ita ability to induce Fe deficiency symptoms, and may in fact be less active in this respect than many other metals. His data showed that increased Fe accumulation in the presence of toxic concentration of Zn would seem to exclude simple antagonism as a cause of chlorosis in some instances, while the different response of Mn in the presence of ferric citrate suggests that antagonism may still be significant on others. Kroll (26) reported that the ferric chelate of ethylenediamine di (o-hydroxyphenylacetic acid) is a very effective substance in correcting lime-induced chlorosis.

Fuehring (16) pointed out that when other trace elements were in balance that Fe requirement of maize was low. Deficiency or excess of another element increased the Fe requirement. He also found that the Fe-Mn interaction was complementary at some levels and antagonistic at others while Fe-Cu was antagonistic in regard to yield of maize tops.

Manganese. Various workers have studied extensively the toxicity of Mn in the nutrition of plants. Somers et al. (49) stated that Mn functions as a catalyst in cellular respiration and suggested a 1.5 to 2.5 Fe/Mn ratio as the optimum range, below and above which plants invariably developed deficiency symptoms. Weinstein and Robbins (61) found that both a high level of Mn and a low level of Fe in solution cultures resulted in a low activity of catalase and cytochrome oxidase in the plants. Mulder and Gerretsen (32) in an experiment with rye observed that an increased demand for Mn was found with increased Cu supply. In a similar experiment with barley such Cu-Mn interaction did not occur. The results of these experiments showed that Cu may activate biological oxidation of Mn compounds by fungi and probably by root cells of barley plants. Shive (46) also reported that increased Fe supply depressed the uptake of Mn. Taper and Leach (51) in their study with dwarf kidney beans observed that in a complete nutrient solution an increase of either Mn or Fe depressed the concentration of the other in leaves regardless of Ca level in the growth media. Their data suggested that a minimum content of each of the metals, Fe and Mn, must be present in the leaf tissues in order that healthy plants may result. Lucas (28) in his investigation on spinach, wheat and onions found that the additions of copper sulfate increased Cu content in plants as much as threefold but did not affect the Mn content of plants growing in soils containing adequate amounts of Cu. In greenhouse studies plants deficient in Cu were high in Mn, but this was not observed in the field. In the same experiment addition of zinc sulfate depressed the Mn content of plants.

Fuehring (16) estimated the concentration of Mn at 49 ppm. in corn tops grown in a solution containing 0.241 ppm. Mn and observed that Mn-Cu and Mn-Zn interactions were complementary, the B-Mn interaction was antagonistic while the Fe-Mn interaction was complementary at some levels and antagonistic at others with regard to yield of maize tops. He also reported that the critical level for Mn in corn tops varied between 50 and 75 ppm.

Copper. Copper has a regulatory function in the plant by preventing excess intake of other elements that are toxic in large amounts. Copper also functions to increase the availability of other elements in the plants.

Gilbert et al. (19) in their study on tung trees reported that there was no significant difference in percentage of nonreducing sugars between leaves from normal and Cu deficient tung trees. Smith and Specht (47) reported that Cu appeared to be about 50 times as toxic as Mn and 12 to 15 times as toxic as Zn in oranges grown in culture solution. Bingham et al. (4) pointed out that uptake of Cu was greatly reduced by application of P. Schropp (44) has shown that Cu was known to affect or to be affected by several other elements, the Cu-N balance being an outstanding example. He also reported an antagonism between Cu and Mn.

Lucas (28) in his study on organic soils found a Cu-Zn relationship. Addition of zinc sulfate increased plant growth of a few crops only when Cu was present. Zinc was not injurious in the presence of Cu. Copper also controlled excessive absorption of Fe. He believed that Zn accenturated Cu deficiency in plants. Hader *et al*. (20) in their experiment with lettuce obtained pronounced interaction between Cu and Fe. The growth of lettuce at any one level of Cu was affected by Fe supply. Brown and Holmes (8) also reported that availability of Cu supply had marked effect on absorption and utilization of Fe by corn. Fuehring (16) has shown that Cu-Mn and Cu-Zn interactions had complementary effects while Fe-Cu and B-Cu had antagonistic effects on the yield of maize tops. He also suggested that the critical level of Cu for maize plants varied between 3 and 5 ppm.

Macronutrients

Tyner (53) in his study with corn under field conditions on N, P and K interactions reported that N and K were found to exert mutual antagonistic influences. The application of N as ammonium sulfate had a marked depressive effect on the percentage K occurring in corn leaves. A reduction in the efficiency of N utilization appeared to accompany and be related to K depression. Phosphorus did not appear to have an effect on N or K content. Neither did N nor K appear to have an effect on P content. He also believed that on soils of low or moderate K supply, application of N fertilization may induce or intensify K deficiency. On soils with low K supplying power, heavy K application may intensify N deficiency symptoms and depress yields. This, however, requires further investigation.

Carles <u>et al</u>. (10) concluded that the uptake of mineral elements in maize is dependant on growth, which in turn, is dependant on the amount of available N in the soil. High amounts of N in the soil might result in a deficit of P which would limit grain yields. Sayre (42) reported that N, P and K entered the corn plant and moved from tissue to tissue independantly of one another. Nitrogen accumulated in the corn plant to the maximum at silking stage and decreased about 4 weeks later in the season. Nitrogen continued to move into grain from other tissues until maturity. Phosphorus accumulation did not cease until about maturity. This element also moved into grain from other tissues. Potassium accumulation occurred until about 3 weeks after silking. There was actual loss of K after this time, largely from the leaves and the stems of the plants. Bennet <u>et al</u>. (1) in their study with corn reported a wide range in response to N. The application of N significantly increased the percentage of N in the leaf. Phosphorus percentage in the leaf was significantly increased due to the N application and these increases were associated with the yield responses which proved to be independant of the N effect. A definite relationship between yield, and N and P contents of leaves existed in their experiment.

Lanza (27) reviewed the role of the secondary elements (Ca, Mg and S) and micronutrients in maize nutrition and concluded that it was not necessary to add these elements to N, P and K fertilization applications for maize cultivation in Italy. Viets _et al_. (56) found that only applied N increased grain yield significantly while P and K did not. Leaf N was probably the dominant determinant of yield, but the leaf P was sometimes important. Bingham _et al_. (4) pointed out that the leaf N appeared to be related to plant size rather than directly to P application. Potassium concentrations were decreased by P fertilization. Colwell (14) found that deficiencies of N and P were important factors in accounting for low yields of both corn and wheat in Mexico. He also obtained significant yield responses from the added N. Thomas (52) reported that the rates above 40 lb. per acre of N resulted in grain yield increases. Nitrogen treatment had no significant effect on the ear weight of corn.

Weinmann (60) concluded that application of P slightly increased the P content of corn grain. Absorption of N, P, K and Ca continued up to early dough stage and nutrient loss from stover occured during maturation. Potassium and Ca were lost from aerial parts of the plant. Reichman (39) showed that in the presence of added P, the yield of forage and grain of corn was increased by applied N for rates up to 80 lb. per acre. In the presence of added N, P also increased the production. Nitrogen and P percentages in the leaves sampled at pollination were highly correlated with the yields of maize and with the total uptake values at the harvest. Hardy (21) reported that low contents of K in the soil were associated with high foliar Mg contents. He suggested that the critical lower limit of N concentration in maize was 2.38 per cent. No critical levels could be established for P concentration in maize. However, maize yields were high where leaf P concentrations were 0.26-0.29 per cent. Fulton and Findley (17) in their experiment with corn found that N at 40 lb. per acre markedly increased grain yields, the rate of increase diminished where further increments of N were applied. Grain yields increased with increasing P application on clay soils. Variations in the amount of P or K applied had little or no effect on the percentage of N in leaf or grain. Giffard (18) in his paper indicated that there appeared a tendency for maize plant to take up certain nutrients, apart from N, in greater quantities when it was top dressed heavily with N.

Venkataraman and Tejwani (54) indicated the following relationships in the nutrient balance of flue-cured tobacco leaf: (a) Calcium depressed the accumulation of K in the leaf; (b) Magnesium had little direct influence on the accumulation of K in the leaf; (c) Calcium and K promoted the accumulation of Mg in the leaf; (d) Both Mg and K influenced the accumulation of Ca in the leaf, the former promoting it and the later depressing it. However, Nelson and Overstreet (34) reported a stimulating effect of Ca on the K absorption as being the result of Ca acting as a cofactor in the utilization of the K. Bingham _et al_. (4) found that the leaf Ca was not affected by P application. On the other hand, absorption of Mg was 40-50 per cent greater at the high rates of P application. Kahin and Hanson (25) pointed out in their nutrient culture experiment that corn and soybeans exhibited cation accumulation characteristic of their families, in that corn plant accumulated more K and less Ca than soybeans grown in the same solution. Altering Ca/K ratio in the solution during a 4 week period produced no significant differences in the plant growth or in Mg contents of either species. Parks _et al_. (36) in their studies with tomato leaflets found that Ca ion supply was significantly and positively correlated with cation contents of leaflets and therefore Ca content of leaf was associated with both Ca and K ion supply. Similarly Mg-Ca interaction was associated with Mg content of leaflets. Magnesium-P interaction was associated with P content of tomato leaflets.

Overstreet *et al.* (35) who postulated the carrier concept of ion transport, showed that Ca may increase or decrease K absorption depending on the level of K. Wadleigh and Shive (57) indicated that absorption of the ammonium ion lowers the rate of absorption of other cations. The presence of ammonium ion in the nutrient solution had the most depressing effect on Ca absorption and the least effect on Mg absorption by corn plant. The data also showed that high K absorption had a depressing effect on Ca and Mg absorption.

Thomas (52) reported that neither applied N nor applied S had an appreciable effect on the yield of corn. Application of N favoured the use of more S by the plant and vice versa. The data of Rendig and McComb (40) showed that an inadequacy of S resulted in a greater change in the amide and sugar content of the alfalfa plant. At a low level of S, the amide N content was high and sugar content low. As the S supply was increased, the amide content decreased and sugar content increased.

MATERIALS AND METHODS

Experimental design

The field experiments under both micronutrient and macronutrient sets were planned on the basis of a central composite, rotatable, incomplete factorial design which has been described in detail by Hader et al. (20). This design is quite useful for the characterization of response surfaces and avoids the necessity of a large number of treatments such as required with a complete factorial design. The statistical analysis methods used were according to those described by Snedecor (48) and Cochran and Cox (13).

Five different micronutrients (Zn, B, Fe, Mn and Cu) were varied in one set of treatments and five macronutrients (N, P, K, Mg and S) in the other set, each varied at five different levels with a total of 27 treatments under each set. In order to obtain an estimate of experimental error, one treatment in each set was replicated 6 times making 32 plots in all.

The rates of variables were coded according to the form -2, -1, 0, +1, +2 (Tables 1 and 2). The coded 0 rate was an intermediate level for each variable while the -2 coded rate was a low level and the +2 a high level leading to a possible toxic effect. The level of the treatments were varied according to the logarithms of their concentrations in order to cover a wide range of values.

Table 1. Rates of Zn, B, Fe, Mn, and Cu concentrations (lbs/acre) applied to the plots under micro nutrient treatments corresponding to the statistical levels (coded values).

Level	Statistical level of coded concentration, log scale	Zn	B	Fe	Mn	Cu
1	-2	5.0	1.8	5.0	5.0	1.8
2	-1	13.5	5.0	13.5	13.5	5.0
3	0	36.8	13.5	36.8	36.8	13.5
4	+1	100.0	36.8	100.0	100.0	36.8
5	+2	272.0	100.0	272.0	272.0	100.0

Table 2. Rates of N, P, K, Mg, and S concetrations (lbs/acre) applied to the plots under macro nutrient treatments corresponding to the statistical levels (coded values).

Level	Statistical level of coded concentration, log scale	N	P	K	Mg	S
1	-2	10.0	10.0	10.0	10.0	10.0
2	-1	27.2	27.2	27.2	27.2	27.2
3	0	73.8	73.8	73.8	73.8	73.8
4	+1	200.0	200.0	200.0	200.0	200.0
5	+2	544.0	544.0	544.0	544.0	544.0

Regression equations of the quadratic form for yield and for elemental constitution were computed from the data and the statistical significance of individual regression coefficients determined by the "t" test. The regression equations were used to determine the nature of the response surfaces for the individual interactions that were found to be statistically significant.

Field methods

Two adjacent field experiments were carried out in the same area, one dealing with micronutrients and the other with macronutrients. The site selected for the experiment had not been fertilized during the past four years and was in fallow the previous year.

On May 3, 1960, seeds of corn which were treated with a fungicide, were drilled with a hand planter at the rate of 2 seeds per hill, keeping 30 cm. spacing between the subsequent hills. Each treatment plot was 6x4 m. having 4 rows of plants with the rows 1 m. apart and 6m. in length. After germination the seedlings were thinned to 25 plants per 6 m. of row.

The plots under micronutrients experiment received a blanket application of 200 lb. per acre of N as ammonium nitrate, 140 lb. per acre of P_2O_5 as superphosphate and 158 lb. per acre of K_2O as potassium sulfate. This was applied in two stages, beside the row at planting time and after germination as a side dressing.

The carriers applied as a source of nutrient variables under the micronutrient treatments were Zn as zinc sulfate, B as sodium borate, Fe as ferrous sulfate, Mn as manganese sulfate and Cu as copper sulfate. For the macronutrients set the carriers applied were N as ammonium nitrate, P_2O_5 as calcium dihydrogen phosphate, K_2O as potassium chloride, Mg as hydrated magnesium chloride and S as hydrated calcium sulfate.

Irrigation water was applied weekly first by sprinklers and later by furrow after the corn became tall.

At the silking stage, 12 leaves from the center 2 rows of each plot were taken and composited for leaf analysis. The sixth leaf from the base of the plant was the one sampled. At this stage corn plants have a large requirement for nutrients.

On October 5, 1960, after a five months growth period the corn plants were harvested for grain and forage yields. Corn ears from 2 m. of the lower end of the 2 center rows of each plot were collected and weighed in a tared container. Grain yields on a bushels per acre basis were reported as shelled corn at 15.5 per cent moisture. Forage was harvested and dried in the open air and reported as lb. per acre on the air dry basis.

Analytical procedures

<u>Preparation of samples</u>. Plant leaf samples were first washed with tap water and then rinsed three times with

distilled water to avoid possible surface contamination from dust. The samples after air drying were dried in the forced ventilation oven at 70°C for 48 hours and ground in a micro-Wiley mill fitted with a 40 mesh sieve. The samples thus obtained were mixed thoroughly, stored in wide mouth bottles and labelled. All the chemical analysis results are reported on the oven dry basis.

Preparation of nitric-perchloric digest of plant tissues. The method of wet digestion as described by Jackson (24) was used. 2.00 gm. samples of leaf material were predigested with a 10 ml. concentrated nitric acid in a 250 ml. beaker and left over night. The predigested material was covered with a watch glass and digested with a 10 ml. concentrated perchloric acid on a hot plate under a hood. The mixture was brought to a temperature of 180°C to 200°C rapidly. The digestion was continued untill the acid liquid was largely volatilized and digestion was stopped when the residue in the beaker was clear white and slightly moist with the acid. The digestion was completed and the residue was transferred to a 100 ml. volumetric flask and made up to volume. Redistilled water and analytical grade chemical reagents were used throughout the micronutrient analysis to avoid any possible contamination.

Zinc analysis. Zinc was determined by the zincon method as described by Platte and Marcy (37). Color was developed by taking a 20 ml. aliquot of the nitric-perchloric digests and making up to a volume of 50 ml. Colorimetric readings in terms of absorbency were read in a Beckman model B spectrophotometer using the blue phototube at 620 mμ wave length.

Boron analysis. Boron was determined colorimetrically by a simplified curcumin method as described by Jackson (24). A 0.5 gm. sample of ground leaf material was dry ashed by ignition in a muffle furnace at 550°C for 8 hours. The ash was taken up with a 10 ml. of 0.1 N HCl and filtered through Whatman No. 42 filter paper. An aliquot of 1 ml. was used in the determination and the whole procedure was carried out in porcelain crucibles to avoid contamination of boron from glass ware.

Iron analysis. Iron was determined colorimetrically as ortho-phenanthroline red ferrous complex using the nitric-perchloric digests according to the procedure suggested by Jackson (24).

Manganese analysis. Manganese was determined colorimetrically using sodium paraperiodate oxidation and developing of the permangnate color on the nitric-perchloric digests according to method described by Jackson (24).

Copper analysis. Copper was determined colorimetrically as the carbamate according to the method suggested by Jackson (24). An aliquot of 4 ml. of the dry ash digest prepared for the B determination was utilized for the determination of Cu.

Nitrogen analysis. Nitrogen was determined on the original leaf material by the Gunning modification of the Kjeldhal method (31) using a 0.5 gm. sample and receiving the distillate in a flask containing boric acid.

Phosphorus analysis. Phosphorus was determined colorimetrically on the nitric-perchloric digests by developing the molybdophosphoric blue color according to the method suggested by Jackson (24). Absorbency readings were taken on a Beckman model B spectrophotometer at wave length 660 mμ.

Sulfur analysis. Sulfur was determined turbidimetrically on the nitric-perchloric acid digests using barium chloride as a precipitant. The method was described by Jackson (24).

Cation analysis. Potassium, magnesium and calcium were determined on the nitric-perchloric acid digests using a Beckman DU flame spectrophotometer with oxygen gas at 12 lb. per sq. in. flame and acetylene gas at 7 lb. per sq. in. flame. The wave lengths used were 765 mμ for K, 285 mμ for Mg and 554 mμ for Ca.

RESULTS AND DISCUSSION

The grain and dry forage yields of corn were obtained after five months growth in the field with five nutrients as variables at five different levels for each. Chemical composition of the sixth leaf from the base of the corn plant at the silking stage was determined. The data were used to calculate the second order regression equations which were used to determine the nature of the response surfaces for the various interactions between nutrients. The following is the example of the regression equation used for yield of grain under micronutrient treatments:

$$\begin{aligned} Y = {} & 70.73 - 1.88\,X_1 - 1.10\,X_2 - 0.75\,X_3 - 3.61\,X_4 - \\ & 0.89\,X_5 + 1.55\,X^2 - 0.85\,X_2{}^2 + 7.14\,X_3{}^2 + 3.29\,X_4{}^2 \\ & + 5.52\,X_5{}^2 - 0.26\,X_1X_2 + 0.94\,X_1X_3 + 12.96\,X_1X_4 - \\ & 2.12\,X_1X_5 + 0.57\,X_2X_3 - 3.93\,X_2X_4 - 2.63\,X_2X_5 + \\ & 1.91\,X_3X_4 + 4.71\,X_3X_5 + 1.48\,X_4X_5 \end{aligned}$$

Where X_1 = coded Zn level, X_2 = coded B level, X_3 = coded Fe level, X_4 = coded Mn level, X_5 = coded Cu level.

Statistical significance of the individual regression coefficients was determined. In most of the cases the correlation coefficients between the actual yields and those calculated from the regression equation were high indicating that a second order regression equation was adequate to describe the treatment effects. The size of the regression coefficients is a measure of the relative effects of the variables or combinations of variables. A negative sign for the regression coefficient value of an interaction term indicates that an increase in the level of one nutrient variable decreased the requirement of the other. This is considered a complementary effect in that one element may be able to partially substitute for the other. A positive sign for the regression coefficient value indicates that an increase in the level of one nutrient resulted in an increase in the requirement for the other. This relationship is considered an antagonistic effect.

Soil characteristics

The experimental area located at the American University of Beirut Farm was in fallow the previous year and had a fairly deep clay soil. Soil samples were collected before any treatment applications were made from nine different locations in the experimental area.

The soil was clay in texture with 21 per cent sand, 25 per cent silt and a clay content of 54 per cent. Consequently, the cation exchange capacity of the soil was high varying from 40.5-42 m. e./100 gm. soil (Av. 41.5). A major part of the cation exchange capacity was saturated with Ca which ranged from 34.2-36.0 m. e./100 gm. soil (Av. 35.1). The pH ranged from 8.0-8.4 (Av. 8.2) which was correlated with the 31.5-32.5 per cent $CaCO_3$ (Av. 32.0) and indicated that the soil was highly calcareous. The soil contained 2.0-2.4 per cent (Av. 2.2) organic matter.

Analysis of the soil for micronutrients indicated a total Zn content of 220-226 ppm. (Av. 223), a B content of 43-59 ppm. (Av 51) and a Cu content of 198-224 ppm. (Av. 211). This indicated a fairly high total supply of Zn and Cu in the soil but the availability was likely to be low because of the highly calcareous condition.

The analysis of soil for macronutrients indicated that the soil had 0.15-o.25 per cent (Av. 0.22) of total N and available P was 0.00030-0.00045 per cent (Av. 0.00034) which is low. The soil was well supplied with exchangable cations with 1.6-2.0 m. e./100 gm. soil (Av. 1.8) of K and 1.3-1.7 m. e./100 gm. soil (Av. 1.5) of Mg. The total S varied from 2.0-2.6 per cent (Av. 2.3) which indicated that soil was well supplied with S.

Micronutrients

Grain yield of corn. The corn grain production in general was adversly affected by addition of micronutrients as indicated by the fact that all linear regression coefficients were negative in sign (Table 3). However, none of the direct effects were statistically significant*. The analysis of variance for grain yield of corn (Table 4) indicated no statistically significant linear or quadratic effects. However, tests of significance for the individual regression coefficients (Table 3) indicated that the Zn-Mn interaction

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* The term "significant" will be used to indicate the 5% level of probability. "Highly significant" will be used to indicate the 1% level of probability.

Table 3. Regression coefficients (b) and their standard errors (s_b) for grain yield of corn (Bu/acre) under micro nutrient treatments.

Coefficient		b	s_b
Mean	b_0	+70.74	±7.58
Zn	b_1	-1.88	±3.79
B	b_2	-1.10	" "
Fe	b_3	-0.75	" "
Mn	b_4	-3.60	" "
Cu	b_5	-0.89	" "
Zn^2	b_{11}	+1.55	±3.43
B^2	b_{22}	-0.85	" "
Fe^2	b_{33}	+7.14	" "
Mn^2	b_{44}	+3.29	" "
Cu^2	b_{55}	+5.52	" "
Zn X B	b_{12}	-0.26	±4.64
Zn X Fe	b_{13}	+0.94	" "
Zn X Mn	b_{14}	+12.96*	" "
Zn X Cu	b_{15}	-2.12	" "
B X Fe	b_{23}	+0.57	" "
B X Mn	b_{24}	-3.93	" "
B X Cu	b_{25}	-2.63	" "
Fe X Mn	b_{34}	+1.91	" "
Fe X Cu	b_{35}	+4.71	" "
Mn X Cu	b_{45}	+1.48	" "

*Significant at odds of 19:1

Table 4. **Analysis of variance for grain yield of corn obtained from micro-nutrient treatments.**

Source	d.f.	s.s.	m.s.
Total	31	10927.05	
Linear	5	458.33	91.66
Quadratic	15	6085.94	380.37
Lack of fit	6	2660.11	443.53
Experimental error	5	1722.67	344.53

was statistically significant showing that the response to one element was affected by the level of the other.

Yields of grain were relatively variable as shown by comparison of the yield of the six checks which received the same treatment (Table 5). However, comparison of the actual yields to the yields calculated from the regression equation was close with a correlation coefficient of 0.774 (highly significant) indicating a fairly close fit of the regression equation to the actual data.

Examination of the relationship between grain yield of corn, as affected by the interaction of Zn and Mn (Fig.1), revealed that increasing levels of Mn at low levels of Zn resulted in sharply decreased grain yields while at the middle levels of Zn, Cu, B and Fe, Mn had little effect on the yield. However, the yields were relatively low, At higher rates of Zn application, the grain yield increased with increase in Mn indicating that the toxic effect of Mn was counteracted by a high Zn level. A similar relationship (Fig.2) was noted in that high Mn levels counteracted the toxicity of high levels of Zn.

It can be concluded that a toxic level of either Zn or Mn can be counteracted by addition of the other. Also it has been shown that indiscriminate addition of micronutrients to a soil may result in severe grain yield decreases. Under the conditions of the experiment it was not advisable to add any of the micronutrients tested for corn grain production.

Table 5. Observed yields of corn grain (bu./acre at 15.5% moisture) with micronutrients as variables. Values for the same treatments calculated from the regression equation are given. Correlation of actual yields with calculated yields was 0.774.

Treatment level	Coded values of X					Actual yield, Bu/a	Calculated yield, Bu/a
	Zn	B	Fe	Mn	Cu		
$Zn_2B_2Fe_2Mn_2Cu_4$	-1	-1	-1	-1	+1	95.8	104.6
$Zn_4B_2Fe_2Mn_2Cu_2$	+1	-1	-1	-1	-1	77.4	82.3
$Zn_2B_4Fe_2Mn_2Cu_2$	-1	+1	-1	-1	-1	115.1	119.5
$Zn_4B_4Fe_2Mn_2Cu_4$	+1	+1	-1	-1	+1	56.8	68.1
$Zn_2B_2Fe_4Mn_2Cu_2$	-1	-1	+1	-1	-1	99.0	91.5
$Zn_4B_2Fe_4Mn_2Cu_4$	+1	-1	+1	-1	+1	74.9	74.2
$Zn_2B_4Fe_4Mn_2Cu_4$	-1	+1	+1	-1	+1	109.0	107.7
$Zn_4B_4Fe_4Mn_2Cu_2$	+1	+1	+1	-1	-1	85.1	80.0
$Zn_2B_2Fe_2Mn_4Cu_2$	-1	-1	-1	+1	-1	81.0	77.2
$Zn_4B_2Fe_2Mn_4Cu_4$	+1	-1	-1	+1	+1	92.0	95.0
$Zn_2B_4Fe_2Mn_4Cu_4$	-1	+1	-1	+1	+1	60.0	62.6
$Zn_4B_4Fe_2Mn_4Cu_2$	+1	+1	-1	+1	-1	97.1	95.8
$Zn_2B_2Fe_4Mn_4Cu_4$	-1	-1	+1	+1	+1	96.7	87.2
$Zn_4B_2Fe_4Mn_4Cu_2$	+1	-1	+1	+1	-1	109.2	95.9
$Zn_2B_4Fe_4Mn_4Cu_2$	-1	+1	+1	+1	-1	77.8	63.9
$Zn_4B_4Fe_4Mn_4Cu_4$	+1	+1	+1	+1	+1	99.9	92.8
$Zn_5B_3Fe_3Mn_3Cu_3$	+2	0	0	0	0	72.6	73.2
$Zn_1B_3Fe_3Mn_3Cu_3$	-2	0	0	0	0	74.1	80.7
$Zn_3B_5Fe_3Mn_3Cu_3$	0	+2	0	0	0	63.4	65.1

Table 5, continued.

Treatment level	Coded values of X					Actual yield, Bu/a	Calculated yield, Bu/a
	Zn	B	Fe	Mn	Cu		
$Zn_3B_1Fe_3Mn_3Cu_3$	0	-2	0	0	0	64.1	69.6
$Zn_3B_3Fe_5Mn_3Cu_3$	0	0	+2	0	0	72.1	97.8
$Zn_3B_3Fe_1Mn_3Cu_3$	0	0	-2	0	0	119.3	100.8
$Zn_3B_3Fe_3Mn_5Cu_3$	0	0	0	+2	0	58.5	76.7
$Zn_3B_3Fe_3Mn_1Cu_3$	0	0	0	-2	0	102.1	91.1
$Zn_3B_3Fe_3Mn_3Cu_5$	0	0	0	0	+2	98.0	91.0
$Zn_3B_3Fe_3Mn_3Cu_1$	0	0	0	0	-2	80.4	94.6
$Zn_3B_3Fe_3Mn_3Cu_3$	0	0	0	0	0	71.9	70.7

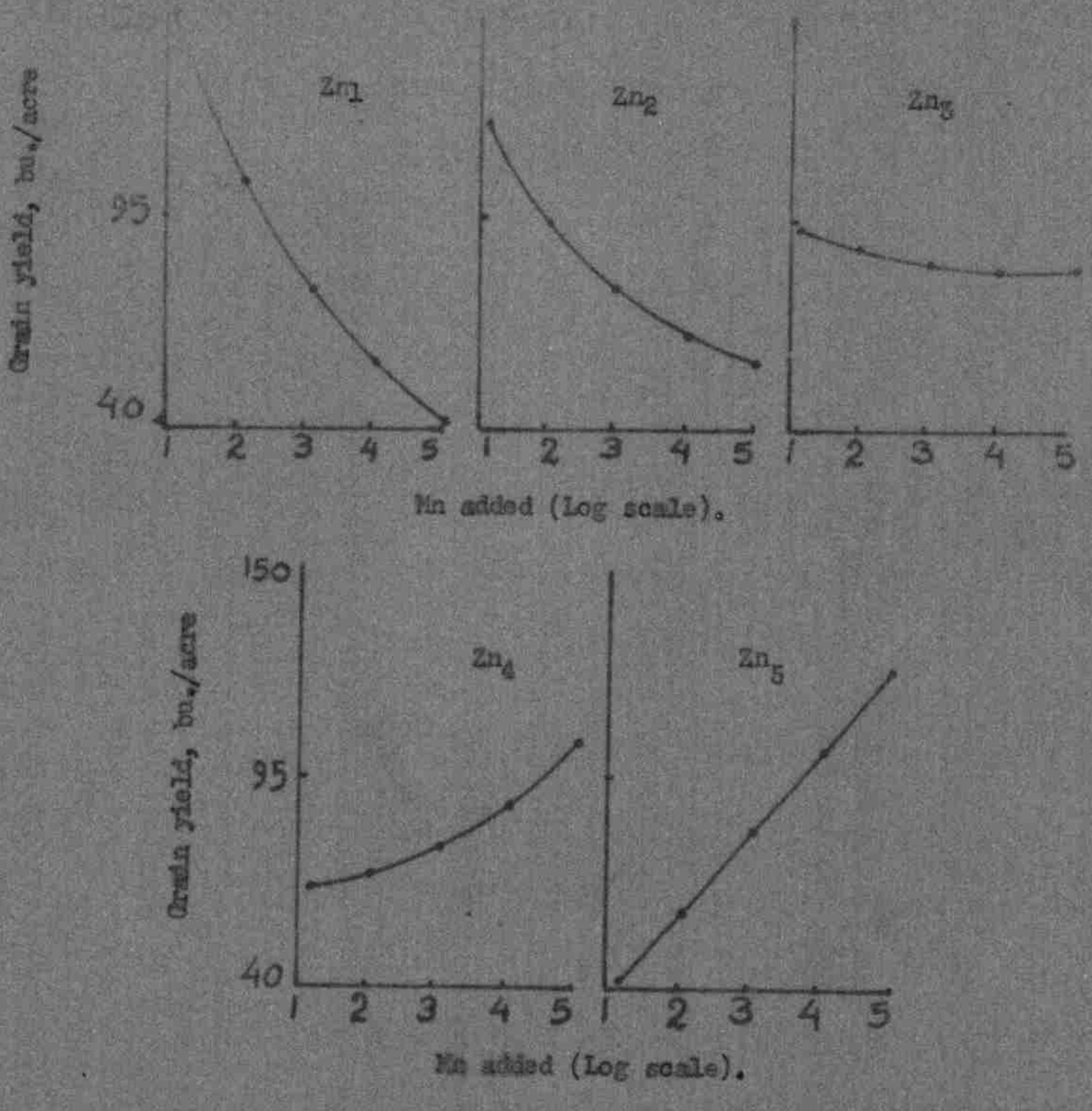

Fig. 1. Grain yield of corn (bu./acre) as influenced by addition of different levels of Zn and Mn under micronutrient treatments with B, Fe and Cu held constant at the middle of five levels(Table 1). Level of Zn was held constant for each graph.

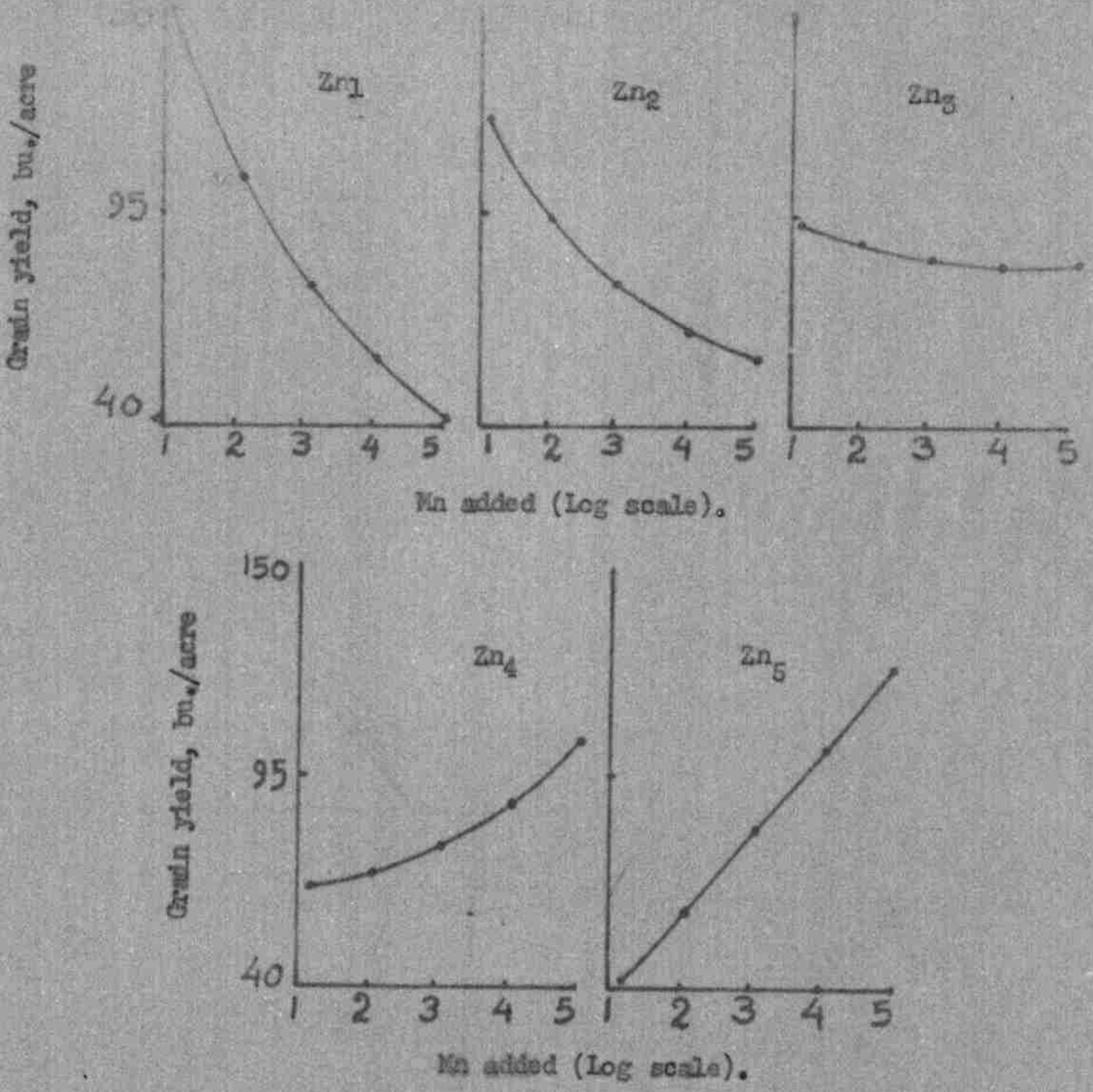

Fig. 1. Grain yield of corn (bu./acre) as influenced by addition of different levels of Zn and Mn under micronutrient treatments with B, Fe and Cu held constant at the middle of five levels(Table 1). Level of Zn was held constant for each graph.

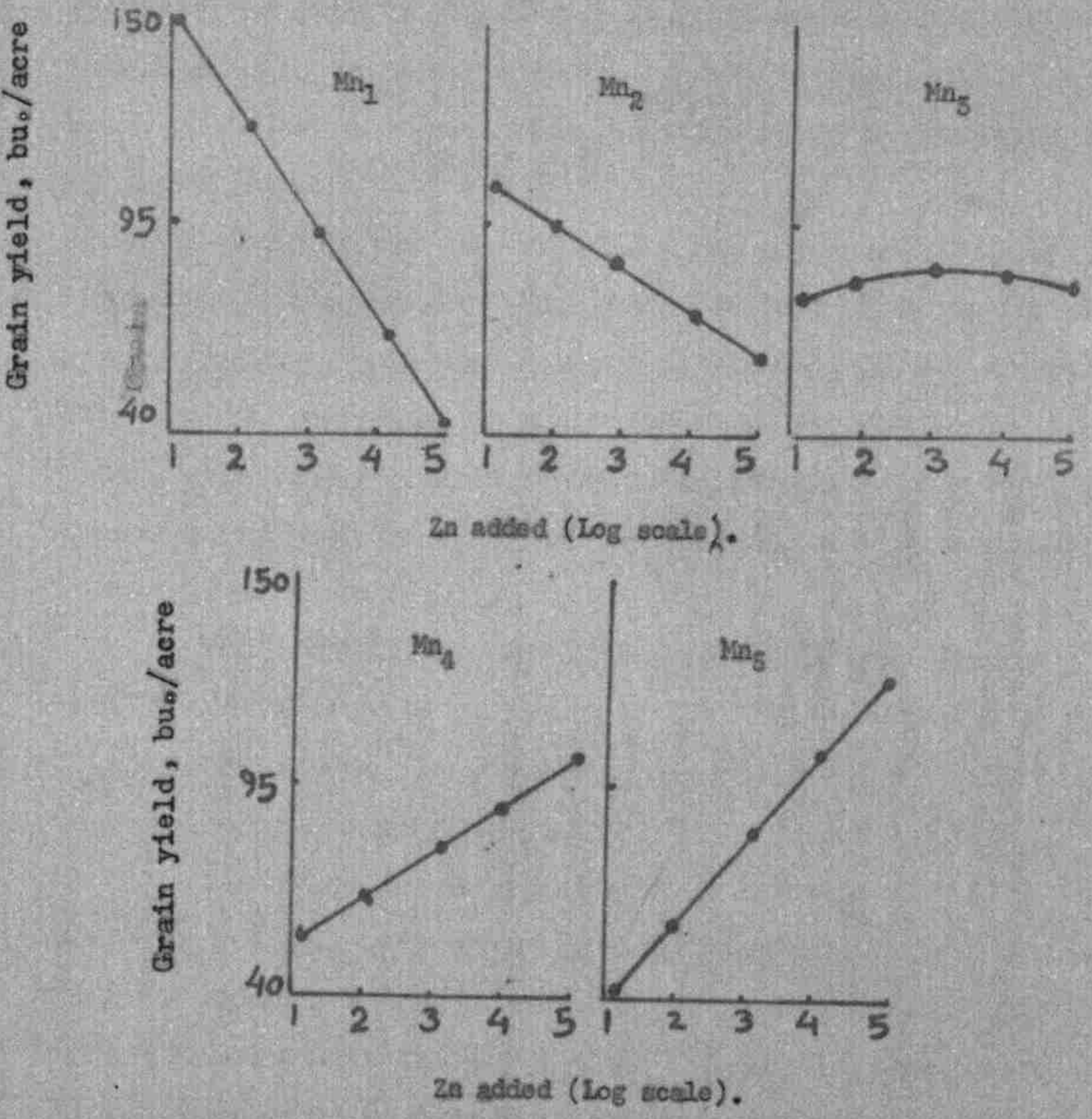

Fig. 2. Grain yield of corn (bu./acre) as influenced by addition of different levels of Zn and Mn under micronutrient treatments with B, Fe and Cu held constant at the middle of five levels (Table 1). Level of Mn was held constant for each graph.

Dry forage yield of corn. In analysis of variance for yield of dry forage (Table 6), the linear treatment effects were highly significant and the quadratic treatment effects were significant. The lack of fit term was not statistically significant.

Study of the individual regression coefficients (Table 7) indicated that the direct effect of Zn was positive and highly significant while the direct effect of Mn was negative and significant. The negative Mn^2 effect was also significant. The regression coefficients for the interaction effects of B-Mn and B-Cu on dry forage yield were significant.

The correlation coefficient between the actual yields and the yields calculated from the regression equation (Table 8) was 0.943 indicating a very close fit of the regression equation to the actual data.

The study of the relationship between dry forage yield of corn as influenced by the interaction of B and Mn (Fig.3) indicated that increasing Mn at low levels of B tended to increase the dry forage yield. At high levels of B, increasing Mn tended to decrease the dry forage yield. When Mn was held constant at its low levels (Fig.4), increasing B increased dry forage yield while at high levels of Mn increasing B tended to decrease dry forage yield of corn. A negative sign of the regression coefficient for the above interaction showed a complementary effect on dry forage yield of corn indicating that an increase in the

Table 6. **Analysis of variance for dry forage yield of corn obtained from micro-nutrient treatments.**

Source	**d.f.**	**s.s.**	**m.s.**
Total	31	27382898.0	
Linear	5	16351144.6	3270228.9**
Quadratic	15	8180938.2	545395.9*
Lack of fit	6	2257721.7	376286.9
Experimental error	5	593093.5	118618.7

***Significant at odds of 19:1**

****Significant at odds of 99:1**

Table 7. **Regression coefficients (b) and their standard errors (s_b) for dry forage yield of corn (lbs/acre) under micro nutrient treatments.**

Coefficient		b	s_b
Mean	b_0	+5655.17	±140.57
Zn	b_1	+792.22**	± 70.26
B	b_2	- 48.71	" "
Fe	b_3	- 66.13	" "
Mn	b_4	-214.29*	" "
Cu	b_5	- 32.13	" "
Zn^2	b_{11}	+ 44.20	± 63.72
B^2	b_{22}	-105.05	" "
Fe^2	b_{33}	+ 75.33	" "
Mn^2	b_{44}	-231.80*	" "
Cu^2	b_{55}	- 55.42	" "
Zn X B	b_{12}	+ 85.31	± 86.10
Zn X Fe	b_{13}	+216.56	" "
Zn X Mn	b_{14}	-212.10	" "
Zn X Cu	b_{15}	-147.19	" "
B X Fe	b_{23}	+ 36.94	" "
B X Mn	b_{24}	-294.44*	" "
B X Cu	b_{25}	+296.69*	" "
Fe X Mn	b_{34}	+155.81	" "
Fe X Cu	b_{35}	+103.44	" "
Mn X Cu	b_{45}	+191.10	" "

*Significant at odds of 19:1

**Significant at odds of 99:1

Table 8. Observed dry forage yield of corn (lb./acre) with micronutrients as variables. Values for the same treatments calculated form the regression equation are given. Correlation of actual yields with calculated yields was 0.943.

Treatment level	Coded values of X					Actual yield, lbs/a	Calculated yield, lbs/a
	Zn	B	Fe	Mn	Cu		
$Zn_2B_2Fe_2Mn_2Cu_4$	-1	-1	-1	-1	+1	4600	4431
$Zn_4B_2Fe_2Mn_2Cu_2$	+1	-1	-1	-1	-1	6750	7083
$Zn_2B_4Fe_2Mn_2Cu_2$	-1	+1	-1	-1	-1	4968	5037
$Zn4B_4Fe_2Mn_2Cu_4$	+1	+1	-1	-1	+1	6716	6723
$Zn_2B_2Fe_4Mn_2Cu_2$	-1	-1	+1	-1	-1	4000	4225
$Zn_4B_2Fe_4Mn_2Cu_4$	+1	-1	+1	-1	+1	5500	5664
$Zn_2B_4Fe_4Mn_2Cu_4$	-1	+1	+1	-1	+1	4775	4675
$Zn_4B_4Fe_4Mn_2Cu_2$	+1	+1	+1	-1	-1	6532	6933
$Zn_2B_2Fe_2Mn_4Cu_2$	-1	-1	-1	+1	-1	5200	5274
$Zn_4B_2Fe_2Mn_4Cu_4$	+1	-1	-1	+1	+1	5336	5348
$Zn_2B_4Fe_2Mn_4Cu_4$	-1	+1	-1	+1	+1	5000	4748
$Zn_4B_4Fe_2Mn_4Cu_2$	+1	+1	-1	+1	-1	4692	4942
$Zn_2B_2Fe_4Mn_4Cu_4$	-1	-1	+1	+1	+1	5060	4965
$Zn_4B_2Fe_4Mn_4Cu_2$	+1	-1	+1	+1	-1	6050	6457
$Zn_2B_4Fe_4Mn_4Cu_2$	-1	+1	+1	+1	-1	3220	3363
$Zn_4B_4Fe_4Mn_4Cu_4$	+1	+1	+1	+1	+1	6164	6245
$Zn_5B_3Fe_3Mn_3Cu_3$	+2	0	0	0	0	8050	7416
$Zn_1B_3Fe_3Mn_3Cu_3$	-2	0	0	0	0	4002	4247
$Zn_3B_5Fe_3Mn_3Cu_3$	0	+2	0	0	0	5244	5138

Table 8, continued.

Treatment level	Coded values of X					Actual yield, lbs/a	Calculated yield, lbs/a
	Zn	B	Fe	Mn	Cu		
$Zn_3B_1Fe_3Mn_3Cu_3$	0	-2	0	0	0	5614	5332
$Zn_3B_3Fe_5Mn_3Cu_3$	0	0	+2	0	0	6244	5824
$Zn_3B_3Fe_1Mn_3Cu_3$	0	0	-2	0	0	6057	6089
$Zn_3B_3Fe_3Mn_5Cu_3$	0	0	0	+2	0	4416	4299
$Zn_3B_3Fe_3Mn_1Cu_3$	0	0	0	-2	0	5428	5157
$Zn_3B_3Fe_3Mn_3Cu_5$	0	0	0	0	+2	5000	5369
$Zn_3B_3Fe_3Mn_3Cu_1$	0	0	0	0	-2	6255	5498
$Zn_3B_3Fe_3Mn_3Cu_3$	0	0	0	0	0	5590	5655

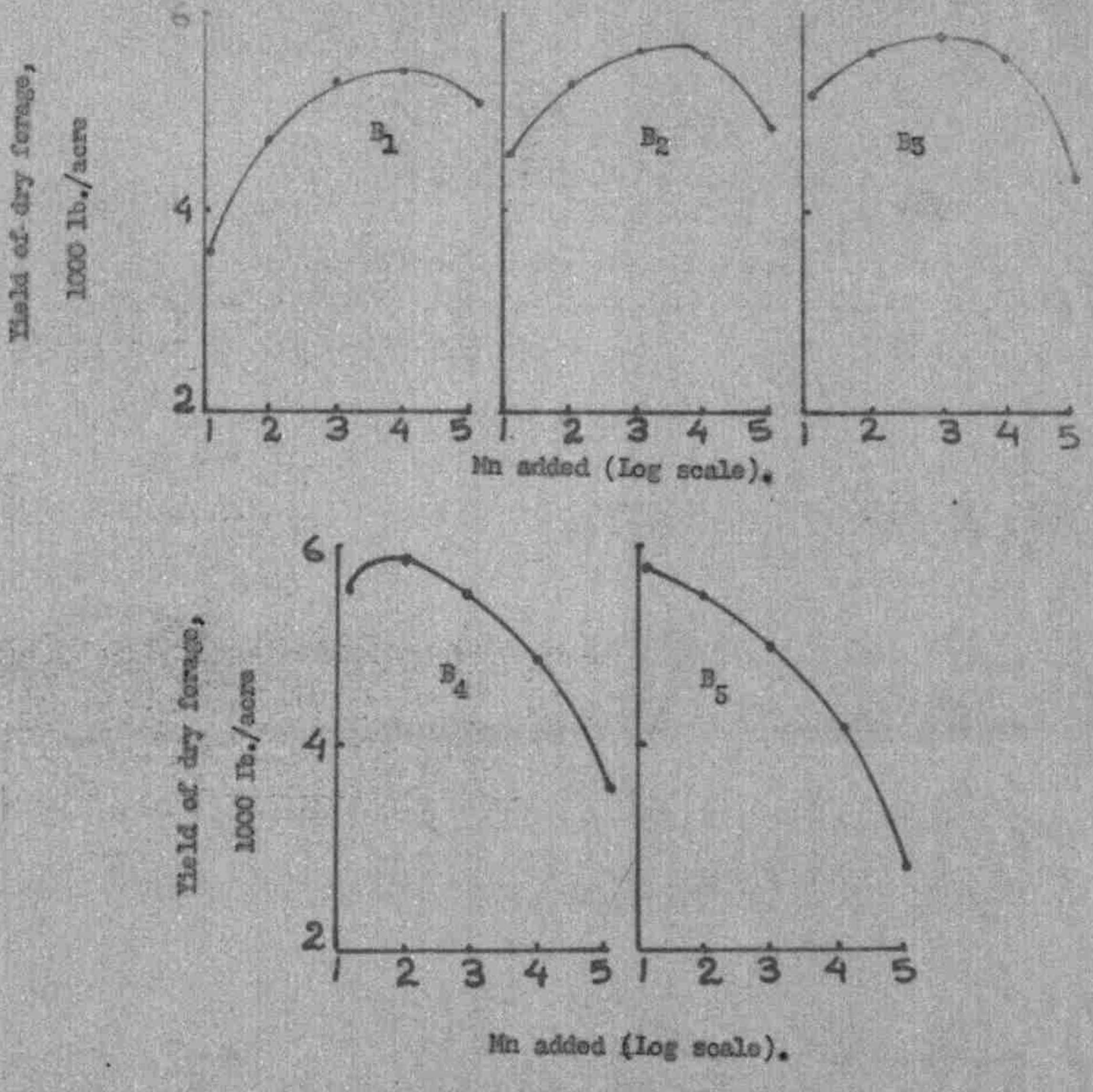

Fig. 3. Dry forage yield of corn (lb./acre) as influenced by addition of different levels of B and Mn under micronutrient treatments with Zn, Fe and Cu held constant at the middle of five levels (Table 1). Level of B was held constant for each graph.

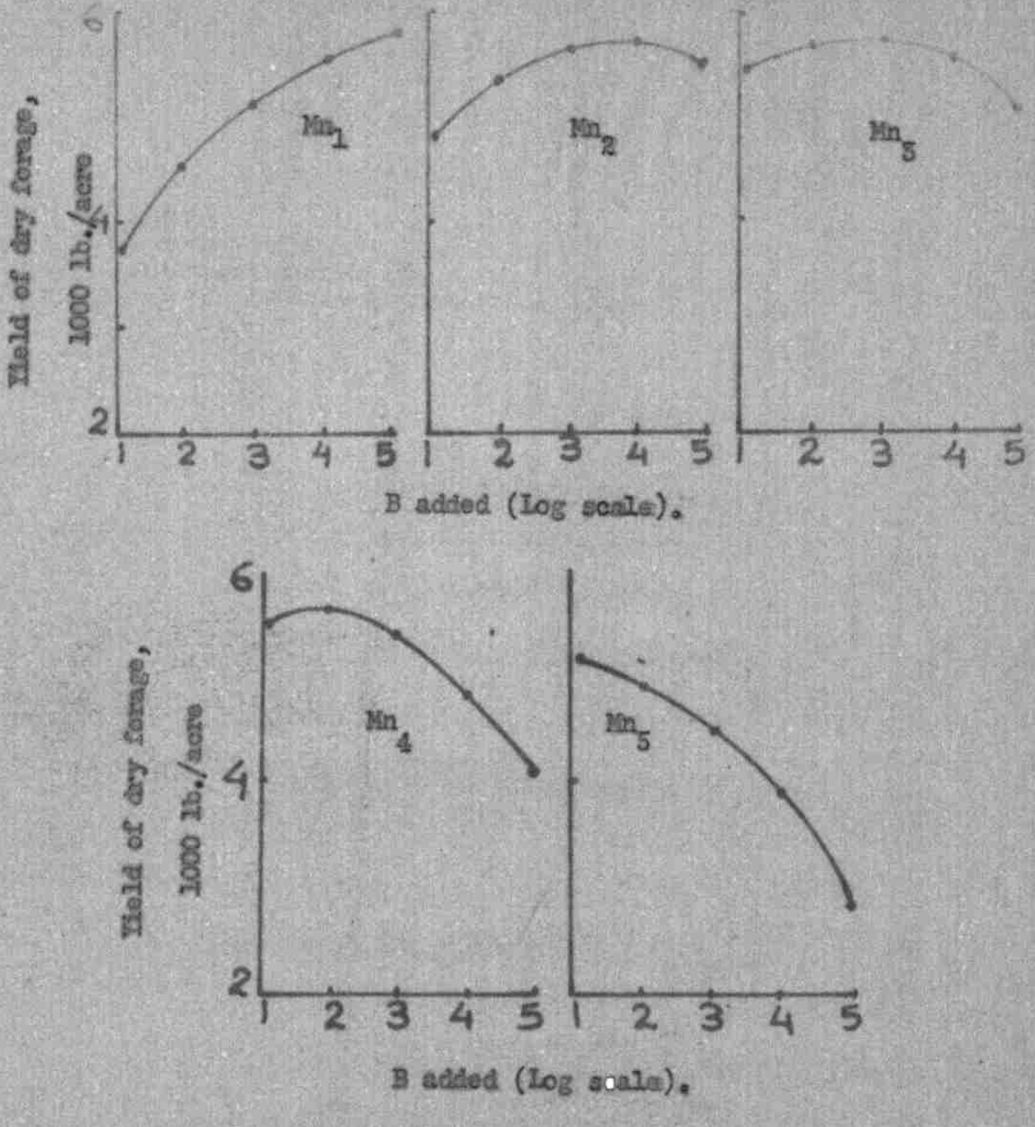

Fig. 4. Dry forage yield of corn (lb,/acre) as influnced by addition of different levels of B, and Mn under micro-nutrient treatments with Zn, Fe and Cu held constant at the middle of five levels (Table 1). Level of Mn was held constant for each graph.

level of Mn or B decreased the requirement for the other.

Study of the relationship between dry forage yield of corn and the B-Cu interaction Fig. 5) indicated that at low levels of B increasing Cu levels resulted in a decreased dry forage yield of corn. At high levels of B increasing Cu levels increased the dry forage yield of corn. Increasing B with Cu held constant at low levels (Fig. 6) resulted in a decreased dry forage yield of corn. However, at high levels of B increasing Cu increased the dry forage yield.

It was also noted from the above study that Cu and Mn differed considerably in their interaction with B in regard to production of dry forage yield in that the Mn-B interaction was complementary while the Cu-B interaction was antagonistic.

It is suggested that under the conditions of this experiment a high level of Zn accompanied by a fairly high level of Fe is necessary for maximum dry forage production of corn. However, since the increase in forage yield is secured at the expense of a decrease in grain yield, Zn application would not be economically justified for corn production on this soil.

Zinc concentration of corn leaves. The analysis of variance for Zn concentration of corn leaves showed that the linear treatment effect was highly significant (Table 9).

The regression coefficient for the effect of Zn

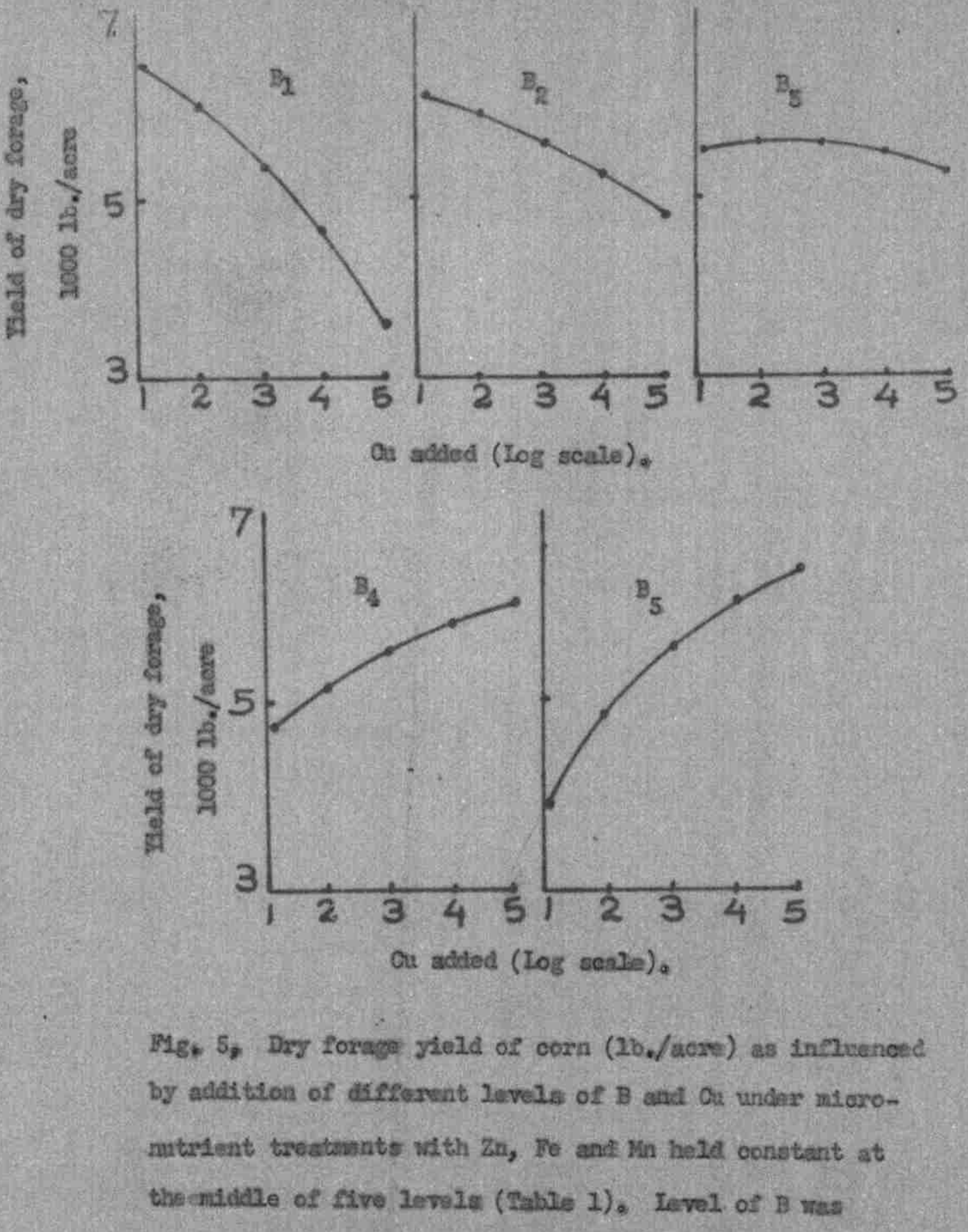

Fig. 5. Dry forage yield of corn (lb./acre) as influenced by addition of different levels of B and Cu under micronutrient treatments with Zn, Fe and Mn held constant at the middle of five levels (Table 1). Level of B was held constant for each graph.

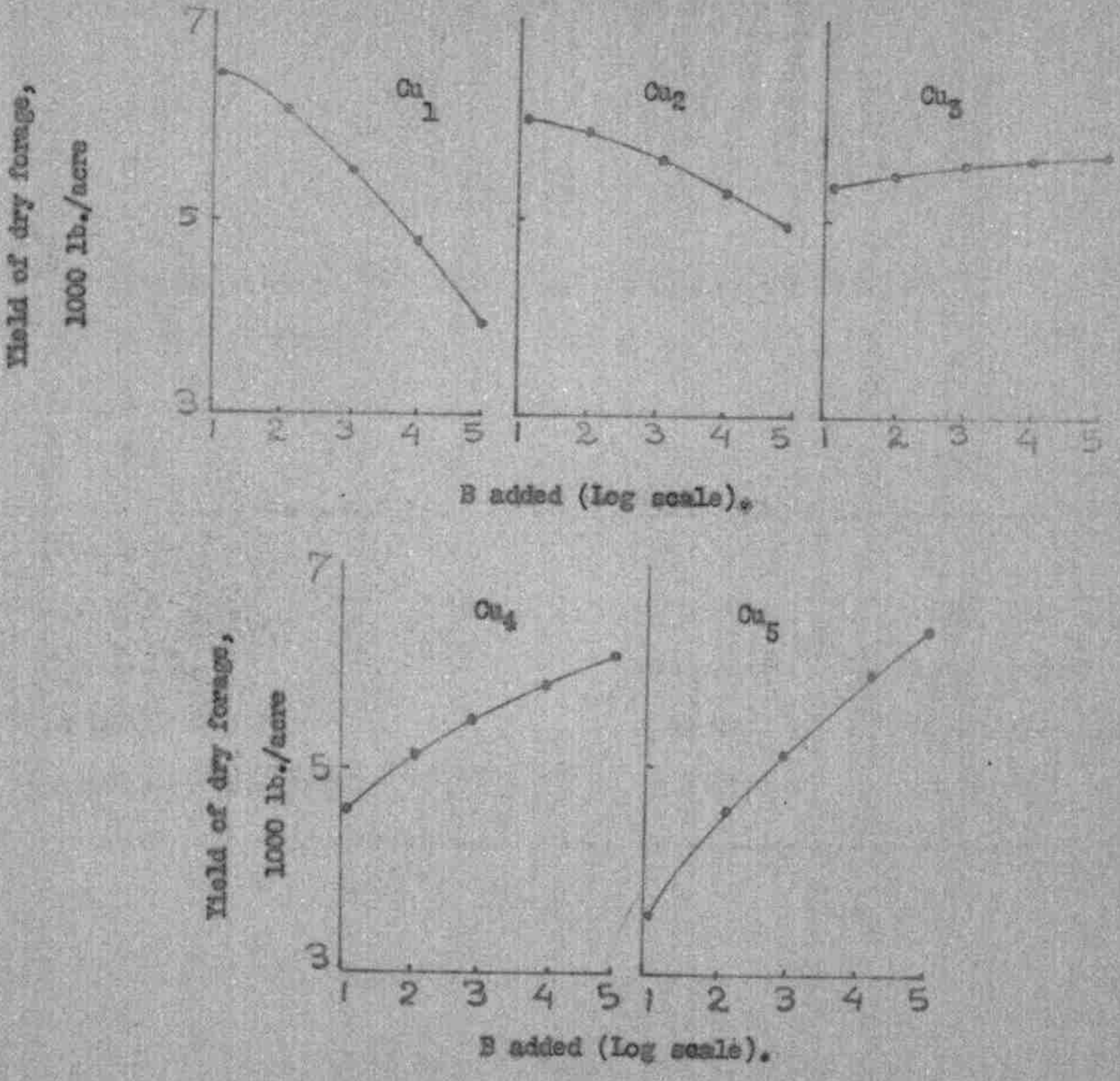

Fig. 6. Dry forage yield of corn (lb./acre) as influenced by addition of different levels of B and Cu under micronutrient treatments with Zn, Fe and Mn held constant at the middle of five levels (Table 1). Level of Cu was held constant for each graph.

Table 9. **Analysis of variance for Zn concentration of corn leaves.**

Source	**d.f.**	**s.s.**	**m.s.**
Total	31	28021.470	
Linear	5	20122.508	4024.502 **
Quadratic	15	6053.453	403.564
Lack of fit	6	376.675	62.710
Experimental error	5	1468.834	293.767

**Significant at odds of 99:1

(Table 10) was positive and statistically significant indicating that increasing Zn applications resulted in increased Zn concentration of corn leaves. In general the heavy metals Cu, Mn and Fe tended to depress the Zn concentration in corn leaves. The quadratic Zn^2 term (positive) was significant.

Zinc applications depressed the grain yield (Table 5) while the dry forage yield (Table 8) was increased markedly. Viets et al. (55) in their study of Zn deficiency in corn grown on newly irrigated soils in central Washington, claimed that 15 ppm. Zn in the leaf from the second node below the ear at the silking stage was an adequate Zn level for yields of 100-125 bu./acre. The above statement is in agreement with the present study which showed that high grain yields (Table 5) were obtained at 20 ppm. Zn concentration in corn leaves (Table 11). Fuehring (16) in a sand culture study found that the critical level of Zn for the dry matter yield of corn tops was about 100 ppm. The same fact was observed in this study by developing curves for the Zn-Mn interaction (Fig. 7) which indicated that increasing Zn at constant levels of Mn resulted in increased forage yield and increased Zn concentration of corn leaves up to about 180 ppm. However, since both forage yield and Zn concentration were still increasing at the highest level of applied Zn, no definite critical level of Zn for forage production could be established except that it must be above 150 ppm. under the conditions of this experiment.

Table 10. **Regression coefficients (b) and their standard errors (s_b) for Zn concentration of corn leaves(ppm.dry weight).**

Coefficient		**b**	**s_b**
Mean	b_0	+48.100	±8.000
Zn	b_1	+28.667**	±3.497
B	b_2	+0.583	" "
Fe	b_3	-3.833	" "
Mn	b_4	-0.666	" "
Cu	b_5	-1.083	" "
Zn^2	b_{11}	+9.807*	±3.171
B^2	b_{22}	+1.932	" "
Fe^2	b_{33}	+5.182	" "
Mn^2	b_{44}	+2.057	" "
Cu^2	b_{55}	-4.644	" "
Zn X B	b_{12}	+3.500	±4.285
Zn X Fe	b_{13}	+1.875	" "
Zn X Mn	b_{14}	+5.750	" "
Zn X Cu	b_{15}	+0.625	" "
B X Fe	b_{23}	-2.250	" "
B X Mn	b_{24}	-0.125	" "
B X Cu	b_{25}	-1.875	" "
Fe X Mn	b_{34}	+3.625	" "
Fe X Cu	b_{35}	-4.750	" "
Mn X Cu	b_{45}	+0.625	" "

***Significant at odds of 19:1**

****Significant at odds of 99:1**

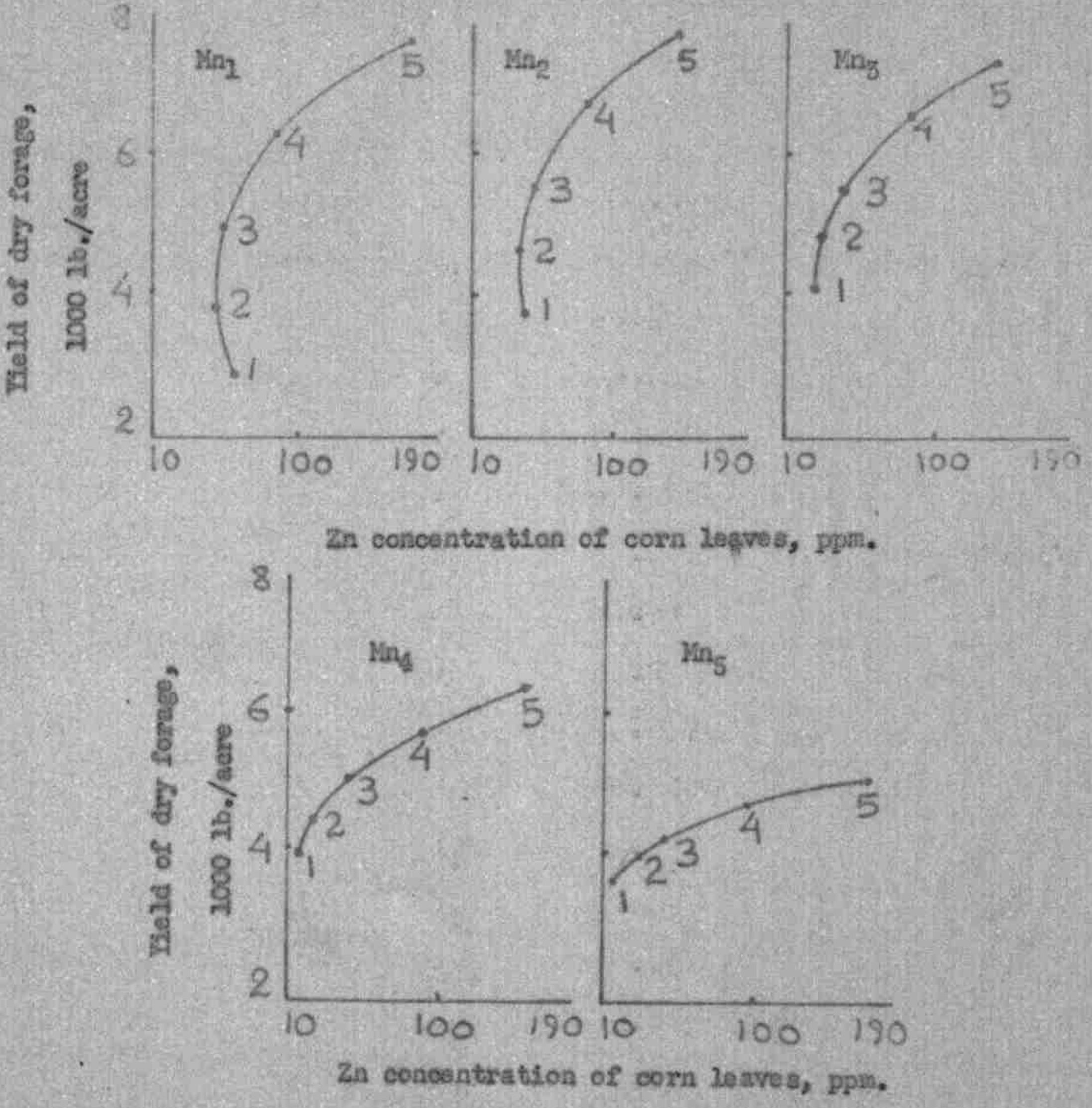

Fig. 7. Relationship between dry forage yield of corn (lb./acre) and Zn concentration (ppm. dry wt.) as affected by addition of different levels of Zn and Mn under micronutrient treatments with B, Fe and Cu at the middle of five levels (Table 1). Numbers at points refer to levels of Zn added. Level of Mn was held constant for each graph.

It was also noted from the curves (Fig. 7) that the forage yield response to Zn was reduced at high levels of Mn.- Fuehring (16) in a nutrient solution study with micronutrients on corn obtained the same Zn-Mn interaction effect on the dry matter yield of corn. This leads to the conclusion that the Zn requirement of corn is much higher for forage production than for grain production.

The correlation coefficient between the observed Zn concentrations of corn leaves and those calculated from the regression equation (Table 11)was 0.966 indicating a very close fit of the regression equation to the actual data.

Boron concentration of corn leaves. Statistical analysis for the B concentration in the corn leaves was carried out on the logarithms of the ppm. because of the very wide range in the values.

The analysis of variance (Table 12) indicated that the linear and quadratic effects were highly significant. The lack of fit term was statistically significant so it was possible that a higher order equation would more adequatly define the B concentration.

Examination of the regression coefficients for the B concentration of corn leaves (Table 13) indicated that the direct effects of B (positive) and Mn (positive) were highly significant. Zinc (positive) and Fe (negative) had a significant effect on the B concentration of corn leaves. The B^2 term (positive) and the Cu^2 term (positive)

Table 11. Observed Zn concentrations of corn leaves (ppm. dry wt.) with micronutrients as variables. Values for the same treatments calculated from the regression equation are given. Correlation of actual Zn concentrations with calculated concentrations was 0.966.

Treatment level	Actual Zn concentration, ppm.	Calculated Zn concentration, ppm.
$Zn_2B_2Fe_2Mn_2Cu_4$	60	56
$Zn_4B_2Fe_2Mn_2Cu_2$	85	85
$Zn_2B_4Fe_2Mn_2Cu_2$	45	43
$Zn_4B_4Fe_2Mn_2Cu_4$	100	98
$Zn_2B_2Fe_4Mn_2Cu_2$	40	35
$Zn_4B_2Fe_4Mn_2Cu_4$	70	65
$Zn_2B_4Fe_4Mn_2Cu_4$	32	26
$Zn_4B_4Fe_4Mn_2Cu_2$	98	96
$Zn_2B_2Fe_2Mn_4Cu_2$	28	29
$Zn_4B_2Fe_2Mn_4Cu_4$	95	96
$Zn_2B_4Fe_2Mn_4Cu_4$	30	30
$Zn_4B_4Fe_2Mn_4Cu_2$	90	93
$Zn_2B_2Fe_4Mn_4Cu_4$	30	27
$Zn_4B_2Fe_4Mn_4Cu_2$	102	102
$Zn_2B_4Fe_4Mn_4Cu_2$	25	24
$Zn_4B_4Fe_4Mn_4Cu_4$	94	93
$Zn_5B_3Fe_3Mn_3Cu_3$	145	145
$Zn_1B_3Fe_3Mn_3Cu_3$	23	30
$Zn_3B_5Fe_3Mn_3Cu_3$	55	57

Table 11, continued.

Treatment level	Actual Zn concentration, ppm.	Calculated Zn concentration, ppm.
$Zn_3B_1Fe_3Mn_3Cu_3$	50	55
$Zn_3B_3Fe_5Mn_3Cu_3$	53	61
$Zn_3B_3Fe_1Mn_3Cu_3$	78	76
$Zn_3B_3Fe_3Mn_5Cu_3$	58	55
$Zn_3B_3Fe_3Mn_1Cu_3$	48	58
$Zn_3B_3Fe_3Mn_3Cu_5$	20	27
$Zn_3B_3Fe_3Mn_3Cu_1$	32	32
$Zn_3B_3Fe_3Mn_3Cu_3$	49	48

Table 12. **Analysis of variance for B concentration of corn leaves (log scale).**

Source	**d.f.**	**s.s.**	**m.s.**
Total	31	1.1202	
Linear	5	0.8724	0.1745**
Quadratic	15	0.2009	0.0134**
Lack of fit	6	0.0407	0.0068*
Experimental error	5	0.0062	0.0012

***Significant at odds of 19:1**

****Significant at odds of 99:1**

Table 13. **Regression coefficient (b) and their standard errors (s_b) for B concentration of corn leaves (ppm. dry weight, log scale).**

Coefficient		b	s_b
Mean	b_0	+1.313	±0.0141
Zn	b_1	+0.021*	±0.0069
B	b_2	+0.184**	" "
Fe	b_3	-0.027*	" "
Mn	b_4	+0.033**	" "
Cu	b_5	-0.005	" "
Zn^2	b_{11}	+0.012	±0.0063
B^2	b_{22}	+0.062**	" "
Fe^2	b_{33}	-0.008	" "
Mn^2	b_{44}	-0.001	" "
Cu^2	b_{55}	+0.025**	" "
Zn X B	b_{12}	+0.035**	±0.0085
Zn X Fe	b_{13}	-0.011	" "
Zn X Mn	b_{14}	+0.003	" "
Zn X Cu	b_{15}	-0.019	" "
B X Fe	b_{23}	-0.017	" "
B X Mn	b_{24}	+0.001	" "
B X Cu	b_{25}	+0.010	" "
Fe X Mn	b_{34}	-0.015	" "
Fe X Cu	b_{35}	+0.024*	" "
Mn X Cu	b_{45}	-0.019	" "

***Significant at odds of 19:1**

****Significant at odds of 99:1**

had a highly significant effect on B concentration of corn leaves. The regression coefficient for the Zn-B interaction (positive) was highly significant, while that for the Fe-Cu interaction (positive) was significant.

The relationship between the yield of dry forage of corn and B concentration of corn leaves, as affected by increasing levels of B at constant levels of Zn (Fig. 8), showed that as the level of B increased, the B concentration of corn leaves also increased. As the level of Zn increased, the amount of B required for the maximum yield increased from about the 2 level to the 4 level of B. However, the B concentration of corn leaves at the highest forage yield remained at about 30 ppm. The effect of increasing Zn with constant levels of B (Fig. 9) indicated that at low levels of B, increasing Zn increased the dry forage yield but decreased the B concentration of the corn leaves. At the higher levels of B increasing Zn tended to increase the B concentration of corn leaves as well as the dry forage yield of corn.

The relationship between the dry forage yield and the B concentration of corn leaves, as affected by Fe-Cu interaction (Fig. 10), indicated that increasing Cu at low levels of Fe decreased the dry forage yield. Increasing Cu at higher levels of Fe tended to increase the dry forage yield. The first increments of Cu tended to decrease the B concentration and the higher increments increased the B concentration of corn leaves. At all levels of Cu (Fig. 11) increasing Fe tended to decrease the B con-

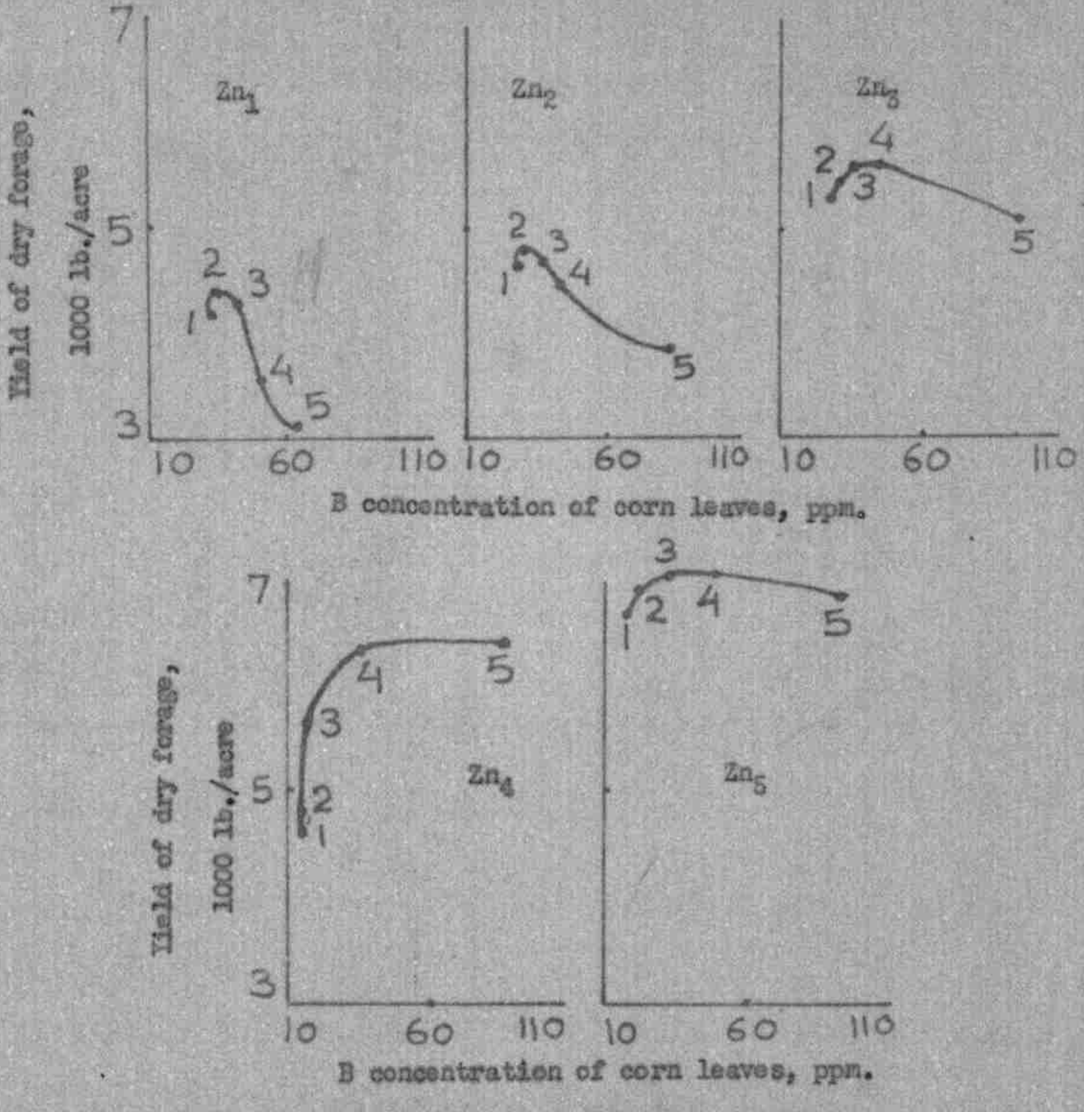

Fig. 8. Relationship between dry forage yield of corn (lb./acre) and B concentration (ppm. dry wt.) as affected by addition of different levels of Zn and B under micornutrient treatments with Fe, Mn, and Cu at the middle of five levels (Table 1). Numbers at points refer to levels of B added. Level of Zn was held constant for each graph.

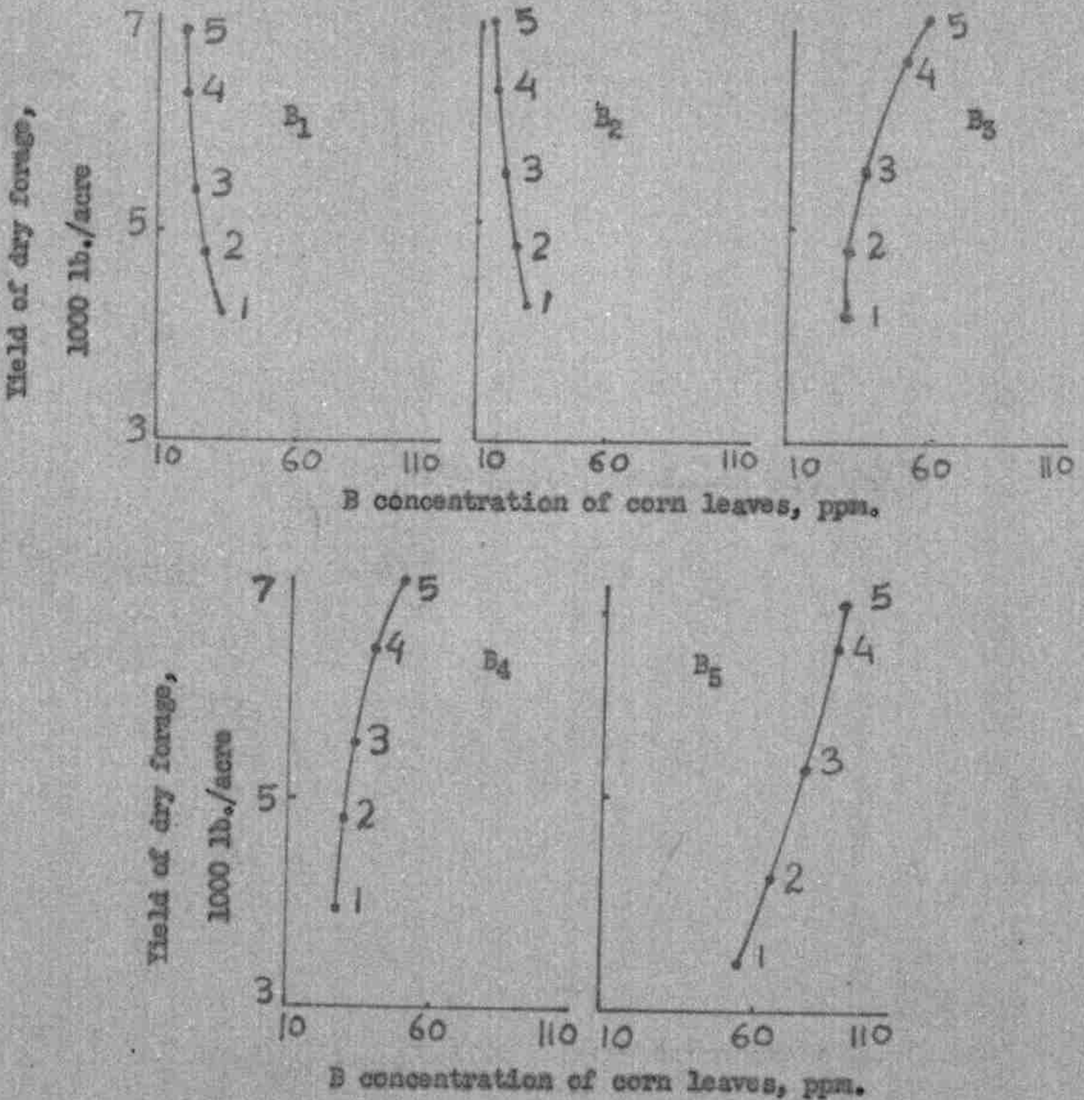

Fig. 9. Relationship between dry forage yield of corn (lb./acre) and B concentration (ppm. dry wt.) as affected by addition of different levels of Zn and B under micronutrient treatments with Fe, Mn, and Cu at the middle of five levels (Table 1). Numbers at points refer to levels of Zn added. Level of B was held constant for each graph.

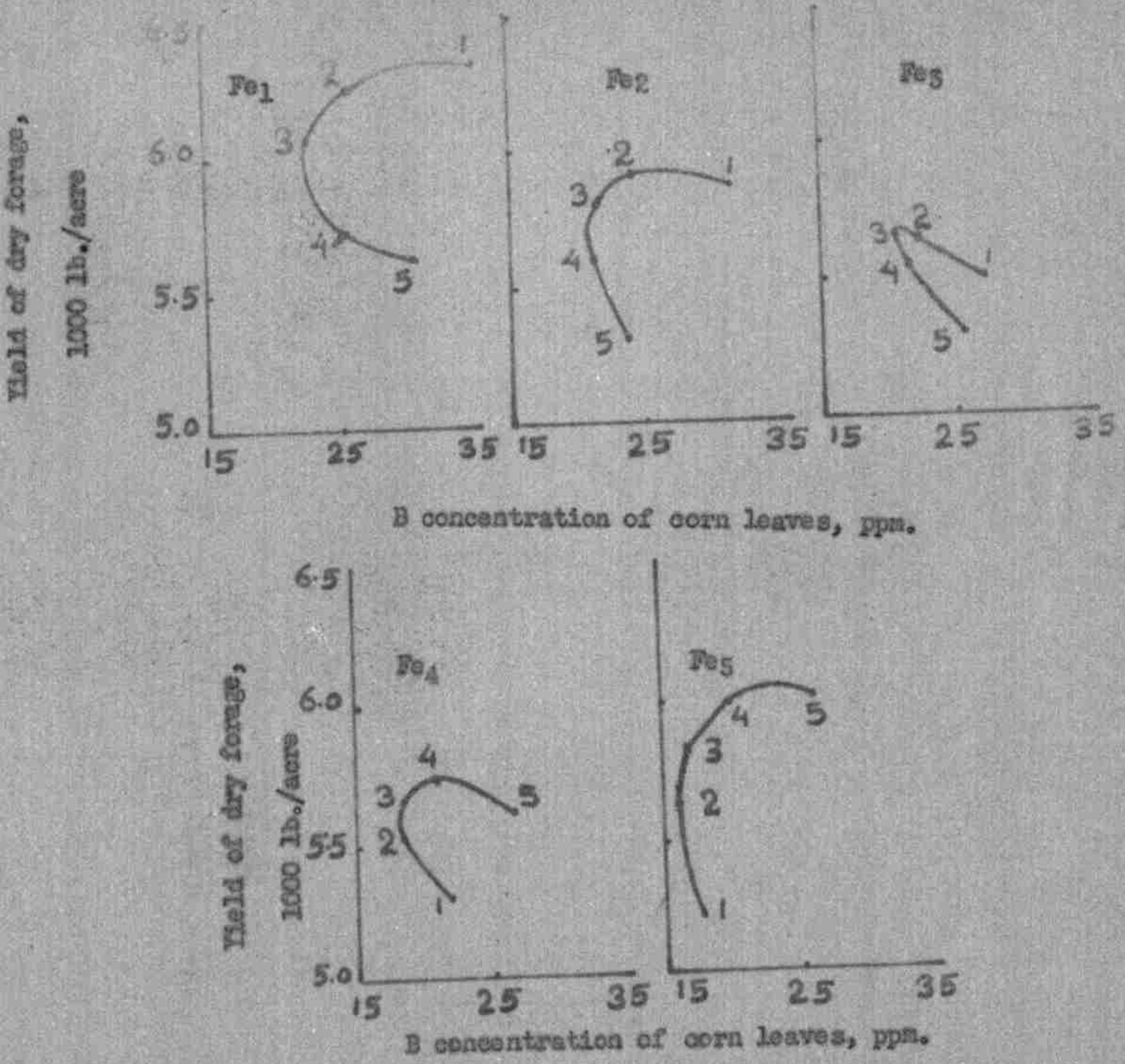

Fig. 10. Relationship between dry forage yield of corn (lb./acre) and B concentration (ppm. dry wt.) as affected by addition of different levels of Fe and Cu under micronutrient treatments with Zn, B, and Mn at the middle of five levels (Table 1). Numbers at points refer to levels of Cu added. Level of Fe was held constant for each graph.

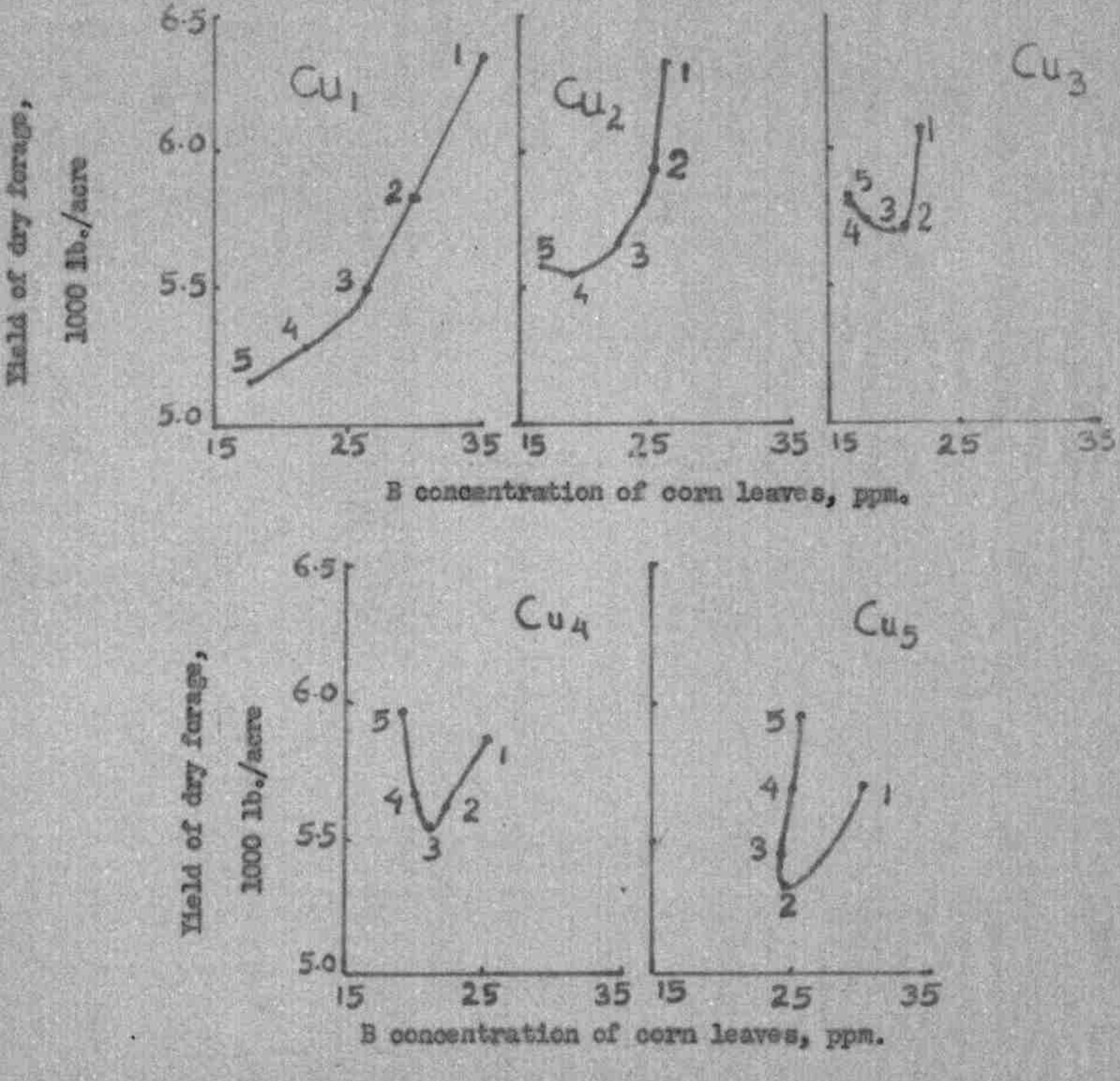

Fig. 11. Relationship between dry forage yield of corn (lb./acre) and B concentration (ppm. dry wt.) as affected by addition of different levels of Fe and Cu under micronutrient treatments with Zn, B, and Mn at the middle of five levels (Table 1). Numbers at points refer to levels of Fe added. Level of Cu was held constant for each graph.

centration of corn leaves. The dry forage yield of corn decreased at the lower levels of Cu with increasing Fe levels. At the higher Cu levels the first increments of Fe decreased the yield while higher increments increased the dry forage yield.

The correlation coefficient between the observed B concentrations and B concentrations calculated from regression equation (Table 14) was 0.757 (highly significant) indicating a fairly close fit of the regression equation to the actual data.

Iron concentration of corn leaves. The analysis of variance for Fe concentration of corn leaves (Table 15) indicated that the quadratic and lack of fit terms were significant.

Examination of the regression equation for the Fe concentration of corn leaves (Table 16) indicated that the linear effect for Zn (negative) was significant. The quadratic effects of B^2 (positive) and Fe^2 (positive) were highly significant. The interaction of Mn and Cu (negative) was highly significant while the Zn-Mn interaction (negative) was significant.

Study of the relationship between the dry forage yield of corn and the Fe concentration of corn leaves, as affected by the Mn-Cu interaction (Fig. 12), revealed that at low levels of Mn, increasing Cu decreased the yield of dry forage and increased Fe concentration in corn leaves but at high levels of Mn the forage yield increased

Table 14. Observed B concentrations of corn leaves (ppm. dry wt.) with micronutrients as variables. Values for the same treatments calculated from the regression equation are given. Correlation of actual B concentrations with calculated concentrations was 0.657.

Treatment level	Actual B concentration, ppm.	Calculated B concentration, ppm.
$Zn_2B_2Fe_2Mn_2Cu_4$	17.0	15.5
$Zn_4B_2Fe_2Mn_2Cu_2$	18.0	16.6
$Zn_2B_4Fe_2Mn_2Cu_2$	34.0	31.5
$Zn_4B_4Cu_4Fe_2Mn_2$	40.0	42.5
$Zn_2B_2Fe_4Mn_2Cu_2$	16.0	14.8
$Zn_4B_2Fe_4Mn_2Cu_4$	14.0	14.9
$Zn_2B_4Fe_4Mn_2Cu_4$	33.0	35.7
$Z^N{}_4B_4Fe_4Mn_2Cu_2$	32.0	34.7
$Zn_2B_2Fe_2Mn_4Cu_2$	24.0	20.6
$Zn_4B_2Fe_2Mn_4Cu_4$	16.0	15.8
$Zn_2B_4Fe_2Mn_4Cu_4$	39.0	36.8
$Zn_4B_4Fe_2Mn_4Cu_2$	64.0	64.3
$Zn_2B_2Fe_4Mn_4Cu_4$	18.0	18.1
$Zn_4B_2Fe_4Mn_4Cu_2$	17.0	17.1
$Zn_2B_4Fe_4Mn_4Cu_2$	30.0	30.6
$Zn_4B_4Fe_4Mn_4Cu_4$	34.0	39.9
Zn5B3Fe3Mn3Cu3	29.0	25.4
$Zn_1B_3Fe_3Mn_3Cu_3$	19.0	20.8
$Zn_3B_5Fe_3Mn_3Cu_3$	100.0	85.3

Table 14, continued.

Treatment level	Actual B concentration, ppm.	Calculated B concentration, ppm.
$Zn_3B_1Fe_3Mn_3Cu_3$	13.0	15.6
$Zn_3B_3Fe_5Mn_3Cu_3$	20.0	16.9
$Zn_3B_3Fe_1Mn_3Cu_3$	18.0	21.6
$Zn_3B_3Fe_3Mn_5Cu_3$	24.0	23.6
$Zn_3B_3Fe_3Mn_1Cu_3$	17.0	17.5
$Zn_3B_3Fe_3Mn_3Cu_5$	29.0	25.5
$Zn_3B_3Fe_3Mn_3Cu_1$	23.0	26.6
$Zn_3B_3Fe_3Mn_3Cu_3$	20.7	20.6

Table 15. **Analysis of variance for Fe concentration of corn leaves.**

Source	**d.f.**	**s.s.**	**m.s.**
Total	31	3034.00	
Linear	5	334.54	66.91
Quadratic	15	1714.73	114.32*
Lack of fit	6	898.73	149.79*
Experimental error	5	86.00	17.20

***Significant at odds of 19:1**

****Significant at odds of 99:1**

Table 16. Regression coefficients (b) and their standard errors (s_b) for Fe concentration of corn leaves (ppm. dry weight)

Coefficient		b	s_b
Mean	b_0	+67.39	±1.692
Zn	b_1	- 2.50*	±0.846
B	b_2	- 1.75	" "
Fe	b_3	+ 1.25	" "
Mn	b_4	- 1.58	" "
Cu	b_5	+ 0.75	" "
Zn^2	b_{11}	+ 1.17	±0.767
B^2	b_{22}	+ 3.55**	" "
Fe^2	b_{33}	+ 4.30**	" "
Mn^2	b_{44}	- 1.58	" "
Cu^2	b_{55}	+ 0.30	" "
Zn X B	b_{12}	+ 2.25	±1.036
Zn X Fe	b_{13}	- 1.75	" "
Zn X Mn	b_{14}	- 2.63*	" "
Zn X Cu	b_{15}	+ 2.25	" "
B X Fe	b_{23}	- 0.25	" "
B X Mn	b_{24}	-0.63	" "
B X Cu	b_{25}	- 0.75	" "
Fe X Mn	b_{34}	+ 0.38	" "
Fe X Cu	b_{35}	- 2.25	" "
Mn X Cu	b_{45}	- 4.13**	" "

*Significant at odds of 19:1

**Significant at odds of 99:1

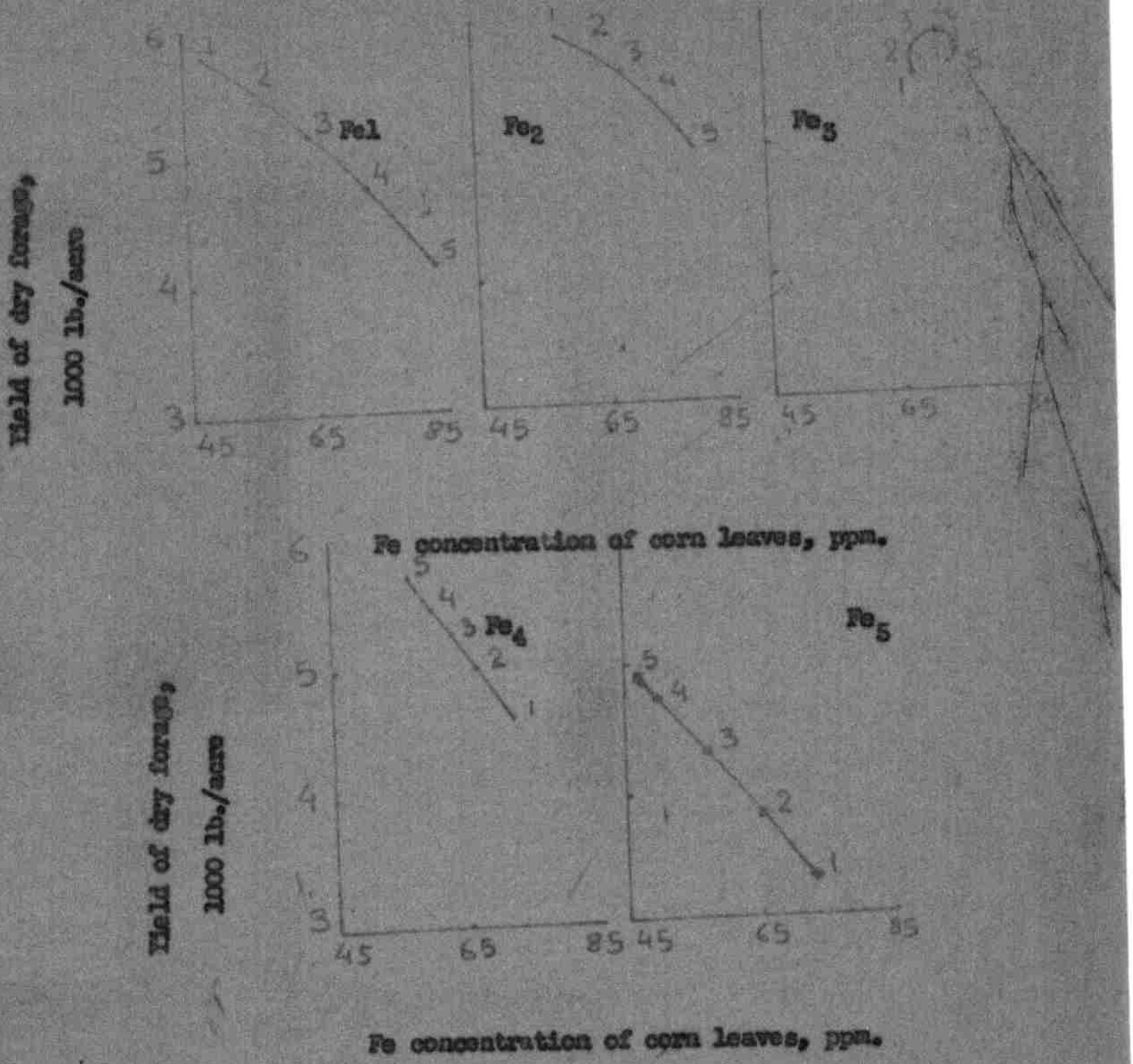

Fig. 12. Relationship between dry forage yield of corn (lb./acre) and Fe concentration (ppm. dry wt.) as affected by addition of different levels of Mn and Cu under micronutrient treatments with Zn, B and Fe at the middle of five levels (Table 1.). Numbers at points refer to levels of Cu added. Level of Fe was held constant for each graph.

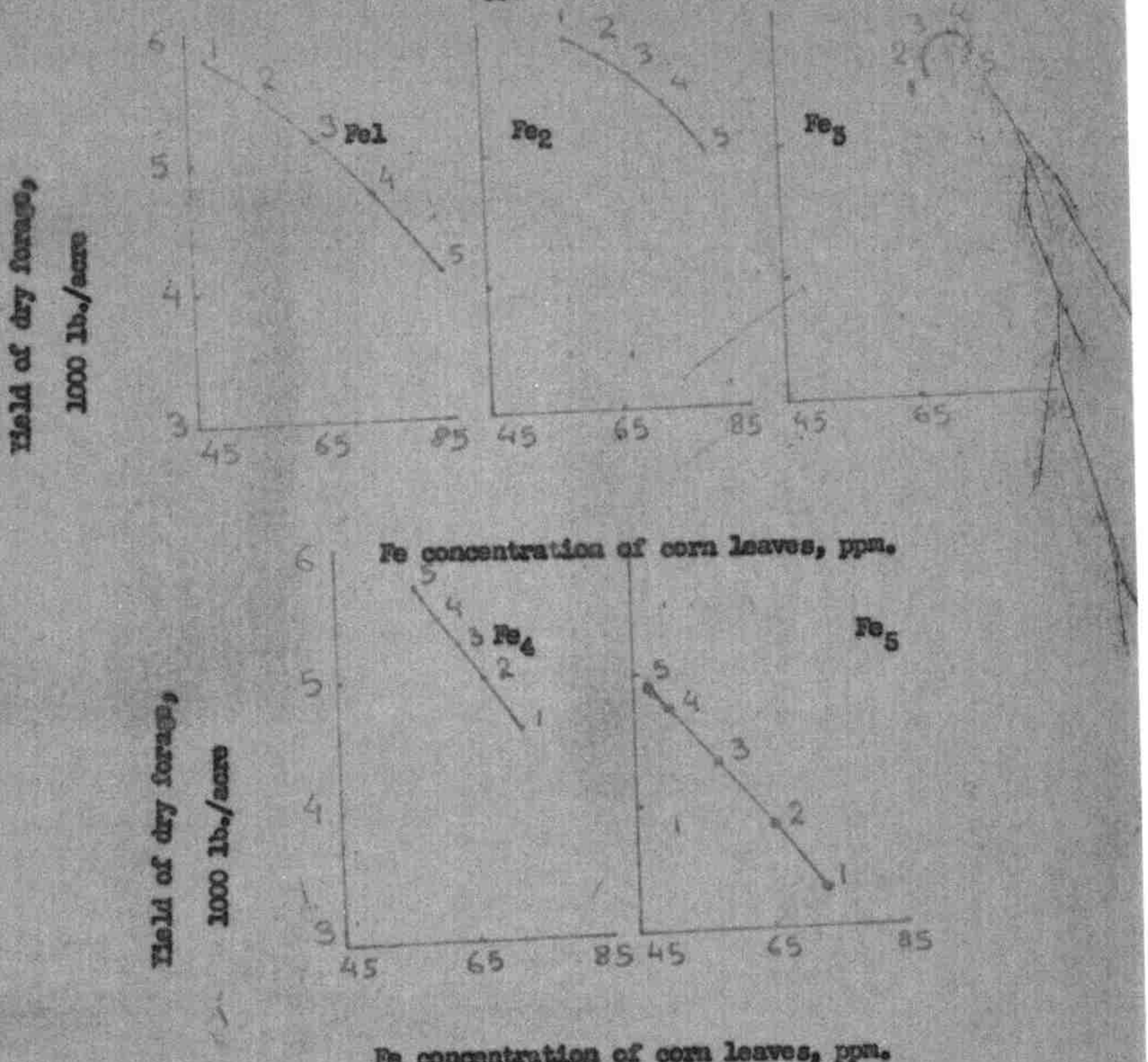

Fig. 12. Relationship between dry forage yield of corn (lb./acre) and Fe concentration (ppm. dry wt.) as affected by addition of different levels of Mn and Cu under micronutrient treatments with Zn, B and Fe at the middle of five levels (Table 1.). Numbers at points refer to levels of Cu added. Level of Fe was held constant for each graph.

and Fe concentration decreased with increasing Cu levels. Apparently the application of Cu can partially counteract the toxicity of high levels of Mn even though the Cu itself was toxic at low Mn levels. The concentration of Fe was not closely correlated with yield since the highest yields were obtained at Fe concentrations anywhere from 50-70 ppm. When Cu was held constant and Mn varied (Fig. 13) the highest yields were obtained around the 2 level of Mn at low levels of Cu and at about the 4 level of Mn at high Cu levels. The concentration of Fe was apparently related to the total supply of Cu and Mn at high levels of application because Fe concentration was decreased. At a low level of applied Cu and Mn, the Fe concentration was increased and accompanied by severe decreases in forage yield. Fuehring (16) in a nutrient solution study with micronutrients on corn found a very similar relationship for the Mn-Cu interaction effect on the Fe concentration of corn leaves and the dry forage yield of corn. This emphasizes the importance of balance among micronutrients even in a highly buffered system such as the calcareous soil used a growth medium in this experiment.

The relationship between the dry forage yield of corn and the concentration of Fe in corn leaves, as influenced by the Zn-Mn interaction (Fig. 14), indicated a decrease in requirement for Mn for maximum yields from about the Mn 4 level at the 1 level of Zn to the Mn 2 level at the 5 level of Zn. The Fe concentration tended to increase

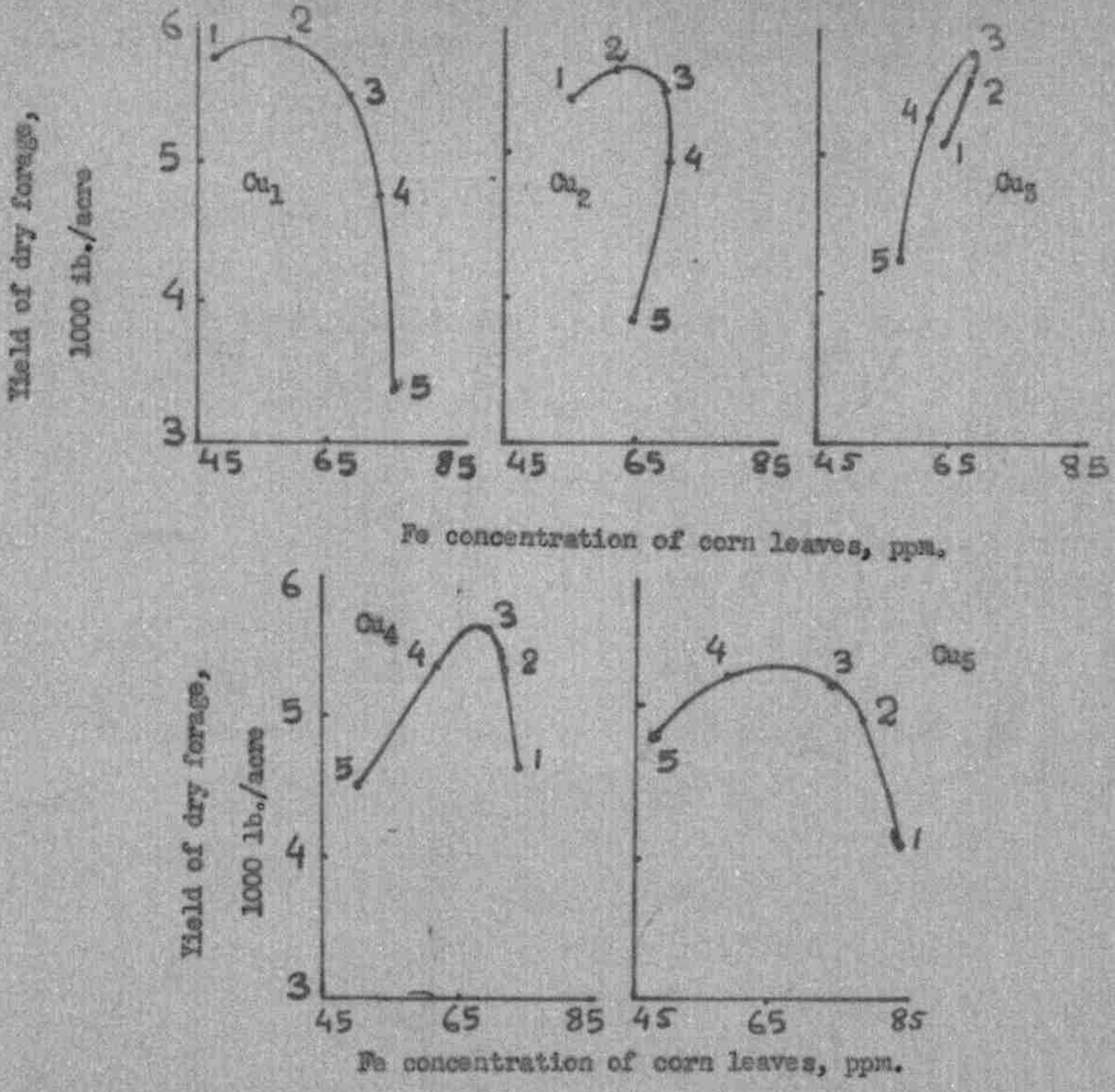

Fig. 13. Relationship between dry forage yield of corn (lb./acre) and Fe concentration (ppm. dry wt.) as affected by addition of different levels of Mn and Cu under micronutrient treatments with Zn, B, and Fe at the middle of five levels (Table 1). Numbers at points refer to levels of Mn added. Levels of Cu were held constant for each graph.

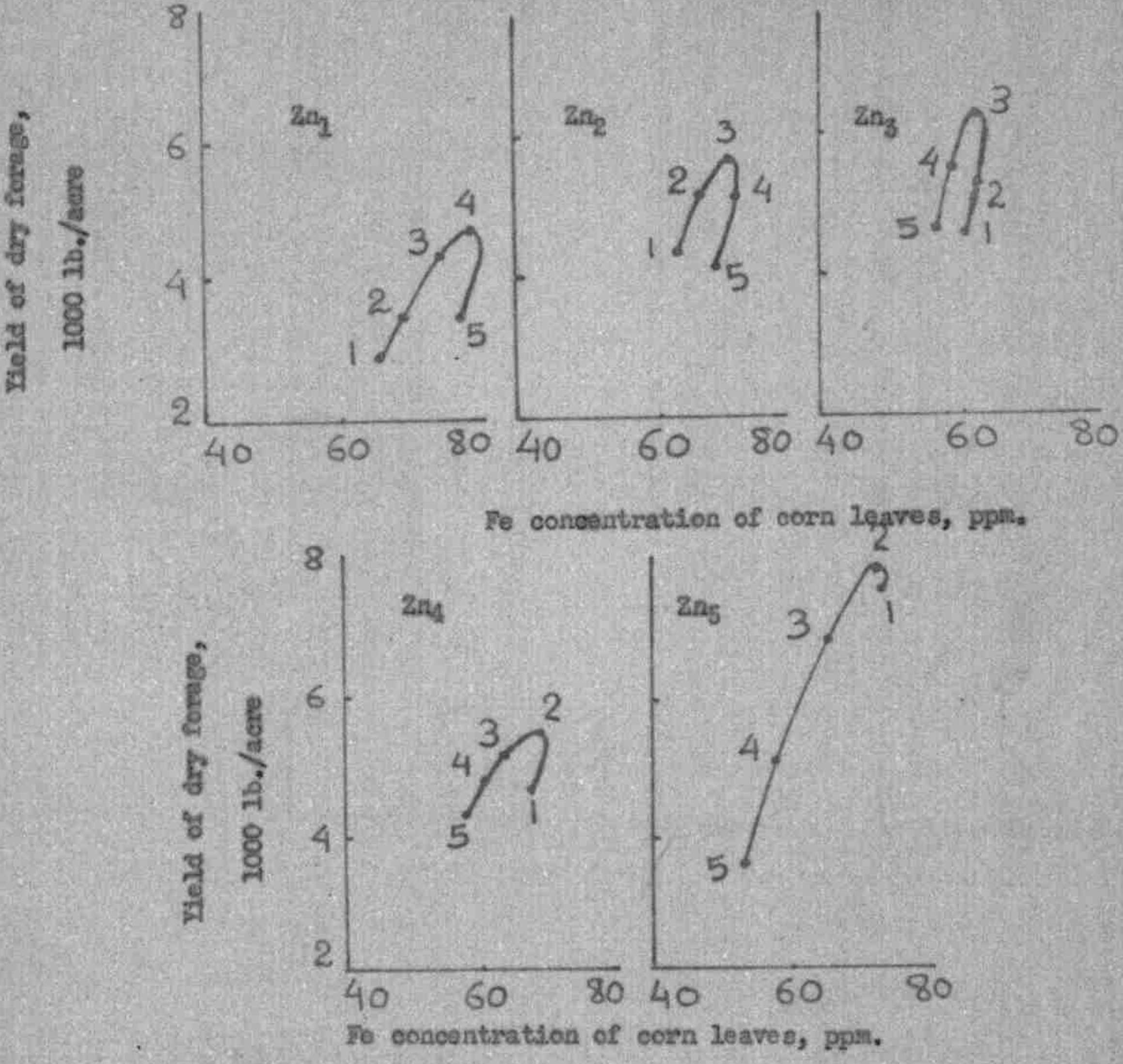

Fig. 14. Relationship between dry forage yield of corn (lb./acre) and Fe concentration (ppm. dry wt.) as affected by addition of different levels of Zn and Mn under micronutrient treatments with B, Fe, and Cu at the middle of five levels (Table 1). Numbers at points refer to levels of Mn added. Levels of Zn were held constant for each graph.

with increasing Mn at low levels of Zn while at high levels of Zn, increasing Mn decreased the Fe concentration. However, at constant levels of Mn (Fig. 15) increasing Zn tended to increase the dry forage yield except at the Mn 5 level where yield was not affected to any extent. The Fe concentrations were decreased by increasing Zn at the higher levels of Mn.

The correlation coefficient between the observed Fe concentrations and the Fe concentrations calculated from the regression equation (Table 17) was 0.815 indicating a close fit of the regression equation to the actual data.

Manganese concentration of corn leaves. The analysis of variance for the Mn concentration of corn leaves (Table 18) indicated a highly significant linear effect while the quadratic effect was significant. The lack of fit term was highly significant. However, since lack of fit represented only about 7 per cent of the total treatment variation it was probably not important.

The regression coefficients for the linear effect of Zn (negative) and Mn (positive) on Mn concentration of corn leaves were highly significant (Table 19). The quadratic effects for Zn^2 (positive) and Mn^2 (positive) were significant. The Fe^2 term (negative) was highly significant. Among the interaction effects, Zn-Cu (positive) was significant.

Examination of the relationship between the dry forage and the Mn concentration of corn leaves, as influ-

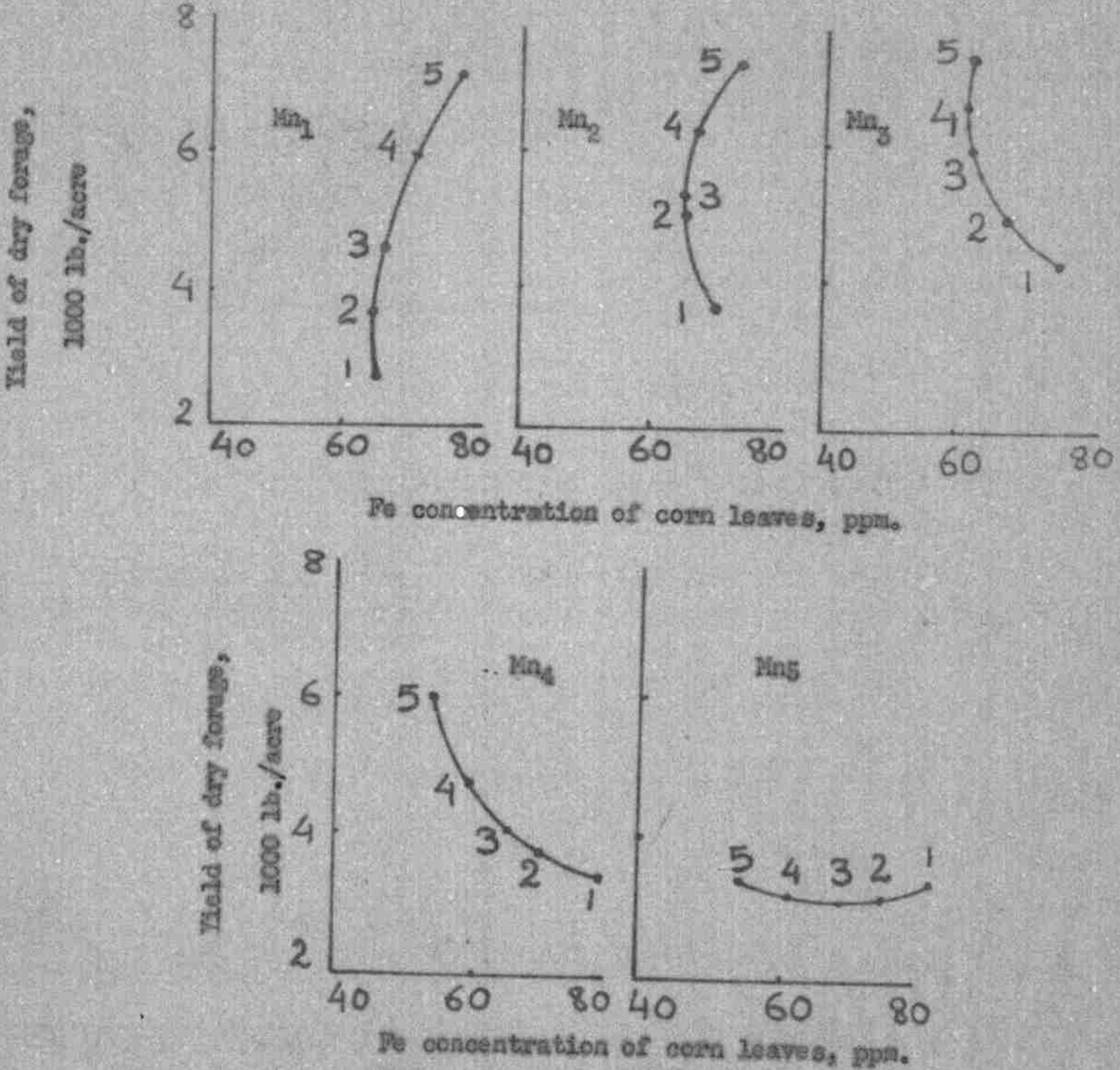

Fig. 15. Relationship between dry forage yield of corn (lb./acre) and Fe concentration (ppm. dry wt.) as affected by addition of different levels of Zn and Mn under micronutrient treatments with B, Fe, and Cu at the middle of five levels (Table1). Numbers at points refer to levelq of Zn added. Level of Mn was held constant for each graph.

Table 17. Observed Fe concentrations of corn leaves (ppm. dry wt.) with micronutrients as variables. Values for the same treatments calculated from the regression equation are given. Correlation of actual Fe concentrations with calculated concentrations was 0.815.

Treatment level	Actual Fe concentration, ppm.	Calculated Fe concentration, ppm.
$Zn_2B_2Fe_2Mn_2Cu_4$	90	83
$Zn_4B_2Fe_2Mn_2Cu_2$	72	66
$Zn_2B_4Fe_2Mn_2Cu_2$	70	67
$Zn_4B_4Fe_2Mn_2Cu_4$	95	88
$Zn_2B_2Fe_4Mn_2Cu_2$	80	82
$Zn_4B_2Fe_4Mn_2Cu_4$	83	86
$Zn_2B_4Fe_4Mn_2Cu_4$	75	75
$Zn_4B_4Fe_4Mn_2Cu_2$	71	73
$Zn_2B_2Fe_2Mn_4Cu_2$	86	82
$Zn_4B_2Fe_2Mn_4Cu_4$	78	70
$Zn_2B_4Fe_2Mn_4Cu_4$	72	67
$Zn_4B_4Fe_2Mn_4Cu_2$	72	67
$Zn_2B_2Fe_4Mn_4Cu_4$	80	80
$Zn_4B_2Fe_4Mn_4Cu_2$	70	71
$Zn_2B_4Fe_4Mn_4Cu_2$	82	86
$Zn_4B_4Fe_4Mn_4Cu_4$	64	64
$Zn_5B_3Fe_3Mn_3Cu_3$	60	67
$Zn_1B_3Fe_3Mn_3Cu_3$	75	77
$Zn_3B_5Fe_3Mn_3Cu_3$	76	78

Table 17, continued.

Treatment level	Actual Fe concentration, ppm.	Calculated Fe concentration, ppm.
$Zn_3B_1Fe_3Mn_3Cu_3$	78	85
$Zn_3B_3Fe_5Mn_3Cu_3$	95	87
$Zn_3B_3Fe_1Mn_3Cu_3$	65	82
$Zn_3B_3Fe_3Mn_5Cu_3$	55	58
$Zn_3B_3Fe_3Mn_1Cu_3$	58	64
$Zn_3B_3Fe_3Mn_3Cu_5$	60	70
$Zn_3B_3Fe_3Mn_3Cu_1$	68	67
$Zn_3B_3Fe_3Mn_3Cu_3$	69	68

Table 18. **Analysis of variance for Mn concentration of corn leaves.**

Source	d.f.	s.s.	m.s.
Total	31	16205.719	
Linear	5	13947.064	2789.413**
Quadratic	15	1055.571	70.371*
Lack of fit	6	1128.251	188.040**
Experimental error	5	74.833	14.960

*Significant at odds of 19:1

**Significant at odds of 99:1

Table 19. **Regression coefficients (b) and their standard errors (s_b) for Mn concentration of corn leaves(ppm.dry weight)**

Coefficient		**b**	**s_b**
Mean	b_0	+103.28	±1.579
Zn	b_1	-6.88**	±0.789
B	b_2	-0.04	" "
Fe	b_3	+0.54	" "
Mn	b_4	+23.04**	" "
Cu	b_5	-1.63	" "
Zn^2	b_{11}	+2.47*	±0.716
B^2	b_{22}	+1.22	" "
Fe^2	b_{33}	-3.03**	" "
Mn^2	b_{44}	+1.84*	" "
Cu^2	b_{55}	+0.59	" "
Zn X B	b_{12}	+1.44	±0.967
Zn X Fe	b_{13}	-1.19	" "
Zn X Mn	b_{14}	-1.56	" "
Zn X Cu	b_{15}	+3.44*	" "
B X Fe	b_{23}	+1.06	" "
B X Mn	b_{24}	-0.81	" "
B X Cu	b_{25}	-0.56	" "
Fe X Mn	b_{34}	+2.06	" "
Fe X Cu	b_{35}	-1.18	" "
Mn X Cu	b_{45}	-0.06	" "

***Significant at odds of 19:1**

****Significant at odds of 99:1**

enced by the Zn-Cu interaction (Fig. 16), indicated that at the lower three constant levels of Zn, increasing Cu increased the dry forage yield but decreased the Mn concentration of corn leaves. At high levels of Zn, increasing Cu decreased the dry forage yield but increased Mn concentration of corn leaves. At all rates of Cu (Fig. 17) increasing Zn levels tended to decrease the Mn concentration. The level of Zn required for the maximum dry forage yield changed from Zn4 at the first 4 levels of Cu to Zn 3 at the highest level of Cu. The yields of dry forage tended to drop off sharply above and below a Mn concentration of about 100 ppm.

The correlation coefficient between the observed Mn concentrations and Mn concentrations calculated from the regression equation (Table 20) was 0.94 indicating a very close fit of the regression equation to actual data.

Copper Concentration of corn leaves. The analysis of variance for Cu concentration of corn leaves (Table 21) indicated that the linear effect was highly significant and the quadratic effect was significant. The lack of fit term was highly significant showing an incomplete fit of the regression equation to the actual data.

The regression coefficients for the Cu concentration of corn leaves (Table 22) indicated highly significant linear effects for Zn (negative) and Cu (positive), while the Fe linear effect (positive) was significant. The quadratic Zn^2 term (positive) was highly significant. Among

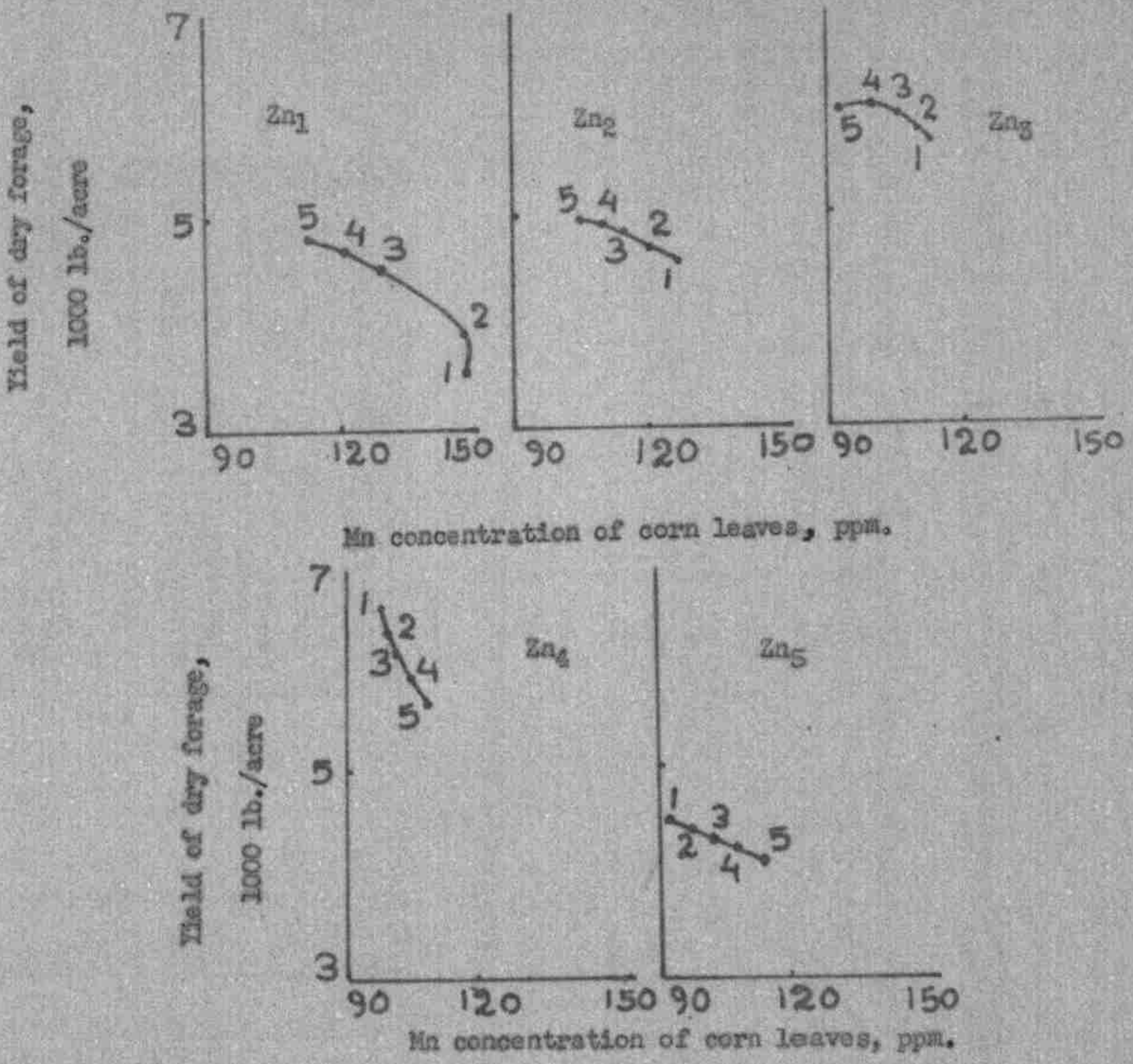

Fig. 16. Relationship between dry forage yield of corn (lb./acre) and concentration (ppm. dry wt.) as affected by addition of different levels of Zn and Cu under micornutrient treatments with B, Fe, and Mn at the middle of five levels (Table 1). Numbers at points refer to levels of Cu added. Level of Zn was held constant for each graph.

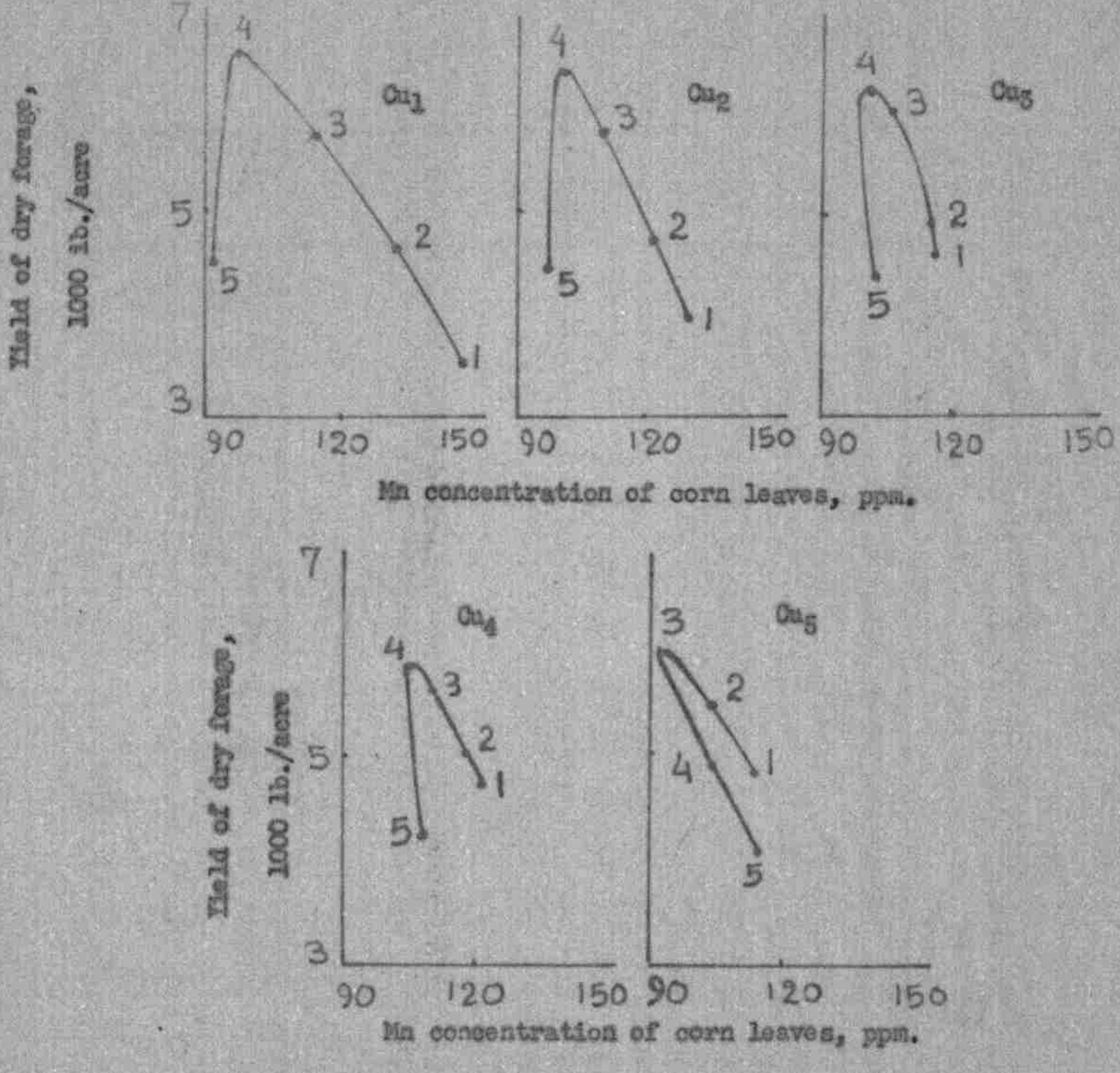

Fig. 17. Relationship between dry forage yield of corn (lb./acre) and Mn concentration (ppm. dry wt.) as affected by addition of different levels of Zn and Cu under micornutrient treatments with B, Fe, and Mn at the middle of five levels (Table 1). Numbers at points refer to levels of Zn added. Level of Cu was held constant for each graph.

Table 20. Observed Mn concentrations of corn leaves (ppm. dry wt.) with micronutrients as variables. Values for the same treatments calculated from the regression equation are given. Correlation of actual Mn concentrations with calculated concentrations was 0.936.

Treatment level	Actual Mn concentration, ppm.	Calculated Mn concentration, ppm.
$Zn_2B_2Fe_2Mn_2Cu_4$	96	87
$Zn_4B_2Fe_2Mn_2Cu_2$	80	76
$Zn_2B_4Fe_2Mn_2Cu_2$	100	92
$Zn_4B_4Fe_2Mn_2Cu_4$	86	84
$Zn_2B_2Fe_4Mn_2Cu_2$	102	94
$Zn_4B_2Fe_4Mn_2Cu_4$	75	100
$Zn_2B_4Fe_4Mn_2Cu_4$	88	82
$Zn_4B_4Fe_4Mn_2Cu_2$	80	77
$Zn_2B_2Fe_2Mn_4Cu_2$	146	141
$Zn_4B_2Fe_2Mn_4Cu_4$	122	124
$Zn_2B_4Fe_2Mn_4Cu_4$	129	126
$Zn_4B_4Fe_2Mn_4Cu_2$	115	117
$Zn_2B_2Fe_4Mn_4Cu_4$	140	137
$Zn_4B_2Fe_4Mn_4Cu_2$	118	120
$Zn_2B_4Fe_4Mn_4Cu_2$	150	174
$Zn_4B_4Fe_4Mn_4Cu_4$	120	124
$Zn_5B_3Fe_3Mn_3Cu_3$	105	100
$Zn_1B_3Fe_3Mn_3Cu_3$	110	127
$Zn_3B_5Fe_3Mn_3Cu_3$	105	108

Table 20, continued.

Treatment level	Actual Mn concentration, ppm.	Calculated Mn concentration, ppm.
$Zn_3B_1Fe_3Mn_3Cu_3$	100	108
$Zn_3B_3Fe_5Mn_3Cu_3$	89	92
$Zn_3B_3Fe_1Mn_3Cu_3$	82	90
$Zn_3B_3Fe_3Mn_5Cu_3$	160	157
$Zn_3B_3Fe_3Mn_1Cu_3$	50	65
$Zn_3B_3Fe_3Mn_3Cu_5$	99	102
$Zn_3B_3Fe_3Mn_3Cu_1$	101	109
$Zn_3B_3Fe_3Mn_3Cu_3$	105	103

Table 21. **Analysis of variance for Cu concentration of corn leaves.**

Source	**d.f.**	**s.s.**	**m.s.**
Total	31	509.500	
Linear	5	154.212	30.842**
Quadratic	15	155.919	10.395*
Lack of fit	6	191.370	31.895**
Experimental error	5	8.000	1.600

*Significant at odds of 19:1

**Significant at odds of 99:1

Table 22. Regression coefficients (b) and their standard errors(s_b) for Cu concentration of corn leaves(ppm.dry weight).

Coefficient		b	s_b
Mean	b_0	+22.875	±0.516
Zn	b_1	-1.458	±0.258
B	b_2	-0.292	" "
Fe	b_3	+0.958*	" "
Mn	b_4	+0.292	" "
Cu	b_5	+2.000**	" "
Zn^2	b_{11}	+1.250**	±0.234
B^2	b_{22}	-0.500	" "
Fe^2	b_{33}	+0.125	" "
Mn^2	b_{44}	-0.500	" "
Cu^2	b_{55}	-0.375	" "
Zn X B	b_{12}	+0.563	±0.316
Zn X Fe	b_{13}	+0.313	" "
Zn X Mn	b_{14}	-0.063	" "
Zn X Cu	b_{15}	+0.813*	" "
B X Fe	b_{23}	-0.938*	" "
B X Mn	b_{24}	-0.313	" "
B X Cu	b_{25}	+0.813*	" "
Fe X Mn	b_{34}	+1.380**	" "
Fe X Cu	b_{35}	+0.563	" "
Mn X Cu	b_{45}	+0.438	" "

*Significant at odds of 19:1

**Significant at odds of 99:1

the interaction effects, the Fe-Mn interaction (positive) was highly significant. The Zn-Cu (positive), B-Fe (negative) and B-Cu (positive) interactions were significant.

The relationship between the dry forage yield and the Cu concentration of corn leaves, as affected by the B-Fe interaction (Fig. 18), indicated that at the first 4 levels of B increasing Fe tended to decrease the dry forage yield but the Cu concentration tended to be increased. At the 5 level of B, increasing Fe above the 2 level increased the dry forage yield and decreased the concentration of corn leaves. However, when Fe was held constant (Fig. 19), increasing B at low levels of Fe increased the Cu concentration while at high levels of Fe, increasing B decreased the Cu concentration.

The dry forage yield tended to be highest at about the 3 level of B and where the Cu concentration was about 20 ppm.

At constant levels of Fe (Fig. 20), increasing Mn at low levels of Fe decreased the Cu concentration while at high levels of Fe the Cu concentration increased with increasing Mn. The highest yield tended to occur between the 2 and 3 levels of Mn at a Cu concentration of about 20 ppm. However, when Mn was kept constant (Fig. 21), increasing Fe at low levels of Mn decreased the dry forage yield as well as Cu concentration of corn leaves. At high levels of Mn, increasing Fe tended to increase the dry forage and Cu concentration of corn leaves. This clearly indicates the antagonistic effect of the Fe-Mn interaction

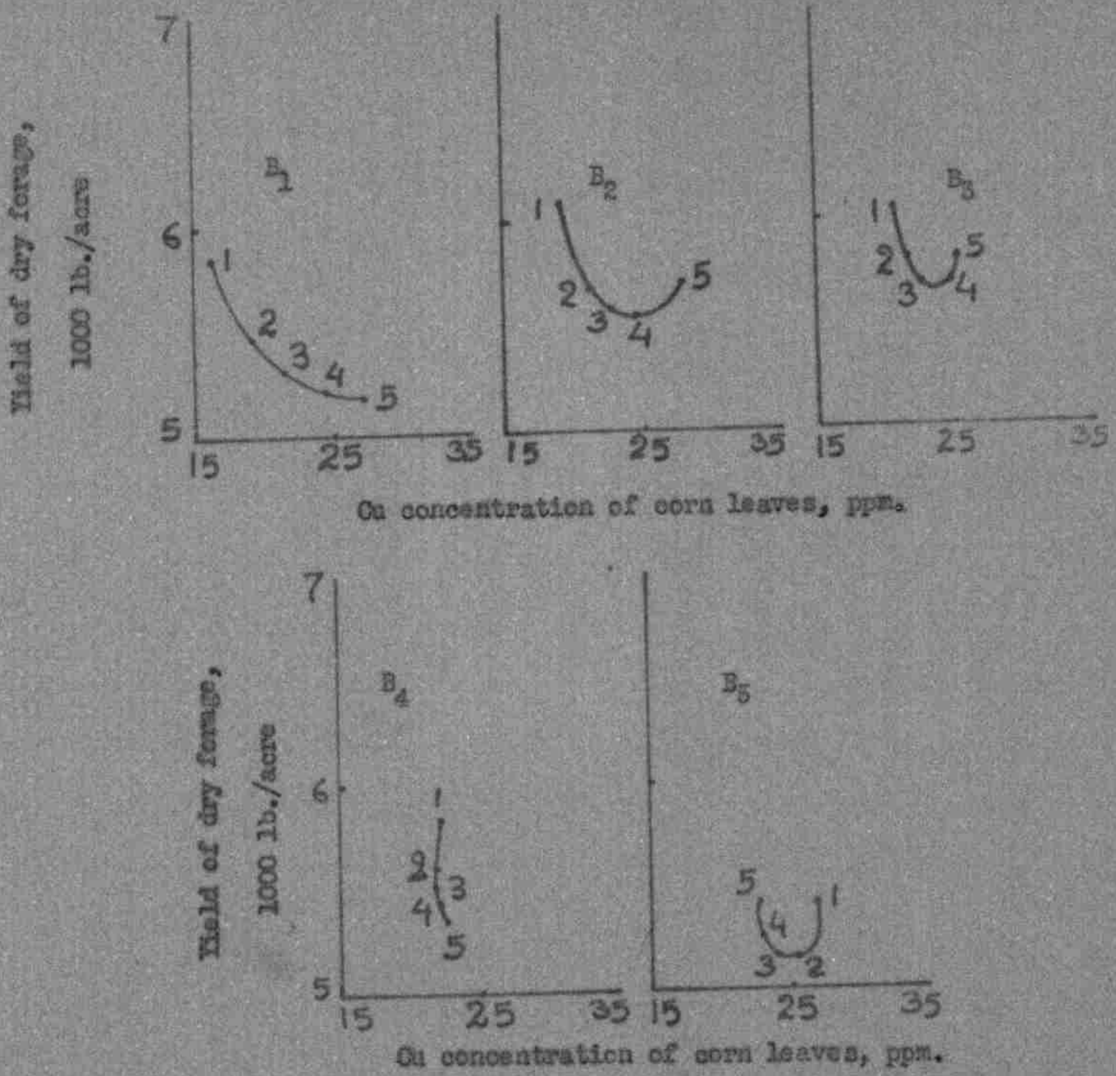

Fig. 18. Relationship between dry forage yield of corn (lb./acre) and Cu concentration (ppm.dry wt.) as affected by different levels of B and Fe under micronutrient treatments with Zn, Mn, and Cu at the middle of five levels (Table 1). Numbers at points refer to levels of Fe added. Level of B was held constant for each graph.

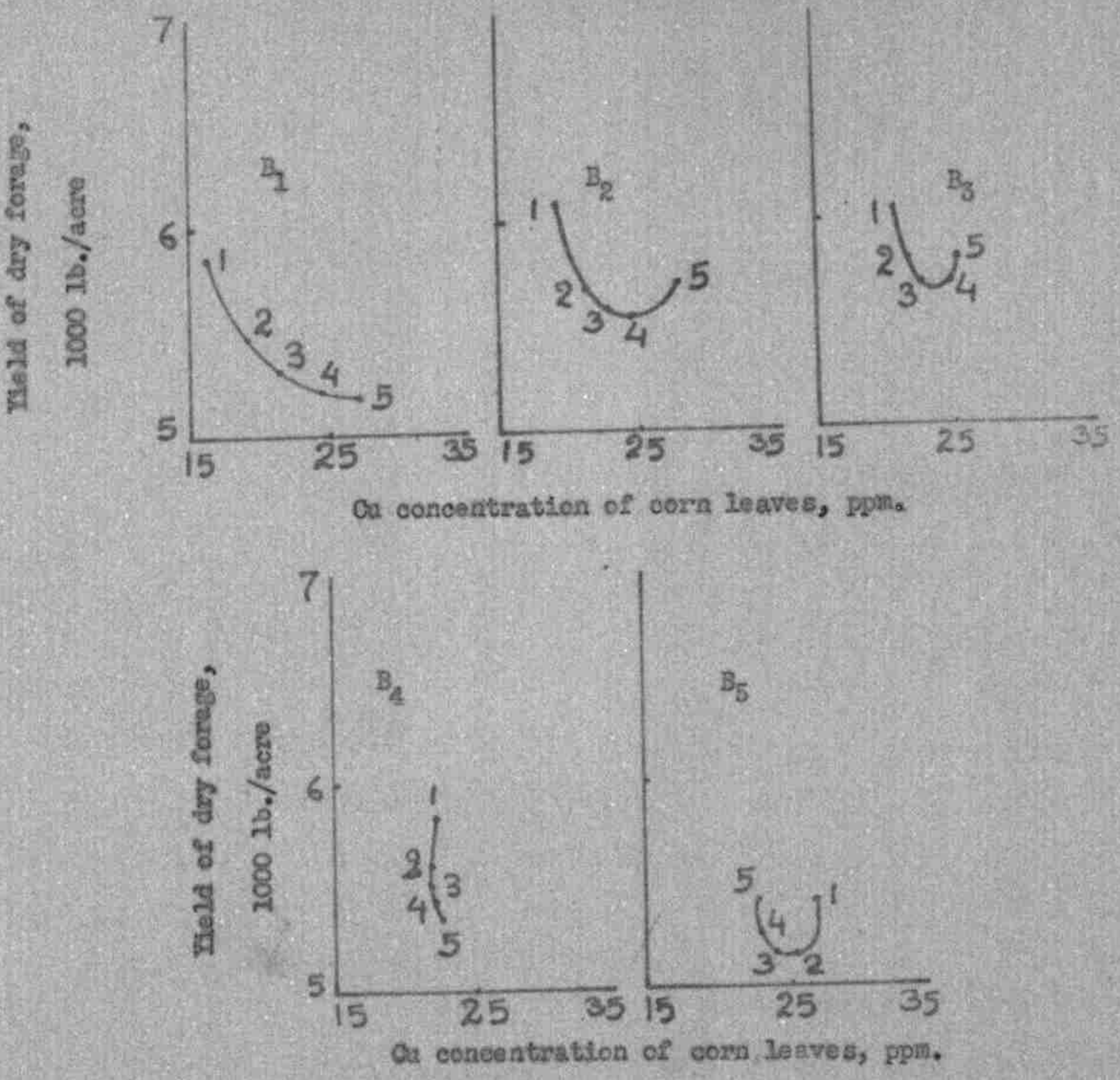

Fig. 18. Relationship between dry forage yield of corn (lb./acre) and Cu concentration (ppm.dry wt.) as affected by different levels of B and Fe under micronutrient treatments with Zn, Mn, and Cu at the middle of five levels (Table 1). Numbers at points refer to levels of Fe added. Level of B was held constant for each graph.

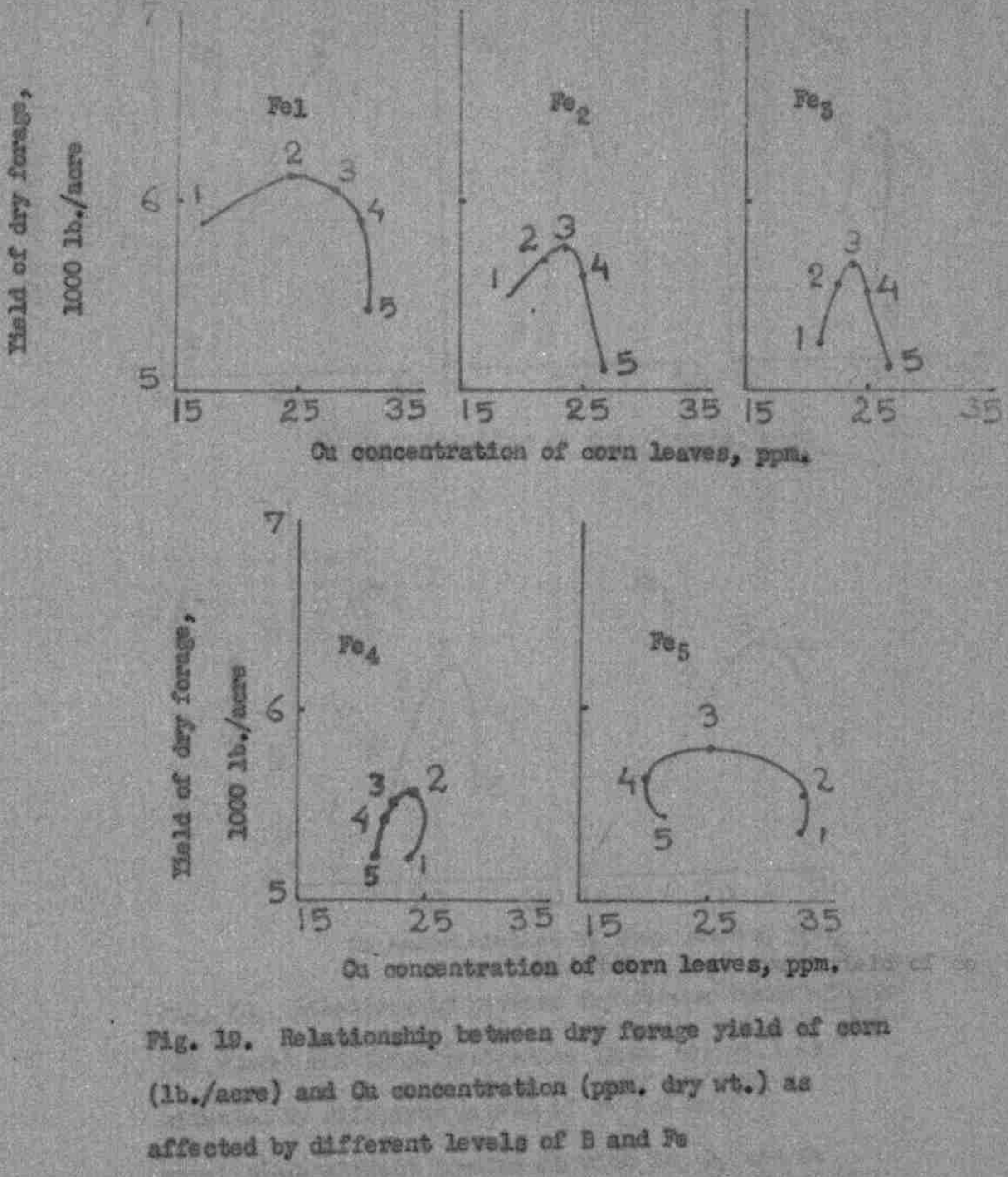

Fig. 19. Relationship between dry forage yield of corn (lb./acre) and Cu concentration (ppm. dry wt.) as affected by different levels of B and Fe under micronutrient treatments with Zn, Mn, and Cu at the middle of five levels (Table 1). Numbers at points refer to levels of B added. Level of Fe was held constant for each graph.

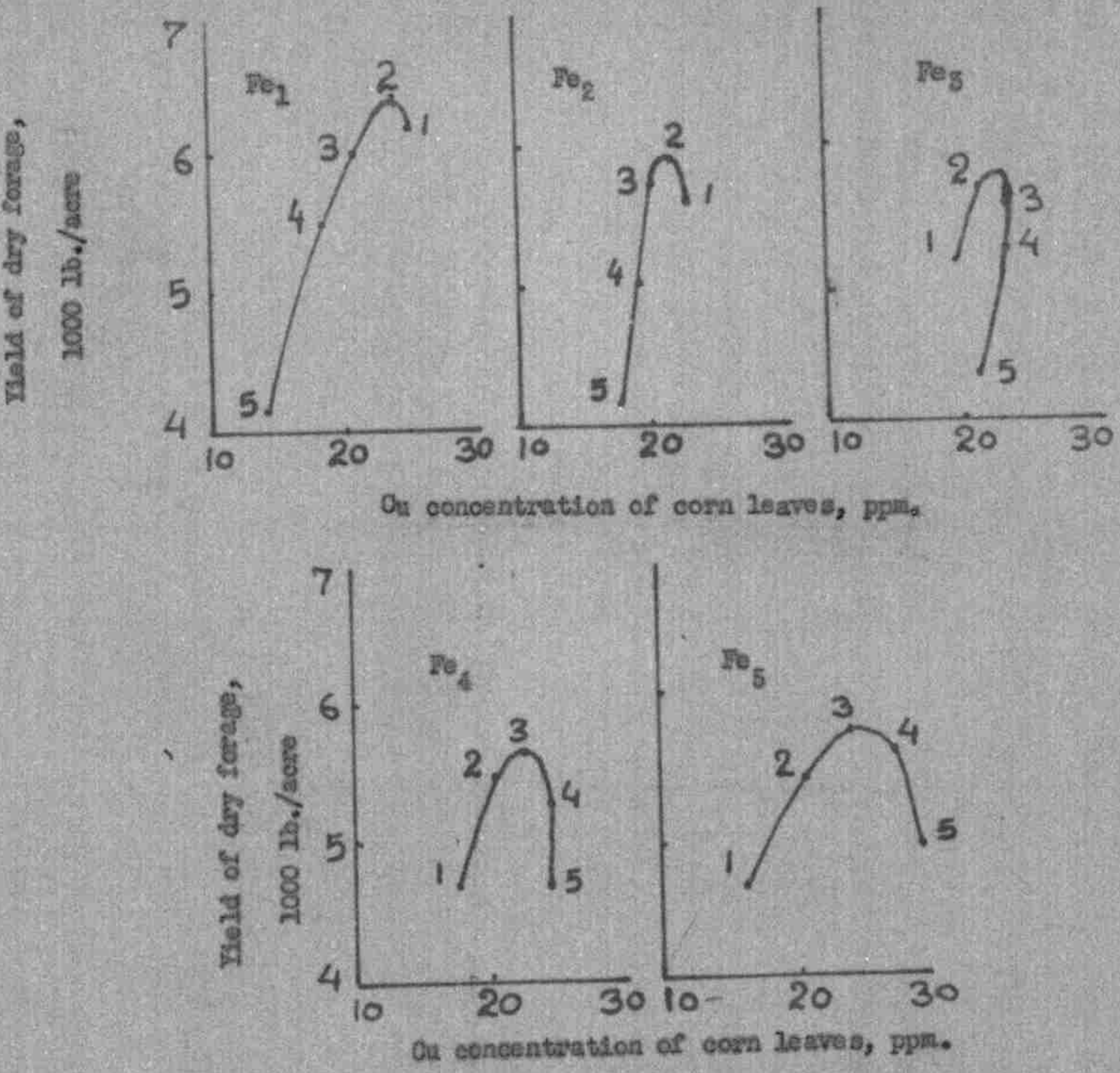

Fig. 20. Relationship between dry forage yield of corn (lb./acre) and Cu concentration (ppm. dry wt.) as affected by different levels of Fe and Mn under micronutrient treatments with Zn, B, and Cu at the middle of five levels (Table 1). Numbers at points refer to levels of Mn added. Level of Fe was held constant for each graph.

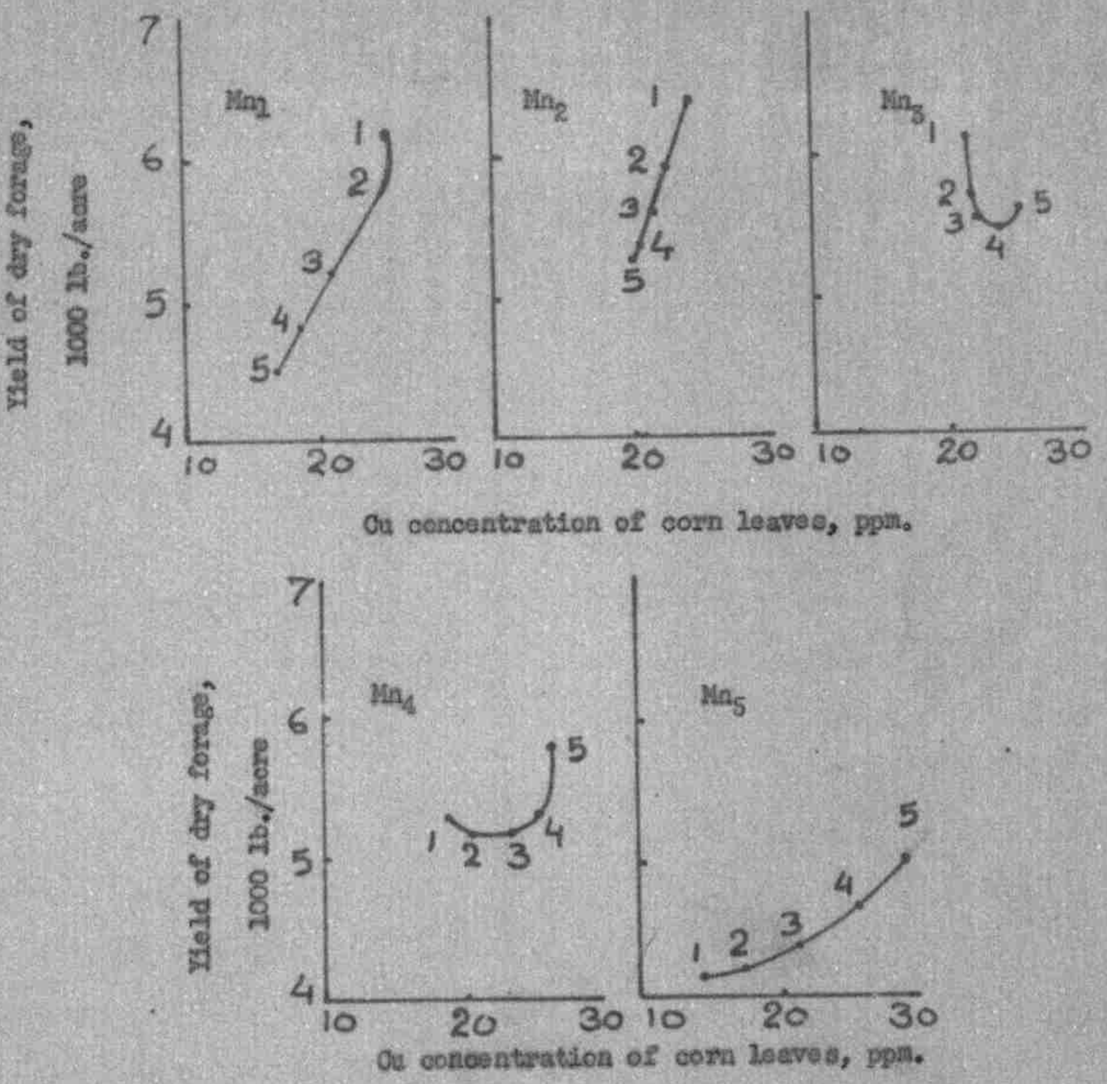

Fig. 21. Relationship between dry forage yield of corn (lb./acre) and Cu concentration (ppm. dry wt.) as affected by addition of different levels of Fe and Mn under micronutrient treatments with Zn, B, and Cu at the middle of five levels (Table 1). Numbers at points refer to levels of Fe added. Level of Mn was held constant for each graph.

on the Cu concentration of corn leaves.

The correlation coefficient between the observed Cu concentrations and the Cu concentrations calculated from the regression equation (Table 23) was 0.77 (highly significant) indicating a close fit of the regression equation to the actual data.

Macronutrients

Grain yield of corn. The observed grain yields of corn, obtained from the treatments where N, P, K, Mg and S nutrients were varied at five different levels, when compared with the yields calculated from the regression equation (Table 24) gave a correlation coefficient of 0.87 (highly significant) indicating a close fit of the regression equation to the actual data.

The analysis of variance for the grain yield of corn (Table 25) indicated that none of the linear and quadratic terms were statistically significant while the lack of fit term was significant showing that the quadratic equation may have been only partially effective.

Examination of the individual regression coefficients for grain yield of corn (Table 2) showed that none of the linear treatment variations were statistically significant. Among the second order terms, however, the N^2 (positive) and Mg-S interaction terms were significant. The positive sign of the coefficient indicated that the Mg-S interaction effect on grain yield of corn was antagonistic.

Study of the relationship between grain yield and

Table 23. Observed Cu concentrations of corn leaves (ppm. dry wt.) with micronutrients as variables. Values for the same treatments calculated from the regression equation are given. Correlation of actual Cu concentrations with calculated concen concentrations was 0.770.

Treatment level	Actual Cu concentration, ppm.	Calculated Cu concentration, ppm.
$Zn_2B_2Fe_2Mn_2Cu_4$	23	24
$Zn_4B_2Fe_2Mn_2Cu_2$	19	19
$Zn_2B_4Fe_2Mn_2Cu_2$	22	25
$Zn_4B_4Fe_2Mn_2Cu_4$	26	25
$Zn_2B_2Fe_4Mn_2Cu_2$	n21	25
$Zn_4B_2Fe_4Mn_2Cu_4$	23	23
$Zn_2B_4Fe_4Mn_2Cu_4$	21	24
$Zn_4B_4Fe_4Mn_2Cu_2$	15	17
$Zn_2B_2Fe_2Mn_4Cu_2$	21	23
$Zn_4B_2Fe_2Mn_4Cu_4$	21	20
$Zn_2B_4Fe_2Mn_4Cu_4$	23	24
$Zn_4B_4Fe_2Mn_4Cu_2$	16	17
$Zn_2B_2Fe_4Mn_4Cu_4$	28	30
$Zn_4B_2Fe_4Mn_4Cu_2$	21	23
$Zn_2B_4Fe_4Mn_4Cu_2$	18	22
$Zn_4B_4Fe_4Mn_4Cu_4$	27	28
Zn5B3Fe3Mn3Cu3	24	25
$Zn_1B_3Fe_3Mn_3Cu_3$	37	31
$Zn_3B_5Fe_3Mn_3Cu_3$	24	20

Table 23, continued.

Treatment level	Actual Cu concentration, ppm.	Calculated Cu concentration, ppm.
$Zn_3B_1Fe_3Mn_3Cu_3$	23	22
$Zn_3B_3Fe_5Mn_3Cu_3$	31	25
$Zn_3B_3Fe_1Mn_3Cu_3$	21	22
$Zn_3B_3Fe_3Mn_5Cu_3$	24	22
$Zn_3B_3Fe_3Mn_1Cu_3$	23	20
$Zn_3B_3Fe_3Mn_3Cu_5$	25	25
$Zn_3B_3Fe_3Mn_3Cu_1$	23	18
$Zn_3B_3Fe_3Mn_3Cu_3$	22	23

Table 24. Observed yields of corn grain (bu./acre at 15.5 % moisture) with macronutrients as variables. Values for the same treatments calculated from the regression equation are given. Correlation of actual yields with calculated yields was 0.870.

Treatment level	Coded values of X					Actual yield, Bu/a	Calculated yield, Bu/a
	N	P	K	Mg	S		
$N_2P_2K_2Mg_2S_4$	-1	-1	-1	-1	+1	117.0	121.0
$N_4P_2K_2Mg_2S_2$	+1	-1	-1	-1	-1	105.8	107.0
$N_2P_4K_2Mg_2S_2$	-1	+1	-1	-1	-1	113.2	117.0
$N_4P_4K_2Mg_2S_4$	+1	+1	-1	-1	+1	43.9	56.9
$N_2P_2K_4Mg_2S_2$	-1	-1	+1	-1	-1	84.6	86.0
$N_4P_2K_4Mg_2S_4$	+1	-1	+1	-1	+1	83.5	91.2
$N_2P_4K_4Mg_2S_4$	-1	+1	+1	-1	+1	85.7	95.0
$N_4P_4K_4Mg_2S_2$	+1	+1	+1	-1	-1	116.2	128.9
$N_2P_2K_2Mg_4S_2$	-1	-1	-1	+1	-1	82.9	71.1
$N_4P_2K_2Mg_4S_4$	+1	-1	-1	+1	+1	130.6	127.2
$N_2P_4K_2Mg_4S_4$	-1	+1	-1	+1	+1	115.1	114.2
$N_4P_4K_2Mg_4S_2$	+1	+1	-1	+1	-1	81.7	80.6
$N_2P_2K_4Mg_4S_4$	-1	-1	+1	+1	+1	107.5	101.3
$N_4P_2K_4Mg_4S_2$	+1	-1	+1	+1	-1	107.3	100.9
$N_2P_4K_4Mg_4S_2$	-1	+1	+1	+1	-1	92.4	88.5
$N_4P_4K_4Mg_4S_4$	+1	+1	+1	+1	+1	106.5	111.0
$N_5P_3K_3Mg_3S_3$	+2	0	0	0	0	154.4	143.6
$N_1P_3K_3Mg_3S_3$	-2	0	0	0	0	135.6	141.2
$N_3P_5K_3Mg_3S_3$	0	+2	0	0	0	91.2	75.3

Table 24, continued.

Treatment level	Coded values of X					Actual yield, Bu/a	Calculated, yield, Bu/a
	N :	P :	K :	Mg :	S;		
$N_3P_1K_3Mg_3S_3$	0	-2	0	0	0	67.6	76.2
$N_3P_3K_5Mg_3S_3$	0	0	+2	0	0	105.4	100.1
$N_3P_3K_1Mg_3S_3$	0	9	-2	0	0	99.1	99.1
$N_3P_3K_3Mg_5S_3$	0	0	0	+2	0	74.2	91.2
$N_3P_3K_3Mg_1S_3$	0	0	0	-2	0	114.5	92.3
$N_3P_3K_3Mg_3S_5$	0	0	0	0	+2	102.2	90.9
$N_3P_3K_3Mg_3S_1$	0	0	0	0	-2	74.7	80.0
$N_3P_3K_3Mg_3S_3$	0	0	0	0	0	97.1	97.9

Table 25. **Analysis of variance for grain yield of corn obtained from macro-nutrient treatments.**

Source	d.f.	s.s.	m.s.
Total	31	14925.8	
Linear	5	178.31	35.66
Quadratic	15	1172.04	78.14
Lack of fit	6	12207.56	2034.59*
Experimental error	5	1367.18	273.44

*Significant at odds of 19:1

table 26. **Regression coefficients (b) and their standard errors (s_b) for grain yield of corn (Bu/acre) under macro nutrient treatments.**

Coefficient		b	s_b
Mean	b_0	+97.95	±6.75
N	b_1	+ 0.61	±3.37
P	b_2	- 0.72	" "
K	b_3	+ 0.25	" "
Mg	b_4	- 0.27	" "
S	b_5	+ 2.53	" "
N^2	b_{11}	+11.12*	±3.06
P^2	b_{22}	- 5.28	" "
K^2	b_{33}	+ 0.43	" "
Mg^2	b_{44}	- 1.55	" "
S^2	b_{55}	- 3.02	" "
N X P	b_{12}	- 5.83	±4.13
N X K	b_{13}	+ 6.84	" "
N X Mg	b_{14}	+ 4.96	" "
N X S	b_{15}	- 6.17	" "
P X K	b_{23}	+ 6.27	" "
P X Mg	b_{24}	- 0.04	" "
P X S	b_{25}	- 6.90	" "
K X Mg	b_{34}	+ 0.83	" "
K X S	b_{35}	- 2.52	" "
Mg X S	b_{45}	+11.57*	" "

***Significant at odds of 19:1**

the Mg-S interaction (Fig. 22) indicated that at low levels of magnesium chloride increasing calcium sulfate levels resulted in decreased grain yield of corn. At high levels of magnesium chloride applications, increasing calcium sulfate gave a high increase in the yield. On the other hand, increasing magnesium chloride at low levels of calcium sulfate (Fig. 23) resulted in severly decreased grain yields while at high levels of calcium sulfate increased grain yields resulted. At low levels of magnesium chloride decreases in yield from calcium sulfate may have been due to the effect of Ca in restricting Mg uptake. This is also indicated by the fact that the Mg concentration of corn leaves was affected by calcium sulfate applications (Table 24). The S^2 term was negative and highly significant indicating a reduction in the Mg concentration at the higher rates of S and Ca application. Also the adverse effect of sulfate on a possible benefit from Cl cannot be ruled out as a possible expanation. At high levels of magnesium chloride the increase in yield from calcium sulfate may have been due to the counteraction of the toxicity of Mg or Cl or both.

It was concluded that for the highest economic yield of grain, the application of N up to about the 4.5 level would be advisable since both the linear and quadratic terms for the N effect on the grain yield were high and positive. Since the N 4.5 level was about 300 lb./acre it is doubtful whether higher rates would be economically

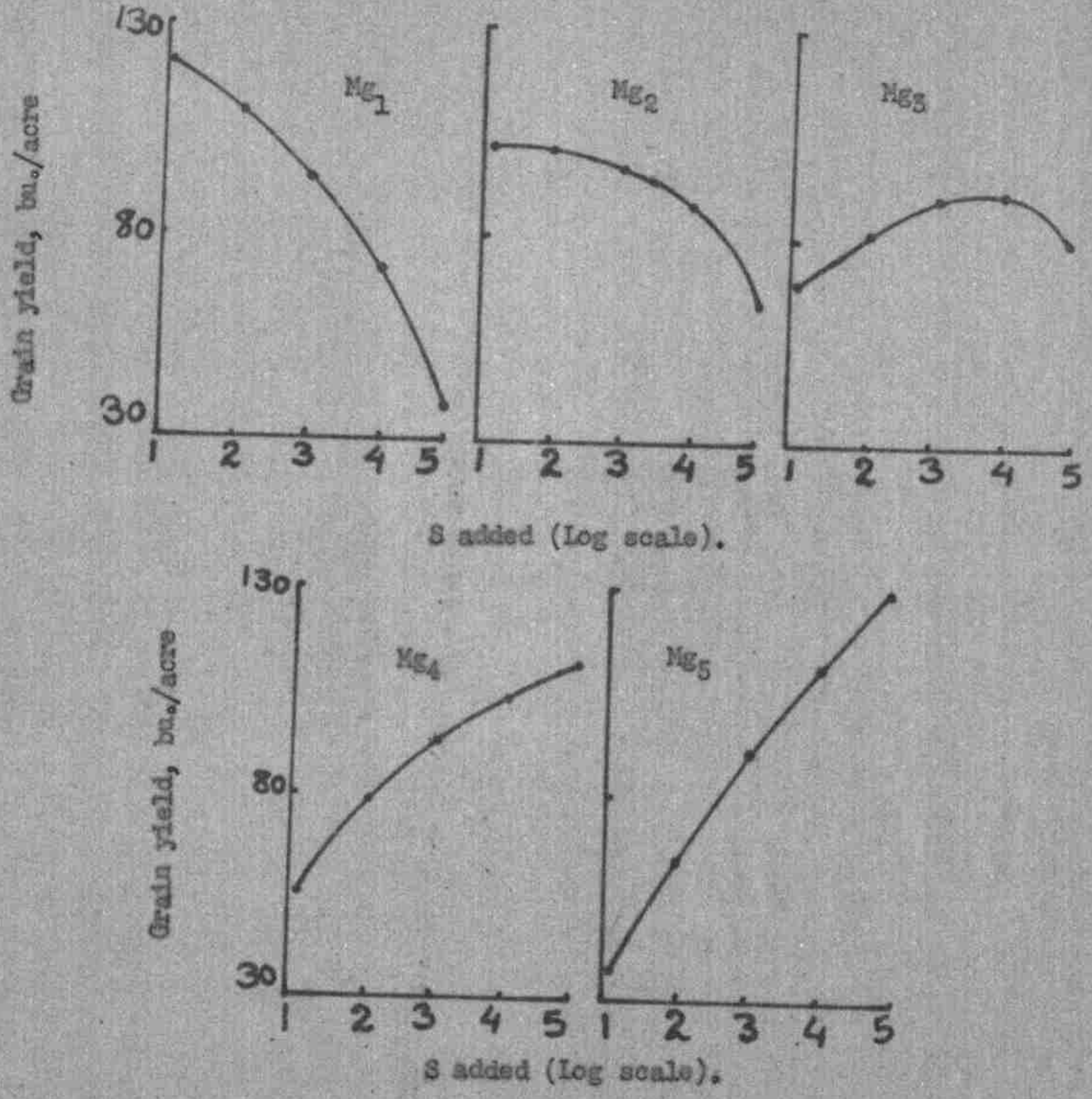

Fig. 22. Grain yield of corn (bu./acre) as influenced by addition of different levels of Mg and S under macronutrient treatments with N, P and K held constant at the middle of five levels (Table 2). Level of Mg was held constant for each graph.

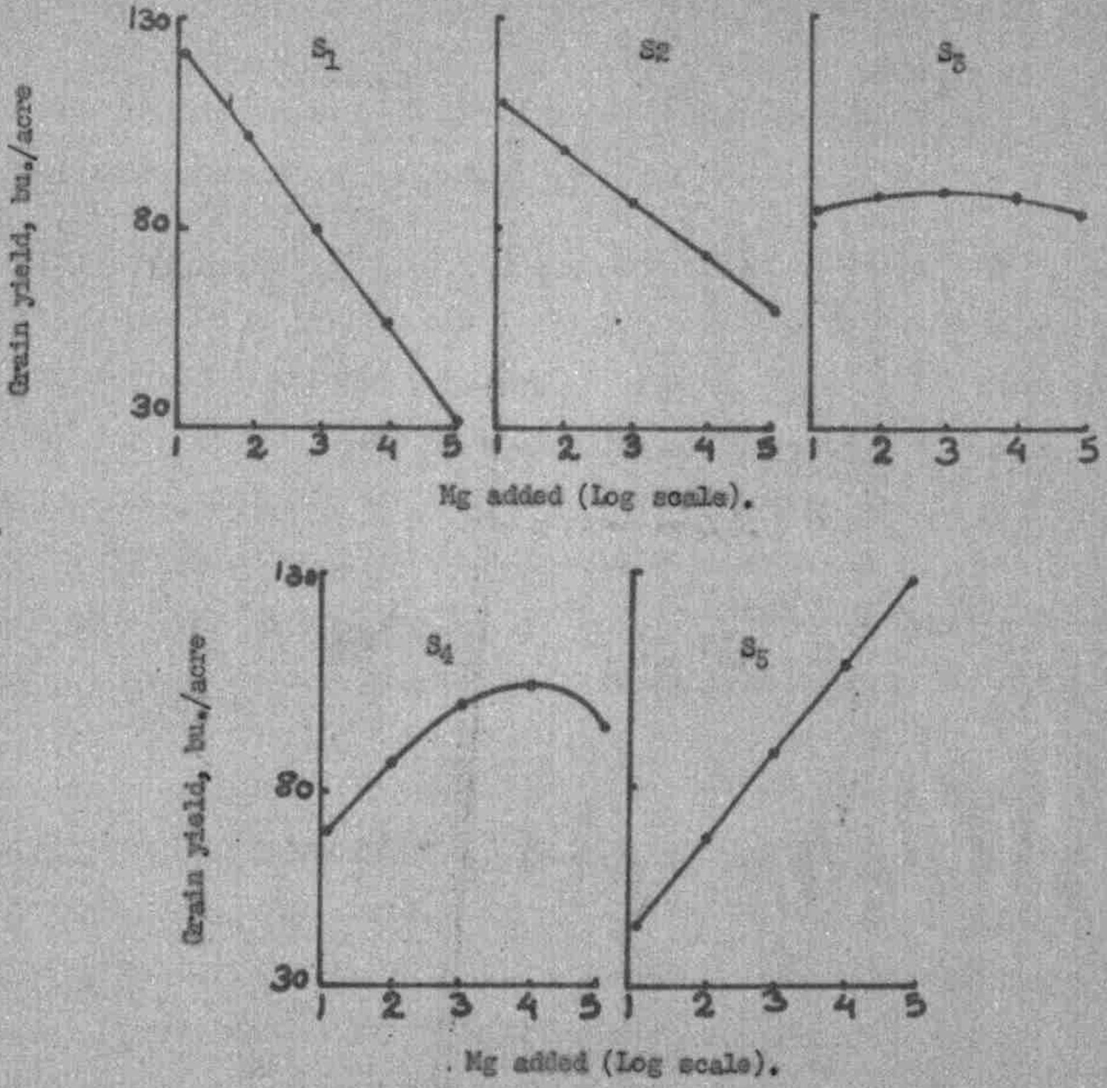

Fig. 23. Grain yield of corn (bu./acre) as influenced by addition of different levels of Mg and S under macronutrient treatments with N, P and K held constant at the middle of five levels (Table 2). Level of S was held constant for each graph.

justified. Calculation of theoritical yields from the regrssion equation indicated that the application of K resulted in decreasing yields. The effect of P, Mg and S were mostly negative so applications of these elements would be unnecessary on this soil for grain production.

Dry forage yield of corn. The analysis of variance (Table 27) showed that the linear treatment effects were not significant while both the quadratic and the lack of fit treatment variation effects were highly significant. The significance of the lack of fit term indicated that possibly a cubic or higher order equation would be required to clearly define the effect of macronutrients.

Examination of the individual regression coefficients (Table 28) indicated no significant direct effect of treatments. Among the quadratic effects, N^2 (positive) was highly significant while Mg^2 (negative) was significant. The N-K, N-Mg, P-S and K-S interactions were highly significant while the N-S, P-K, P-Mg and Mg-S interactions were significant indicating that the interaction effects of macronutrients on dry forage production of corn may be of more importance than the direct effects.

The correlation coefficient between the actual yields of dry forage and the yields calculated from the regression equation (Table 29) was 0.789 indicating a fairly close fit of the regression equation to the actual data.

Examination of the relationship between the dry forage yield and the P-S interaction (Fig. 24) indicated

Table 27 . **Analysis of variance for dry forage yield of corn obtained from macro-nutrient treatments.**

Source	d.f.	s.s.	m.s.
Total	31	51051860.9	
Linear	5	663899.1	132779.8
Quadratic	15	31073713.6	2071580.9**
Lack of fit	6	18769218.3	3128203.1**
Experimental error	5	545030.0	109006.0

**Significant at odds of 99:1

Table 28. **Regression coefficients (b) and their standard errors (s_b) for dry forage yield of corn (lbs/acre) under macro nutrient treatments.**

Coefficient		b	s_b
Mean	b_0	+3941.40	±134.76
N	b_1	+ 85.46	± 67.35
P	b_2	+ 16.96	" "
K	b_3	+136.88	" "
Mg	b_4	+ 31.79	" "
S	b_5	- 18.04	" "
N^2	b_{11}	+592.59**	±61.08
P^2	b_{22}	- 79.41	" "
K^2	b_{33}	- 80.16	" "
Mg^2	b_{44}	-195.16*	" "
S^2	b_{55}	+ 0.34	" "
N X P	b_{12}	+153.56	±82.54
N X K	b_{13}	+398.44**	" "
N X Mg	b_{14}	-432.94**	" "
N X S	b_{15}	+228.31*	" "
P X K	b_{23}	+300.69*	" "
P X Mg	b_{24}	-243.19*	" "
P X S	b_{25}	+464.06**	" "
K X Mg	b_{34}	- 32.81	" "
K X S	b_{35}	+547.94**	" "
Mg X S	b_{45}	-237.44*	" "

*Significant at odds of 19:1

**Significant at odds of 99:1

Table 29. Observed dry forage yields of corn (lb./acre) with macronutrients as variables. Values for the same treatments calculated from the regression equation are given. Correlation of actual yields with calculated yields was 0.789.

Treatment level	Coded values of X					Actual yield, lbs/a	Calculated yield, lbs/a
	N :	P :	K :	Mg :	S :		
$N_2P_2K_2Mg_2S_4$	-1	-1	-1	-1	+1	2484	3030
$N_4P_2K_2Mg_2S_2$	+1	-1	-1	-1	-1	3864	4548
$N_2P_4K_2Mg_2S_2$	-1	+1	-1	-1	-1	4002	3756
$N_4P_4K_2Mg_2S_4$	+1	+1	-1	-1	+1	3588	4573
$N_2P_2K_4Mg_2S_2$	-1	-1	+1	-1	-1	2825	2917
$N_4P_2K_4Mg_2S_4$	+1	-1	+1	-1	+1	3726	5050
$N_2P_4K_4Mg_2S_4$	-1	+1	+1	-1	+1	4416	4810
$N_4P_4K_4Mg_2S_2$	+1	+1	+1	-1	-1	3956	4489
$N_2P_2K_2Mg_4S_2$	-1	-1	-1	+1	-1	7820	7059
$N_4P_2K_2Mg_4S_4$	+1	-1	-1	+1	+1	2254	2694
$N_2P_4K_2Mg_4S_4$	-1	+1	-1	+1	+1	4094	3605
$N_4P_4K_2Mg_4S_2$	+1	+1	-1	+1	-1	3450	3098
$N_2P_2K_4Mg_4S_4$	-1	-1	+1	+1	+1	4094	3943
$N_4P_2K_4Mg_4S_2$	+1	-1	+1	+1	-1	4094	4080
$N_2P_4K_4Mg_4S_2$	-1	+1	+1	+1	-1	4600	3658
$N_4P_4K_4Mg_4S_4$	+1	+1	+1	+1	+1	5290	5578
$N_5P_3K_3Mg_3S_3$	+2	0	0	0	0	8142	6482
$N_1P_3K_3Mg_3S_3$	-2	0	0	0	0	5060	6140
$N_3P_5K_3Mg_3S_3$	0	+2	0	0	0	3456	3656

Table 29, continued.

Treatment level	Coded values of X					Actual yield, lbs/a	Calculated yield, lbs/a
	N :	P :	K :	Mg :	S:		
$N_3P_1K_3Mg_3S_3$	0	-2	0	0	0	4370	3588
$N_3P_3K_5Mg_3S_3$	0	0	+2	0	0	4370	3894
$N_3P_3K_1Mg_3S_3$	0	0	-2	0	0	3456	3347
$N_3P_3K_3Mg_5S_3$	0	0	0	+2	0	1932	3222
$N_3P_3K_3Mg_1S_3$	0	0	0	+2	0	4968	3096
$N_3P_3K_3Mg_3S_5$	0	0	0	0	+2	5290	3907
$N_3P_3K_3Mg_3S_1$	0	0	0	0	-2	3174	3978
$N_3P_3K_3Mg_3S_3$	0	0	0	0	0	3845	3941

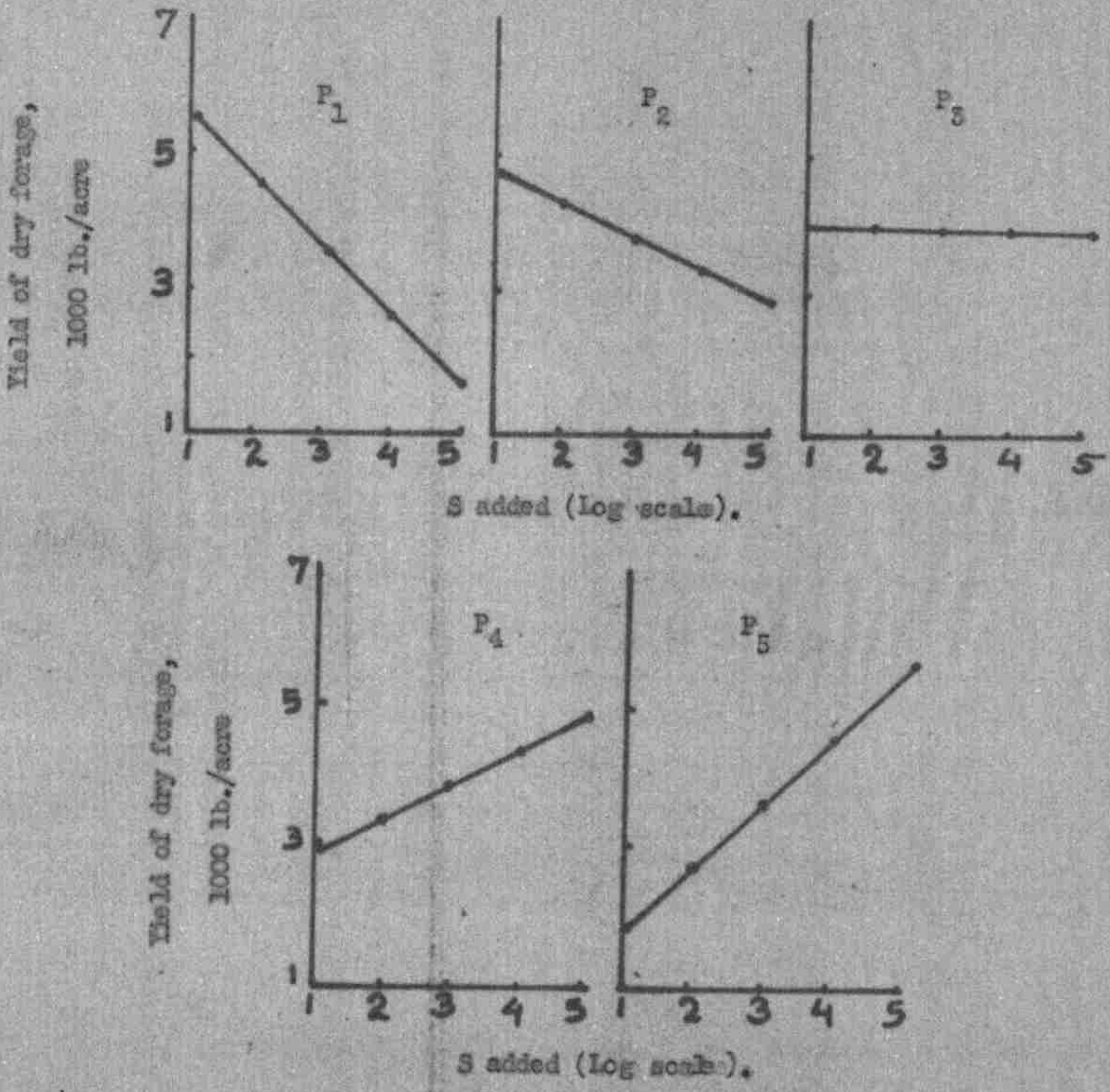

Fig. 24. Dry forage yield of corn (lb./acre) as influnced by addition of different levels of P and S under macronutrient treatments with N, K and Mg held constant at the middle of f ive levels (Table 2). Level of P was held constant for each graph.

that at low levels of P, increasing S decreased dry forage yield. However, at high levels of P, the reverse effect was observed. A similar effect of decrease in the dry forage yield at low levels of S and increase in dry forage at high levels of S was noted when P was increased (Fig. 25). This indicates that forage yield response of corn to applications of P or S depends greatly on the level of the other. Apparently the balance between P and S is important but it is not a simple relationship since increasing both P and S simultaneously resulted first in decreased yields and finally increased the yields at high rates.

Study of the relationship between the dry forage yields and the K-S interaction (Fig. 26) showed that increasing S, at low levels of K, decreased the dry forage yield while at high levels of K, the yield of dry forage was increased. Similarly, when S was held constant (Fig. 27), increasing K decreased the dry forage yield at low levels of S while at high levels of S, increasing K increased the dry forage yield of corn.

The fact that K was applied as potassium chloride probably influenced the response to K by reason of the chloride ions affecting the uptake and utilization of the sulfate ions.

As with the K-S and P-S interactions, the N-K, N-S and P-K interaction terms had positive regression coefficient values indicating an antagonistic effect. An increase in the amount of one nutrient increased the require-

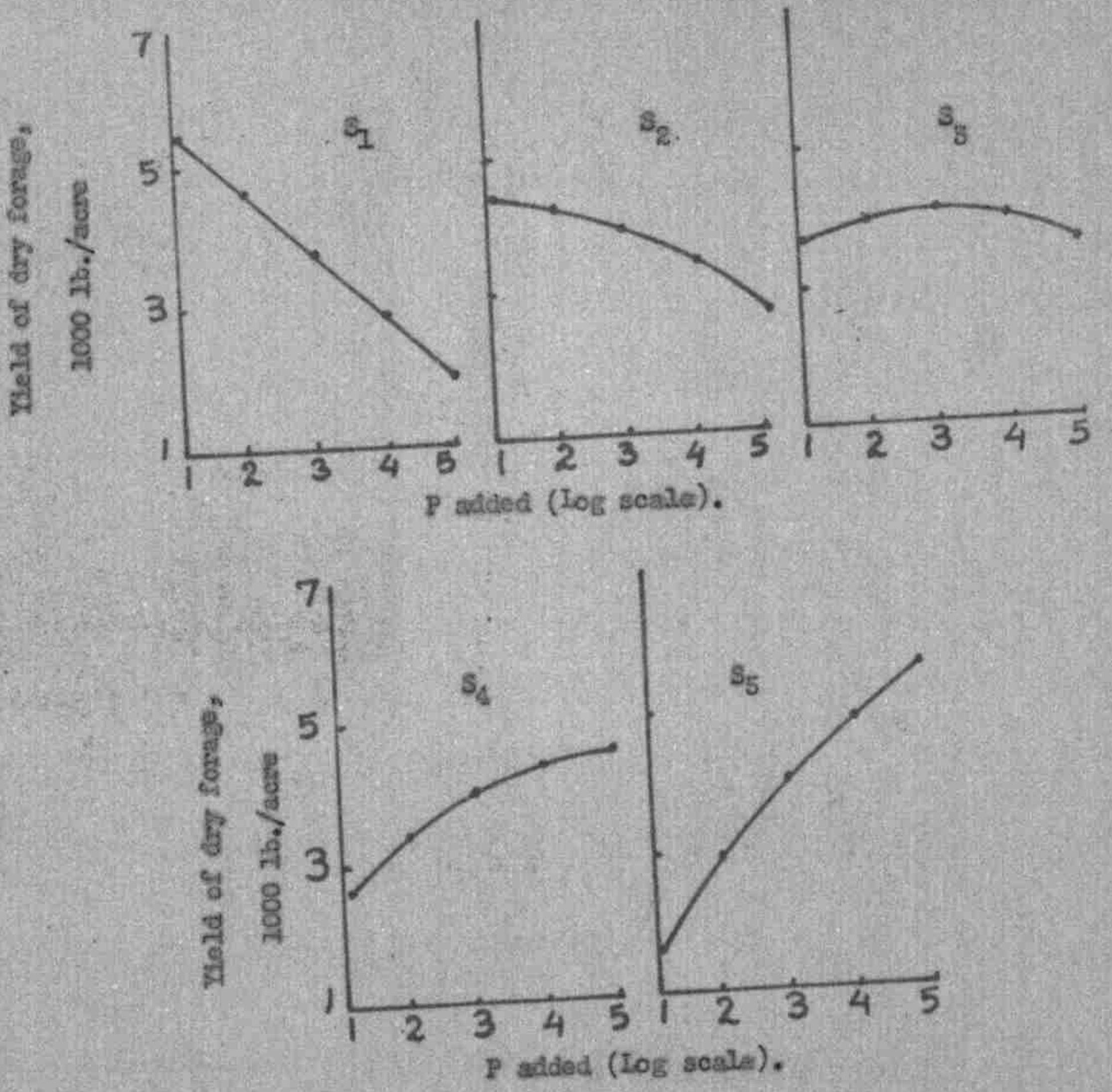

Fig. 25. Dry forage yield of corn (lb./acre) as influenced by addition of different levels of P and S under macronutrient treatments with N, K and Mg held constant at the middle of five levels (Table 2). Level of S was held constant for each graph.

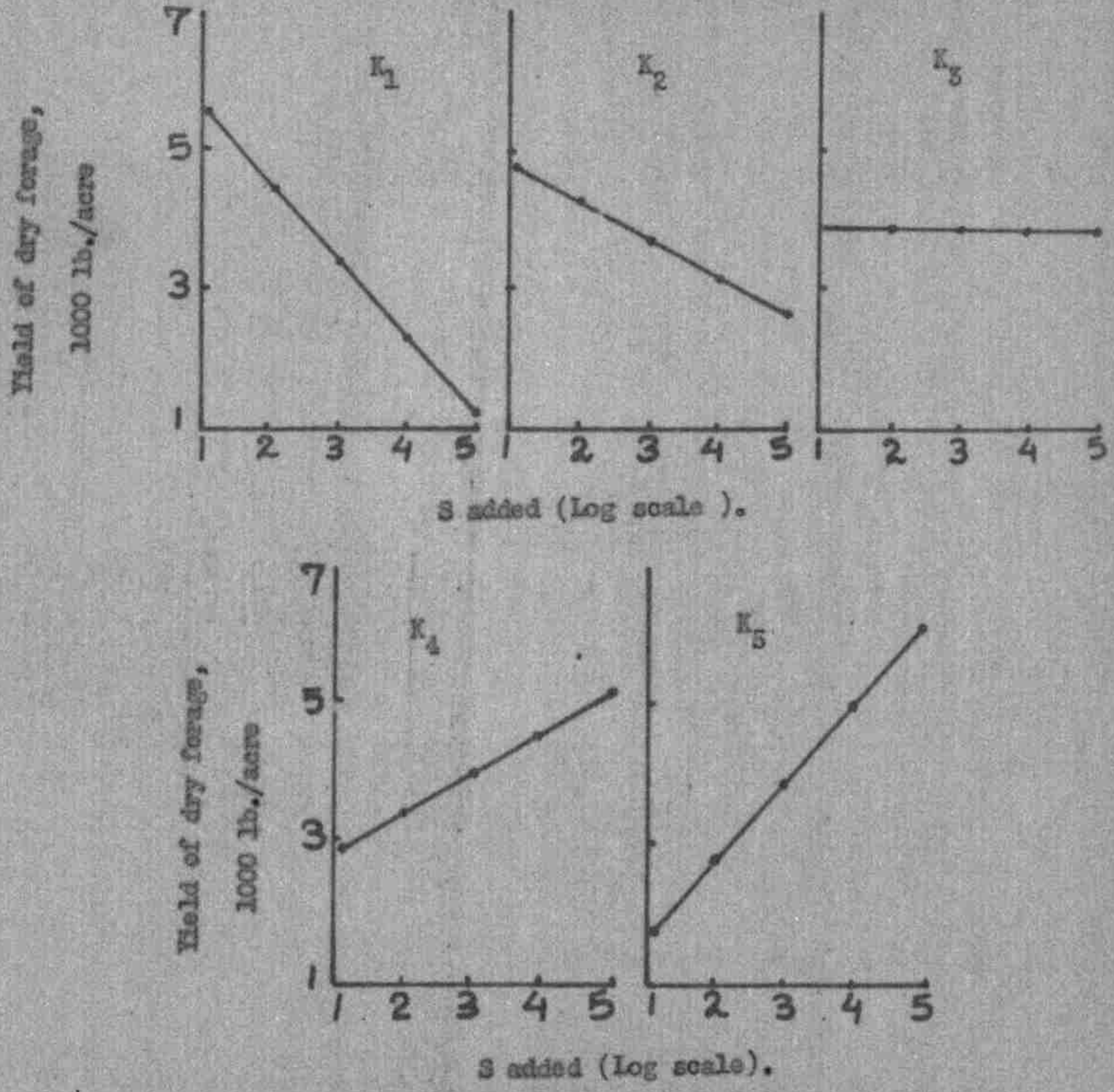

Fig. 26. Dry forage yield of corn (lb./acre) as influenced by addition of different levels of K and S under macro-nutrient treatments with N, P and Mg held constant at the middle of five levels (Table 2). Level of K was held constant for each graph.

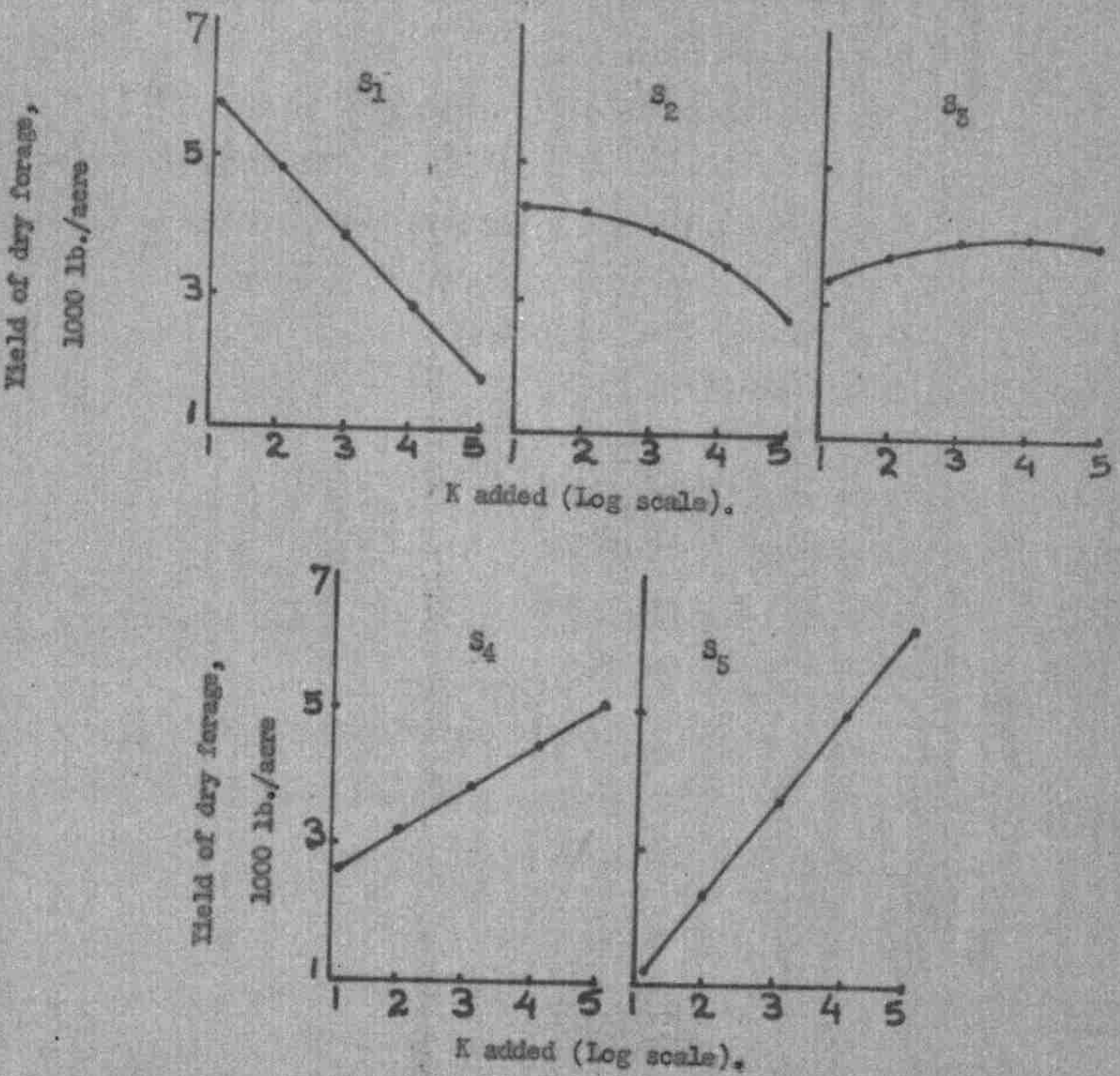

Fig. 27. Dry forage yield of corn (lb./acre) as influenced by addition of different levels of K and S under macronutrient treatments with N, P and Mg held constant at the middle of five levels (Table 2). Level of S was held constant for each graph.

ment of the other for yield of forage. The N-Mg, P-Mg and Mg-S interaction terms had negative regression coefficient values showing a complementary effect. An increase in the amount of one element decreased the requirement of the other.

Calculation from the regression equation of the optimum combination of macronutrients for the maximum forage yield of corn indicated that high rates of N, P, K and S combined with a low rate of Mg were required. This is considerably differrent from the requirements for maximum grain production where only a high rate of N was required. Also, since the value of forage is much less than the value of grain and a high rate of P, K or S tended to decrease the grain yield, it is probable that the addition of these elements would not be economically justified. Apparently high N and low Mg were required for both grain and forage production while P, K and S additions are necessary for high forage production but not for grain production under the conditions of this experiment.

Nitrogen concentration of corn leaves. The analysis of variance for the N concentration of corn leaves (Table 30) indicated highly significant linear and quadratic effects. The lack of fit term was highly significant but since it accounted for only about 26 per cent of the total treatment variability, it probably did not seriously affect the results.

Examination of the regression coefficients for N concentration of corn leaves (Table 31) indicated highly significant positive linear effects of N and K on N concentration of corn leaves and a highly significant negative linear effect of P on the N concentration of corn leaves

Table 30. Analysis of variance for N concentration of corn leaves.

Source	d.f.	s.s.	m.s.
Total	31	1.7184	
Linear	5	0.4908	0.0982**
Quadratic	15	0.7767	0.0518**
Lack of fit	6	0.4381	0.0730**
Experimental error	5	0.0128	0.0026

**Significant at odds of 99:1

Table 31. **Regression coefficients (b) and their standard errors (s_b) for N concentration of corn leaves (% dry weight).**

Coefficient		b	s_b
Mean	b_0	+2.4566	±0.0207
N	b_1	+0.1104**	±0.0104
P	b_2	-0.0454**	" "
K	b_3	+0.0779**	" "
Mg	b_4	+0.0262	" "
S	b_5	+0.0229	" "
N^2	b_{11}	+0.0508**	±0.0094
P^2	b_{22}	-0.0354*	" "
K^2	b_{33}	-0.0642**	" "
Mg^2	b_{44}	+0.0246*	" "
S^2	b_{55}	-0.0304*	" "
N X P	b_{12}	-0.0994**	±0.0127
N X K	b_{13}	+0.0669**	" "
N X Mg	b_{14}	-0.0644**	" "
N X S	b_{15}	-0.0269	" "
P X K	b_{23}	+0.0406*	" "
P X Mg	b_{24}	-0.0131	" "
P X S	b_{25}	-0.0281	" "
K X Mg	b_{34}	+0.0331*	" "
K X S	b_{35}	+0.0556**	" "
Mg X S	b_{45}	-0.0606**	" "

*Significant at odds of 19:1
**Significant at odds of 99:1

which indicated that increasing levels of both N and K increased the N concentration of corn leaves while P decreased it. Among the quadratic effects N^2 (positive) and K^2 (negative) were highly significant while P^2 (negative), Mg^2 (positive) and S^2 (negative) were significant. The regression coefficients for the N-P, N-K, N-Mg, K-S and Mg-S interactions were highly significant while the P-K and N-Mg interactions were significant.

The correlation coefficient between the actual N concentrations and N concentrations calculated from the regression equation was (Table 32) 0.94 (highly significant) indicating a very close fit of the regression equation to the actual.

Examination of the relationship between the dry forage yield and the N concentration of corn leaves as affected by the N-P interaction (Fig. 28) indicated that at low levels of N, increasing P tended to decrease the dry forage yield and increase the N concentration of corn leaves. Apparently the P effect on the corn yield was not due to restriction of N absorption since total N uptake remained almost constant. At high levels of N, increasing P increased the dry forage yield but decreased the N concentration of corn leaves. When P was held constant (Fig. 29) increasing N resulted in decreased yields to the N 3 level and then increasing yields of the dry forage above the 3 level at all levels of P. In general increasing N caused increased N concentration as expected. However, at

Table 32. Observed N concentrations of corn leaves (per cent dry wt.) with macronutrients as variables. Values for the same treatments calculated from the regression equation are given. Correlation of actual N concentrations with calculated concentrations was 0.940.

Treatment level	Actual N concentration, %	Calculated N concentration, %
$N_2P_2K_2Mg_2S_4$	2.20	2.23
$N_4P_2K_2Mg_2S_2$	2.64	2.58
$N_2P_4K_2Mg_2S_2$	2.26	2.22
$N_4P_4K_2Mg_2S_4$	2.37	2.24
$N_2P_2K_4Mg_2S_2$	1.77	1.88
$N_4P_2K_4Mg_2S_4$	2.88	2.89
$N_2P_4K_4Mg_2S_4$	2.39	2.43
$N_4P_4K_4Mg_2S_2$	2.59	2.49
$N_2P_2K_2Mg_4S_2$	2.36	2.38
$N_4P_2K_2Mg_4S_4$	2.48	2.40
$N_2P_4K_2Mg_4S_4$	2.30	2.24
$N_4P_4K_2Mg_4S_2$	2.44	2.25
$N_2P_2K_4Mg_4S_4$	2.33	2.42
$N_4P_2K_4Mg_4S_2$	2.80	2.75
$N_2P_4K_4Mg_4S_2$	2.52	2.49
$N_4P_4K_4Mg_4S_4$	2.62	2.50
$N_5P_3K_3Mg_3S_3$	2.72	2.88
$N_1P_3K_3Mg_3S_3$	2.47	2.44
$N_3P_5K_3Mg_3S_3$	1.97	2.22

Table 32, continued.

Treatment level	Actual N concentration, %	Calculated N concentration, %
$N_3P_1K_3Mg_3S_3$	2.53	2.41
$N_3P_3K_5Mg_3S_3$	2.39	2.36
$N_3P_3K_1Mg_3S_3$	1.88	2.04
$N_3P_3K_3Mg_5S_3$	2.46	2.61
$N_3P_3K_3Mg_1S_3$	2.52	2.50
$N_3P_3K_3Mg_3S_5$	2.36	2.38
$N_3P_3K_3Mg_3S_1$	2.18	2.29
$N_3P_3K_3Mg_3S_3$	2.48	2.46

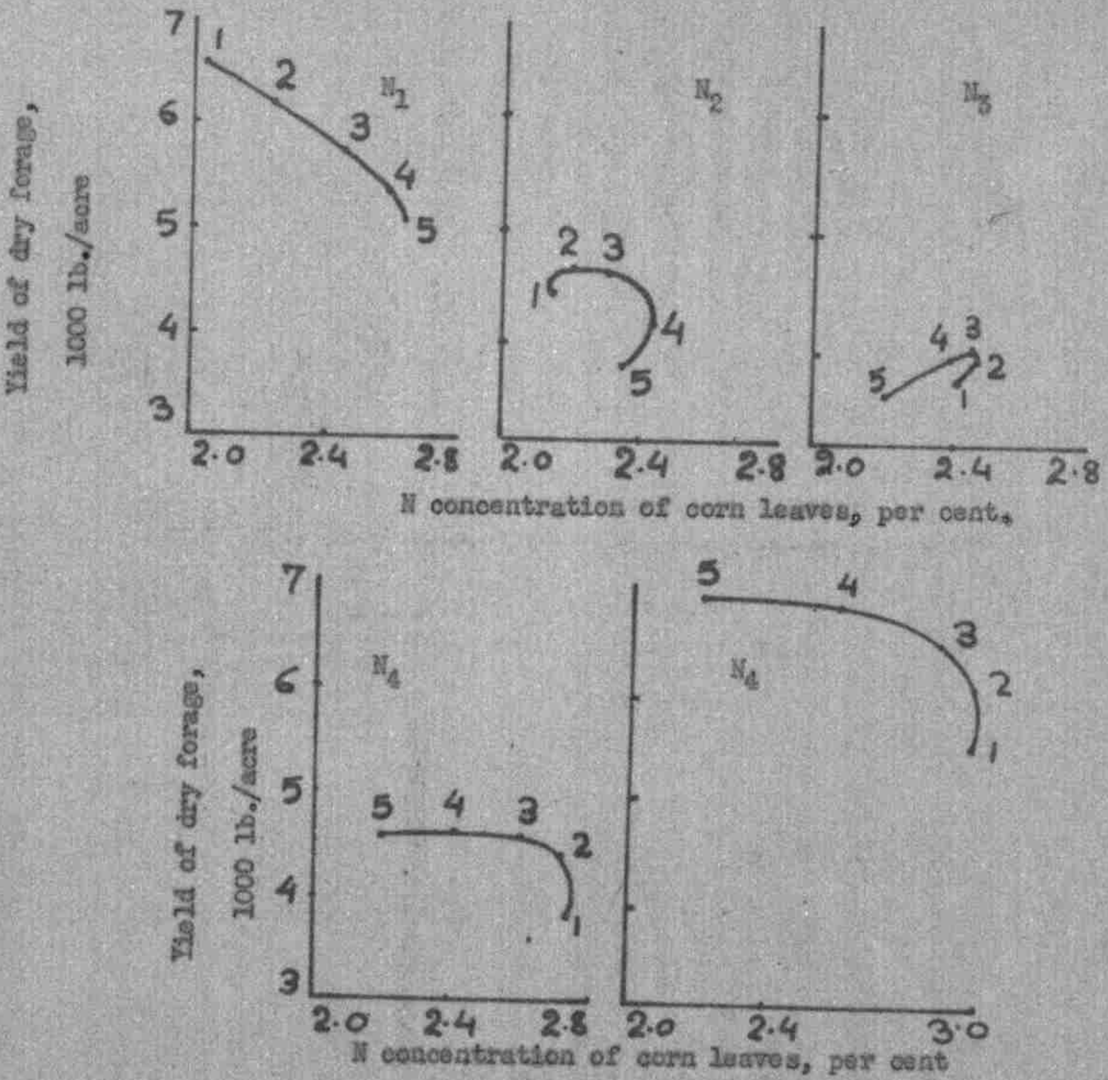

Fig. 28. Relationship between dry forage yield of corn (lb./acre) and N concentration (per cent dry wt.) as affected by addition of different levels of N and P under macronutrient treatments with K, Mg, and S at the middle of five levels (Table 2). Numbers at points refer to levels of P added. Level of N was held constant for each graph.

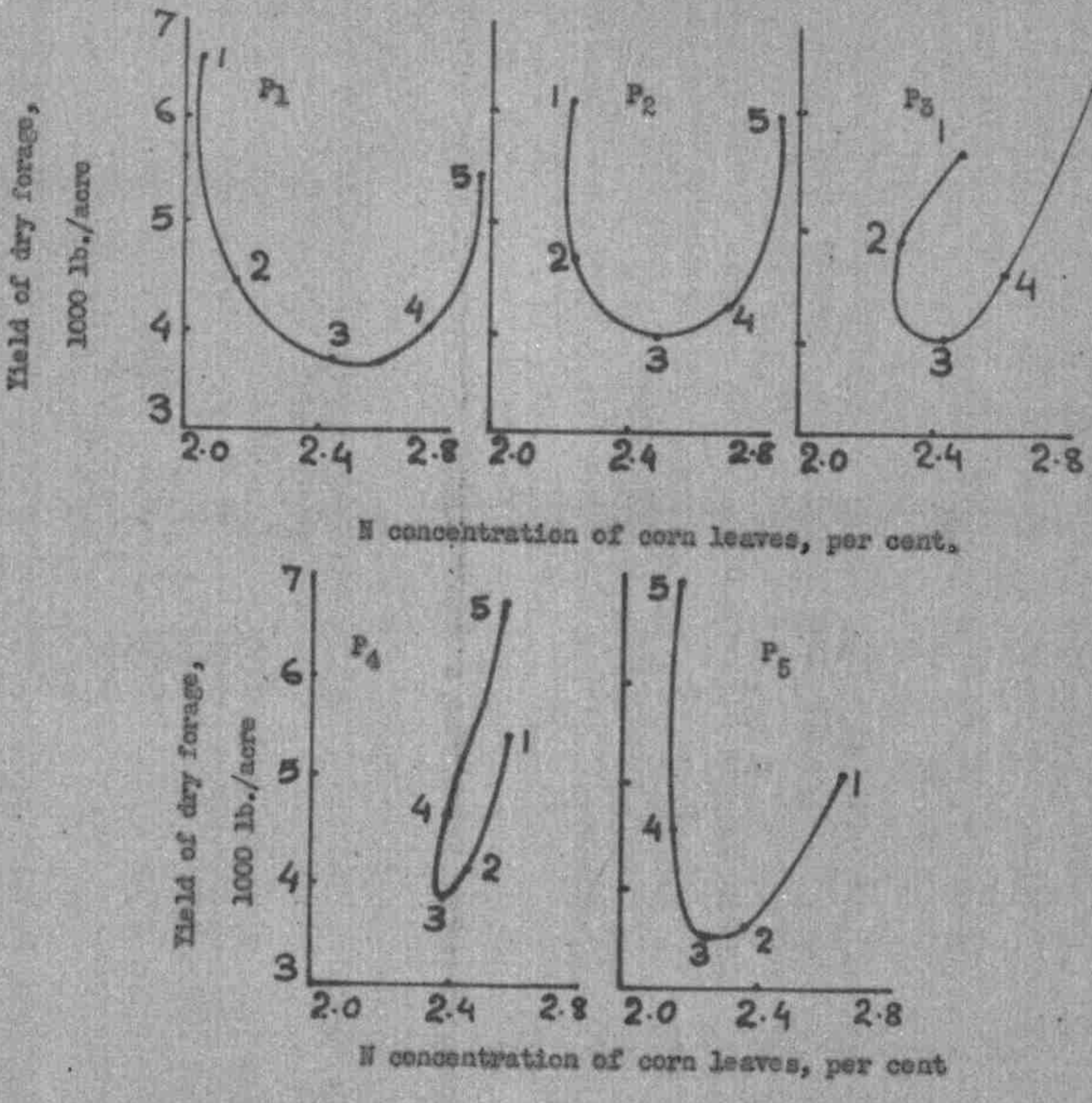

Fig. 29. Relationship between dry forage yield of corn (lb./acre) and N concentration (per cent dry wt.) as affected by addition of different levels of N and P under macronutrient treatments with K, Mg, and S at the middle of five levels (Table 2). Numbers at points refer to levels of N added. Level of P was held constant for each graph.

the higher levels of P the first increments of N resulted in a decrease in the dry forage yield.

The relationship between the dry forage yield and the per cent of N in corn leaves as affected by the interaction of N and K (Fig. 30) showed that at low levels of N increasing K decreased the dry forage yield while the N concentration tended to be highest around the 3 or 4 level of K. At high levels of N, increasing K increased dry forage yield as well as N concentration of corn leaves. This indicated that at high levels of N there was a considerable dry forage yield response to applied K. However, when K was held constant and N increased (Fig. 31), the first increments of N resulted in a severe decrease in yield and also a slight decrease in N concentration. At the higher K levels the trend was less pronounced and the highest yield occured at the high level of applied N and at an N concentration of about 3 per cent. The critical level of N concentration in corn leaves appeared to be higher as the level of applied K increased.

The N-Mg and Mg-S interactions were complementary in their effect on the percentage of N in corn leaves. The K-S, P-K and K-Mg interactions were antagonistic in their effect on the N percentage in corn leaves. All four interactions involving K were significantly antagonistic indicating that a high supply of N, P, Mg or S increased the amount of K required for maximum N uptake by corn plants. plants.

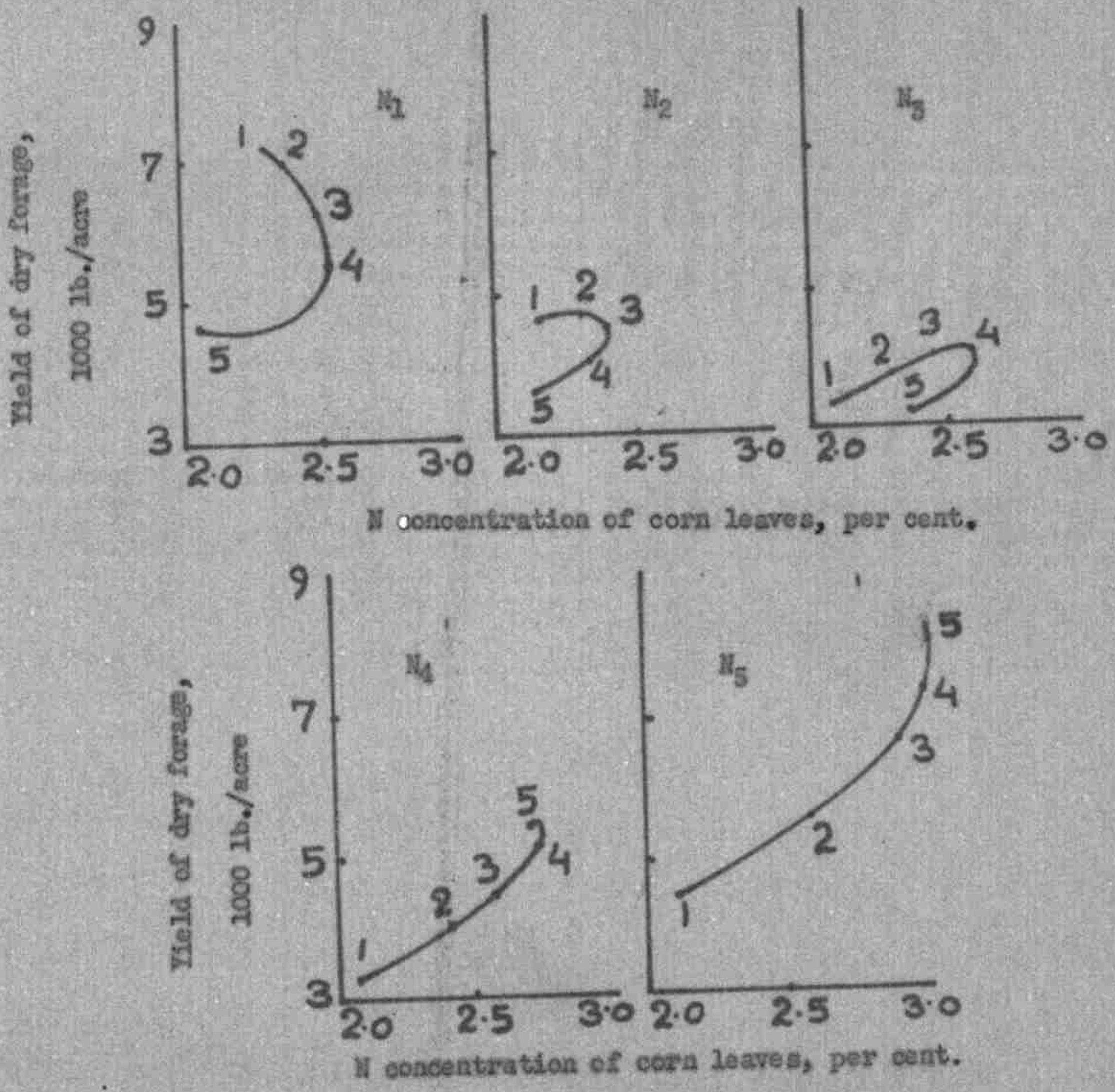

Fig. 30. Relationship between dry forage yield of corn (lb./acre) and N concentration (per cent dry wt.) as affected by addition of different levels of N and K under macronutrient treatments with P, Mg, and S at the middle of five levels (Table 2). Numbers at points refer to levels of K added. Level of N was held constant for each graph.

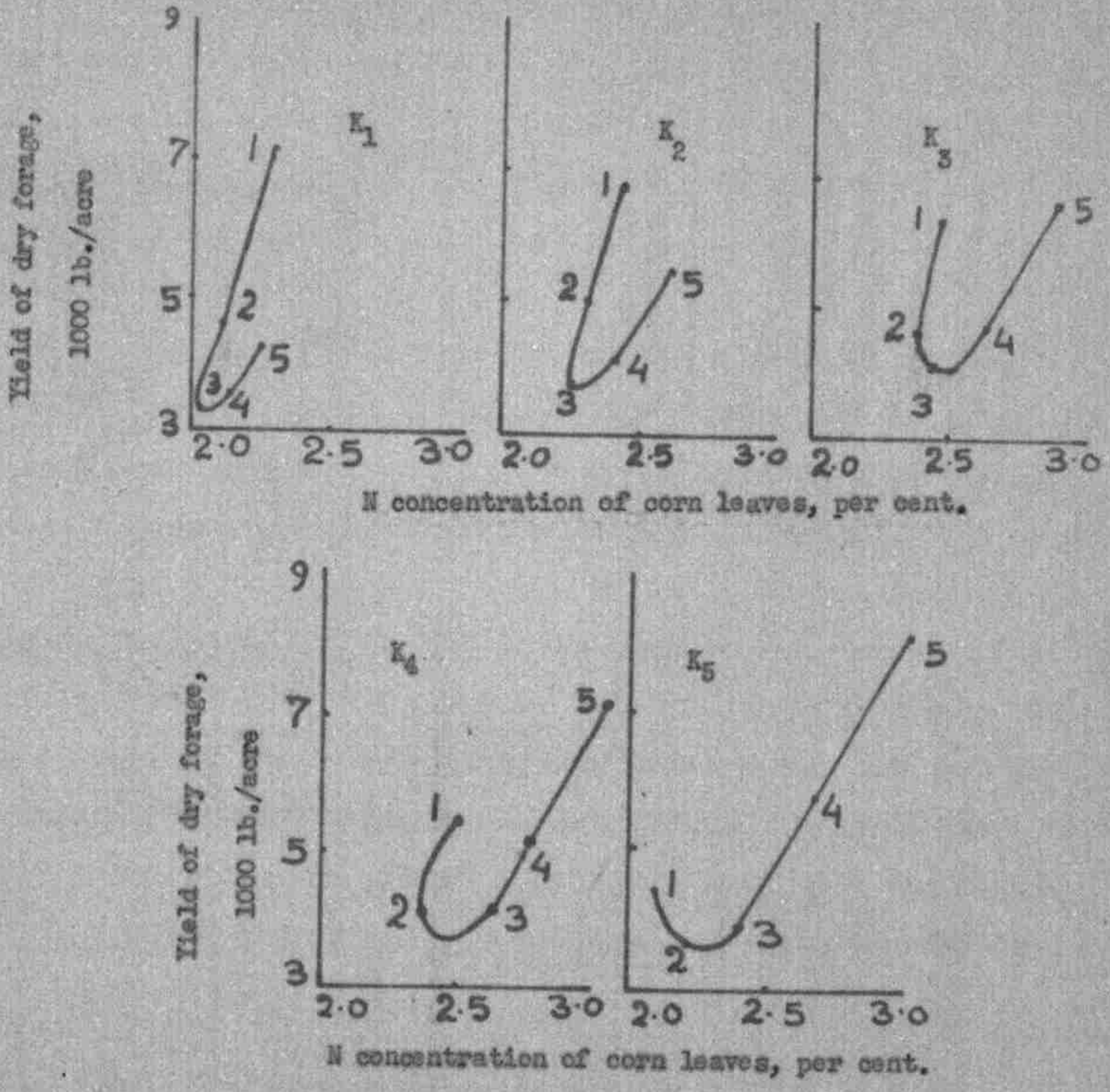

Fig. 51. Relationship between dry forage yield of corn (lb./acre) and N concentration (per cent dry wt.) as affected by addition of different levels of N and K under macronutrient treatments with P, Mg, and S at the middle of five levels (Table 2). Numbers at points refer to levels of N added. Level of K was held constant for each graph.

Phosphorous concentration of corn leaves. The analysis of variance for the P concentration of corn leaves (Table 33) indicated that the linear and quadratic variation effects were highly significant. The lack of fit term was also highly significant and accounted for 35 per cent of the total treatment variation indicating an incomplete fit of the quadratic equation.

Examination of the individual regression coefficients (Table 34) indicated that the linear effects of P and S were highly significant and the Mg effect was significant. Among the quadratic effects P^2, K^2, and S^2 were highly significant. The N^2 and Mg^2 effects were significant. The N-Mg, N-S and P-K interactions were highly significant while the N-P, N-K and P-S interactions were significant. All the regression coefficients for the direct linear effects of the individual elements were positive while those for the quadratic squared terms were negative indicating that the higher levels of these elements tended to depress the P concentration of corn leaves.

The correlation coefficient between the observed P concentrations and the P concentrations calculated from the regression equation (Table 35) was 0.785 (highly significant) which again indicated an incomplete fit of the regression equation to the actual data.

Study of the relationship between the dry forage yield and the per cent of P as influenced by the N-Mg interaction (Fig. 32) showed that at low levels of N, in-

Table 33. **Analysis of variance for P concentration of corn leaves.**

Source	**d.f.**	**s.s.**	**m.s.**
Total	31	0.0331	
Linear	5	0.0089	0.0018**
Quadratic	15	0.0126	0.0008**
Lack of fit	6	0.0115	0.0019**
Experimental error	5	0.0002	0.00004

****Significant at odds of 99:1**

Table 34. **Regression coefficients (b) and their standard errors (s_b) for P concentration of corn leaves (% dry weight).**

Coefficient		b	s_b
Mean	b_0	+0.2455	±0.0008
N	b_1	+0.0010	±0.0012
P	b_2	+0.0178**	" "
K	b_3	+0.0008	" "
Mg	b_4	+0.0040*	" "
S	b_5	+0.0061**	" "
N^2	b_{11}	-0.0040*	±0.0010
P^2	b_{22}	-0.0071**	" "
K^2	b_{33}	-0.0109**	" "
Mg^2	b_{44}	-0.0035*	" "
S^2	b_{55}	-0.0139**	" "
N X P	b_{12}	+0.0039*	±0.0014
N X K	b_{13}	+0.0051*	" "
N X Mg	b_{14}	-0.0073**	" "
N X S	b_{15}	+0.0060**	" "
P X K	b_{23}	+0.0058**	" "
P X Mg	b_{24}	+0.0004	" "
P X S	b_{25}	-0.0036*	" "
K X Mg	b_{34}	+0.0024	" "
K X S	b_{35}	-0.0026	" "
Mg X S	b_{45}	+0.0028	" "

***Significant at odds of 19:1**
****Significant at odds of 99:1**

Table 35. Observed P concentrations of corn leaves (per centdry wt.) with macronutrients as variables. Values for the same treatments calculated from the regression equation are given. Correlation of actual P concentrations with calculated concentrations was0.785.

Treatment level	Actual P concentration, %	Calculated P concentration, %
$N_2P_2K_2Mg_2S_4$	0.217	0.196
$N_4P_2K_2Mg_2S_2$	0.195	0.176
$N_2P_4K_2Mg_2S_2$	0.212	0.212
$N_4P_4K_2Mg_2S_4$	0.218	0.231
$N_2P_2K_4Mg_2S_2$	0.198	0.170
$N_4P_2K_4Mg_2S_4$	0.231	0.197
$N_2P_4K_4Mg_2S_4$	0.194	0.198
$N_4P_4K_4Mg_2S_2$	0.223	0.201
$N_2P_2K_2Mg_4S_2$	0.210	0.201
$N_4P_2K_2Mg_4S_4$	0.219	0.229
$N_2P_4K_2Mg_4S_4$	0.187	0.198
$N_4P_4K_2Mg_4S_2$	0.217	0.198
$N_2P_2K_4Mg_4S_4$	0.186	0.169
$N_4P_2K_4Mg_4S_2$	0.236	0.238
$N_2P_4K_4Mg_4S_2$	0.234	0.249
$N_4P_4K_4Mg_4S_4$	0.234	0.232
$N_5P_3K_3Mg_3S_3$	0.202	0.228
$N_1P_3K_3Mg_3S_3$	0.294	0.253
$N_3P_5K_3Mg_3S_3$	0.117	0.118

Table 35, continued.

Treatment level	Actual P concentration, %	Calculated P concentration, %
$N_3P_1K_3Mg_3S_3$	0.117	0.181
$N_3P_3K_5Mg_3S_3$	0.188	0.204
$N_3P_3K_1Mg_3S_3$	0.193	0.201
$N_3P_3K_3Mg_5S_3$	0.236	0.239
$N_3P_3K_3Mg_1S_3$	0.204	0.231
$N_3P_3K_3Mg_3S_5$	0.202	0.202
$N_3P_3K_3Mg_3S_1$	0.155	0.190
$N_3P_3K_3Mg_3S_3$	0.249	0.246

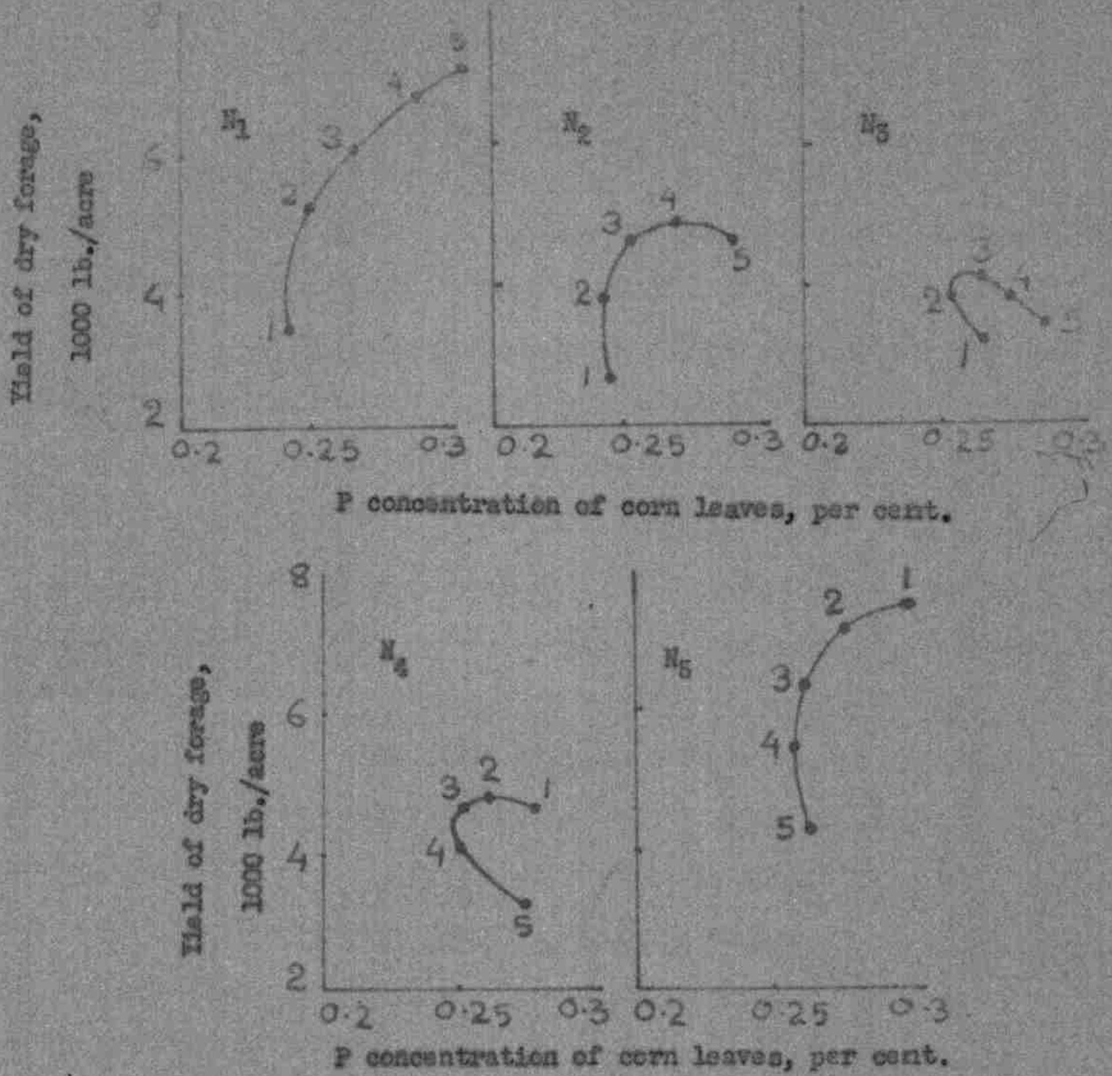

Fig. 32. Relationship between dry forage yield of corn (lb./acre) and P concentration (per cent dry wt.) as affected by addition of different levels of N and Mg under macronutrient treatments with P, K, and S at the middle of five levels (Table 2). Numbers at points refer to levels of Mg added. Level of N was held constant for each graph.

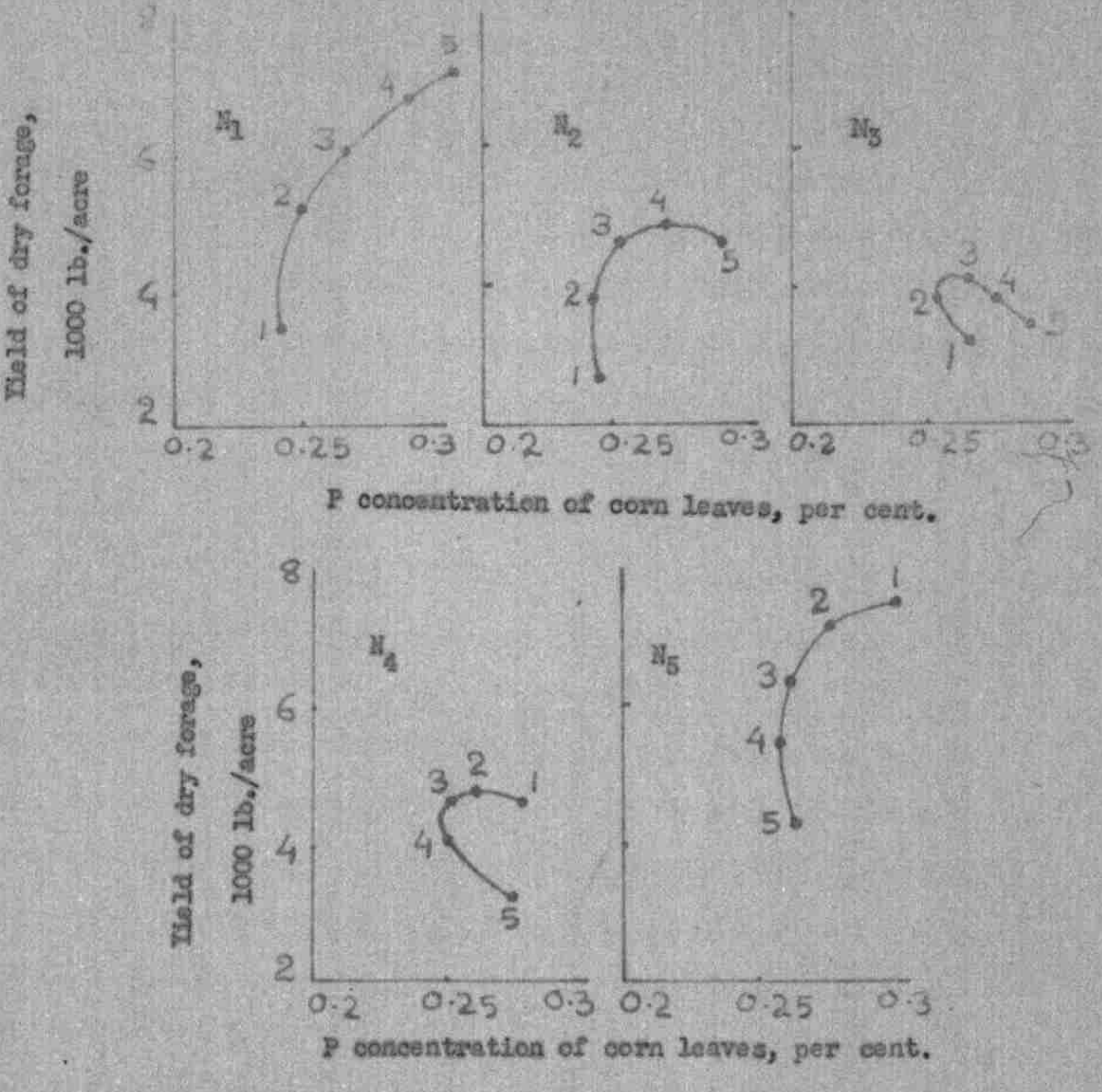

Fig. 32. Relationship between dry forage yield of corn (lb./acre) and P concentration (per cent dry wt.) as affected by addition of different levels of N and Mg under macronutrient treatments with P, K, and S at the middle of five levels (Table 2). Numbers at points refer to levels of Mg added. Level of N was held constant for each graph.

creasing Mg, increased the forage yield as well as the P concentration of corn leaves while at high levels of N, Mg addition decreased the dry forage yield and the P concentration of corn leaves. However, when N was increased at constant levels of Mg (Fig. 33), the first increments of N decreased the dry forage yield while increasing higher rates of N, increased the dry forage yield. The P concentration tended to be increased by increasing N at low Mg levels while at high Mg levels P was decreased.

Examination of the relationship between the dry forage yield of corn and the P concentration as affected by the N-S interaction (Fig. 34) indicated that at low levels of N increasing S decreased the dry forage yield while the P concentration increased up to about the 3 or 4 level of S. At high levels of N, increasing S, increased dry forage yield with a tendency for an increase in the P concentration of corn leaves. When S was held constant (Fig. 35), the first increments of N tended to greatly decrease the dry forage yield while the higher increments of N increased the yield of dry forage. At high S levels, the P concentration of the corn leaves was reduced by increasing N. The highest yields tended to be associated with a P concentration of about 0.25 per cent.

Like the N-S interaction described above, the N-P, N-K and P-K significant interactions were antagonistic in their effect on P concentration of corn leaves while the P-S significant interaction, like the N-Mg interaction de-

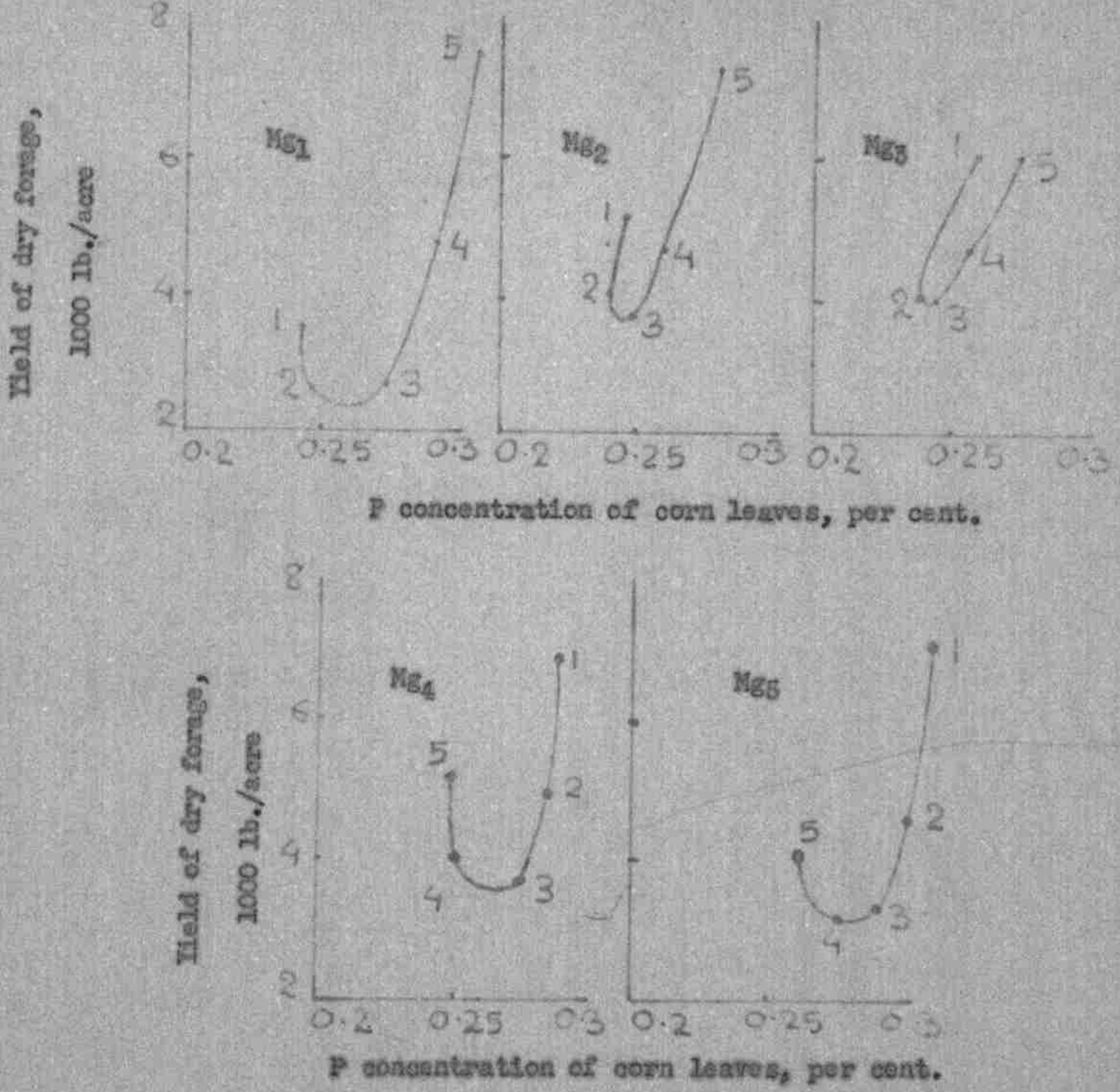

Fig. 33. Relationship between dry forage yield of corn (lb./acre) and P concentration (per cent dry wt.) as affected by addition of different levels of N and Mg under macronutrient treatments with P, K, and S at the middle of five levels (Table 2). Numbers at points refer to levels of N added. Level of Mg was held constant for each graph.

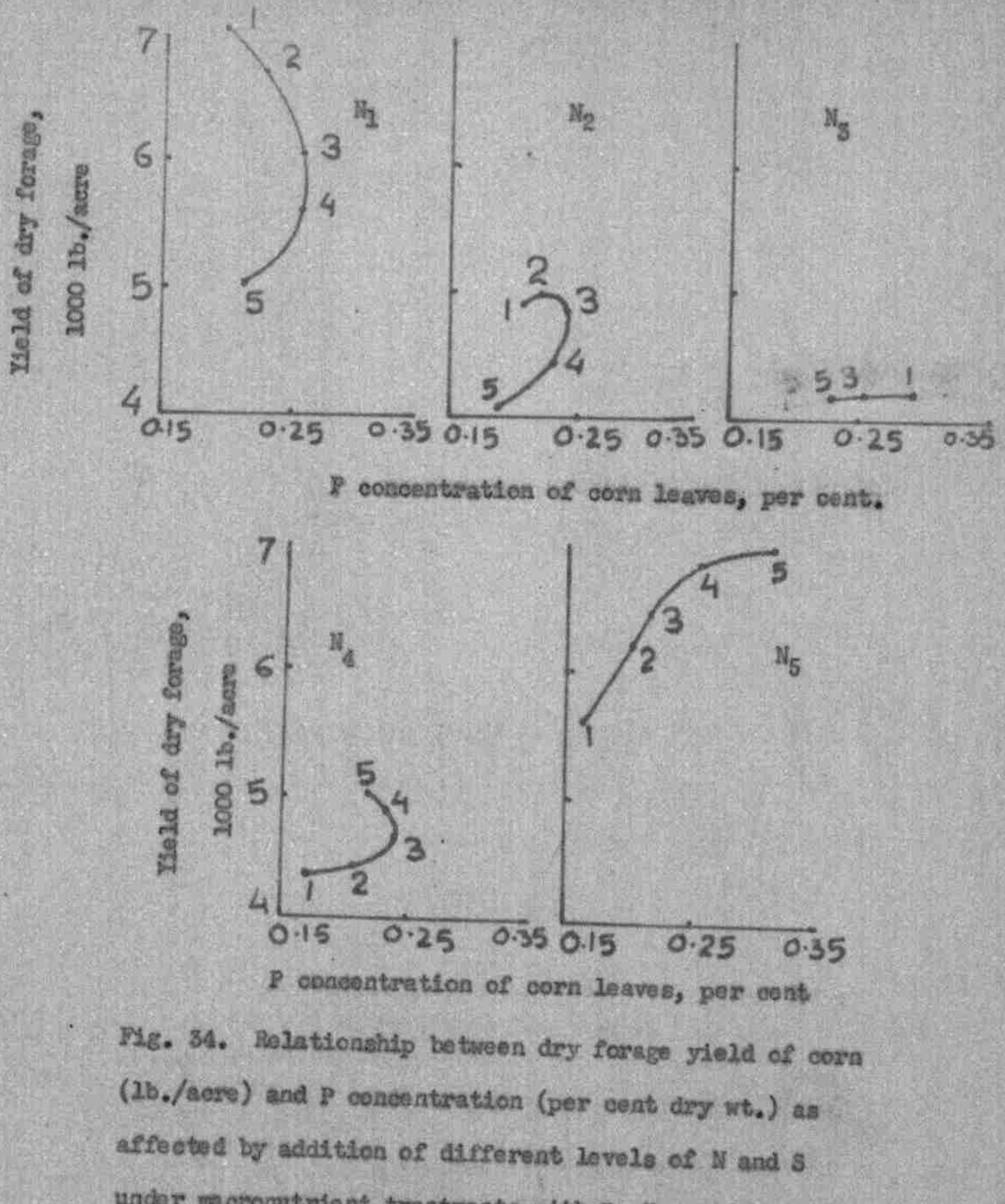

Fig. 34. Relationship between dry forage yield of corn (lb./acre) and P concentration (per cent dry wt.) as affected by addition of different levels of N and S under macronutrient treatments with P, K., and Mg at the middle of five levels (Table 2). Numbers at points refer to levels of S added. Level of N was held constant for each graph.

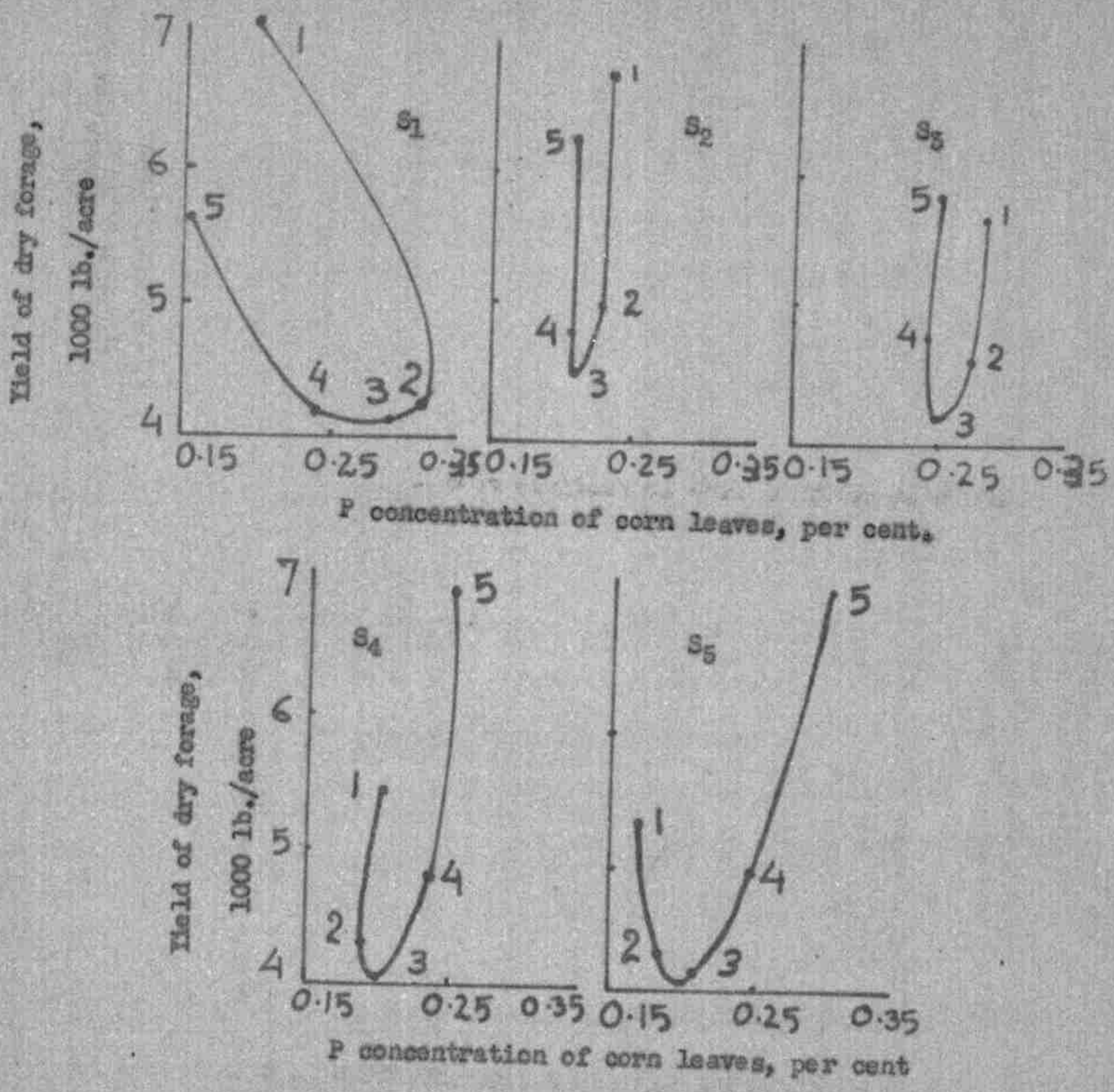

Fig. 35. Relationship between dry forage yield of corn (lb./acre) and P concentration (per cent dry wt.) as affected by addition of different levels of N and S under macronutrient treatments with P, K, and Mg at the middle of five levels (Table 2). Numbers at points refer to levels of N added. Level of S was held constant for each graph.

scribed above, was complementary.

Potassium concentration of corn leaves. The analysis of variance for the K concentration of corn leaves (Table 36) indicated significant linear and quadratic effects. The lack of fit term was also significant.

An examination of the regression equation coefficients (Table 37) indicated the significant linear effects for K and Mg. Both terms had negative values indicating that increasing K and Mg, decreased the K concentration in corn leaves while the K^2 significant regression coefficient was positive showing that higher levels of K increased the K concentration of corn leaves. The quadratic effects for P^2 and S^2 were highly significant and the effect for N^2 was significant. The positive sign indicated that increasing levels of all three increased the K concentration of corn leaves. The Mg-S interaction was significant and negative showing a complementary effect. An increasing level of Mg decreased the requirement of S for the uptake of K.

The correlation coefficient between the actual K concentrations and K concentrations calculated from the regression equation was 0.95 which indicated a very close fit of the regression equation to the actual data.

Study of relationship between the dry forage yield of corn and the K concentration of corn leaves as influenced by the Mg-S interaction (Fig. 36) indicated that at low levels of Mg, increasing S, increased the dry forage

Table 36. **Analysis of variance for K concentration of corn leaves.**

Source	**d.f**	**s.s**	**m.s.**
Total	31	2.698	
Linear	5	0.394	0.0788*
Quadratic	15	1.501	0.1000*
Lack of fit	6	0.724	0.1207*
Experimental error	5	0.079	0.0158

***Significant at odds of 19:1**

Table 37. **Regression coefficients (b) and their standard errors (s_b) for K concentration of corn leaves (% Dry weight).**

Coefficient		b	s_b
Mean	b_0	+4.849	±0.005
N	b_1	-0.016	±0.026
P	b_2	+0.025	" "
K	b_3	-0.068*	" "
Mg	b_4	-0.099*	" "
S	b_5	+0.031	" "
N^2	b_{11}	+0.062*	±0.023
P^2	b_{22}	+0.195**	" "
K^2	b_{33}	+0.054*	" "
Mg^2	b_{44}	+0.012	" "
S^2	b_{55}	+0.093**	" "
N X P	b_{12}	+0.067	±0.031
N X K	b_{13}	-0.029	" "
N X S	b_{15}	+0.041	" "
N X Mg	b_{14}	-0.037	" "
P X K	b_{23}	-0.033	" "
P X Mg	b_{24}	+0.042	" "
P X S	b_{25}	+0.002	" "
K X Mg	b_{34}	+0.016	" "
K X S	b_{35}	-0.027	" "
Mg X S	b_{45}	-0.174**	" "

*Significant at odds of 19:1

**Significant at odds of 99:1

Table 38. Observed K concentrations of corn leaves (per cent dry wt.) with macronutrients as variables. Values for the same treatments calculated from the regression equation are given. Correlation of actual K concentrations with calculated concentrations was 0.950.

Treatment level	Actual K concentration, %	Calculated K concentration, %
$N_2P_2K_2Mg_2S_4$	5.67	5.65
$N_4P_2K_2Mg_2S_2$	5.19	5.14
$N_2P_4K_2Mg_2S_2$	5.09	5.15
$N_4P_4K_2Mg_2S_4$	5.89	5.85
$N_2P_2K_4Mg_2S_2$	5.26	5.26
$N_4P_2K_4Mg_2S_4$	5.56	5.47
$N_2P_4K_4Mg_2S_4$	5.29	5.31
$N_4P_4K_4Mg_2S_2$	5.06	5.12
$N_2P_2K_2Mg_4S_2$	5.31	5.36
$N_4P_2K_2Mg_4S_4$	4.99	4.94
$N_2P_4K_2Mg_4S_4$	5.05	5.11
$N_4P_4K_2Mg_4S_2$	5.38	5.43
$N_2P_2K_4Mg_4S_4$	5.00	5.01
$N_4P_2K_4Mg_4S_2$	5.06	5.06
$N_2P_4K_4Mg_4S_2$	5.26	5.37
$N_4P_4K_4Mg_4S_4$	4.99	5.00
$N_5P_3K_3Mg_3S_3$	5.03	5.06
$N_1P_3K_3Mg_3S_3$	5.32	5.12
$N_3P_5K_3Mg_3S_3$	5.87	5.68
$N_3P_1K_3Mg_3S_3$	5.55	5.75

Table 38, continued.

Treatment level	Actual K concentration, %	Calculated K concentration, %
$N_3P_3K_5Mg_3S_3$	5.01	4.92
$N_3P_3K_1Mg_3S_3$	5.28	5.19
$N_3P_3K_3Mg_5S_3$	4.87	4.69
$N_3P_3K_3Mg_1S_3$	5.08	5.09
$N_3P_3K_3Mg_3S_5$	5.28	5.28
$N_3P_3K_3Mg_3S_1$	5.32	5.15
$N_3P_3K_3Mg_3S_3$	4.85	4.85

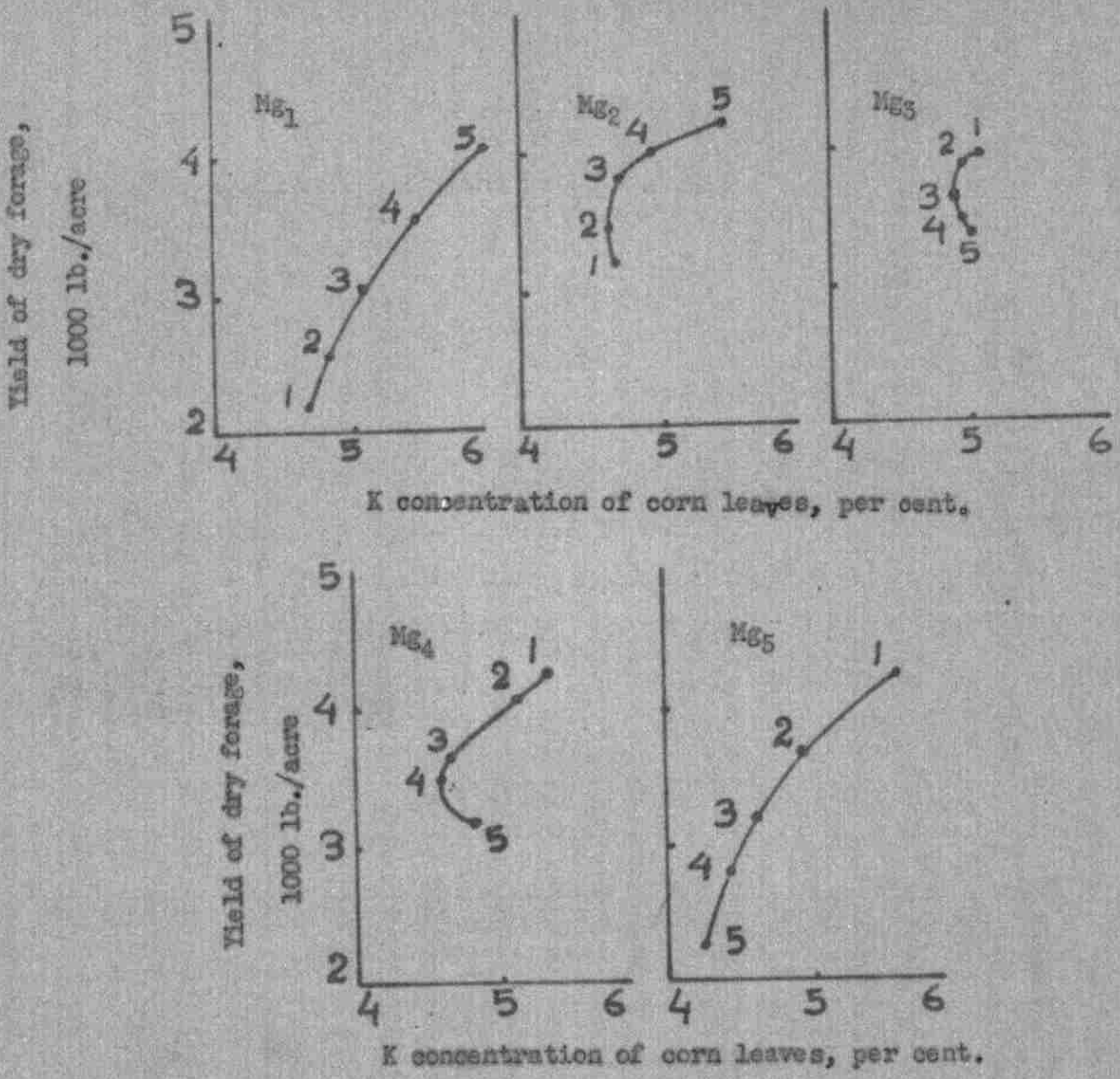

Fig. 38. Relationship between dry forage yield of corn (lb./acre) and K concentration (per cent dry wt.). as affected by addition of different levels of Mg and S under macronutrient treatments with N, P, and K at the middle of five levels (Table 2). Numbers at points refer to levels of S added. Level of Mg was held constant for each graph.

yield and K concentration of corn leaves. At high levels of Mg, the trend was for decreased yield and K concentration of corn leaves. When the S level was held constant (Fig. 37), increasing Mg at low levels of S increased the dry forage yield of corn and K concentration of corn leaves. At highnlevels of S the trend for a decresed dry forage yield and the K concentration of corn leaves. The yield of dry forage tended to drop off appreciably below a K concentration of about 5 per cent.

Magnesium concentration of corn leaves. The analysis of variance for the Mg concentration of corn leaves (Table 39) showed significant linear and quadratic variation effects while the lack of fit term was highly significant and accounted for 33 per cent ot the total treatment variablity indicating an incomplete fit of the regression equation to the actual data.

The regression coefficients for the Mg concentration of corn leaves (Table 40) revealed that the linear effect for Mg was highly significant and positive while the K linear effect was significant and positive indicating that both increased the Mg concentration of corn leaves. Among the quadratic effects, S^2 was highly significant and negative which means that with increasing S, Mg concentration first decreased and then increased. The quadratic effect of K^2 was significant and negative showing that with increasing K, Mg concentration first increased and then decreased. The N-P, N-Mg and K-S interactions were

Table 39. **Analysis of variance for Mg concentration of corn leaves.**

Source	**d.f.**	**s.s.**	**m.s.**
Total	31	0.01139	
Linear	5	0.00217	0.00044*
Quadratic	15	0.00529	0.00035*
Lack of fit	6	0.00369	0.00062**
Experimental error	5	0.00024	0.00005

***Significant at odds of 19:1**

****Significant at odds of 99:1**

Table 40. Regression coefficients (b) and their standard errors (s_b) for Mg concentration of corn leaves (%dry weight).

Coefficient		b	s_b
Mean	b_0	+0.1592	±0.0028
N	b_1	-0.0031	±0.0014
P	b_2	+0.0009	" "
K	b_3	+0.0038*	" "
Mg	b_4	+0.0080**	" "
S	b_5	+0.0013	" "
N^2	b_{11}	+0.0012	±0.0013
P^2	b_{22}	+0.0020	" "
K^2	b_{33}	-0.0050*	" "
Mg^2	b_{44}	+0.0010	" "
S^2	b_{55}	-0.0079**	" "
N X P	b_{12}	+0.0063*	±0.0017
N X K	b_{13}	+0.0003	" "
N X Mg	b_{14}	+0.0061*	" "
N X S	b_{15}	-0.0016	" "
P X K	b_{23}	+0.0025	" "
P X Mg	b_{24}	+0.0039	" "
P X S	b_{25}	+0.0036	" "
K X Mg	b_{34}	-0.0001	" "
K X S	b_{35}	-0.0054*	" "
Mg X S	b_{45}	+0.0030	" "

*Significant at odds of 19:1

**Significant at odds of 99:1

significant.

The correlation coefficient between the observed Mg concentrations of corn leaves and the Mg concentrations calculated from the regression equation was (Table 41) 0.56 indicating that the second order regression equation was only partially effective.

Examination of the relationship between dry forage yield and the Mg concentration of corn leaves as influenced by the positive N-P interaction (Fig. 38) indicated that at low levels of N increasing P tended to decrease the dry forage yield and the Mg concentration of corn leaves while at high levels of N increasing P tended to increase the dry forage yield and the Mg concentration of corn leaves. However, when P was held constant (Fig. 39), the first increments of N decreased the dry forage yield while the higher increments increased it. The Mg concentration of corn le leaves was decreased by increasing N at low levels of P while the Mg concentration tended to be increased by increasing N at high levels of P. This indicates an antagonistic effect between N and P on the Mg concentration of corn le leaves.

The relationship between the dry forage yield and the Mg concentration of corn leaves as influenced by the positive N+Mg interaction (Fig. 40) showed that when N was held constant, increasing Mg at low levels of N tended to increase the dry forage yield while at high levels of N, the dry forage yield decreased. The Mg concentration tend-

Table 41. Observed Mg concentrations of corn leaves (per cent dry wt.) with macronutrients as variables. Values for the same treatments calculated from the regression equation are given. Correlation of calculated Mg concentrations with actual concentrations was 0.560.

Treatment level	Actual Mg concentration, %	Calculated Mg concentration, %
$N_2P_2K_2Mg_2S_4$	0.179	0.161
$N_4P_2K_2Mg_2S_2$	0.135	0.130
$N_2P_4K_2Mg_2S_2$	0.125	0.127
$N_4P_4K_2Mg_2S_4$	0.175	0.136
$N_2P_2K_4Mg_2S_2$	0.175	0.171
$N_4P_2K_4Mg_2S_4$	0.135	0.119
$N_2P_4K_4Mg_2S_4$	0.155	0.147
$N_4P_4K_4Mg_2S_2$	0.144	0.148
$N_2P_2K_2Mg_4S_2$	0.146	0.148
$N_4P_2K_2Mg_4S_4$	0.163	0.153
$N_2P_4K_2Mg_4S_4$	0.165	0.163
$N_4P_4K_2Mg_4S_2$	0.144	0.156
$N_2P_2K_4Mg_4S_4$	0.163	0.155
$N_4P_2K_4Mg_4S_2$	0.154	0.158
$N_2P_4K_4Mg_4S_2$	0.144	0.156
$N_4P_4K_4Mg_4S_4$	0.180	0.180
$N_5P_3K_3Mg_3S_3$	0.153	0.158
$N_1P_3K_3Mg_3S_3$	0.164	0.170
$N_3P_5K_3Mg_3S_3$	0.179	0.169

Table 41, continued.

Treatment level	Actual Mg concentration, %	Calculated Mg concentration, %
$N_3P_1K_3Mg_3S_3$	0.144	0.165
$N_3P_3K_5Mg_3S_3$	0.145	0.147
$N_3P_3K_1Mg_3S_3$	0.123	0.132
$N_3P_3K_3Mg_5S_3$	0.189	0.179
$N_3P_3K_3Mg_1S_3$	0.126	0.147
$N_3P_3K_3Mg_3S_5$	0.100	0.130
$N_3P_3K_3Mg_3S_1$	0.144	0.125
$N_3P_3K_3Mg_3S_3$	0.161	0.159

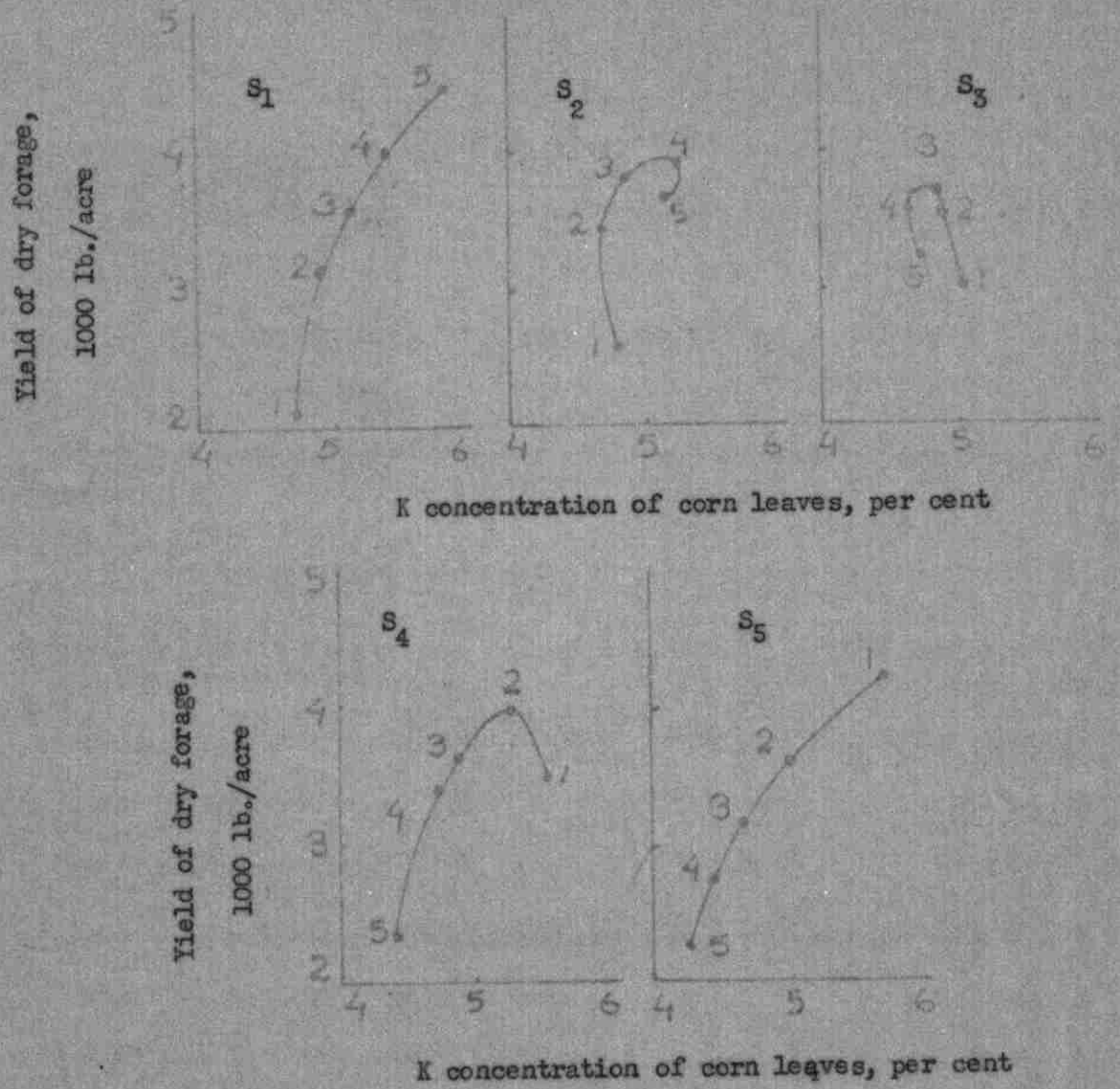

Fig.37. Relationship between dry forage yield of corn (lb./acre) and K concentration (per cent dry wt.) as affected by addition of different levels of Mg and S under macronutrient treatments with N, P and K at the middle of five levels (Table 2). Numbers at points refer to levels of Mg added. Level of S was held constant for each graph.

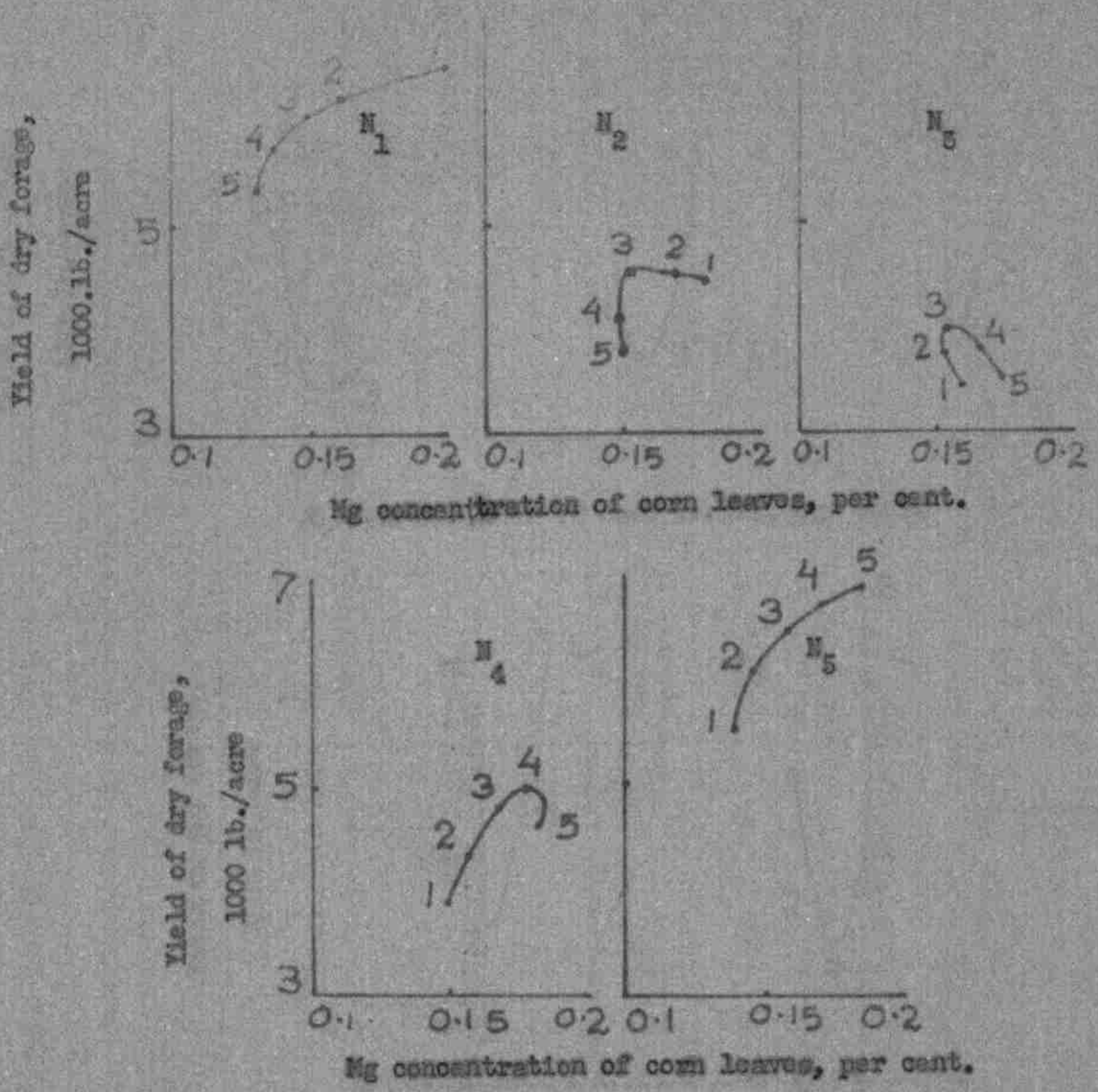

Fig. 58. Relationship between dry forage yield of corn (lb./acre) and Mg concentration (per cent dry wt.) as affected by different levels of applied N and P under macronutrient treatments with K, Mg and S at the middle of five levels (table 2). Numbers at points refer to levels of P added. Level of N was held constant for each graph.

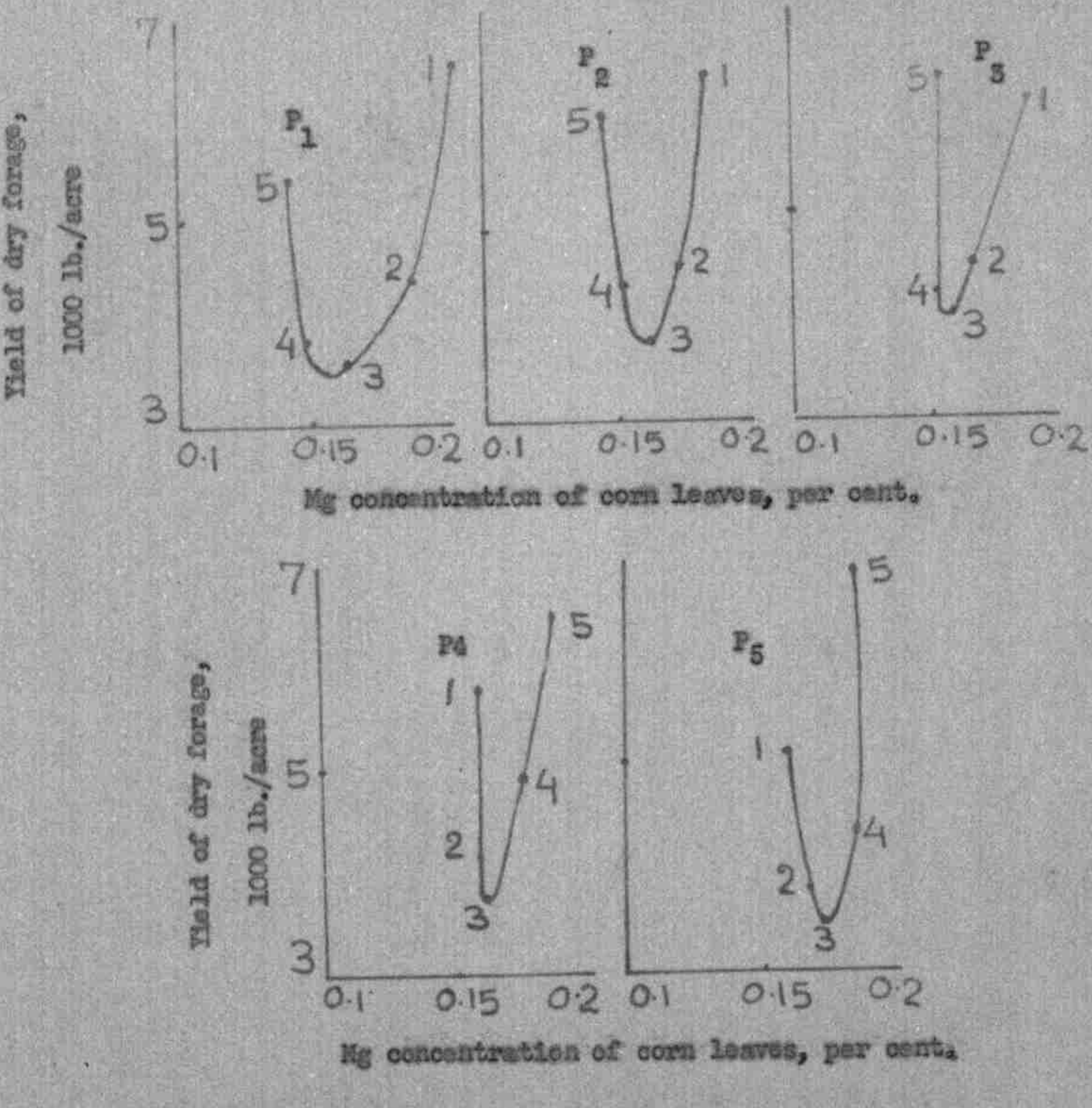

Fig. 59. Relationship between dry forage yield of corn (lb./acer) and Mg concentration (per cent dry wt.) as affected by addition of different levels of N and P under macronutrient treatments with K, Mg and S at the middle of five levels (Table 2). Numbers at points refer to levels of N added. Level of P was held constant for each graph.

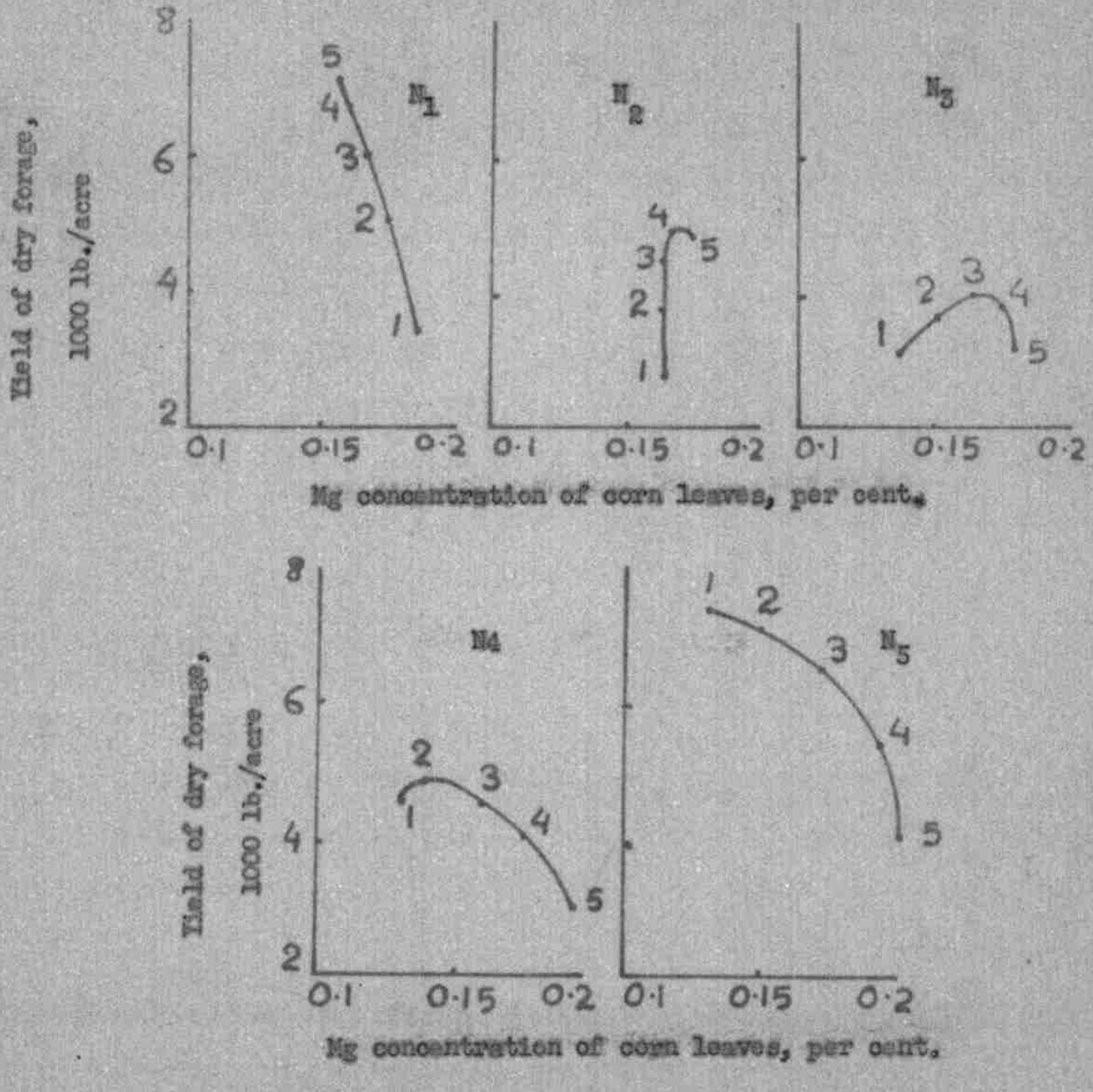

Fig. 40. Relationship between dry forage yield of corn (lb./acre) and Mg concentration (per cent dry wt.) as affected by addition of different levels of N and Mg under macronutrient treatments with P, K and S at the middle of five levels (Table 2). Numbers at points refer to levels of Mg added. Level of N was held constant for each graph.

ed to increase with increasing Mg except at the lowest level of applied N. However, when Mg was held constant ((Fig. 41), the first increments of N decreased the dry forage yield while the higher increments of N increased the dry forage yield. At low levels of Mg the yield increased above the 2 level of N while at high levels of Mg it increased above the 4 level. The Mg concentration decreased with increasing N at low Mg levels while at higher Mg levels it increased slightly.

The K-S interaction term was negative in value indicating a complementary effect on the Mg concentration. An increase in K or S tended to decrease the requirement of the other for Mg uptake.

Sulfur concentration of corn leaves. The analysis of variance for S concentration of corn leaves (Table 42) indicated that the linear and quadratic effects were highly significant. The lack of fit term was also highly significant and accounted for 28 per cent of the total treatment variation indicating an incomplete fit of the regression equation to the actual data.

The regression coefficients for the S concentration of corn (Table 43) revealed that all the linear effects were highly significant indicating that N, P, Mg and S increased the S concentration of corn leaves. All the quadratic effects except the P-Mg interaction were highly significant due to the very small experimental error for the S concentration of corn leaves found in this experiment.

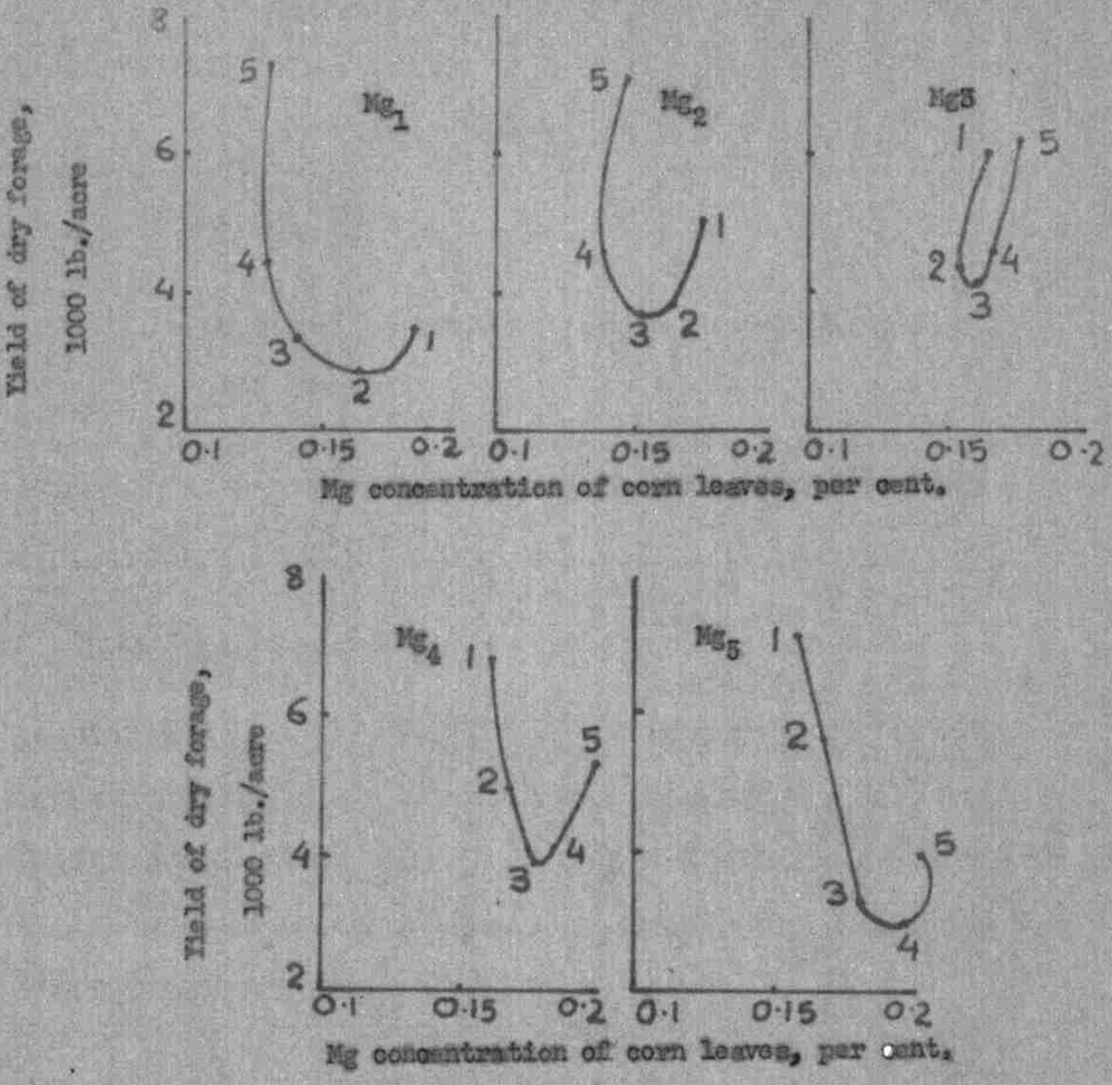

Fig. 41. Relationship between dry forage yield of corn (lb./acre) and Mg concentration (per cent dry wt.) as affected by addition of different levels of N and Mg under macronutrient treatments with P, K and S at the middle of five levels (Table 2). Numbers at points refer to levels of N added. Level of Mg was held constant for each graph.

Table 42. **Analysis of variance for S concentration of corn leaves.**

Source	**d.f.**	**s.s.**	**m.s.**
Total	31	0.020012	
Linear	5	0.002216	0.000443**
Quadratic	15	0.012111	0.000807**
Lack of fit	6	0.005682	0.000947**
Experimental error	5	0.000003	0.0000006

****Significant at odds of 99:1**

Table 43. **Regression coefficients (b) and their standard errors (s_b) for S concentration of corn leaves (% dry weight).**

Coefficient		b	s_b
Mean	b_0	+0.1994	±0.0001
N	b_1	+0.0023**	±0.0002
P	b_2	+0.0022**	" "
K	b_3	-0.0041**	"" "
Mg	b_4	+0.0024**	" "
S	b_5	+0.0078**	" "
N^2	b_{11}	+0.0089**	±0.0002
P^2	b_{22}	+0.0079**	" "
K^2	b_{33}	-0.0014**	" "
Mg^2	b_{44}	+0.0084**	" "
S^2	b_{55}	-0.0006**	
N X P	b_{12}	-0.0129**	±0.0002
N X K	b_{13}	-0.0019**	" "
N X Mg	b_{14}	-0.0040**	" "
N X S	b_{15}	-0.0028**	" "
P X K	b_{23}	-0.0051**	" "
P X Mg	b_{24}	-0.0004	" "
P X S	b_{25}	-0.0062**	" "
K X Mg	b_{34}	+0.0028**	" "
K X S	b_{35}	+0.0050**	" "
Mg X S	b_{45}	+0.0103**	" "

***Significant at odds of 19:1**

****Significant at odds of 99:1**

However, it was observed that the K and K^2 highly significant values were negative indicating that increasing K application decreased the S concentration of corn leaves.

The correlation coefficient between the actual S concentrations and the S concentrations calculated from the regression equation was (Table 44) 0.833 which indicated a close fit of the regression equation to the actual data.

The relationship between dry forage yield of corn and the N-P interaction (Fig. 42) indicated that increasing P at low levels of N decreased the dry forage yield but tended to increase the S concentration of corn leaves. At high levels of N, increasing P up to about the 4 level tended to increase the dry forage yield and decrease the S concentration of corn leaves. Above the N 4 level, increasing P tended to increase the S concentration. When N was varied at constant levels of P (Fig. 43), the first increments of N decreased the yield while the higher increments increased the forage yield. The sulfur concentration of the corn leaves increased with increasing N at low levels of P while at high levels of P, the tendency was for decreased S concentrations.

The relationship between dry forage yield and the S concentration of corn leaves as affected by the Mg-S interaction (Fig. 44) indicated that with increasing S at low levels of Mg, the dry forage yield was increased and the S concentration also tended to increase except that

Table 44. Observed S concentrations of corn leaves (per cent dry wt.) with macronutrients as variables. Values for the same treatments calculated from the regression equation are given. Correlation of actual S concentrations with calculated concentrations was 0.833.

Treatment level	Actual S concentration, %	Calculated S concentration, %
$N_2P_2K_2Mg_2S_4$	0.199	0.120
$N_4P_2K_2Mg_2S_2$	0.249	0.244
$N_2P_4K_2Mg_2S_2$	0.270	0.250
$N_4P_4K_2Mg_2S_4$	0.219	0.214
$N_2P_2K_4Mg_2S_2$	0.200	0.187
$N_4P_2K_4Mg_2S_4$	0.238	0.239
$N_2P_4K_4Mg_2S_4$	0.232	0.218
$N_4P_4K_4Mg_2S_2$	0.228	0.209
$N_2P_2K_2Mg_4S_2$	0.188	0.185
$N_4P_2K_2Mg_4S_4$	0.238	0.249
$N_2P_4K_2Mg_4S_4$	0.260	0.256
$N_4P_4K_2Mg_4S_2$	0.266	0.216
$N_2P_2K_4Mg_4S_4$	0.247	0.250
$N_4P_2K_4Mg_4S_2$	0.213	0.210
$N_2P_4K_4Mg_4S_2$	0.235	0.217
$N_4P_4K_4Mg_4S_4$	0.222	0.244
$N_5P_3K_3Mg_3S_3$	0.235	0.239
$N_1P_3K_3Mg_3S_3$	0.209	0.230
$N_3P_5K_3Mg_3S_3$	0.201	0.235

Table 44, continued.

Treatment level	Actual S concentration, %	Calculated S concentration, %
$N_3P_1K_3Mg_3S_3$	0.235	0.227
$N_3P_3K_5Mg_3S_3$	0.165	0.186
$N_3P_3K_1Mg_3S_3$	0.197	0.202
$N_3P_3K_3Mg_5S_3$	0.236	0.238
$N_3P_3K_3Mg_1S_3$	0.204	0.228
$N_3P_3K_3Mg_3S_5$	0.219	0.212
$N_3P_3K_3Mg_3S_1$	0.149	0.181
$N_3P_3K_3Mg_3S_3$	0.204	0.199

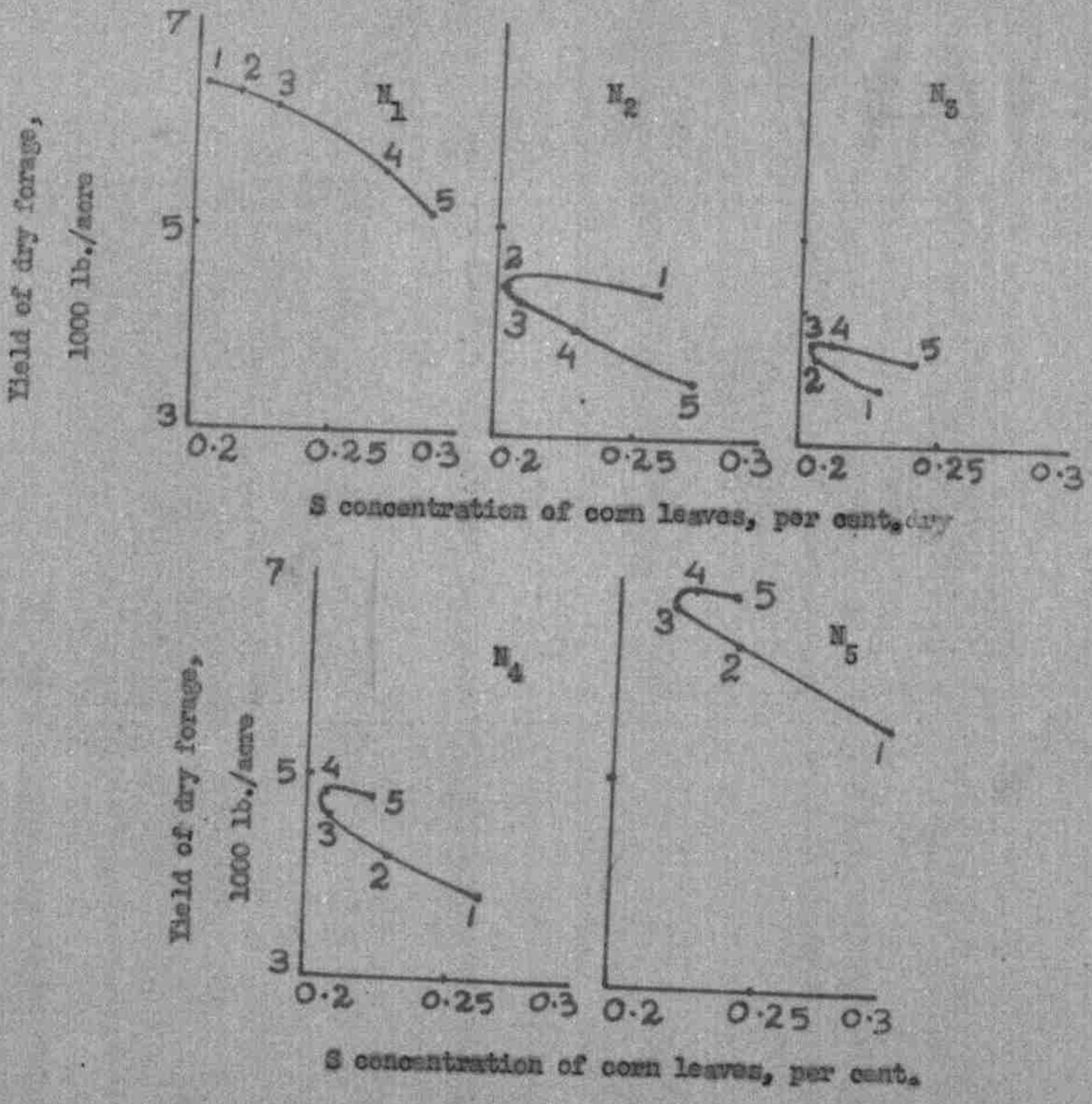

Fig. 42. Relationship between dry forage yield of corn (lb./acre) and S concentration (per cent dry wt.) as affected by addition of different levels of N and S under macronutrient treatments with P, K and Mg at the middle of five levels (Table 2). Numbers at points refer to levels of P added. Level of N was held constant for each graph.

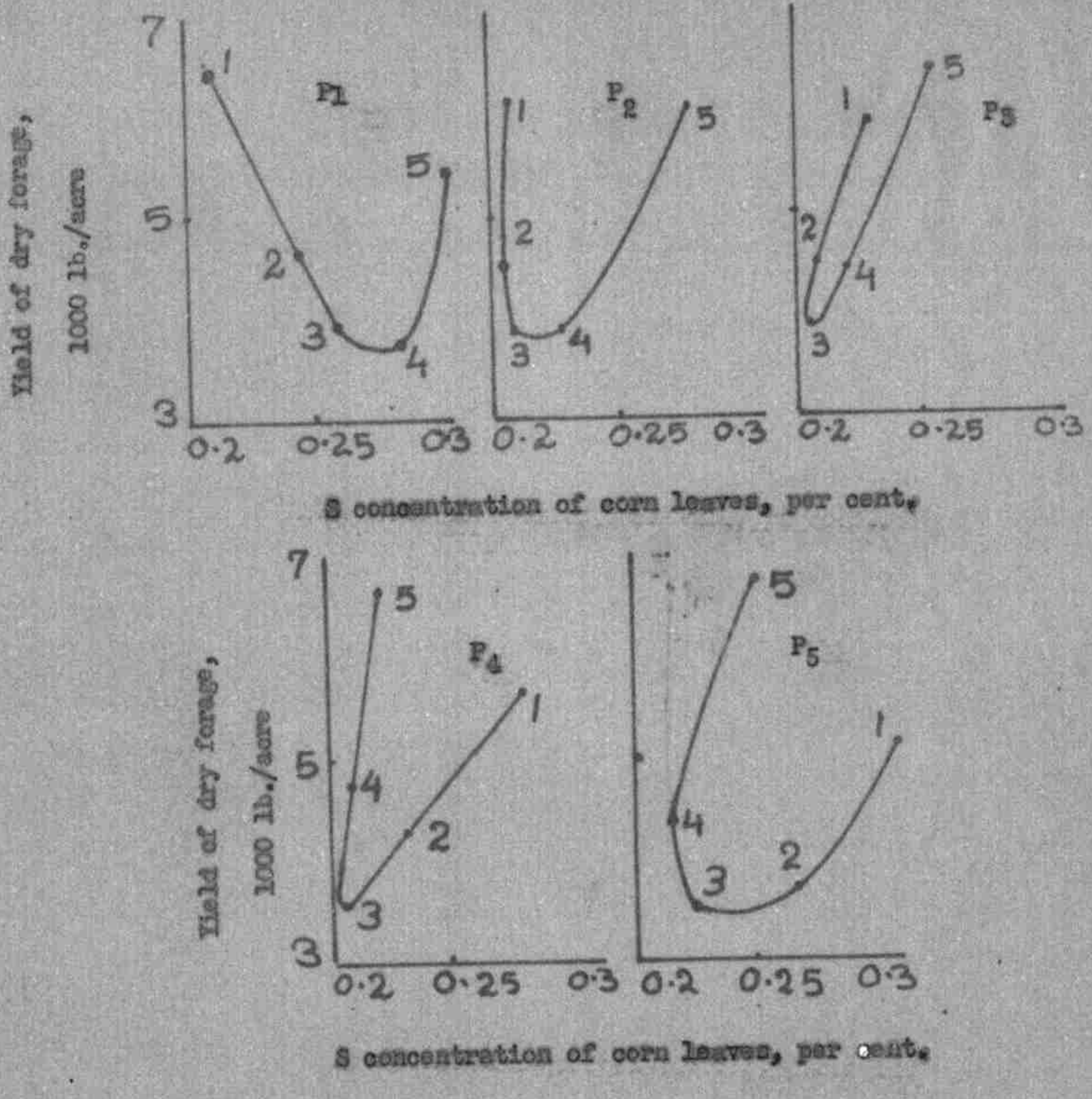

Fig. 43. Relationship between dry forage yield of corn (lb/acre) and S concentration (per cent dry wt.) as affected by addition of different levels of N andP under macronutrient treatments with K, Mg and S at the middle of five levels (table 2). Numbers at points refer to levels of N added. Level of P was held constant for each graph.

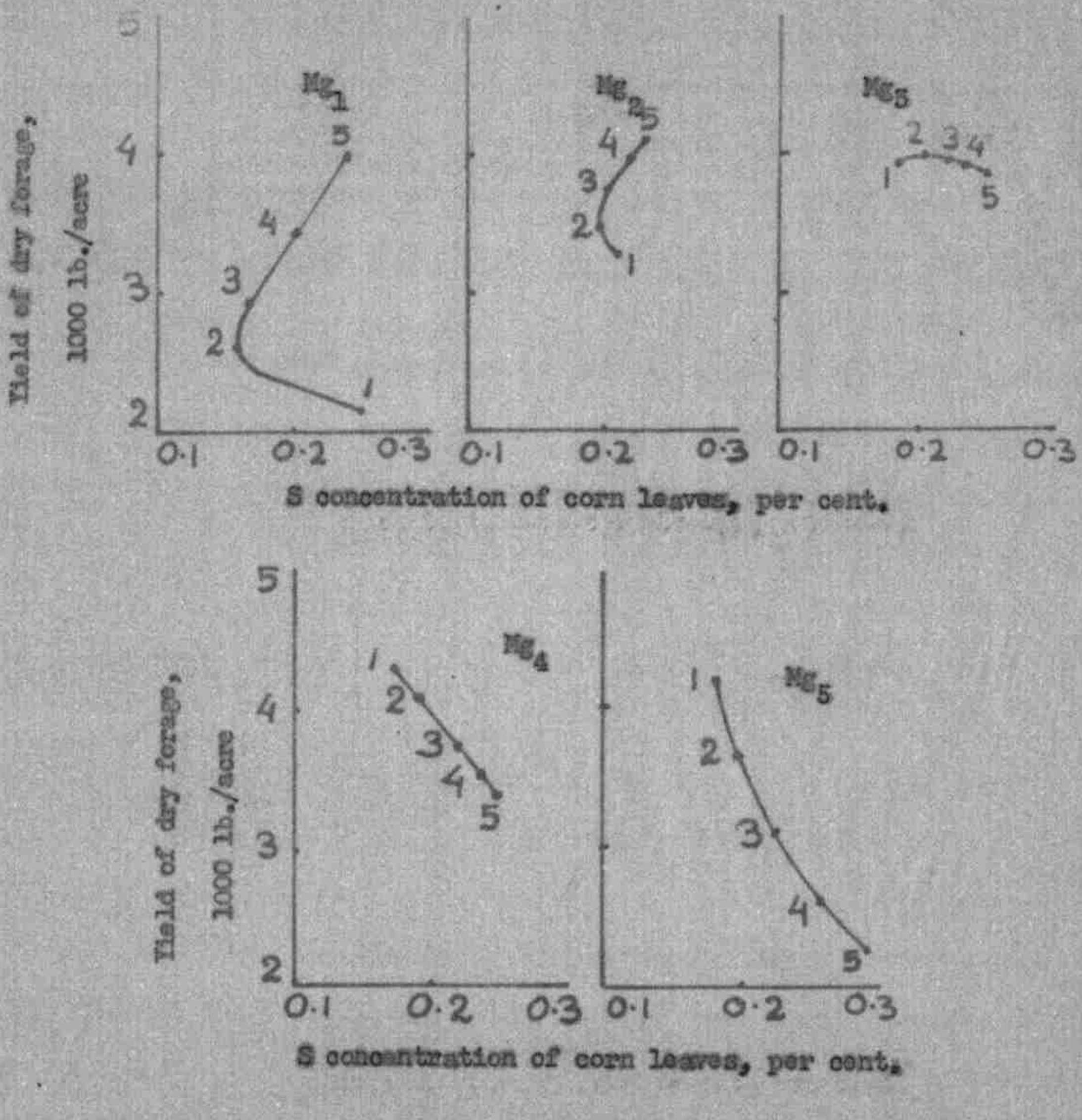

Fig. 44. Relationship between dry forage yield of corn (lb./acre) and S concentration (per cent dry wt.) as affected by addition of different levels of Mg and S under macronutrient treatments with N, P and K at the middle of five levels (Table 2). Numbers at points refer to levels of S added. Level of Mg was held constant for each graph.

the first increments of S resulted in decreased S concentration. At high levels of Mg, increasing S, decreased yield of dry forage as well as S concentration of corn leaves. However, when S was held constant (Fig. 45), increasing Mg tended to increase the dry forage yield at low levels of S while at high levels the tendency was for the decreased yields. The best level of applied Mg varied from about 4.5 at the S1 level to about 2 at the S 5 level indicating the decrease in the requirement for Mg as the level of applied S was increased. Increasing Mg tended to increase the S concentration except at the 1 level of S where it was decreased. The forage yields tended to be h highest when the S concentration of the leaves was close to 0.2 per cent.

Like the N-P, the following interactions were complementary: N-K, N-Mg, N-S, P-K and P-S. Thus, all the interactions involving N were complementary in nature indicating that less N is required for a high S concentration when P, K, Mg or S is high and vice versa. The K-Mg and K-S interactions, like the Mg-S interaction, were antagonistic in their effect on the S concentration of corn leaves.

Calcium Concentration of corn leaves. Analysis of variance for the Ca concentration of corn leaves (Table 45) showed no significant effect for any of the variability effects. However, the highest value was for the quadratic effects.

Examination of the regression coefficients for the

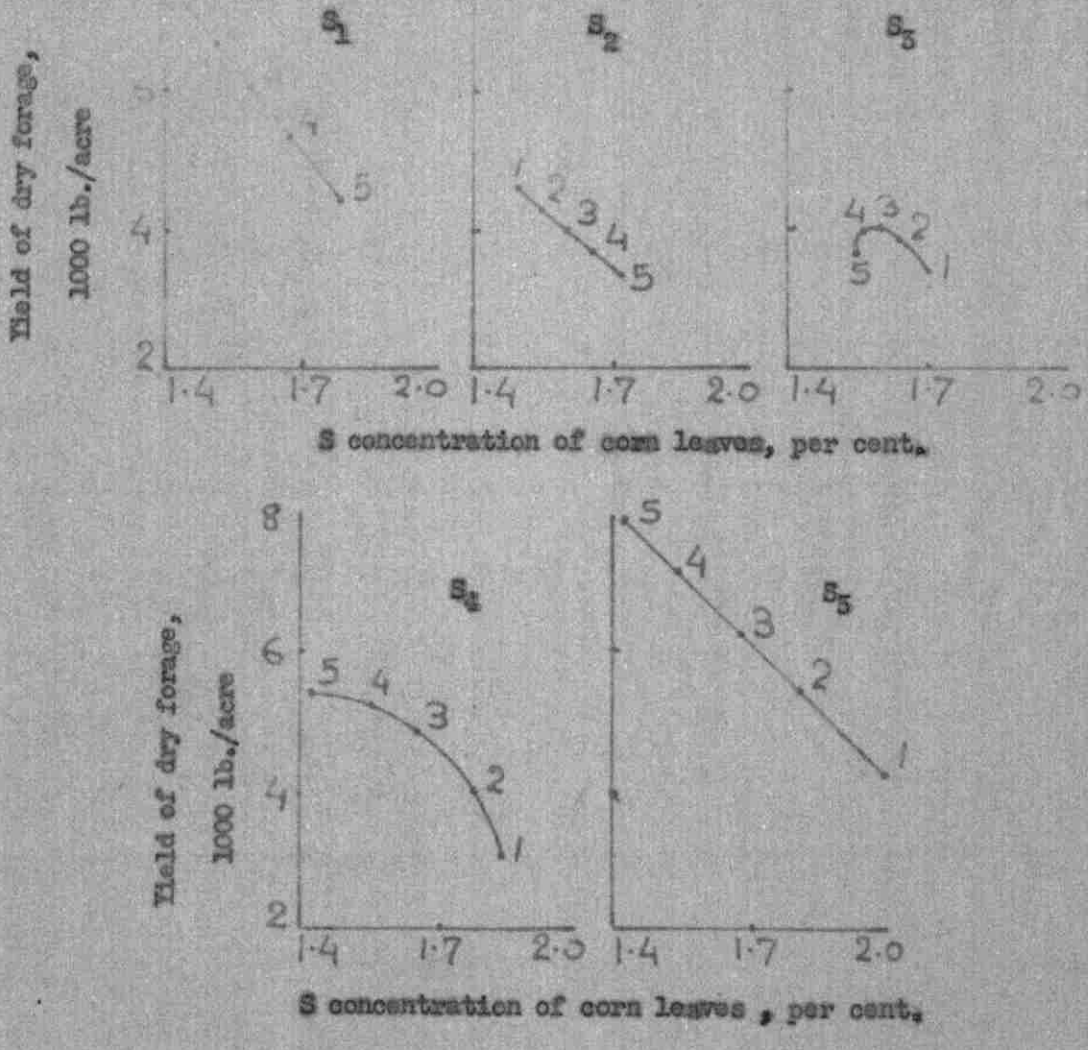

Fig. 45. Relationship between dry forage yield of corn (lb./acre) and S concentration (per cent dry wt.) as affected by addition of different levels of Mg and S under macronutrient treatments with N, P and K at the middle of five levels (Table 2). Numbers at points refer to levels of Mg added. Level of S was held constant for each graph.

Table 45. **Analysis of variance for Ca concentration of corn leaves.**

Source	d.f.	s.s	m.s.
Total	31	0.550	
Linear	5	0.102	0.021
Quadratic	15	0.359	0.024
Lack of fit	6	0.060	0.010
Experimental error	5	0.029	0.006

Ca concentration of corn leaves (Table 46) indicated that the linear effect of K was significant and negative showing that K decreased the Ca concentration of corn leaves. Among the quadratic effects, P^2 was highly significant and positive.while S^2 was significant and positive. However, the P and S linear effects were negative. Both of these elements were applied with Ca as the carrier which might be the reason for the increase in Ca concentration of corn leaves at high rates of application for P or S. The interaction effects of N-K, N-S and P-S were significant.

The correlation coefficient between the actual Ca concentrations and Ca concentrations calculated from the regression equation (Table 47) was 0.71 indicating an incomplete fit of the regression equation to the actual data.

Examination of the relationship between the dry forage yield and the Ca concentration of corn leaves as affected by the N-K interaction (Fig. 46), indicated that at low levels of N increasing K decreased the dry forage yield but increased the Ca concentration in the corn leaves. At high levels of N, increasing K decreased the Ca concentration in corn leaves but increased the dry forage yieldof corn. At constant levels of K (Fig. 47), the first increments of N decreased the yield while the higher levels of N increased the yields. Increasing N, increased the Ca concentration at low K levels while at high K levels it was decreased.

The relationship betweenthe dry forage yield and

Table 46. **Regression coefficients (b) and their standard errors (s_b) for Ca concentration of corn leaves (% dry weight).**

Coefficient		b	s_b
Mean	b_0	+1.586	±0.010
N	b_1	+0.031	±0.015
P	b_2	-0.037	" "
K	b_3	-0.042*	" "
Mg	b_4	+0.011	" "
S	b_5	-0.011	" "
N^2	b_{11}	+0.014	±0.014
P^2	b_{22}	+0.058**	" "
K^2	b_{33}	+0.009	" "
Mg^2	b_{44}	+0.005	" "
S^2	b_{55}	+0.053*	" "
N X P	b_{12}	+0.008	±0.019
N X K	b_{13}	-0.058*	" "
N X Mg	b_{14}	+0.022	" "
N X S	b_{15}	-0.052**	" "
P X K	b_{23}	+0.002	" "
P X Mg	b_{24}	-0.013	" "
P X S	b_{25}	+0.051*	" "
K X Mg	b_{34}	-0.034	" "
K X S	b_{35}	-0.035	" "
Mg X S	b_{45}	-0.016	" "

***Significant at odds of 19:1**

****Significant at odds of 99:1**

Table 47. Observed Ca concentrations of corn leaves (per cent dry wt.) with macronutrients as variables. Values for the same treatments calculated from the regression equation are given. Correlation of actual Ca concentrations with calculated concentrations was 0.710.

Treatment level	Actual Ca concentration, %	Calculated Ca concentration, %
$N_2P_2K_2Mg_2S_4$	1.79	1.73
$N_4P_2K_2Mg_2S_2$	1.85	1.87
$N_2P_4K_2Mg_2S_2$	1.50	1.48
$N_4P_4K_2Mg_2S_4$	1.80	1.80
$N_2P_2K_4Mg_2S_2$	1.85	1.81
$N_4P_2K_4Mg_2S_4$	1.55	1.55
$N_2P_4K_4Mg_2S_4$	1.85	1.80
$N_4P_4K_4Mg_2S_2$	1.46	1.48
$N_2P_2K_2Mg_4S_2$	1.79	1.75
$N_4P_2K_2Mg_4S_4$	1.88	1.87
$N_2P_4K_2Mg_4S_4$	1.80	1.75
$N_4P_4K_2Mg_4S_2$	1.84	1.87
$N_2P_2K_4Mg_4S_4$	1.73	1.66
$N_4P_2K_4Mg_4S_2$	1.84	1.86
$N_2P_4K_4Mg_4S_2$	1.59	1.57
$N_4P_4K_4Mg_4S_4$	1.55	1.55
$N_5P_3K_3Mg_3S_3$	1.78	1.70
$N_1P_3K_3Mg_3S_3$	1.44	1.58
$N_3P_5K_3Mg_3S_3$	1.74	1.74

Table 47, continued.

Treatment level	Actual Ca concentration, %	Calculated Ca concentration, %
$N_3P_1K_3Mg_3S_3$	1.83	1.89
$N_3P_3K_5Mg_3S_3$	1.50	1.54
N3P3K1Mg3S3	1.68	1.71
$N_3P_3K_3Mg_5S_3$	1.59	1.63
$N_3P_3K_3Mg_1S_3$	1.56	1.59
$N_3P_3K_3Mg_3S_5$	1.69	1.78
$N_3P_3K_3Mg_3S_1$	1.84	1.82
$N_3P_3K_3Mg_3S_3$	1.59	1.59

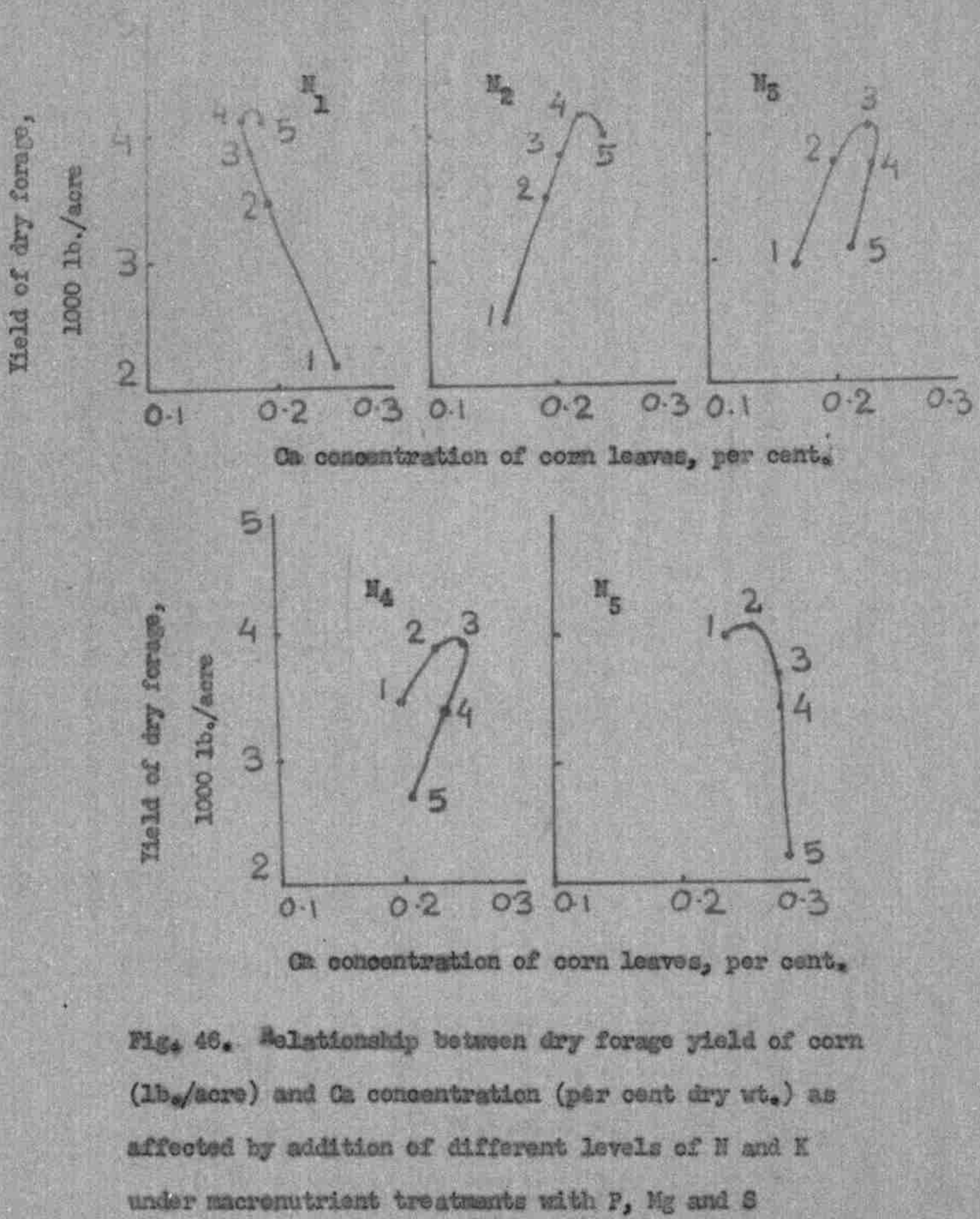

Fig. 46. Relationship between dry forage yield of corn (lb./acre) and Ca concentration (pêr cent dry wt.) as affected by addition of different levels of N and K under macronutrient treatments with P, Mg and S at the middle of five levels (Table 2). Numbers at points refer to levels of K added. Level of N was held constant for each graph.

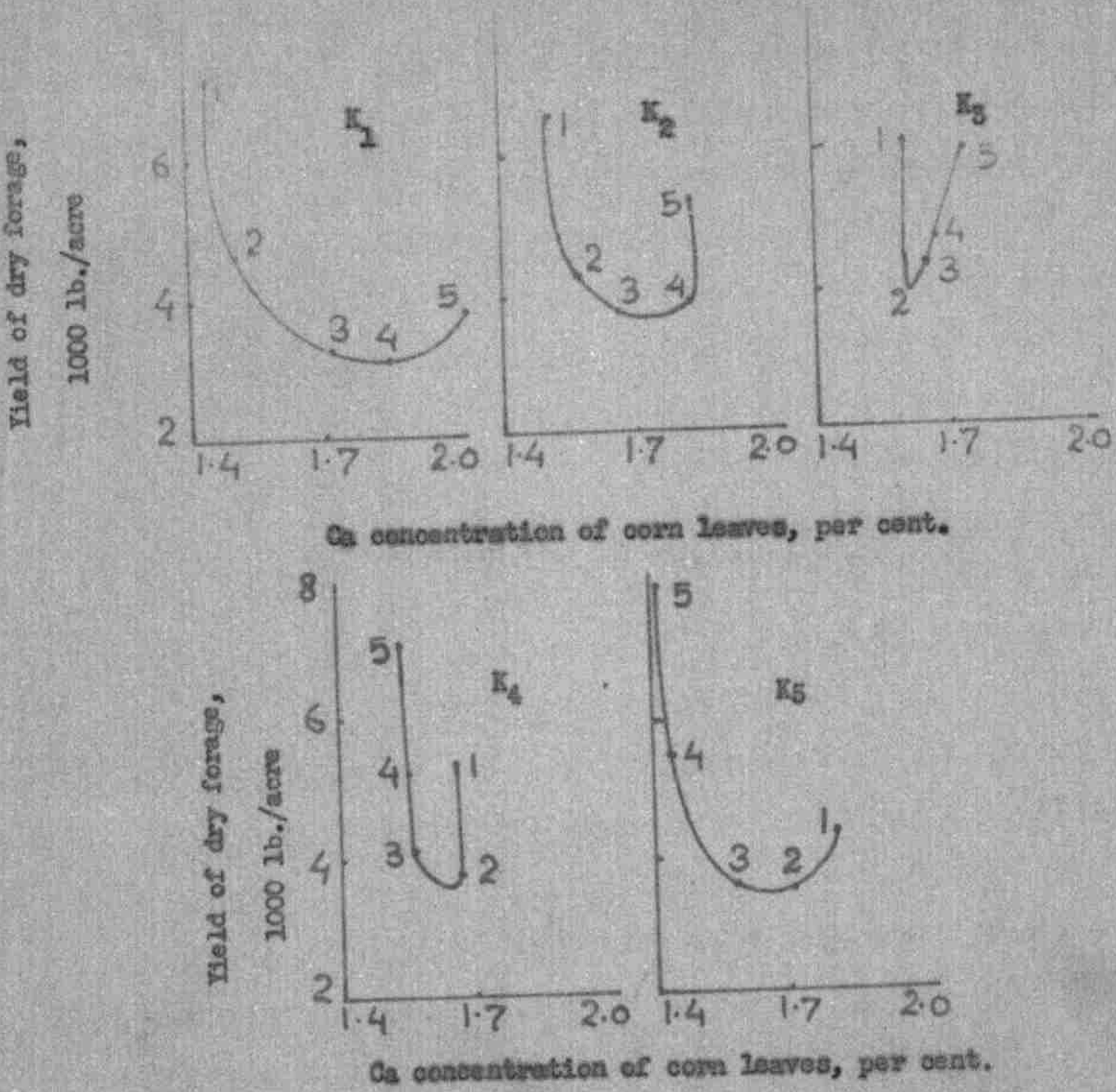

Fig. 47. Relationship between dry forage yield of corn
(lb./acre
(lb./acre) and Ca concentration (per cent dry wt.) as affected by addition of different levels of N and K under macromutrient treatments with P, Mg and S at the middle of five levels (Table 2). Numbers at points refer to levels of N added. Level of K was held constant for each graph.

and the Ca concentrations of corn leaves (Fig. 48) as affected by the N-S interaction indicated that at low levels of N increasing S levels resulted in decreased yield with a tendency for increased Ca concentration. At high levels of N increasing S increased dry forage yield but tended to decrease Ca concentration. When S was held constant (Fig. 49), the first increments of N tended to decrease yield. While the higher increments increased the yield of dry forage. The Ca concentration increased with increasing N at low levels of S and tended to decrease with increasing N at high levels of S. Highest yields of corn forage tended to occur at a Ca concentration of about 1.6 per cent with decreasing yields above this value.

Unlike the N-S and N-K interactions, the P-S interaction was antagonistic in its effect on the Ca concentration of corn leaves. Since both P and S were applied in the form of Ca salts it was unexpected that an increase in one would result in a higher requirement for the other in order to maintain the Ca concentration in the corn leaves.

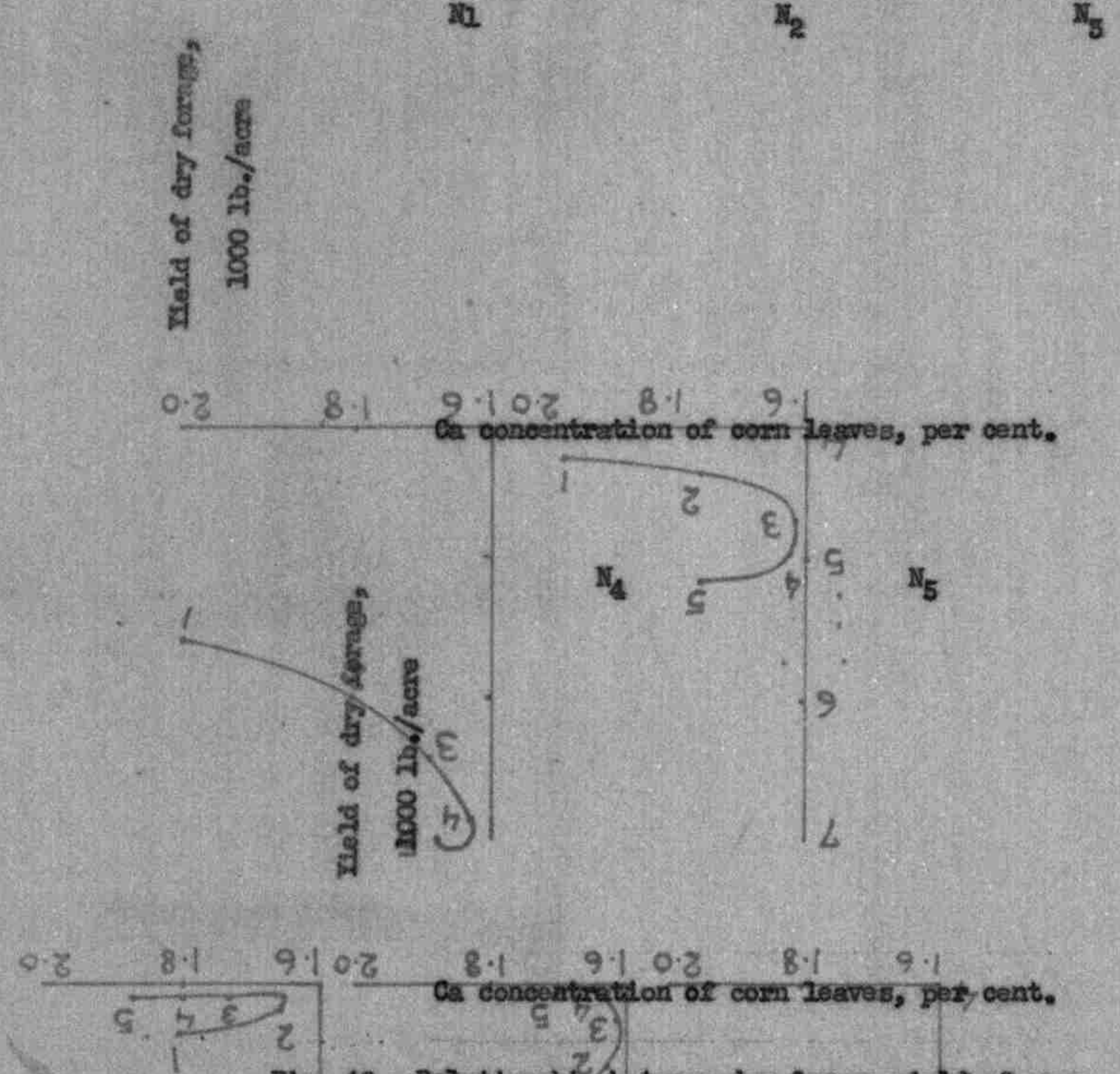

Fig. 48. Relationship between dry forage yield of corn (lb./acre) and Ca concentration (per cent dry wt.) as affected by addition of different levels of N and S under macronutrient treatments with P, K and Mg at the middle of five levels (Table 2). Numbers at points refer to levels of S added. Level of N was held constant for each graph.

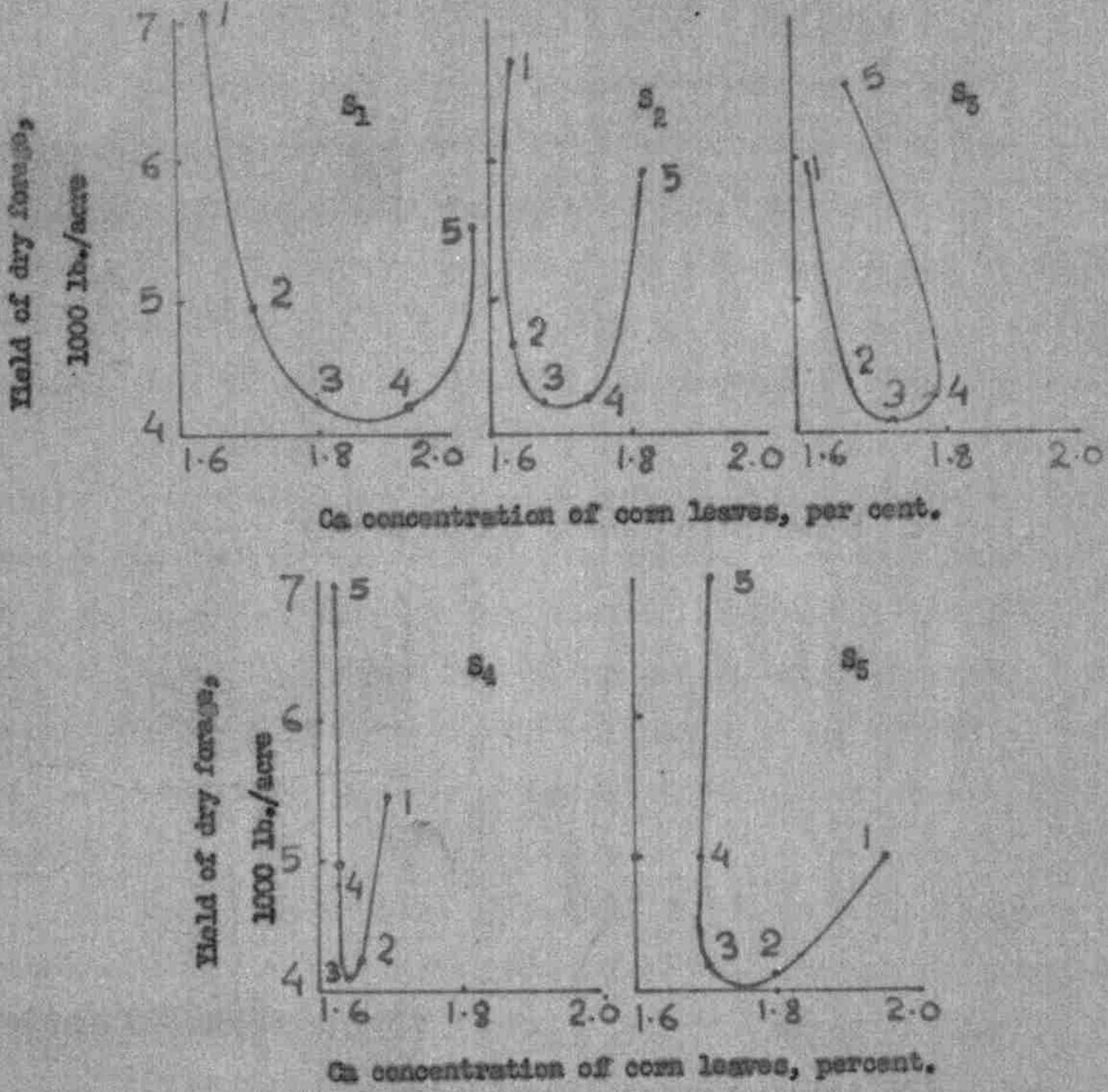

Fig. 49. Relationship between dry forage yield of corn (lb./acre) and Ca concentration (per cent dry wt.) as affected by addition of different levels of N and S under macronutrient treatments with P, K and Mg at the middle of five levels (Table 2). Numbers at points refer to levels of N added. Level of S was held constant for each graph.

SUMMARY AND CONCLUSIONS

An exploratory field experiment was conducted in 1960 at the American University of Beirut Farm with the objective of evaluating the existence and magnitude of interaction effects of micronutrients (Zn, B, Fe, Mn and Cu) and macronutrients (N, P, K, Mg and S) on vegetative growth, grain yield of corn and chemical composition of corn leaves.

The central composite, rotatable, incomplete factorial design was used to investigate response surfaces involving 5 variables each at 5 levels ranging from very high to very low rates of application. The design included 27 treatments under each micronutrient and macronutrient set. One of the treatments in each set was replicated 6 times in order to permit estimation of the experimental error.

Leaf samples were collected at the silking stage and analysed for Zn, B, Fe, Mn and Cu from the micronutrient treatments set and N, P, K, Mg, S and Ca from the macronutrient treatments set.

Corn was harvested for grain and dry forage yields and reported as bu.per acre of shelled corn at 15.5 per cent moisture and lb. per acre on the air dry basis respectively.

Regression equations of the quadratic form were developed for yield and for elemental composition. Statistical significance of the individual regression coefficients was determined by the "t" test.

A negative sign of the regression coefficient value for an interaction term indicated a complementary effect while a positive sign indicated an antagonistic effect.

Micronutrients

1. In general, corn grain production under the conditions of this experiment was adversely affected by all micronutrient additions indicating that their indiscriminate use is likely to result in severe economic loss. The interaction of Zn-Mn was antagonistic and significant showing that the response to one element was affected by the level of the other. The toxic effect of either Zn or Mn was counteracted by the other.

2. The yield of dry forage of corn increased markedly with Zn applications. It was found that a high level of Zn accompanied by a fairly high level of Fe was necessary for maximum dry forage production of corn. However, since the increase in the dry forage yield with the Zn application was secured at the expense of a decrease in yield of grain, Zn application would not be economically feasible under the conditions of this experiment. The significant B-Mn interaction was complementary while the significant Cu-B interaction was antagonistic in its effect on the yield of dry forage.

3. Zinc applications depressed the grain yield of corn. High grain yields were obtained at 20 ppm. Zn concentration in corn leaves. However, Zn requirement of

corn was higher for forage production and the highest yields were obtained at Zn concentrations in corn leaves above 150 ppm.

4. Boron application directly increased the B concentration of corn leaves ranging from 10-100 ppm. B between the low and high B applications.] The Mn effect on B concentration was positive and highly significant while the Fe effect on B concentration was negative and significant. The highly significant Zn-B interaction was complementary while the significant Fe-Cu interaction was antagonistic in its effect on B concentration. Above and below about 30 ppm. B, the dry forage yield of corn tended to decrease.

5. Iron concentration of corn leaves was decreased by Zn application. The highly significant Mn-Cu and sigficant Zn-Mn interactions were complementary. The concentration of Fe was not closely correlated with dry forage yields since high yields were obtained at Fe concentrations anywhere from 50 to 70 ppm.

6. The application of Mn increased the Mn concentration of corn leaves while Zn decreased it. The significant Zn-Cu interaction was antagonistic. The yield of dry forage tended to drop off sharply above and below a Mn concentration of about 100 ppm.

7. Applications of Cu and Fe increased the Cu concentration of corn leaves while the Zn decreased it. The highly significant Fe-Mn interaction and significant Zn-Cu interactions were antagonistic while the significant B-Cu interaction was complementary in its effect on Cu concentration.

of corn leaves. The high dry forage yields tended to occur around 20 ppm. Cu concentration of corn leaves.

Macronutrients

1. The grain yield of corn was not greatly affected by the linear effect of macronutrients. The significant Mg-S interaction was antagonistic indicating that increasing amounts of Mg or S increased the requirement of the other. For the highest economic yield of grain, rates of N up to 300 lb. per acre would be justified. However, P, K, Mg and S applications would be unnecessary under the conditions of this experiment.

2. The results obtained in this experiment showed that the macronutrient requirements for dry forage were considerably different than the requirement for grain production. The highly significant N-K, P-S, K-S and significant N-S and P-K interactions were antagonistic while the significant N-Mg and significant P-Mg and Mg-S interactions were complementary. The optimum combination of macronutrients for the maximum forage yield of corn indicated that high rates of N, P, K and S combined with a low rate Mg were required. However, since P, K and S decreased grain production and grain is more valuable than forage it is doubtful that application of those elements would be practical.

3. Nitrogen concentration of corn was significantly increased by N and K but decreased by P applications.

The highly significant N-P, N-Mg and Mg-S interactions were complementary while the highly significant N-K, K-S and significant P-K and K-Mg interactions were antagonistic which indicated that a high supply of N, P, Mg or S increased the amount of K necessary for N uptake by corn plants. The amount of N in corn leaves for high yield of dry forage varied from 2.0 to 3.0 percent with no definite critical level.

4. Phosphorus concentration of corn leaves was significantly increased by P, Mg and S applications. The highly significant N-S and P-K and the significant N-P and N-K interactions were antagonistic while the highly significant N-Mg and significant P-S interactions were complementary. In general, the highest yields tended to be associated with P concentration in corn leaves of about 0.25 per cent.

5. Potassium concentration of corn leaves was decreased by increasing K and Mg applications. The significant Mg-S interaction was complementary in its effect on K concentration of corn leaves. The yield of dry forage tended to drop off appreciably below a K concentration of about 5 per cent in the corn leaves.

6. Magnesium concentration of corn leaves was greatly increased by Mg and K applications. The significant N-P and N-Mg interactions were antagonistic while the significant K-S interaction was complementary.

7. Sulfur concentration of corn leaves was increased by increasing N, P, Mg and S and decreased by K applications. The following pairs of interactions were highly significant and complementary : N-P, N-K, N-Mg, N-S, P-K and P-S. While the K-Mg, K-S and Mg-S highly significant interactions were antagonistic. The level of S cconcentration of corn leaves associated with high dry forage yields was about 0.2 per cent.

8. Calcium concentration of corn leaves was decreased by K application while P and S increased it. The N-K and N-S significant interactions were complementary while the significant P-S interaction was antagonistic in its effect on the Ca concentration of corn leaves. The level of Ca in corn leaves for high dry forage yields was about 1.6 per cent.

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