INTERRELATIONSHIPS OF NITROGEN PHOSPHORUS, POTASSIUM, MAGNESIUM AND SODIUM ON THE GROWTH AND COMPOSITION OF SUGAR BEETS

by

KARIM EDDEEN KAMEL HUSSIENI

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Approved

H. D. Fuehring
In Charge of Major Work

Robert A. Nichols

W. W. Worzella

Osozep

Chairman, Graduate Committee

American University of Beirut
1961

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HUSSIENI

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ABSTRACT

A field experiment was conducted on a calcareous soil to study the effects and interrelationships of the macronutrients N, P, K, Mg and Na on the growth and composition of sugar beets using a central composite, rotatable, incomplete factorial design involving 5 variables, each at 5 levels of application. Quadratic regression equations were developed for characterization of the response surfaces for yield of roots, yield of tops, percentage of sucrose, yield of sugar and chemical composition of sugar beet leaves.

In general, all variables had a positive effect on yield of roots. Nitrogen followed by Na gave the highest significant increases in yield of beet roots. The Mg-Na interaction was highly significant and complementary in effect. The yield of tops was significantly increased by N and to a lesser extent by Na. The highly significant N-P interaction was antagonistic in effect. The percentage of sucrose was not significantly affected by any of the elements varied. Application of N and Na gave highly significant increases in yield of sugar followed by Mg and K while the slight increase from P was not significant. The highly significant P-K interaction was antagonistic whereas the highly significant K-Mg, K-Na and Mg-Na interactions were complementary indicating that those three cations may partially substitute for each other in sugar beet nutrition. The leaf composition of beets was considerably affected by the addition of macro elements and the interactions

between them. However, no definite critical concentrations could be established in most cases since the point of highest yield depended on the balance among all the applied nutrients. In general, it was found that addition of K, Mg and Na depressed the Ca concentration while the yield of sugar was increased.

The maximum theoretical yield under the conditions of this experiment and within the limit of the levels of the variables used was found to be about 8.3 tons of sugar/acre (40 tons of sugar beet) with the combination 5N, 1P, 3K, 1Mg and 5Na.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF FIGURES

Figure		Page

Figure | Page

Figure | Page

I. INTRODUCTION

In 1605 Oliver de Serres, a French agronomist observed that some varieties of wild beet contained sugar, and in 1750 Andrew Marggraf, a German chemist, obtained sugar crystals from beet roots. No practical application of Marggraf's discovery was carried out during his life, until his pupil Frank Karl Achard successfully continued Marggraf's experiments and subsequently established the first sugar beet factory in 1801. The efforts of Marggraf and Achard created extreme attention in all Europe and later on in the U.S.A., and a period of intensive research and investigation started in the 19th century and continued up to the present. It was difficult for the beet sugar industry to survive, because of the competition from cane sugar produced in the tropics. The sugar beet industry was supported by governments because of the necessity for national independence from external sugar supplies, the high prices of sugar during wars and blockades, and the beneficial influence of this industry on both agricultural and national economies.

Since Marggraf's discovery until the present the sugar beet crop has become increasingly more important in the world economy. The production has been revolutionized by plant breeders, agronomists, and engineers. The actual world production of sugar is about 35 million tons (89) with a price value of about two billion dollars, and it is estimated that about one third of this world sugar production is from sugar beets. The future of the sugar beet crop is very promising because the world sugar consumption is increasing continuously as a result of the increase in world population and the increase in per capita consumption of sugar with rising standards of living.

In the Middle East, the first beet sugar factory was established in Iran in 1900 (89). Additional factories were established in Turkey, Afghanistan and Syria, and more recently in Iraq and Lebanon.

In Lebanon sugar beet production started in the Beka'a plain in 1949, after the establishment of the sugar beet factory in Syria. In 1956 about 3500 dunums of land were planted to sugar beets and the average yield was about 10 tons per acre with sugar percentage ranging from 16.5-22.0 (6). The future success of sugar beet production in Lebanon is dependent on many factors among which adequate soil fertility management is one of the most important. While the sugar beet is inherently adaptable to a wide variety of soil conditions, it requires generous supplies of plant nutrients along with proper nutrient balance for maximum yields. The fertilizer elements used in greatest quantity in sugar beet production are N, P and K, and Ca, Mg, S and Na along with various micronutrients are also required. Although Na is not considered an essential nutrient for plant growth, it has been proved to be beneficial to the growth of sugar beets in many instances. More information is required with regard to the relationship of Na to other plant nutrients.

In designing field or pot experiments on the effect of fertilizers, all factors that might possibly affect the yield are too numerous to be included in any one trial, and for this reason it was decided to use a central composite, rotatable, factorial design as described by Hader et al. (33) in order to study a number of variables simultaneously with a reasonable number of treatments. Five macro-nutrient elements (N, P, K, Mg and Na) were varied at five different rates of application in order to study the following:

1. The yield of beet sugar as affected by each element individually and in combination with others.

2. The optimum rates of application for maximum yield of sugar.

3. The composition of sugar beet plants as affected by levels of N, P, K, Mg and Na application.

REVIEW OF LITERATURE

Many problems related to the fertilization of sugar beet have been investigated in a field, green house, and laboratory experiments. Some problems were answered easily whereas others are still under investigation. It is the purpose of this chapter to review the available information related to the interrelationships of macronutrient elements and sugar beet production.

Effect of Nitrogen

In 1918 Kraus and Kraybill (12) investigated the interrelation of N supply and carbohydrates balance in plants and concluded that when the supply of N was low to the point where carbohydrates utilization did not keep balance with photosynthesis the carbohydrates accumulated. On the other hand, with an abundant supply of N, the tendency was for carbohydrates to be utilized or consumed to produce nitrogenous compounds. This hypothesis was tested by Gardner and Robertson (29). They found that the sucrose percentage decreases with increasing concentration of nitrate in the leaves and they concluded that maximum yield of sugar was reached at a lower level of nitrate than the maximum yield of roots. The results of a number of workers Russell (76), Haddock (35, 36), Nelson et al. (66), Frakes and Childs (26), Ririe et al.(73), Krantz and Mackenzie (51), Carlson and Herrin (15), Ulrich (87, 88) and Hac et al.(31) was in general agreement with the hypothesis that there existed a negative correlation between N application and percentage of sugar in roots. Hill (40) in a field experiment reported that the correlation coefficient of percentage sugar with nitrate concentration in sugar beet petioles was equal to - 0.505.

The effect of N application on sugar beet yield of roots and yield of sugar was studied extensively by many workers including Haddock (35, 36), Ulrich (87, 88), Hills (42, 41), Nelson et al. (66), Afansieve et al. (2, 1), Tolman et al. (84), Russell (76), Dowine (23), Swift (81), Hanson (37), Whitney et al. (95), Walker et al. (92), Baird (10), Culbertson (20), Boawn (14), Cormany (17), Doneen (21), Hanson (37) and Vaugh and Haddock (90). These workers agreed that in all cases application of N increased root tonnage and decreased percentage of sugar. In many cases they found that the increase of root tonnage was more than the decrease of sugar percentage and as a result the yield of sugar was increased. The relationship between soil total N content and yield of sugar beet was studied by Rhoades and Harris (72). They reported that the percentage sucrose was negatively correlated with total N concentration in the soil. Baird (10) conducted a field experiment in South Dakota and he obtained results similar to those of Rhoades and Harris. Tolman et al. (84) conducted a survey of soil organic matter levels and their relation to N need and concluded that the percentage increase of root yield over the check from the application of 400 lb. of N per acre is negatively correlated with soil organic matter percentage. He obtained a 24 percent increase in yield from a soil containing 0.5 percent organic matter and only 4.0 percent increase for soil containing 2.5 percent organic matter.

The critical level of N in the beet plant has been investigated in field and pot experiments by Ulrich (86). He concluded that sucrose percentage decreased with increasing nitrate concentration of petioles, whereas the yield of roots increased sharply with nitrate concentration of petioles until a level of 1000 ppm is reached above which yield kept constant. Results of Carlson and Herring (15) were in agreement with those obtained by Ulrich. The critical level was found to be 1000 ppm nitrate concentration of petioles. Hanson and Haddock (37) reported that they were able to get significant response of beet to N application when the nitrate concentration of petioles was 1500 ppm, but no response was obtained when the nitrate concentration was 3000 ppm.

Krantz and Mackenzie (51) concluded that nitrate concentration of beet petioles was highly correlated with N application and degree of response. They found that for optimum yield the nitrate concentration of petioles should be maintained above the critical level until about 11-12 weeks before harvest. When the nitrate concentration was higher than the critical level 3-9 weeks before harvest the sucrose percentage was decreased. Ulrich (88) reported the results of a sand culture experiment in which sugar beets were grown under controlled temperature and light conditions and concluded that plants with a high nutrient level of N failed to "sugar up" or to accumulate sugar after 83 days, while growth of tops and roots continued, on the other hand plants with a lower supply of N started to accumulate sugar after 83 days of growth. Haddock (34) found that the nitrate concentration of petioles was relatively high early in the season and decreased rapidly until the end of July, and reached a minimum in October. Haddock (35) conducted field experiments and concluded that the soil must provide 10 lb. of N for each ton of beets produced. Under conditions where the soil is able to supply more than this quantity, addition of N would not give a significant increase but might have an adverse effect on yield and sugar percentage.

Hills and Axtell (41) tested five different N carriers and they found that all of them significantly increased yield tonnage and gross sugar, but none of them affected the percentage sucrose. There were no differences between N carriers in effect on yield. The concentrations of nitrate in petioles indicated that calcium nitrate application gave the highest significant values as compared to sodium nitrate or ammonium sulfate. Hills and Axtell (41) mentioned that Ulrich obtained similar results and he found that no differences in yield or sucrose percentage were obtained among plants fertilized with anhydrous ammonia, calcium cyanamide, ammonium nitrate, urea, ammonium sulfate, sodium nitrate, or calcium nitrate. However, the results of other workers (91, 94, 8, 19, 12) were in disagreement with those obtained by Hills and Axtell. They concluded that sodium nitrate was the best carrier for N fertilization.

Walker et al.(93) conducted a sand culture experiment and concluded that the glutamic acid content of leaves is a good indication of the nutrient status of N in sugar beet. This was also emphasized by Hac et al. (31, 32) who found that there was a negative correlation between glutamic acid concentration in leaves and the percentage sucrose in roots.

The effect of N application on the growth of sugar beet tops was also investigated. Haddock (36) found that yield of tops increased as available N increased and likewise the top/root ratio tended to increase. He also found that growth of tops is more nearly proportioned to the available nitrogen in the soil, while root growth reached a maximum after which yield remained constant. However, when N supply is in excess of that required to stimulate root growth, the percentage sugar is depressed in roots and increased in leaves. Haddock also concluded that the top/root ratio may serve as an indication for the N nutrient status of beets. When N was the only variable growth factor, he mentioned that, under normal irrigation and fertilization, this ratio should approach 0.5 in the Great Basin area in Utah.

The interaction of N with other elements has been investigated. Tolman et al. (83) conducted field experiments in Utah, Idaho, Washington, Montana, and South Dakota. They found that the response of sugar beets to N in tonnage of beets and gross sugar was greater as the available P increased. Alexander et al. (5) reported the results of field experiments and concluded that the N and P concentration of leaves decreased with age, whereas Ca, Mg, Na, and K concentrations increased with age. The sugar beet composition was affected by N application as follows: N and P percentages of leaf blades were increased, whereas K, Na, and Ca concentrations decreased.

Effect of Phosphorus

The implication is sometimes made that P has some special effect on the growth of roots that it does not have on the above-ground portion of the plant. Russell (76) reviewed many field experiments conducted in England and concluded that sugar beet response to P was in terms of root growth, but there was no effect on sugar percentage. Larson (52) concluded that P application did not affect the percentage of sucrose. Hill (40) concluded that P application increased sugar beet root tonnage. Many results obtained by other workers (43, 50, 61) showed no response of sugar beet to P application. This brought attention to the available P supply of the soil in relation to sugar beet degree of response as a result of P application. Thorne and Tolman (82) conducted field experiments and concluded that soils containing available P_2O_5 (carbon dioxide soluble) less than 5 ppm. responded highly to P application. On the other hand there was no response at a level of more than 50 ppm. of P_2O_5. Responses of soils between 5-50 ppm were somewhat less related to yield. Carlson and Herring (15) conducted field experiments in four different locations. Sugar beet response to P application was recorded in one location where available P_2O_5 was 8.3 ppm.(sodium bicarbonate soluble). On the other hand no response was obtained in the other 3 locations where available P_2O_5 was 83-89 ppm. Olsen et al. (68) found that in a calcareous soil calcium metaphosphate was less available than superphosphate in the early stages of sugar beet growth, but had about the same availability thereafter; ammonium phosphate and superphosphate were about equally available. Alpha tricalcium phosphate supplied the least amount of P at all stages of growth. Measurements with radioactive P showed that the sugar beets absorbed about 10-12 percent of the applied P. Pendelton and Robbins (69) reported that the sugar beet crop removed P from the soil in amounts about half as great as the N removed and about the same quantity of K as of N. The P and K concentrations of sugar beet foliage were more constant than the concentration of N. Allos and Macksoud (6) conducted a field experiment in the Beka'a valley of Lebanon (calcareous soil) and they concluded that sugar beet tonnage was increased significantly by N and P application, while sugar percentage did not vary significantly.

The critical level of phosphate in sugar beet petioles was determined by Ulrich (86). He found this critical level was 1000 ppm PO_4 above which there was no increase in yield. Haddock (34) concluded that phosphate concentration of sugar beet petioles tended to decrease rapidly till July, after which the rate of decline became very gradual and reached a minimum in October. The absolute amount of phosphate was much smaller than the amount of nitrate early in the season, but becomes greater at harvest time. The uptake of P by sugar beet was more highly influenced by the amount of available N in the soil than the uptake of N was influenced by the amount of available P. Hills and Veaco (43) conducted twelve field experiments to determine the response of sugar beets to P application and they concluded that no response in yield was obtained when the concentration of phosphate (PO_4) in the petioles of check plots was higher than the critical level determined by Ulrich (1000 ppm).

The interaction of P with other elements was also investigated. Grunes (30) proved that the response of beet to P application was much higher when the supply of N was adequate or added. The uptake of P from the soil was increased when N supply was high. Using radioactive P measurements he proved that the yield of sugar beet roots is highly correlated with percent P absorbed from fertilizer applications. Alexander et al. (5) found that application of P decreased the percentage of Mg and Ca in leaves and increased the Na percentage.

The interrelationship of P with other elements was investigated by Tolman (85) who conducted a field experiment and concluded that when N is very deficient in the soil the application of P did not result in any increase of sugar beet yield and in some cases tended to depress the yield. Application of N + P gave a good response which was higher than the added response of each element alone. Gardner and Robertson (29) reported that P application increased sugar beet yield 3.5 tons per acre but when P and N were added the increase was 7.0 tons per acre.

Effect of Potassium

Potassium is one of the essential elements in the nutrition of the plants. Several lines of evidence substantiate the view that the function of K is not a structural one but is associated with the metabolism of plants. Perhaps one of the most direct effects of K on the yield of sugar beets and other root crops is its role in photosynthesis and root growth. The role of K in carbon dioxide assimilation and carbohydrates accumulation was extensively studied by many workers including Robinowitch (74), Pirson (71), and Eaton (25). They concluded that K is needed for efficient carbon dioxide assimilation. Black (12) reported that K deficiency resulted in a reduction in sucrose percentage in sugar cane as well as a reduction in total yield of sugar.

The effect of K on root development has received considerable attention because of the marked effect of K on root crops. According to Black (12) a good crop of potato tubers contained about twice as much K as the tops, and during tuber development some of this K was translocated from the tops. Black also reported a culture experiment in which the potato yield of tubers was increased about 15 times as a result of K application while top growth was not affected. Also the percentage of starch was increased from 53 to 66 percent.

Carlson and Herring (15) reported the results of four field experiments and concluded that when available K was more than 1000 lb. per acre, addition of K decreased root weight and gross sugar while in one field where exchangable K was 880 lb. per acre addition of K increased both sugar and root yield. Russell (76) reported the results of a large series of manurial experiments carried out over the sugar beet areas of England. Potassium was found to increase yield of sugar per acre, and to be correlated with the amount of exchangable K (acetic acid soluble). 4.7 cwt. of extra sugar per acre was obtained when the amount of exchangable K was below 5 mg. per 100 g. of soil. This response was decreased as available K increased and was omly 0.8 cwt. when exchangable K was higher than 10 mg. per 100 g. of soil. Russell also concluded that the primary source of K for plants was the exchangable K, and its level in the soil was an important factor in determining the responsiveness of a crop to K fertilization. Ulrich (86) concluded that the critical level of K in sugar beet petioles was 2.0 percent. Below this level, application of K would sharply increase the yield while above this critical level the yield tended to be constant.

Alexander et al. (5) studied the interaction of K with other elements on the composition of beet leaf blades, they concluded that application of K decreased the percentage of Na, and application of N decreased the percentage of K whereas application of N + P highly increased the percentage of K. They also found that the proportion of K in the leaves to the total nutrient content was also significantly depressed by the overall action of N fertilization.

Samuels et al. (78) reported the results of more than 200 field experiments with K fertilization on sugar cane and concluded that when the K content of sugar cane leaves was higher than 2.0 percent (dry wt. basis) no effect of K fertilization was to be expected, while values of less than 1.8 percent indicated that a response to K fertilization could be expected.

Effect of Magnesium

Apart from its role of being an integral part of the chlorophyl molecule, Mg has a definite effect on the rate of photosynthesis (71, 74, 39).

Mg is also believed by some workers to be intimately associated with the movement of P within the plants. Since many calcareous soils are notably deficient in P, it may be that abundance of Mg would increase the efficiency of P utilization within the plant. Alexander and Cormany (3) conducted an exploratory test in the Arkansas Valley of Colorado in which sugar beets were sprayed with eighteen compounds and they recorded that two spraying with magnesium sulfate at the rate of 5 lb. per acre significantly increased the percent sucrose. Also, potassium chloride at the rate of 10 lb. per acre approached the effect of magnesium sulfate. Downie and Swink (24) in a field experiment conducted in 1948 at Rocky Ford, Colorado obtained results similar to those obtained by Alexander and Cormany. In 1949 Downie and Swink repeated the same experiment in the same area but they failed to substantiate the results obtained in 1948.

In view of the results obtained by Alexander and Cormany, and Downie and Swink, Holst (45) conducted a field experiment in the Arkansas Valley of Colorado in which magnesium sulfate at the rate of 10, 20, 30 and 40 lb. per acre was sprayed or side dressed to sugar beet plants and he obtained results which did not show any significant increase in yield of roots or sugar, and sugar percentage. However, spraying 10 lb. of magnesium sulfate per acre gave the highest response compared to the other treatments.

Effect of Sodium

Sodium is the latest element being considered as a candidate for the essential nutrients list. This consideration had been subjected to a great deal of controversial discussion. It has not yet been demonstrated that Na is actually required for plant growth and reproduction, but it was clearly proved that most plants could complete their life cycles in cultures where the Na level was kept as low as possible. On the other hand it was clearly indicated that maximum yield of many plants cannot be obtained without Na. Sauchella (79) suggested that Na should be considered as a "stimulating element" awaiting further research to prove its essentiality conclusively.

From 1900 till now many experiments were carried out to study the requirement of most of the higher plants for Na. Among the workers was Harmer (37) who concluded that all crops investigated may be placed in one of the two main classes a) Benefited by Na in deficiency of K. b) Benefited by Na in sufficiency of K. Each of the classes may be subdivided into two tentative subclasses (slight to medium and large benefit), with regard to their response to Na. The sugar beet is a classic example of Na loving crop and is classified under plants which are largely benefited by Na in sufficiency of K.

Many hypotheses were established to explain the beneficial effect of Na. However, more investigations are still needed to clarify the role of Na in plant nutrition.

Black (12) reported the result of an experiment conducted by Holt _et al._ and concluded that the low yield of cotton in the absence of K showed that Na could not completely substitute for K, and the failure of Na to increase the yield of cotton at a high level of K indicated that Na had no independent effect of its own. Appling et al. (9) observed that when soil was deficient in K the cotton plants accumulated K greatly in the upper, immature leaves and Na accumulation was greatest in the lower leaves. This behavior suggested that Na may act for K in its role in balancing organic and inorganic anions, but not in its essential role in metabolic reactions.

Sodium in some cases was found to have a favorable effect in its own right. Black (12) reported an experiment in which comparison was made of two nitrogen carriers sodium nitrate and calcium nitrate at three levels of K application. He found that at all levels of K sodium nitrate gave a significant increase of fodder beets, whereas calcium nitrate failed to give any response. Whehnut (94) found that sodium nitrate was a superior source of N in an experiment carried on oats. He concluded that since in this experiment the amounts of applied N, P, K, and lime were uniform for all plots, the increase in yield appeared to be due to the utilization of Na. The response of sugar beets, rutabagas, carrots, celery, corn, barley, oats, alfalfa, and potatoes to the addition of Na was studied by Truog et al. (83). He found that the yields of sugar beets, rutabagas, carrots, and celery were all increased by the addition of Na even when the level of K supply was adequate or high. He also concluded that crops which highly responded to Na absorbed a considerable amount of Na especially under a low level of K (celery contained 4 percent) whereas crops that gave little or no response to Na absorbed only small amounts, less than 0.2 percent.

Larson and Pierre (53) studied the interrelationship of Na and K on the yield and cation composition of table beets, flax, oats, and corn in two soils, Harpster silt loam (calcareous) and Carrington loam. They found that Na and K were equally effective in increasing the yield of table beets on both soils. The combination of 2Na + K level produced the largest yield. There was no Na - K interaction on yield of roots but at all levels of K increasing the Na level resulted in a marked increase in the Na content of the foliage and in reduction of the K content. But in some cases addition of K or Na may have no effect on decreasing the uptake of the other, the result depends on the levels of Na and K in the soil and the relative ease of absorbtion of K and Na by the plants. The calcium content of beet foliage was decreased by increasing the Na level at the two lowest K levels but had no effect at the 2K level. Likewise, K decreased Ca content of beet foliage at the lowest Na level. Mg content was reduced by increasing the Na supply at nearly all K levels and likewise was decreased by K at all Na levels. Based on this study they concluded that it seemed probable that crops that absorb the most Na with the least depression in K will respond the most to Na fertilization. The correlation coefficient of the total Na + K content of beets tops with yield of roots was 0.91 and 0.93 for the two soils compared with values of 0.24 and 0.46 for K alone versus yield. This showed that the K content of crops such as beets that absorb large amount of Na should not be considered as an index for predicting yields.

Cope, et al. (18) conducted a greenhouse experiment to determine the effect of Na on the growth of certain crops, oats, Ladino clover, sudan grass, alfalfa, and corn and concluded that K produced greater increases in the yields of those crops than did Na application, but yields of all the crops studied were equally high when half the K applied was substituted by Na. Addition of Na to Mardin silt loam increased the release of nonexchangable K in the soil by about 40 percent as measured by the uptake of K by Ladino clover and alfalfa. Addition of K to the soil decreased the amount of this element released from the nonexchangable form.

Marshall and Sturgis (60) reported the results of twenty field experiments conducted in different soils carefully selected to include areas that were acidic, pH 5.2-5.9, low in available K, 0.14-0.25 m.e./100 g., and low in available Na, 0.1-0.4 m.e./100 g., and they found that in general sodium nitrate gave higher response of cotton yield than did ammonium nitrate when N was the only fertilizer applied. In seven experiments sodium nitrate gave significantly higher yields than did ammonium nitrate when N carriers were applied in a mixture with P but without K. In 17 out of 18 experiments to evaluate the influence of sodium nitrate on the use of soil P, sodium nitrate significantly increased the yield of cotton more than did ammonium nitrate in a mixture containing no P. The application of Na as sodium chloride at a rate equivalent to 48 lb. of K_2O per acre significantly increased the yield of cotton.

Whehnut and Collins (94) conducted a field experiment to investigate the effect of Na and K applied to Norfolk sandy loam at two residual K levels on the yield and content of Na and K of oats forage. They found that marked oats yield responses were obtained with both Na and K. A significantly higher yield was obtained on the high residual K plot than on the other. Addition of Na to the soil markedly increased the Na content of oats foliage. The high residual K of the soil greatly increased the K content of oats foliage. Increases in the exchangable Na of the soil due to the addition of Na were small but significant. Addition of 120 lb. of K_2O per acre greatly increased the exchangable K content of the soil. Nathan (65) conducted a field experiment using Pangola grass and concluded that this grass required a high supply of K and when Na was added it can substitute for approximately two thirds of the K requirement without showing any reduction in yield.

Leonard and Bear (58) reported that Na increased the yield of table beets even when the K level was high. They also found that increase in the yield was associated with high Na + K content of the plants. Lehr (55) concluded that Na + Ca + K together with Mg play a complicated and vital role which was called "cationic equilibrium." The absolute quantities of each element were not a good indication for yield, whereas the relative amount was the one to be considered. When the yield of sugar beet roots was graphed against their composition of K, Na and Ca in m.e./100 g., the higher content of monovalent K + Na gave the higher yield. On the other hand relatively high contents of Ca or divalent cations corresponded to low yields. The results of Italie (47), Holt (44) and Kandy (49) were in general agreement with Lehr. Howard (46) proved that Na can substitute for Ca in cotton. He found that when Ca was low, Na maintained the yield. This finding was also emphasized by Bear (11).

Andrews (7) believes that Na may increase the availability of P in the soil. Arnold (8) conducted field and greenhouse experiments to study the effect of Na on cotton and concluded that sodium nitrate was more effective than ammonium nitrate. The K content of leaves was increased with K application to the soil. Likewise, the addition of Na increased the Na content of the leaves. The percentage of K in the leaves ranged from 0.65 where no K was added to 4.03 where K was added at the rate of 54 lb. per acre. The Na content of the leaves from the plots which received sodium nitrate decreased as the rate of K applied increased. The percentage Na in the leaves from plots to which no Na was added remained constant as the rate of applied K was varied. There was no indication that the sum of Na + K in m.e./100 g. of plant material was constant at the different rates of applied K.

Growther and Garner (19) compared the response of sugar beets to sodium nitrate and ammonium sulfate in 24 experiments conducted from 1945-1948. Each carrier was tested at two rates on plots with sodium chloride and plots without sodium chloride and in all plots a normal dressing of K and P was given. The average gains in cwt. sugar per acre from ammonium sulfate and sodium nitrate were 6.2 and 10.2 on plots without sodium chloride and 7.0 and 7.9 on plots with sodium chloride.

Dorph-Peterson and Stenbjerg (22) grew sugar beets in a pot experiment with increasing quantities of K and Na and found that an application of either of these two substances reduced the increase in yield obtained from the other. The Na effect was produced by various Na salts, hence, Na must have been responsible for the yield increases.

The Na effect was found to be partly due to the increase in K availability and uptake. But the greater part of the Na effect was accounted for by the Na absorbed by the plants.

MATERIALS AND METHODS

Experimental Design

Five macro-nutrient elements, N, P, K, Mg, and Na were included as variables in a central composite, rotatable, incomplete factorial design as described by Hader et al. (33). Each element was varied at five different levels (Table 1). Coded levels were as follows -2, -1, 0, + 1, + 2. It was assumed that the 0 level represented an average rate, and the other rates covered a wide range of application from possible deficiency, -2, to possible excess, + 2.

Carriers of the elements varied were ammonium sulfato-nitrate for N, concentrated superphosphate for P, potassium sulfate for K, magnesium sulfate for Mg, and sodium sulfate for Na.

The design used required 27 treatment combinations (Table 2) with one of them replicated six times in order to obtain an estimate of the experimental error. This design is quite useful in connection with experimental determination and calculation of response surfaces and avoids the necessity of a large number of treatments.

Statistical Analysis

The statistical methods used were according to those described by Cochran and Cox (16). Regression equations of the quadratic form for yield and elemental constitution were computed from the data. The form of the equation for five variables is as follows: $Y = b_0 + b_1 x_1 + b_2 x_2 +$

Table 1. Rates of application of N, P_2O_5, K_2O, Mg and Na for sugar beets.

Level.	Coded rate.	lb. per acre.	Kg. per dunum.
1	-2	10.0	1.14
2	-1	27.2	3.09
3	0	73.8	8.40
4	+1	200.0	22.75
5	+2	544.0	61.80

Table 2. Treatment combinations of nutrients applied for sugar beets.

Treatment	Levels of application				
	N	P_2O_5	K_2O	Mg	Na
A	2	2	2	2	4
B	4	2	2	2	2
C	2	4	2	2	2
D	4	4	2	2	4
E	2	2	4	2	2
F	4	2	4	2	4
G	2	4	4	2	4
H	4	4	4	2	2
I	2	2	2	4	2
J	4	2	2	4	4
K	2	4	2	4	4
L	4	4	2	4	2
M	2	2	4	4	4
N	4	2	4	4	2
O	2	4	4	4	2
P	4	4	4	4	4
Q	5	3	3	3	3
R	1	3	3	3	3
S	3	5	3	3	3
T	3	1	3	3	3
U	3	3	5	3	3
V	3	3	1	3	3
W	3	3	3	5	3
X	3	3	3	1	3
Y	3	3	3	3	5
Z	3	3	3	3	1
CK_1	3	3	3	3	3
CK_2	3	3	3	3	3
CK_3	3	3	3	3	3
CK_4	3	3	3	3	3
CK_5	3	3	3	3	3
CK_6	3	3	3	3	3

$$b_3 x_3 + b_4 x_4 + b_5 x_5 + b_{11} x^2_1 + b_{22} x^2_2 + b_{33} x^2_3 + b_{44} x^2_4 + b_{55} x^2_5 + b_{12} x_1 x_2 + b_{13} x_1 x_3 + b_{14} x_1 x_4 + b_{15} x_1 x_5 + b_{23} x_2 x_3 + b_{24} x_2 x_4 + b_{25} x_2 x_5 + b_{34} x_3 x_4 + b_{35} x_x x_5 + b_{45} x_4 x_5.$$

Where x_1 = Coded level of N

x_2 = Coded level of P_2O_5

x_3 = Coded level of K_2O

x_4 = Coded level of Mg

x_5 = Coded level of Na

b = regression coefficient for treatment effect

The statistical significance of individual regression coefficients was determined by the "t" test. The regression equations were used to determine the nature of the response surface for the individual interactions that were found to be statistically significant. Correlation coefficients "r" of the actual yields compared with yields calculated from the regression equation were computed. Analyses of variance for the experimental data were also done and the significance of the linear, quadratic, and lack of fit terms was determined by the critical "F" test.

Field Methods

This experiment was conducted at the American University Farm. After plowing was done the land was disced with a disc-harrow and ridges were made 50 cm. apart. Each plot consisted of 4 rows 10 m. in length. On April 5, 1960 seeds of sugar beet (Beta Vulgaris) Hilleshog variety were drilled in the upper part of the ridges at a depth of about 3 cm. Fertilizers were applied on April 14 by side dressing in bands placed in the shoulder of the ridge. Irrigation was done every week using sprinklers for the first month and by the furrow method later on. The first thinning was made when seedlings formed 3 or 4 real leaves by removing all seedlings except 2 or 3 seedling per hill at distances of 20 cm. apart. A second thinning was made one week later leaving only one plant per hill. On October 20th, 8 m. from the center of the two middle rows of each plot was harvested. Tops and roots were separated. A count of the number of beets from the harvested area of each plot was made and the fresh weight recorded. Four beets were taken at random from each plot for sugar analysis.

Leaf Sampling

Leaf sampling for all treatments was done about three weeks before harvesting. One recently matured leaf was collected from each of ten plants at random within the two center rows of each plot.

Analytical Procedures

Preparation of Leaf Samples. Leaves were washed first in tap water and soap, and then rinsed 3 times in tap water and another three times in distilled water to remove any contamination from dust. The samples were air dried and placed in a ventilated oven at 70°C. for 48 hours. Samples were ground in a Wiley mill using a 40 mesh screen. The samples were mixed thorougly and kept in small covered glass jars. All chemical analysis results were reported on the oven dry basis.

Preparation of the nitric-perchloric acid digest of plant tissue. The method of wet oxidation as described by Jackson (48) was used. A 1.5 g. sample of oven dried plant tissue was predigested with 10 ml. of concentrated nitric acid in a 250 ml. beaker and was left over night. Then 10 ml. of perchloric acid was added, the beakers were covered with watch glasses and placed on a hot plate at a temperature of about 180-200° C. Digestion was continued about four hours until the liquid was clear, the samples were filtered and transferred to 250 ml. volumetric flasks using boiling distilled water.

Nitrogen analysis. Nitrogen was determined on the ground oven dried plant tissue by the Gunning modification of the Kjeldahl method as described by Jackson (48).

Phosphorus analysis. Phosphorus was determined on the nitric-perchloric digests by the chlorostanous-reduced molybdophosphoric blue color method in a hydrochloric acid system as described by Jackson (48). Absorbancy readings were taken on a Beckman Model B spectrophotometer using a blue phototube at a wave length of 660 mu.

Cation analysis. K, Mg, Ca, and Na were determined on the nitric-perchloric digests using a Beckman D.U - emission spectrophotometer with acetylene flame. The gas pressure was 12 and 7 lb./sq. in. for oxygen and acetylene respectively. Wave length settings were 770 mu for K, 285 mu for Mg, 590 mu for Na, and 554 mu for Ca.

Soil analysis. A soil sample was collected from the experimental plot before planting. Soil analysis was done as follows:

pH reading. pH reading was done on the 1:2.5 soil water suspension, using a pH meter with a glass and a calomel electrode.

Total Nitrogen: Nitrogen was determined by the Kjeldahl method as described by Russel (75).

Available Phosphorus. Available P was extracted from the soil according to the procedure of Olsen et al. as described by Jackson (48) and the concentration of P was determined by the chlorostannous-reduced molybdophosphoric blue color method in hydrochloric acid system as described by Jackson (48). Absorbancy readings were taken on the Beckmen Model B spectrophotometer using a blue phototube at a wave length setting of 660 mu.

Cation Exchange Capacity: The cation exchange capacity was determined by the sodium acetate method as described by Jackson (48). Readings on the extracts were made on the flame spectrophotometer as described for plant analysis.

Exchangable Cations: Exchangable K, Na, Ca, and Mg were extracted from the soil by the ammonium acetate method as described by Jackson (48).

Readings were made on the extracts using the flame spectrophotometer as described previously.

Calcium Carbonate Equivalent: Percentage of calcium carbonate was determined by digestion with excess 1.0 N HCl, and by back titration with 0.1 N NaOH.

Organic Matter Content: Organic matter was determined by the Schollenberger method of wet oxidation by chromic acid with external heat applied as described by Jackson (48).

Soil Texture: Soil texture was determined using the hydrometer method as described by Piper (70).

Sugar analysis. Sucrose percent in roots was extracted and determined according to the procedure described in A.O.A.C. (63).

RESULTS AND DISCUSSION

Interrelationships of the macronutrient elements N, P, K, Mg, and Na on the yield of roots, tops, and gross sugar, and on the percentage of sucrose of sugar beets were studied in a field experiment conducted on a calcareous soil in the central Beka'a Plain of Lebanon. Elements were studied at five levels of each using the central composite, rotatable, incomplete factorial design described by Cohran and Cox (16). The use of this design permits calculation of the regression equation in the quadratic form. The magnitude of the individual regression coefficients indicates the relative effect of the variable and allows determination of the statistical significance. A negative sign for the regression coefficient for an interaction term indicates that an increase in the level of one element decreased the requirement for the other. This type of relationship has been denoted as a complementary effect. If the sign of the regression coefficient was positive, an increase in the level of one element increased the requirement of the other. This relationship has been called an antagonistic effect.

Results of Soil Analysis

The soil is classified under the category of Light Chestnut. The physical analysis (Table 3) indicated that this soil has a clay texture. However, the permeability of the soil to water as observed in the field was good, and this may be explained by the high calcium saturation of the colloidal complex. The moisture content of the air dried soil was 7.7

Table 3. Results of physical and chemical analysis of the surface soil for the experimental plot as compared with the average value for the same soil category according to Salib (77).

Soil property		Experimental soil	Average Light Chestnut
Moisture content of the air dried soil, percent.		7.7	7.1
Moisture content at Field Carrying Capacity, percent.		27.7	-
Sand, percent.		22.03	11.02
Silt, percent.		26.94	24.35
Clay, percent.		51.03	64.63
Texture.		Clay	Clay
pH		8.1	8.2
Calcium Carbonate, percent.		19.5	37.9
Organic Matter, percent.		1.62	2.75
Total Nitrogen, percent.		0.112	0.139
Available Phosphorus (ppm. of P)	1. Olsen Method	10.20	3.36
	2. Bray and Kurtz No. 1	6.70	3.55
Cation Exchange Capacity. m. e. / 100 g.		41.44	52.90
Exchangable Cations m. e. / 100 g.	Calcium	36.01	51.24
	Magnesium	1.48	
	Potassium	1.99	1.36
	Sodium	1.77	0.30

percent. The pH of the soil was 8.1 and the calcium carbonate content was 19.5 percent. The total N content was found to be 0.112 percent indicating a relatively low supply of N. The organic matter percentage was also low, 1.625 percent. The available P as determined by the Olsen method was found to be 10.2 ppm. and 6.7 ppm. as determined by the Bray and Kurtz No. 1 method. According to Russel (75) this soil falls in the category of a medium level of available P. The cation exchange capacity was found to be 41.44 m.e./100 g. The exchangable cations determination indicated that Ca saturation was about 86 percent of the soil exchange complex. Exchangable Mg, K, and Na were 1.48, 1.99, and 1.77 m.e./100 g. respectively. The available K as calculated in lb. per acre was 1550 indicating a high level according to Russel (75). Comparison of the soil analysis results with the average values for the same soil category in the same area as determined by Salib (77) indicated that this soil was fairly representative.

Yield of Roots

The correlation coefficient between observed yields and yields calculated from the regression equation (Table 4) was 0.996 indicating a very close fit of the regression equation to the actual data.

The analysis of variance for the yield of roots (Table 5) indicated that only the linear effect was statistically significant.* The lack of

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*The term "significant" will be used to denote statistical significance at the 5% level. The term "highly significant" will be used to denote statistical significance at the 1% level.

Table 4. Observed yield of beet roots (lb. fresh weight per plot) as affected by various levels of N, P, K, Mg and Na. Yields for the same treatments calculated from the regression equation are given. Correlation of actual yields with calculated yield was 0.996.

Treatment level N	P	K	Mg	Na	Actual yield lb. per plot	Calculated yield lb. per plot
2	2	2	2	4	94.5	92.1
4	2	2	2	2	56.5	59.4
2	4	2	2	2	46.0	45.1
4	4	2	2	4	113.0	114.7
2	2	4	2	2	70.0	67.1
4	2	4	2	4	106.0	105.7
2	4	4	2	4	94.0	89.9
4	4	4	2	2	100.5	102.2
2	2	2	4	2	97.5	94.5
4	2	2	4	4	110.0	109.6
2	4	2	4	4	67.5	63.3
4	4	2	4	2	107.0	106.4
2	2	4	4	4	80.5	73.4
4	2	4	4	2	103.0	100.4
2	4	4	4	2	93.0	86.5
4	4	4	4	4	103.5	99.7
5	3	3	3	3	125.5	122.7
1	3	3	3	3	67.0	77.4
3	5	3	3	3	87.5	92.9
3	1	3	3	3	90.0	92.7
3	3	5	3	3	68.5	78.0
3	3	1	3	3	70.0	68.7
3	3	3	5	3	89.0	98.7
3	3	3	1	3	85.5	83.9
3	3	3	3	5	89.0	94.0
3	3	3	3	1	68.0	71.1
3	3	3	3	3	94.0	87.5
3	3	3	3	3	90.5	87.5
3	3	3	3	3	75.0	87.5
3	3	3	3	3	88.5	87.5
3	3	3	3	3	83.5	87.5
3	3	3	3	3	101.5	87.5

Table 5. Analysis of variance for yield of beet roots (lb. fresh wt. per plot).

Source	d. f.	S. S.	M. S.	F value
Linear effect	5	4336.2	867.23	10.56 *
Quadratic effect	15	4081.3	272.08	3.32
Lack of fit	6	679.5	113.26	1.38
Experimental error	5	409.8	81.96	-
Total	31	9506.8		

* Significant at odds of 19:1

fit term was not significant suggesting no need for applying a cubic or higher order regression equation.

Study of the regression coefficients (b) and their standard errors (S_b) (Table 6) indicated that the direct effects of N and Na were significant, whereas among quadratic effects only the Mg-Na interaction was highly significant. All elements studied gave a positive effect on the root tonnage. Nitrogen gave the highest increase followed by Na, K, and Mg, whereas P gave the lowest response. The regression equation for interaction effects indicated that the N-P, N-Mg, N-Na, and P-K interactions were positive in sign which indicated that an increase in one of the elements increased the requirement for the other (antagonistic effect). The following interactions were found to be negative N-K, P-Mg, P-Na, K-Mg, K-Na and Mg-Na. This revealed that an increase in the supply of one element decreased the requirement for the other (complementary effect).

The high response of beet tonnage to N application was not surprising as the soil analysis indicated that the N supply of the soil was not high, and this was in agreement with the results obtained by many workers, (72, 10, 84) that when N supply is low the application of N will significantly increase the beet tonnage. The positive N-P interaction revealed that the response of beet tonnage to N or P application was greater as the supply of the other element increased. The results of Tolman and Johnson (84), and Alexander et al. (4) were in agreement with this finding. The interaction of N with Na and Mg revealed the presence of antagonistic relationships, whereas the N-K interaction was complementary in effect.

Table 6. Regression coefficients (b) and their standard errors (s_b) for yield of beet roots (lb. fresh weight per plot).

Coefficient		b	s_b
Mean	b_0	+ 87.49	± 3.61
N	b_1	+ 11.35*	± 1.58
P	b_2	+ 0.06	"
K	b_3	+ 2.32	"
Mg	b_4	+ 3.69	"
Na	b_5	+ 5.73*	"
N^2	b_{11}	+ 3.14	± 1.67
P^2	b_{22}	+ 1.33	"
K^2	b_{33}	− 3.54	"
Mg^2	b_{44}	+ 0.95	"
Na^2	b_{55}	− 1.23	"
N-P	b_{12}	+ 5.66	± 2.26
N-K	b_{13}	− 0.34	"
N-Mg	b_{14}	+ 0.84	"
N-Na	b_{15}	+ 2.22	"
P-K	b_{23}	+ 3.53	"
P-Mg	b_{24}	− 2.91	"
P-Na	b_{25}	− 2.03	"
K-Mg	b_{34}	− 3.91	"
K-Na	b_{35}	− 3.78	"
Mg-Na	b_{45}	− 10.84 **	"

*Significant at odds of 19:1

**Significant at odds of 99:1

The slight response of beets tonnage to P application could be accounted for by the presence of a relatively high level of available P in the soil (Table 3). The regression coefficient for K was positive in sign and the magnitude was less than for N, Na, and Mg but higher than for P. However, the response to K was counteracted by the negative sign of the regression coefficient of the K^2 term and the overall effect of K was to increase the yield slightly. It will be noted that although the soil was high in available K, 1550 lb. per acre, there was still a slight response to the application of K, which suggested that K is highly needed for sugar beet production and that even under conditions where the absolute amount of available K is high, the uptake of K by plants may be checked by the high percentage of Ca saturation in calcareous soils. The effect of the K-N interaction was negative whereas the K-P interaction was positive. The relationships of K with the other cations Mg and Na were found to be complementary.

The Mg effect on increasing the root tonnage was third in magnitude among the elements. The Mg-N interaction was found to be antagonistic whereas the Mg interaction with Na and K was complementary.

Sodium gave a significant increase in yield tonnage. The interaction of Na with N was found to be positive which suggested that for maximum response to N, an adequate supply of Na was required. The results obtained by some workers (60,94), which showed that sodium nitrate was the best carrier for N fertilization, might be explained by this antagonistic interrelationship between N and Na. Interactions of Na with other elements were negative and the Na-Mg interaction was highly significant. The complementary interrelationship found for the Na-K interaction emphasized the hypothesis that Na can partially substitute for K in sugar beet fertilization (44).

Yield of Tops

The correlation coefficient between actual yield of beet tops and yields calculated from the regression equation (Table 7) was 0.912 indicating a close fit of the regression equation to the actual data.

The analysis of variance for beet tops (Table 8) indicated highly significant linear effects, whereas the quadratic effects were non-significant. The lack of fit term was highly significant which suggested the need for applying a cubic or higher order equation to specify the interaction clearly.

Examination of the regression coefficients (b) and their standard errors (S_b) (Table 9) indicated that the effects of N, Na, N^2, and N-P were highly significant and N-Na, P-Na, and Mg-Na were significant. Nitrogen gave the highest increase of beet tops followed by Na, whereas P only slightly increased the yield of tops. On the other hand Mg and K slightly decreased the yield of tops. Among the quadratic effects N-P, N-Mg, N-Na, P-Mg, and P-Na proved to have antagonistic relationships whereas N-K, P-K, K-Mg, K-Na, and Mg-Na were complementary. As it was found by many workers (36) N increased the top growth and K and P only slightly affected the yield. Nitrogen and Na as studied each one alone or in combination affected both yield of roots and of tops similarly.

Table 7. Observed yield of beet tops (lb. green weight per plot) as affected by various levels of N, P, K, Mg and Na Yields of the same treatments calculated from the regression equation are given. Correlation of actual yields with calculated yields was 0.912.

Treatment levels N	P	K	Mg	Na	Actual yield	Calculated yield
2	2	2	2	4	20.5	19.1
4	2	2	2	2	15.0	16.0
2	4	2	2	2	7.5	9.4
4	4	2	2	4	41.0	42.4
2	2	4	2	2	25.0	24.7
4	2	4	2	4	24.5	24.7
2	4	4	2	4	18.5	16.7
4	4	4	2	2	17.5	18.1
2	2	2	4	2	23.5	20.5
4	2	2	4	4	20.5	22.5
2	4	2	4	4	14.0	13.9
4	4	2	4	2	27.5	25.3
2	2	4	4	4	14.5	15.1
4	2	4	4	2	22.0	20.6
2	4	4	4	2	17.5	14.1
4	4	4	4	4	27.5	29.1
5	3	3	3	3	37.0	35.3
1	3	3	3	3	14.5	18.7
3	5	3	3	3	14.0	16.4
3	1	3	3	3	16.0	15.9
3	3	5	3	3	13.0	13.9
3	3	1	3	3	12.5	14.0
3	3	3	5	3	18.0	19.9
3	3	3	1	3	20.5	19.9
3	3	3	3	5	26.8	25.4
3	3	3	3	1	12.5	16.4
3	3	3	3	3	20.5	16.9
3	3	3	3	3	16.5	16.9
3	3	3	3	3	17.0	16.9
3	3	3	3	3	14.0	16.9
3	3	3	3	3	15.0	16.9
3	3	3	3	3	20.6	16.9

Table 8. Analysis of variance for yields of beet tops (lb. fresh weight per plot).

Source	d. f.	S. S.	M. S.	F value
Linear effect	5	415.05	83.01	11.04 * *
Quadratic effect	15	440.57	24.37	3.86
Lack of fit	6	643.06	107.18	14.08 * *
Experimental error	5	38.04	7.61	-
Total	31	1536.72		

* * Significant at odds of 99:1

Table 9. Regression coefficients (b) and their standard errors (s_b) for yield of beet tops (lb. green weight per plot).

Coefficient		b	s_b
Mean	b_0	+ 16.858	± 0.113
N	b_1	+ 4.146 **	± 0.563
P	b_2	+ 0.062	"
K	b_3	- 0.062	"
Mg	b_4	- 0.312	"
Na	b_5	+ 2.254 **	"
N^2	b_{11}	+ 2.540 **	± 0.510
P^2	b_{22}	- 0.147	"
K^2	b_{33}	- 0.710	"
Mg^2	b_{44}	+ 0.915	"
Na^2	b_{55}	+ 1.015	"
N-P	b_{12}	+ 3.594 **	± 0.687
N-K	b_{13}	- 1.406	"
N-Mg	b_{14}	+ 0.009	"
N-Na	b_{15}	+ 2.344 *	"
P-K	b_{23}	- 0.956	"
P-Mg	b_{24}	+ 0.406	"
P-Na	b_{25}	+ 2.281 *	"
K-Mg	b_{34}	- 0.344	"
K-Na	b_{35}	- 1.219	"
Mg-Na	b_{45}	- 2.219 *	"

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

In both cases the relationship between N and Na was found to be antagonistic and suggested that Na must have some role in increasing the effect of N fertilization. The same antagonistic relationships was found in both root and tops growth for the following elements, P-K, P-Mg and P-N. Among cations and for both roots and tops growth a similar complementary relationship existed.

Sucrose Percentage

The correlation coefficient between the actual sucrose percentages and those calculated from the regression equation (Table 10) was 0.901 indicating a close fit of the regression equation to the actual data.

The analysis of variance (Table 11) indicated that linear and quadratic effects were non-significant. The lack of fit was also non-significant. Examination of the individual regression coefficients (b) and their standard errors (S_b) (Table 12) indicated that only the N-P interaction was significant. Nitrogen in addition to K, Mg, and Na decreased the percentage of sucrose whereas P slightly increased it. The effect of N was in agreement with the results obtained by other workers (35, 36, 76). The individual effect of Na was similar to that of N, however, the positive sign of the N-Na interaction suggested that Na is needed to counterbalance the depression effect of N on percentage of sucrose. The sign of the N-P interaction was also positive indicating that increasing P supply may also tend to alleviate the depression effect of N on percentage of sucrose.

Table 10. Observed percent sucrose (fresh weight basis) as affected by various levels of N, P, K, Mg, and Na. Yields for the same treatments calculated from the regression equation are given. Correlation of actual yields with calculated yields was 0.901.

Treatment level N	P	K	Mg	Na	Actual Percentage of sucrose	Calculated percentage of sucrose.
2	2	2	2	4	17.9	20.4
4	2	2	2	2	22.5	19.7
2	4	2	2	2	23.2	21.1
4	4	2	2	4	17.5	19.3
2	2	4	2	2	21.0	22.5
4	2	4	2	4	21.1	19.2
2	4	4	2	4	20.4	19.2
4	4	4	2	2	20.8	21.9
2	2	2	4	2	20.2	22.3
4	2	2	4	4	21.7	20.1
2	4	2	4	4	19.8	19.0
4	4	2	4	2	20.2	21.9
2	2	4	4	4	17.5	20.4
4	2	4	4	2	19.6	17.3
2	4	4	4	2	21.8	19.9
4	4	4	4	4	19.9	21.2
5	3	3	3	3	16.3	17.5
1	3	3	3	3	20.0	18.5
3	5	3	3	3	21.0	20.9
3	1	3	3	3	20.6	20.4
3	3	5	3	3	21.0	21.2
3	3	1	3	3	21.7	21.3
3	3	3	5	3	19.9	20.3
3	3	3	1	3	21.0	20.4
3	3	3	3	5	22.7	21.0
3	3	3	3	1	21.4	22.8
3	3	3	3	3	20.8	20.6
3	3	3	3	3	19.2	20.6
3	3	3	3	3	21.3	20.6
3	3	3	3	3	21.0	20.6
3	3	3	3	3	22.1	20.6
3	3	3	3	3	18.7	20.6

Table 11. Analysis of variance for percentage of sucrose (fresh weight basis).

Source	d. f.	S. S.	M. S.	F value
Linear effect	5	6.95	1.390	0.82
Quadratic effect	15	59.19	3.946	2.33
Lack of fit	6	1.59	0.260	0.153
Experimental error	5	8.47	1.694	
Total	31	76.20		

Table 12. Regression coefficients (b) and their standard errors (s_b) for percent sucrose in beet roots. (fresh weight basis).

Coefficient		b	b_s
Mean	b_0	+ 20.60	± 0.53
N	b_1	- 0.25	± 0.25
P	b_2	+ 0.12	± 0.26
K	b_3	- 0.01	"
Mg	b_4	- 0.03	"
Na	b_5	- 0.45	"
N^2	b_{11}	- 0.64	"
P^2	b_{22}	+ 0.02	± 0.24
K^2	b_{33}	+ 0.16	"
Mg^2	b_{44}	- 0.07	"
Na^2	b_{55}	+ 0.33	"
N-P	b_{12}	+ 0.94 *	± 0.32
N-K	b_{13}	- 0.01	"
N-Mg	b_{14}	+ 0.17	"
N-Na	b_{15}	+ 0.48	"
P-K	b_{23}	+ 0.33	"
P-Mg	b_{24}	+ 0.21	"
P-Na	b_{25}	- 0.21	"
K-Mg	b_{34}	- 0.33	"
K-Na	b_{35}	+ 0.31	"
Mg-Na	b_{45}	+ 0.48	"

* Significant at odds of 19:1

Yield of Sugar

The correlation coefficient between actual yield of sugar and yield calculated from the regression equation (Table 13) was 0.984 indicating a close fit of the regression equation to the actual data.

The analysis of variance for yield of sugar (Table 14) indicated that both linear and quadratic effects were highly significant. The lack of fit term was significant suggesting the possible need for using a cubic or higher order equation.

Examination of the regression coefficients (Table 15) indicated that the following coefficients were highly significant, N, Na, P-K, K-Mg, and Mg-Na whereas the following coefficients were significant K, Mg, K^2, N-Na, P-Na and K-Na. As with the yield of roots the linear effects were found to be positive for all the elements studied. The interaction relationship between elements for yield of sugar were also found to be in agreement in sign with the relationships for yield of roots.

Effect of Nitrogen

Examination of the effect of 5 levels of N on the yield of sugar (Fig. 1) as affected by 5 levels of P (other elements were kept constant at the 3 level) indicated that the response to applied N was considerably greater with increasing P levels (complementary relationship).

The interaction of N-K on the yield of sugar (Fig. 1) indicated that the response to N was not appreciably affected by the K supply.

Table 13. Observed yield of sugar (lb. per plot) as affected by various levels of N, P, K, Mg, and Na. Yields for the same treatments calculated from the regression equation are given. Correlation of the actual yields with calculated yields was 0.984.

Treatment level N	P	K	Mg	Na	Actual Yield	Calculated Yield
2	2	2	2	4	16.9	17.6
4	2	2	2	2	12.7	12.6
2	4	2	2	2	10.7	10.8
4	4	2	2	4	19.8	20.2
2	2	4	2	2	14.7	14.2
4	2	4	2	4	22.4	22.5
2	4	4	2	4	19.2	19.1
4	4	4	2	2	20.9	20.0
2	2	2	4	2	19.7	19.1
4	2	2	4	4	23.9	23.7
2	4	2	4	4	13.4	13.5
4	4	2	4	2	21.6	20.8
2	2	4	4	4	14.1	14.0
4	2	4	4	2	20.2	18.8
2	4	4	4	2	20.3	23.8
4	4	4	4	4	20.6	19.6
5	3	3	3	3	20.4	22.0
1	3	3	3	3	13.4	14.4
3	5	3	3	3	18.4	19.1
3	1	3	3	3	18.5	18.6
3	3	5	3	3	14.4	16.1
3	3	1	3	3	15.2	14.1
3	3	3	5	3	17.7	19.3
3	3	3	1	3	17.6	16.5
3	3	3	3	5	20.2	19.4
3	3	3	3	1	14.6	16.0
3	3	3	3	3	19.6	17.9
3	3	3	3	3	18.4	17.9
3	3	3	3	3	17.0	17.9
3	3	3	3	3	18.6	17.9
3	3	3	3	3	18.5	17.9
3	3	3	3	3	19.0	17.9

Table 14. Analysis of variance for yield of sugar for sugar beets (lb. per plot).

Source	d. f.	S. S.	M. S.	F value
Linear effect	5	128.164	25.63	33.1 **
Quadratic effect	15	142.272	9.49	12.82 **
Lack of fit	6	28.08	4.68	6.32 *
Experimental error	5	3.730	0.74	-
Total	31	302.250		

* Significant at odds of 19:1

** Significant at odds of 99:1

Table 15. Regression coefficients (b) and their standard errors (s_b) for yield of sugar (lb. per plot).

Coefficient		b	s_b
Mean	b_0	+ 17.921	± 0.352
N	b_1	+ 1.963 **	± 0.176
P	b_2	+ 0.071	"
K	b_3	+ 0.504 *	"
Mg	b_4	+ 0.696 *	"
Na	b_5	+ 0.863 **	"
N^2	b_{11}	- 0.058	± 0.159
P^2	b_{22}	+ 0.329	"
K^2	b_{33}	- 0.583 *	"
Mg^2	b_{44}	+ 0.129	"
Na^2	b_{55}	+ 0.067	"
N-P	b_{12}	+ 0.344	± 0.216
N-K	b_{13}	- 0.094	"
N-Mg	b_{14}	+ 0.281	"
N-Na	b_{15}	+ 0.819 *	"
P-K	b_{23}	+ 1.081 **	"
P-Mg	b_{24}	- 0.369	"
P-Na	b_{25}	- 0.656 *	"
K-Mg	b_{34}	- 1.281 **	"
K-Na	b_{35}	- 0.569 *	"
Mg-Na	b_{45}	- 1.819 **	"

*Significant at odds of 19:1

**Significant at odds of 99:1

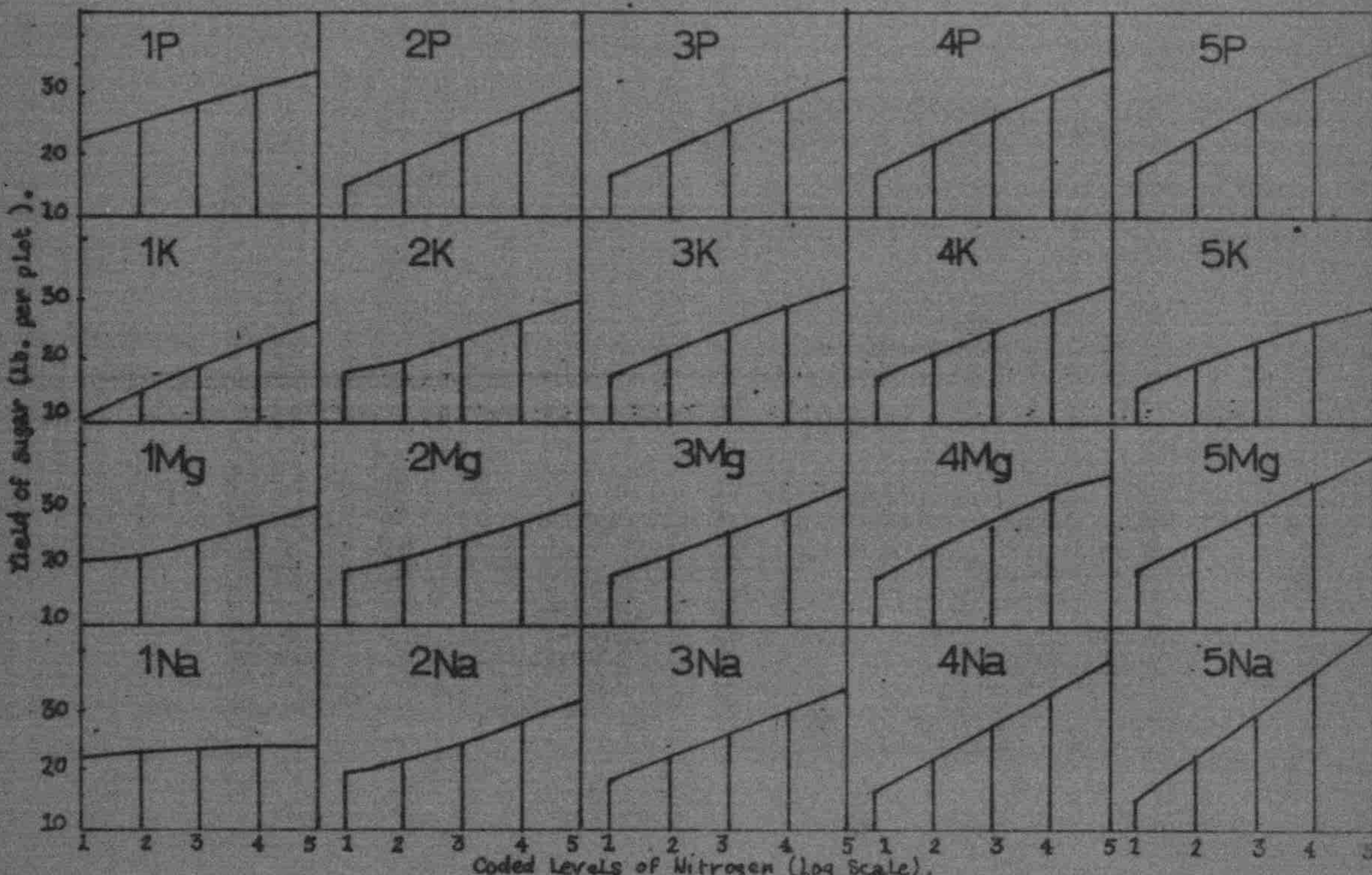


Figure 1. Yield of sugar as affected by five levels of N in combination with one of the element P, K, Mg and Na alone with other elements held constant at the mid level, 3.

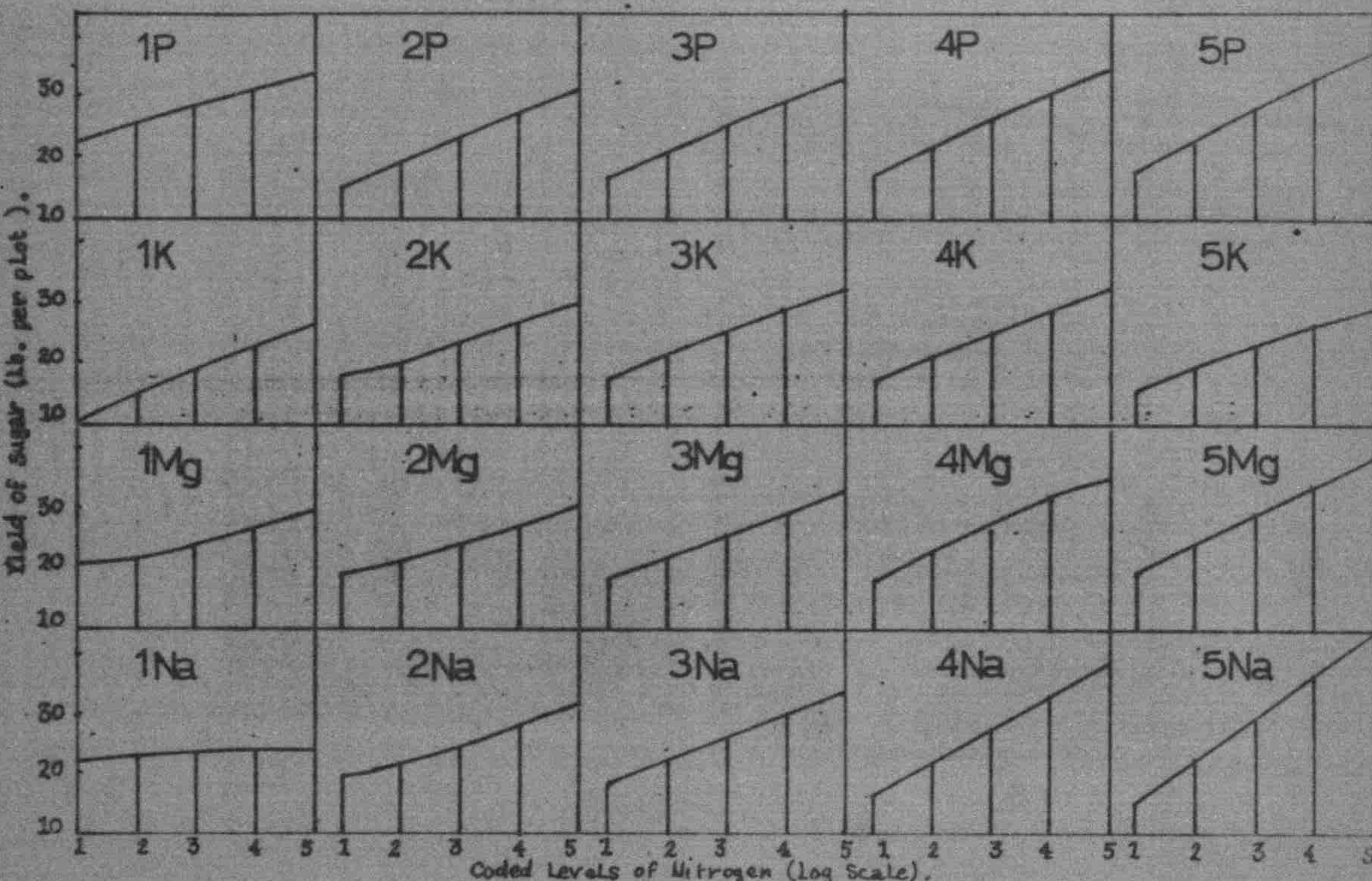


Figure 1. Yield of sugar as affected by five levels of N in combination with one of the element P, K, Mg and Na alone with other elements held constant at the mid level, 3.

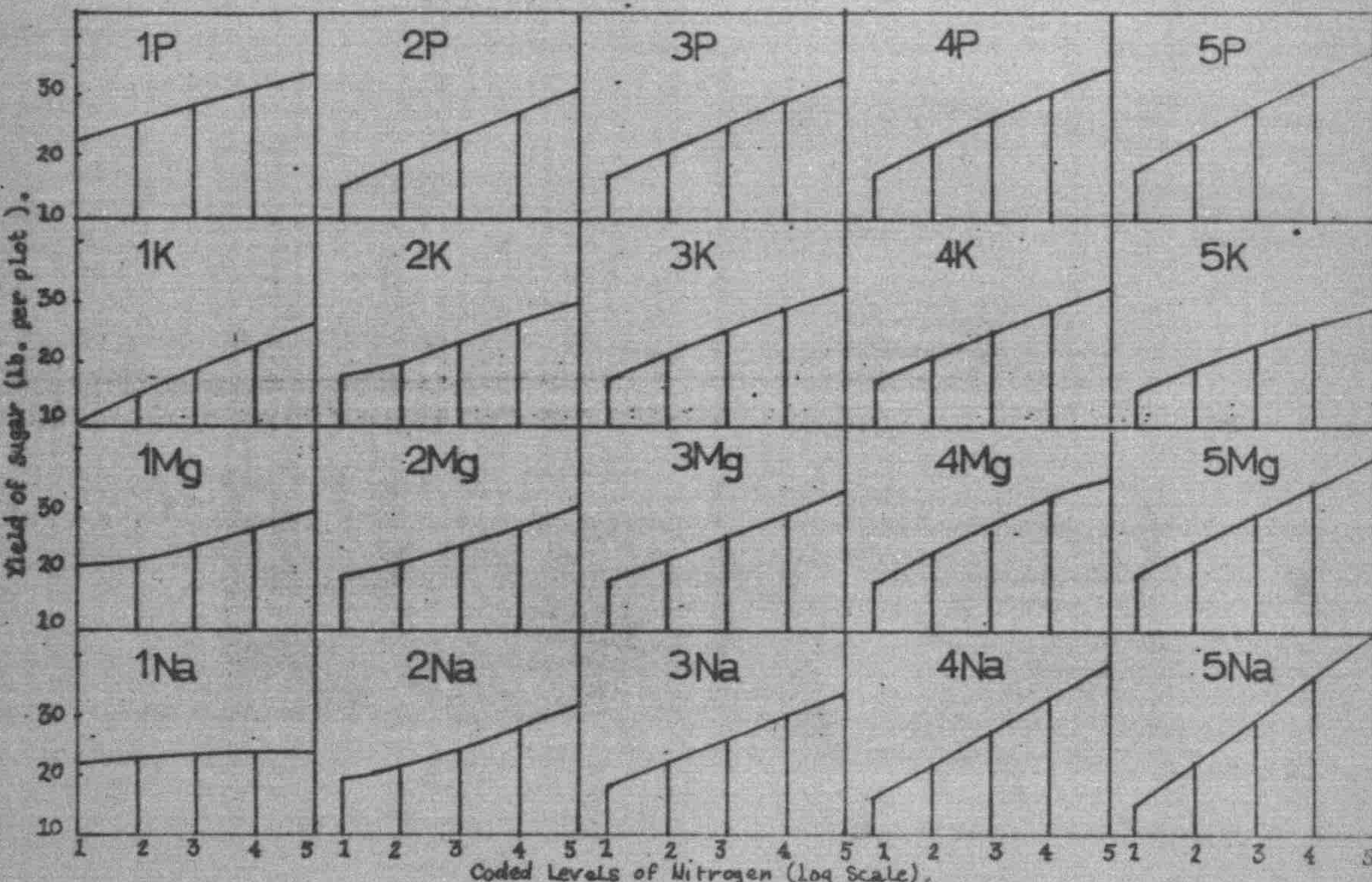


Figure 1. Yield of sugar as affected by five levels of N in combination with one of the elements P, K, Mg and Na alone with other elements held constant at the mid level, 3.

The relationships between N and Mg was found to be antagonistic. The response to N was increased considerably (Fig. 1) as the Mg supply was increased.

The N-Na interaction was also antagonistic (Fig. 1). Nitrogen gave only a very slight increase in yield of sugar when the level of Na was low. As the Na supply increased, the response to N increased greatly and reached a maximum at the 5Na level.

The overall response to N as summarized from the previous discussion indicated that the need for N fertilization in this experiment was very high. The response to N was considerably increased if P, Mg and Na were applied individually at high rates (other elements held constant at the 3 level) whereas K did not seriously affect the response to N.

Effect of Phosphorus

Examination of the yield response of sugar to 5 levels of P as affected by the N supply (other elements were held constant at the 3 level) revealed that at low supply of N (Fig. 2) increasing the rate of P application slightly depressed the yield of sugar. The depression effect of P was counteracted by increasing the N supply and at the 5N level, application of P increased the yield slightly. These results were in agreement with the work of Grunes (30).

The P-K interaction (Fig. 2) indicated an antagonistic relationship. Phosphorus depressed the yield of sugar when K was low, but increased the yield at high levels of K.

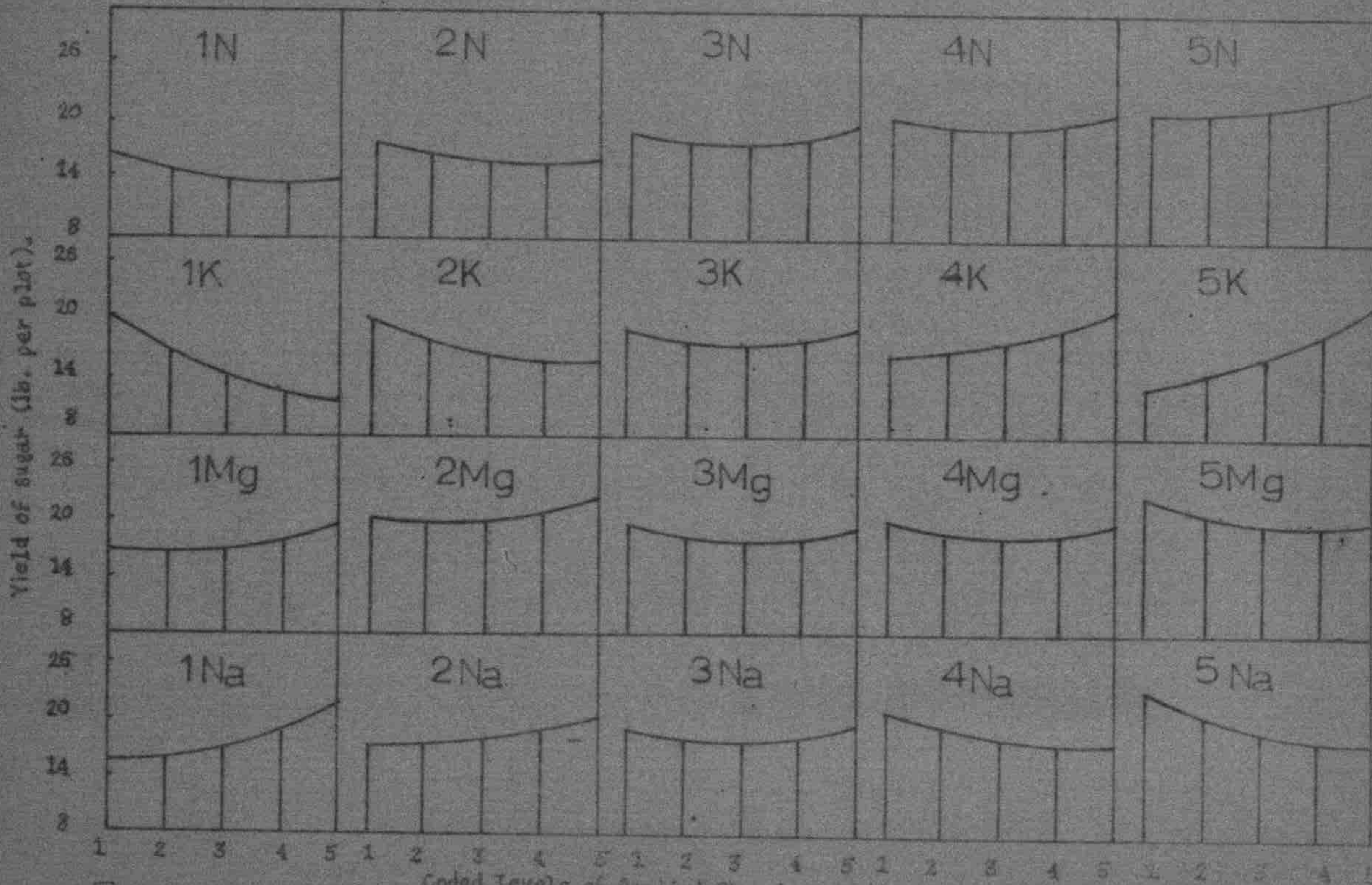


Figure 2. Yield of sugar as affected by five levels of P in combination with one of the elements N, K, Mg and Na alone with other elements held constant at the unit level 3.

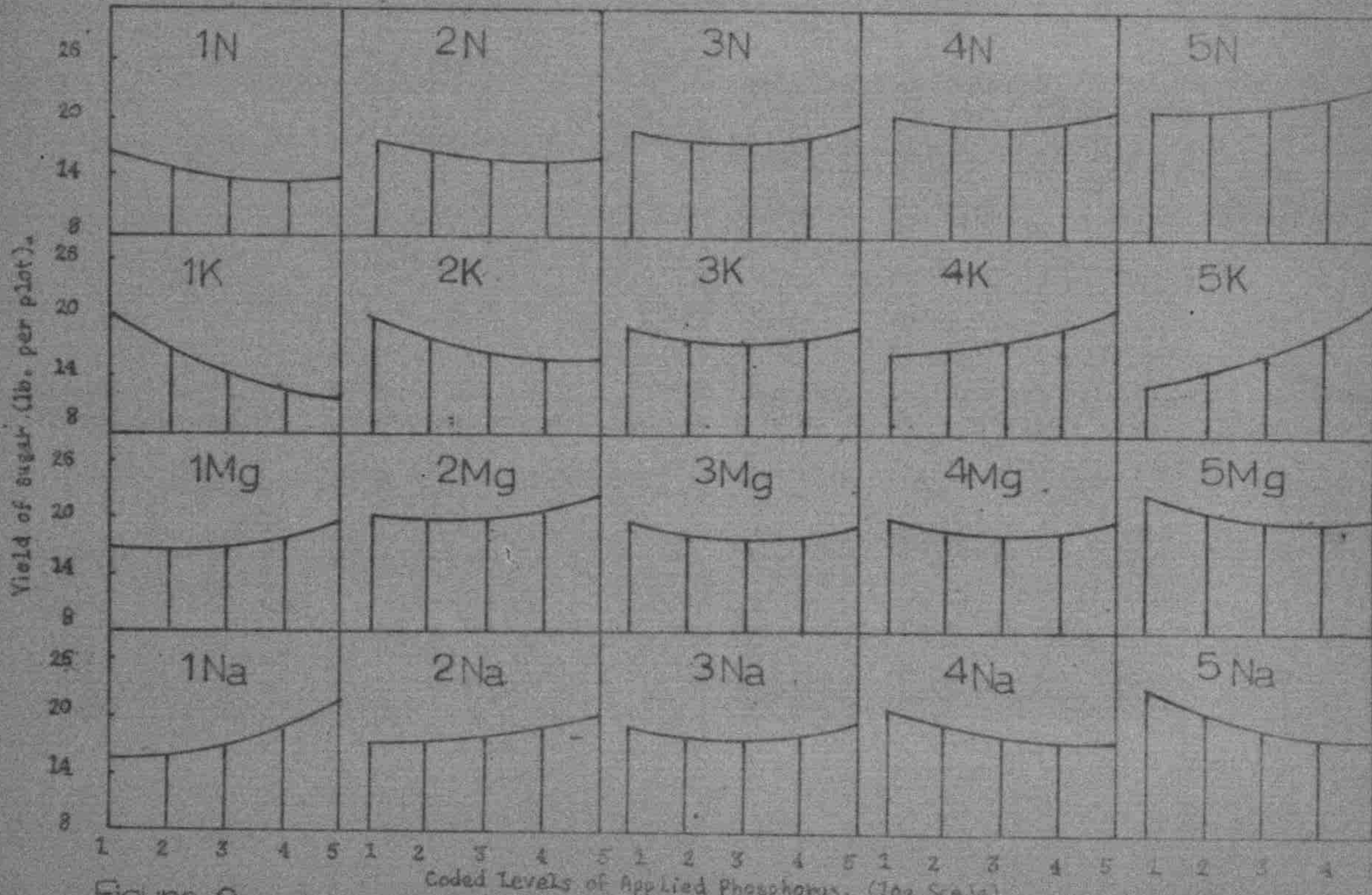


Figure 2. Yield of sugar as affected by five levels of P in combination with one of the elements N, K, Mg and Na alone with other elements held constant at the mid level 3.

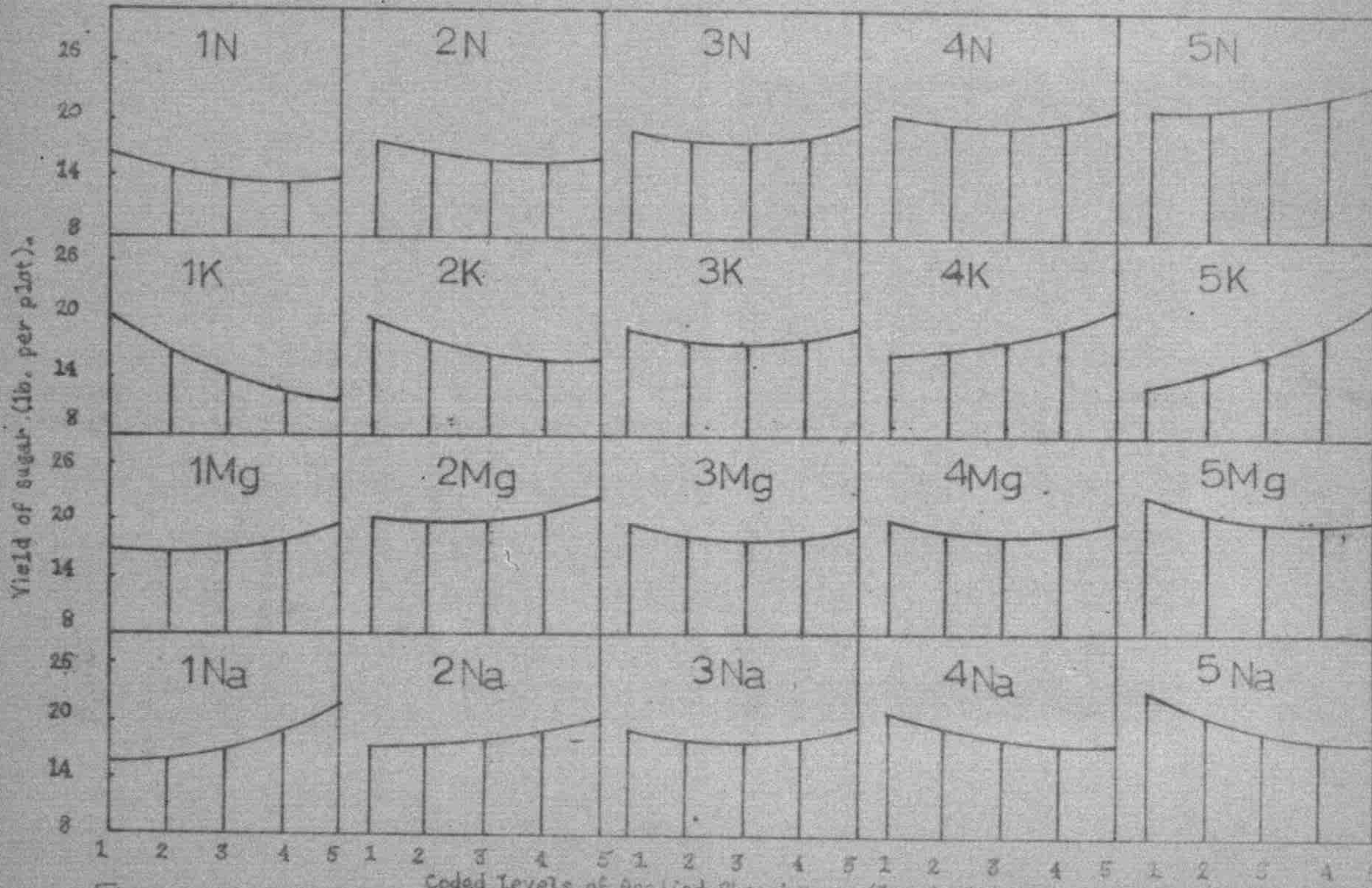


Figure 2. Yield of sugar as affected by five levels of P in combination with one of the elements N, K, Mg and Na alone with other elements held constant at the mid level 3.

The P-Mg interaction (Fig. 2) was found to be complementary in effect. Phosphorus slightly increased the yield of sugar at low levels of Mg, whereas at higher levels of Mg application of P depressed the yield.

The P-Na interaction (Fig. 2) was found to be similar to the P-Mg interaction indicating the presence of a complementary relationship. Phosphorus increased the yield when the Na level was low but at high levels of Na the P application considerably depressed the yield.

As a summary for the overall P effect on the yield of sugar in regard to other macro elements we may conclude that when all other elements were at the 3 level, the application of P gave no beneficial effect on yield of sugar but when N and K levels were individually high, or Na and Mg were individually low, the application of P was found to be beneficial.

Effect of Potassium

The K-N interaction (other elements held constant at the 3 level) indicated (Fig. 3) that response to K was not significantly affected by the N supply. The response to K was slight at all levels of N with the highest yield at the 3 or 4 level of K.

The response to K as affected by the levels of P (Fig. 3) indicated that K has a depressing effect on the yield of sugar when P is low, whereas K gave a considerable yield response at higher rates of P.

Potassium gave a large increase in yield of sugar (Fig. 3) when the supply of Mg was low. The response to K was reduced as the Mg level

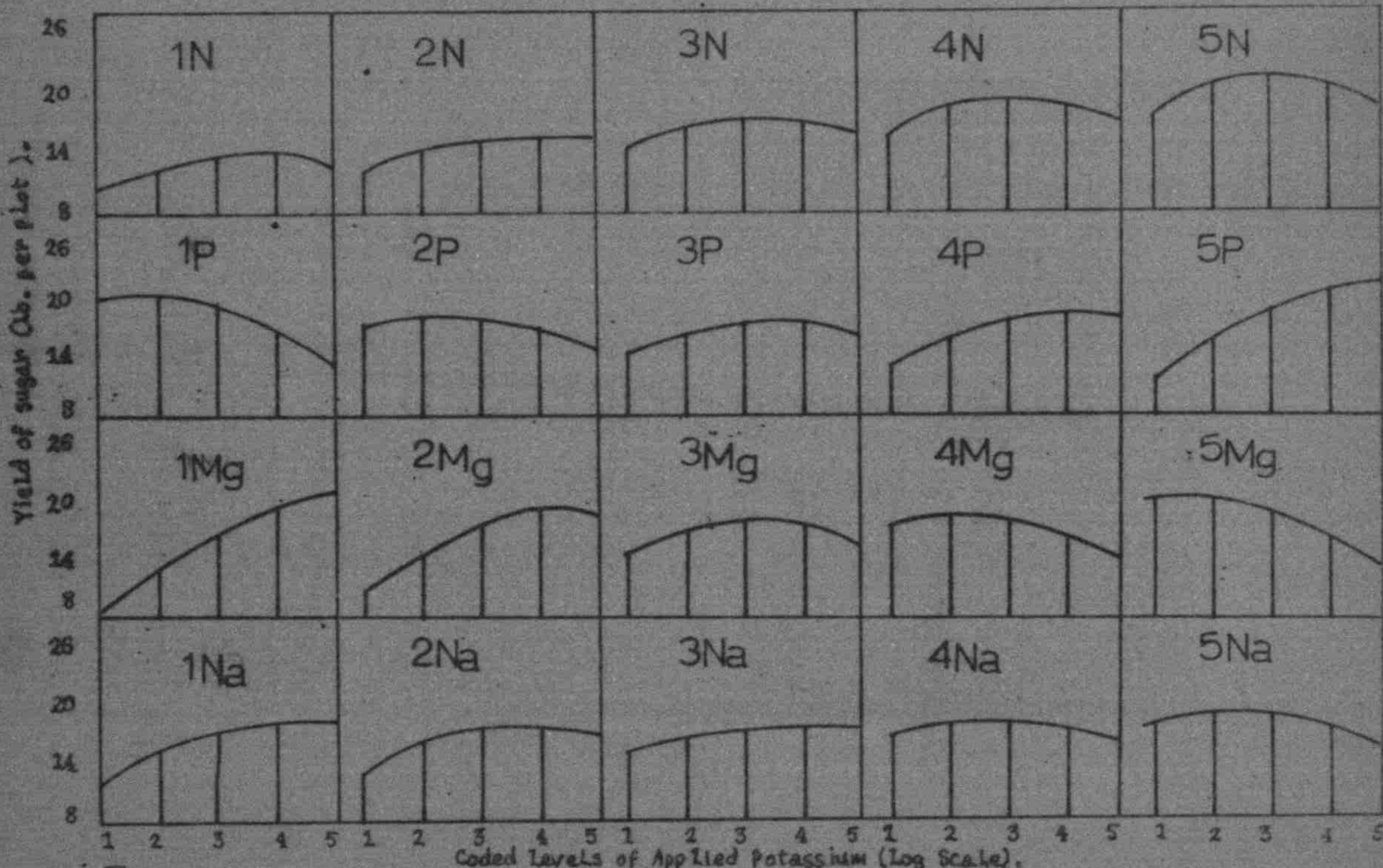


Figure 3. Yield of sugar as affected by five levels of K in combination with one of the elements N, P, Mg and Na alone with other elements held constant at the mid level, 3.

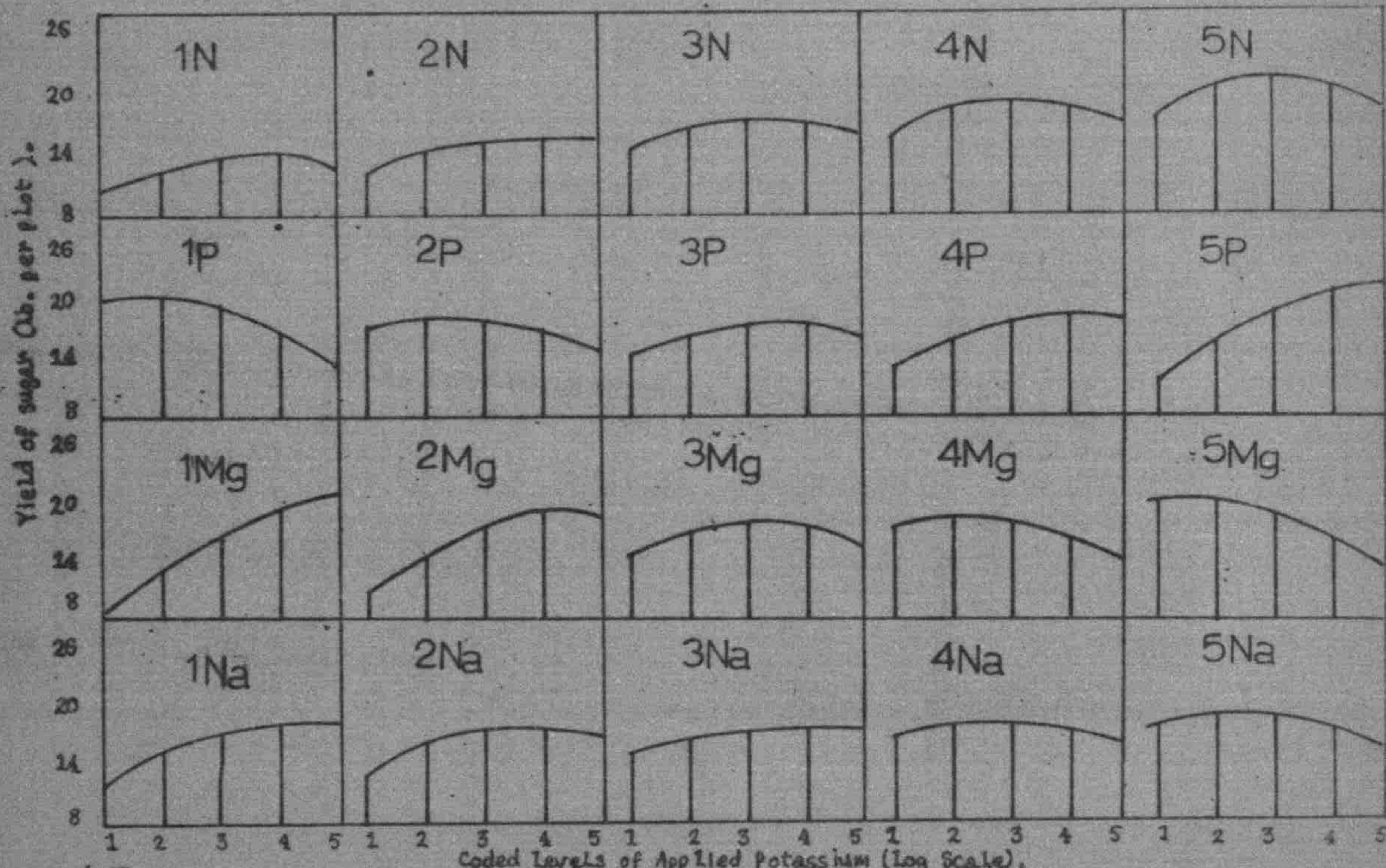


Figure 3. Yield of sugar as affected by five levels of K in combination with one of the elements N, P, Mg and Na alone with other elements held constant at the mid level 3.

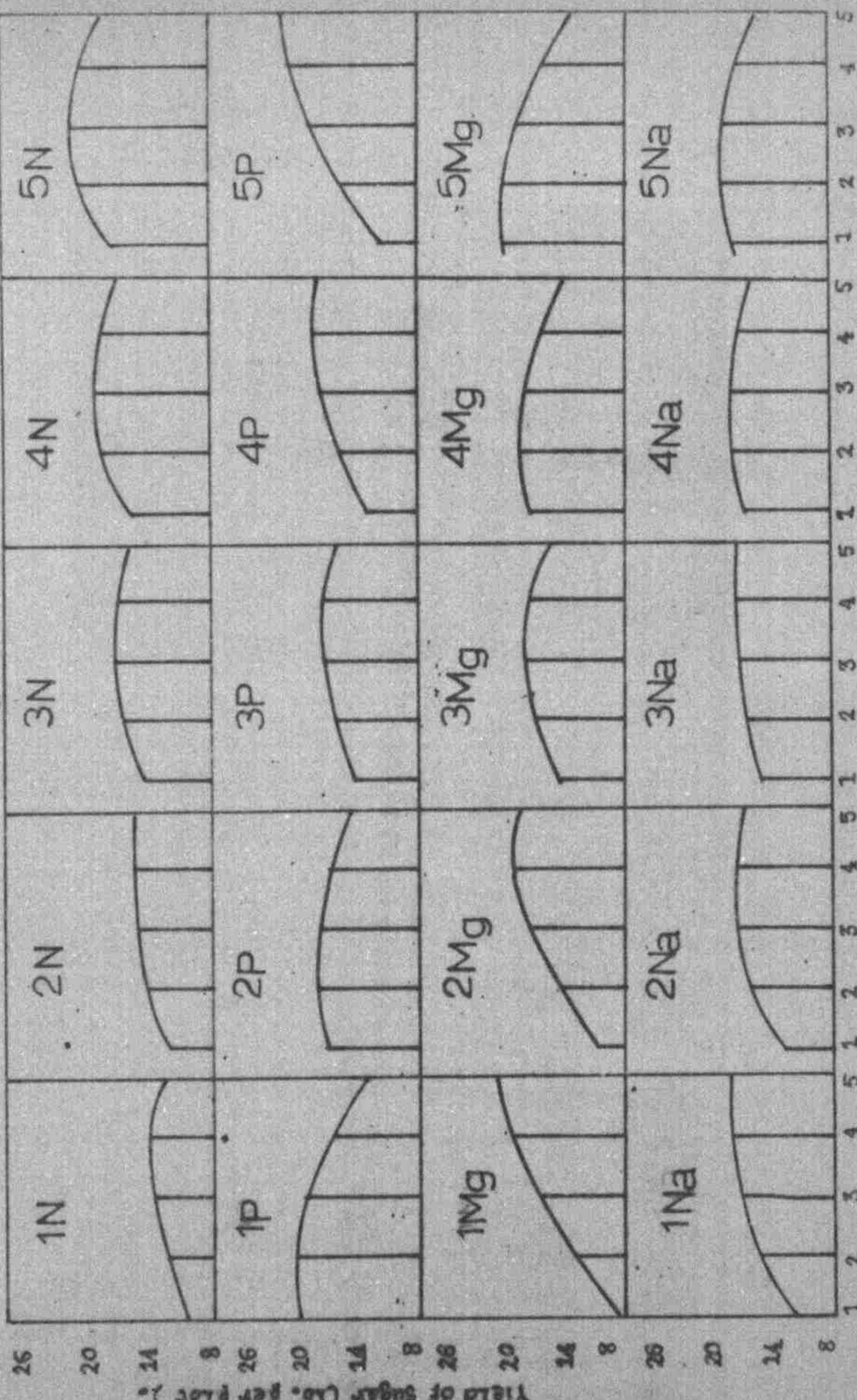


Figure 3. Yield of sugar as affected by five levels of K in combination with one of the elements N, P, Mg and Na alone with other elements held constant at the mid level 3.

was increased and at high rates of Mg, the yield of sugar tended to be decreased when K was applied.

The overall effect of K on the yield of sugar as summarized from the previous discussion revealed that K application did not affect the yield appreciably when all elements were present at the 3 level. If the P level individually increased or the Na and Mg levels individually decreased K application gave a considerable increase in yield of sugar.

Effect of Magnesium

Determination of the effect of 5 levels of Mg as influenced by the supply of N (other elements held constant at the 3 level) indicated (Fig. 4) that Mg failed to increase the yield of sugar when the N supply was low. At the higher levels of N the application of Mg resulted in a slight increase in yield of sugar.

Study of the Mg effect in regard to the P supply indicated (Fig. 4) that Mg increased the yield of sugar when the level of P was low. As the supply of P increased the response to Mg was reduced and at the higher levels of P the application of Mg failed to give any response.

The Mg effects on yield of sugar as influenced by the K supply (Fig. 4) indicated a complementary relationship. Magnesium highly increased the yield of sugar when the level of K was low. Increasing the level of K reduced the beneficial effect of Mg, whereas at high level of K the application of Mg decreased the yield of sugar.

The highly significant Mg-Na interaction (Fig. 4) was similar to that for the Mg-K interaction but higher in magnitude. This emphasized

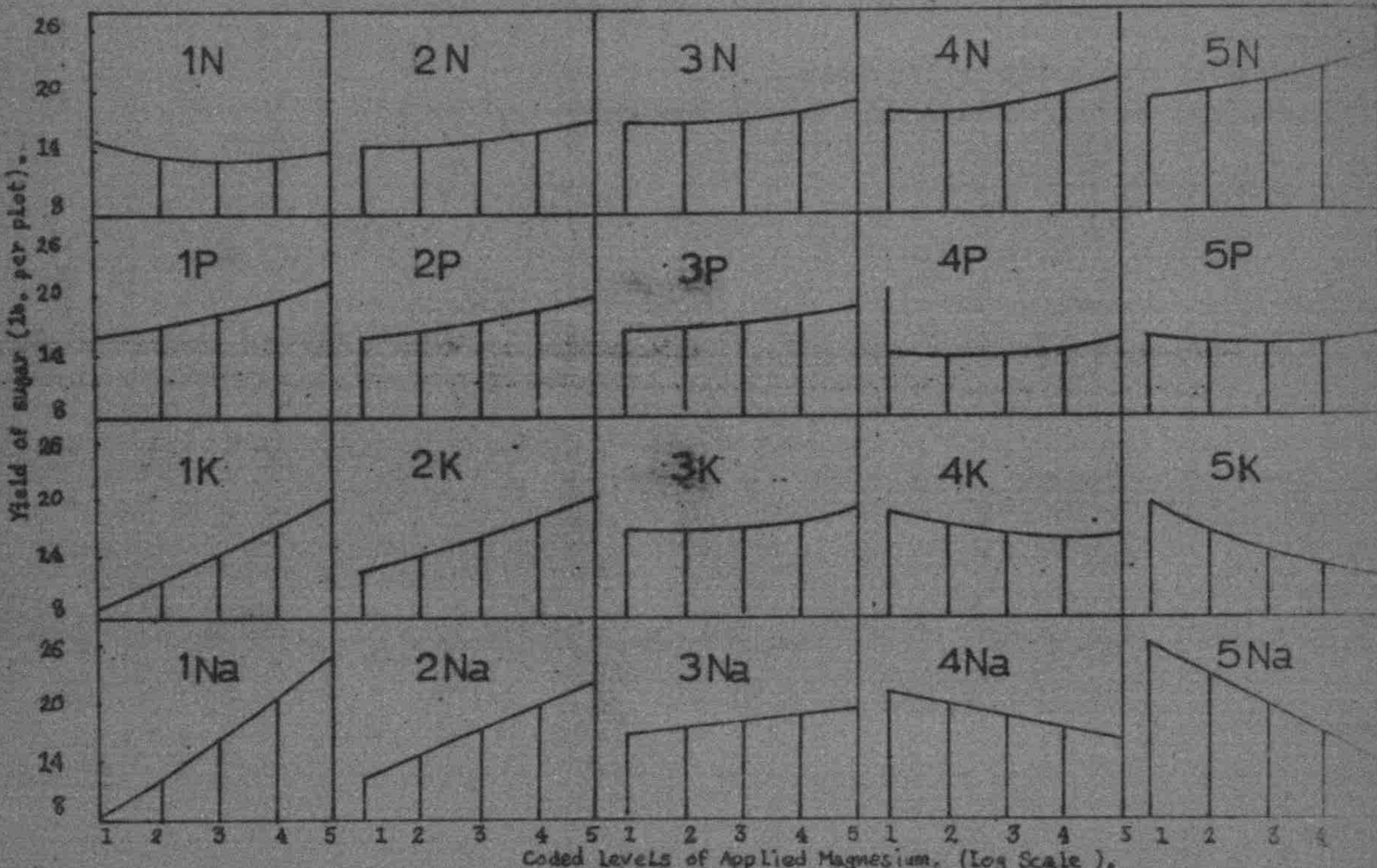


Figure 4. Yields of sugar as affected by five levels of Mg in combination with one of the elem
N, P, K and Na alone with other elements held constant at the mid level,3 .

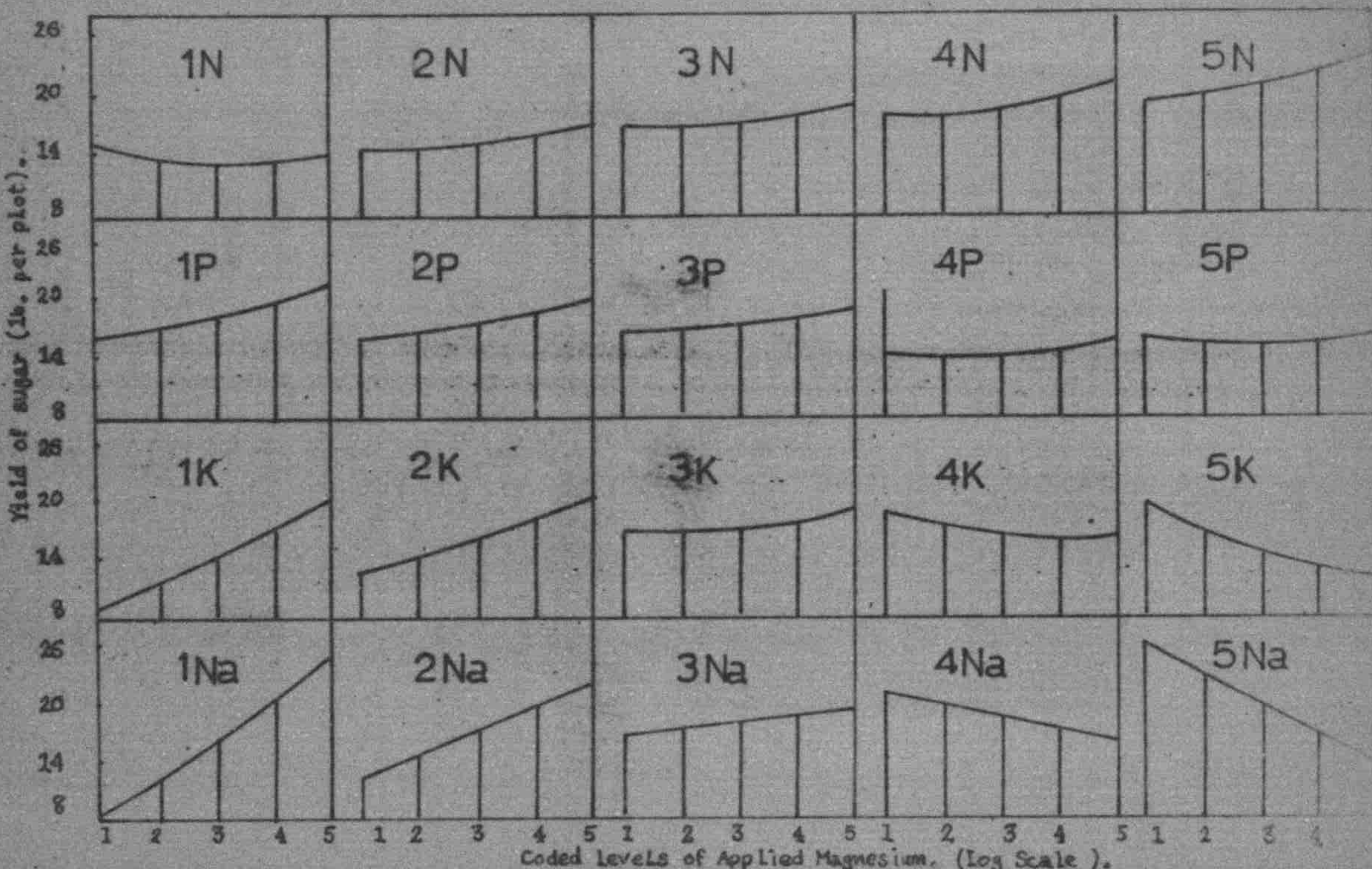


Figure 4. Yields of sugar as affected by five levels of Mg in combination with one of the elem
N, P, K and Na alone with other elements held constant at the mid level,3 .

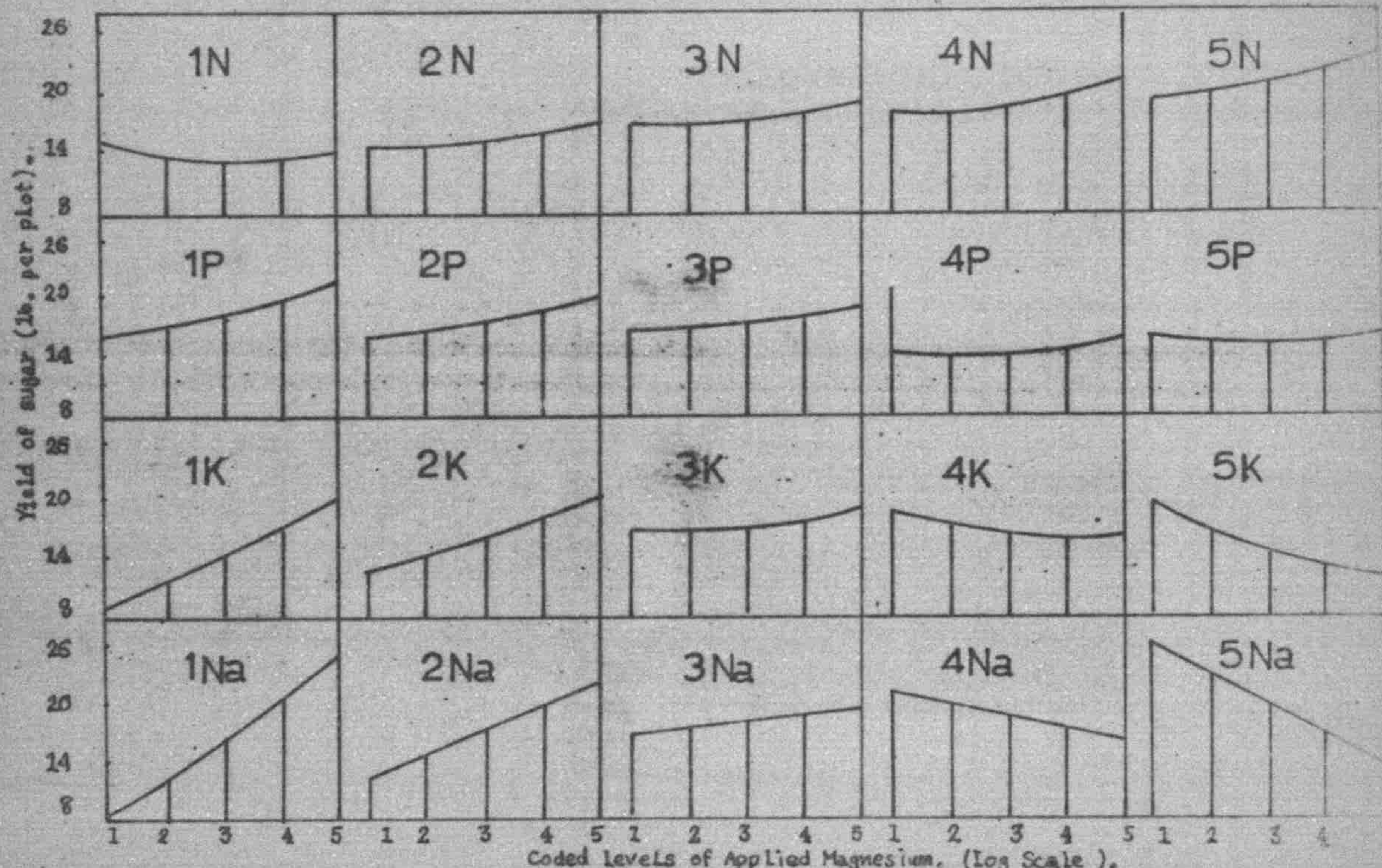


Figure 4. Yields of sugar as affected by five levels of Mg in combination with one of the
N, P, K and Na alone with other elements held constant at the mid level, 3.

the complementary relationship between the cations Mg, K, and Na.

The previous discussion revealed that Mg failed to increase the yield of sugar when all elements were added at the 3 level but if the level of N was high or the level of P, K or Na individually low, the response to Mg was increased.

Effect of Sodium

When all other elements were kept constant at the 3 level, the application of five levels of Na (Fig. 5) increased the yield of sugar as indicated from the positive sign of Na coefficient (Table 15).

The response to Na was significantly affected by the N supply. Examination of this relationship (Fig. 5) indicated that Na depressed the yield when the N level was low. However, as the N level increased the response to Na increased and at high N level a considerable increase in yield of sugar resulted from increasing Na application. This emphasized the important antagonistic relationship between Na and N.

Study of the response to Na as affected by the P supply (Fig. 5) revealed a complementary relationship. Response to Na was obtained only when the P level was low. On the other hand, with an abundant supply of P, Na application depressed the yield.

Examination of the complementary Na-K interaction (Fig. 5) indicated that response to Na was obtained at lower levels of K. However, a high level of K resulted in a decrease in yield of sugar with increasing Na application.

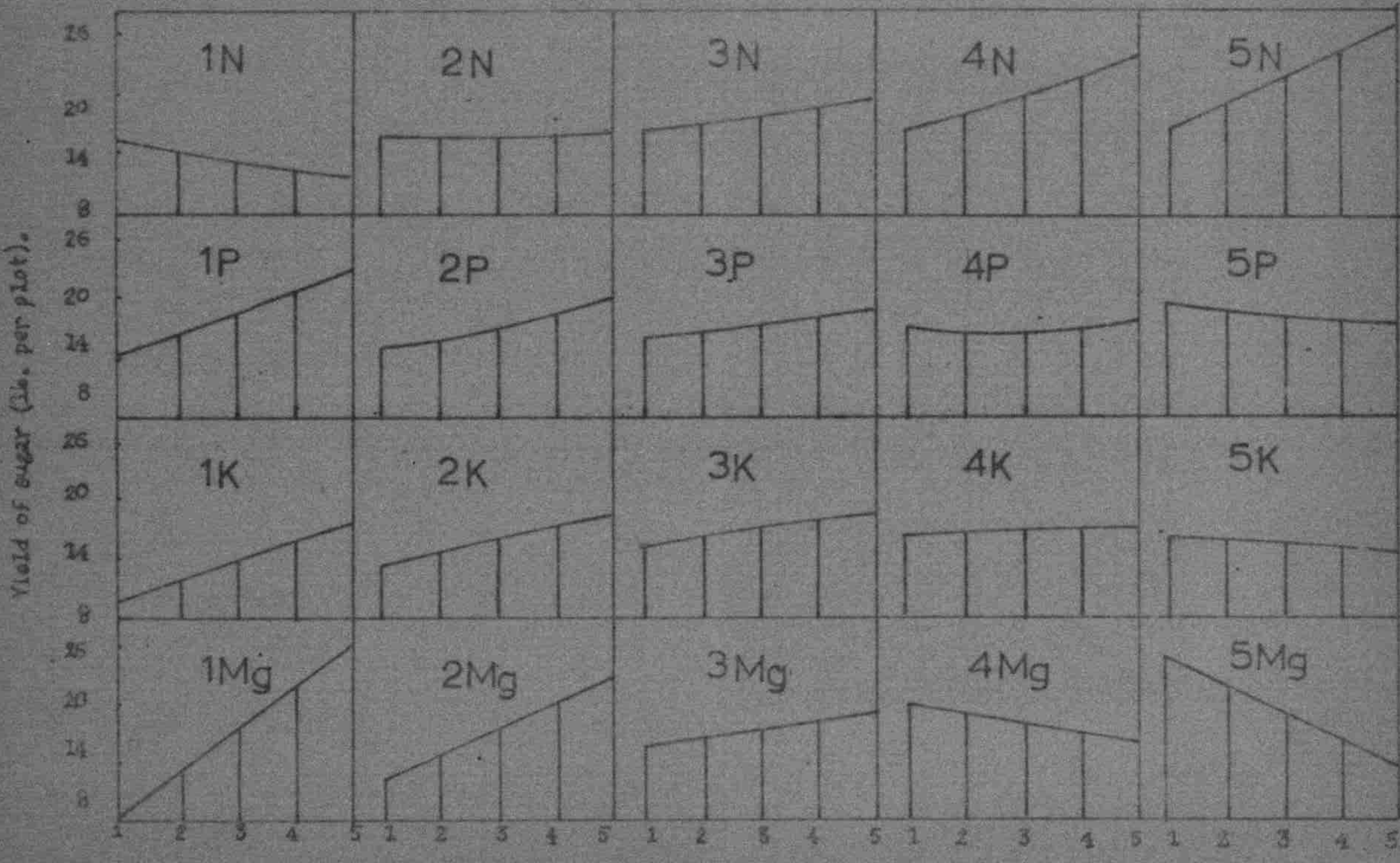


Figure 5. Yield of sugar as affected by five levels of Na in combination with one of the elements N, P, K and Mg along with other elements held constant at the mid level, 3.

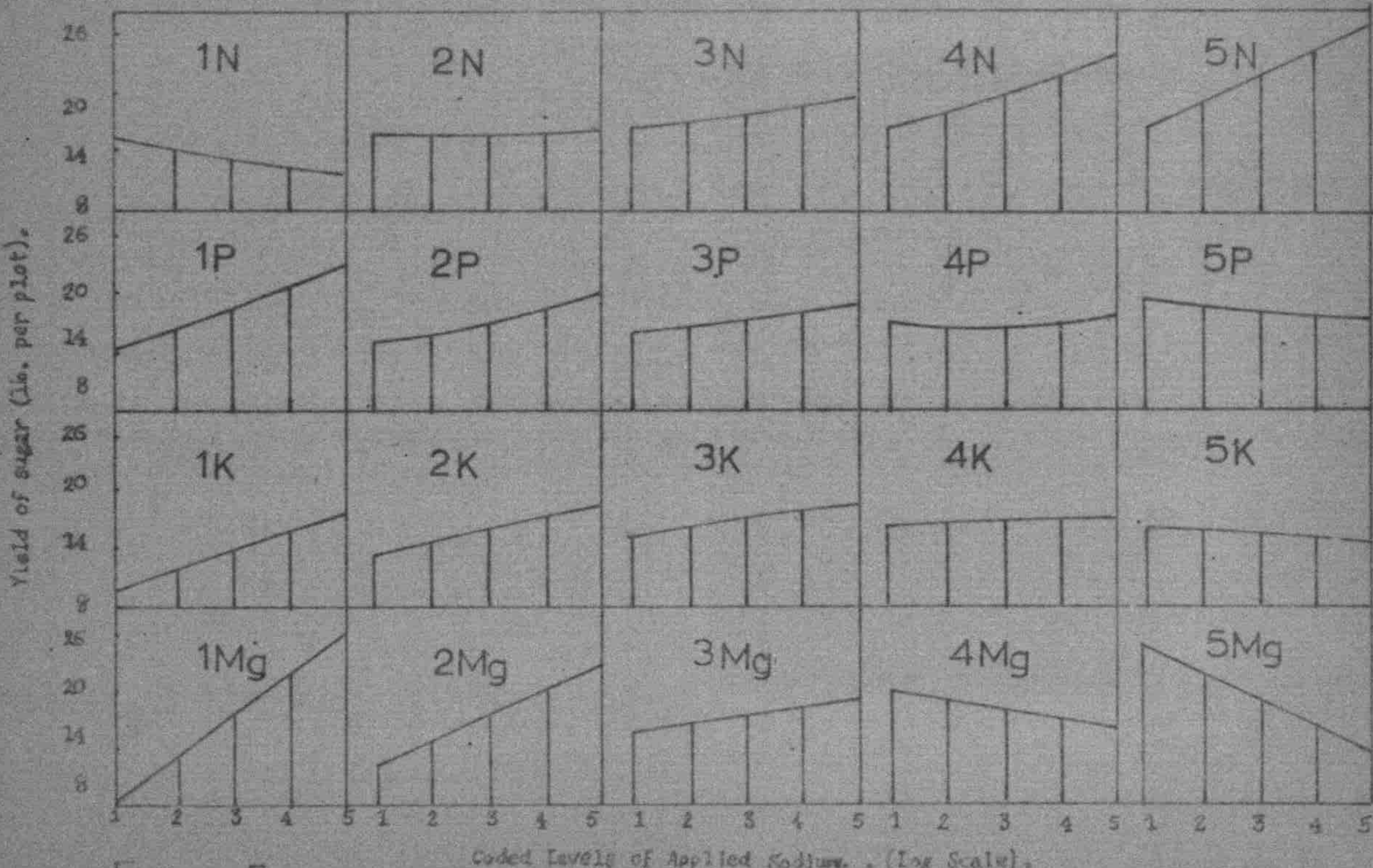


Figure 5. Yield of sugar as affected by five levels of Na in combination with one of the elements N, P, K and Mg alone with other elements held constant at the mid level, 3.

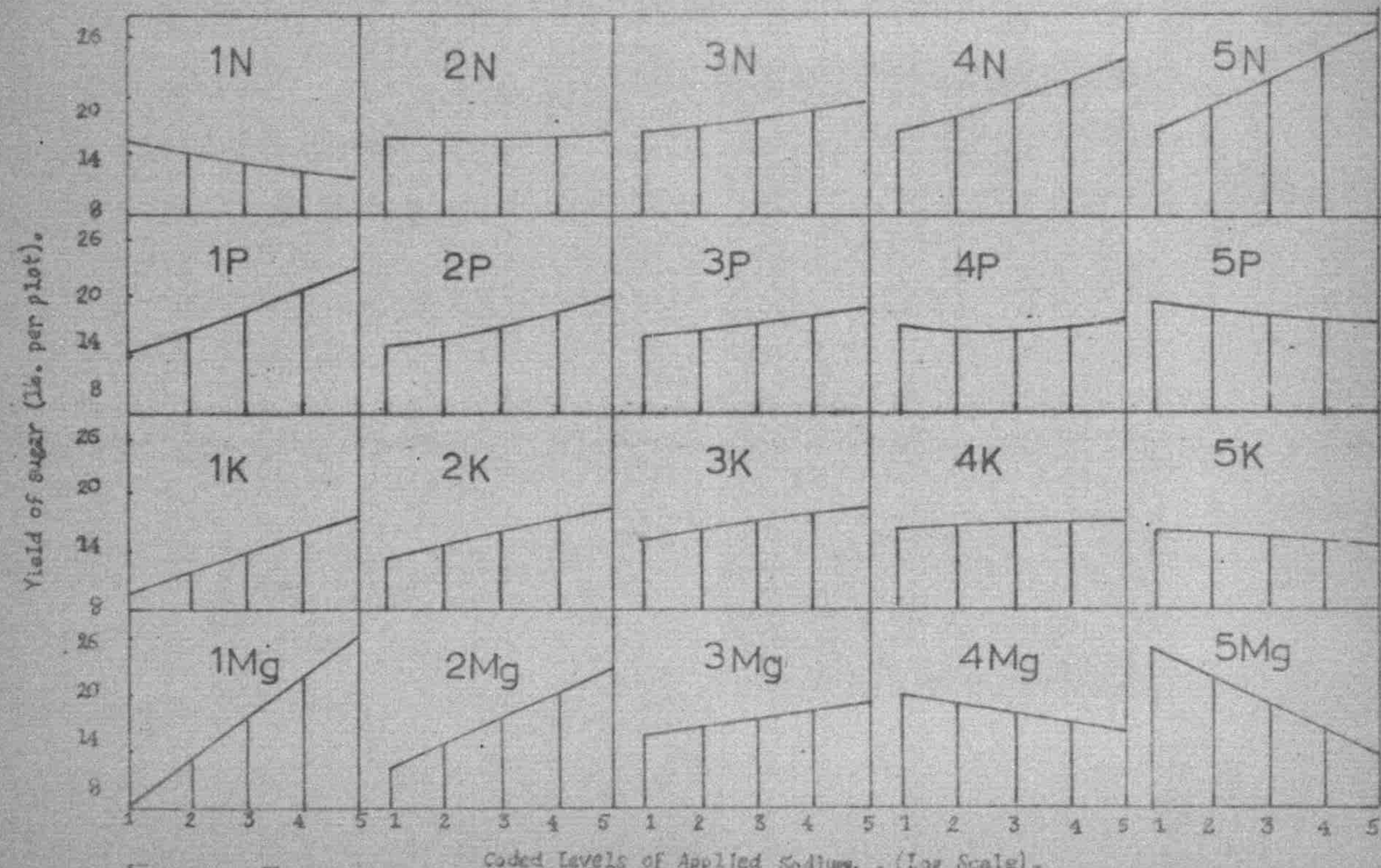


Figure 5. Yield of sugar as affected by five levels of Na in combination with one of the elements N, P, K and Mg alone with other elements held constant at the mid level, 3.

Response to Na as affected by Mg supply was similar to that of the complementary interactions Na-P and Na-K but was greater in magnitude.

The over-all response to Na as summarized from the previous discussion revealed that Na gave some increase in yield of sugar when other elements were held constant at the 3 level but response to Na was considerably increased at a high N level, or at a low P, K and Mg level.

The previous discussion was restricted to two variable interactions. In order to study certain of the interactions as influenced by a third variable, the response surfaces determined from the predicted yields calculated from the regression equation were utilized to illustrate the interactions among three elements at various treatment level combination in a three dimensional form (Fig. 6-17).

The Na-K interaction as Affected by Mg

The Na-K interaction as affected by 3 levels of Mg was examined by calculating the theoretical yields of sugar with the regression equation and plotting the response surfaces (Fig. 6) which indicated that at the 2 Mg level, increasing the K levels considerably increased the yield when the Na level was low. As the Na supply increased, K gave less response on yield of sugar. On the other hand when K was low Na increased the yield considerably but as the level of K was increased response to Na was reduced. Maximum yield of sugar was obtained when K and Na were at about the 3 and 5 levels respectively, whereas the minimum yield was obtained at the combination 1K + 1Na. At the 3 Mg level, the response to both K and Na was considerably less and at the 4 Mg level the tendency was for

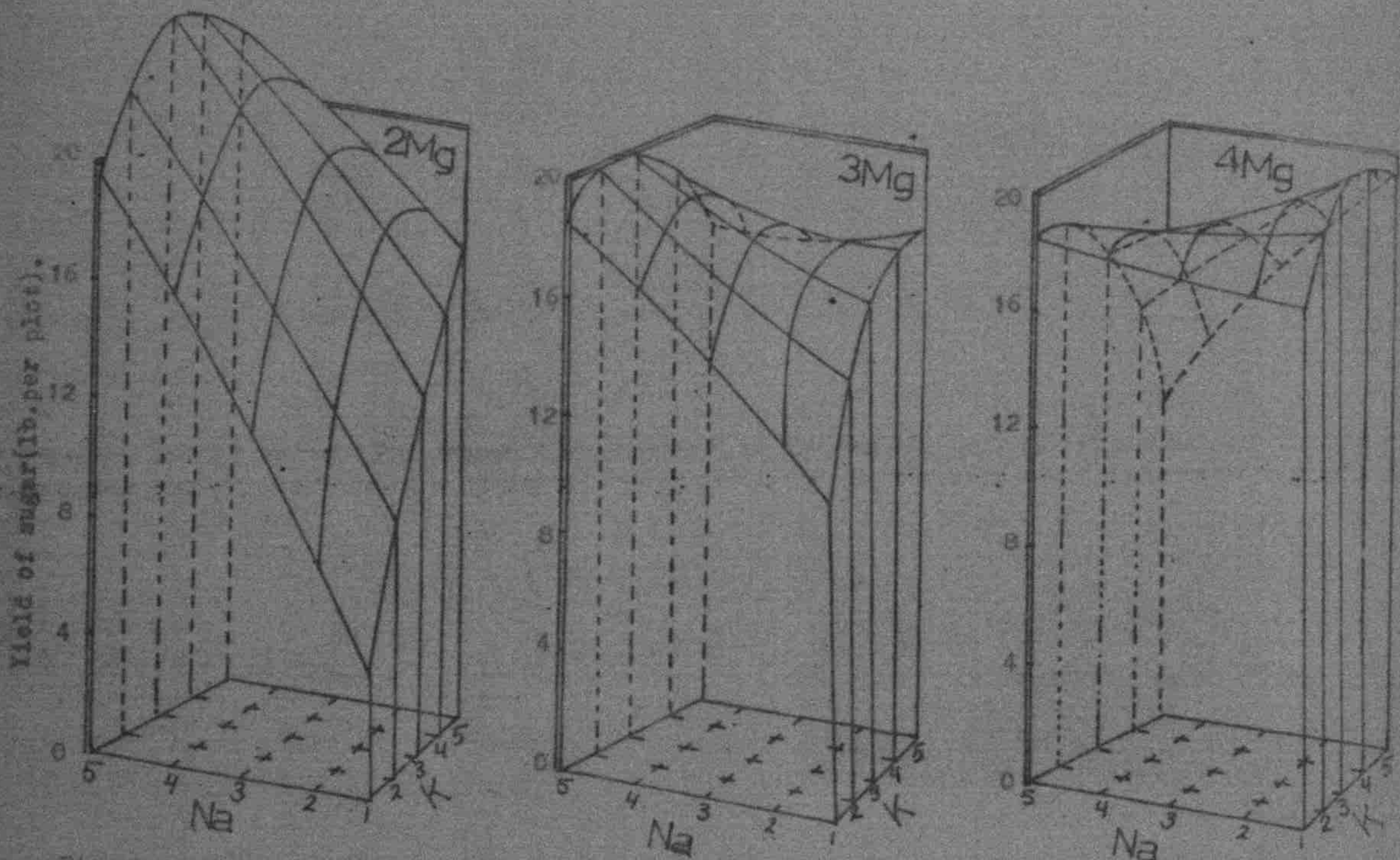


Figure 6. Yield of sugar as affected by the Na-K interaction with Mg held constant at each of three levels. N and P were kept constant at the middle of 5 levels.

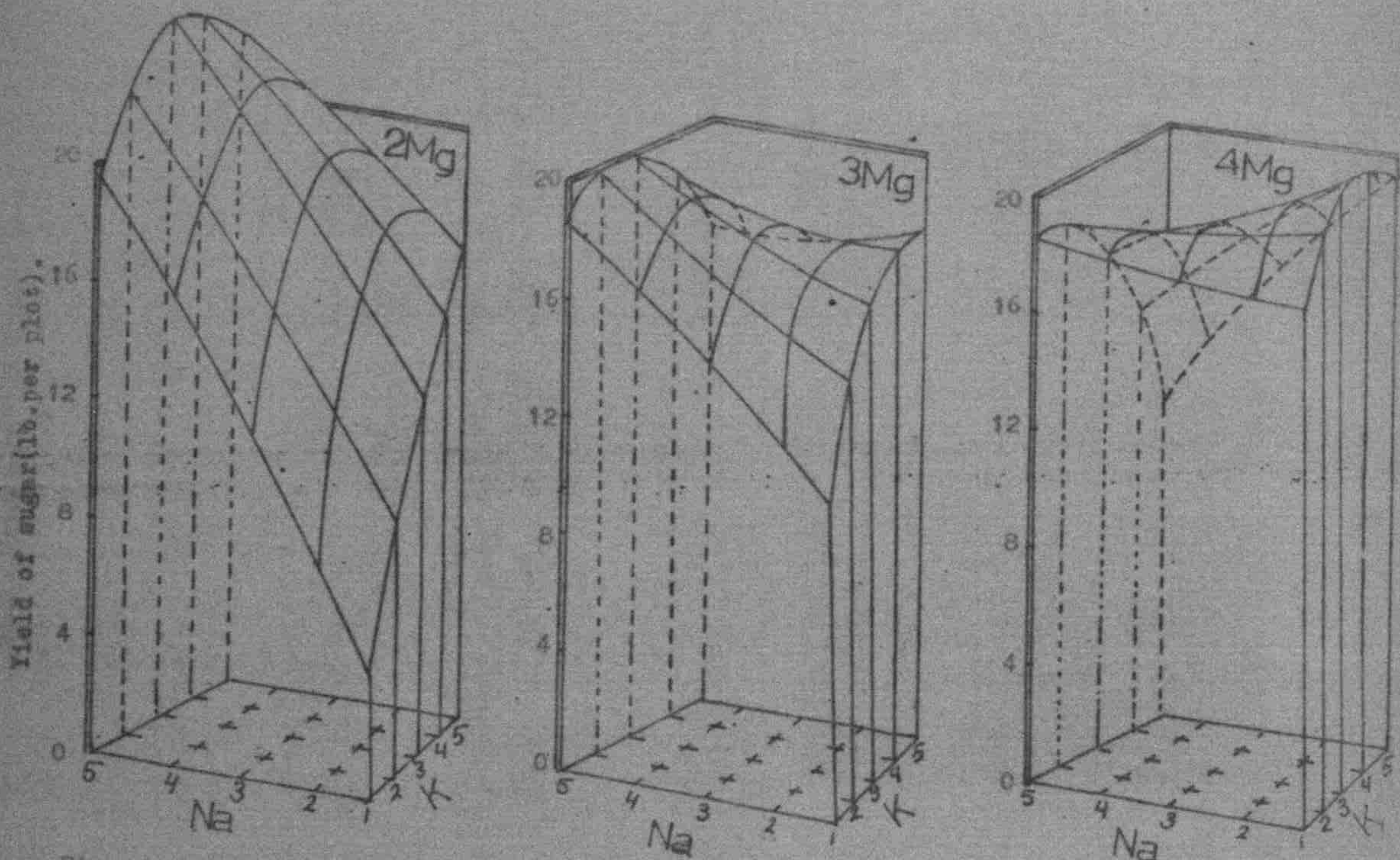


Figure 6. Yield of sugar as affected by the Na-K interaction with Mg held constant at each of three levels. N and P were kept constant at the middle of 5 levels.

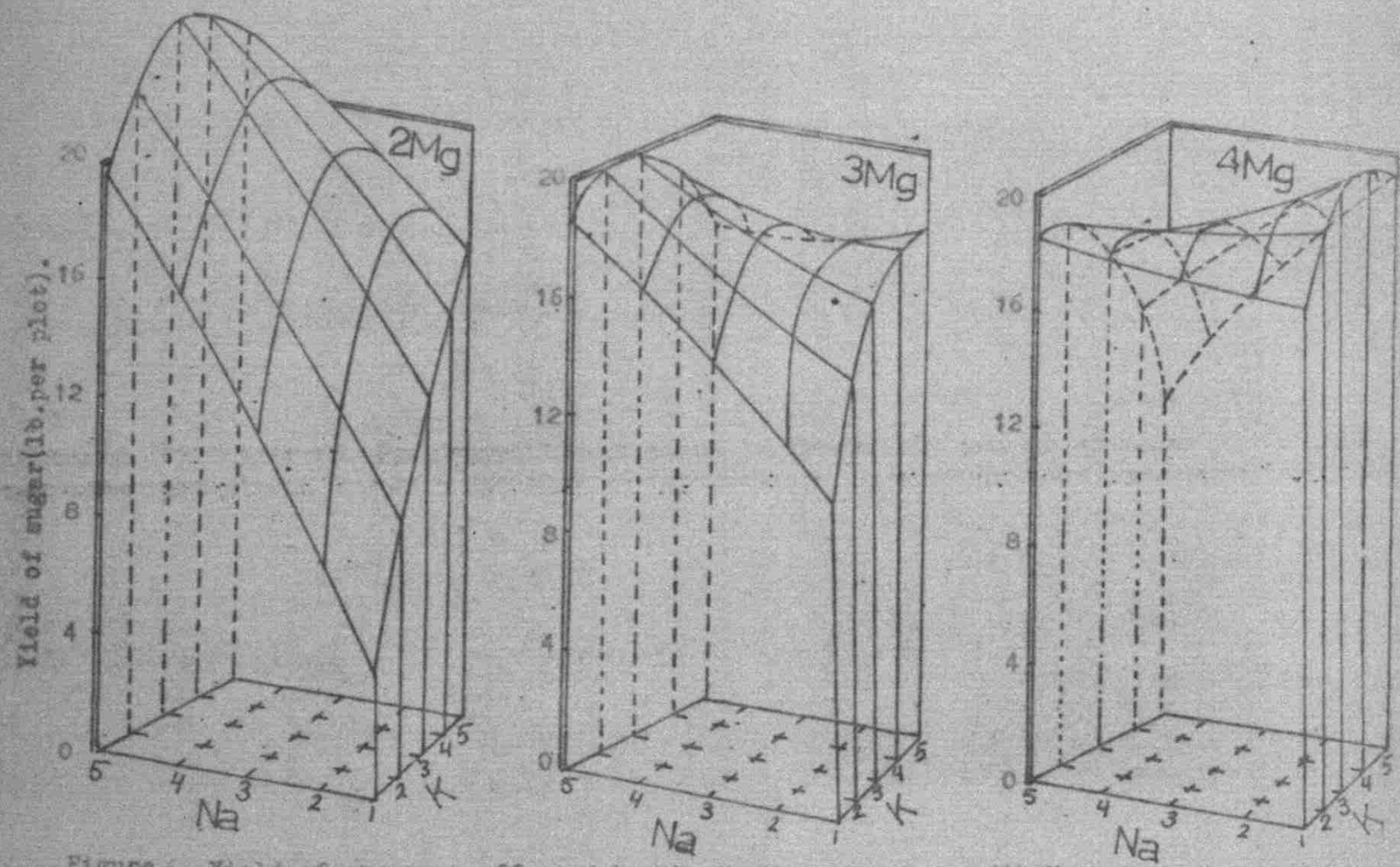


Figure 6. Yield of sugar as affected by the Na-K interaction with Mg held constant at each of three levels. N and P were kept constant at the middle of 5 levels.

reduced yield of sugar with increasing Na or K except that at the low level of one the other gave a small increase. The indications were that there was a considerable overlap of function of the 3 cations Na, K, and Mg. It would appear that the best combination for the maximum yield of sugar would be a low rate of applied Mg, a medium level of applied K and a high rate of applied Na. This was true for a soil where the exchangable Mg, Na, and K would be considered adequate for high yields of crops. However, the high level of available Ca in this calcareous soil probably effectively reduced the uptake of the other cations.

The Na-K Interaction as Affected by N

Examination of the response surfaces for yield of sugar as affected by various levels of Na and K at three levels of N while other elements were kept constant indicated (Fig. 7) that at the 2N level both Na and K increased the yield of sugar most when the level of the other was low, whereas when both K and Na were high, the yield of sugar was depressed. At the 3N level the same trend was observed. At the 4N level the response to Na was considerably increased and the response to K was not affected. This result revealed that when the N supply was high the response to Na was much higher than the response to K. All increments of Na increased the yield whereas only the first three increments of K increased the yield. Maximum yield of sugar was obtained when both N and Na were at high levels and K was at the 3 level.

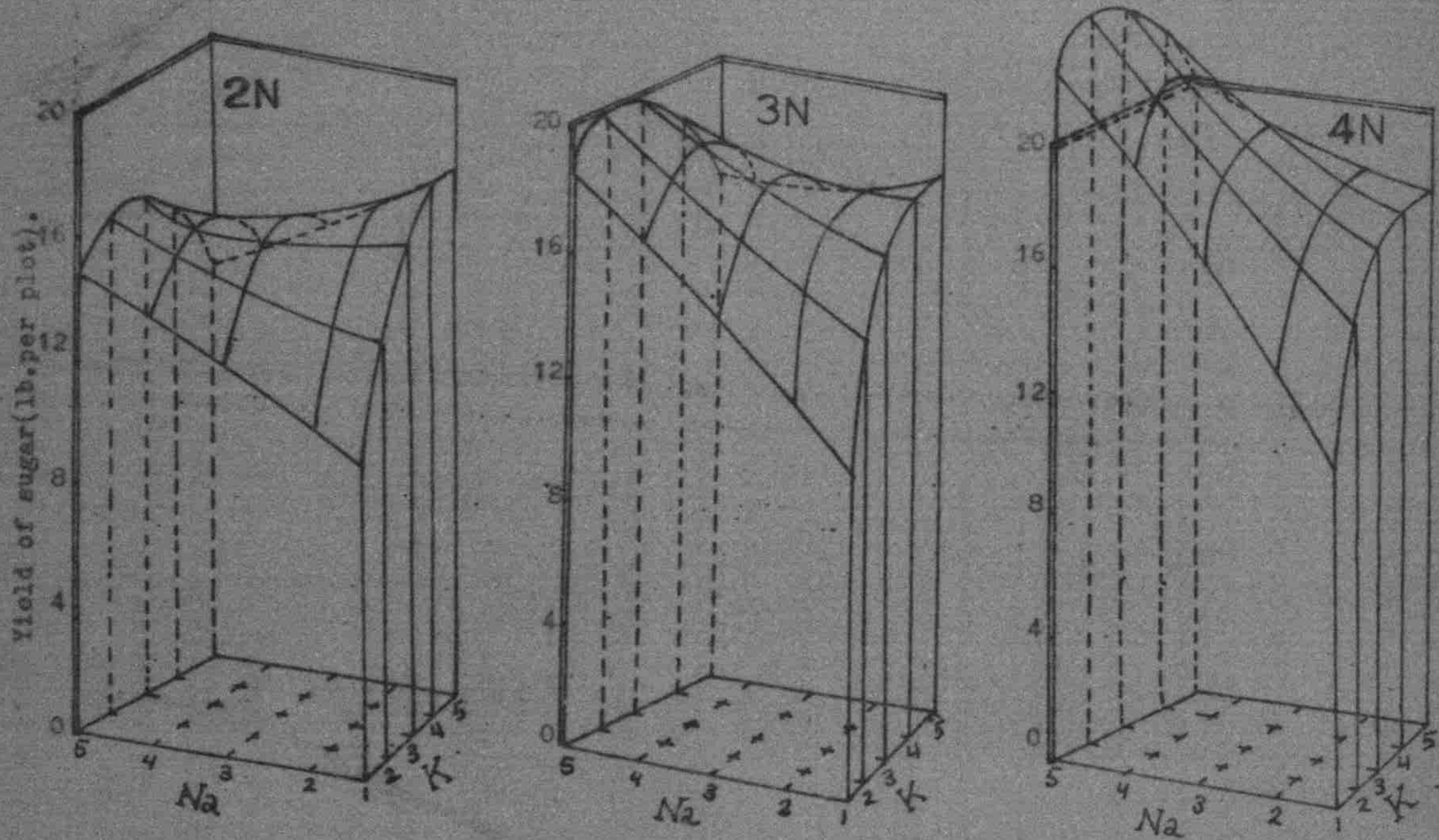


Figure 7. Yield of sugar as affected by the Na-K interaction with N held constant at each of three levels. P and Mg were kept constant at the middle of 5 levels.

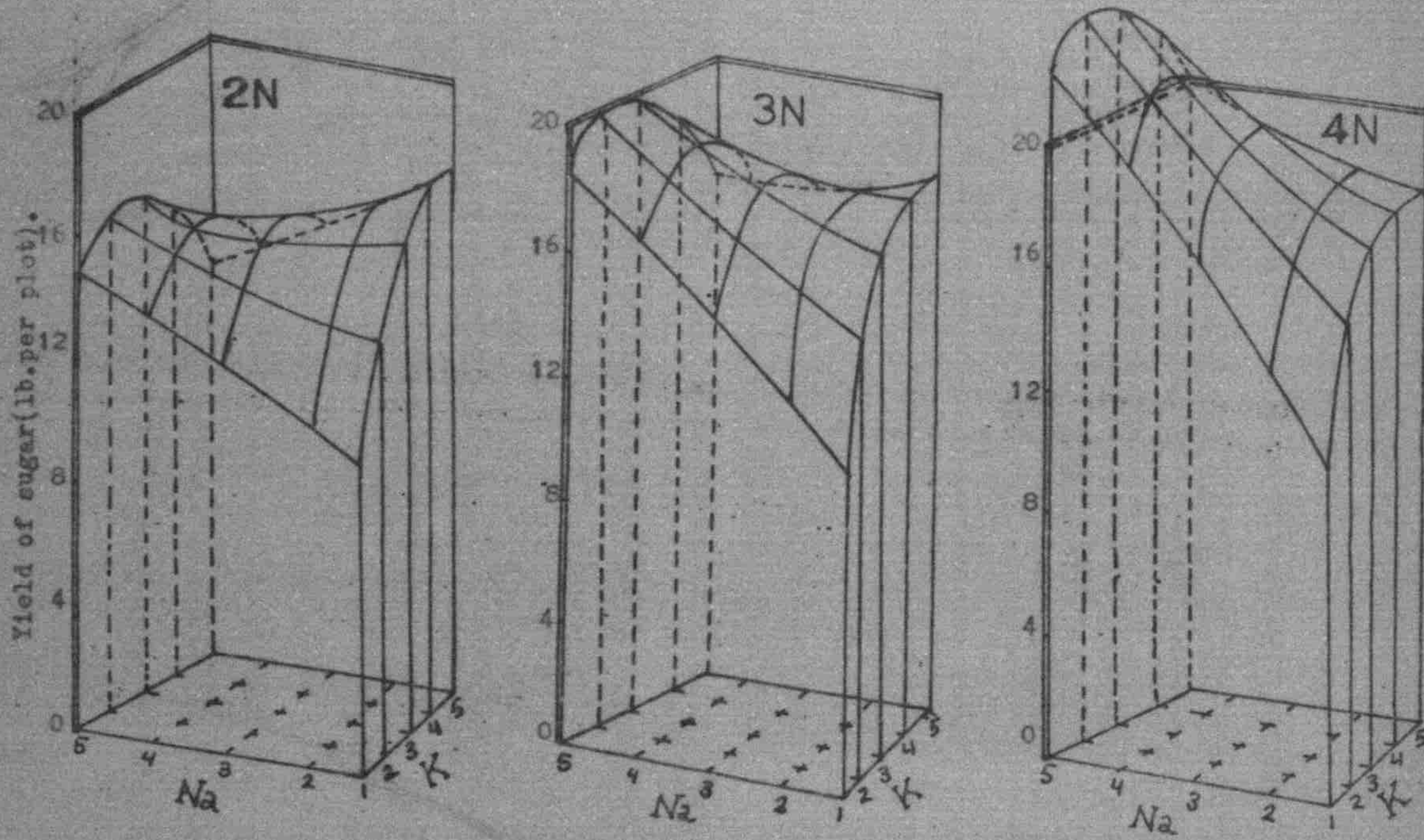


Figure 7. Yield of sugar as affected by the Na-K interaction with N held constant at each of three levels. P and Mg were kept constant at the middle of 5 levels.

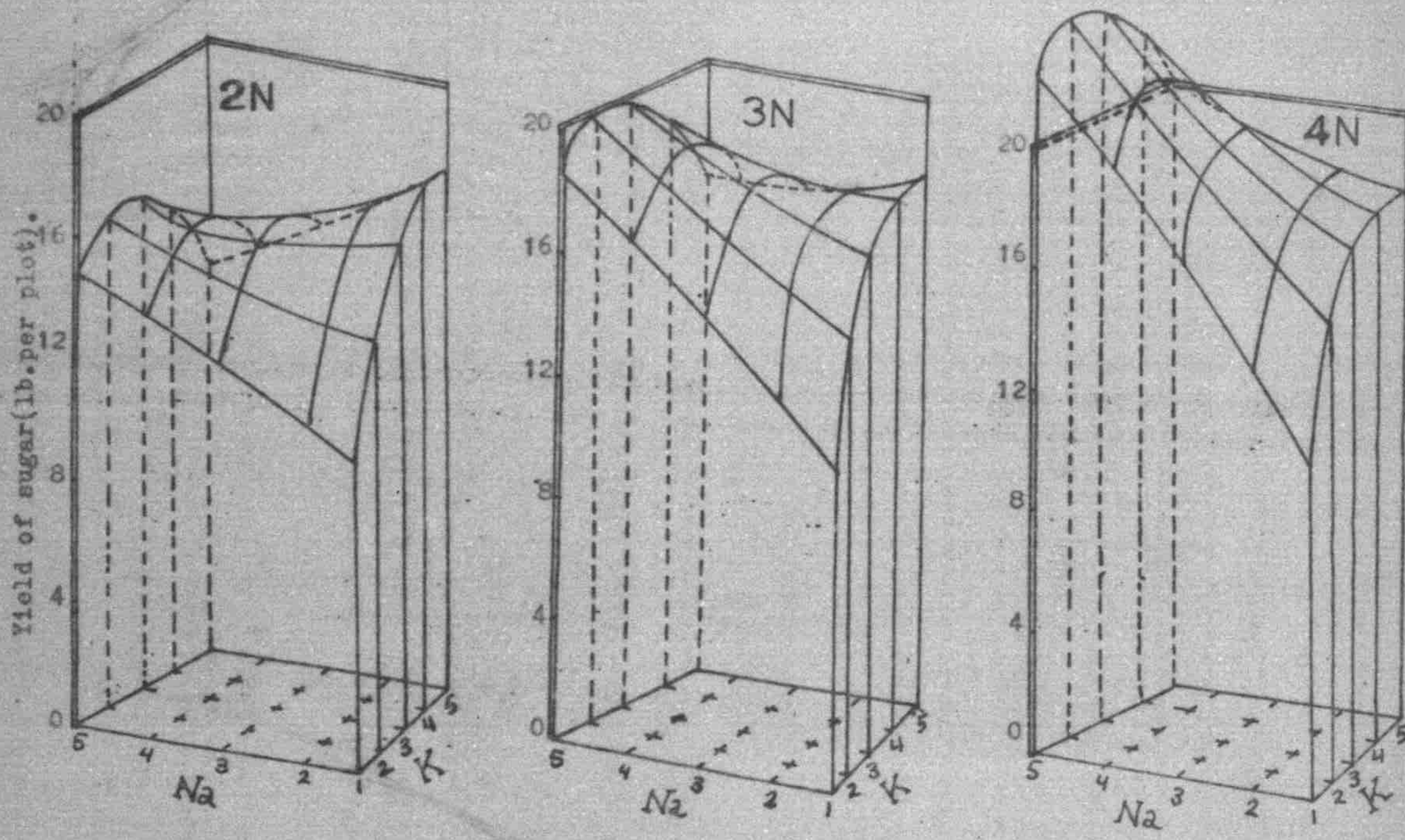


Figure 7. Yield of sugar as affected by the Na-K interaction with N held constant at each of three levels. P and Mg were kept constant at the middle of 5 levels.

The Na-K Interaction as Affected by P

Examination of the Na-K interaction as affected by 3 levels of P indicated (Fig. 8) that at a low supply of P, response to Na was much higher than the response to K. However, highest yield was obtained from the 5Na + 3K treatment. When the supply of P was increased, the response to Na was reduced while the response to K was considerably increased. This resulted from the positive coefficient for the P-K interaction and the negative coefficient for the P-Na interaction.

The previous discussion revealed that when N and P were at the 3 level response to either Na or K was obtained only when the other element was low. At a low level of P, the application of Na was beneficial while the response to K was reduced. On the other hand, at a high level of P, the application of K was beneficial while the response to Na was reduced.

The Na-Mg Interaction as Affected by K

The Na-Mg interaction as affected by 3 levels of K was examined by calculating the theoretical yield of sugar with the regression equation and plotting the response surfaces (Fig. 9) which indicated that at all levels of K, either Na or Mg increased the yield of sugar most when the level of the other was low (complementary relationship). The yield was decreased if one was increased at a high level of the other. The response to both Na and Mg tended to be less with increasing levels of K. These results emphasized the complementary relationships between the cations Na, K, and Mg.

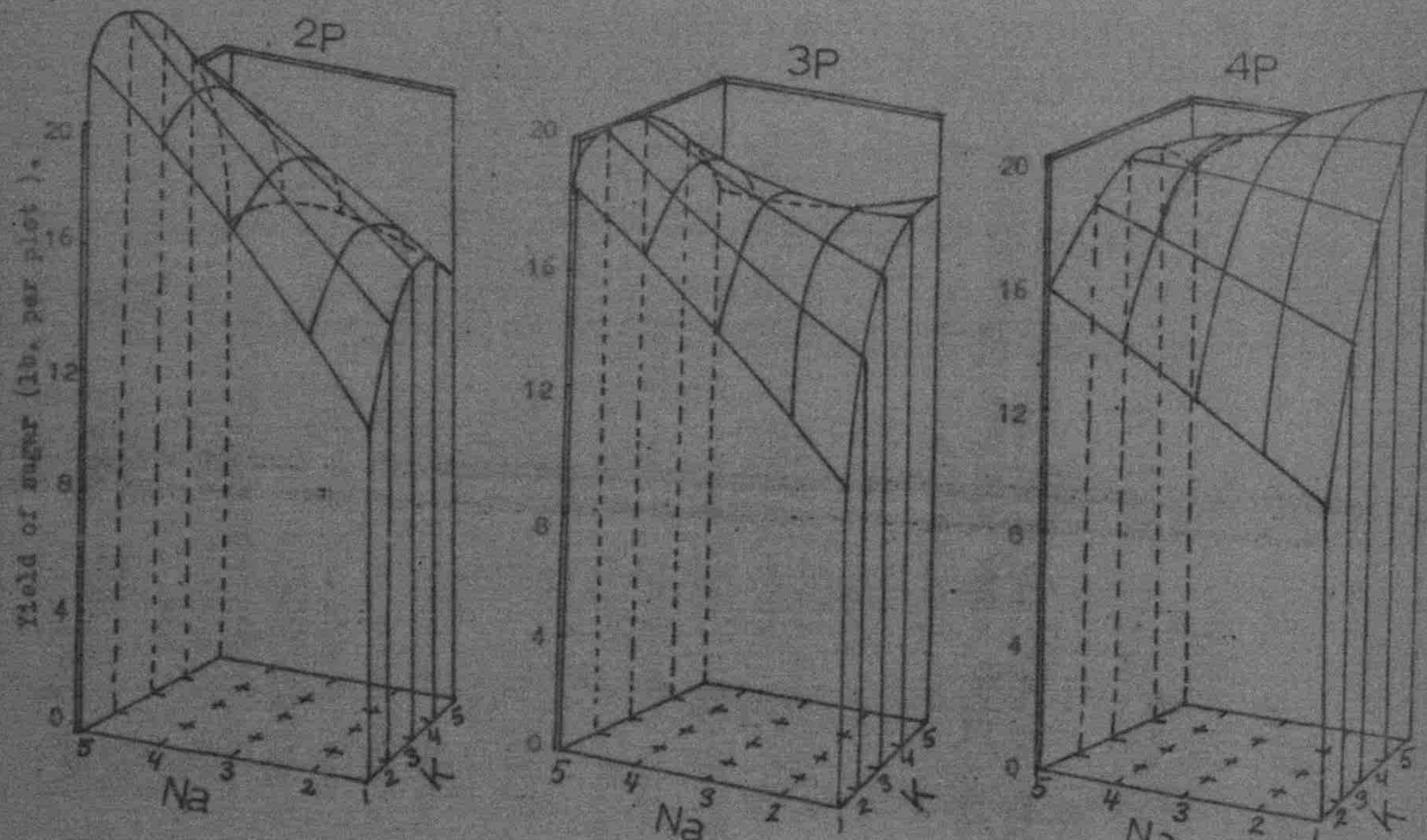


Figure 3. Yield of sugar as affected by the Na-K interaction with P held con°tant at each of three levels. N and Mg were kept constant at the middle of 5 levels.

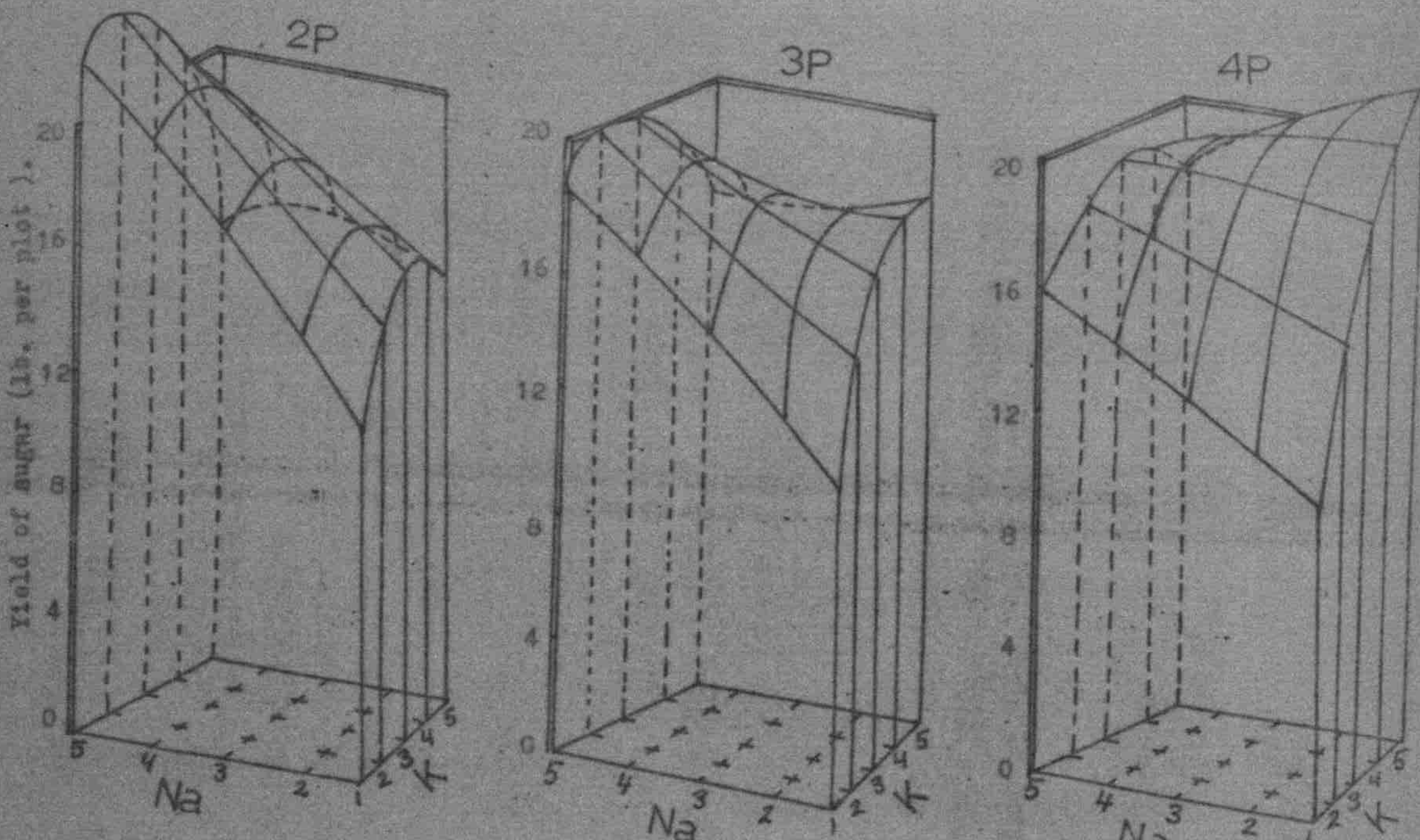


Figure 8. Yield of sugar as affected by the Na-K interaction with P held constant at each of three levels. N and Mg were kept constant at the middle of 5 levels.

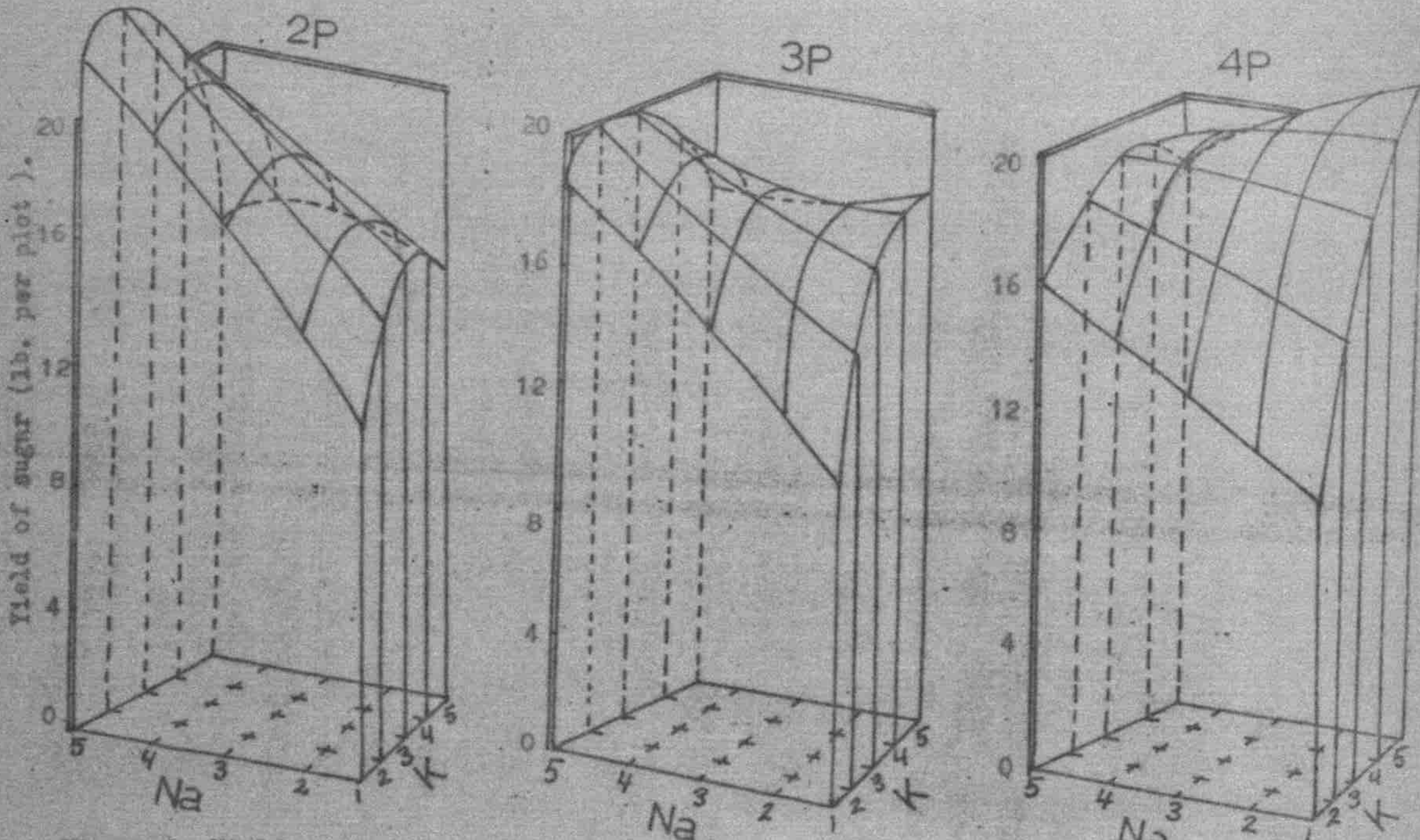


Figure 8. Yield of sugar as affected by the Na-K interaction with P held constant at each of three levels. N and Mg were kept constant at the middle of 5 levels.

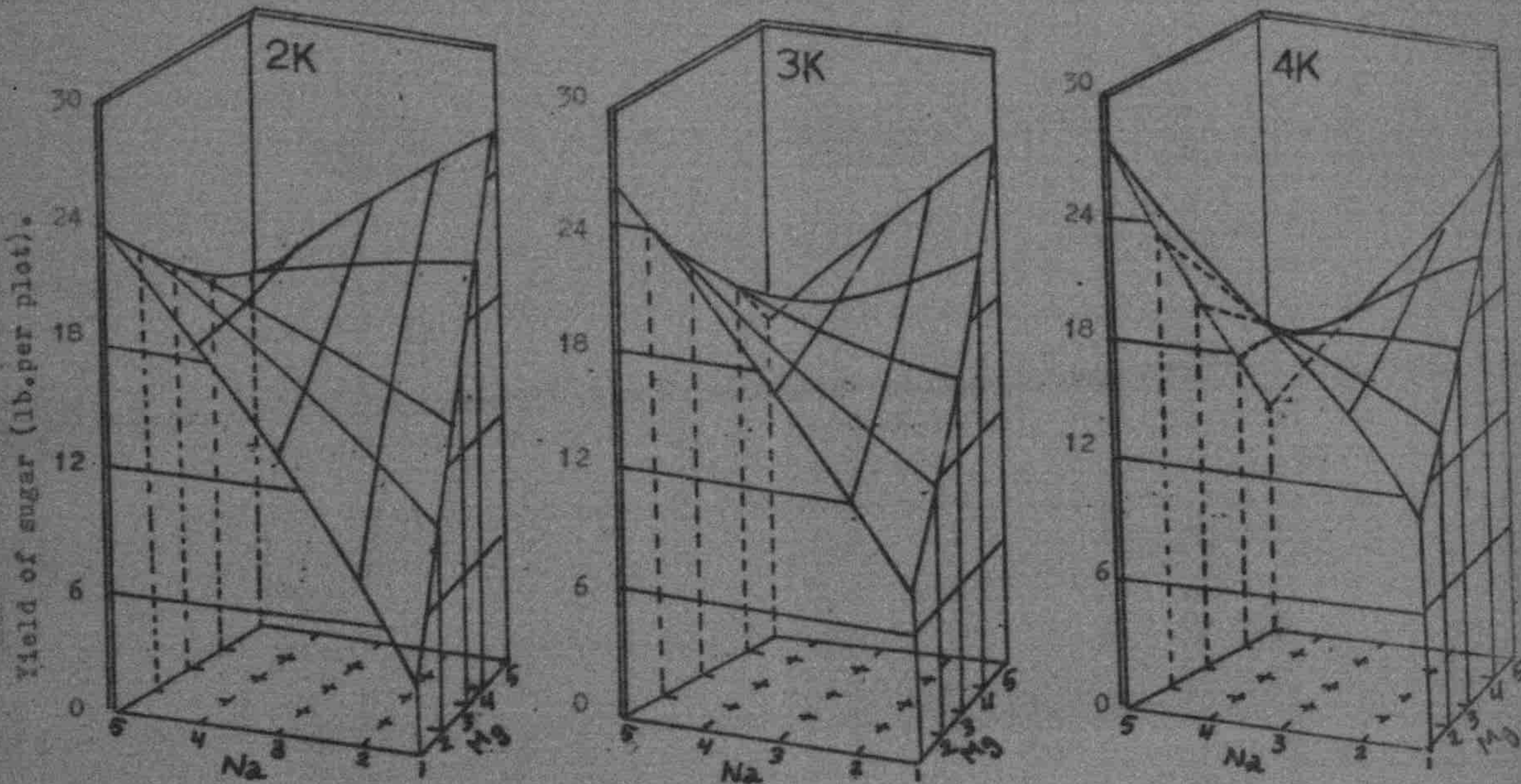


Figure 9. Yield of sugar as affected by the Na-Mg interaction with K held constant at each of three levels. N and P were kept constant at the middle of 5 levels.

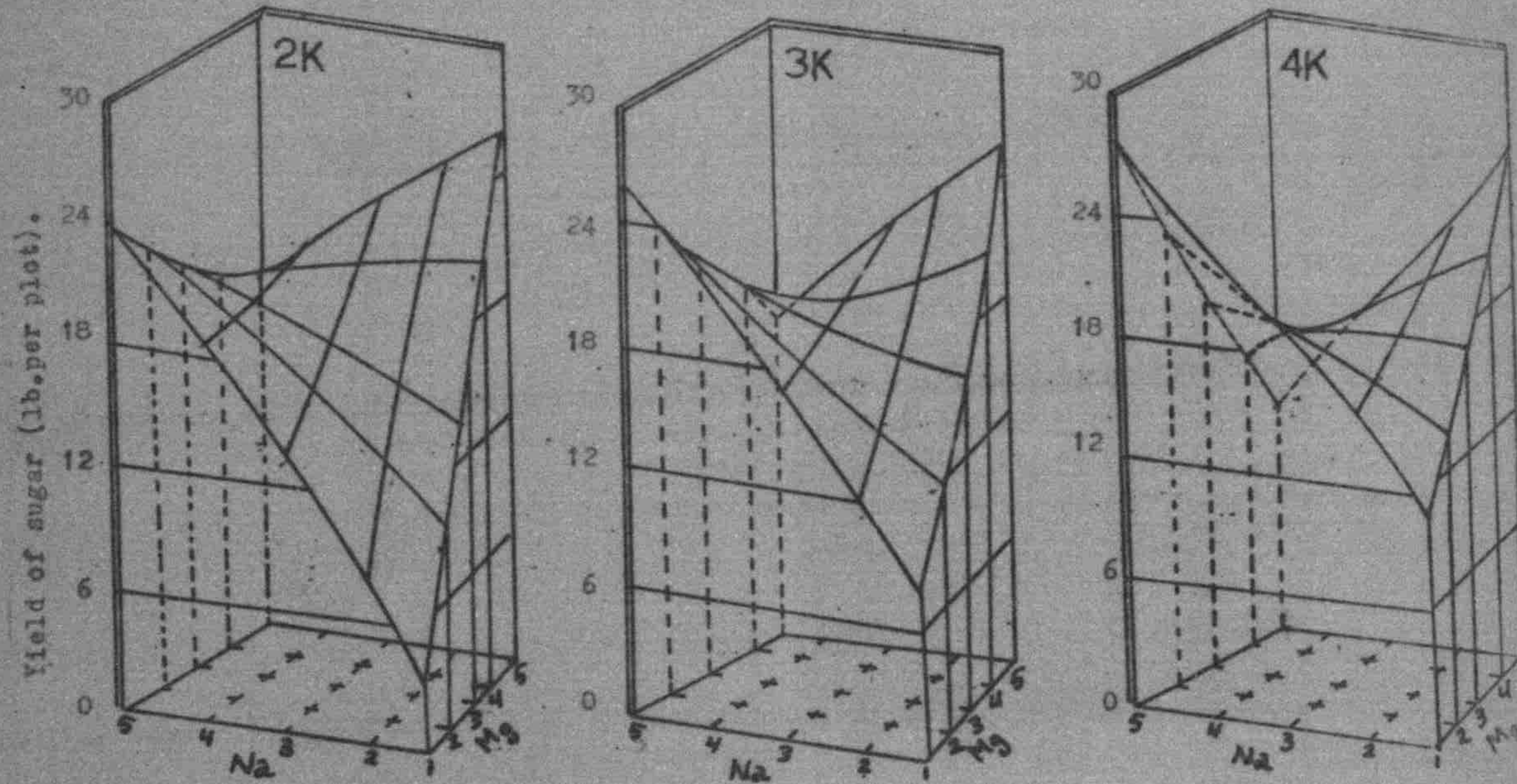


Figure 9. Yield of sugar as affected by the Na-Mg interaction with K held constant at each of three levels. N and P were kept constant at the middle of 5 levels.

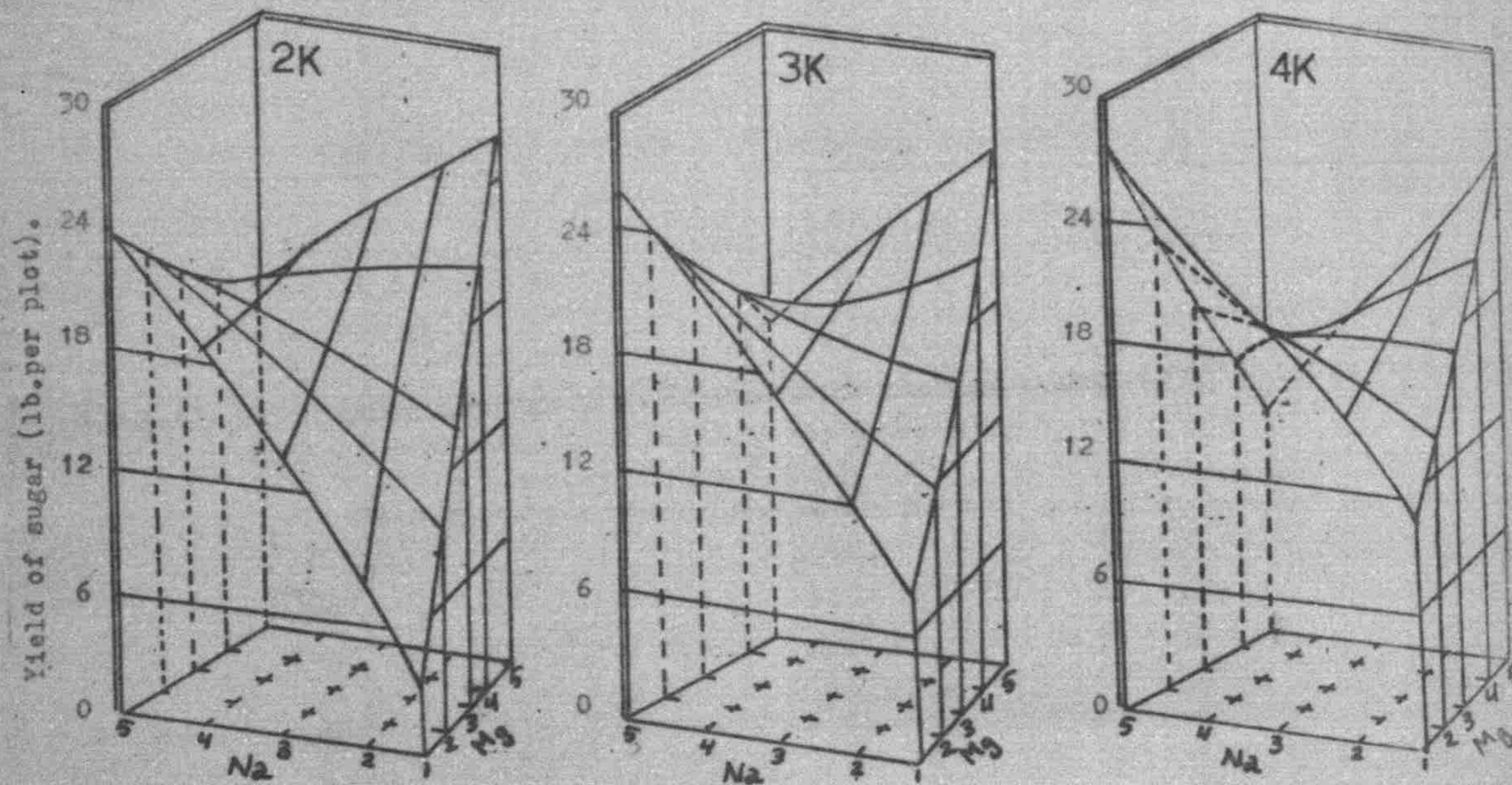


Figure 9. Yield of sugar as affected by the Na-Mg interaction with K held constant at each of three levels. N and P were kept constant at the middle of 5 levels.

The Na-Mg Interaction as Affected by N

Examination of the response surface for yield of sugar as affected by various levels of N while other elements were held constant at the 3 level indicated (Fig. 10) that both Na and Mg increased the yield of sugar most when the level of other was low. Increasing the supply of N to the 4N level resulted in an increase in the responses to Na and Mg with the Na response increased to a greater extent than the Mg response. This was related to the higher positive value for the Na-N interaction regression coefficient (+ 0.819) as compared to that for the N-Mg interaction (+ 0.281).

It has been established that one of the physiological functions of cations in the plant was their role in neutralizing the inorganic and organic acids in plants. This relationship suggested that more cations were needed when the supply of N was increased to balance the nitrates and organic anions in the plants. The saddle shape for the Na-Mg interaction response surface suggested that addition of Na or Mg is more beneficial when the supply of the other is low than addition of high rates of both elements at the same time. This revealed that there must be a critical level for the sum of the cations in the plants. It was found that (Fig. 9) the depression from high rates of Na + Mg was greater when the supply of K was high. The effect of Mg supply on the Na-K interaction (Fig. 6) also suggested this complementary relationship.

The Na-Mg Interaction as Affected by P

Examination of the response surfaces for yield of sugar as affected

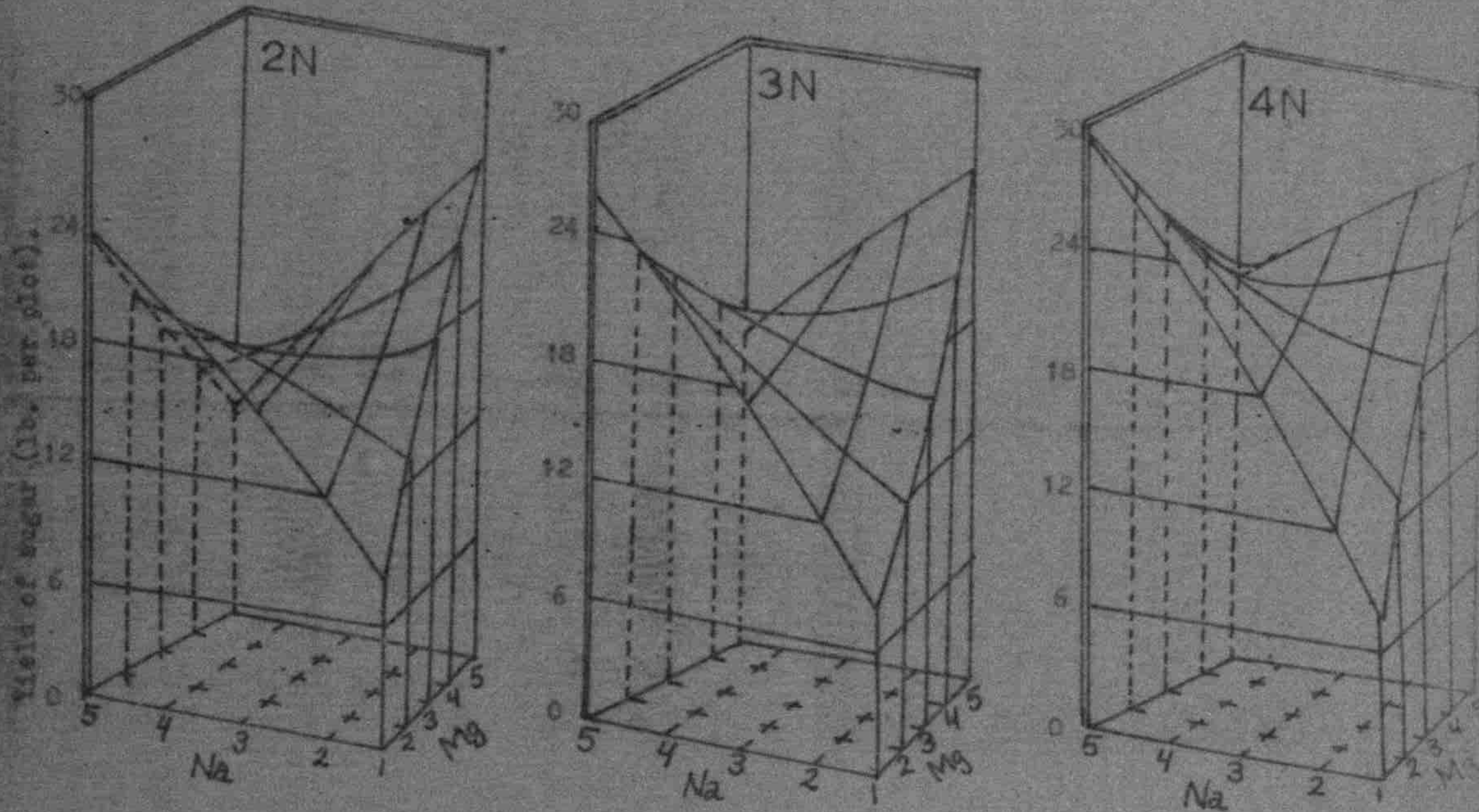


Figure 10. Yield of sugar as affected by the Na-Mg interaction with N held constant at each of three levels. P and K were kept constant at the middle of 5 levels.

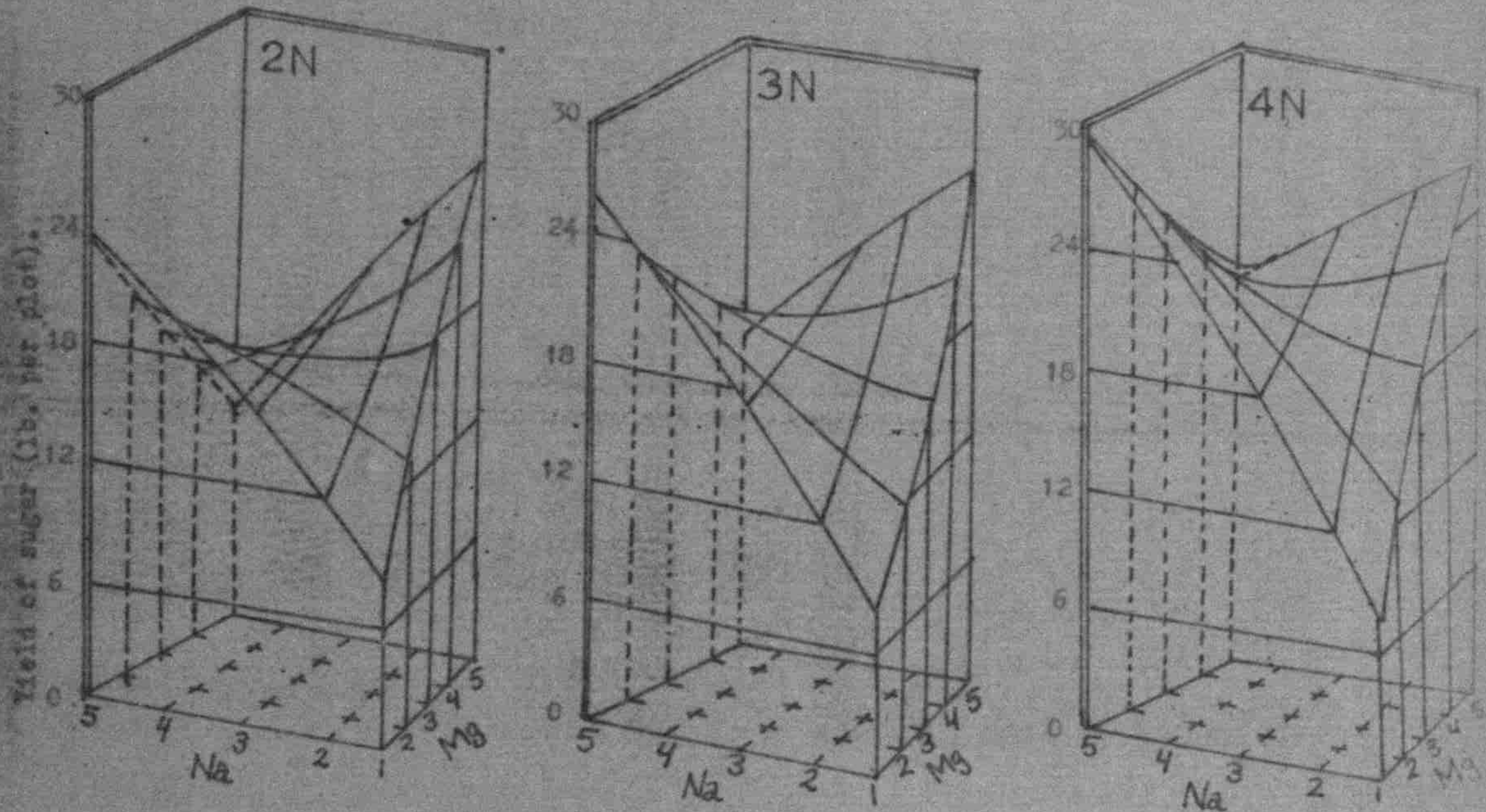


Figure 10. Yield of sugar as affected by the Na-Mg interaction with N held constant at each of three levels. P and K were kept constant at the middle of 5 levels.

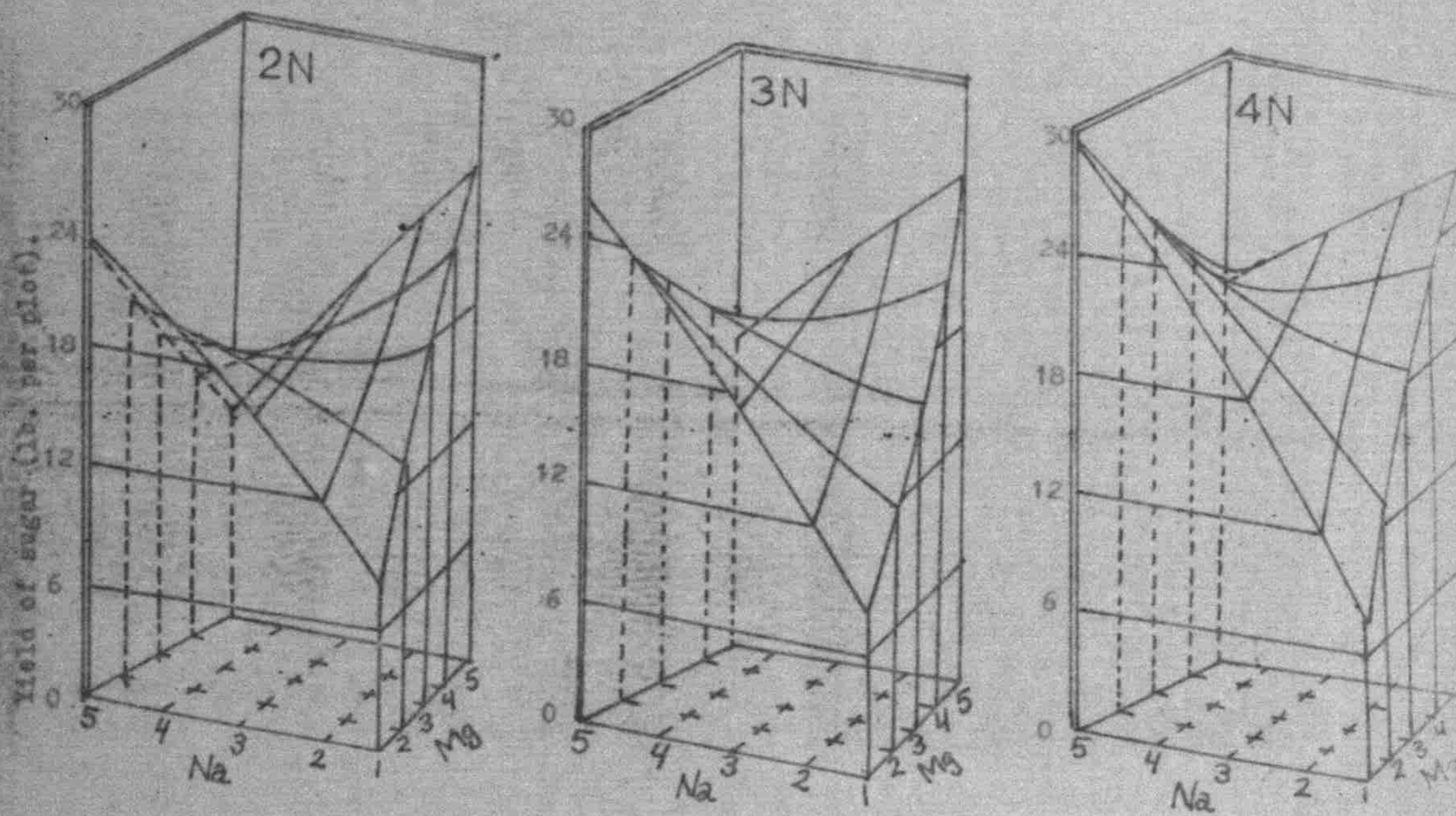


Figure 10. Yield of sugar as affcted by the Na-Mg interaction with N held constant at each of three levels. P and K were kept constant at the middle of 5 levels.

by various levels of Na and Mg at each of three levels of P while other elements were held constant at the 3 level indicated (Fig. 11) that the response to Na and Mg was slightly decreased as the P level was increased. It was also found that at the 4P level, application of high rates of both Mg and Na considerably depressed the yield whereas at the 2P level, the depression was less severe. It was concluded that at all levels of P the highest yield was obtained when either Mg or Na was applied at a high rate while the other was low. Increasing the rate of P application appeared to give no appreciable increase in yield of sugar.

The N-Na Interaction as Affected by K

The N-Na interaction as affected by 3 levels of K was examined by calculating the theoretical yields of sugar with the regression equation and plotting the response surfaces (Fig. 12) which indicated that at the 2K level both N and Na failed to increase the yield of sugar appreciably when one of them was applied at a low level of the other, whereas both N and Na greatly increased the yield at a high level of the other. The maximum yield was obtained at the combination 5N-5Na. On increasing the level of K to the 3K level, the response to N was not affected whereas response to Na was decreased. At the 4K level, response to both N and Na was depressed, but the depression effect on Na was more than that for N

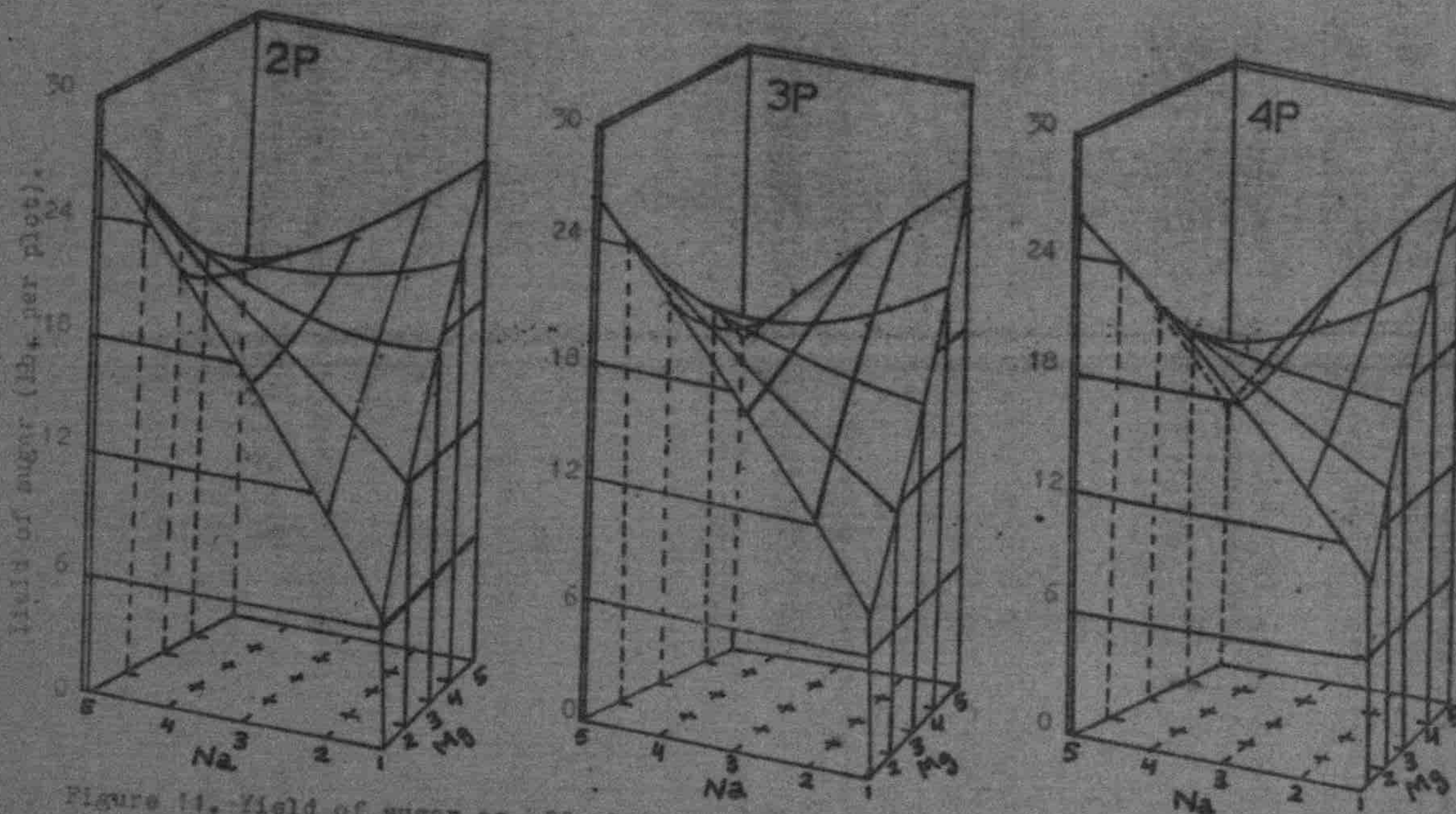


Figure 11. Yield of sugar as affected by the Na-Mg interaction with P held constant at each of three levels. N and K were kept constant at the middle of 5 levels.

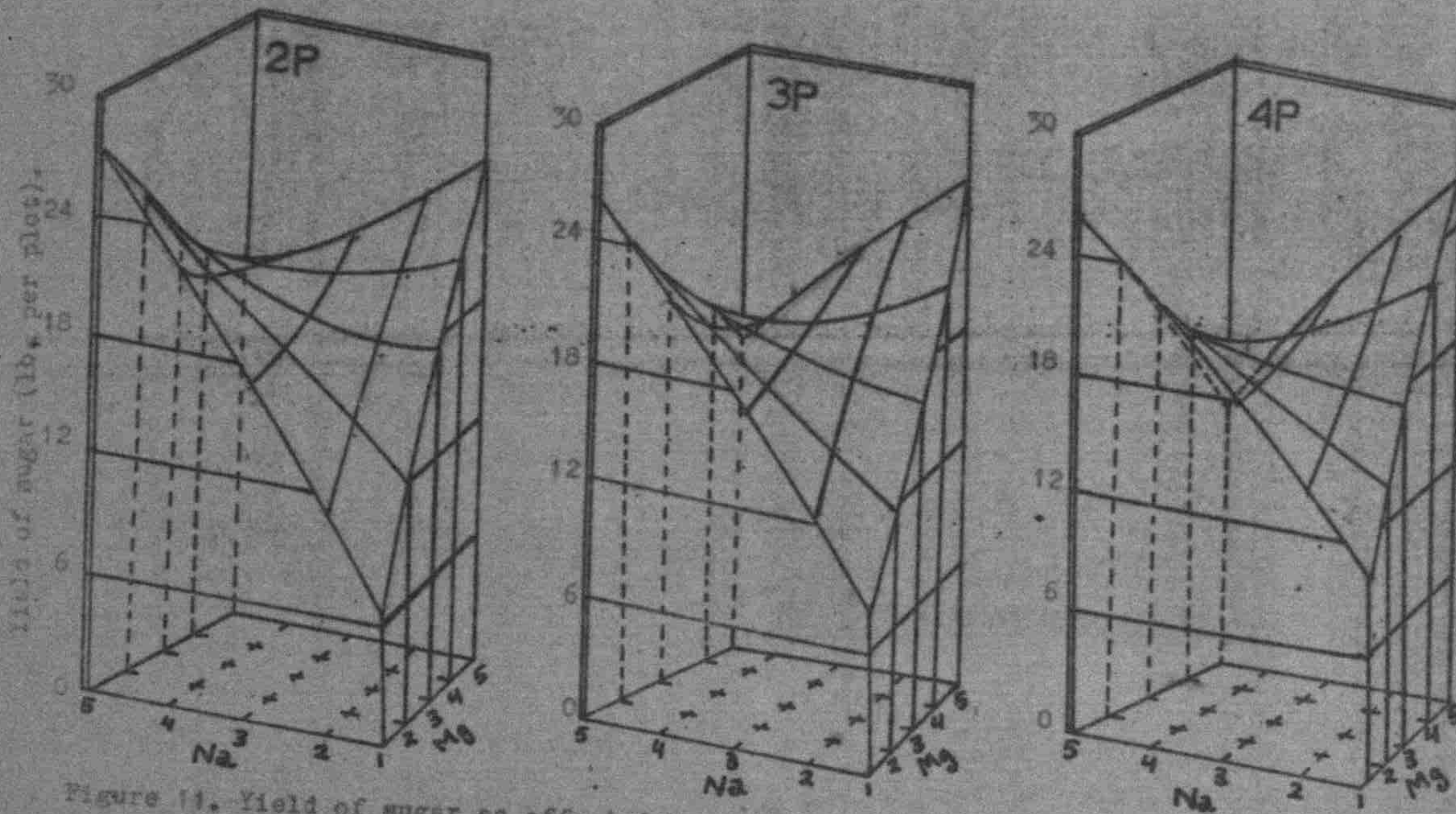


Figure 11. Yield of sugar as affected by the Na-Mg interaction with P held constant at each of three levels. N and K were kept constant at the middle of 5 levels.

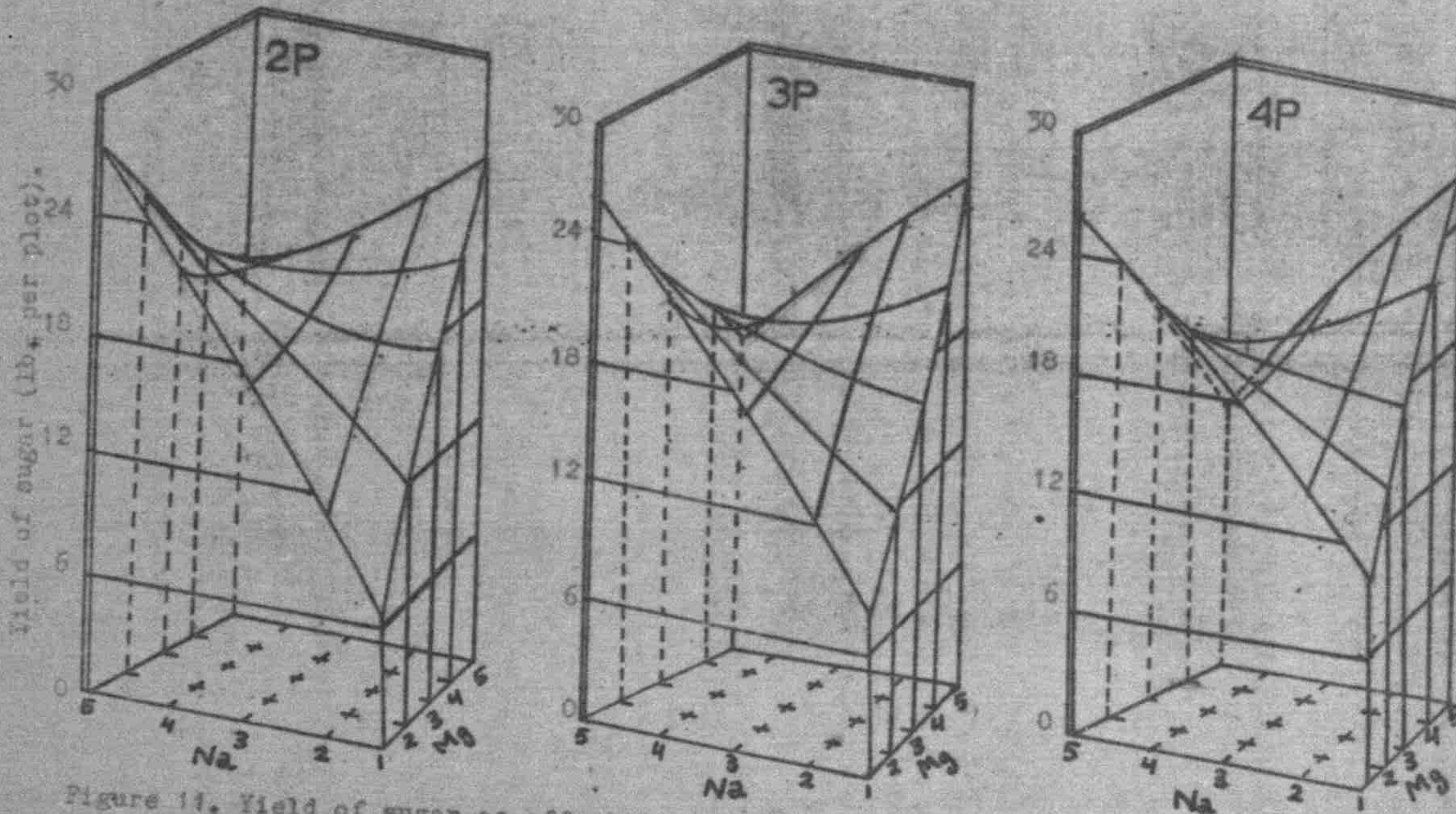


Figure 11. Yield of sugar as affected by the Na-Mg interaction with P held constant at each of three levels. N and K were kept constant at the middle of 5 levels.

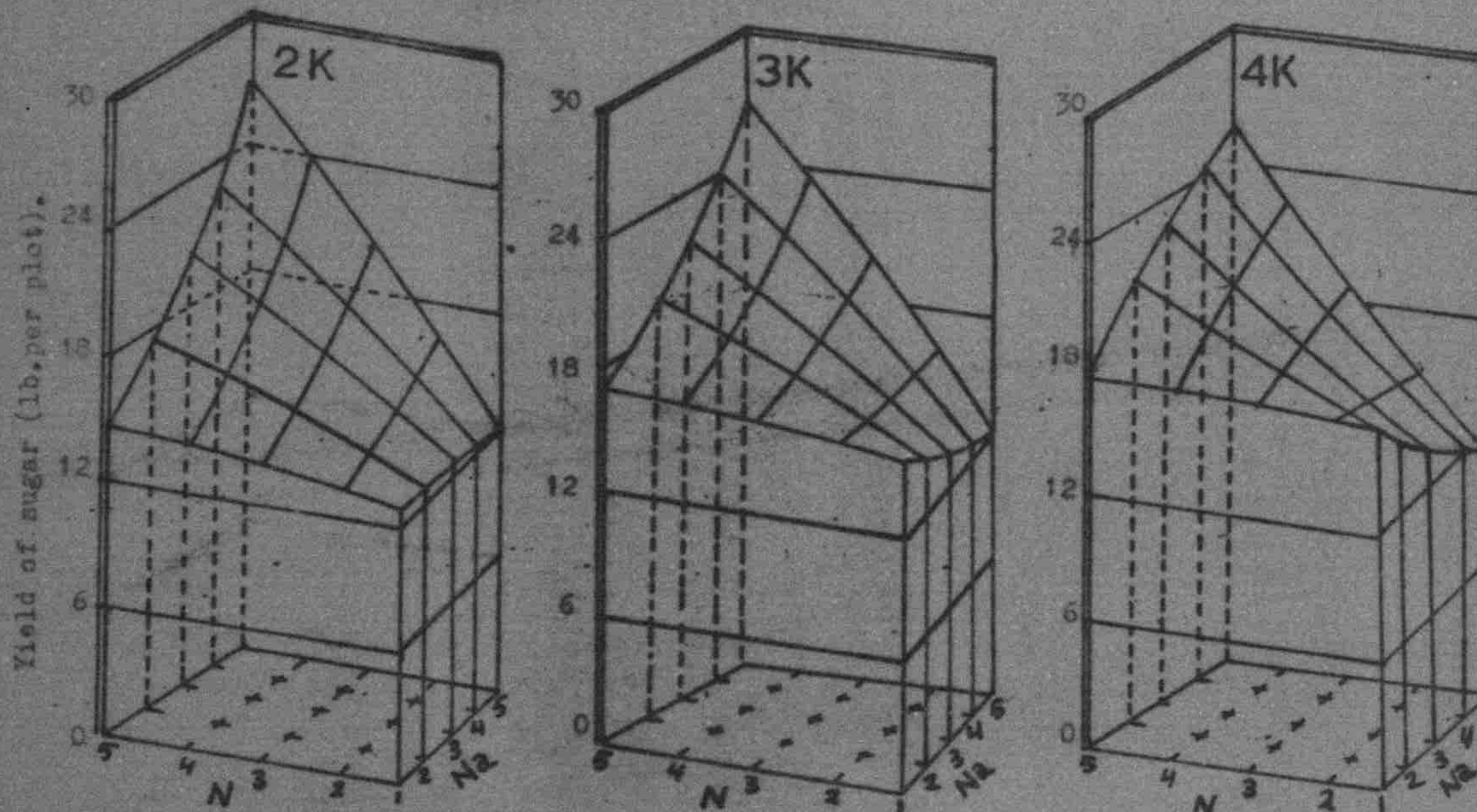


Figure 12. Yield of sugar as affected by the Na-N interaction with K held constant at each of three levels. P and Mg were kept constant at the middle of 5 levels.

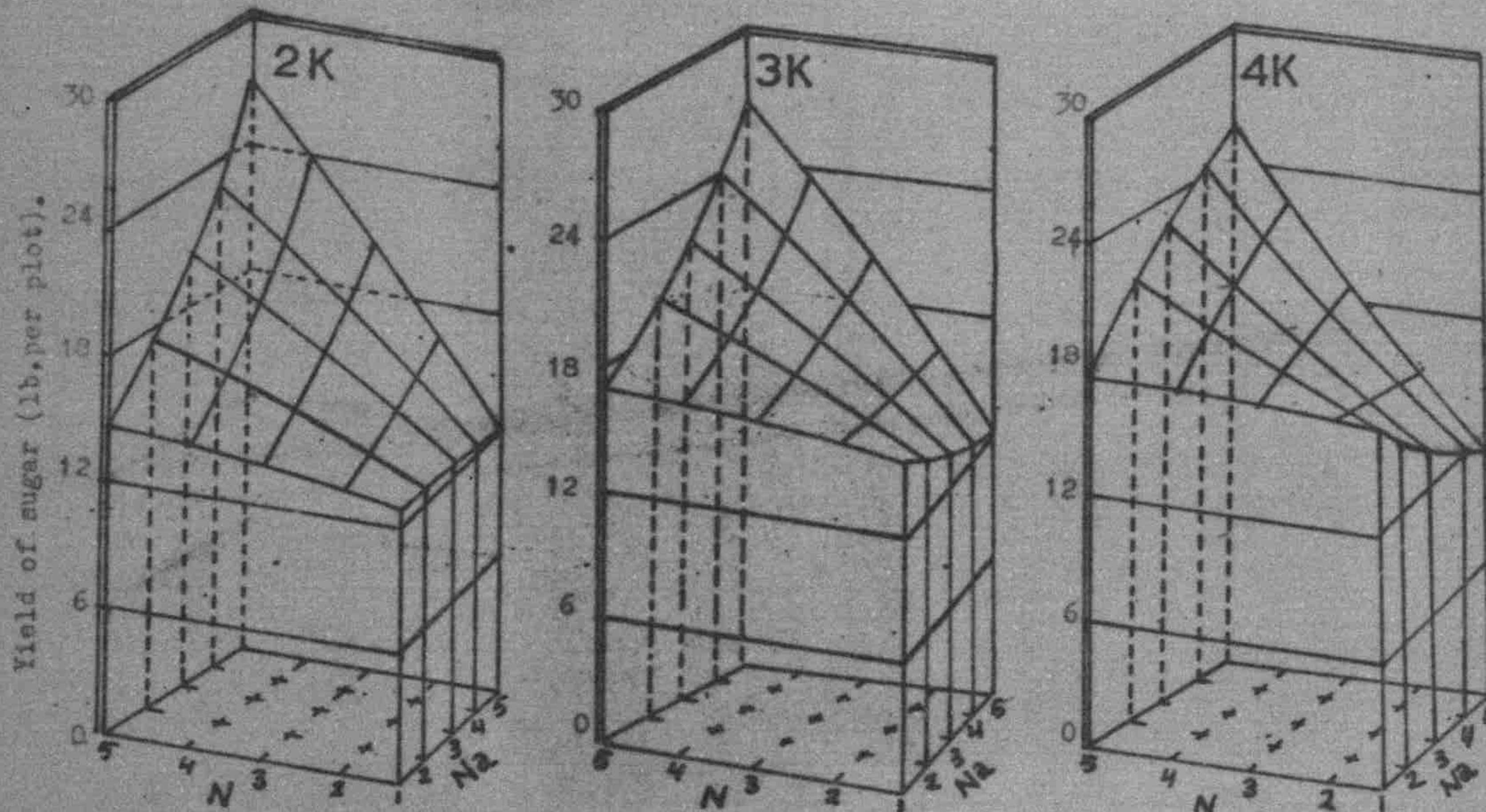


Figure 12. Yield of sugar as affected by the Na-N interaction with K held constant at each of three levels. P and Mg were kept constant at the middle of 5 levels.

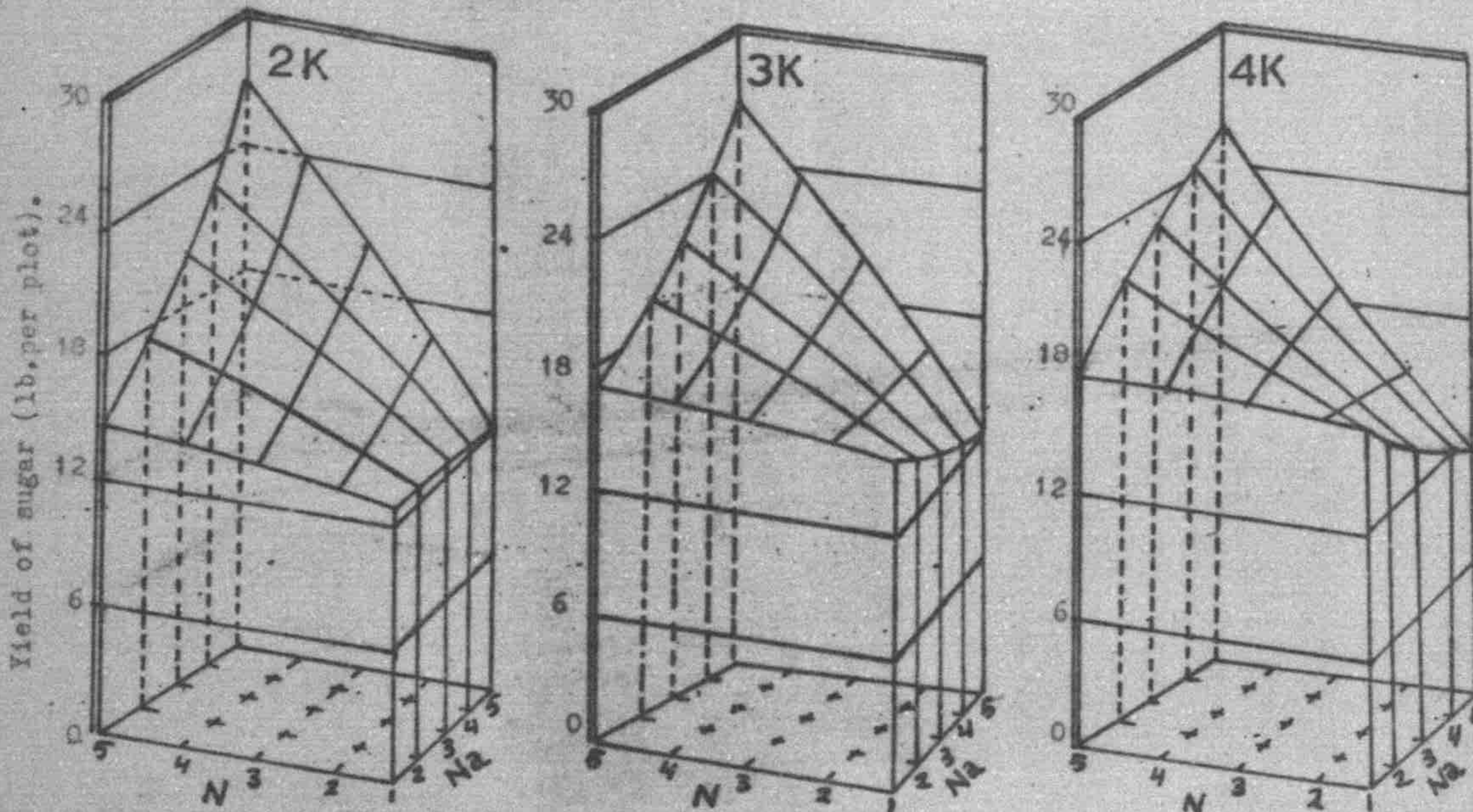


Figure 12. Yield of sugar as affected by the Na-N interaction with K held constant at each of three levels. P and Mg were kept constant at the middle of 5 levels.

because the regression coefficient for the Na-K interaction was greater in magnitude (-0.569) that the coefficient for the N-K interaction (-0.094). It was noted that at the 3K and 4K levels, increasing the rate of Na at a low level of N resulted in a decrease in the yield of sugar, but this depression effect of Na was counteracted by high rates of N application and even at the 4K level Na considerably increased the yield if the supply of N was high.

Under the conditions of this experiment where the available K was high (Table 3), application of a high rate of K slightly reduced the maximum yield obtained from the 5N + 5Na treatment combination (P and Mg held constant at the 3 level). Response to application of K was obtained only if the rate of P was high or the rate of Mg was low (Fig. 3).

The N-Na Interaction as Affected by Mg

Examination of the response surface for yield of sugar as affected by various levels of N and Na at the 2Mg level indicated (Fig. 13) that increasing N did not affect the yield at a low level of Na while it considerably increased the yield of sugar when the level of Na was high. On the other hand, Na increased the yield at all levels of N. As the Mg level was increased the response to Na was considerably decreased at all levels of N. The maximum yield was obtained at the 5N + 5Na treatment.

In general, the yield of sugar was depressed as the Mg level was increased. This indicated that high yields of sugar could be obtained with a high rate of Na + N without Mg. The application of Mg would be beneficial only if the applied level of P, K, or Na was low (Fig. 4).

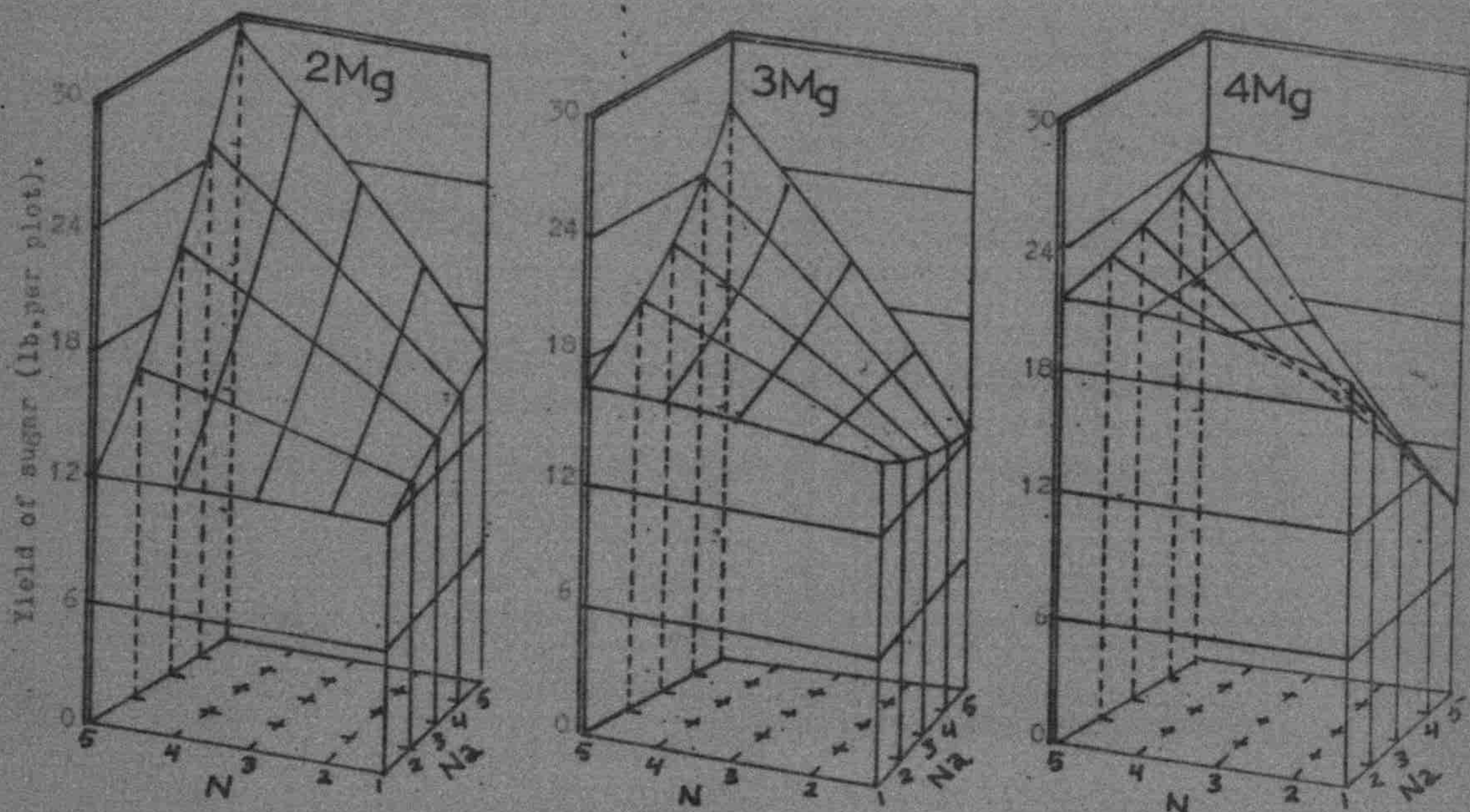


Figure 13. Yield of sugar as affected by the Na-N interaction with Mg held [illegible] at each of three levels. P and K were kept constant at the middle levels.

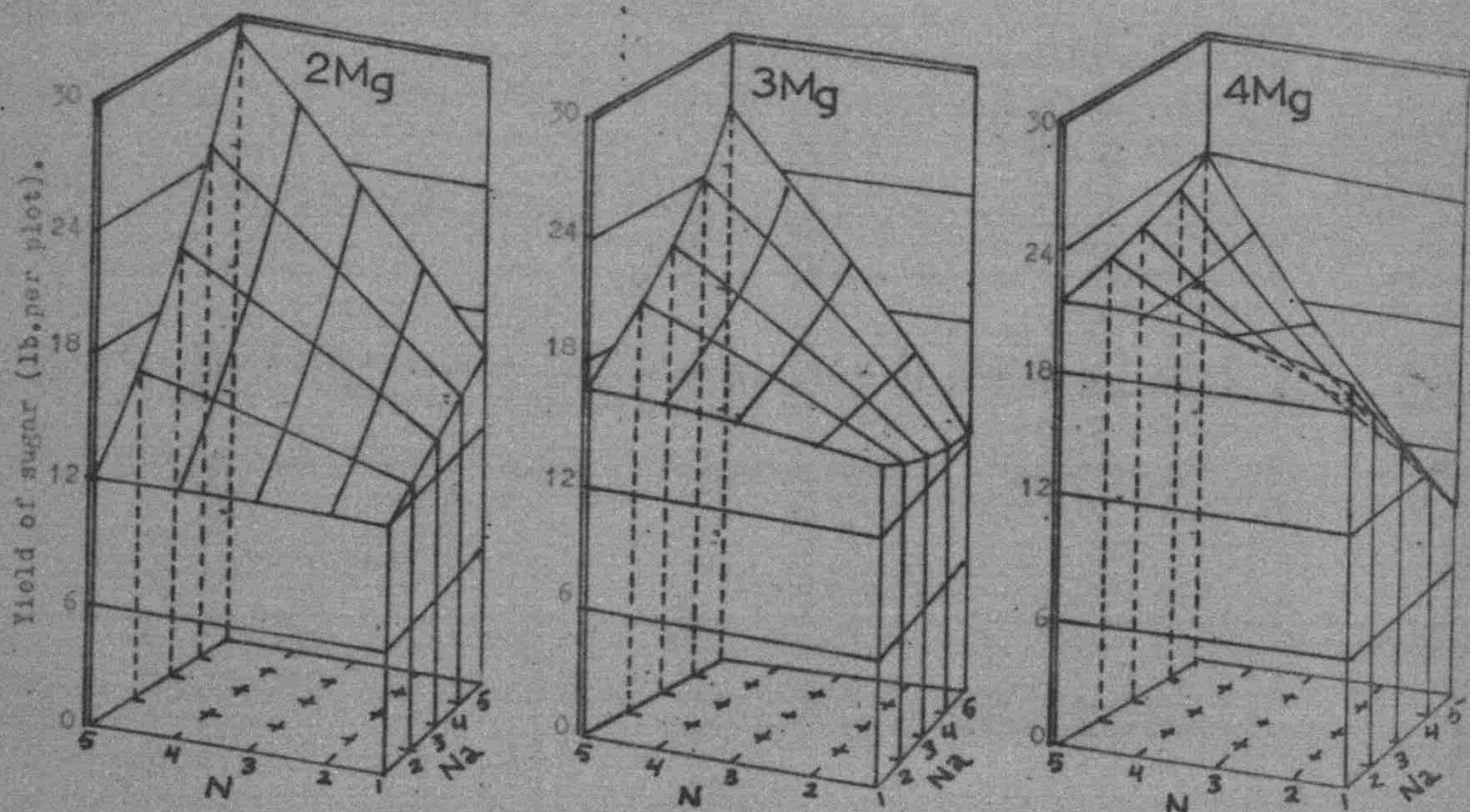


Figure 13. Yield of sugar as affected by the Na-N interaction with Mg held constant at each of three levels. P and K were kept constant at the middle levels.

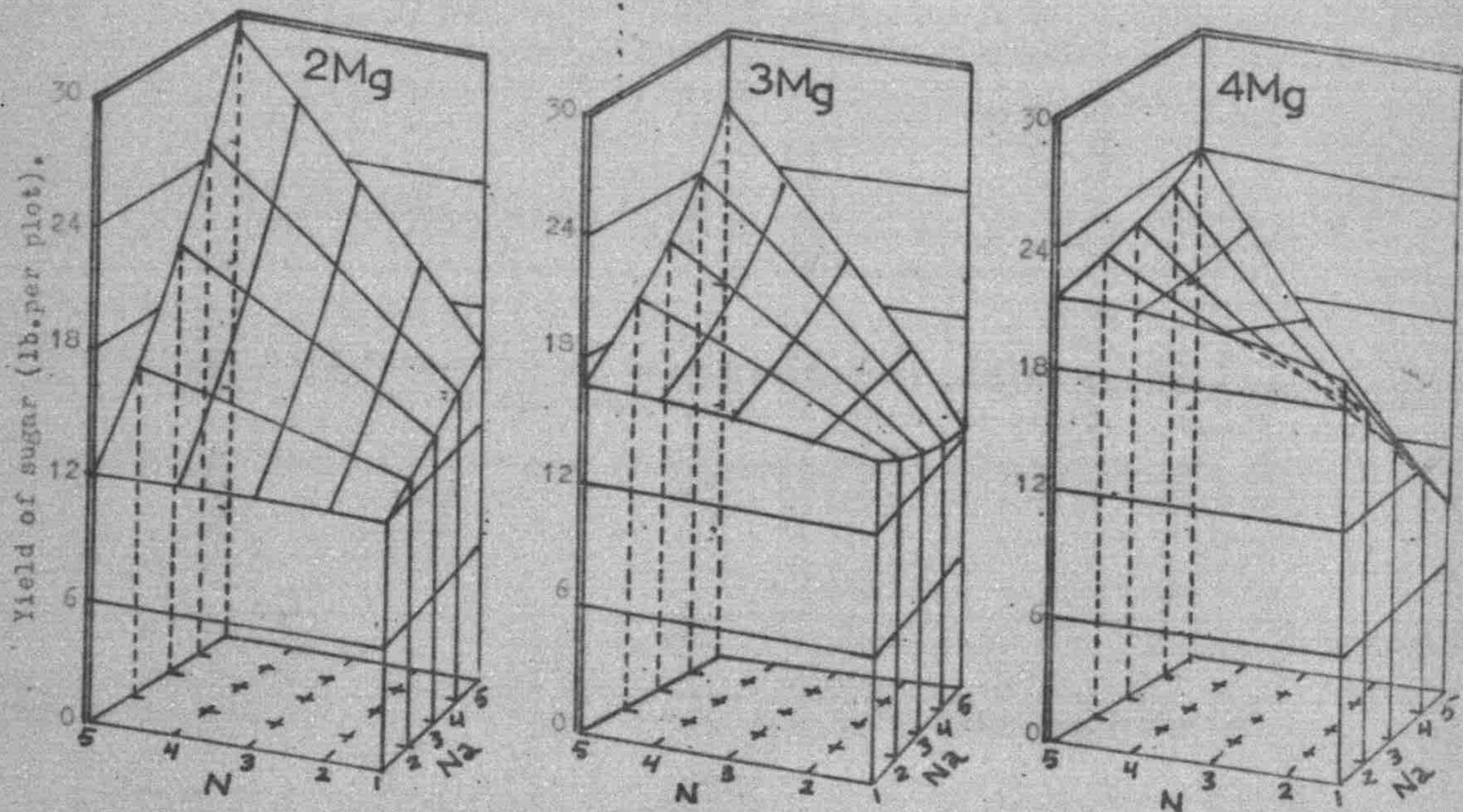


Figure 13. Yield of sugar as affected by the Na-N interaction with Mg held [illegible] at each of three levels. P and K were kept constant at the middle [illegible] levels.

The N-Na Interaction as Affected by P

Examination of the response surface for yield of sugar as affected by various levels of N and Na at three levels of P indicated (Fig. 14) that P affected the N-Na interaction in about the same way as Mg did (Fig. 13). At all levels of P, the combination 5N - 5Na gave the highest yield. In general, the response to Na was depressed at higher levels of P while the response to N was not affected. Increase P tended to decrease the yield of sugar. The application of P would be beneficial only if the level of K was high. It was indicated (Fig. 2) that at high levels of K the addition of P considerably increased the yield and this increase was higher than the yield depression resulting from the P-Na interaction.

The K-P Interaction as Affected Na

The effect of 3 levels of Na on the response surfaces for yield of sugar as affected by the K-P interaction (Mg and N were constant at the 3 level) indicated (Fig. 15) that at all levels of Na, response to P or K was obtained only if the level of the other element was high (antagonistic relationship). At the 2Na level maximum yield was obtained at the 5K - 5P treatment. As the level of Na was increased response to K was greatly reduced and the depression effect of P was increased and maximum yield of sugar was obtained at the 1K - 1P combination. This revealed that Na application to sugar beet decreased the need for both P and K fertilization. The combination of low K - P together with a high Na level gave about the same yield of sugar as obtained at the high K - P combination together with a low Na level.

The P-K Interaction as Affected by Mg

Examination of the effect of 3 levels of Mg on the P-K interaction

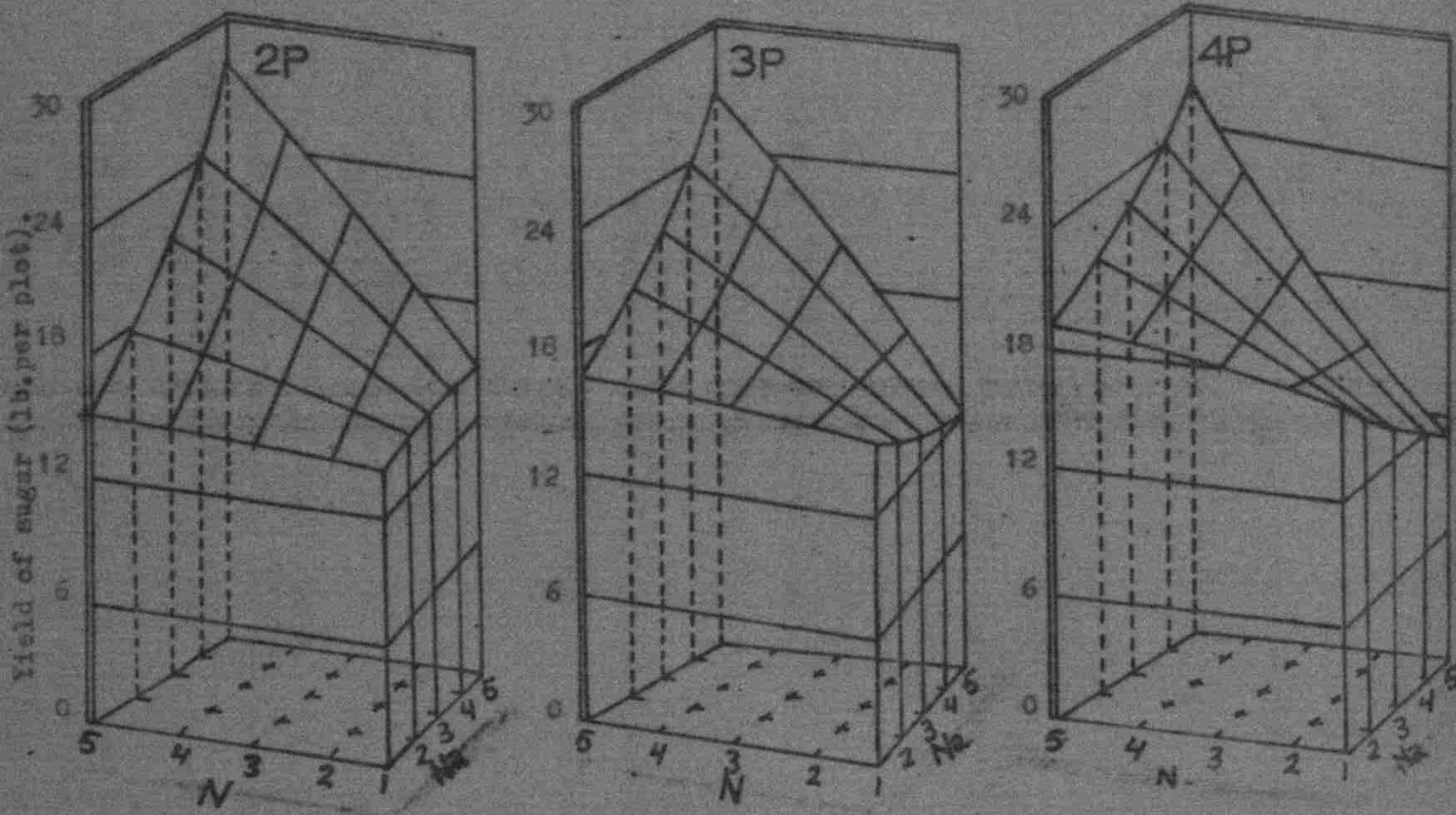


Figure 14. Yield of sugar as affected by the Na-N interaction with P held constant at each of three levels. K and Mg were kept constant at the middle of 5 levels.

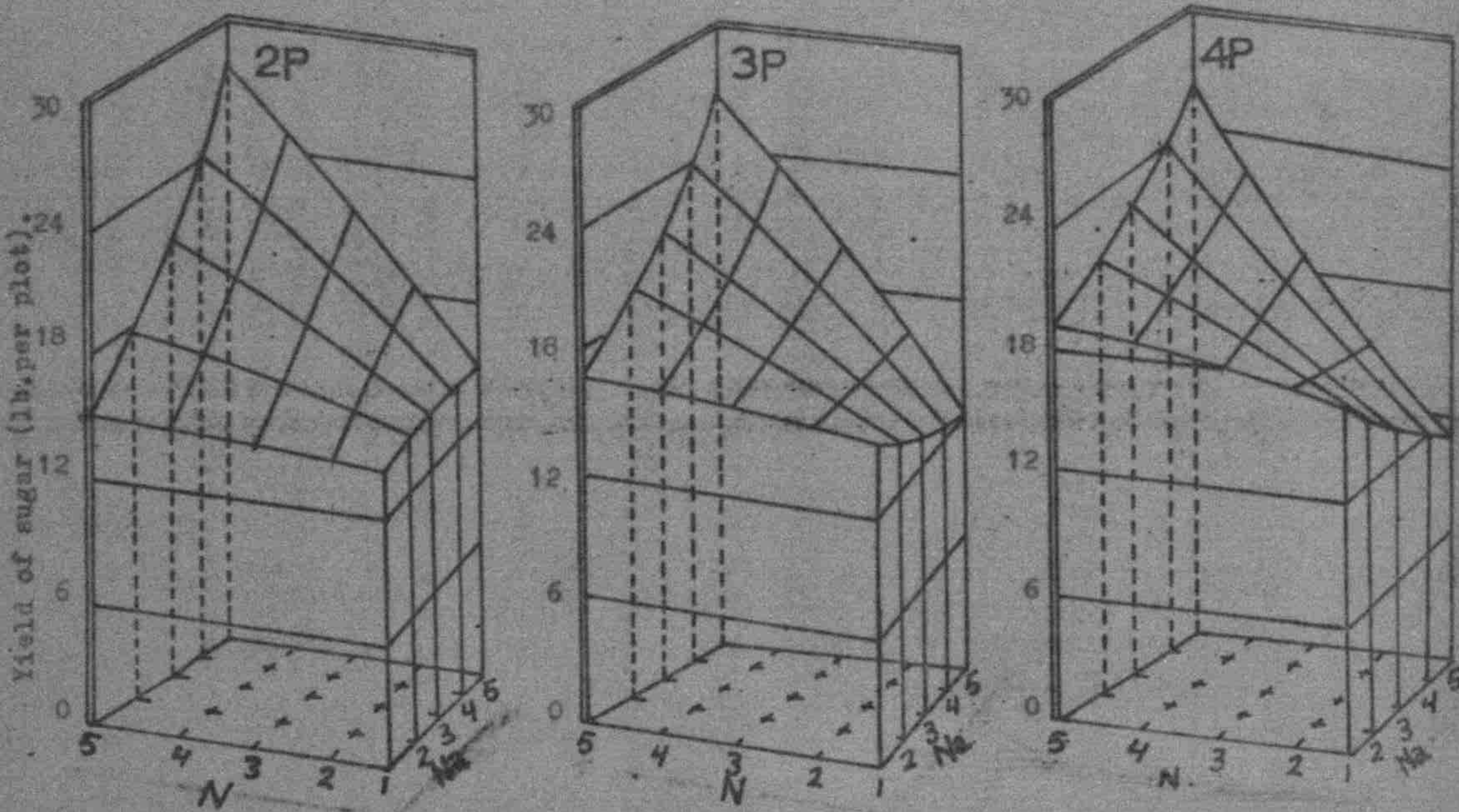


Figure 14. Yield of sugar as affected by the Na-N interaction with P held constant at each of three levels. K and Mg were kept constant at the middle of 5 levels.

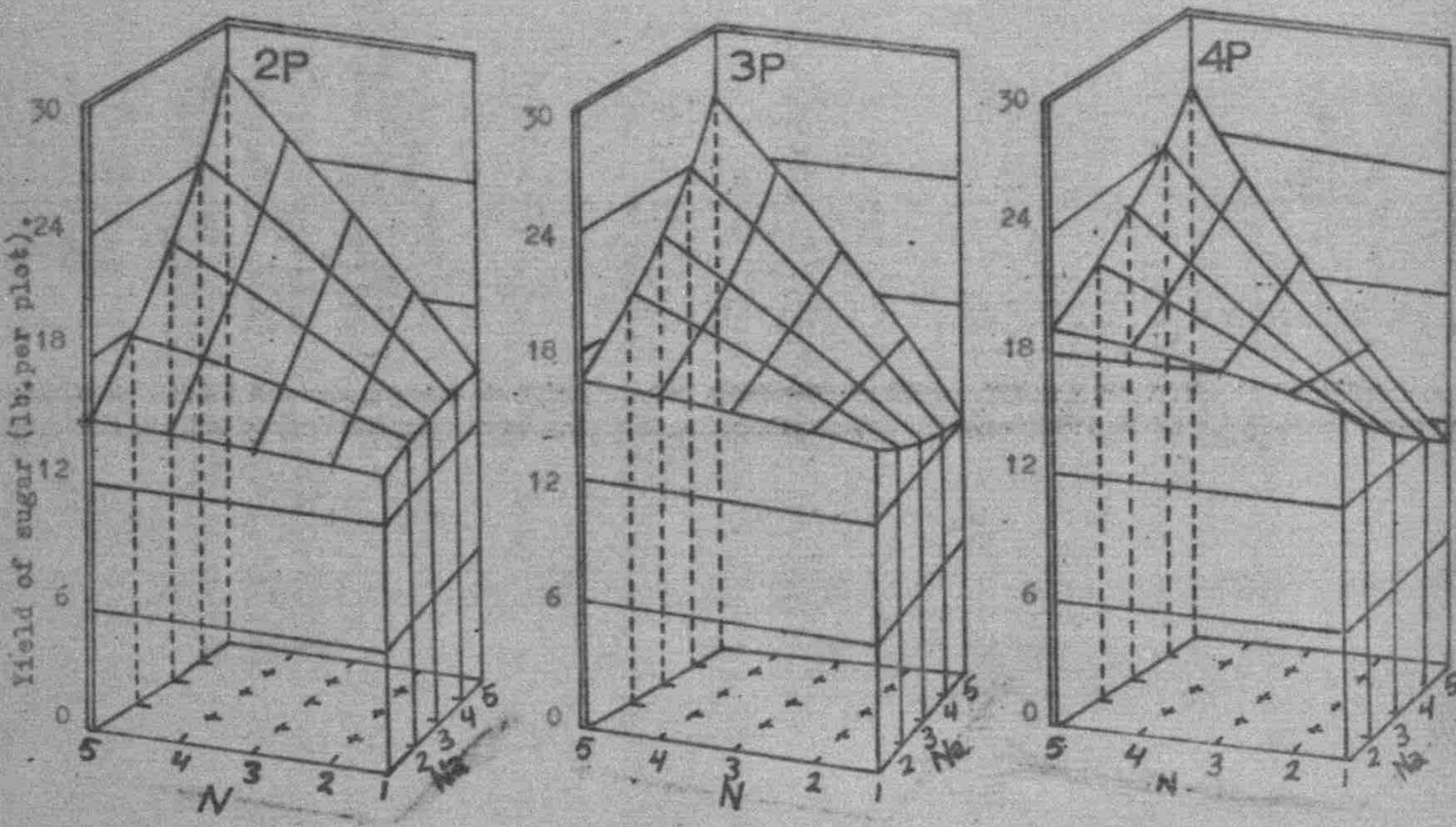


Figure 14. Yield of sugar as affected by the Na-N interaction with P held constant at each of three levels. K and Mg were kept constant at the middle of 5 levels.

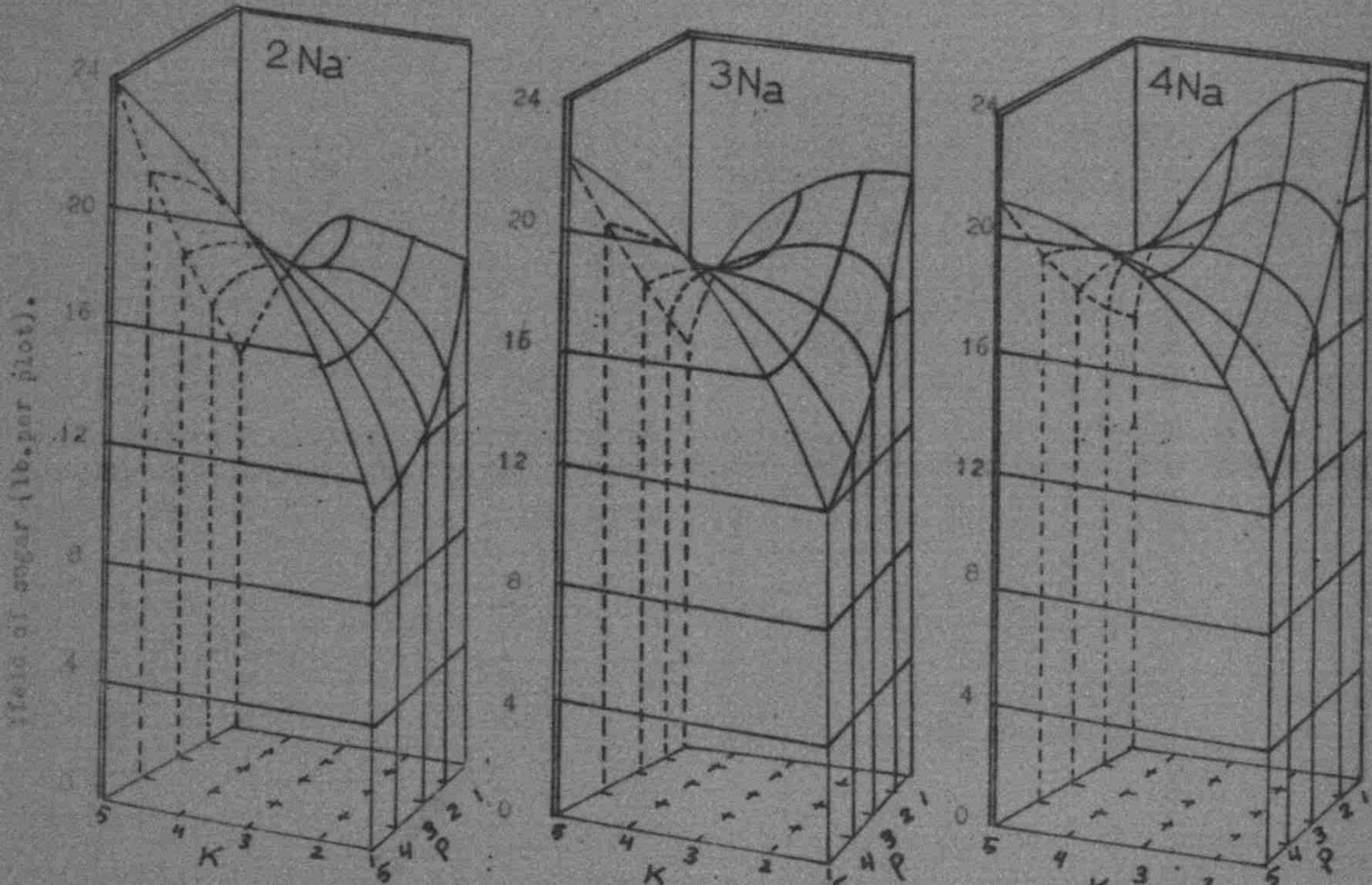


Figure 15. Yield of sugar as affected by the K-P interaction with Na held constant at each of three levels. N and Mg were kept constant at the middle of 5 levels.

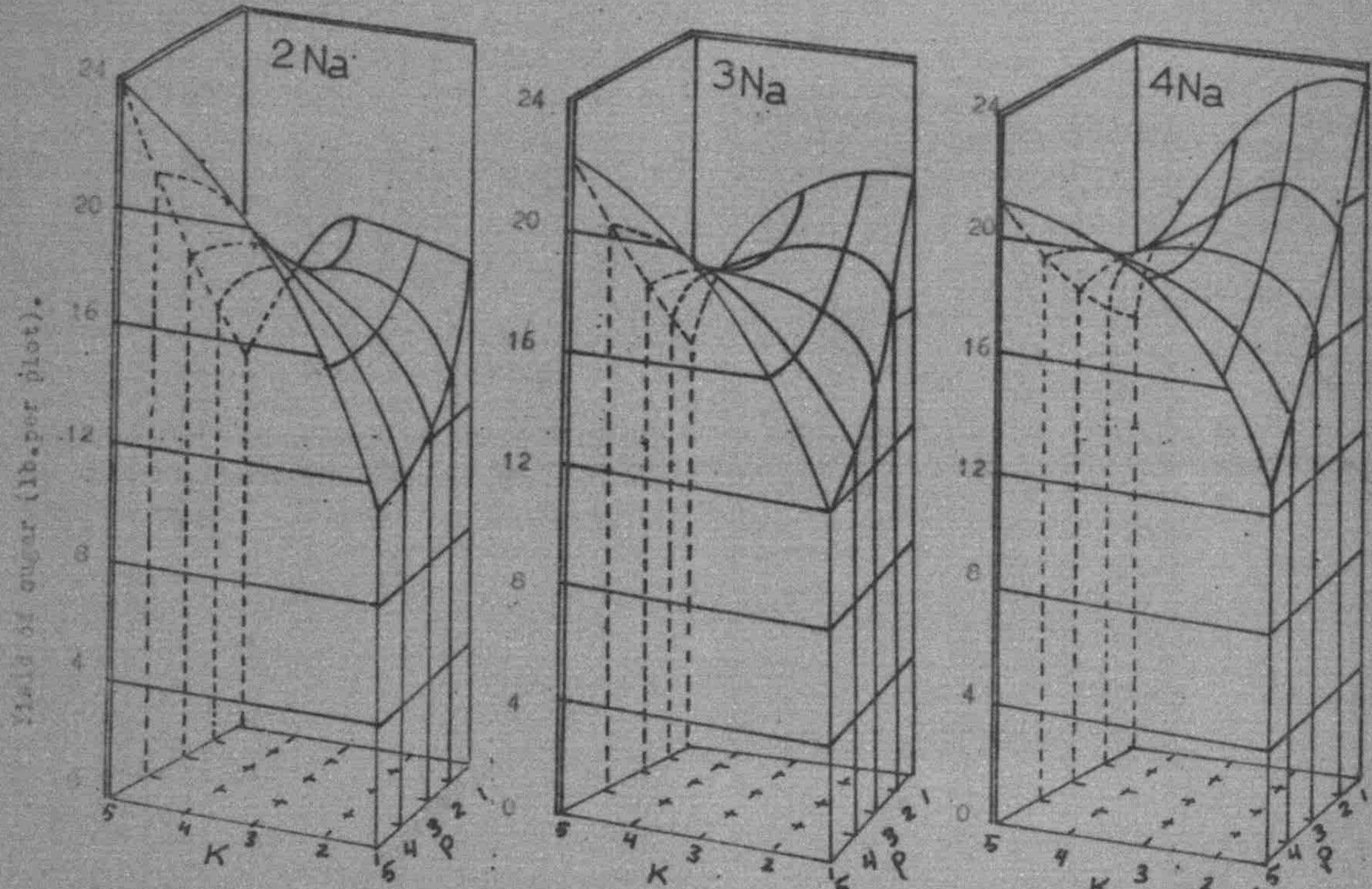


Figure 15. Yield of sugar as affected by the K-P interaction with Na held constant at each of three levels. N and Mg were kept constant at the middle of 5 levels.

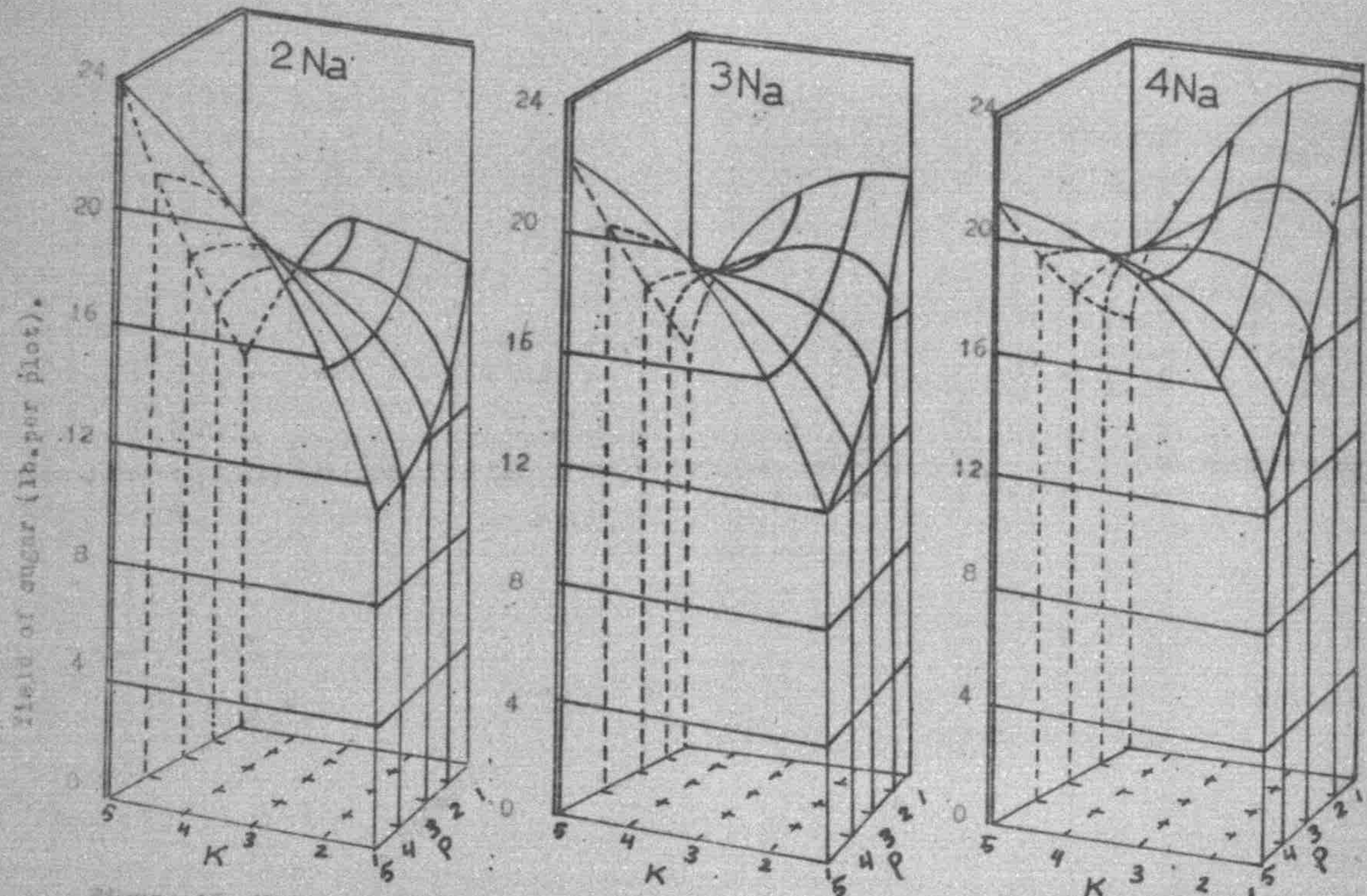


Figure 15. Yield of sugar as affected by the K-P interaction with Na held constant at each of three levels. N and Mg were kept constant at the middle of 5 levels.

(Fig. 16) was found to be similar to the effect of Na (Fig. 15) indicating that response to K and P was reduced as the Mg level was increased. When the Mg supply was low maximum yield of sugar was obtained at the 5K - 5P combination whereas with a high Mg supply the same yield of sugar was obtained at the 1K - 1P combination suggesting that a high rate of Mg application reduced the need for P and K.

The P-K Interaction as Affected by N.

Increasing N (Fig. 17) tended to result in a slightly higher response to increasing P and in a slightly lower response to increasing K. In general, the yield of sugar tended to go up with increasing N. This emphasized the need for a high rate of N under the conditions of this experiment.

Optimum Rates for Maximum Yield of Sugar

The ultimate purpose of any fertilizer experiment is to predict the optimum economic rates of fertilizer application. The use of the regression equation in this experiment provides a good tool for predicting the possible yields obtained from various combinations of the macronutrients studied. However, from the practical point of view, it is not possible to test all the possible combinations because within the scope of the experiment there were an infinite number of combinations.

Examination of the interaction data indicated that high rates of N and Na and low rates of Mg and P would result in the probable highest yield. It was also indicated that a medium level of K tended to be best. By trial and error method of substituting various selected combination of

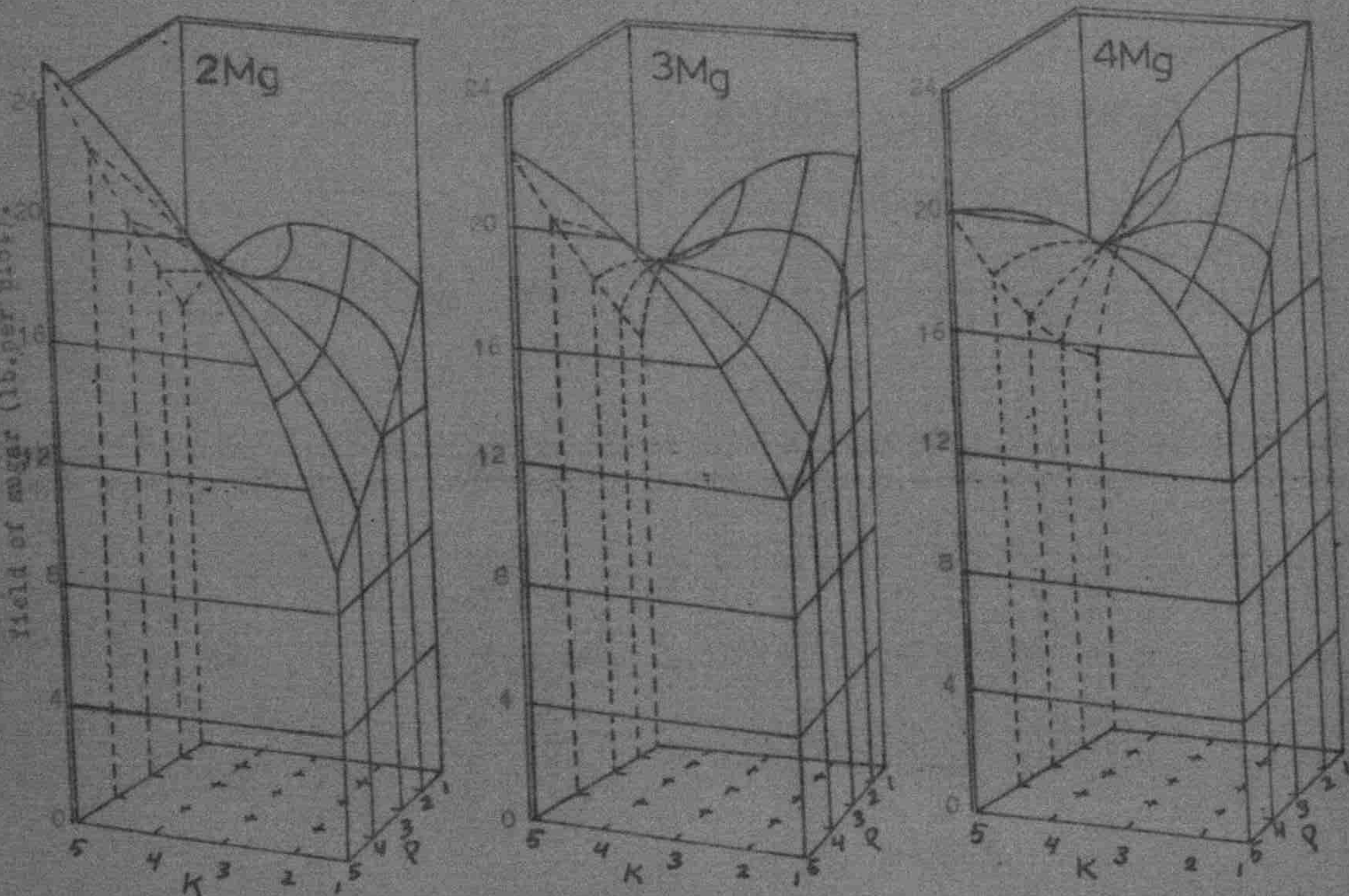


Figure 15. Yield of sugar as affected by the K-P interaction with Mg held constant at each of three levels. K and Mn were kept constant at the [illegible] of [illegible] levels.

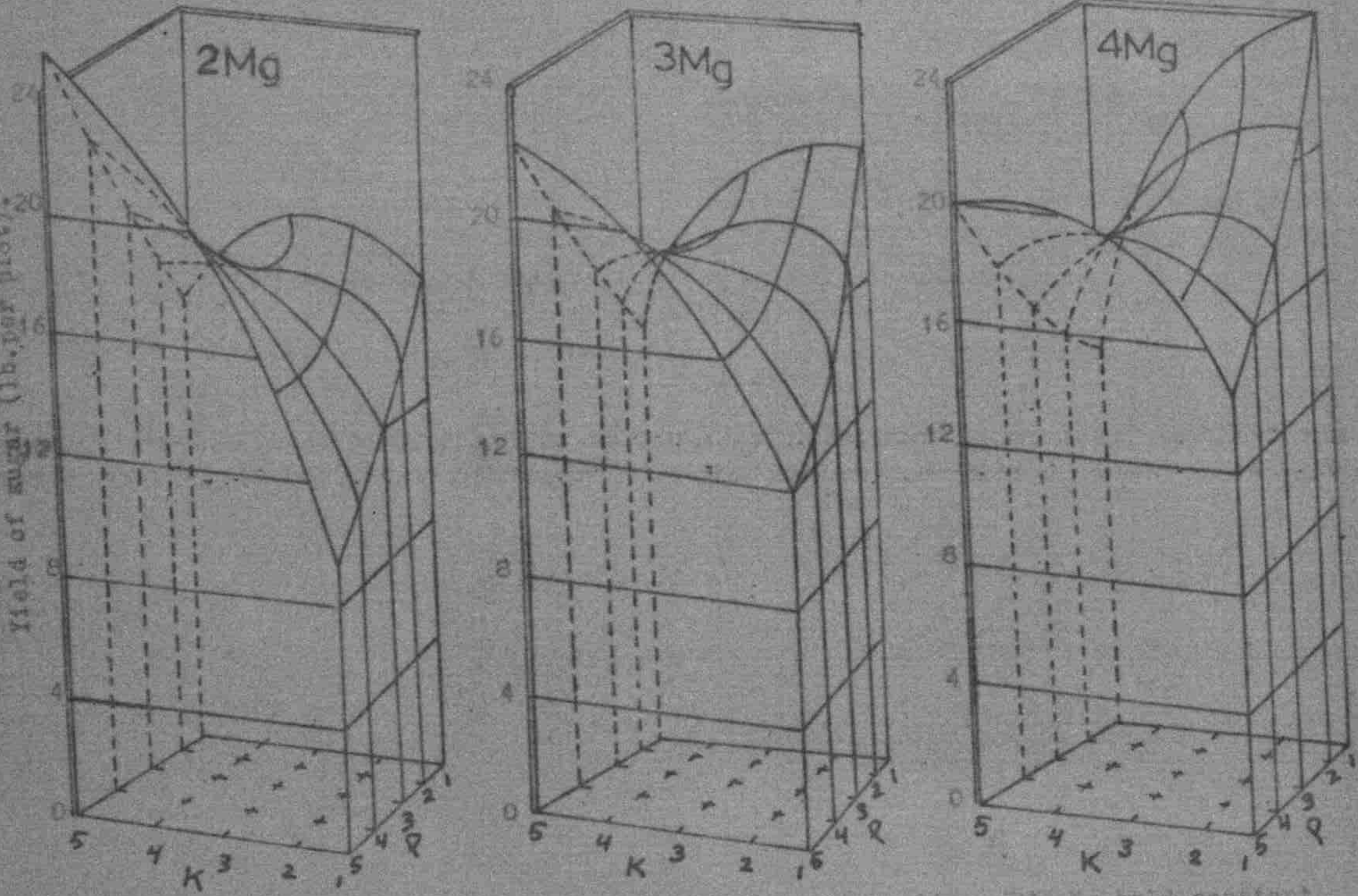


Figure 16. Yield of sugar as affected by the K-P interaction with Mg held constant at each of three levels. N and Na were kept constant at the middle of the levels.

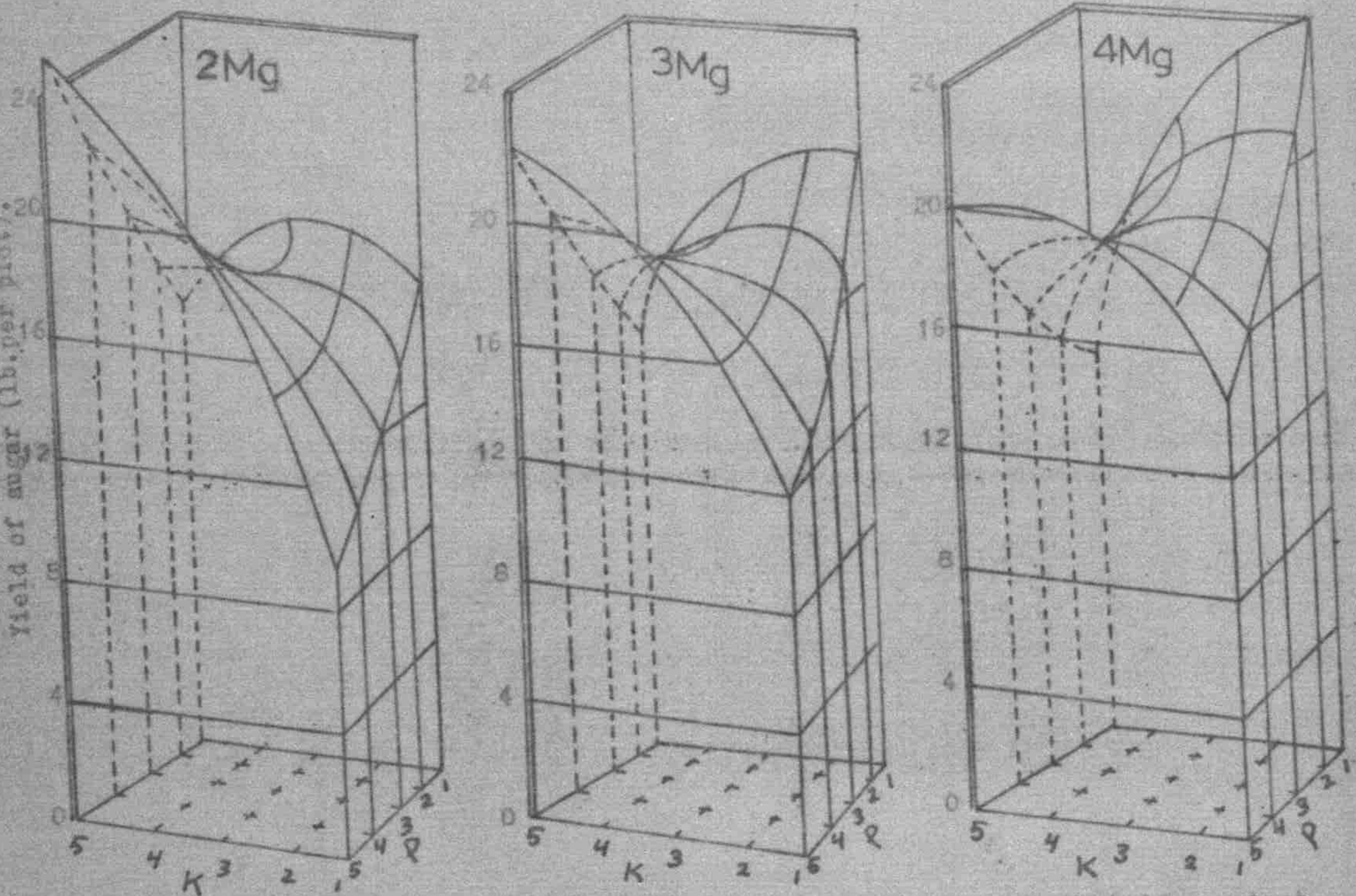


Figure 15. Yield of sugar as affected by the K-P interaction with Mg held constant at each of three levels. N and Na were kept constant at the middle of 5 levels.

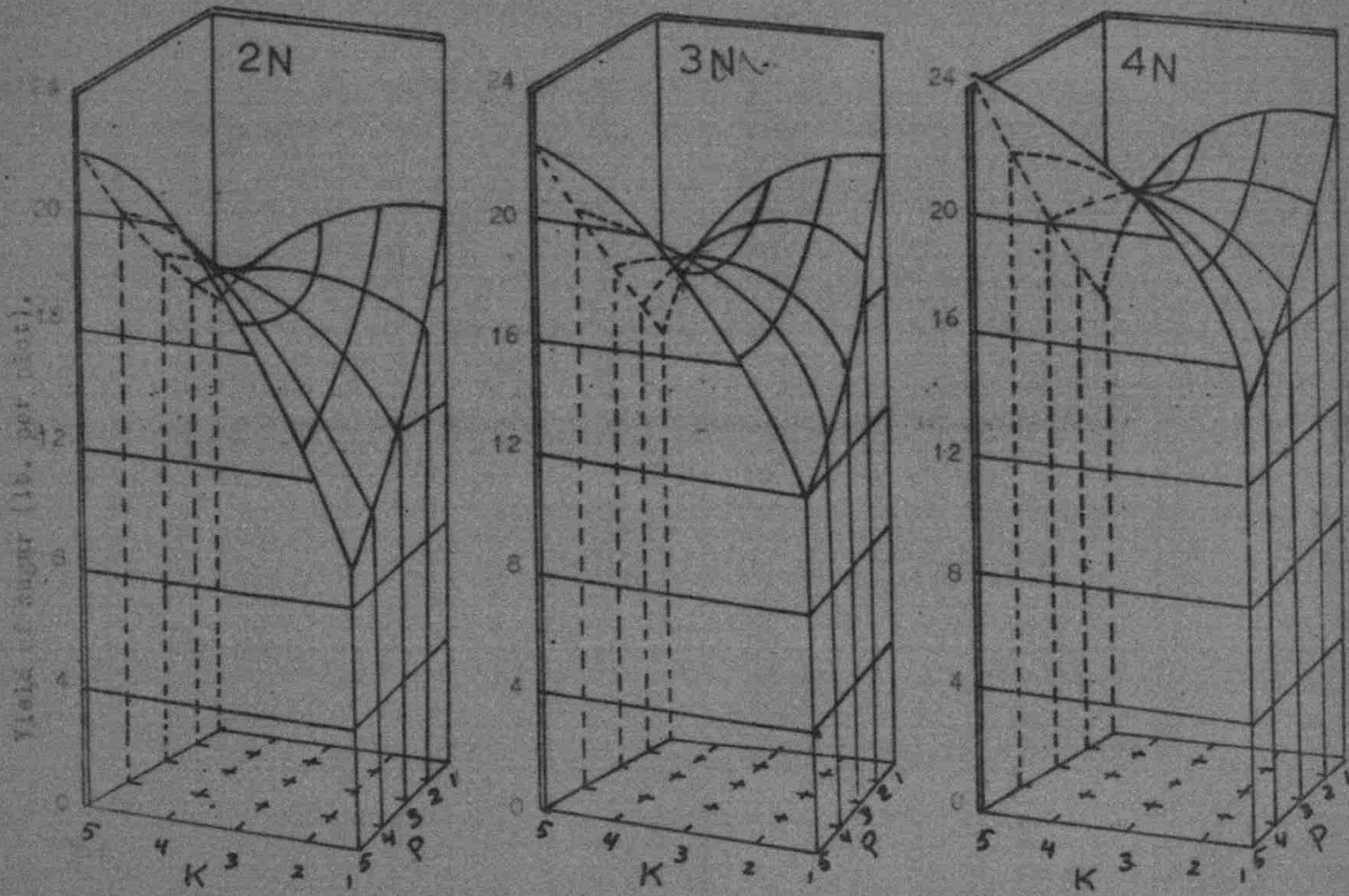
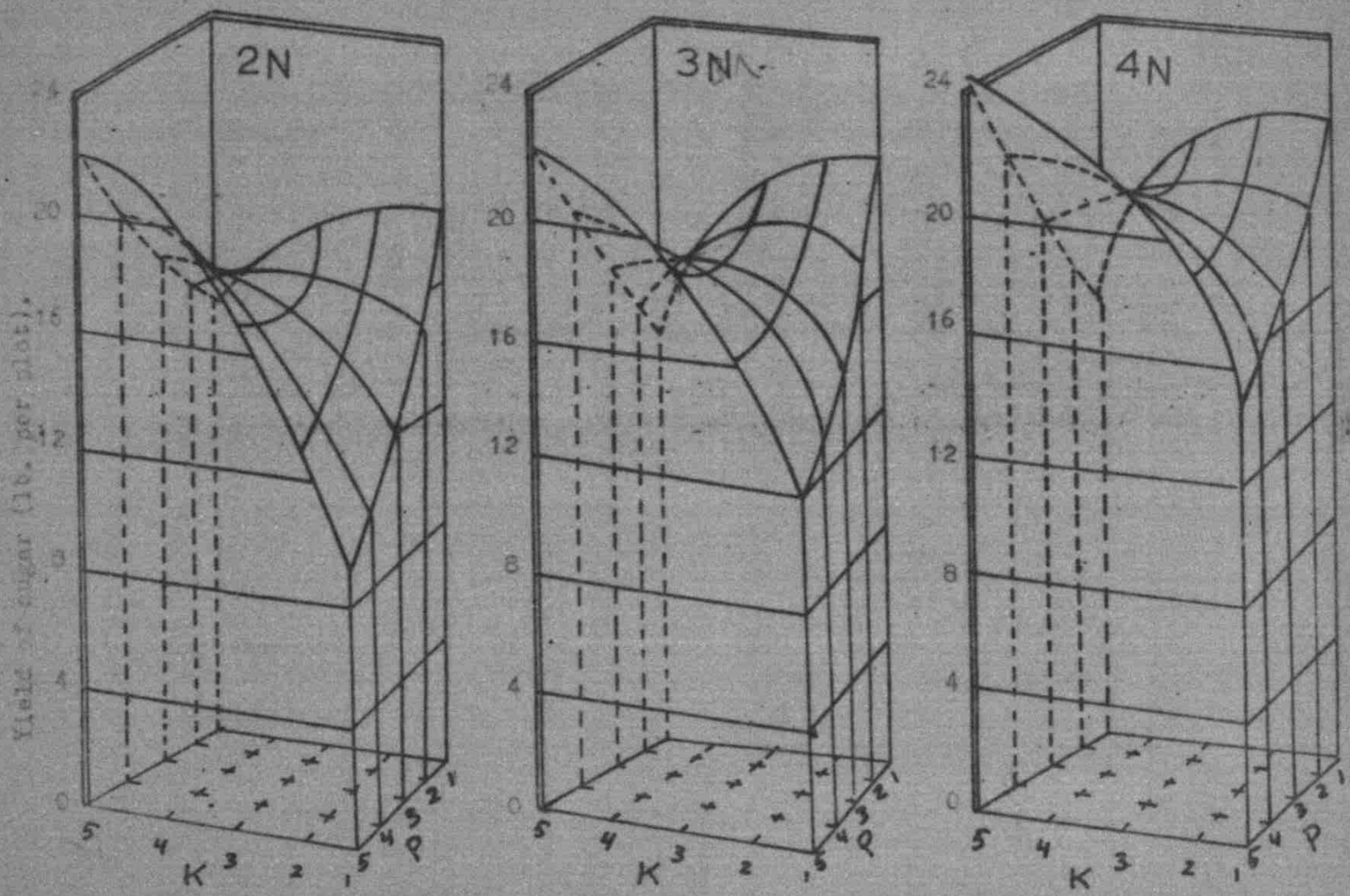


Figure [illegible]. Yield of sugar as affected by the K-P interaction with N held constant at each of three levels. [illegible] and [illegible] were held constant at the middle of ranges.



[illegible] 17. Yield of sugar as affected by the K-P interaction with N held constant at each of three levels. Mg and Na were held constant at the middle of [illegible] levels.

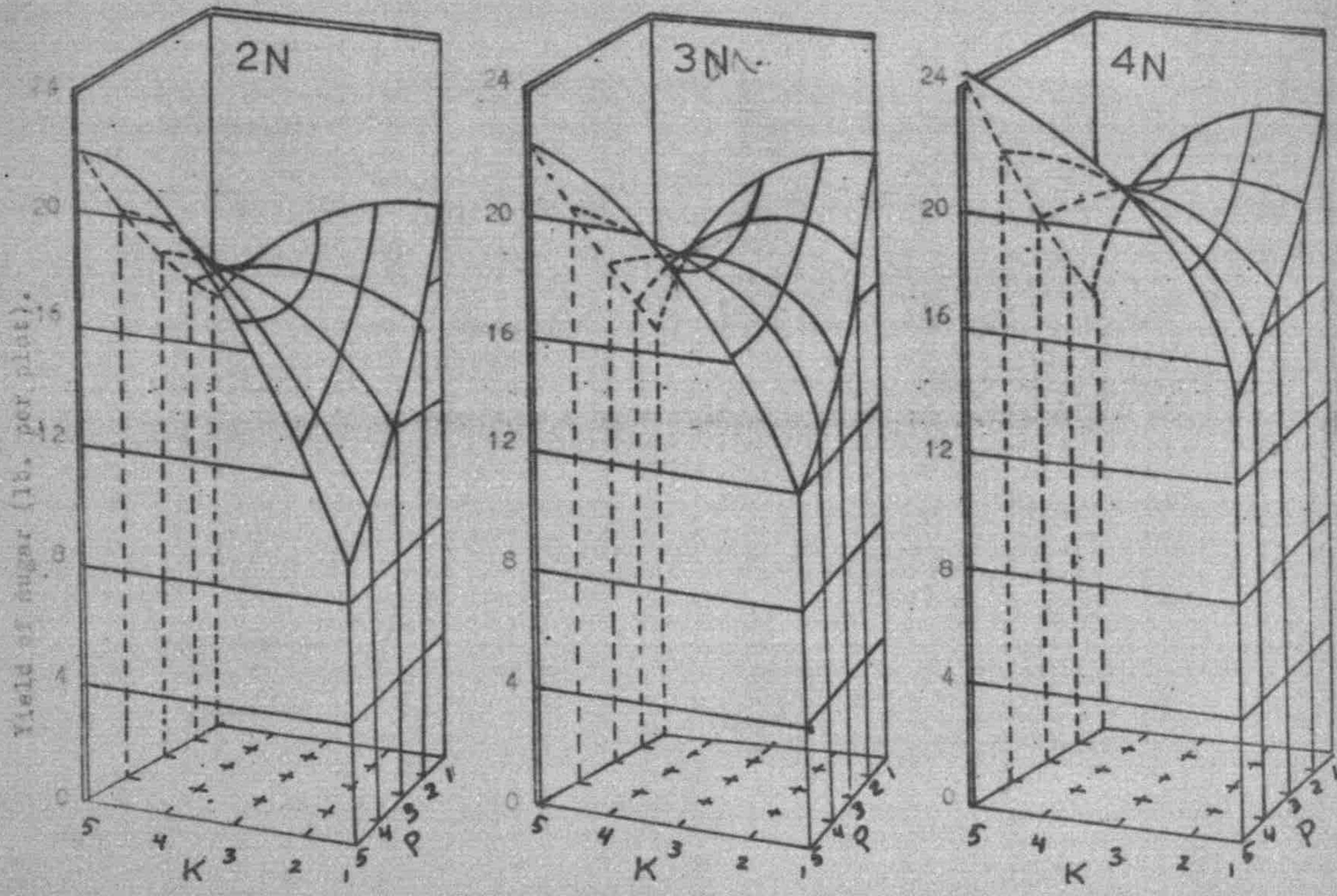


Figure 17. Yield of sugar as affected by the K-P interaction with N held constant at each of three levels. Mg and Na were held constant at the middle of 5 levels.

nutrients into the regression equation the combination for optimum yield of sugar was obtained. The trials were limited to the limits of the extreme rates of variables used in the actual experiment (1 and 5) because the predictions are increasingly less accurate the further the variables were away from the center 3 level. So even though it was indicated that N and Na were still increasing the yeild beyond the 5 level, the increase in yield beyond that point would not be economically feasible. Also, at the very high rates above the 5 level, the total salt effect of the fertilizers would eventually affect plant growth.

Solving the regression equation for the combination 5N, 1P, 3K, 1Mg, and 5Na, resulted in a theoretical yield of 33.1 lb. of sugar per plot and this was considered to be close to the maximum possible yield within the rates used since changing any of the elements resulted in a decrease in yield. This would be a yield of about 8.3 tons of sugar per acre or about 40 tons of beets per acre. From the economic point of view and using local prices for sugar beets and nitrogen fertilizer the last increment of nitrogen would not pay for itself. It was found that the N level could be reduced to the 4.5 level with only about a lb. per plot reduction in sugar yield. The 5 level of N was 544 lb./acre while the 4.5 level was 331 lb., a reduction of 213 lb. N/acre. Also, it was found that K could be reduced from the 3 to about the 2 level with only a very slight decrease in yield. Since the 1 level of Mg and P_2O_5 were only 10 lb./acre, dropping the levels to 0 would result in only a slight difference in yield. Therefore, it was concluded that under the condition of this experiment the following combination of fertilizers would give the highest economic yield of sugar beets:

4.5 N or about 330 lb./acre (37.5 kg./dunum)

0 P_2O_5

2 K_2O or about 30 lb./acre (3.4 kg./dunum)

0 Mg

5 Na or about 540 lb./acre (61.4 kg./dunum).

Nitrogen Concentration of Beets Tops

The correlation coefficient between observed N concentrations of beets tops and N concentrations calculated from the regression equation (Table 16) was 0.927 indicating a close fit of the regression equation to the observed data.

The analysis of variance for N content of beets tops (Table 17) indicated that only the quadratic effect was significant. The lack of fit term was not significant suggesting that there was no need to use a cubic or higher order equation.

The determination of the regression coefficients (b) and their standard errors (S_b) indicated (Table 18) that the linear effect of P (positive) was highly significant. Among the quadratic coefficients, only the N-Na interaction (negative) was highly significant, whereas the N-P (positive), P-Mg (positive), K-Mg (negative) and Mg-Na (negative) interactions

Table 16. Observed N concentration of beet tops (percent dry weight) as affected by various levels of N, P, K, Mg and Na. Nitrogen concentrations for the same treatments calculated from the regression equation are given. Correlation of actual N concentrations with calculated N concentrations was 0.927.

Treatment levels					Actual N concentration percent	Calculated N concentration percent
N	P	K	Mg	Na		
2	2	2	2	4	3.42	3.31
4	2	2	2	2	2.88	2.86
2	4	2	2	2	2.56	2.53
4	4	2	2	4	3.00	2.92
2	2	4	2	2	2.88	2.95
4	2	4	2	4	2.82	2.84
2	4	4	2	4	2.32	3.32
4	4	4	2	2	3.08	3.17
2	2	2	4	2	3.00	2.87
4	2	2	4	4	2.69	2.51
2	4	2	4	4	3.54	3.37
4	4	2	4	2	3.54	3.43
2	2	4	4	4	2.91	2.86
4	2	4	4	2	2.85	2.89
2	4	4	4	2	2.85	2.88
4	4	4	4	4	2.88	2.85
5	3	3	3	3	2.61	2.66
1	3	3	3	3	2.69	2.81
3	5	3	3	3	3.07	3.15
3	1	3	3	3	2.72	2.81
3	3	5	3	3	2.89	3.03
3	3	1	3	3	2.99	3.03
3	3	3	5	3	2.69	2.92
3	3	3	1	3	3.04	2.99
3	3	3	3	5	2.91	3.14
3	3	3	3	1	3.10	3.14
3	3	3	3	3	2.94	2.92
3	3	3	3	3	2.91	2.92
3	3	3	3	3	2.97	2.92
3	3	3	3	3	3.13	2.92
3	3	3	3	3	2.78	2.92
3	3	3	3	3	2.94	2.92

Table 17. Analysis of variance for N concentration of beet tops (percent of dry weight)

Source	d. f.	S. S.	M. S.	F value
Linear effect	5	0.2576	0.0515	4.02
Quadratic effect	15	1.1640	0.0776	6.06*
Lack of fit	6	0.2816	0.0469	3.64
Experimental error	5	0.0634	0.0128	
Total	31	1.7666		

* Significant at odds of 19:1

Table 18. Regression coefficients (b) and their standard errors (s_b) for N concentration of beet tops (percent dry weight).

Coefficient		b	s_b
Mean	b_0	2.9160	± 1.216
N	b_1	− 0.0375	± 0.0230
P	b_2	+ 0.0842 *	"
K	b_3	− 0.0008	"
Mg	b_4	− 0.0167	"
Na	b_5	+ 0.0233	"
N^2	b_{11}	− 0.0444	± 0.0210
P^2	b_{22}	+ 0.0168	"
K^2	b_{33}	+ 0.0281	"
Mg^2	b_{44}	+ 0.0093	"
Na^2	b_{55}	+ 0.0443	"
N-P	b_{12}	+ 0.0750	± 0.0283
N-K	b_{13}	+ 0.0050	"
N-Mg	b_{14}	+ 0.0037	"
N-Na	b_{15}	− 0.1787 **	"
P-K	b_{23}	+ 0.0012	"
P-Mg	b_{24}	+ 0.0875 *	"
P-Na	b_{25}	+ 0.0300	"
K-Mg	b_{34}	− 0.0825 *	"
K-Na	b_{35}	− 0.0250	"
Mg-Na	b_{45}	− 0.0862 *	"

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

were significant.

The relationship determined between yield of sugar and leaf concentration of N as affected by various levels of applied N at each of five levels of Na (Fig. 18) indicated that the N concentration increased with N application at a low levels of Na. However, at high Na levels, the N concentration tended to decrease with increasing N application, at the 1Na level considerable increase of the N content resulted in a slight increase of the yield of sugar (luxury consumption), but yield was considerably increased along with N content at the 2Na and 3Na level. Further increments of Na (4 and 5 levels) resulted in considerable increase of yield with decreasing N concentration. When N was held constant (Fig. 19) increasing Na application considerably increased the N concentration at low levels of N, but at high levels of N the Na application depressed the concentration of N. The yield of sugar decreased with increasing Na levels at the 1N level, and was not affected at the 2N level whereas at the 3N level both N content and yield of sugar were slightly increased with increasing Na application. On the other hand, at the higher N levels, the yield of sugar was increased considerably along with decreasing N concentration. These results indicated that there was a close functional relationship between Na and N in regard to sugar production. This relationship suggested that high yield of sugar could be obtained when both Na and N were applied at a high rate, but if either N or Na was at the low level while the other element was increased there was an excess consumption of N without an

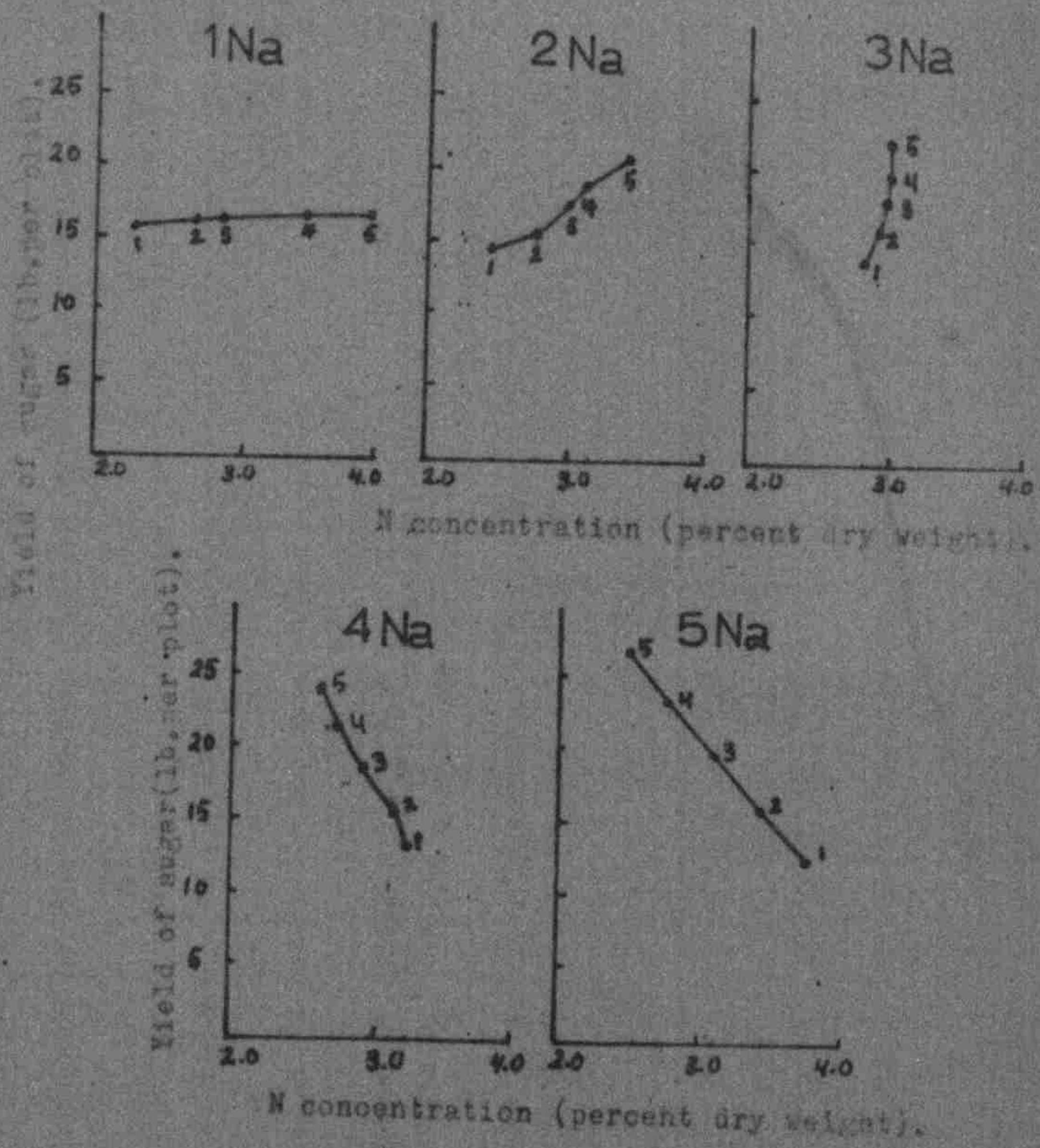


Figure 18. Relationship between yield of sugar (lb. per plot) and N concentration (percent dry weight) as affected by addition of different levels of N and Na with P, K and Mg held constant at the middle of five levels (Table 1). Numbers at points refer to levels of N added. Level of Na was held constant for each graph.

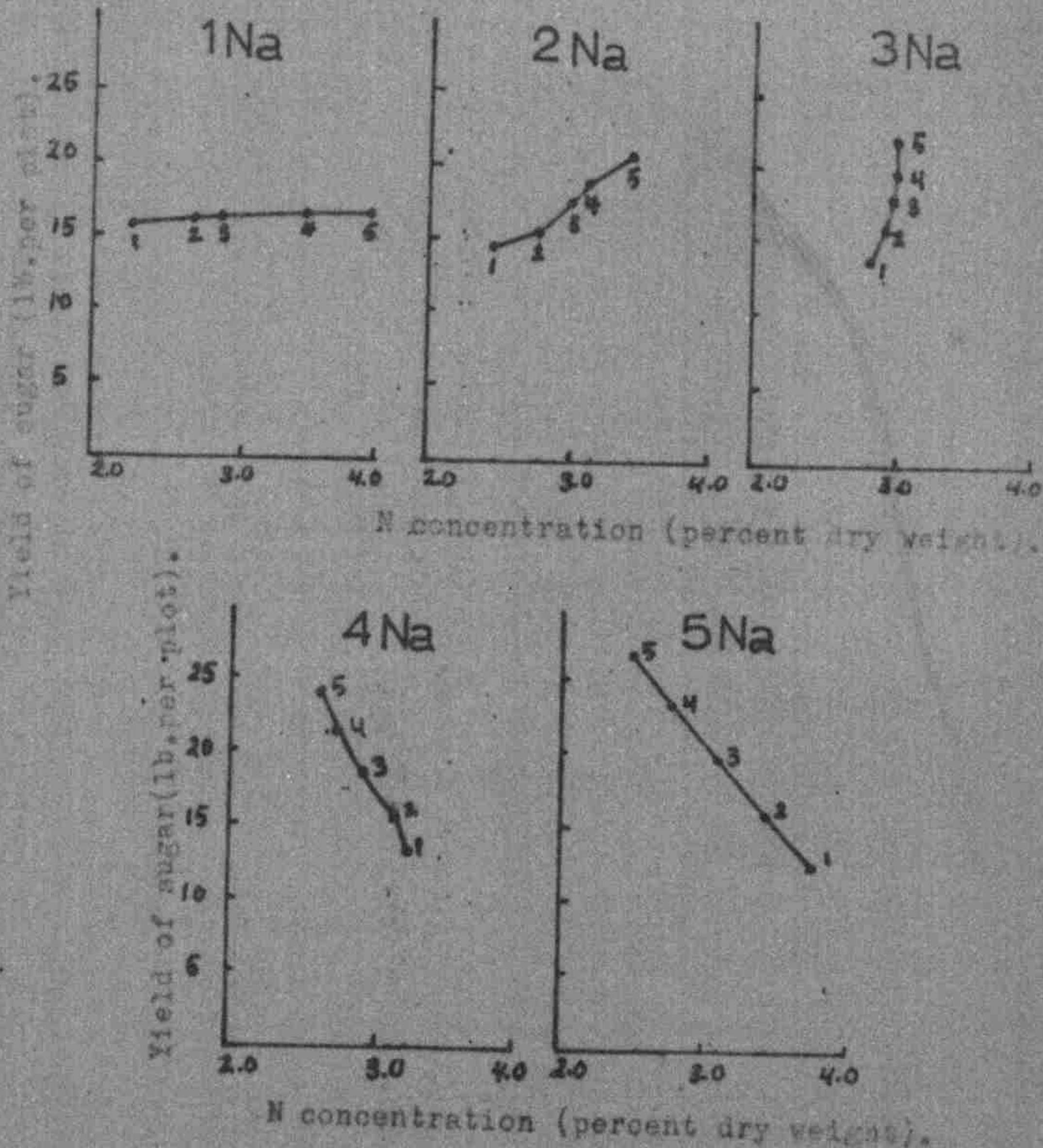


Figure 18. Relationship between yield of sugar (lb. per plot) and N concentration (percent dry weight) as affected by addition of different levels of N and Na with P, K and Mg held constant at the middle or fixed levels (Table 1). numbers at points refer to levels of N added. Level of Na was held constant for each graph.

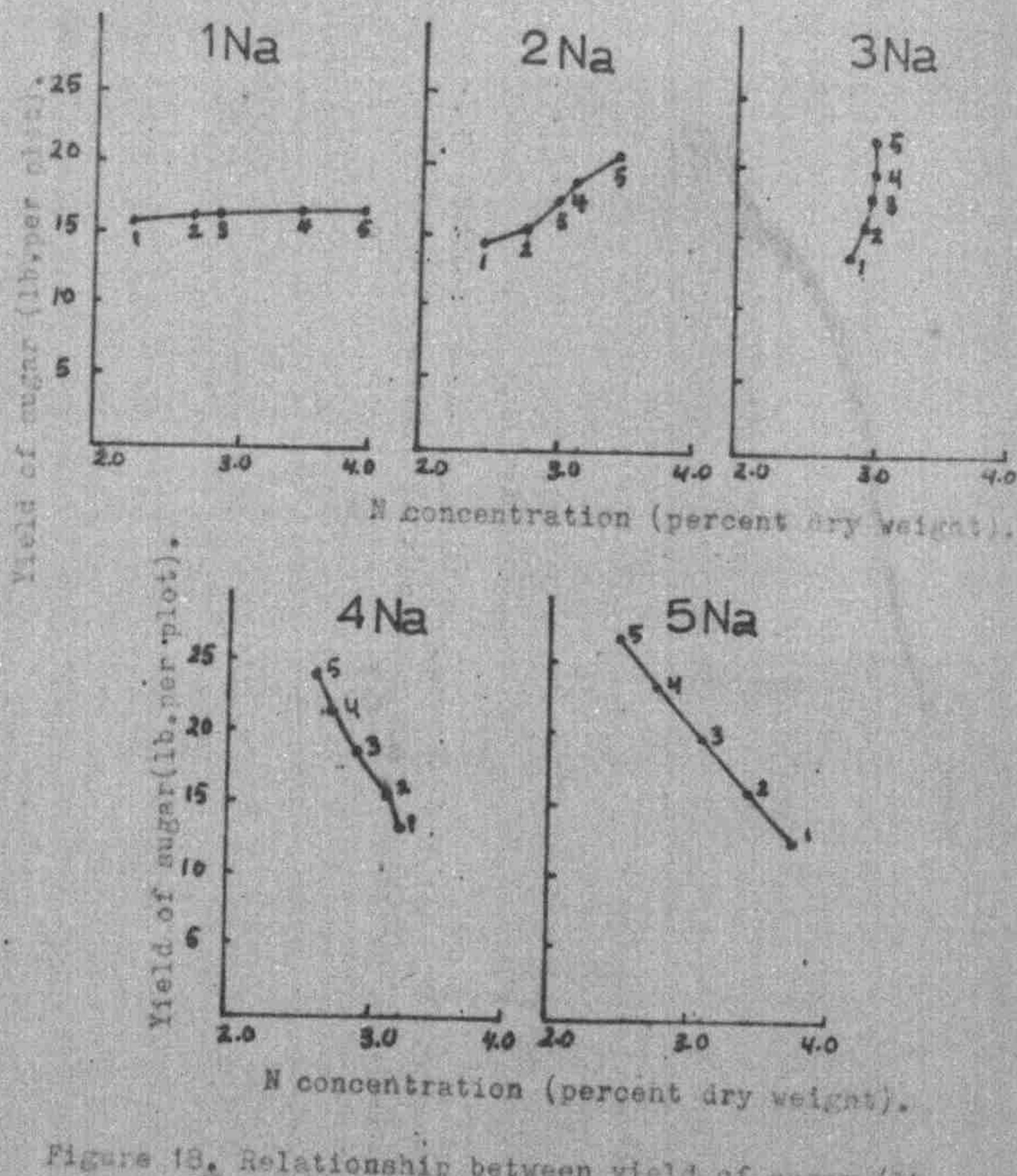


Figure 18. Relationship between yield of sugar (lb. per plot) and N concentration (percent dry weight) as affected by addition of different levels of N and Na with P, K and Mg held constant at the middle of five levels (Table 1). Numbers at points refer to levels of N added. Level of Na was held constant for each graph.

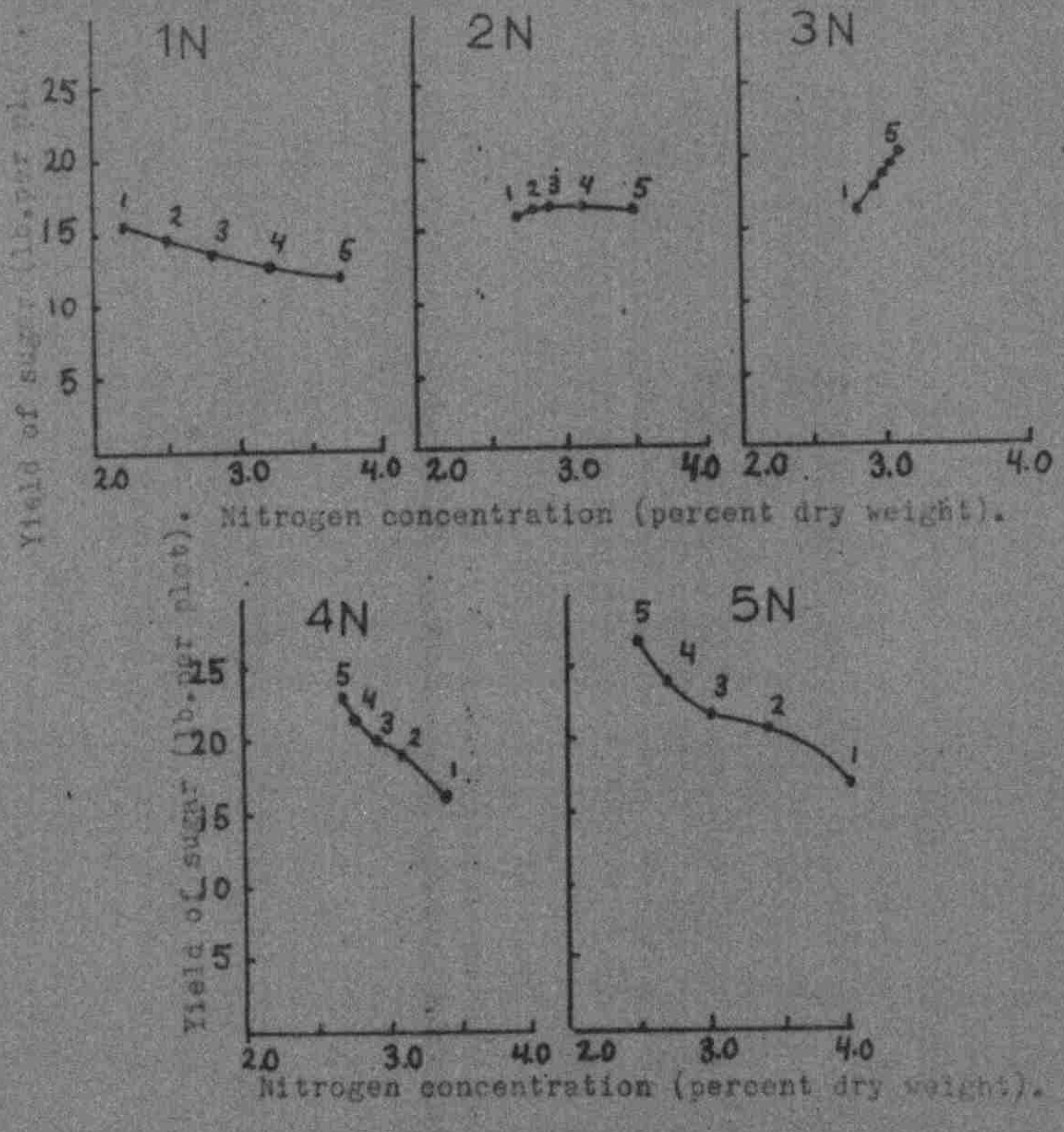


Figure 19. Relationship between yield of sugar (lb.per plot) and N concentration (percent dry weight) as affected by addition of different levels of N and Na with P, K and Mg held constant at the middle of five levels (Table 1). Numbers at points refer to levels of Na added. Level of N was held constant for each graph.

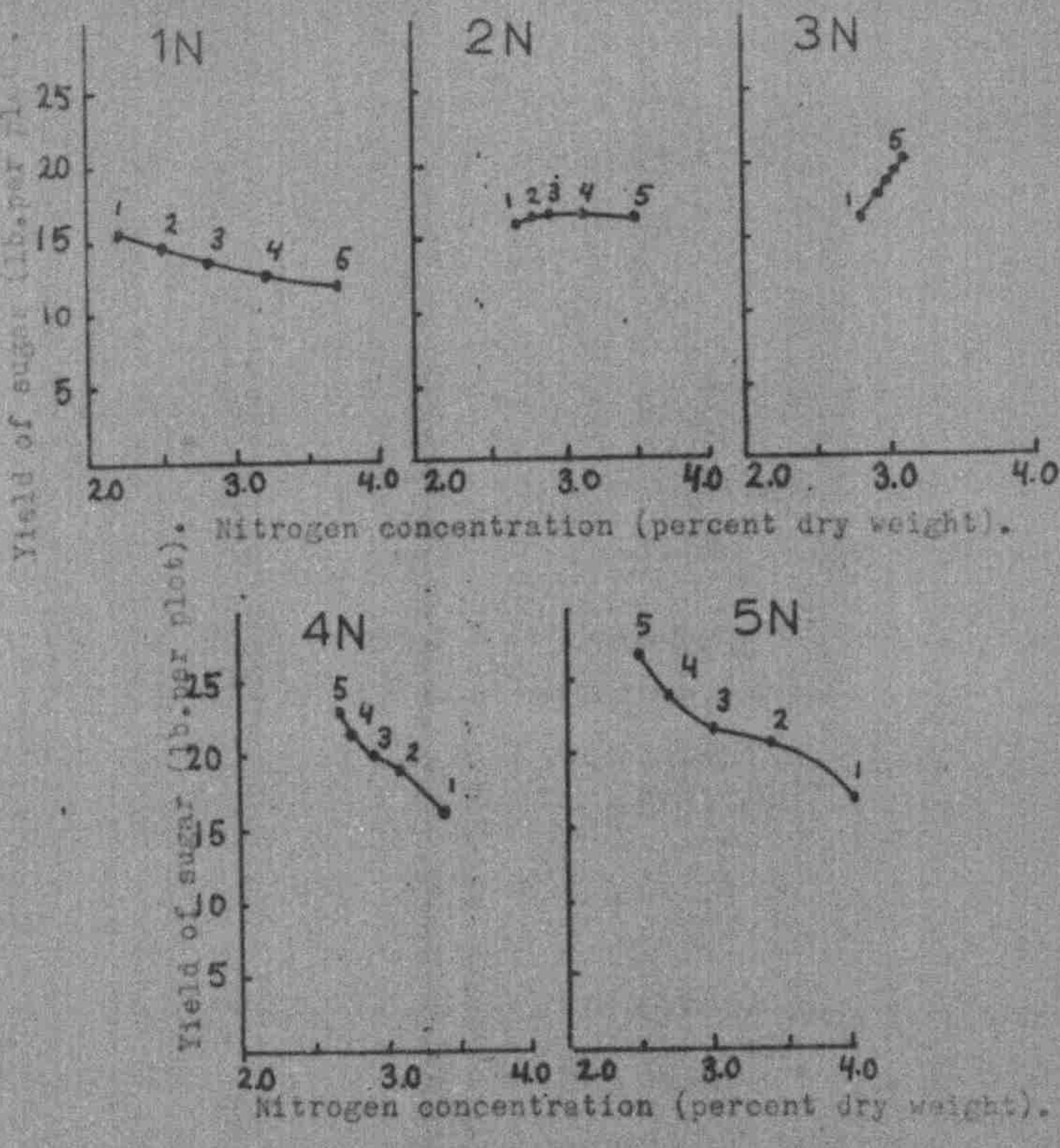


Figure 19. Relationship between yield of sugar (lb.per plot) and N concentration (percent dry weight) as affected by addition of different levels of N and Na with P, K and Mg held constant at the middle of five levels (Table 1). Numbers at points refer to levels of Na added. Level of N was held constant for each graph.

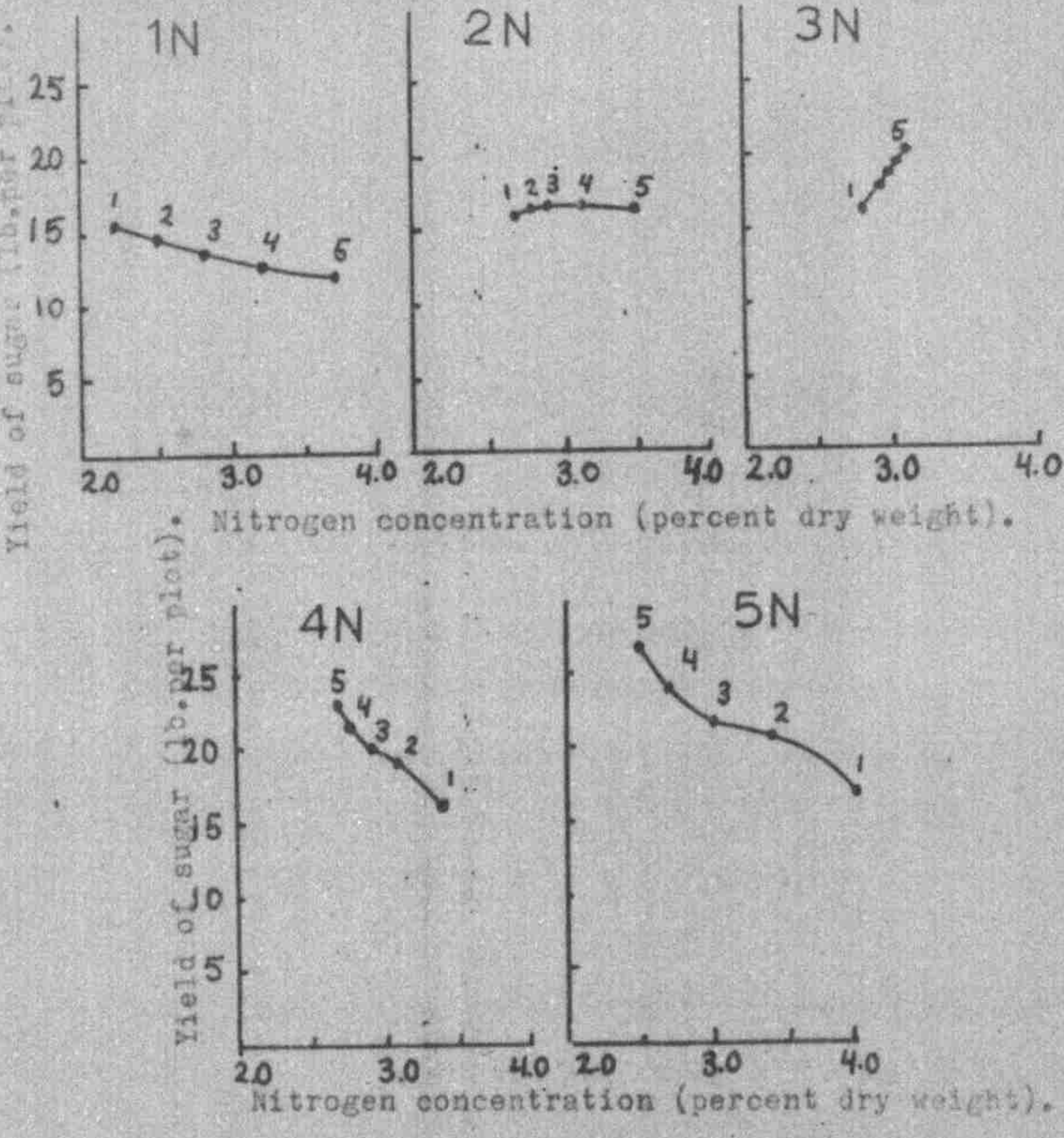


Figure 19. Relationship between yield of sugar (lb.per plot) and N concentration (percent dry weight) as affected by addition of different levels of N and Na with P, K and Mg held constant at the middle of five levels (Table 1). Numbers at points refer to levels of Na added. Level of N was held constant for each graph.

increase in yield. When either N or Na was at the high level, increasing the level of the other depressed the N content and considerably increased the yield of sugar.

Examination of the relationship between yield of sugar and N content as influenced by the Na-Mg interaction (Fig. 20 and 21) suggested that high N concentration of beets resulted if either Na or Mg was high and the other was low. When both Mg and Na were high or low the N content was low. In all cases, the high yield of sugar tended to occur at an N concentration between 3 and 3.5 percent.

Examination of the N content and yield of sugar as affected by the Mg-K interaction (Fig. 22 and 23) indicated that high yield and N concentration resulted if either Mg or K was high while the other element was low. When both elements were high or low, the N concentration and yield were low. In general, the yield of sugar was positively correlated with the N concentration of beet tops. A critical level of about 3.0 percent of total N was observed (Fig. 23). Below this level, a considerable increase in yield was associated with increasing N concentration, and above this level, only a slight increase or a reduction in yield was obtained with increasing N concentration.

Study of the N concentration of beet tops and yield of sugar interrelationship as influenced by the Mg-P interaction revealed that when P was held constant, the application of Mg resulted in a reduction of the N concentration while the yield of sugar was increased (Fig. 24). Less reduction in N content and gain in yield of sugar was obtained as

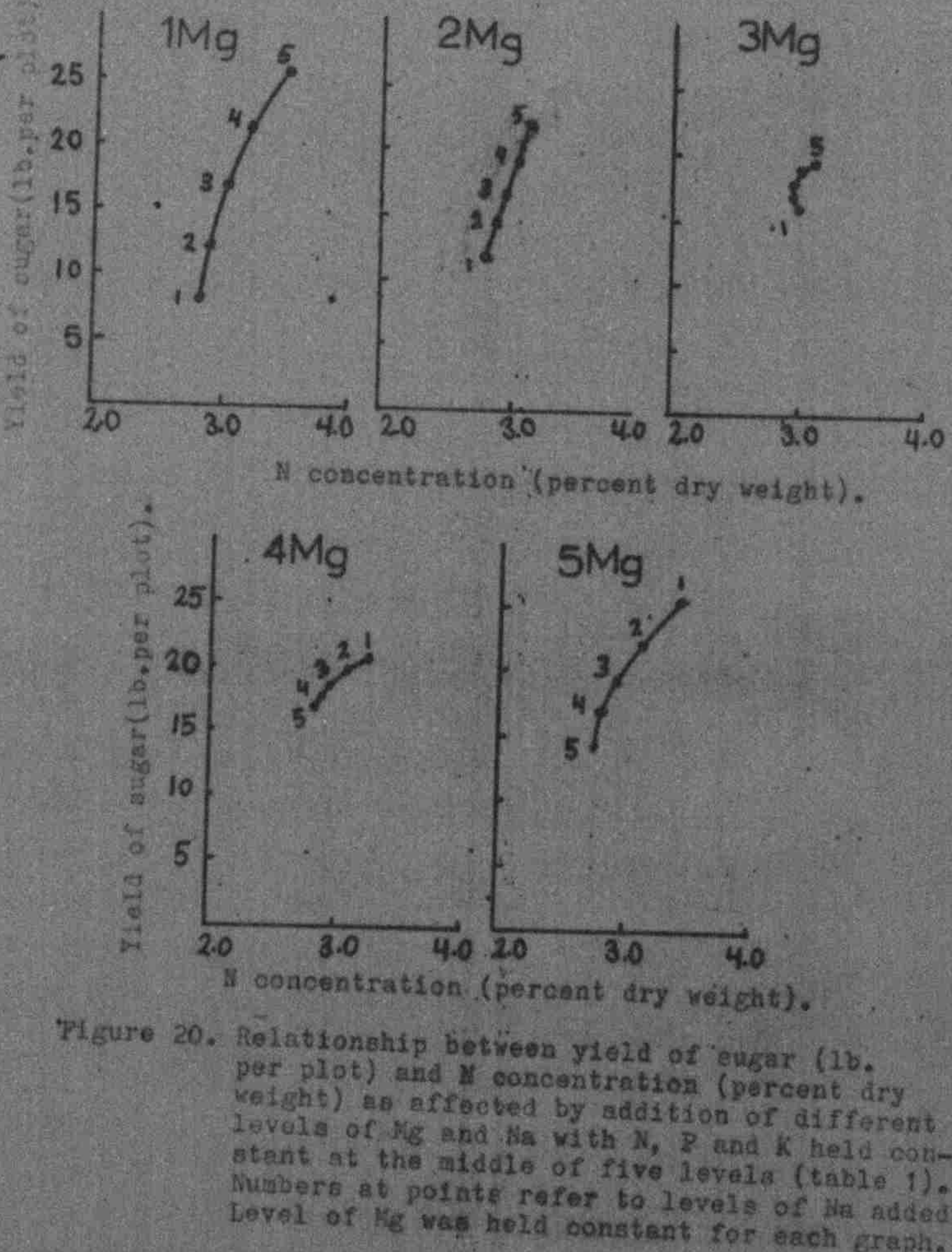


Figure 20. Relationship between yield of sugar (lb. per plot) and N concentration (percent dry weight) as affected by addition of different levels of Mg and Na with N, P and K held constant at the middle of five levels (table 1). Numbers at points refer to levels of Na added. Level of Mg was held constant for each graph.

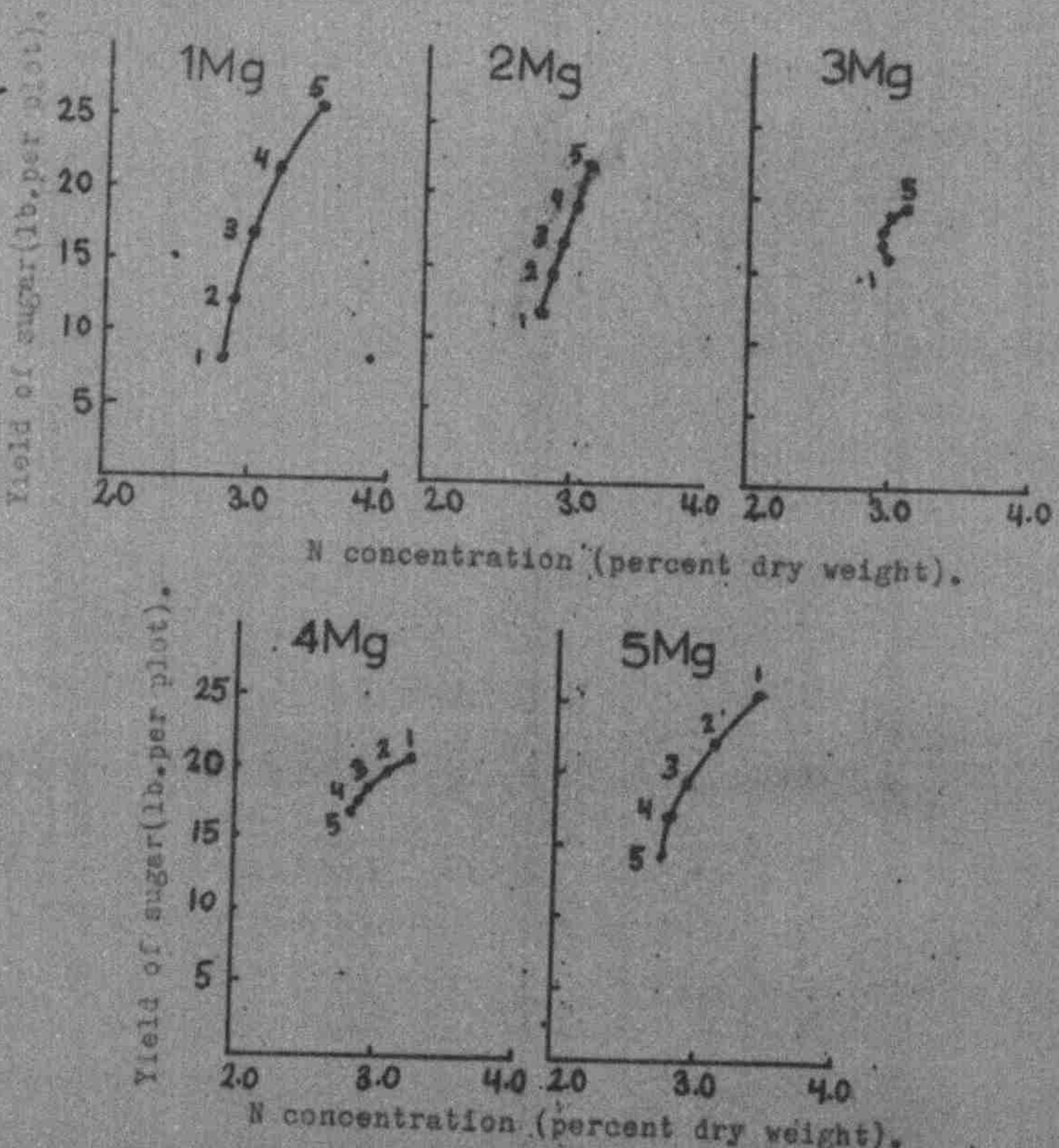


Figure 20. Relationship between yield of sugar (lb. per plot) and N concentration (percent dry weight) as affected by addition of different levels of Mg and Na with N, P and K held constant at the middle of five levels (table 1). Numbers at points refer to levels of Na added. Level of Mg was held constant for each graph.

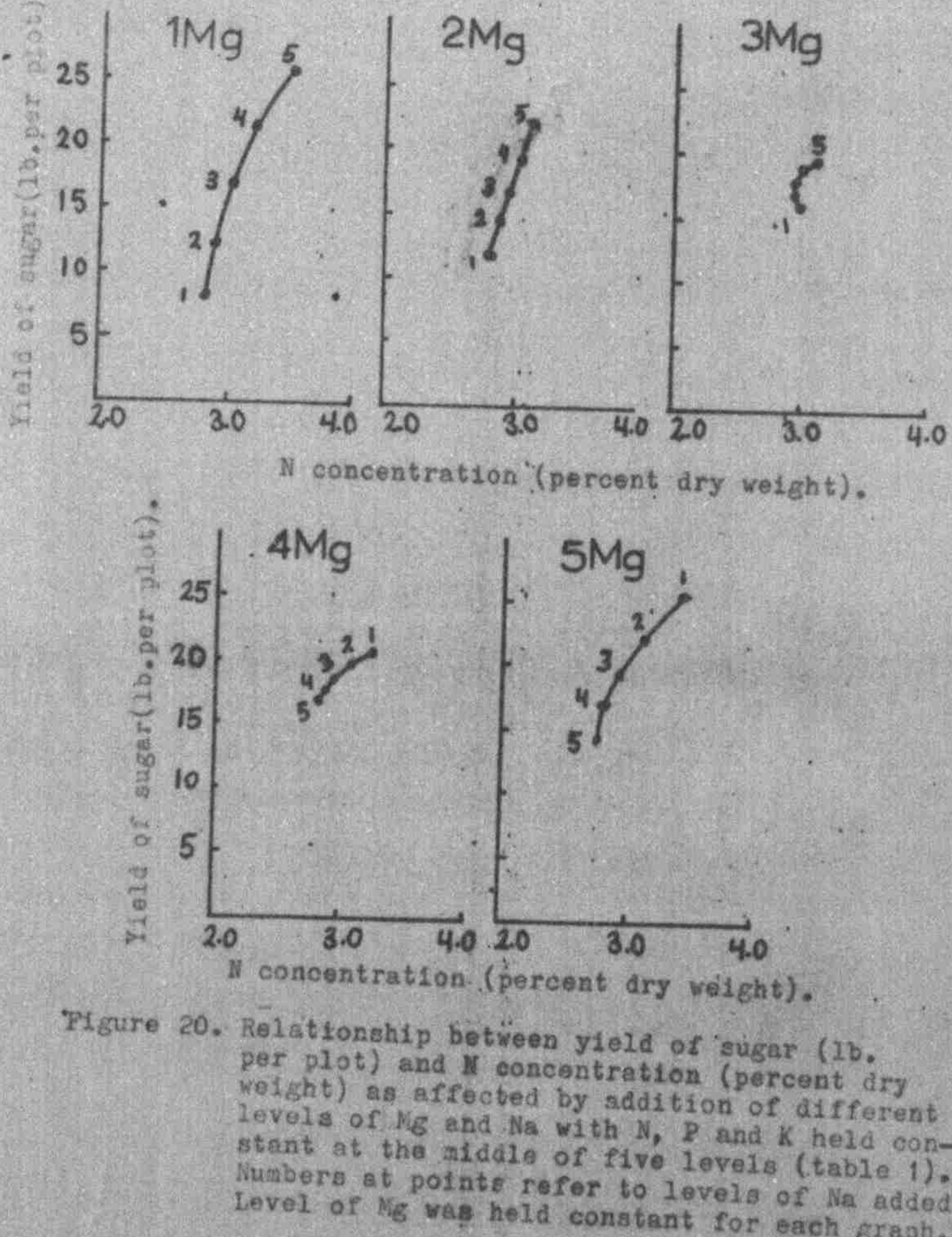


Figure 20. Relationship between yield of sugar (lb. per plot) and N concentration (percent dry weight) as affected by addition of different levels of Mg and Na with N, P and K held constant at the middle of five levels (table 1). Numbers at points refer to levels of Na added. Level of Mg was held constant for each graph.

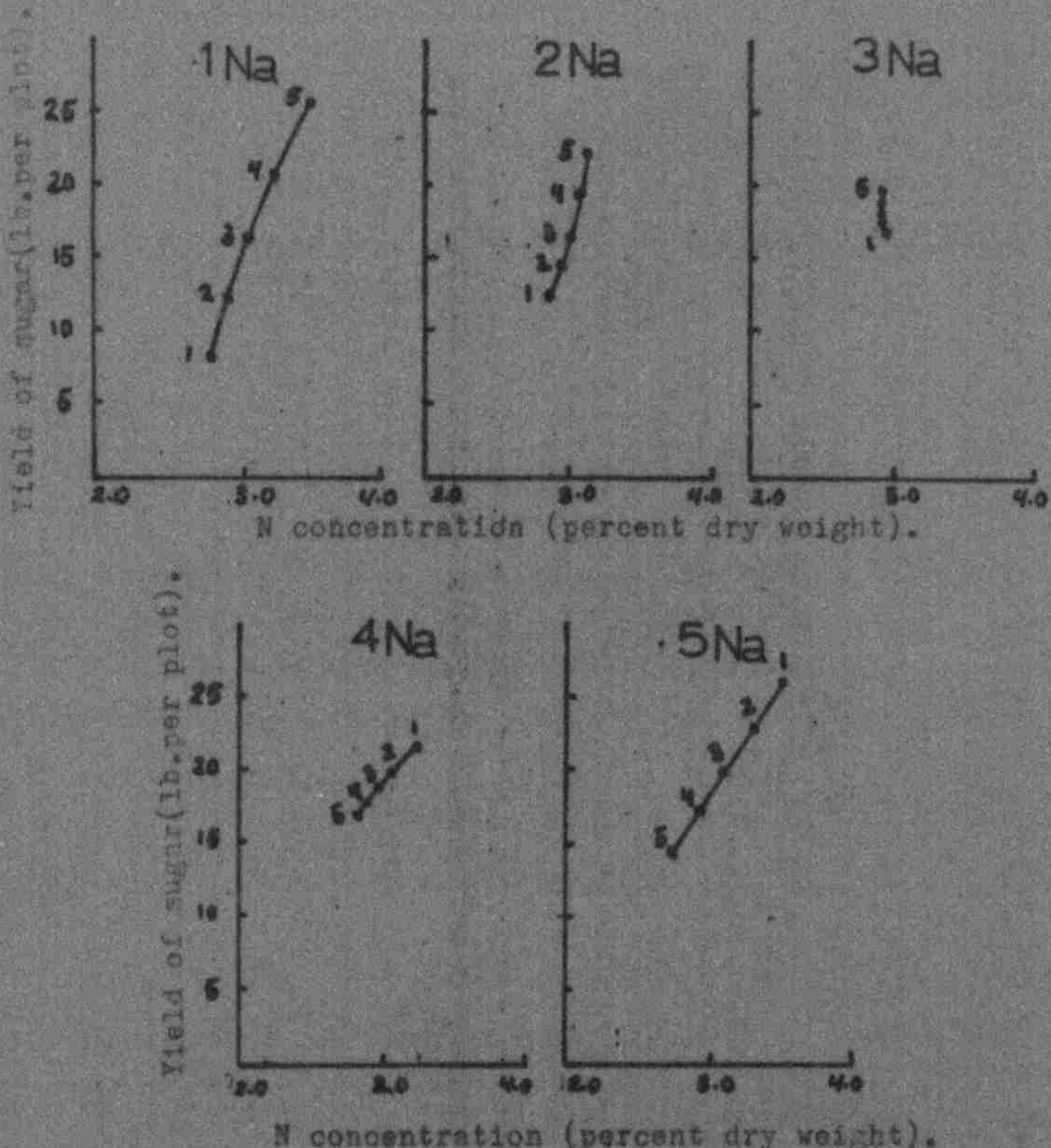
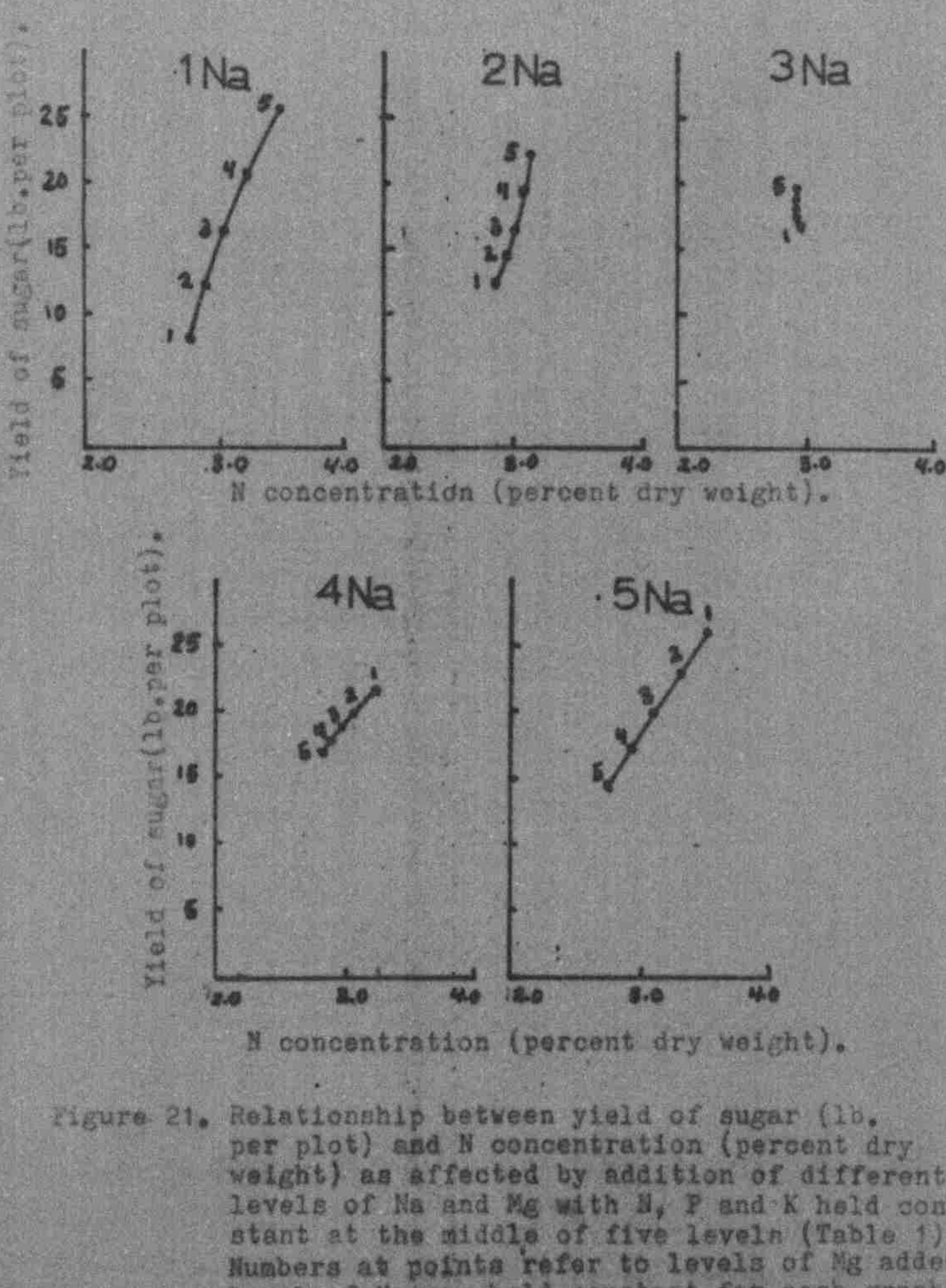


Figure 21. Relationship between yield of sugar (lb. per plot) and N concentration (percent dry weight) as affected by addition of different levels of Na and Mg with N, P and K held constant at the middle of five levels (Table 1). Numbers at points refer to levels of Mg added. Level of Na was held constant for each graph.



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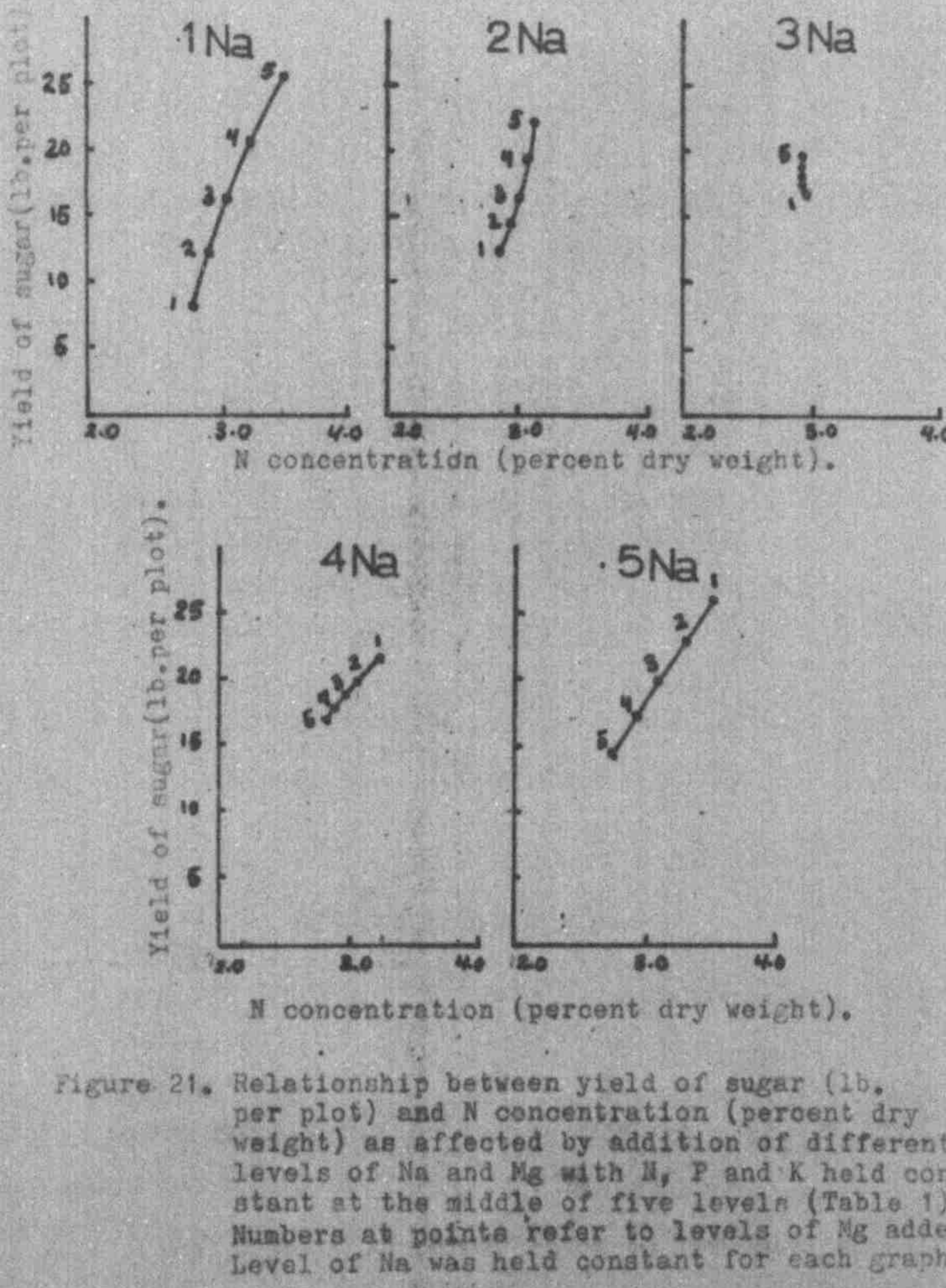


Figure 21. Relationship between yield of sugar (lb. per plot) and N concentration (percent dry weight) as affected by addition of different levels of Na and Mg with N, P and K held constant at the middle of five levels (Table 1). Numbers at points refer to levels of Mg added. Level of Na was held constant for each graph.

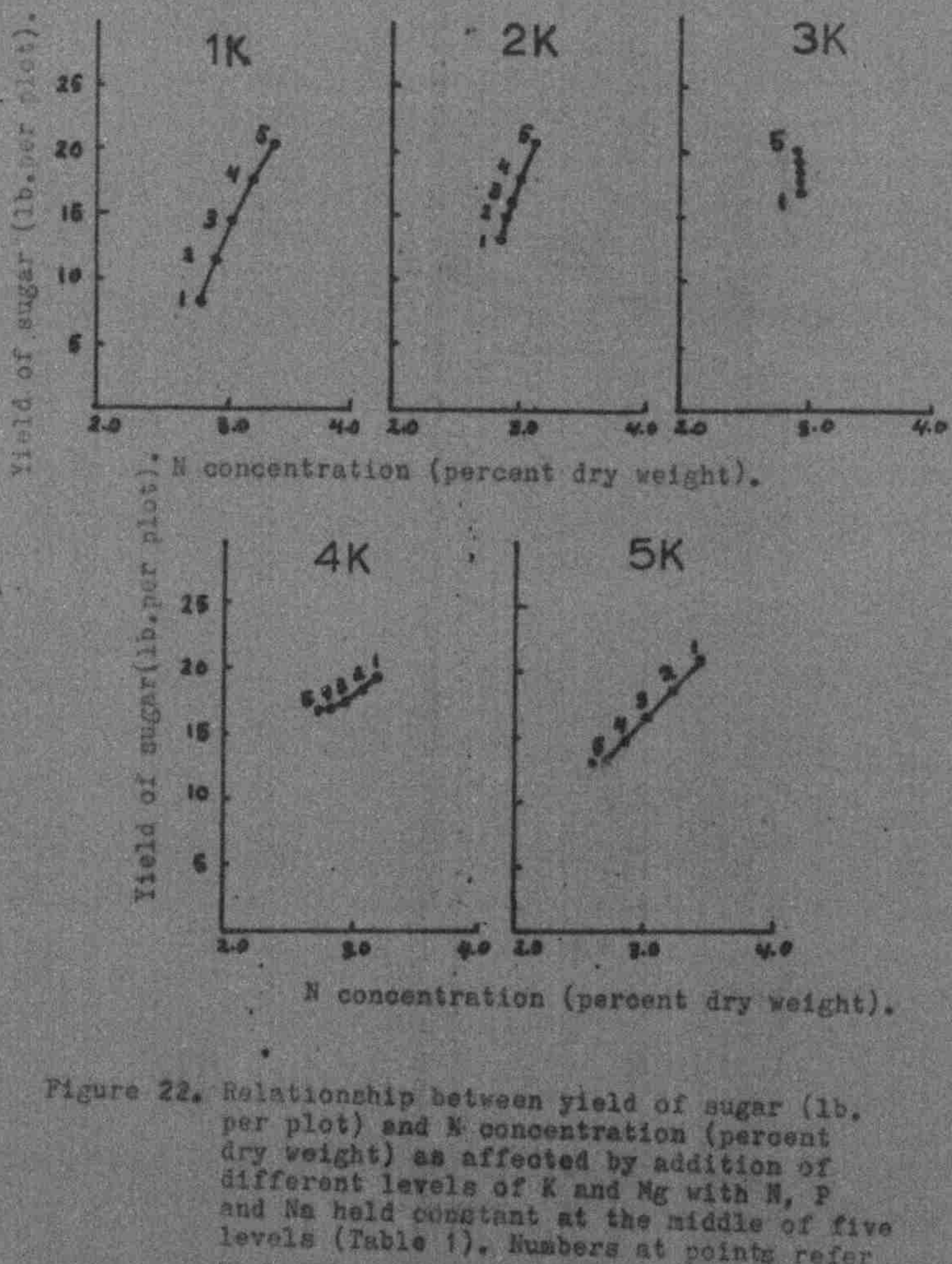


Figure 22. Relationship between yield of sugar (lb. per plot) and N concentration (percent dry weight) as affected by addition of different levels of K and Mg with N, P and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of Mg added. Level of K was held constant for each graph.

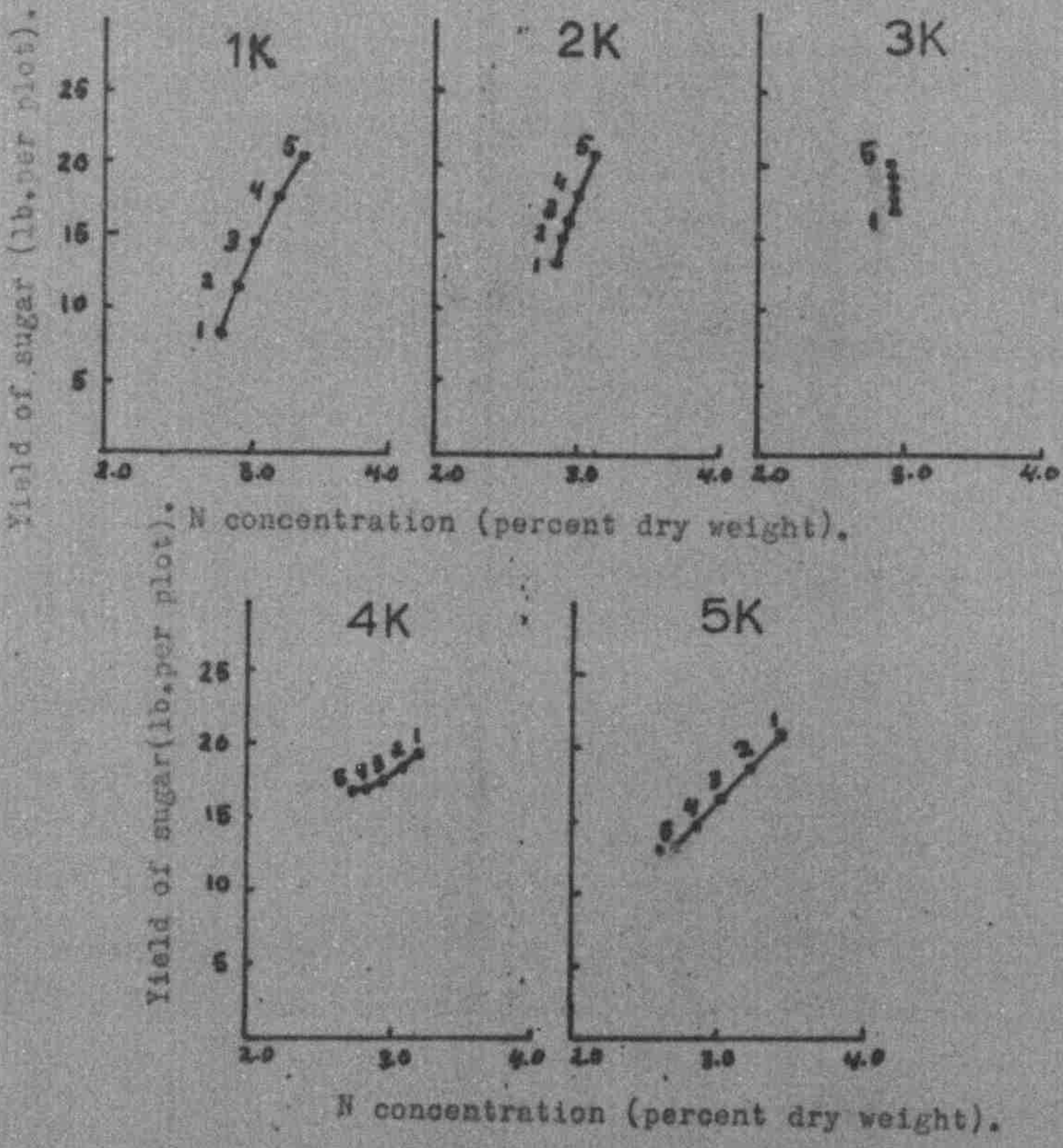


Figure 22. Relationship between yield of sugar (lb. per plot) and N concentration (percent dry weight) as affected by addition of different levels of K and Mg with N, P and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of Mg added. Level of K was held constant for each graph.

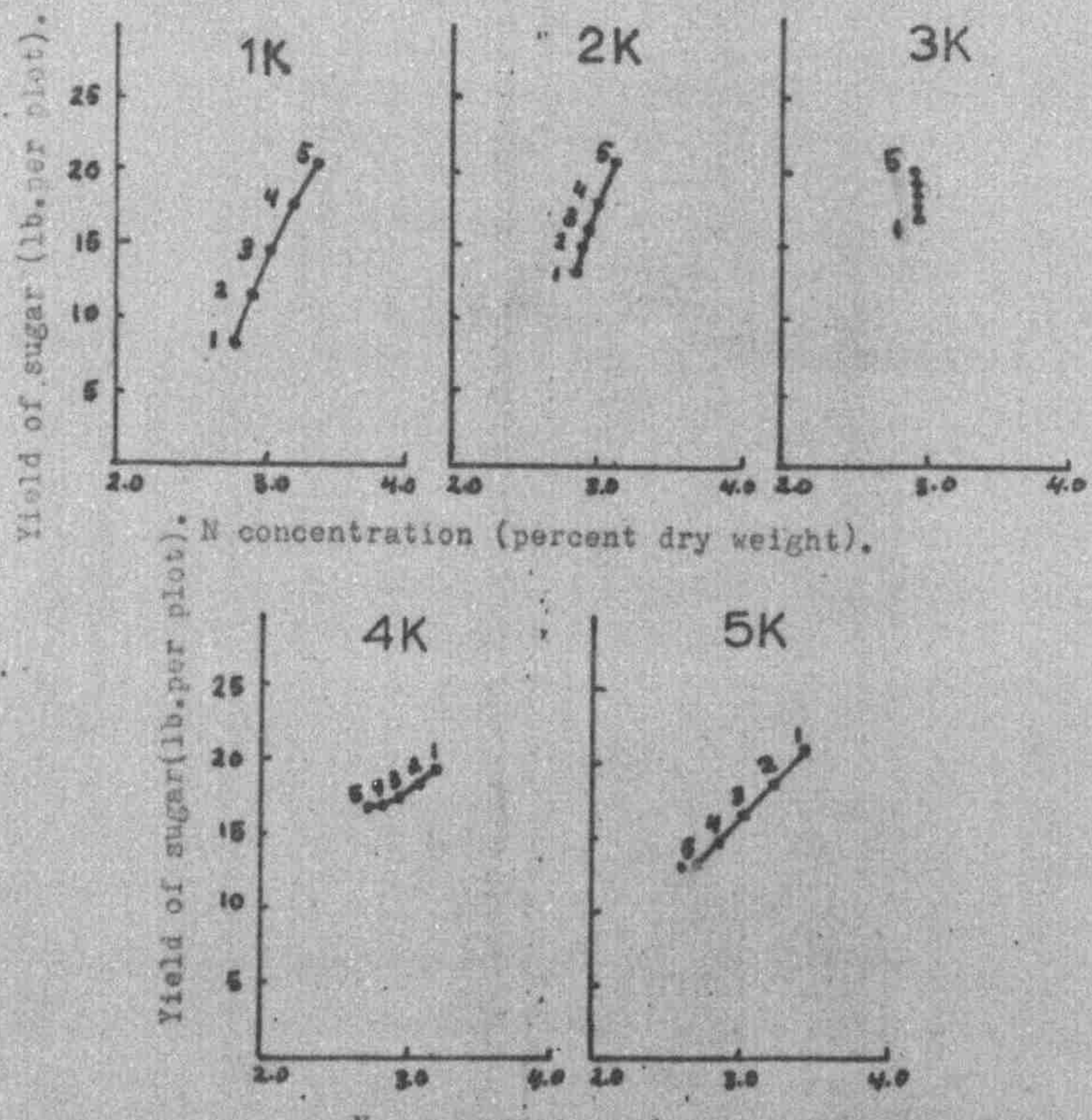


Figure 22. Relationship between yield of sugar (lb. per plot) and N concentration (percent dry weight) as affected by addition of different levels of K and Mg with N, P and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of Mg added. Level of K was held constant for each graph.

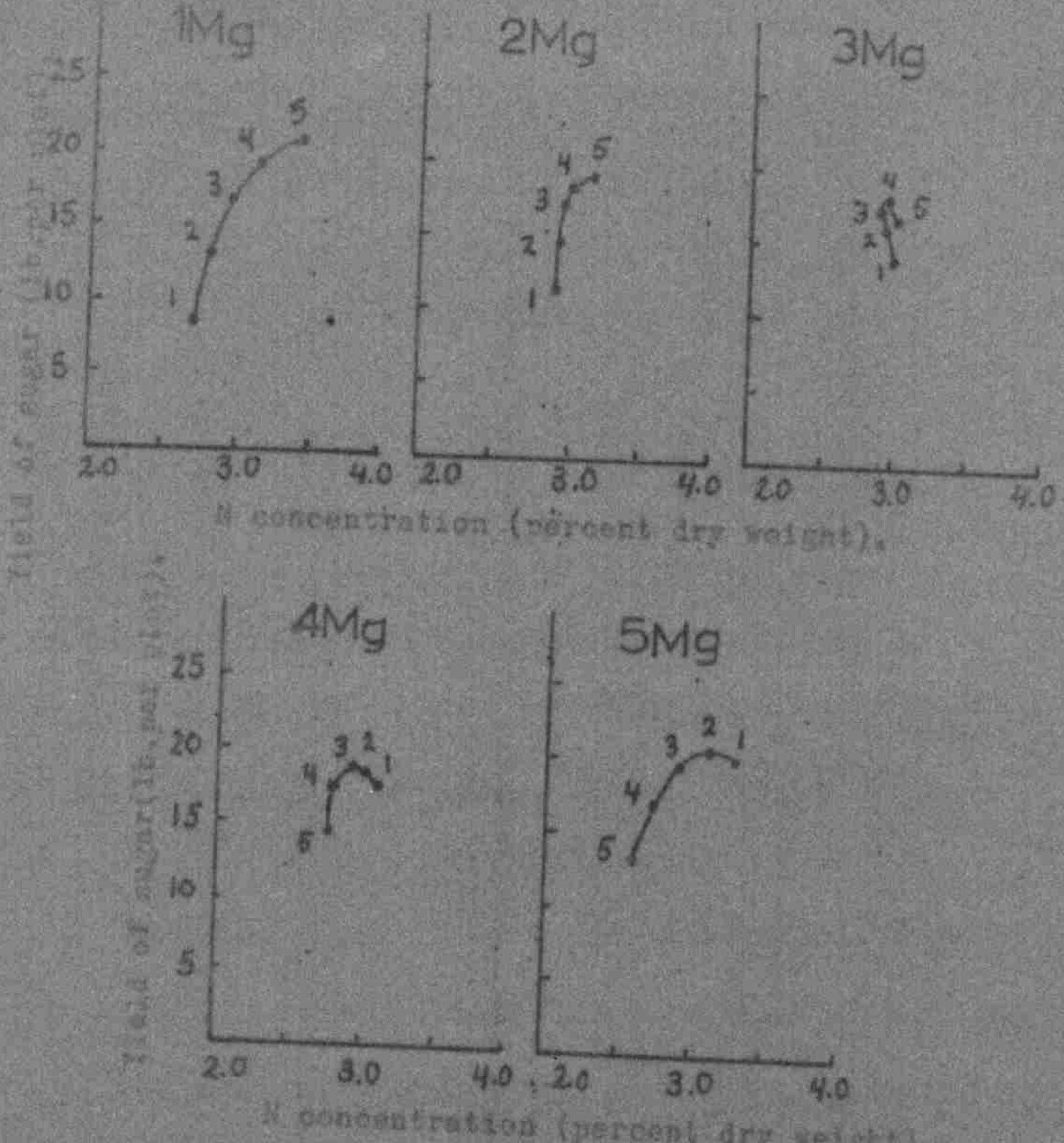
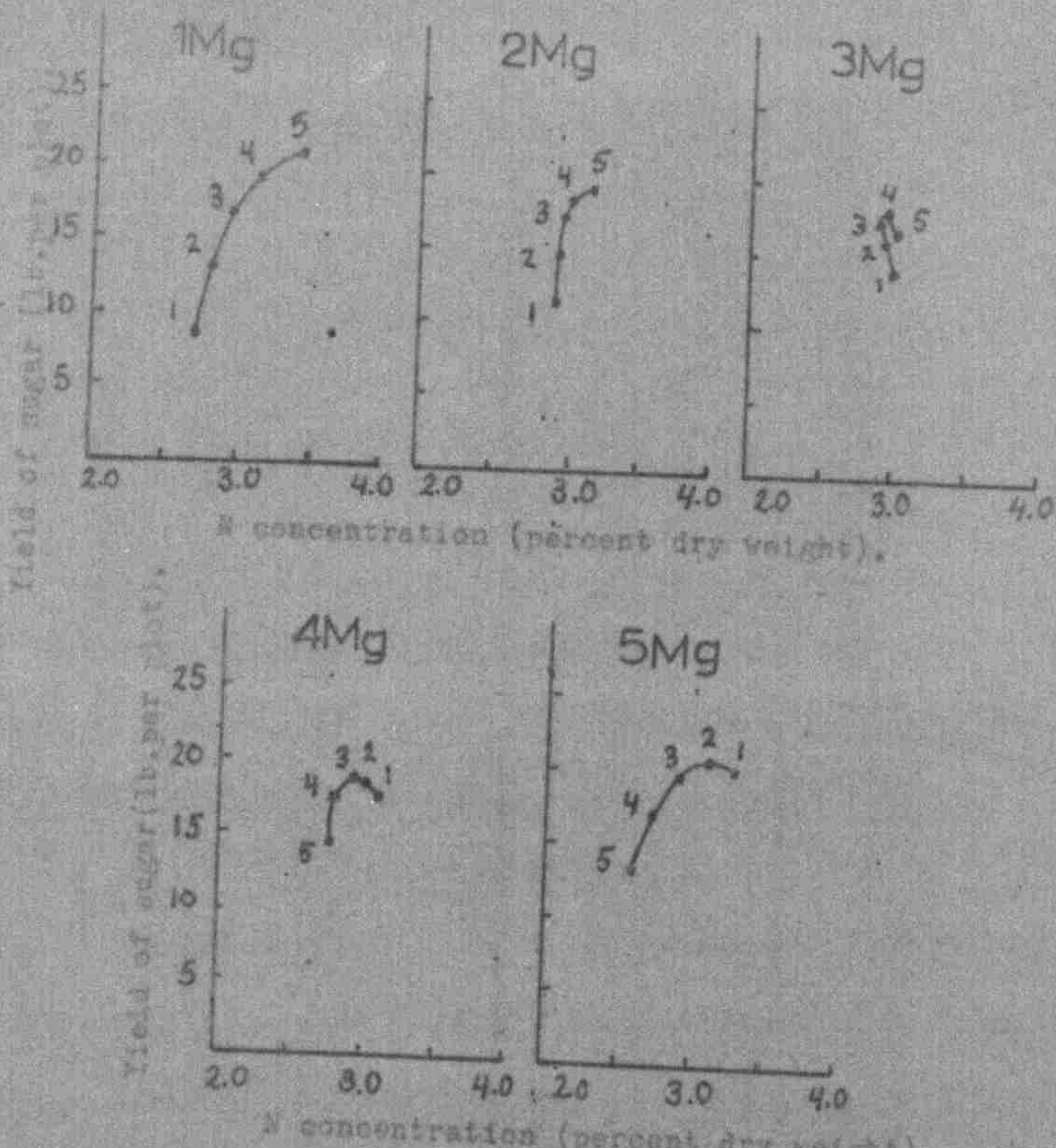


Figure 23. Relationship between yield of sugar (lb. per plot) and N concentration(percent dry weight) as affected by addition of different levels of K and Mg with N, P and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of K added. Level of Mg was held constant for each graph.



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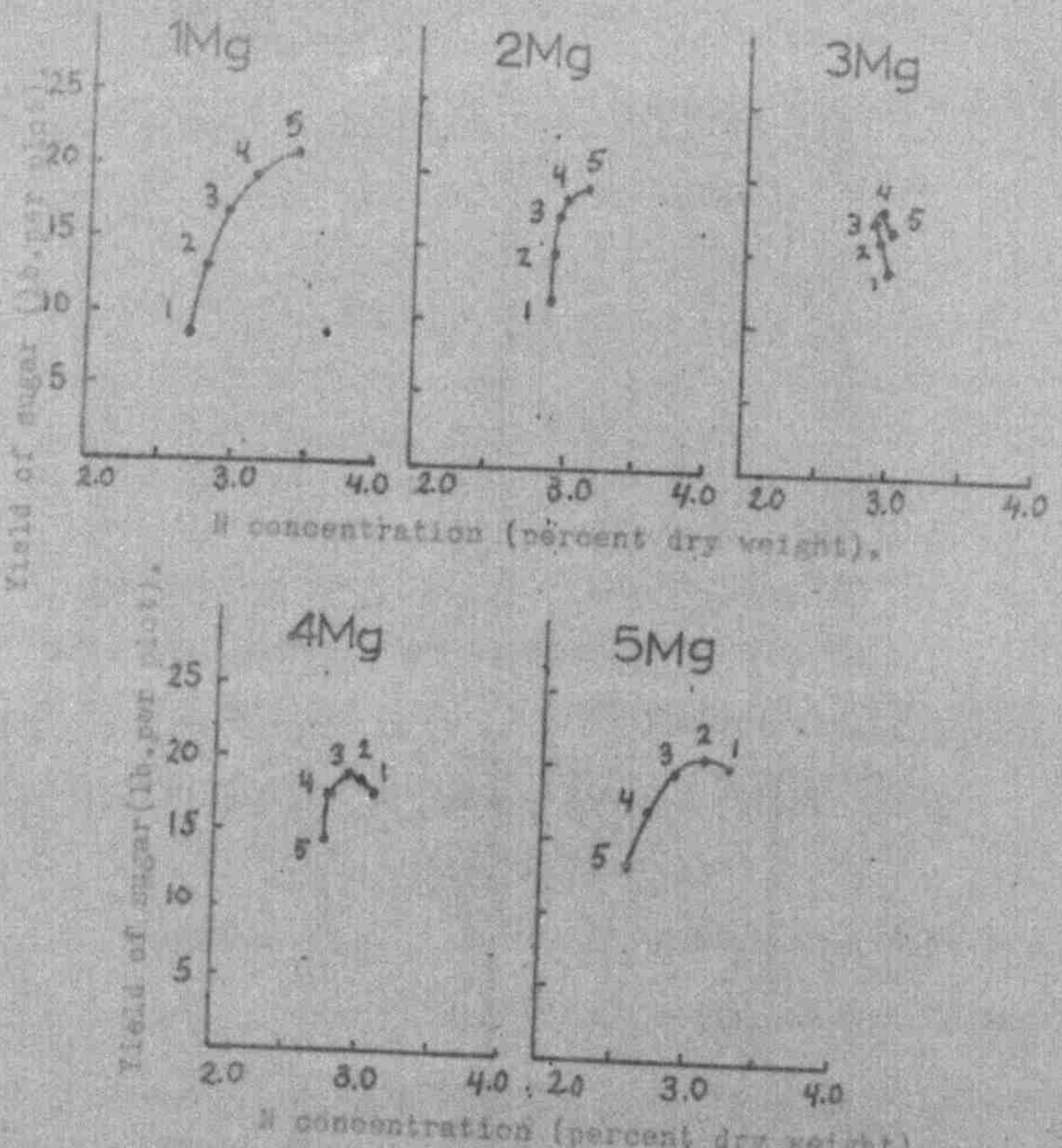

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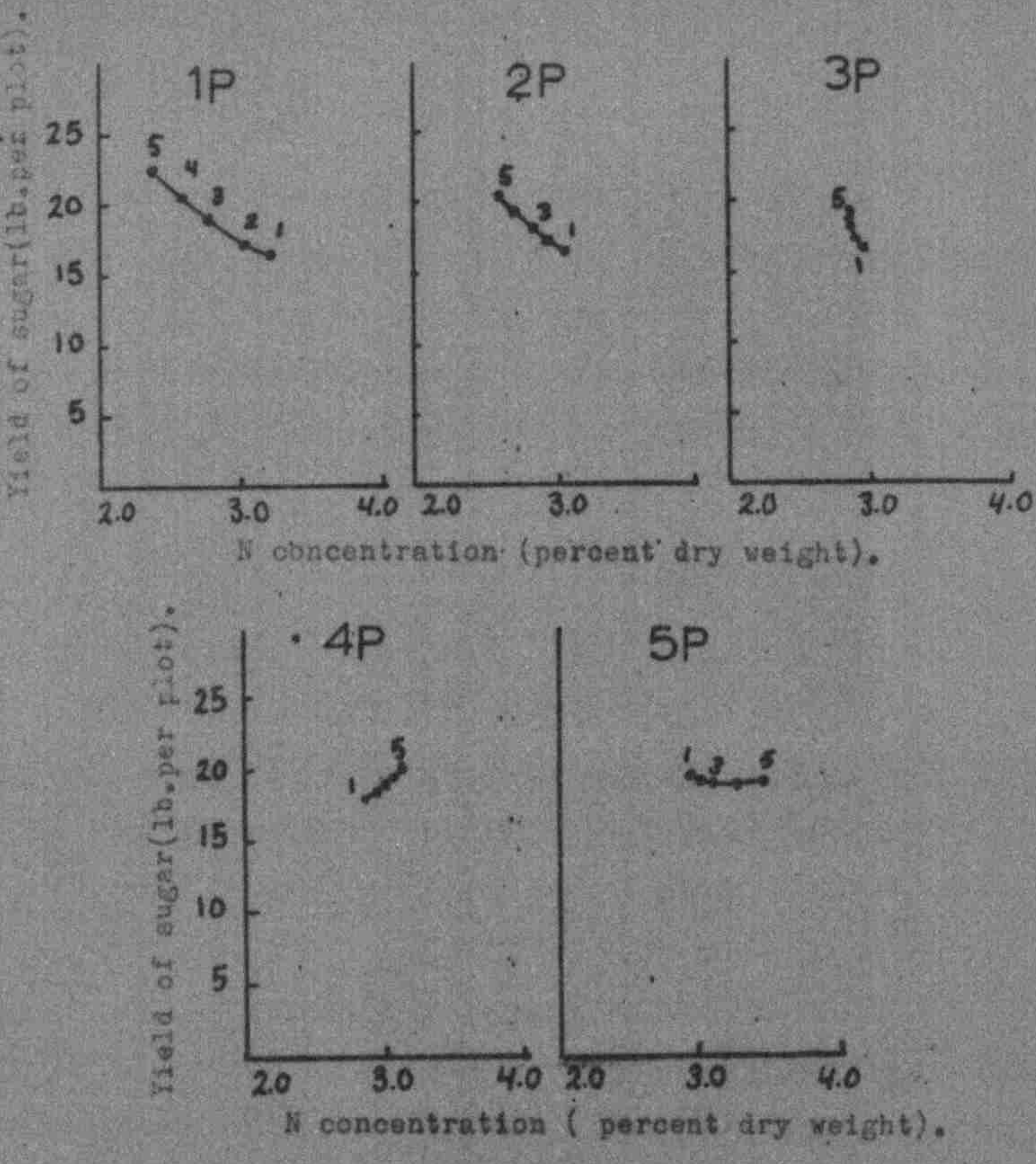


Figure 24. Relationship between yield of sugar (lb. per plot) and N concentration (percent dry weight) as affected by addition of different levels of P and Mg with N, K and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of Mg added. Level of P was held constant for each graph.

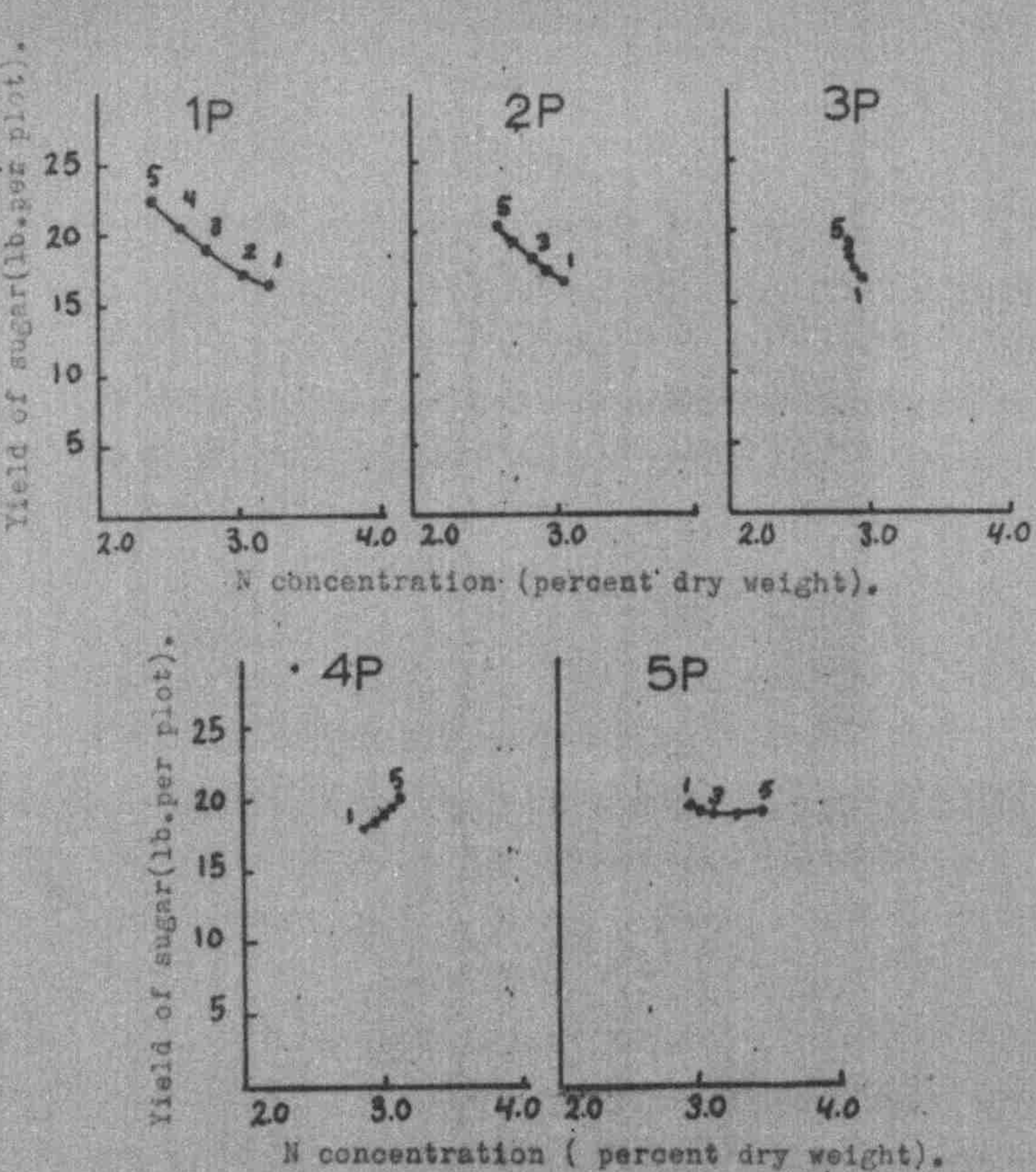


Figure 24. Relationship between yield of sugar (lb. per plot) and N concentration (percent dry weight) as affected by addition of different levels of P and Mg with N, K and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of Mg added. Level of P was held constant for each graph.

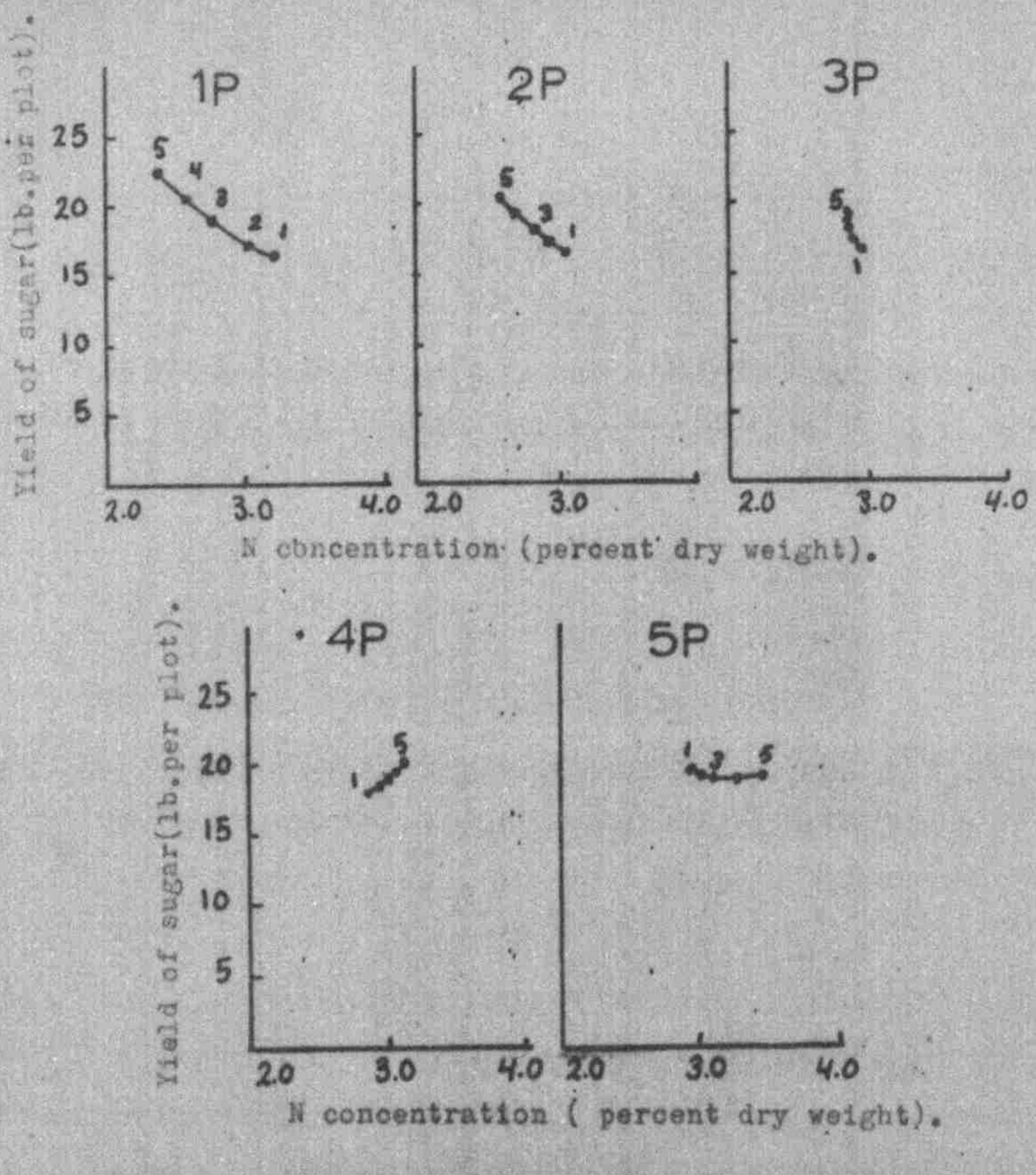


Figure 24. Relationship between yield of sugar (lb. per plot) and N concentration (percent dry weight) as affected by addition of different levels of P and Mg with N, K and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of Mg added. Level of P was held constant for each graph.

the P level was increased to the 3 level. At the higher levels of P, increasing Mg application decreased the N concentration while the yield of sugar was not seriously affected. When the level of Mg was held constant (Fig. 25), increasing the P rates at the 1Mg level resulted in a slight reduction of the N concentration and a slight increase in yield. As the Mg level was increased, increasing the P application resulted in increased N concentration while the yield was only slightly affected. In general, the tendency was for yield of sugar to be negatively correlated with N content at both the high and low levels of Mg. No definite critical level of total N concentration was observed.

Phosphorus Concentration of Beets Tops

The correlation coefficient between observed P concentration (percentage dry weight) of beets tops and the P concentration calculated from the regression equation (Table 19) was 0.413 an incomplete fit of the regression equation to the observed data.

The analysis of variance for P concentration (Table 20) indicated that the linear effect was highly significant while the quadratic effect was significant at the 5% level. The lack of fit term was not significant indicating that there was no need to use a higher order equation.

Determination of the regression coefficients (Table 21) indicated that among the linear effects, the P (positive), Mg (negative) and Na (negative) were highly significant whereas among quadratic effects the Mg-K interaction (negative) was significant.

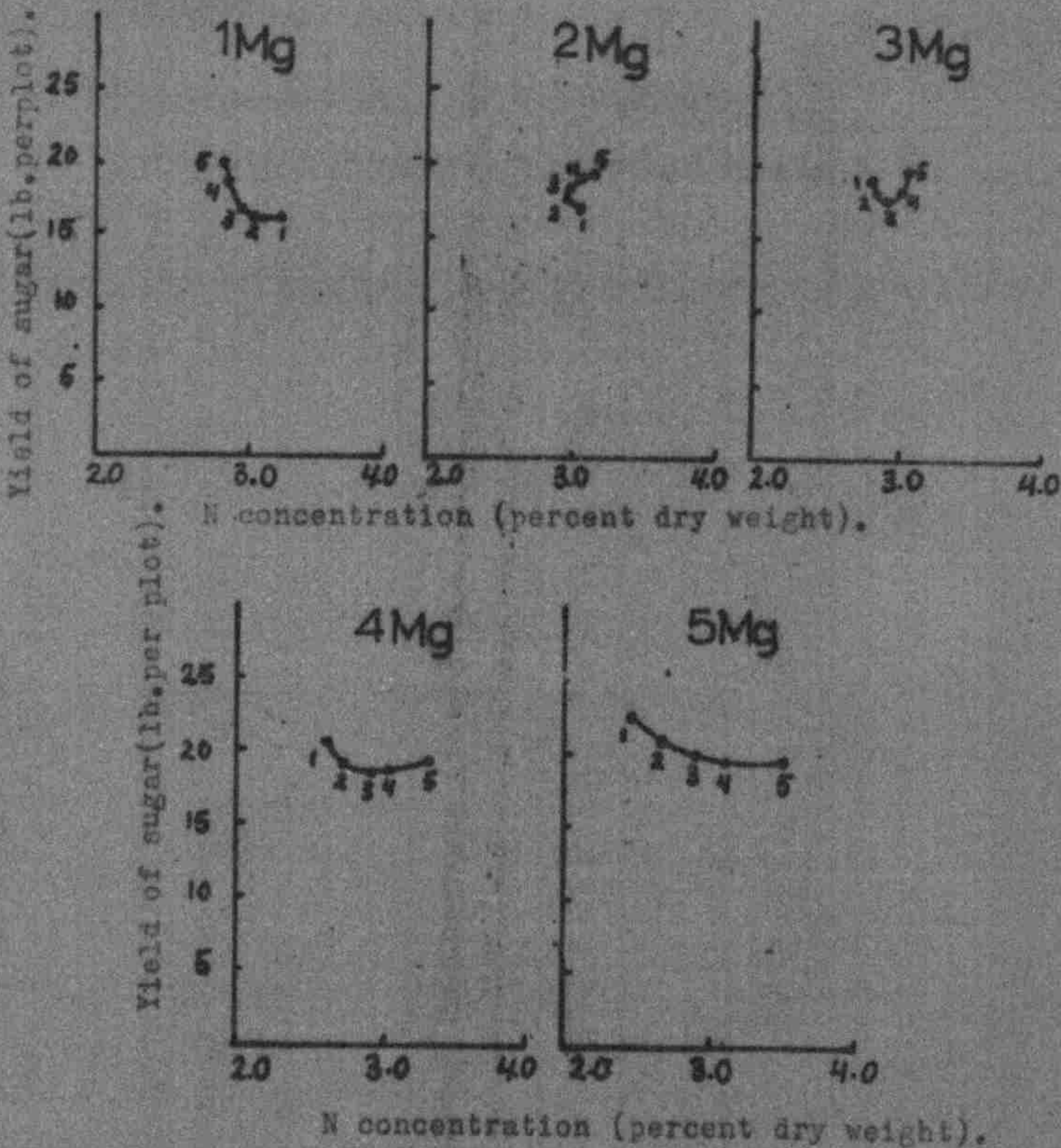


Figure 25. Relationship between yield of sugar (lb. per plot) and N concentration (percent dry weight) as affected by addition of different levels of Mg and P with N, K and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of P added. Level of Mg was held constant for each graph.

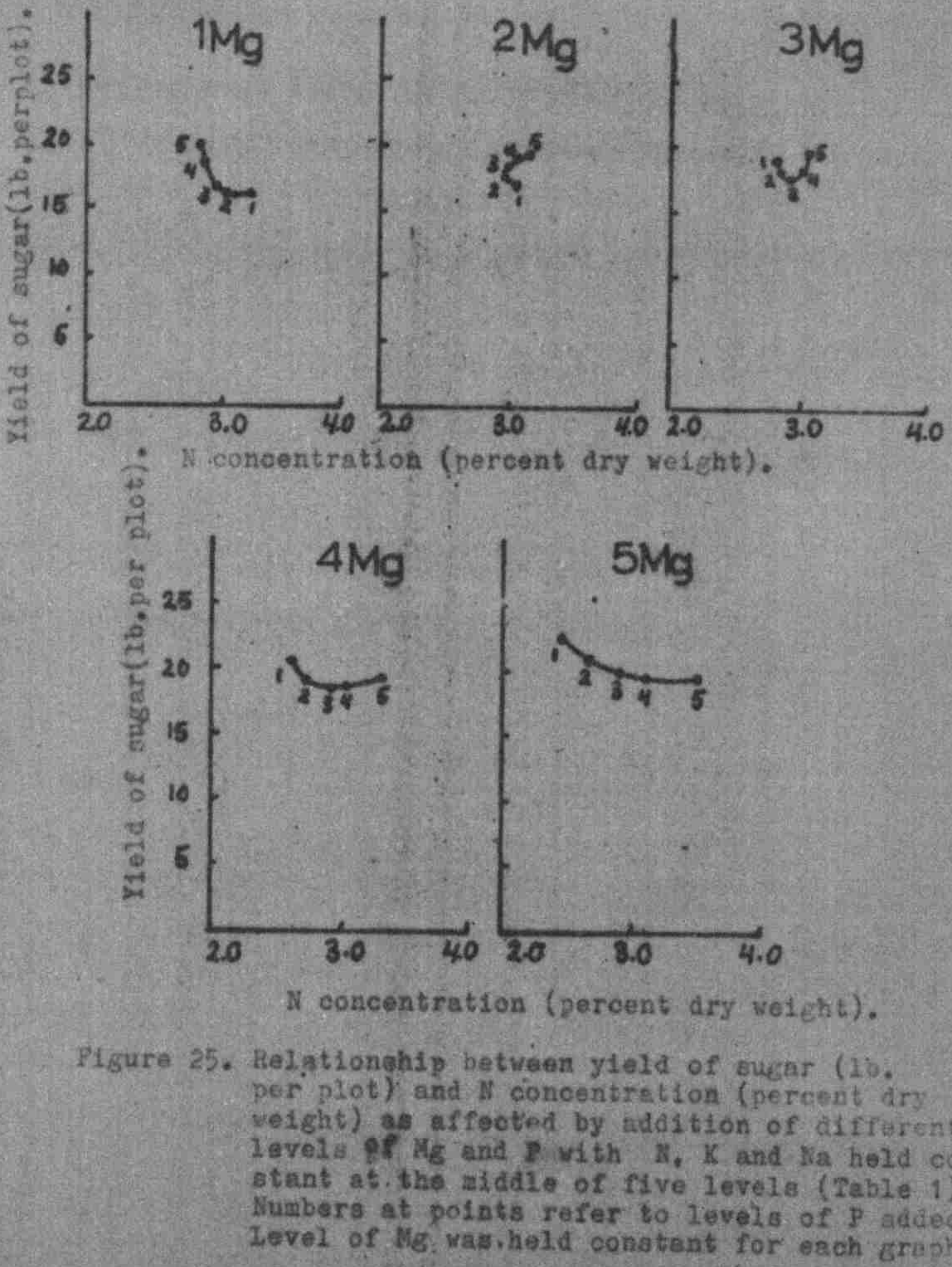
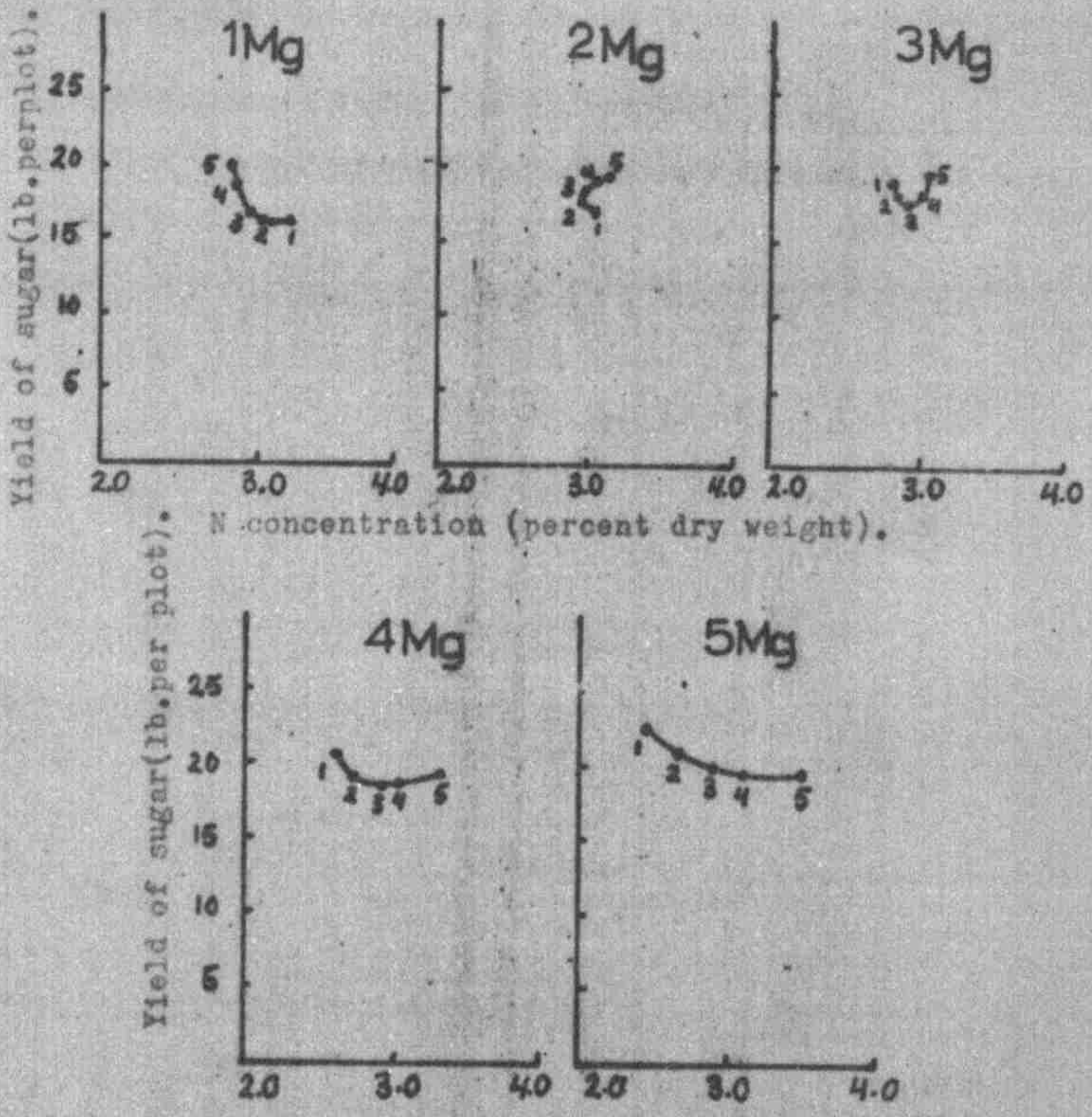


Figure 25. Relationship between yield of sugar (lb. per plot) and N concentration (percent dry weight) as affected by addition of different levels of Mg and P with N, K and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of P added. Level of Mg was held constant for each graph.



N concentration (percent dry weight).

Figure 25. Relationship between yield of sugar (lb. per plot) and N concentration (percent dry weight) as affected by addition of different levels of Mg and P with N, K and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of P added. Level of Mg was held constant for each graph.

Table 19. Observed P concentration of beet tops (percent dry weight) as affected by various levels of N, P, K, Mg and Na. Phosphorus concentrations for the same treatments calculated from the regression equation are given. Correlation of actual P concentration with calculated P concentration was 0.413.

Treatment levels N	P	K	Mg	Na	Actual P Concentration per cent	Calculated P concentration per cent
2	2	2	2	4	0.233	0.150
4	2	2	2	2	0.240	0.265
2	4	2	2	2	0.261	0.293
4	4	2	2	4	0.233	0.169
2	2	4	2	2	0.233	0.273
4	2	4	2	4	0.173	0.116
2	4	4	2	4	0.245	0.195
4	4	4	2	2	0.267	0.325
2	2	2	4	2	0.228	0.254
4	2	2	4	4	0.174	0.105
2	4	2	4	4	0.248	0.186
4	4	2	4	2	0.251	0.295
2	2	4	4	4	0.154	0.099
4	2	4	4	2	0.100	0.152
2	4	4	4	2	0.169	0.227
4	4	4	4	4	0.174	0.138
5	3	3	3	3	0.170	0.176
1	3	3	3	3	0.175	0.204
3	5	3	3	3	0.328	0.320
3	1	3	3	3	0.175	0.217
3	3	5	3	3	0.174	0.151
3	3	1	3	3	0.141	0.199
3	3	3	5	3	0.121	0.124
3	3	3	1	3	0.175	0.206
3	3	3	3	5	0.169	0.077
3	3	3	3	1	0.181	0.308
3	3	3	3	3	0.177	0.181
3	3	3	3	3	0.173	0.181
3	3	3	3	3	0.174	0.181
3	3	3	3	3	0.208	0.181
3	3	3	3	3	0.125	0.181
3	3	3	3	3	0.173	0.181

Table 2D. Analysis of variance for P concentration of beet tops (percent dry weight).

Source	d. f.	S. S.	M. S.	F value
Linear effect	5	0.0384	0.00768	21.33330**
Quadratic effect	15	0.0296	0.00197	5.47220*
Lack of fit	6	0.0001	0.00001	0.000003
Experimental error	5	0.0018	0.00036	
Total	31	0.0699		

* Significant at odds of 19:1

** Significant at odds of 99:1

Table 21. Regression coefficients (b) and their standard errors (s_b) for P concentration of beet tops (percent dry weight).

Coefficient		b	s_b
Mean	b_0	0.1808	± 0.075
N	b_1	− 0.0070	± 0.0038
P	b_2	+ 0.0258 **	"
K	b_3	− 0.0120	"
Mg	b_4	− 0.0206 **	"
Na	b_5	− 0.0579 **	"
N^2	b_{11}	+ 0.0022	± 0.0035
P^2	b_{22}	+ 0.0220	"
K^2	b_{33}	− 0.0015	"
Mg^2	b_{44}	− 0.0039	"
Na^2	b_{55}	+ 0.0029	"
N-P	b_{12}	+ 0.0102	± 0.0047
N-K	b_{13}	− 0.0009	"
N-Mg	b_{14}	− 0.0026	"
N-Na	b_{15}	− 0.0058	"
P-K	b_{23}	+ 0.0048	"
P-Mg	b_{24}	+ 0.0037	"
P-Na	b_{25}	+ 0.0012	"
K-Mg	b_{34}	− 0.0159 *	"
K-Na	b_{35}	+ 0.0043	"
Mg-Na	b_{45}	+ 0.0074	"

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

The relationship between yield of sugar and P concentration as affected by various levels of applied Mg at each of five levels of K (Fig. 26) indicated that the P concentration of beet tops increased slightly with increasing Mg application at the 1K level but decreased with Mg application at the higher K levels. Increasing Mg application increased the yield considerably at low levels of K while at high levels of K the yield of sugar was decreased indicating the complementary relationship between K and Mg. When the Mg level was held constant (Fig. 27) the P concentration tended to be increased with increasing K application at low Mg levels whereas at the higher levels of Mg, the P concentration was considerably decreased with increasing K application. The yield of sugar was increased by increasing K at low level of Mg while at high Mg levels the yield of sugar was decreased. The high concentration of P was associated with the highest yields. A critical level was observed (Fig. 27) and its magnitude was determined by the Mg level ranging from 0.15 at the high Mg level to 0.25 at the low Mg level suggesting that with a low supply of Mg more P consumption is needed to give maximum yield of sugar while with a high Mg supply less P concentration is needed for maximum yields of sugar.

Study of the relationship between yield of sugar and P concentration of leaves as affected by the P-N interaction (Fig. 28) indicated that when the P supply was held constant, the P concentration was decreased with N application at the low P levels while at high P levels the P concentration was slightly increased with N application. It was observed

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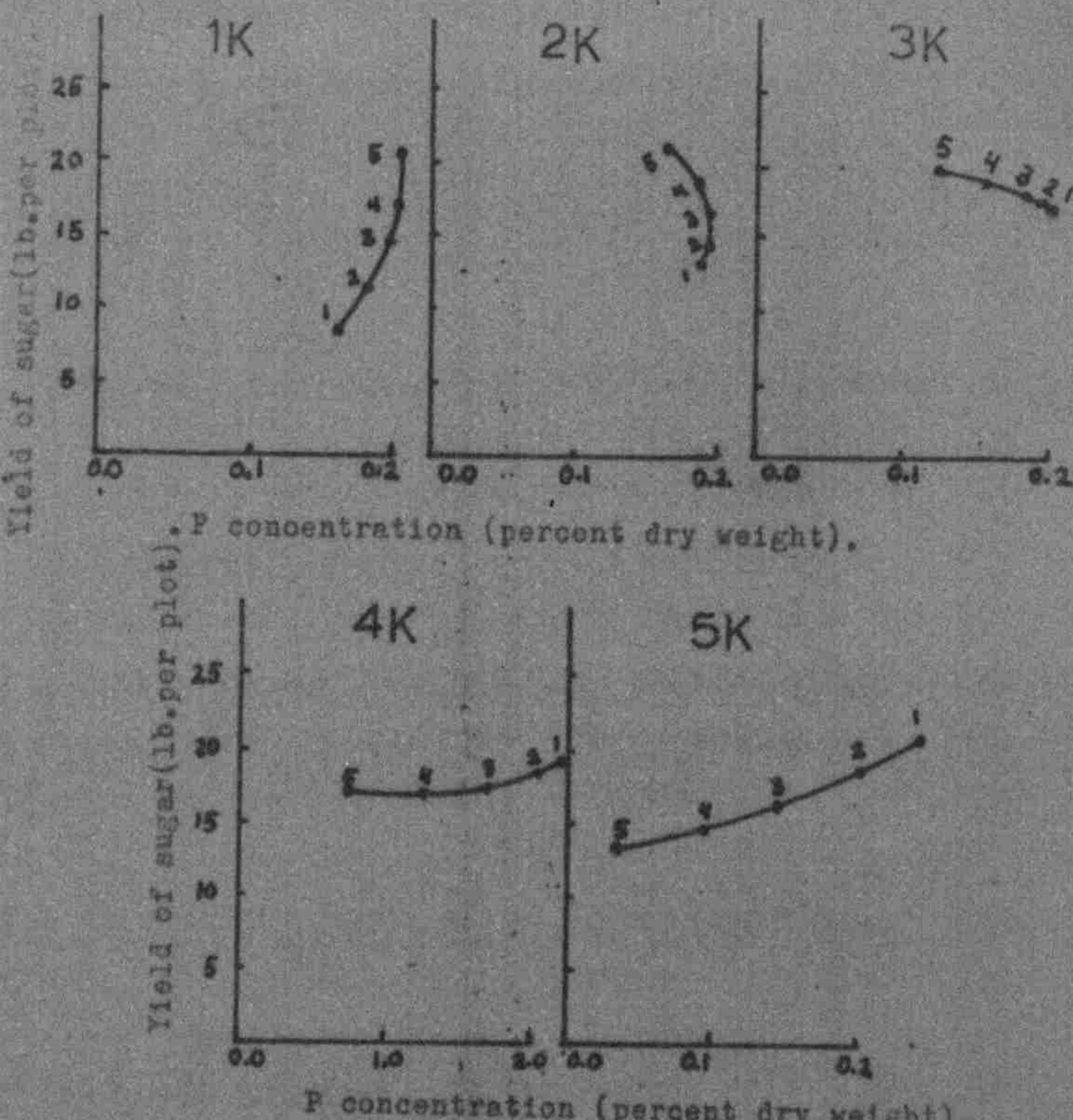
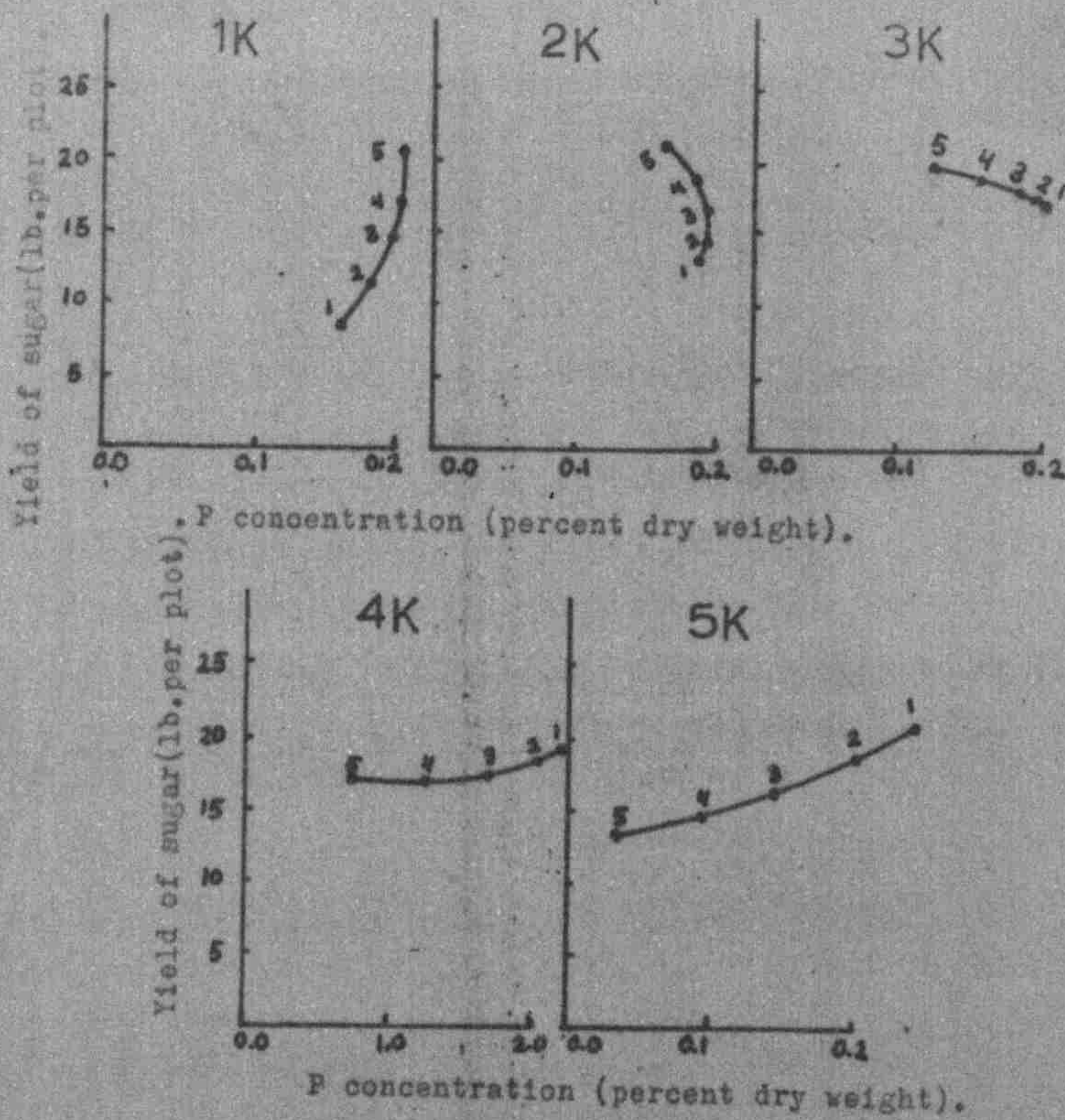


Figure 26. Relationship between yield of sugar (lb. per plot) and P concentration (percent dry weight) as affected by addition of different levels of K and Mg with N, P and Na held constant at the middle of five levels (Table 1). Numbers at points refer to level of Mg added. Level of K was held constant for each graph.



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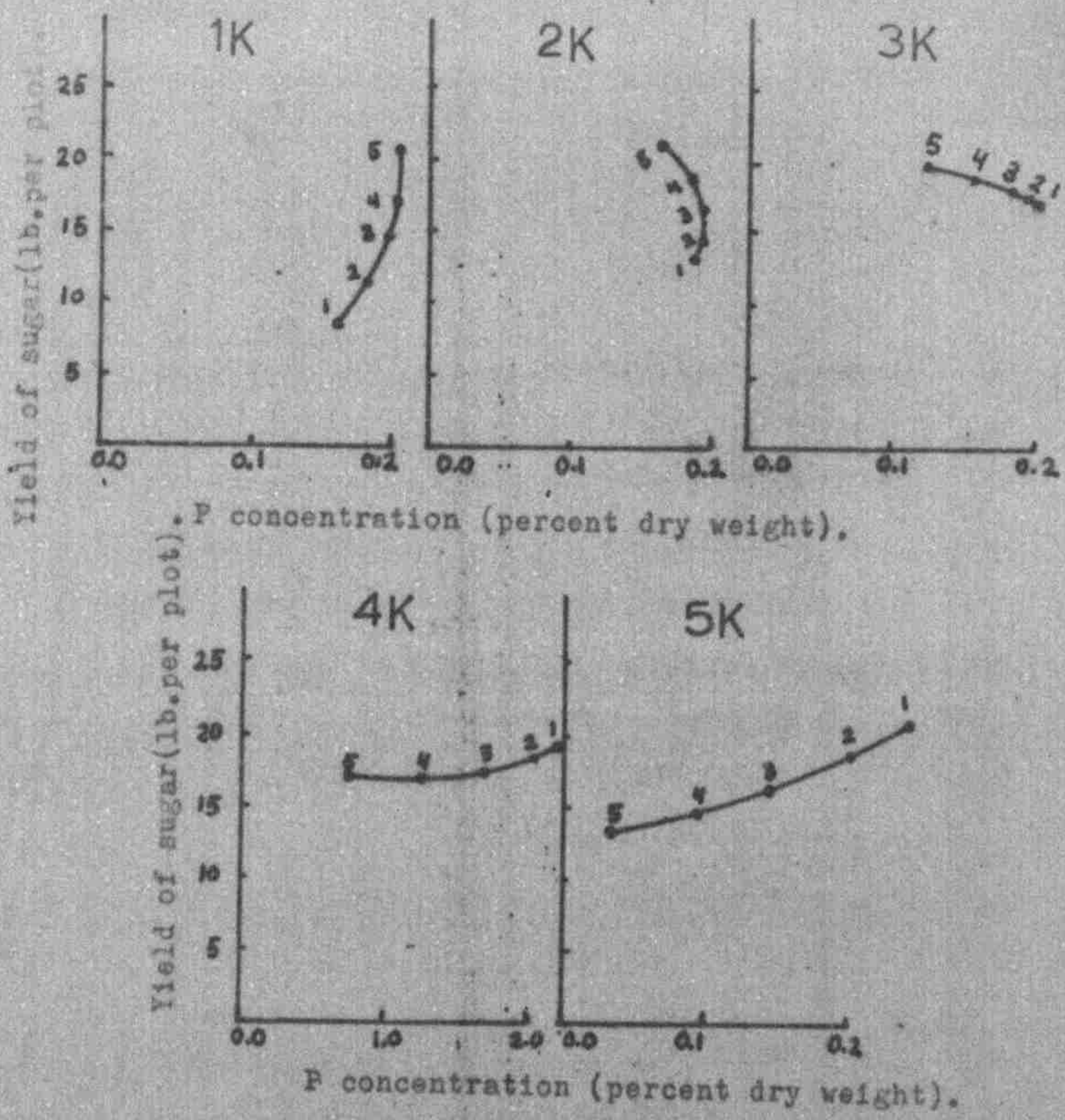

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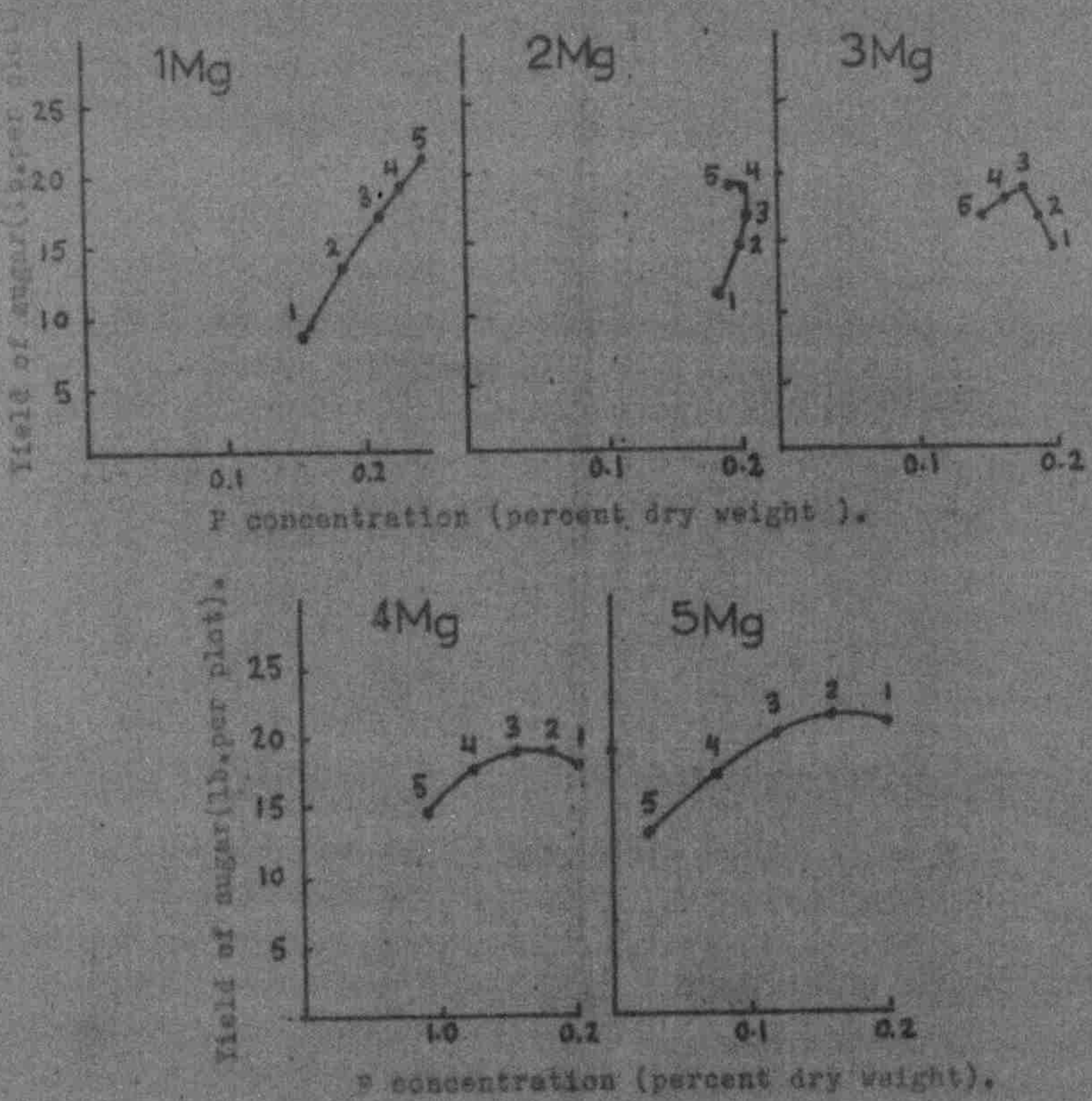
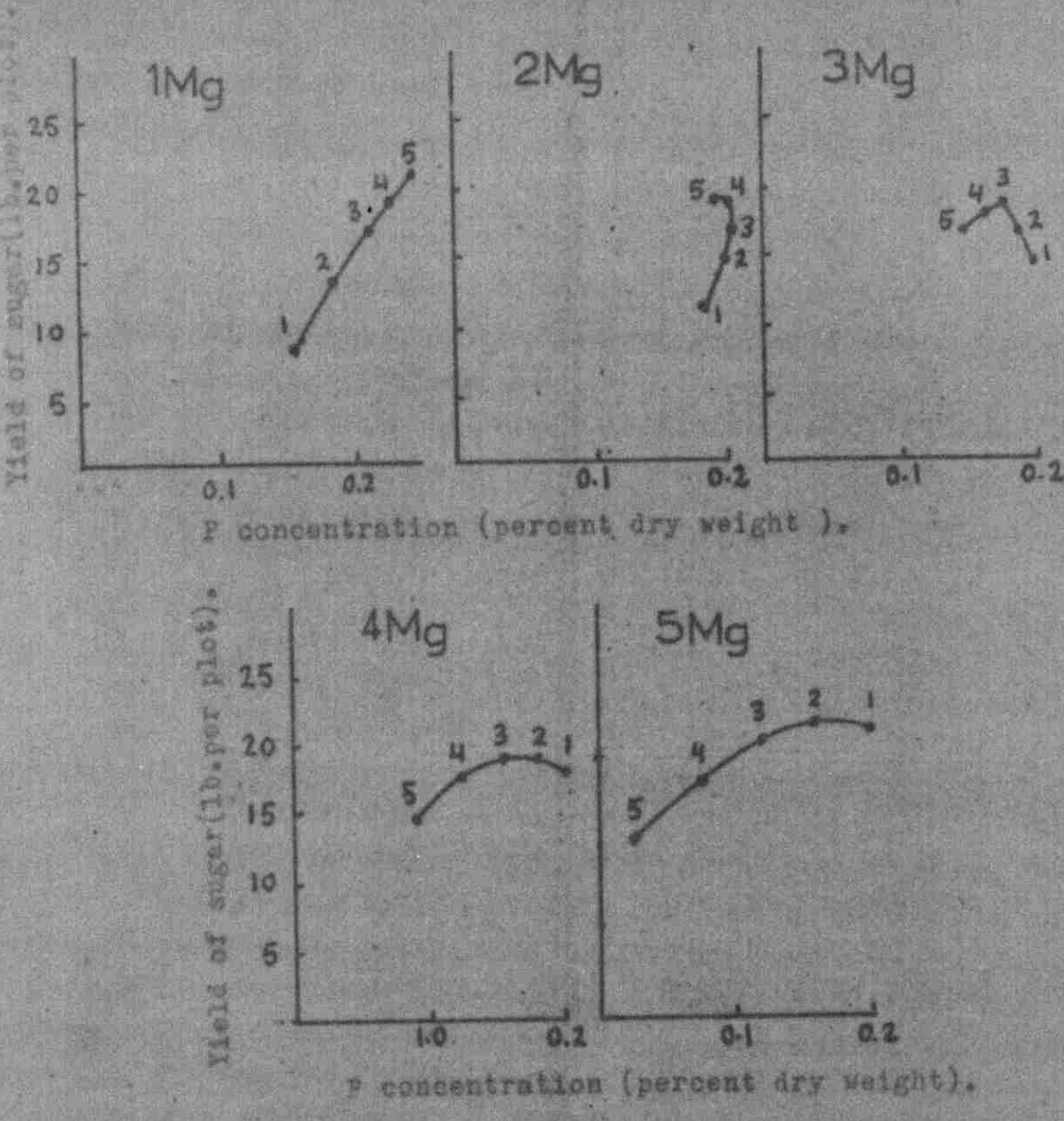


Figure 27. Relationship between yield of sugar (lb. per plot) and P concentration (percent dry weight) as affected by addition of different levels of Mg and K with N, P and Na held constant at the middle of five levels (Table 1). Numbers at points refer to level of K added. Level of Mg was held constant for each graph.



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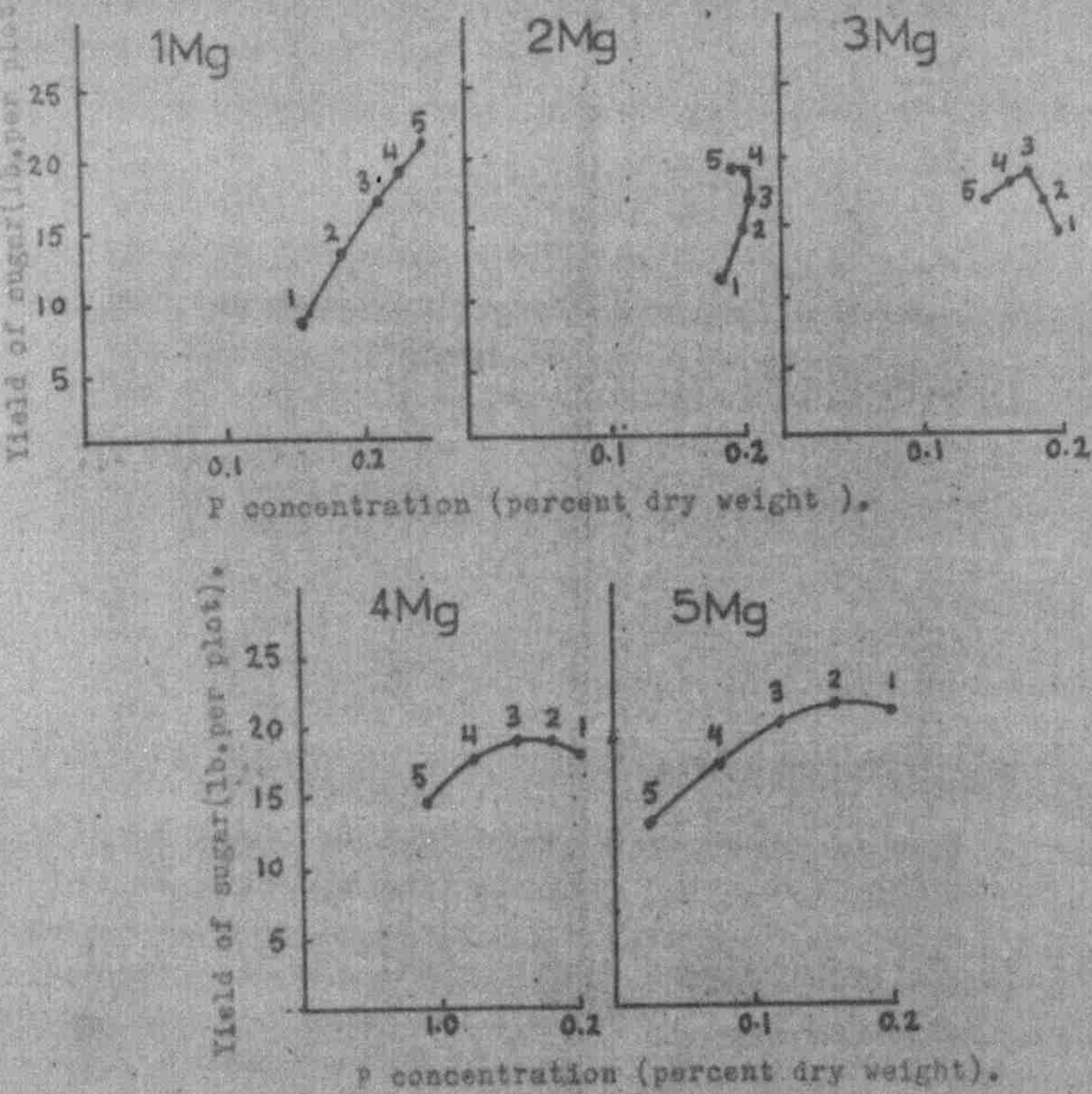

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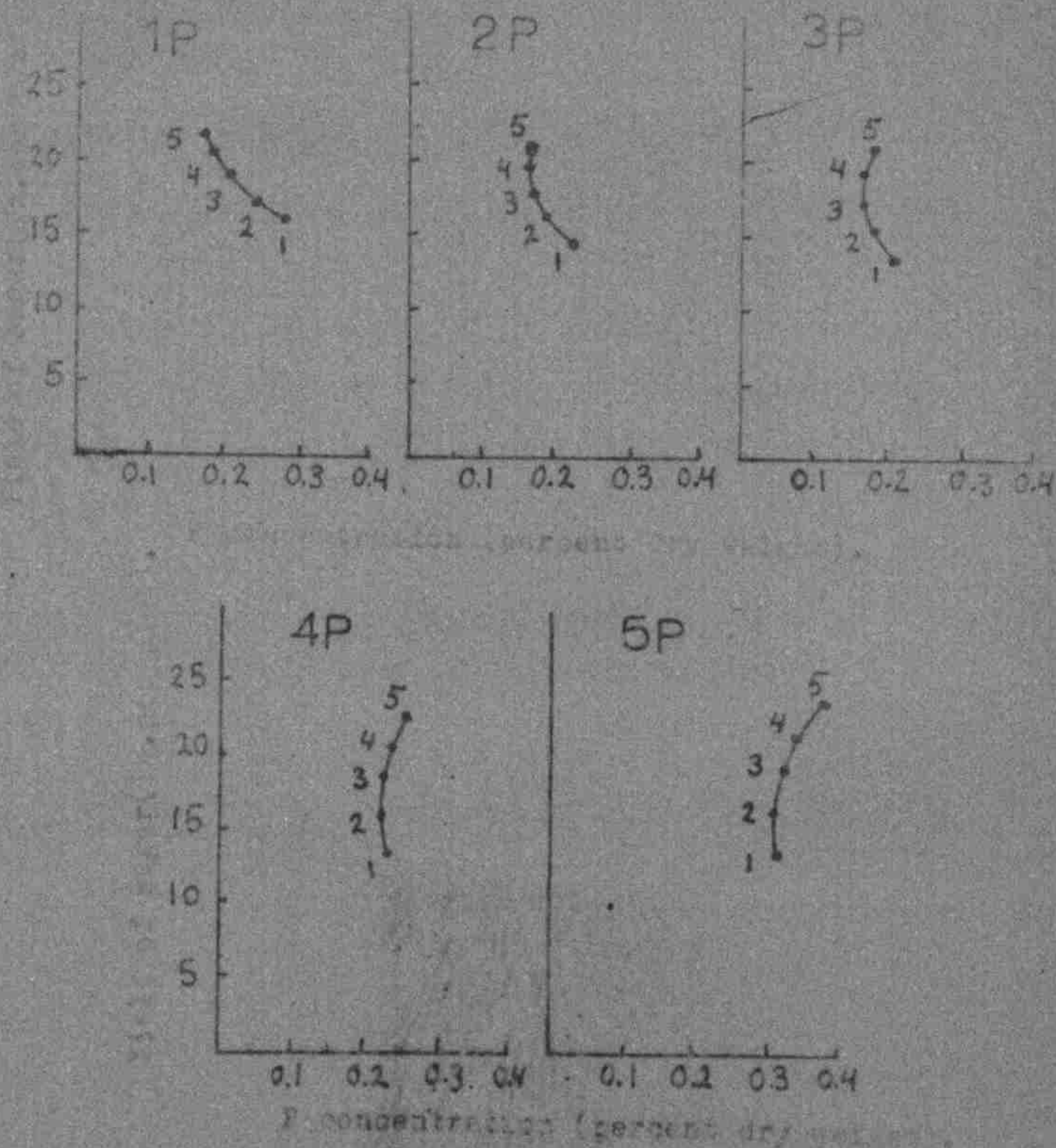


[illegible] Relationship between yield of [illegible] with P concentration (percent [illegible]) as affected by addition of different [illegible] P and N with K, Mg and Ca held [illegible] middle of five levels (Table 1). [illegible] points refer to levels of N added. [illegible] was held constant for each graph.

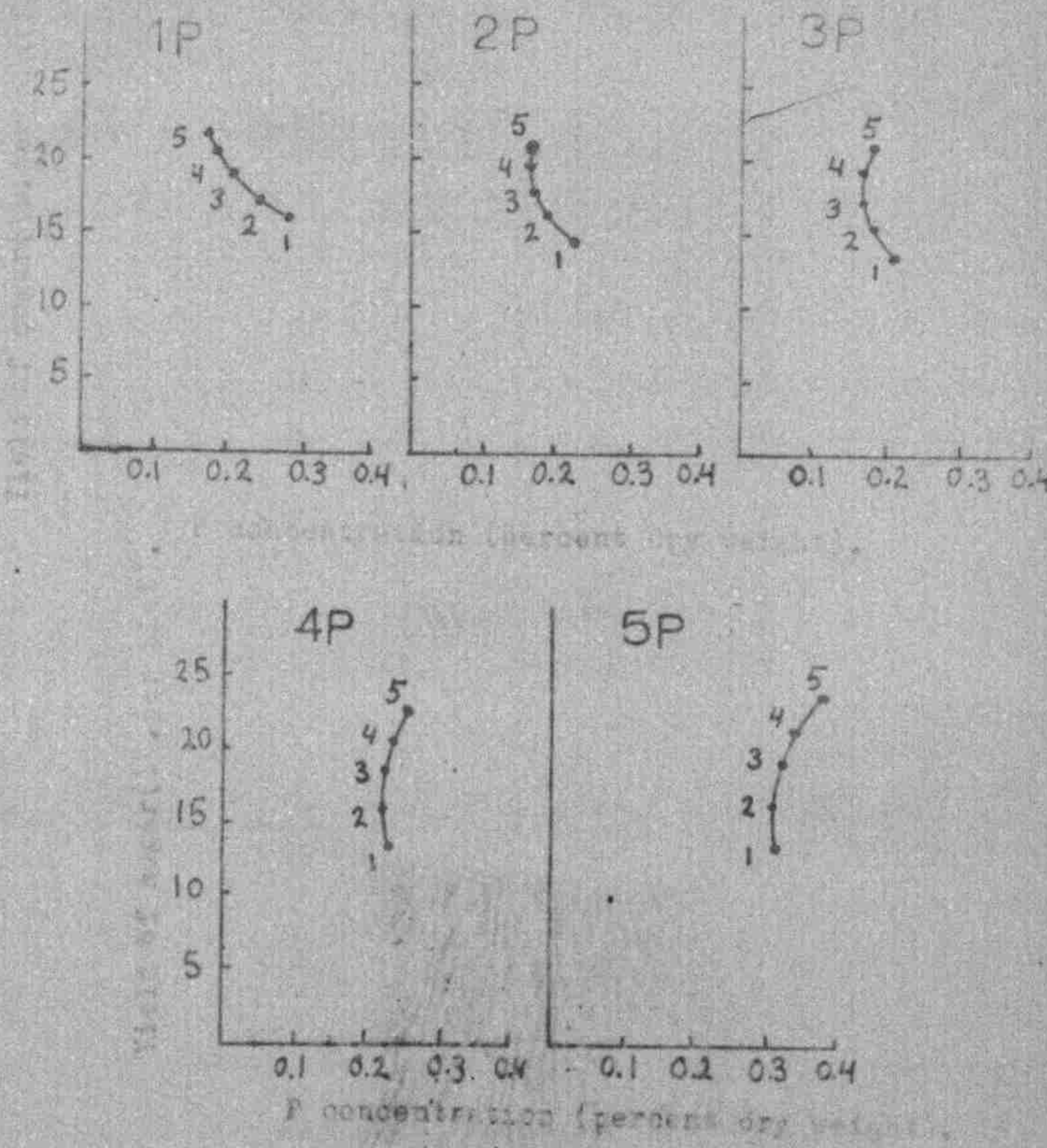


FIGURE [illegible]. Relationship between yield of [illegible] plot) with P concentration (percent [illegible]) as affected by addition of different levels of P and N with K, Mg and Ca held constant at the middle of five levels (Table 1). [illegible] points refer to levels of N added. Level of P was held constant for each group.

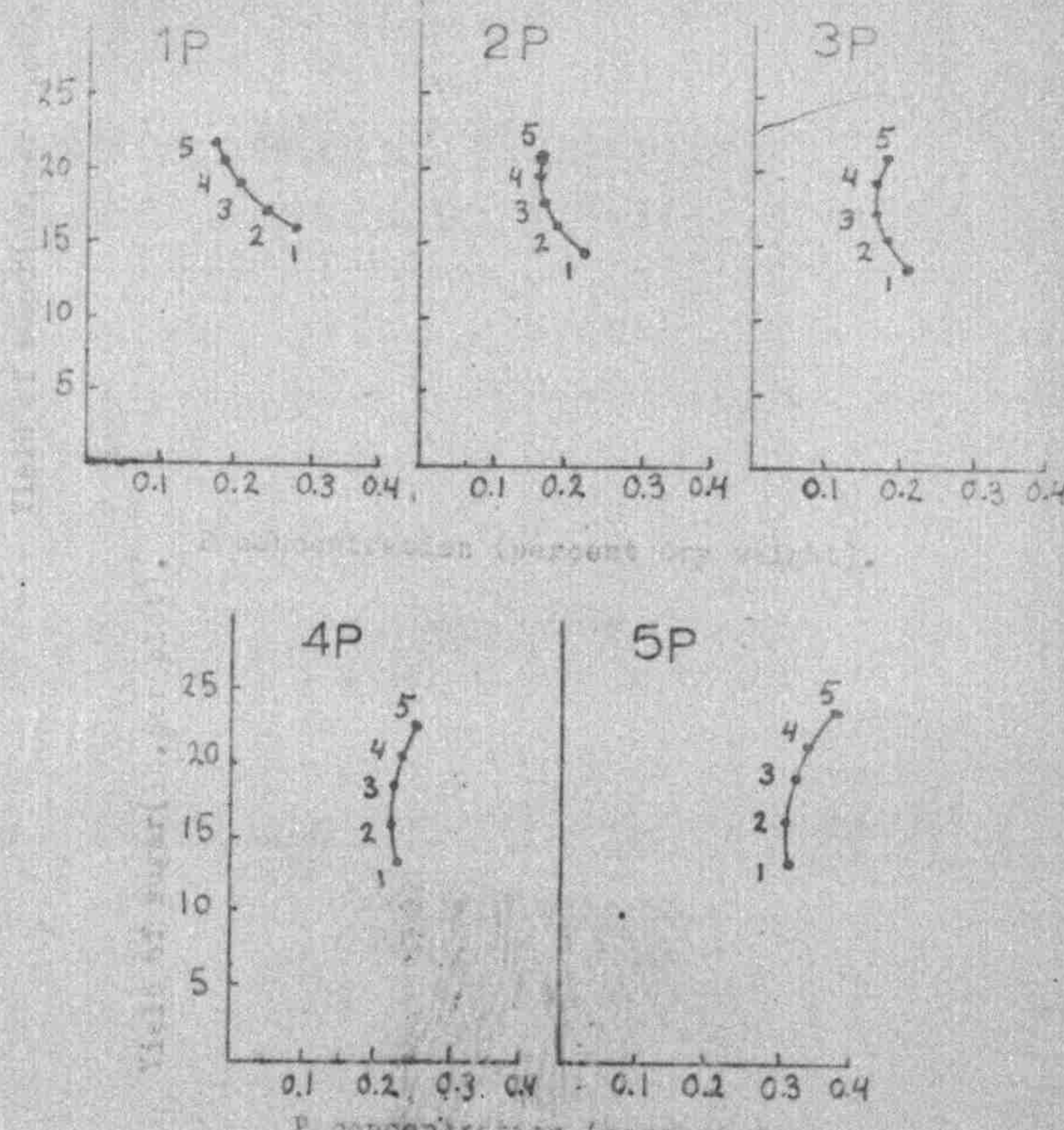


Figure [illegible]. Relationship between yield [illegible] plot) with P concentration (percent [illegible]) as affected by addition of different levels of P and N with K, Mg and Ca held [illegible] middle of five levels (Table 1). [illegible] Numbers by points refer to levels of N added. [illegible] was held constant for each group.

that the yield of sugar was increased with increasing N application at all levels of P but the increase was greater at the higher P levels. When the N level was held constant (Fig. 29), the tendency for the first 2 or 3 increments of P was to depress the P concentration while further increments of P increased the P concentration. The magnitude of the depression was reduced and the increasing effect was more as the N level was increased. The yield of sugar tended to be depressed by increasing P applications. No definite critical level for the P concentration was observed.

Potassium Concentration of Beet Tops

The correlation coefficient between K concentrations of beet tops and the K concentrations calculated from the regression equation (Table 22) was 0.849 indicating a close fit of the regression equation to the observed data.

The analysis of variance for K concentrations of beet leaves (Table 23) indicated that the linear and quadratic effects were significant. The lack of fit term was also significant indicating the possible need for a higher order equation.

Examination of the regression coefficients for linear and quadratic effects indicated that the negative N effect, the positive Mg^2 effect, and the negative Mg-K interaction were significant. The negative Na linear effect was highly significant.

The relationship between K content and yield of sugar as affected

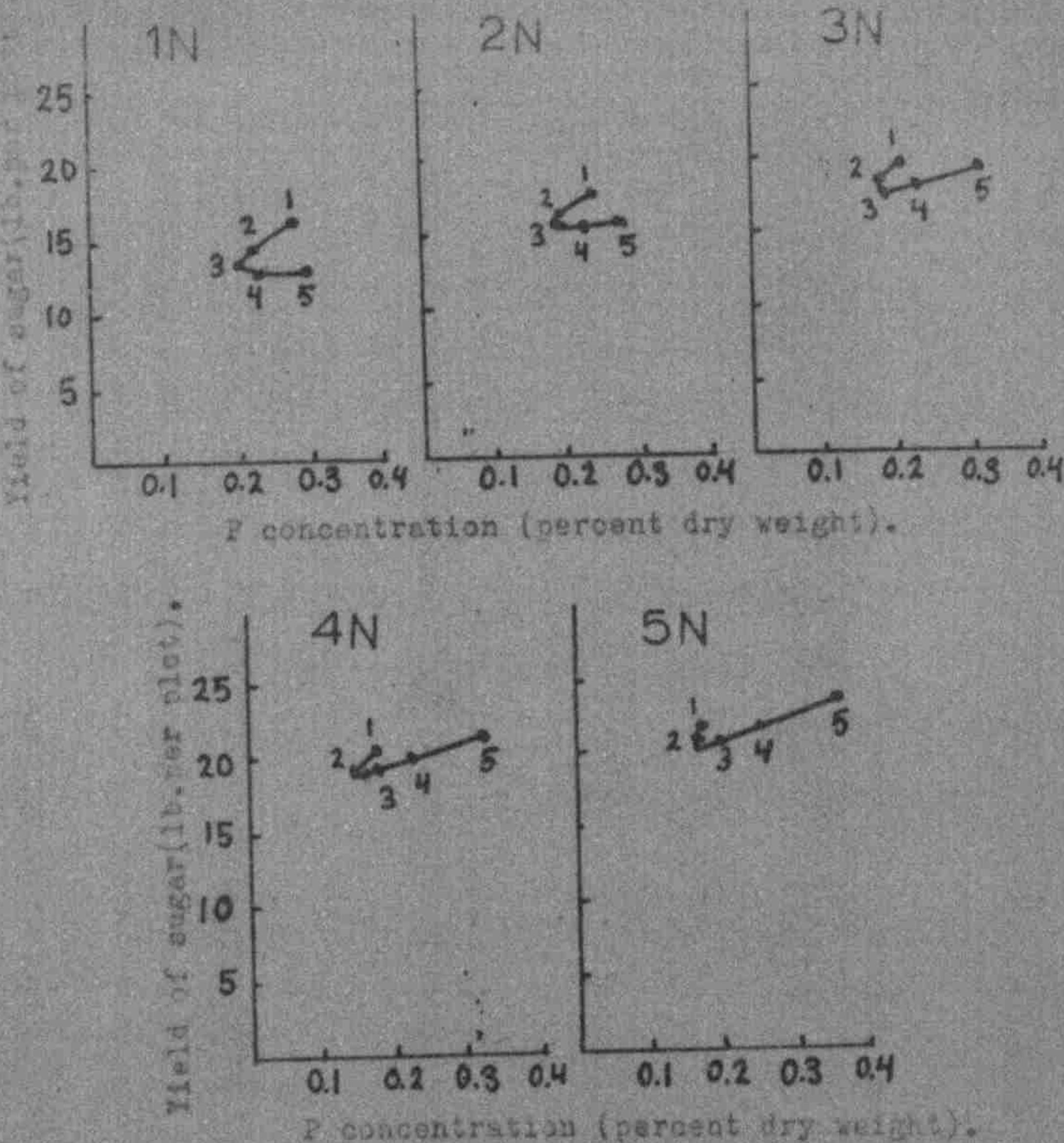
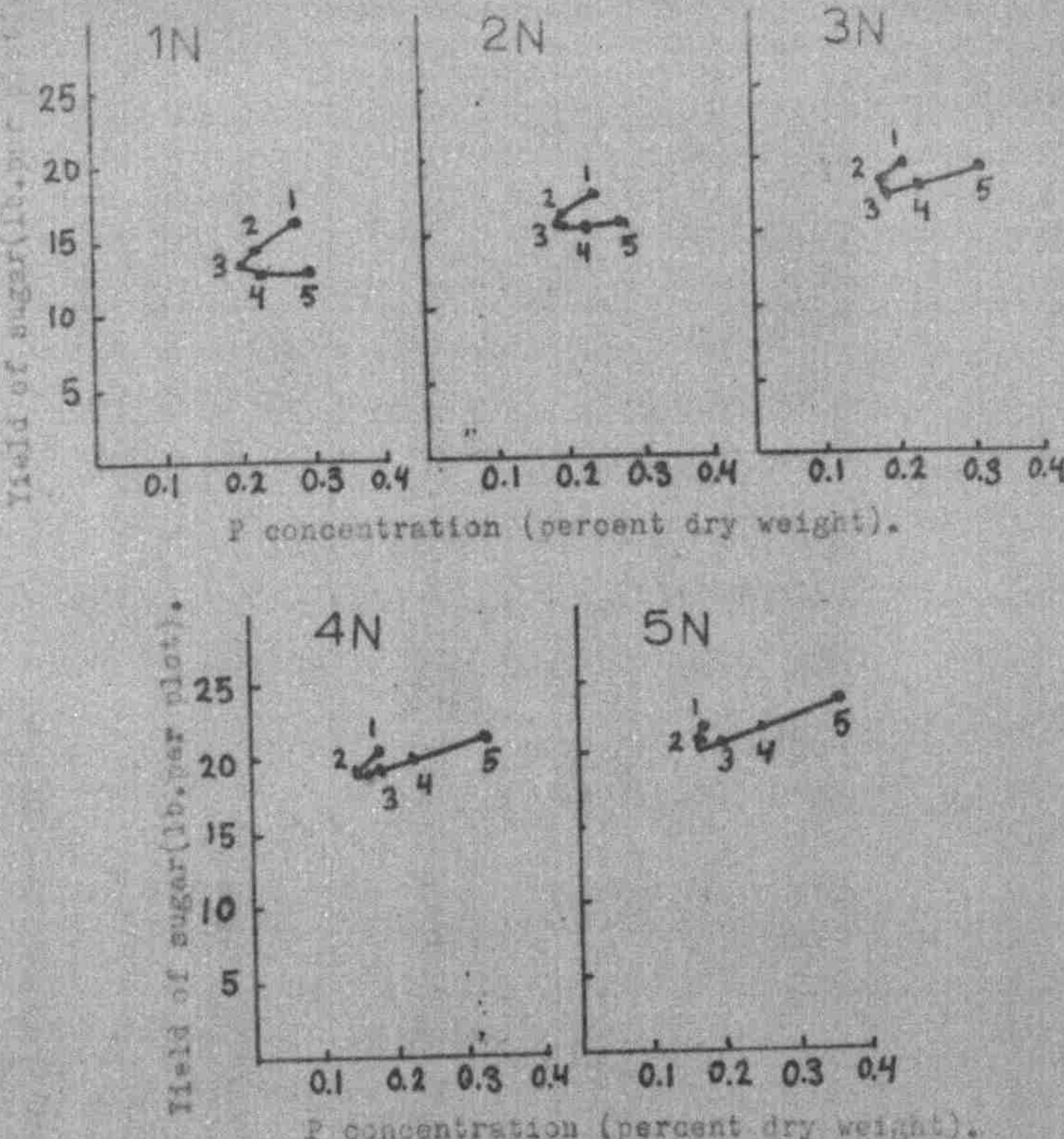


Figure 29. Relationship between yield of sugar (lb. per plot) and P concentration (percent dry weight) as affected by addition of different levels of N and P with K, Mg and Na held constant at the middle of five levels (Table 1). Numbers at points refer to level of P added. Level of N was held constant for each graph.



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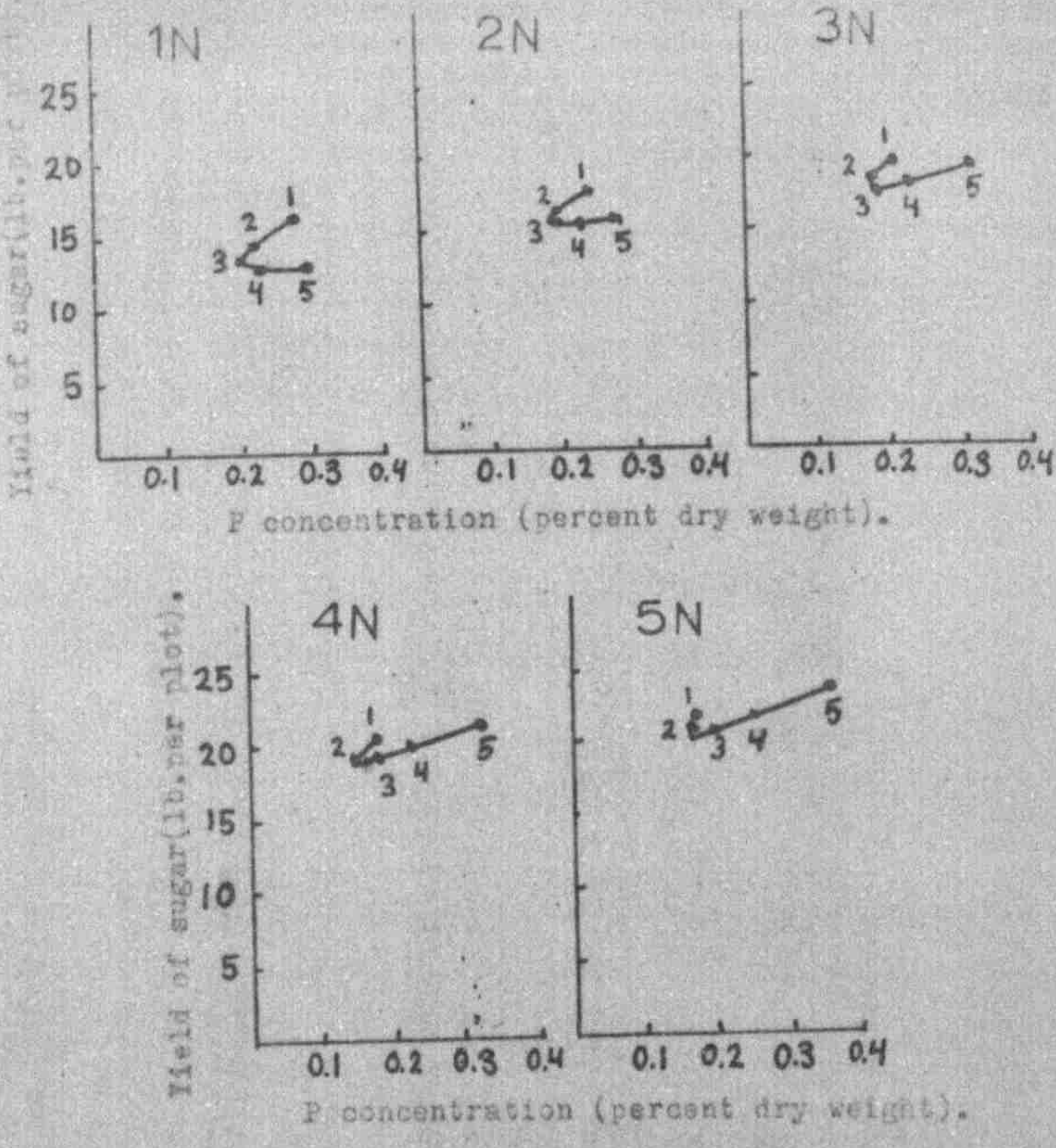

Figure 29. Relationship between yield of sugar (lb. per plot) and P concentration (percent dry weight) as affected by addition of different levels of N and P with K, Mg and Na held constant at the middle of five levels (Table 1). Numbers at points refer to level of P added. Level of N was held constant for each graph.

Table 22. Observed K concentration of beet tops (percent dry weight) as affected by various levels of N, P, K, Mg and Na. Potassium concentrations for the same treatments calculated from the regression equation are given. Correlation of actual K concentrations with calculated K concentrations was 0.849.

Treatment levels N	P	K	Mg	Na	Actual K concentration percent	Calculated K concentration percent
2	2	2	2	4	4.259	4.280
4	2	2	2	2	5.670	4.895
2	4	2	2	2	6.989	6.560
4	4	2	2	4	5.248	4.768
2	2	4	2	2	6.990	6.564
4	2	4	2	4	6.225	5.748
2	4	4	2	4	6.082	5.952
4	4	4	2	2	8.469	7.540
2	2	2	4	2	9.308	9.178
4	2	2	4	4	5.527	5.342
2	4	2	4	4	6.000	6.166
4	4	2	4	2	5.911	5.278
2	2	4	4	4	4.970	5.138
4	2	4	4	2	6.048	5.418
2	4	4	4	2	7.090	6.810
4	4	4	4	4	4.953	4.480
5	3	3	3	3	2.722	4.252
1	3	3	3	3	6.187	6.012
3	5	3	3	3	4.735	5.566
3	1	3	3	3	4.760	5.282
3	3	5	3	3	5.679	6.502
3	3	1	3	3	5.643	6.170
3	3	3	5	3	6.817	7.082
3	3	3	1	3	5.519	6.670
3	3	3	3	5	4.239	4.170
3	3	3	3	1	5.303	6.538
3	3	3	3	3	5.384	5.636
3	3	3	3	3	5.197	5.636
3	3	3	3	3	5.924	5.636
3	3	3	3	3	6.518	5.636
3	3	3	3	3	6.710	5.636
3	3	3	3	3	5.500	5.636

Table 23. Analysis of variance for K concentration of beet tops (percent dry weight).

Source	d. f.	S. S.	M. S.	F value
Linear effect	5	14.991	2.998	7.67*
Quadratic effect	15	15.740	1.949	4.98*
Lack of fit	6	13.422	2.237	6.72*
Experimental error	5	1.954	0.391	
Total	31	46.107		

* Significant at odds of 19:1

Table 24. Regression coefficients (b) and their standard errors (s_b) for K concentration of beet tops (percent dry weight).

Coefficient		b		s_b
Mean	b_0	5.636		± 2.350
N	b_1	-0.440	*	± 0.127
P	b_2	+ 0.071		"
K	b_3	+ 0.083		"
Mg	b_4	+ 0.103		"
Na	b_5	- 0.639	**	"
N^2	b_{11}	- 0.126		± 0.115
P^2	b_{22}	- 0.053		"
K^2	b_{33}	+ 0.175		"
Mg^2	b_{44}	+ 0.306	*	"
Na^2	b_{55}	- 0.047		"
N-P	b_{12}	+ 0.030		± 0.156
N-K	b_{13}	+ 0.298		"
N-Mg	b_{14}	- 0.389		"
N-Na	b_{15}	+ 0.308		"
P-K	b_{23}	+ 0.186		"
P-Mg	b_{24}	- 0.346		"
P-Na	b_{25}	+ 0.054		"
K-Mg	b_{34}	- 0.580	*	"
K-Na	b_{35}	+ 0.030		"
Mg-Na	b_{45}	- 0.038		"

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

by K application at each of five levels of Mg (Fig. 30) revealed that at low Mg levels yield of sugar and K concentration were increased with increasing K application, whereas at the high Mg levels the K concentration and yield tended to be decreased with K application. When the K level was held constant (Fig. 31), increasing the Mg applications resulted in increasing yield and K concentration at low levels of K and decreasing yield and K concentration at high levels of K.

Examination of the K content and yield of sugar relationships as affected by the N-Mg interaction indicated that when the N level was held constant (Fig. 32) at the 1N and 2N levels, the Mg application resulted in considerable increase of K content while yield of sugar was not seriously affected (luxury consumption). At the 3N, 4N and 5N levels, the yield of sugar was increased and the K concentration was decreased with increasing Mg applications. When the supply of Mg was held constant (Fig. 33) at the 1Mg level, the K concentration was increased with increasing N application. As the Mg level was increased the tendency was for N application to decrease the K content. No definite critical level of K in beet leaves could be established since high yields of sugar were obtained at K concentrations from 3.5 to 9.5 percent.

Magnesium Concentration of Beet Tops

The correlation coefficient between the observed Mg concentrations and Mg concentrations calculated from the regression equation was 0.711 (Table 24) indicating a good fit of the regression equation to the actual data.

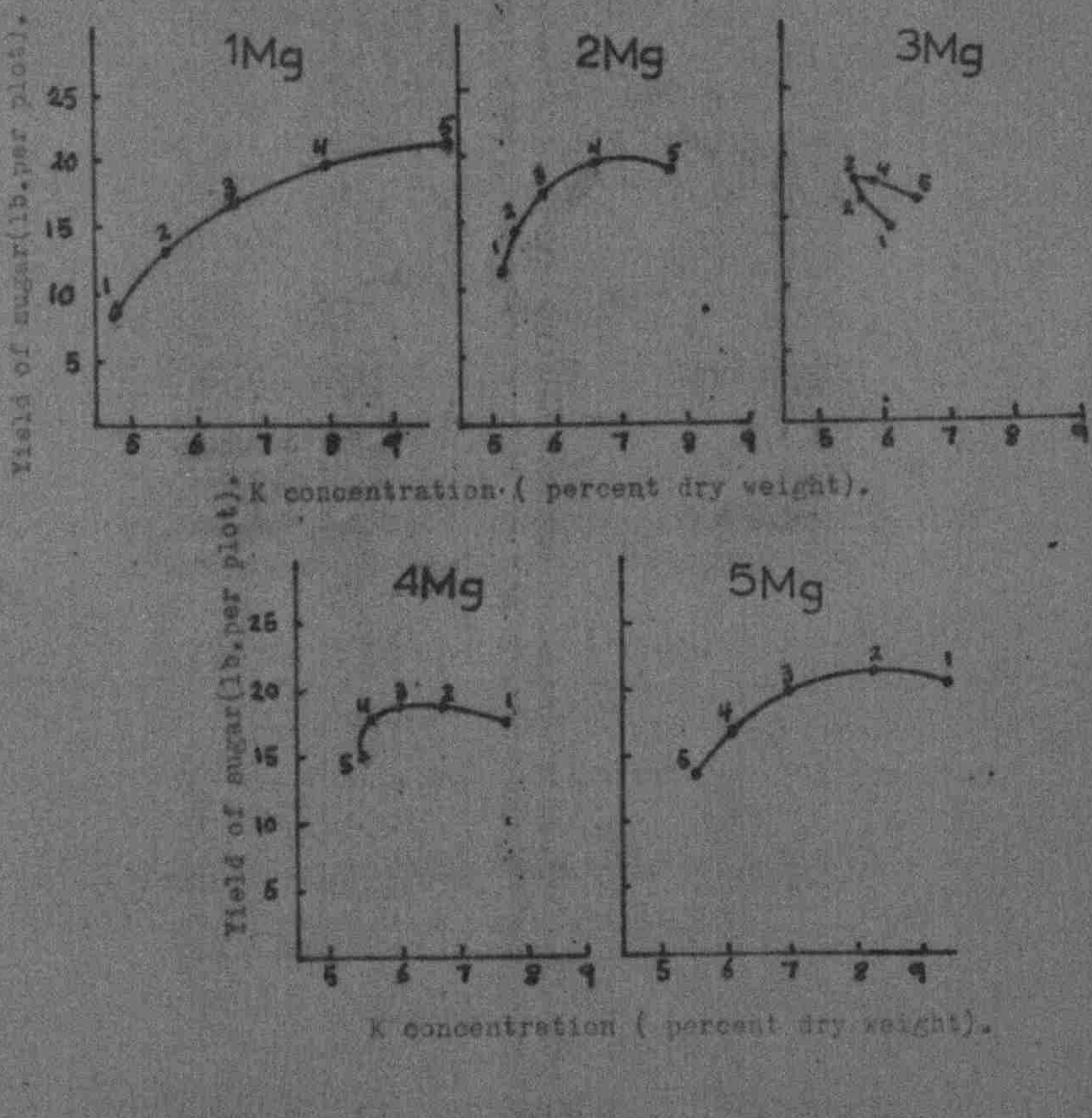

Figure 30. Relationship between yield of sugar (lb. per plot) and K concentration (percent dry weight) as affected by addition of different levels of Mg and K with N, P, and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of K added. Level of Mg was constant for each graph.

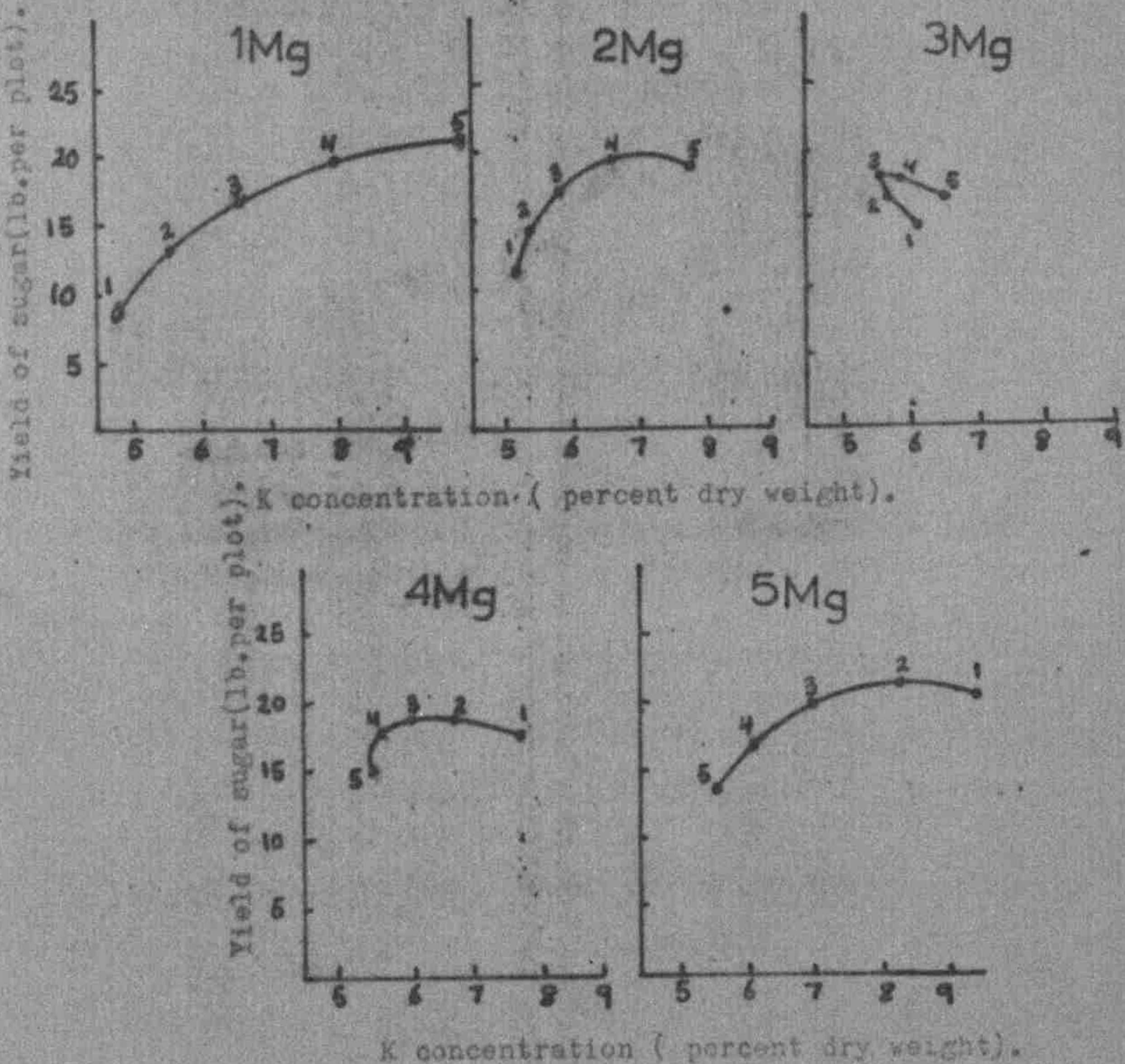

Figure 30. Relationship between yield of sugar (lb. per plot) and K concentration (percent dry weight) as affected by addition of different levels of Mg and K with N, P, and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of K added. Level of Mg was held constant for each graph.

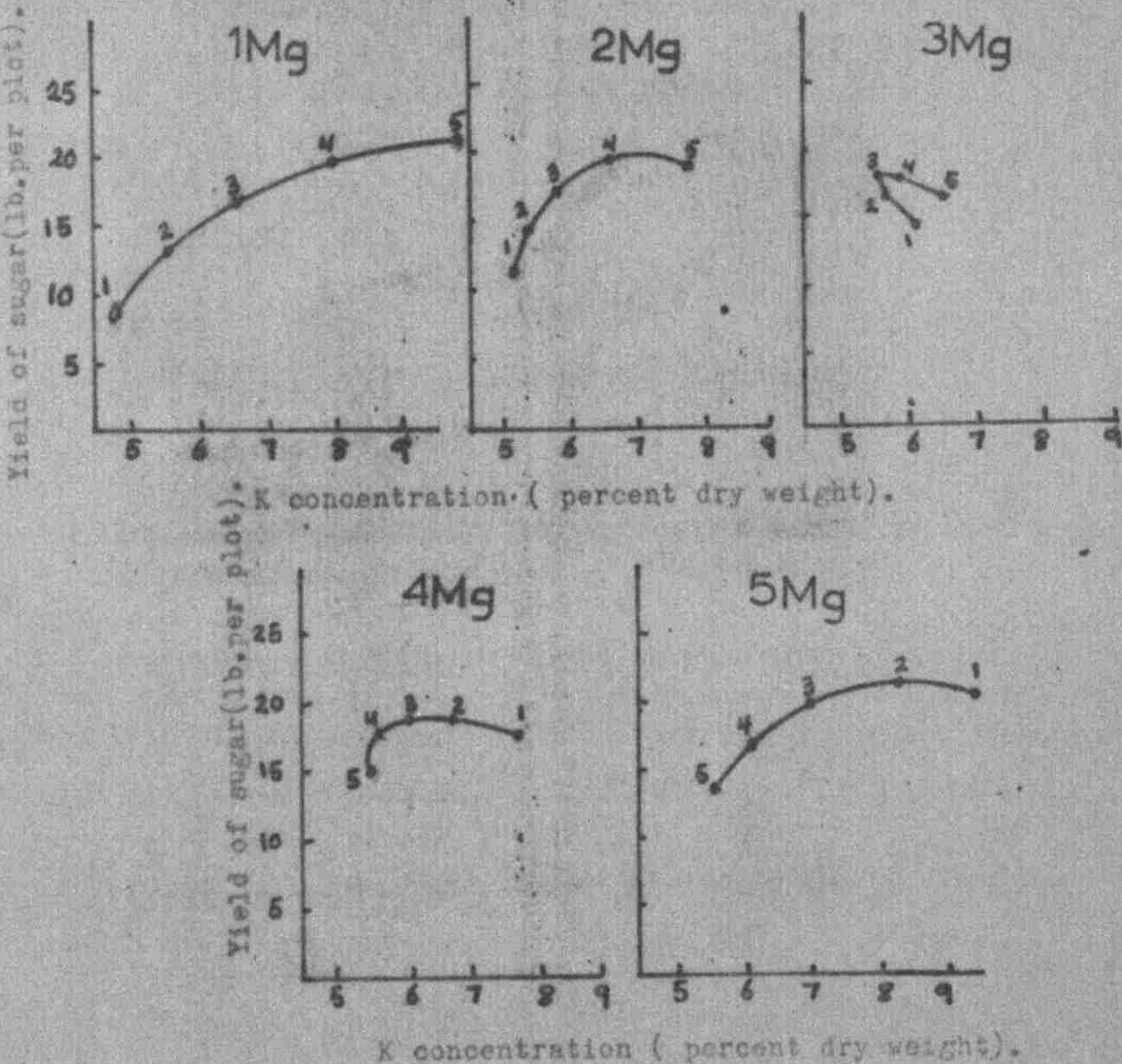

Figure 30. Relationship between yield of sugar (lb. per plot) and K concentration (percent dry weight) as affected by addition of different levels of Mg and K with N, P, and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of K added. Level of Mg was held constant for each graph.

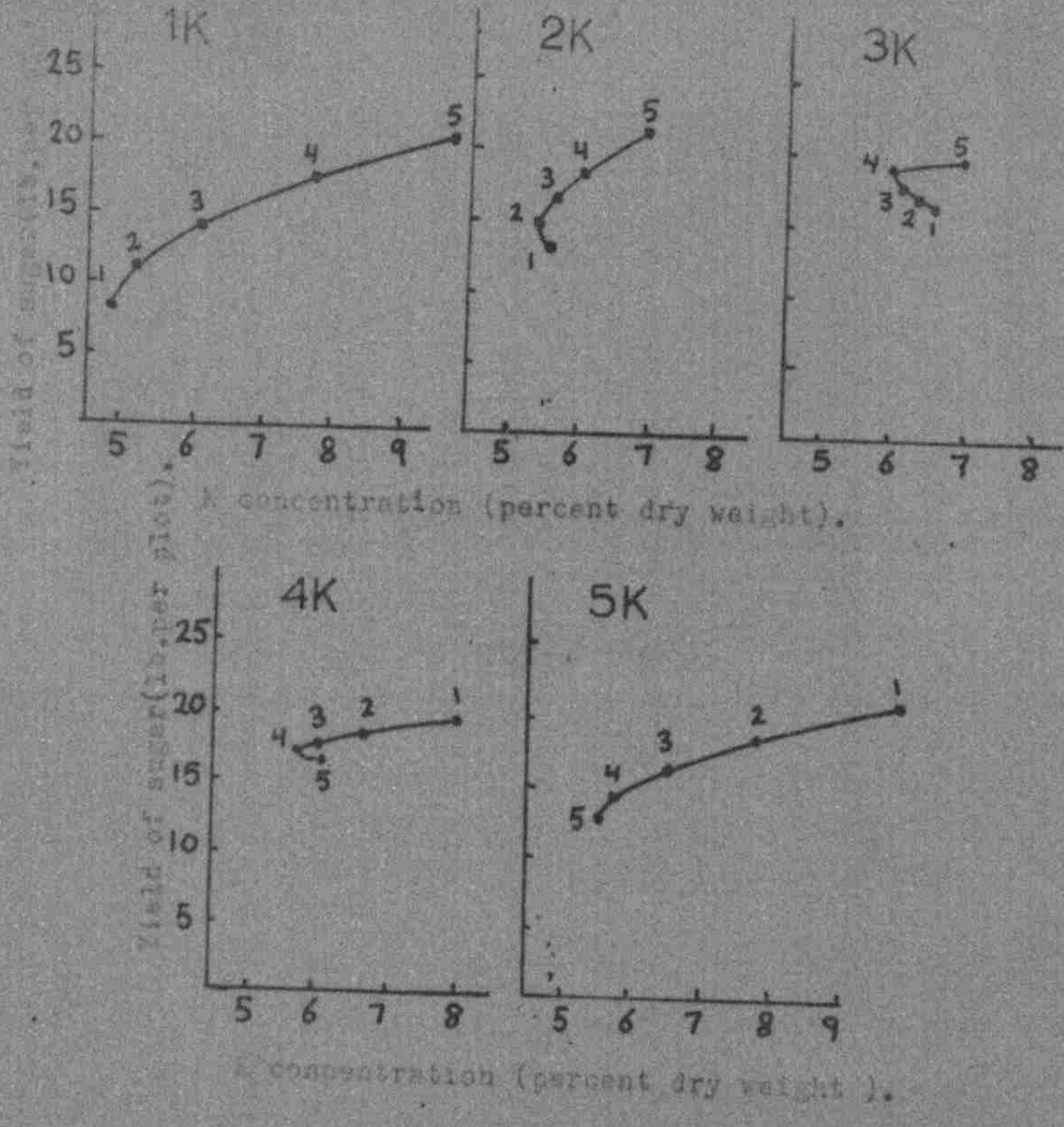

Figure 31. Relationship between yield of sugar (lb. per plot) and K concentration (percent dry weight) as affected by addition of different levels of K and Mg with N, P and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of Mg added. Level of K was held constant for each graph.

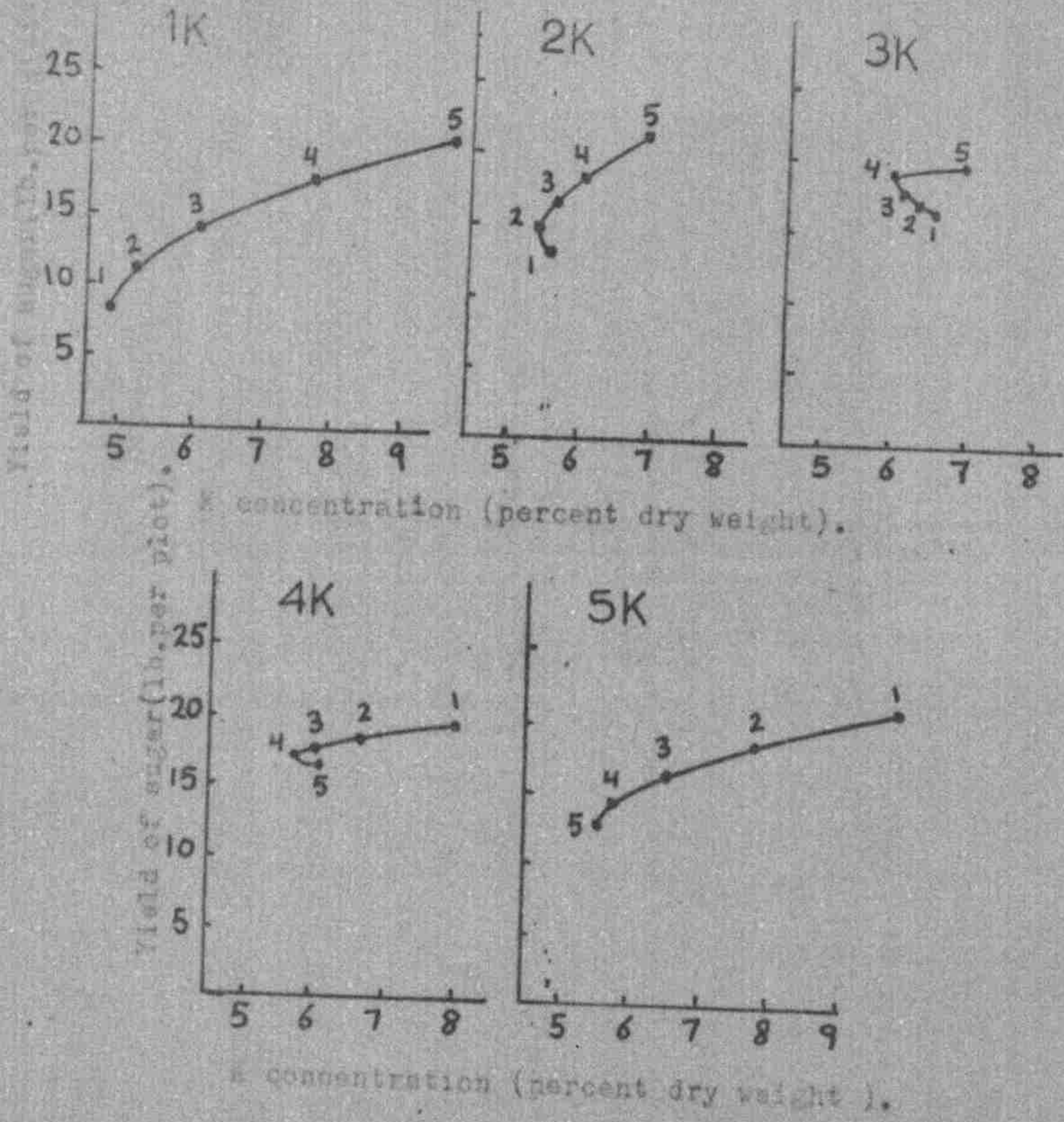

Figure 71. Relationship between yield of sugar (lb. per plot) and K concentration (percent dry weight) as affected by addition of different levels of K and Mg with N, P and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of Mg added. Level of K was held constant for each graph.

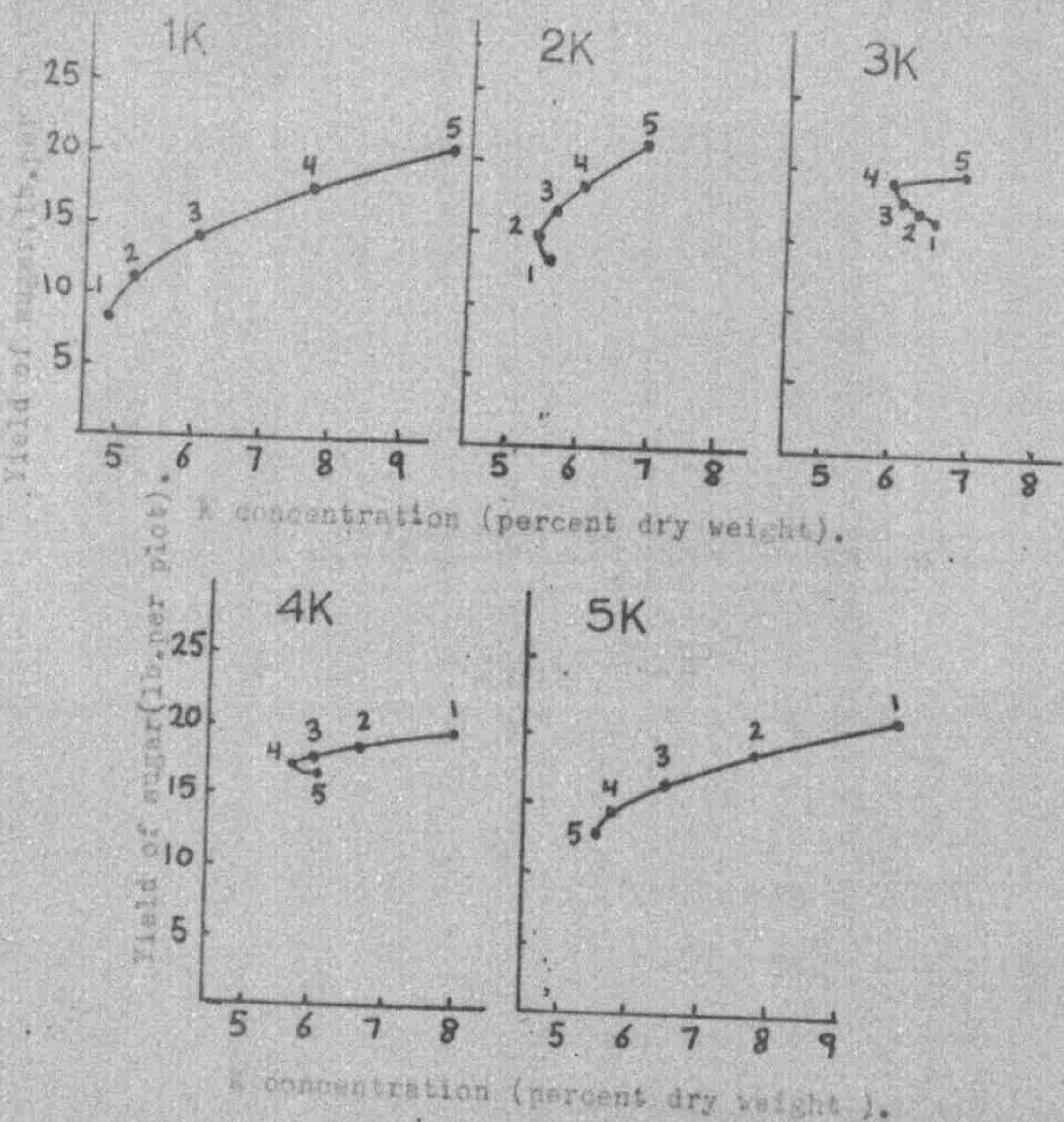

Figure 31. Relationship between yield of sugar (lb. per plot) and K concentration (percent dry weight) as affected by addition of different levels of K and Mg with N, P and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of Mg added. Level of K was held constant for each graph.

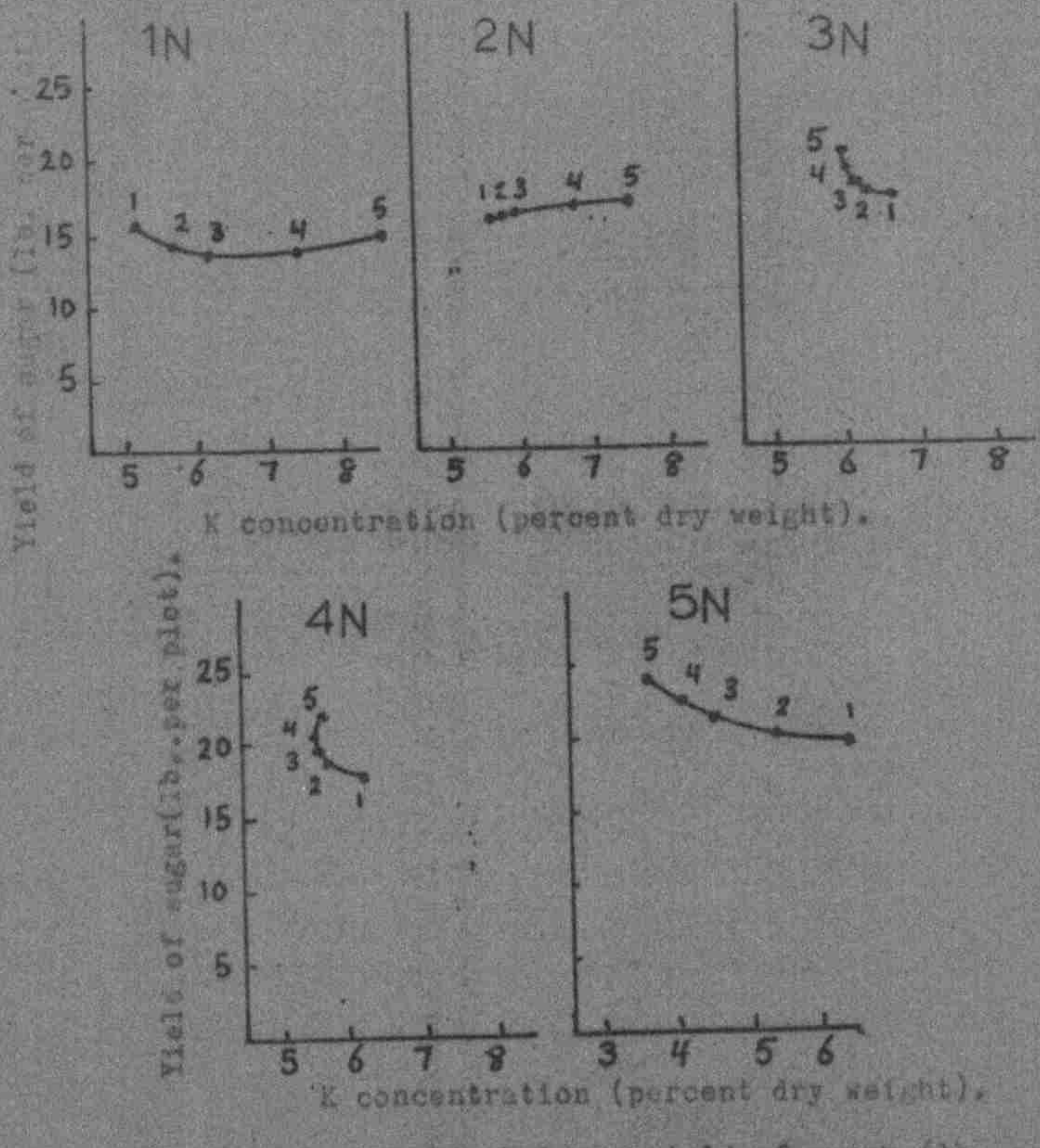

Figure 32. Relationship between yield of sugar (lb. per plot) and K concentration (percent dry weight) as affected by addition of different levels of Mg and N with P,K and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of Mg added. Level of N was held constant for each graph.

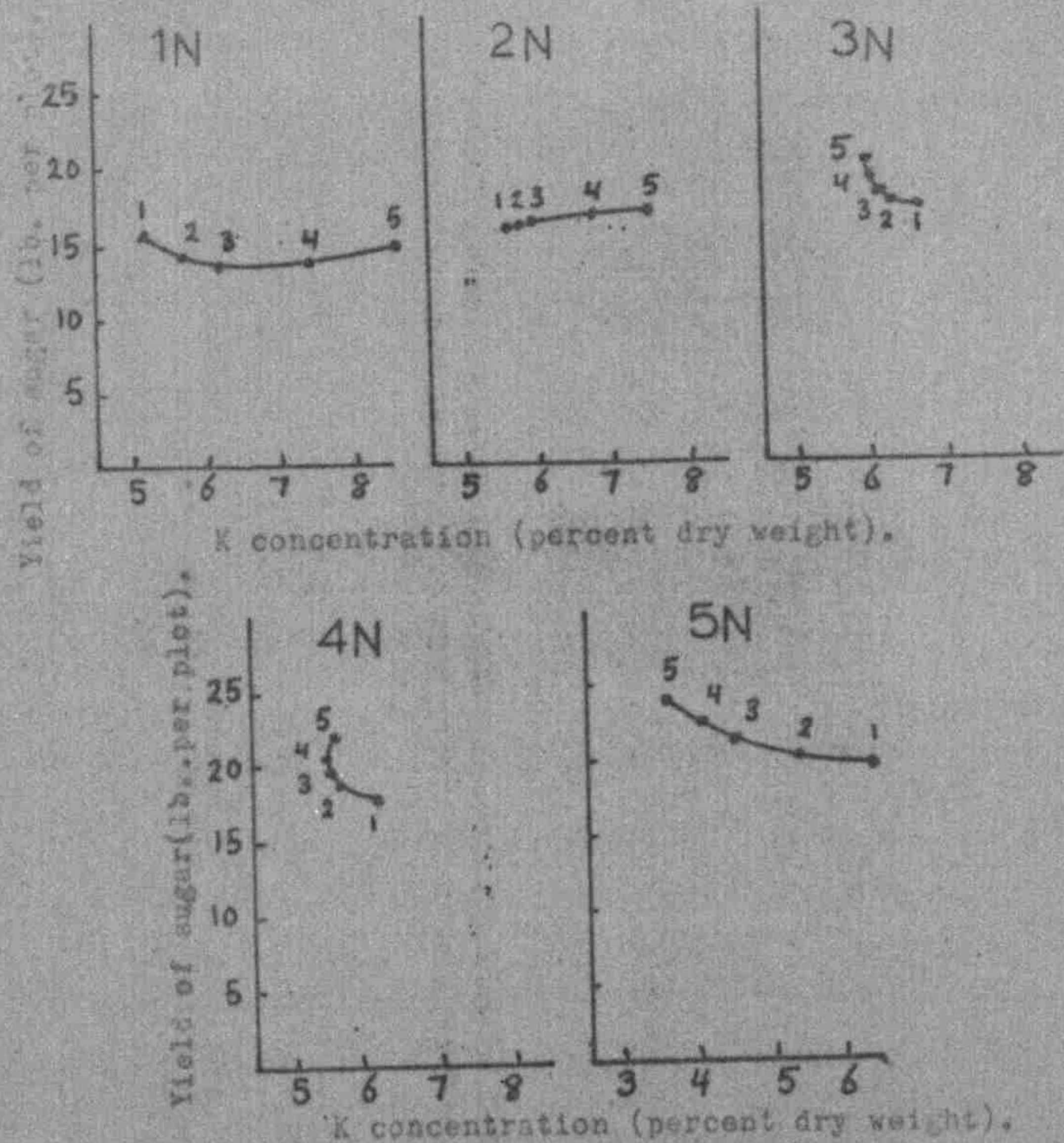

Figure 32. Relationship between yield of sugar (lb. per plot) and K concentration (percent dry weight) as affected by addition of different levels of Mg and N with P,K and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of Mg added. Level of N was held constant for each graph.

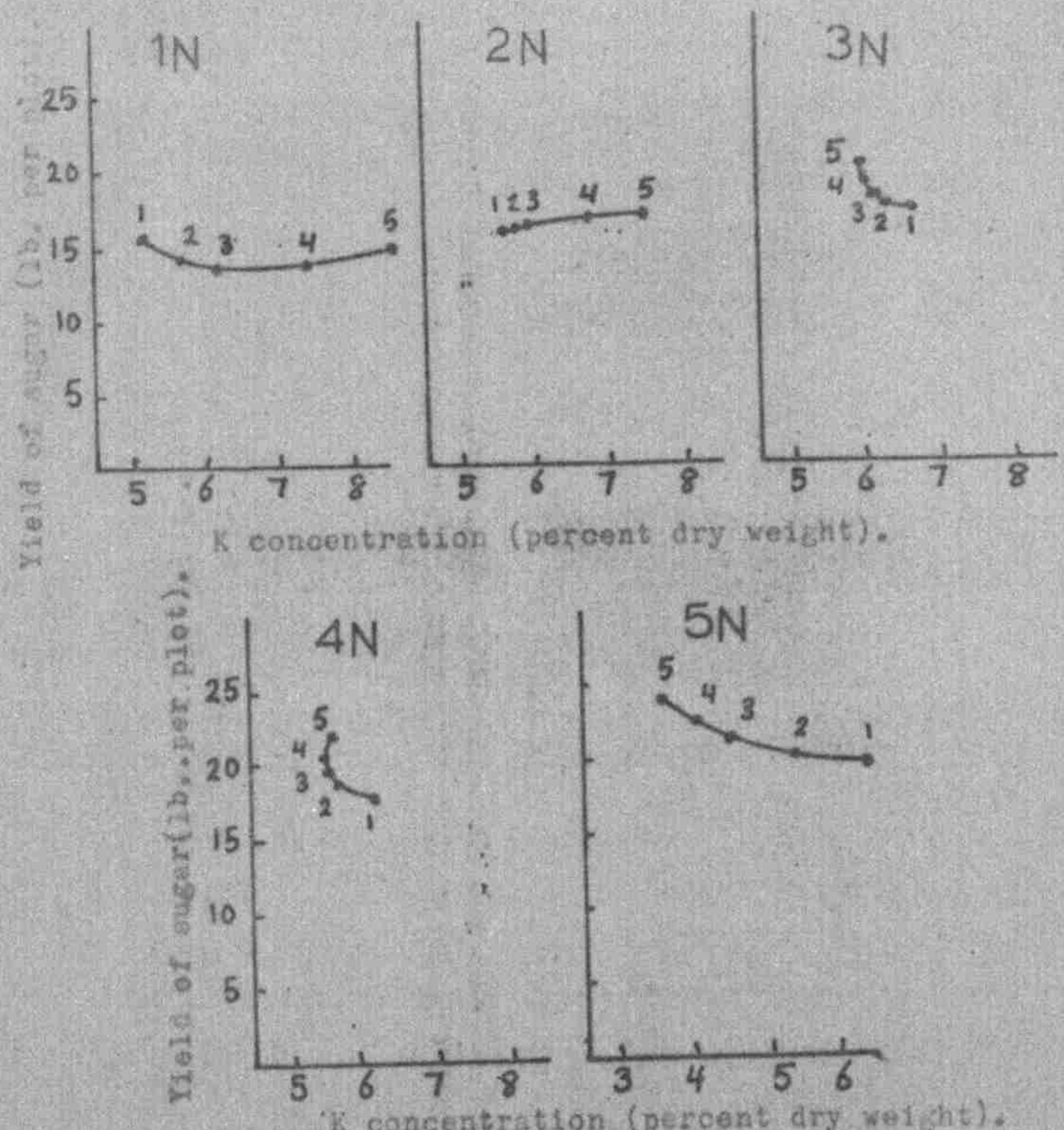

Figure 32. Relationship between yield of sugar (lb. per plot) and K concentration (percent dry weight) as affected by addition of different levels of Mg and N with P, K and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of Mg added. Level of N was held constant for each graph.

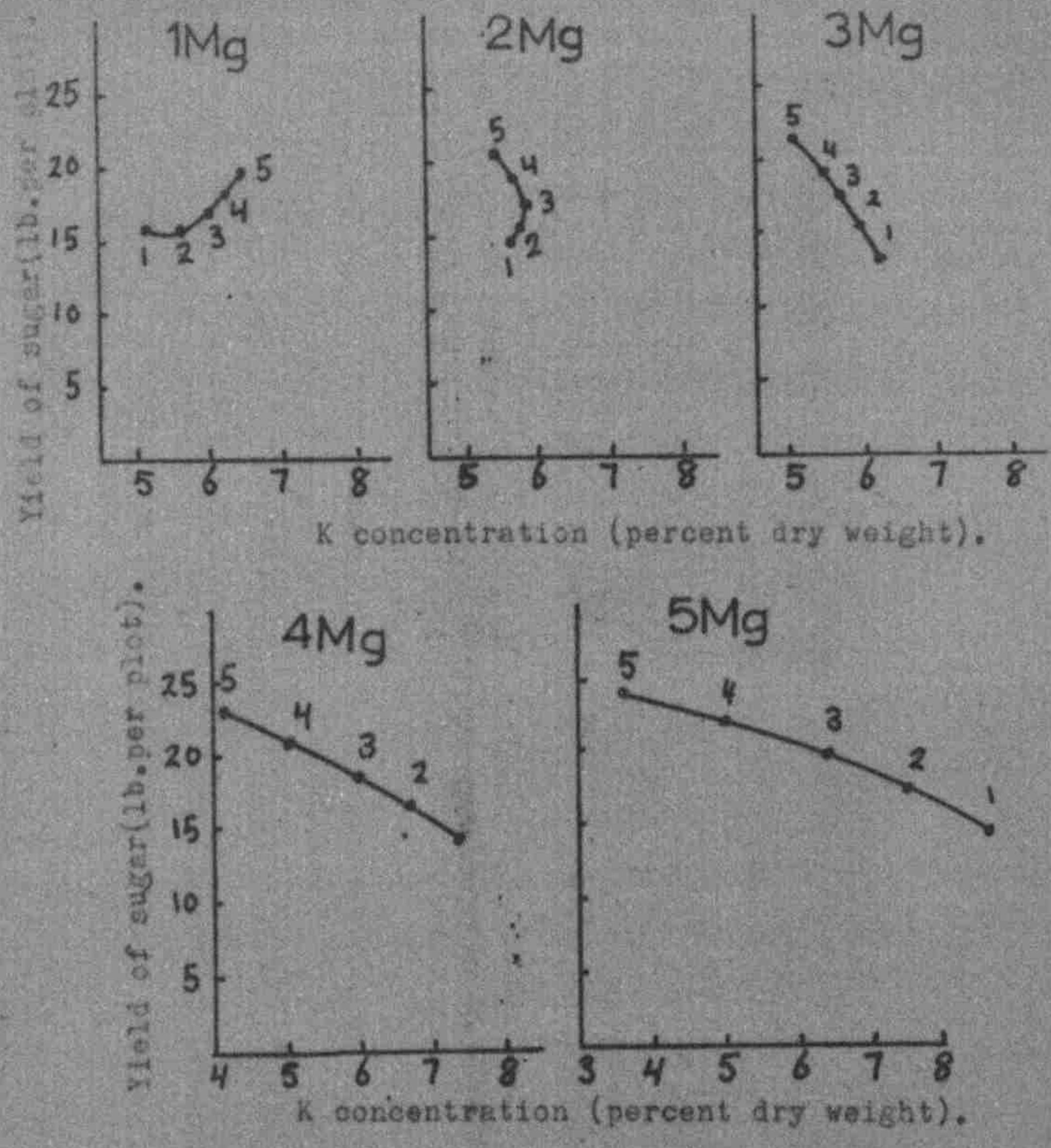

Figure 33. Relationship between yield of sugar (lb. per plot) and K concentration (percent dry weight) as affected by addition of different levels of N and Mg with P, K and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of N added. Level of Mg was held constant for each graph.

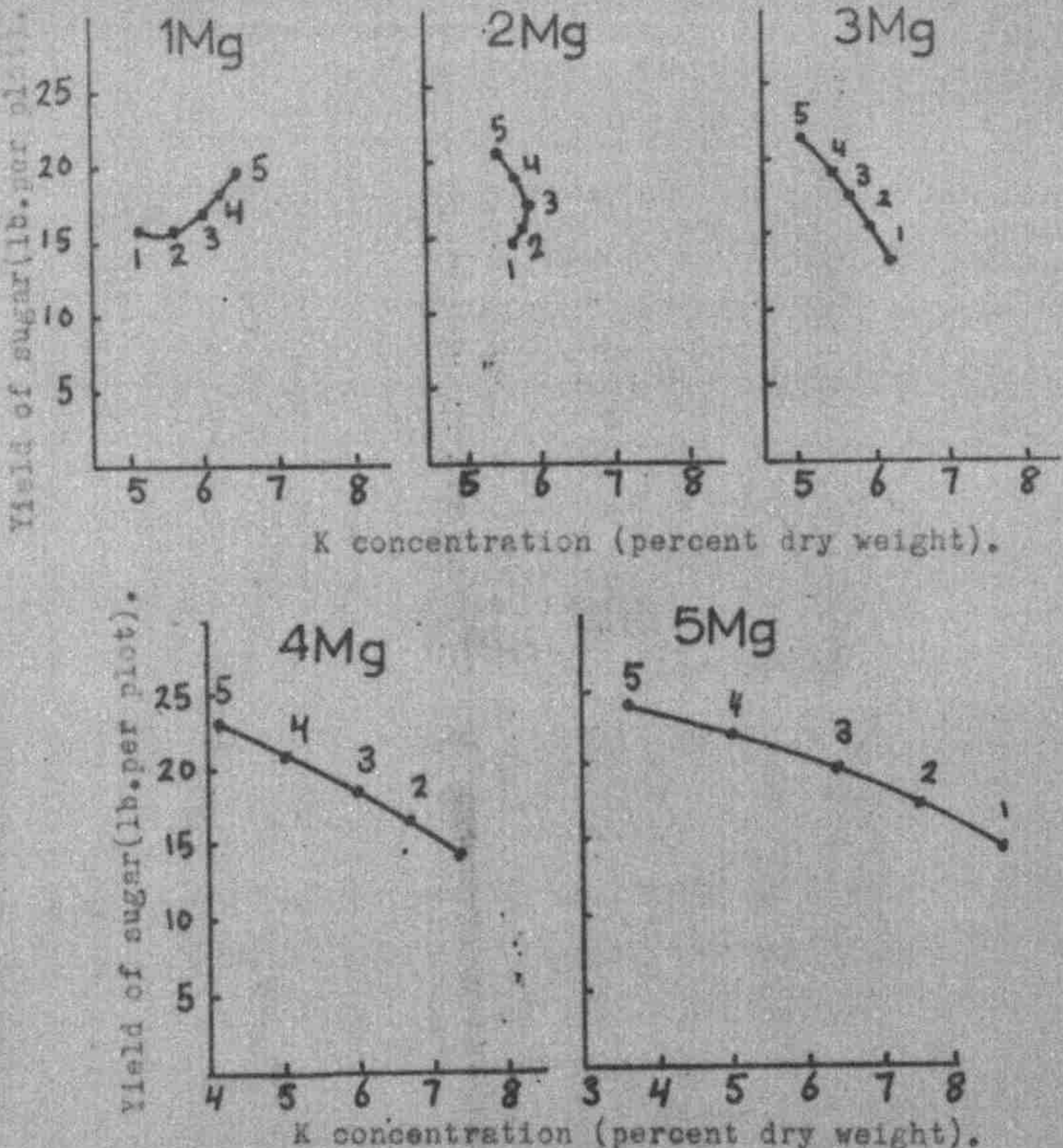

Figure 33. Relationship between yield of sugar (lb. per plot) and K concentration (percent dry weight) as affected by addition of different levels of N and Mg with P, K and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of N added. Level of Mg was held constant for each graph.

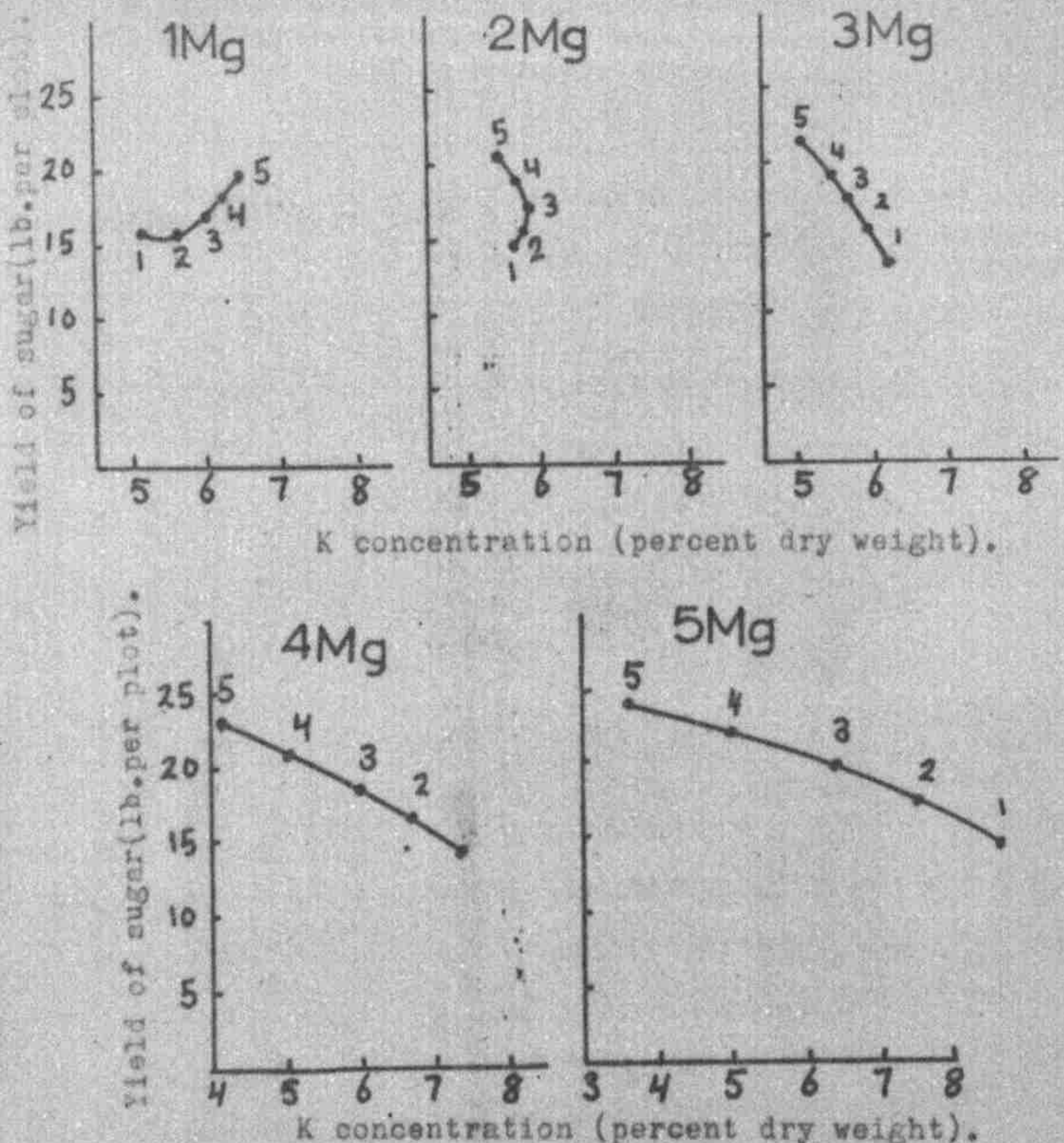

Figure 33. Relationship between yield of sugar (lb. per plot) and K concentration (percent dry weight) as affected by addition of different levels of N and Mg with P, K and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of N added. Level of Mg was held constant for each graph.

Table 25. Observed Mg concentration of beet tops (percent dry weight) as affected by various levels of N, P, K, Mg and Na. Magnesium concentrations for the same treatments calculated from the regression equation are given. Correlations of actual Mg concentrations with calculated Mg concentrations was 0.711.

Treatment Levels N	P	K	Mg	Na	Actual Mg concentrations percent	Calculated Mg concentrations percent
2	2	2	2	4	.792	.858
4	2	2	2	2	.885	.905
2	4	2	2	2	.802	.660
4	4	2	2	4	.733	.722
2	2	4	2	2	.640	.536
4	2	4	2	4	.206	.234
2	4	4	2	4	.694	.498
4	4	4	2	2	2.267	2.088
2	2	2	4	2	.755	.778
4	2	2	4	4	.574	.552
2	4	2	4	4	.864	.882
4	4	2	4	2	1.078	1.016
2	2	4	4	4	.974	.923
4	2	4	4	2	1.059	1.036
2	4	4	4	2	.981	.932
4	4	4	4	4	1.091	1.074
5	3	3	3	3	1.143	1.153
1	3	3	3	3	.645	.757
3	5	3	3	3	.763	1.023
3	1	3	3	3	.706	.567
3	3	5	3	3	.704	.885
3	3	1	3	3	.705	.649
3	3	3	5	3	1.125	1.079
3	3	3	1	3	;707	.879
3	3	3	3	5	.682	.533
3	3	3	3	1	.676	.953
3	3	3	3	3	.741	0.759
3	3	3	3	3	.886	0.759
3	3	3	3	3	.729	0.759
3	3	3	3	3	.644	0.759
3	3	3	3	3	.825	0.759
3	3	3	3	3	.850	0.759

The analysis of variance for Mg concentration (Table 25) indicated that both linear and quadratic effects were highly significant. The lack of fit term was significant indicating the possible need for a higher order equation.

Examination of the regression coefficients for Mg concentration (Table 26) indicated that the highly significant linear effects of N, P, and Na were positive, whereas the highly significant quadratic effects N-P, P-K and Mg-Na were antagonistic, and the highly significant quadratic effects N-Na was complementary. The significant linear K effect was positive and the significant quadratic N-K effect was antagonistic whereas the significant N-Mg, P-Mg, P-Na and K-Na effects were complementary.

Determination of the relationship between Mg content and yield of sugar as affected by N application at each of five levels of Na (Fig. 34) indicated that the Mg concentration decreased with N application at low levels of Na and increased with N application at high levels of Na. The yield of sugar was increased with increasing N levels. The yield of sugar tended to decrease with Mg concentration below about 1.0 percent. When the N level was kept constant (Fig. 35) the Na applications considerably depressed the Mg content at low levels of N. However, the depression was less in magnitude as the N level was increased and at the 5N level, the Mg concentration was slightly increased with Na application. The yield of sugar was positively correlated with Mg content at the 1N and the 5N levels but not affected

Table 26. Analysis of variance for Mg concentration of beet tops (percent dry weight).

Source	d. f.	S. S.	M. S.	F value
Linear effect	5	0.957	0.191	23.63 * *
Quadratic effect	15	1.829	0.121	15.05 * *
Lack of fit	6	0.378	0.068	7.78 *
Experimental error	5	0.041	0.0081	
Total	31	3.205		

* Significant at odds of 19:1

* * Significant at odds of 99:1

Table 27. Regression coefficients(b) and their standard errors (s_b) for Mg concentration of beet tops (percent dry weight).

Coefficient		b	s_b
Mean	b_0	0.759	± 0.037
N	b_1	+ 0.099 **	± 0.0216
P	b_2	+ 0.114 **	"
K	b_3	+ 0.059 *	"
Mg	b_4	+ 0.050	"
Na	b_5	- 0.105 **	"
N^2	b_{11}	+ 0.049 *	± 0.0166
P^2	b_{22}	+ 0.009	"
K^2	b_{33}	+ 0.002	"
Mg^2	b_{44}	+ 0.055 *	"
Na^2	b_{55}	- 0.004	"
N-P	b_{12}	+ 0.142 **	± 0.0225
N-K	b_{13}	+ 0.080 *	"
N-Mg	b_{14}	- 0.058 *	"
N-Na	b_{15}	- 0.177 **	"
P-K	b_{23}	+ 0.105 **	"
P-Mg	b_{24}	- 0.083 *	"
P-Na	b_{25}	- 0.060 *	"
K-Mg	b_{34}	+ 0.015	"
K-Na	b_{35}	- 0.089 *	"
Mg-Na	b_{45}	+ 0.112 **	"

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

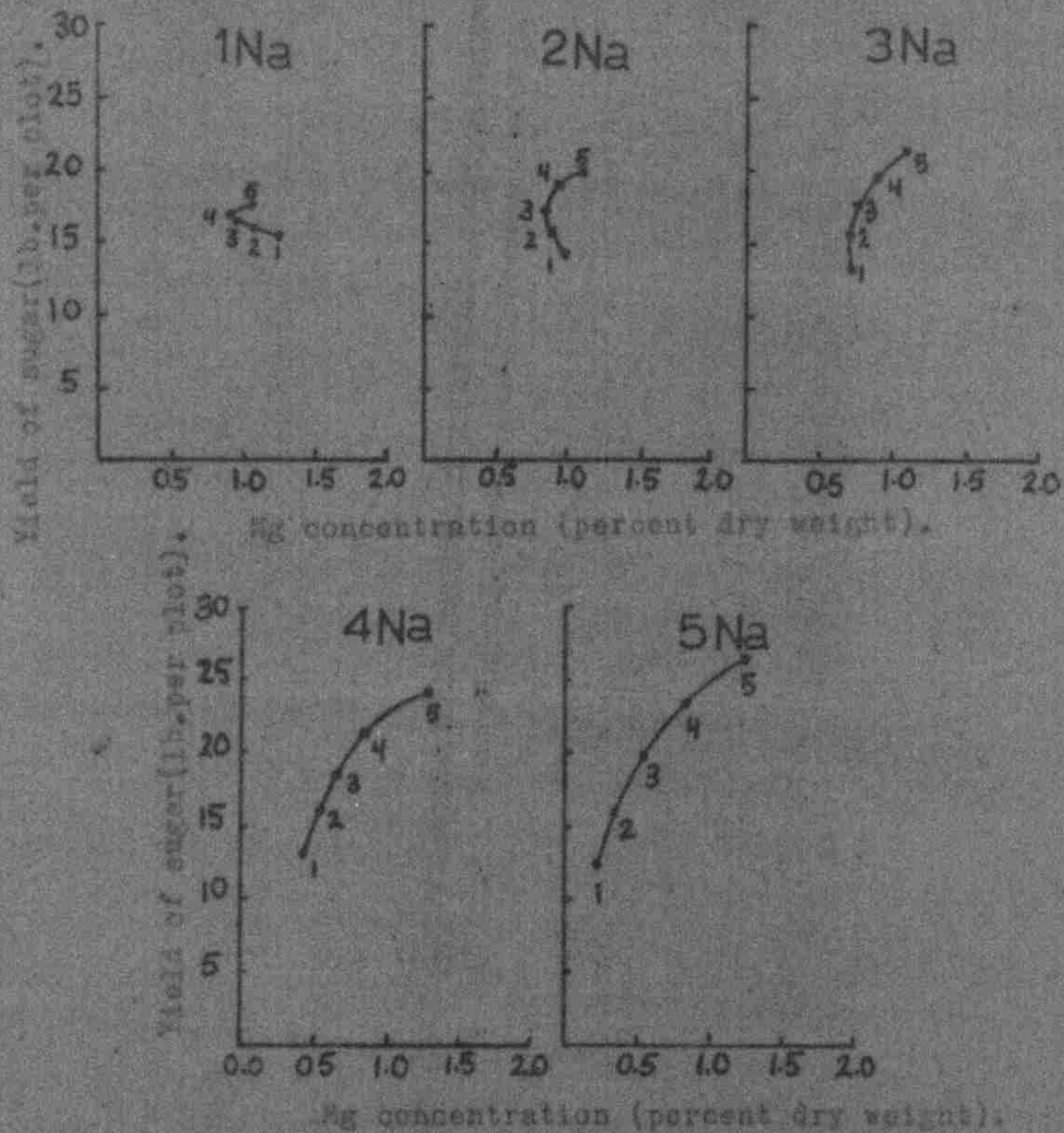

Figure 34. Relationship between yield of sugar (lb.per plot) and Mg concentration (percent dry weight) as affected by addition of different levels of N and Na with P,K and Mg held constant at the middle of five levels (Table 1).Numbers at points refer to levels of N added. Level of Na was held constant for each graph.

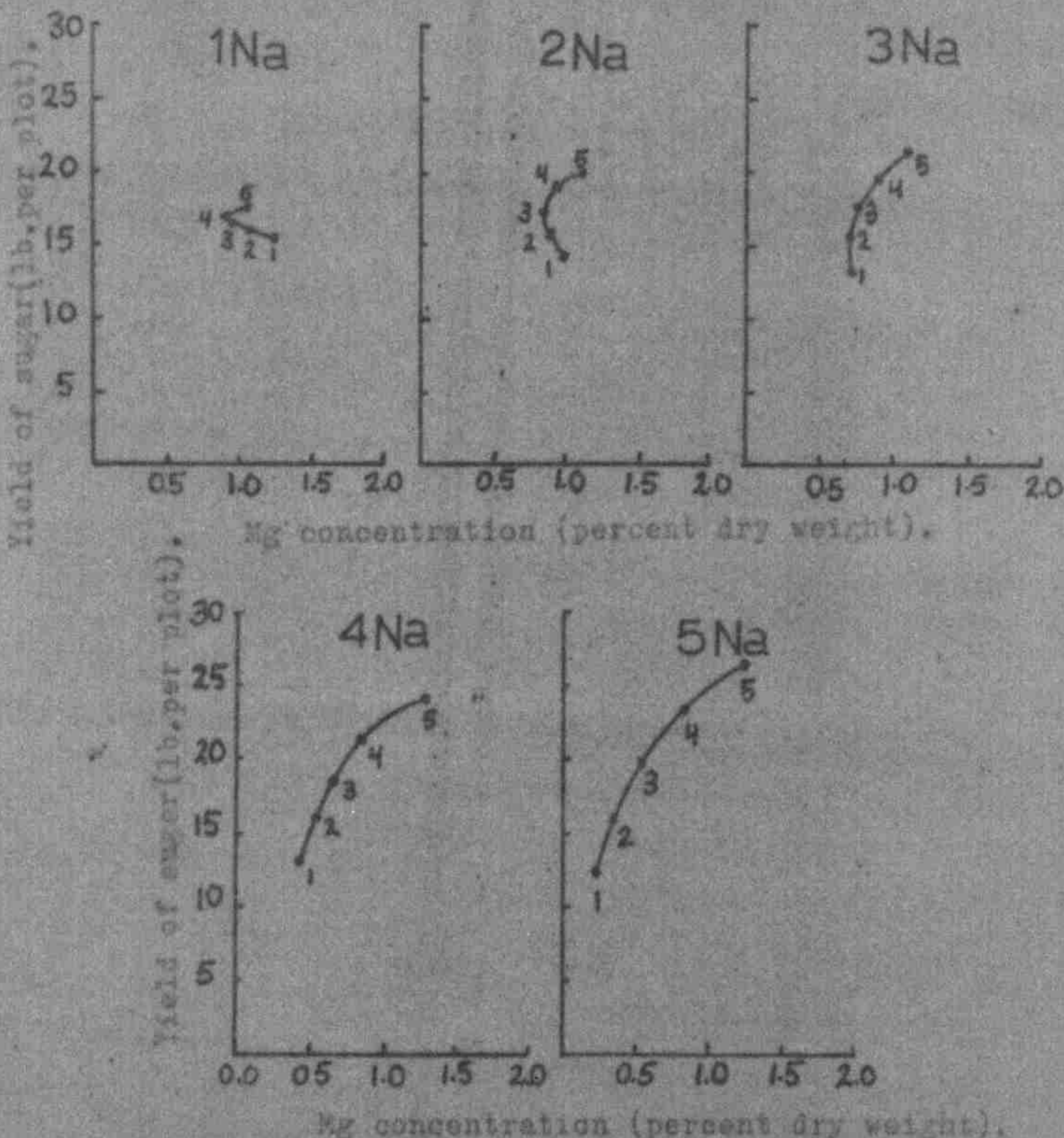

Figure 34. Relationship between yield of sugar (lb. per plot) and Mg concentration (percent dry weight) as affected by addition of different levels of N and Na with P, K and Mg held constant at the middle of five levels (Table 1). Numbers at points refer to levels of N added. Level of Na was held constant for each graph.

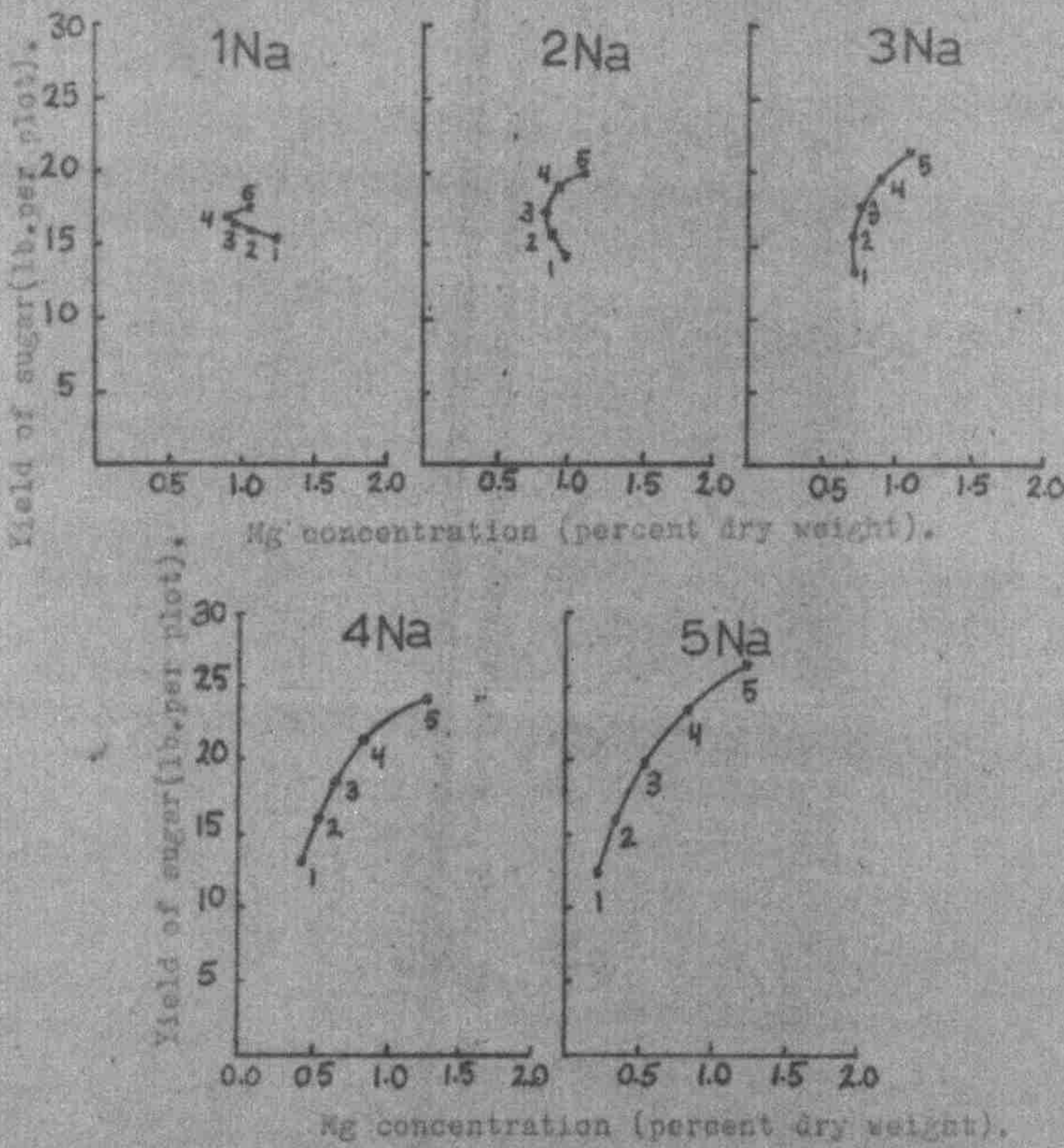

Figure 34. Relationship between yield of sugar (lb.per plot) and Mg concentration (percent dry weight) as affected by addition of different levels of N and Na with P,K and Mg held constant at the middle of five levels (Table 1). Numbers at points refer to levels of N added. Level of Na was held constant for each graph.

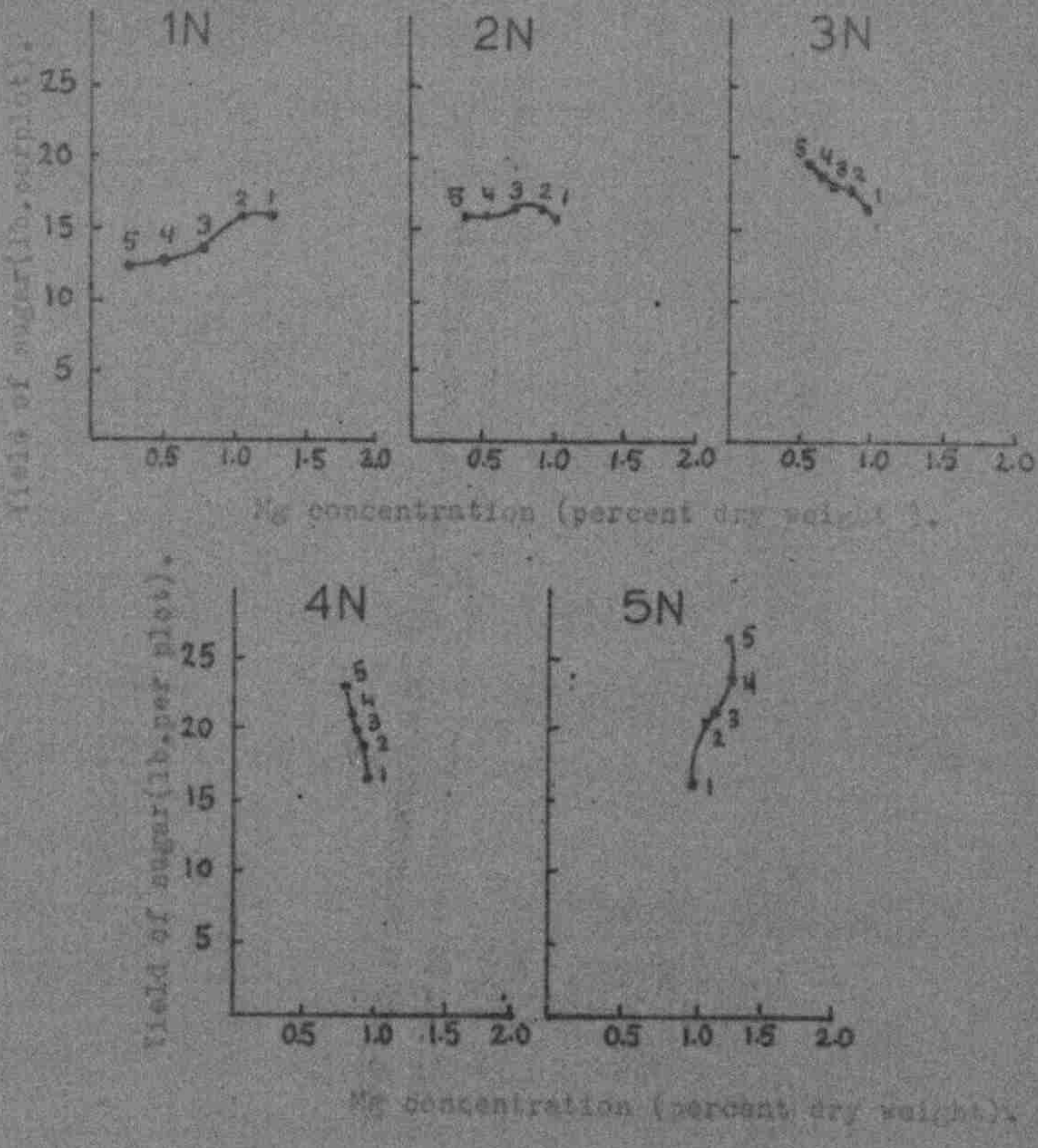

Figure 35. Relationship between yield of sugar (lb. per plot) and Mg concentration (percent dry weight) as affected by addition of different levels of [illegible] and Na with P, K and Mg held constant at one of five levels (Table 1). Numbers at points refer to the level of Na added. Level of N constant for each graph.

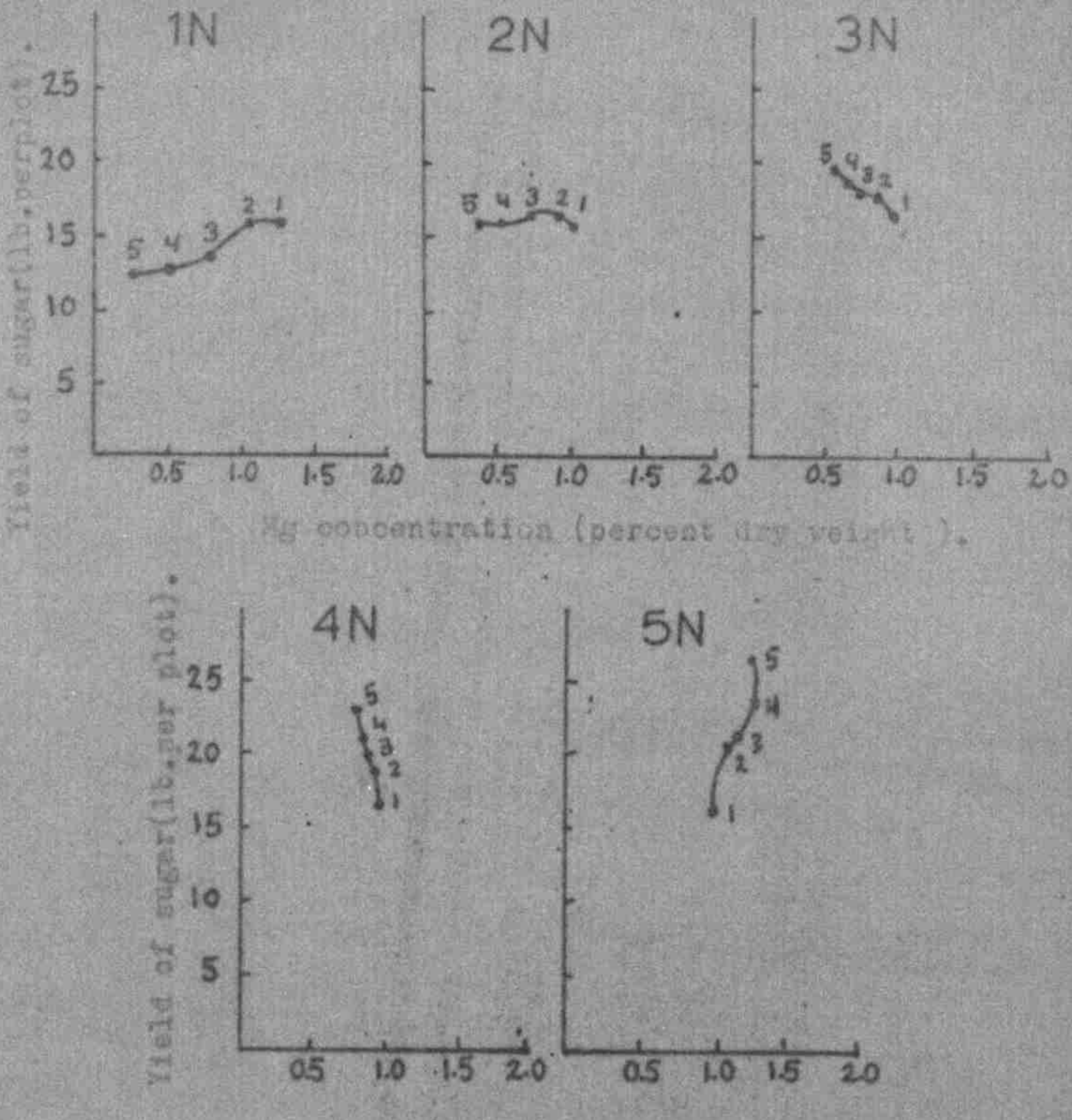

Figure 35. Relationship between yield of sugar (lb. per plot) and Mg concentration (percent dry weight) as affected by addition of different levels [illegible] and Na with P, K and Mg held constant at [illegible] of five levels (Table 1). Numbers at points [illegible] to the level of Na added. Level of N was [illegible]stant for each graph.

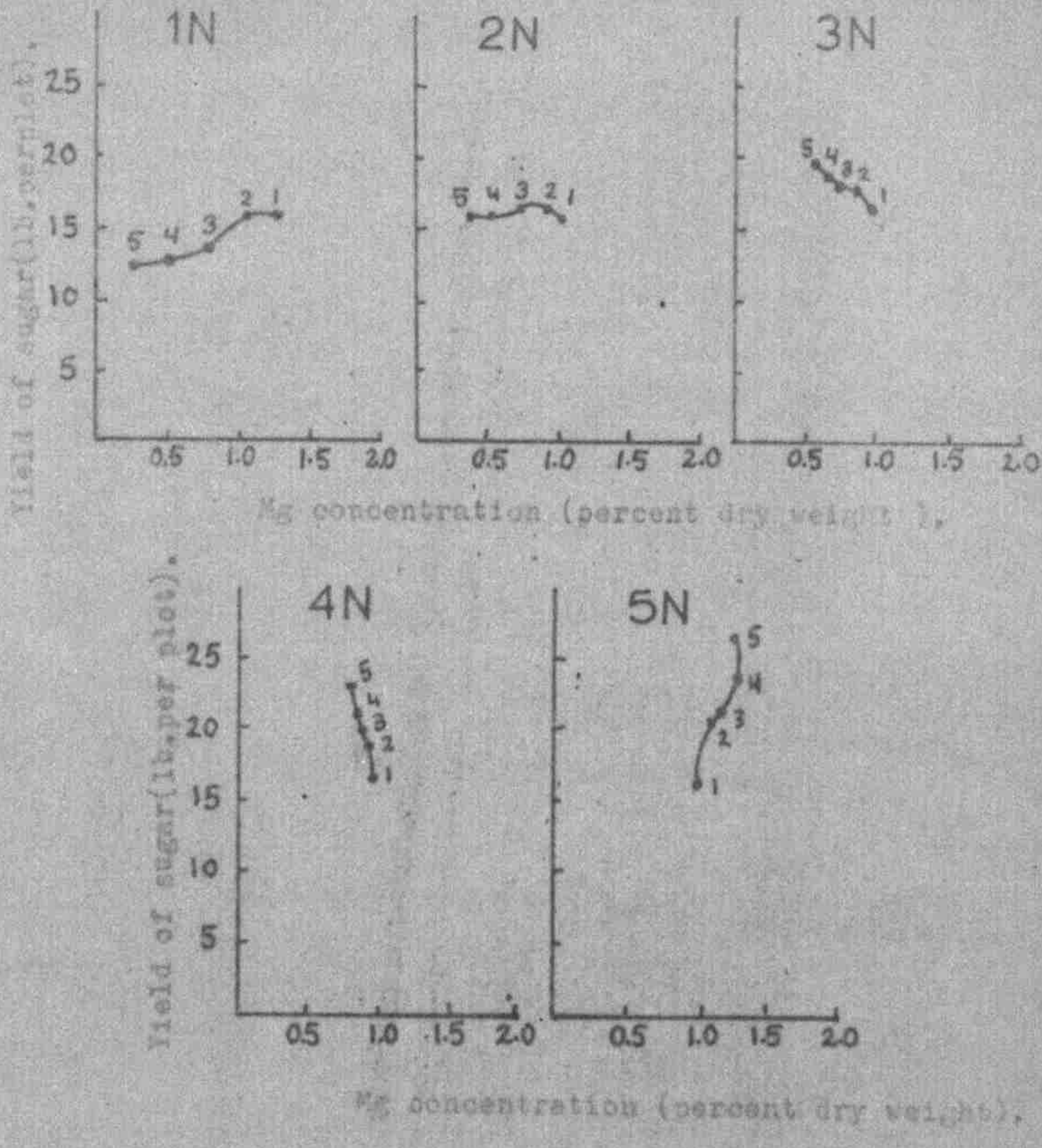

Figure 35. Relationship between yield of sugar (lb. per plot) and Mg concentration (percent dry weight) as affected by addition of different levels of N and Na with P, K and Mg held constant at the [illegible] of five levels (Table 1). Numbers at points [illegible] to the level of Na added. Level of N was [illegible]stant for each graph.

at the 2N level, whereas it was negatively correlated with Mg concentration at the 3N and 4N levels indicating that probably the Mg concentration had very little direct effect on yield.

Examination of the relationship between yield of sugar and Mg concentration as affected by N application at each of five levels of P (Fig. 36) indicated that N application decreased the Mg concentration at low P levels while Mg concentration was considerably increased with increasing N application at high P levels. When the N level was held constant, the Mg concentration and yield of sugar (Fig. 37) were decreased with P application at the 1N level. No serious change in yield of sugar as well as Mg concentration was observed at the 2N level but at the 3N level Mg concentration increased with P application whereas yield of sugar was slightly reduced at the first 3 increments of P and slightly increased at the 4 and 5P levels. It was found that at high levels of N, increasing the P rates resulted in considerable increase in Mg concentration while the yield of sugar was only slightly increased indicating that when the N level was high, the application of P induced a luxury consumption of Mg by beet plants.

Study of the yield of sugar in relation to Mg concentration of leaves as affected by P application at each of five levels of K indicated (Fig. 38) that at the 1K level, P application resulted in reduction of both Mg concentration and yield of sugar. At higher levels of K, the tendency for both yield of sugar and Mg content was to increase with increasing P application. The effect of 5 levels of P indicated

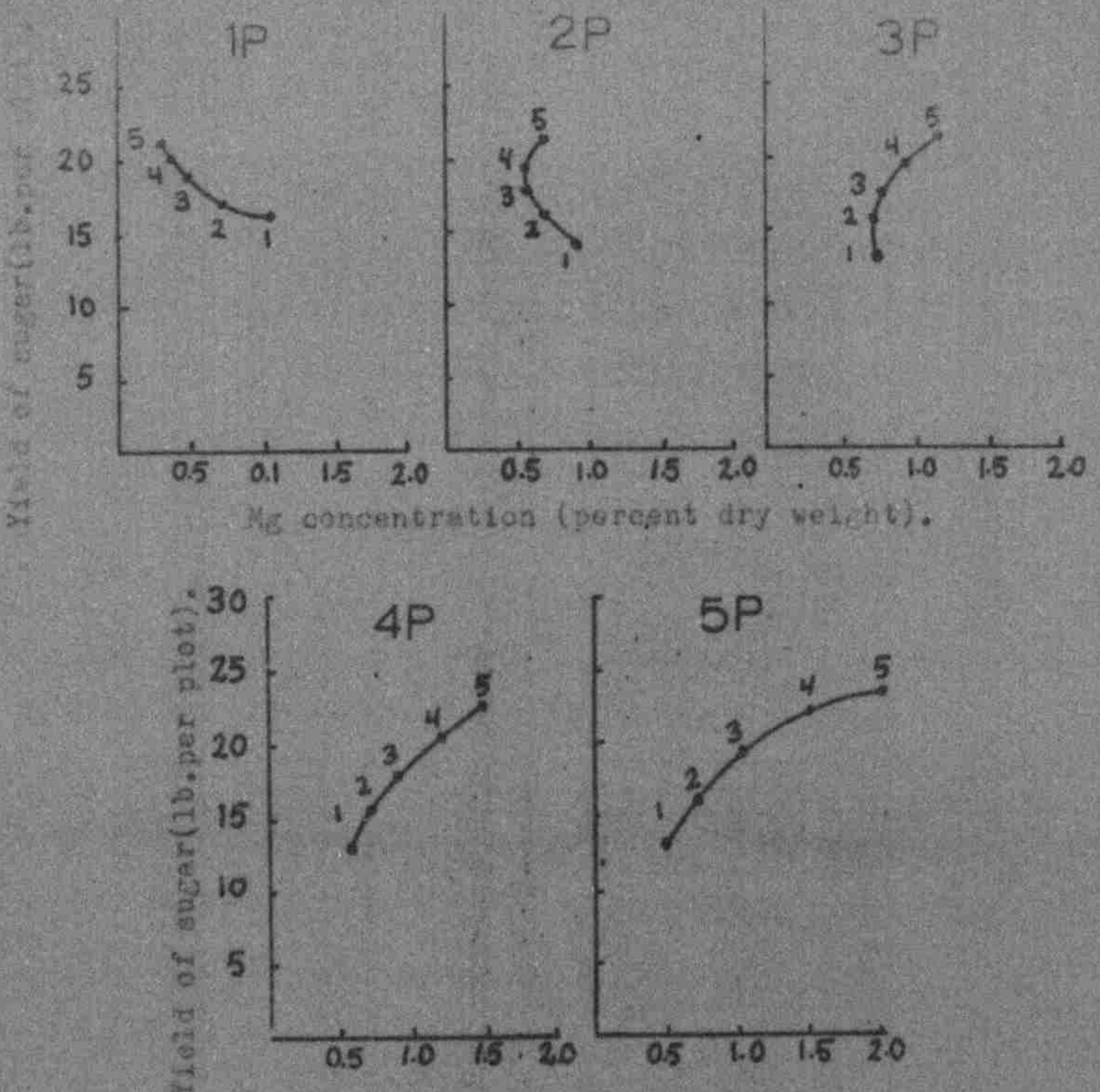

Figure 36. Relationship between yield of sugar (lb. per plot) and Mg concentration (percent dry weight) as affected by addition of different levels of P and N with K, Mg and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of N added. Level of P was held constant for each graph.

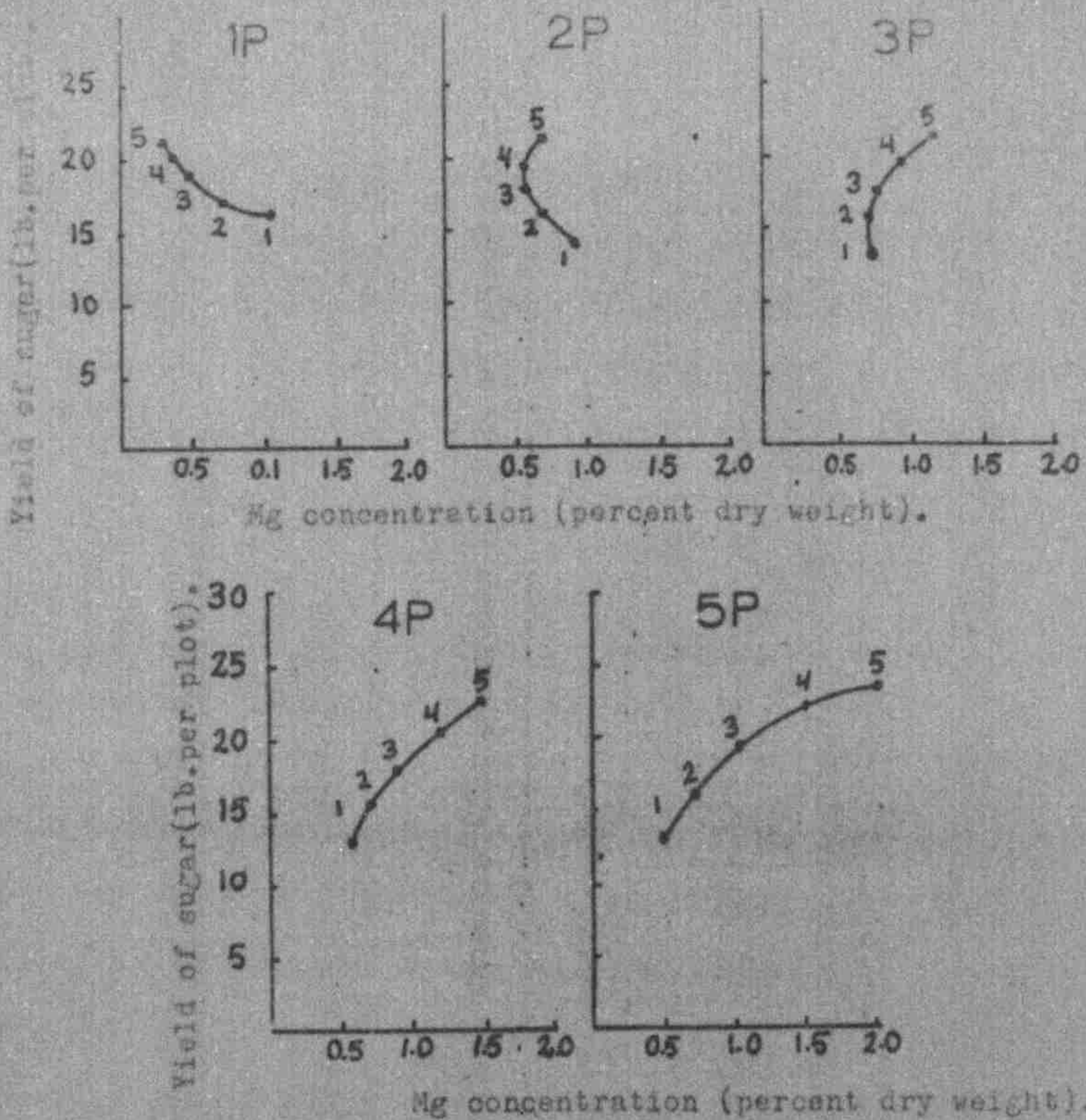

Figure 36. Relationship between yield of sugar (lb. per plot) and Mg concentration (percent dry weight) as affected by addition of different levels of P and N with K, Mg and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of N added. Level of P was held constant for each graph.

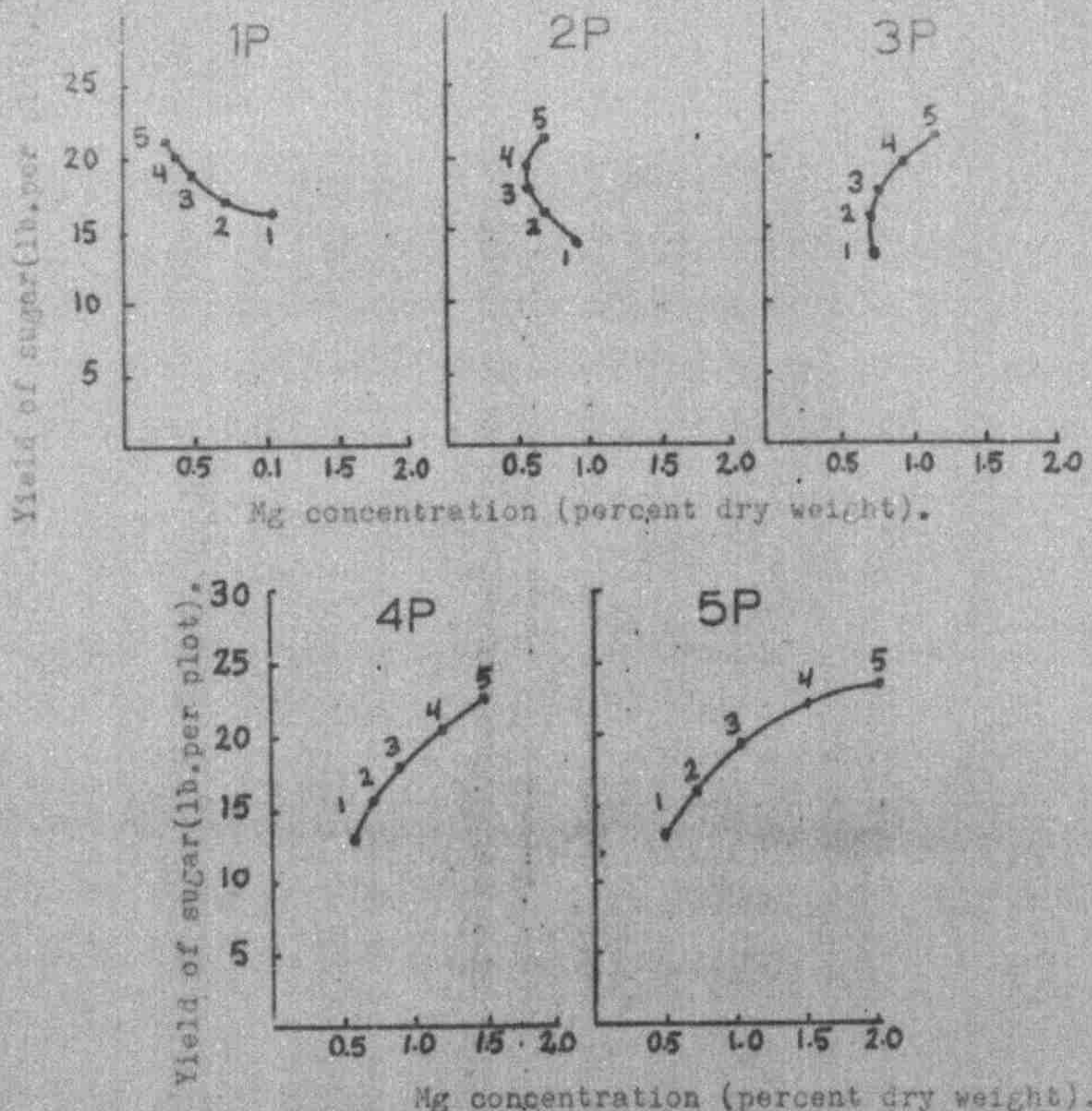

Figure 36. Relationship between yield of sugar (lb. per plot) and Mg concentration (percent dry weight) as affected by addition of different levels of P and N with K, Mg and Na held constant at the middle of five levels (Table 1) Numbers at points refer to levels of N added. Level of P was held constant for each graph.

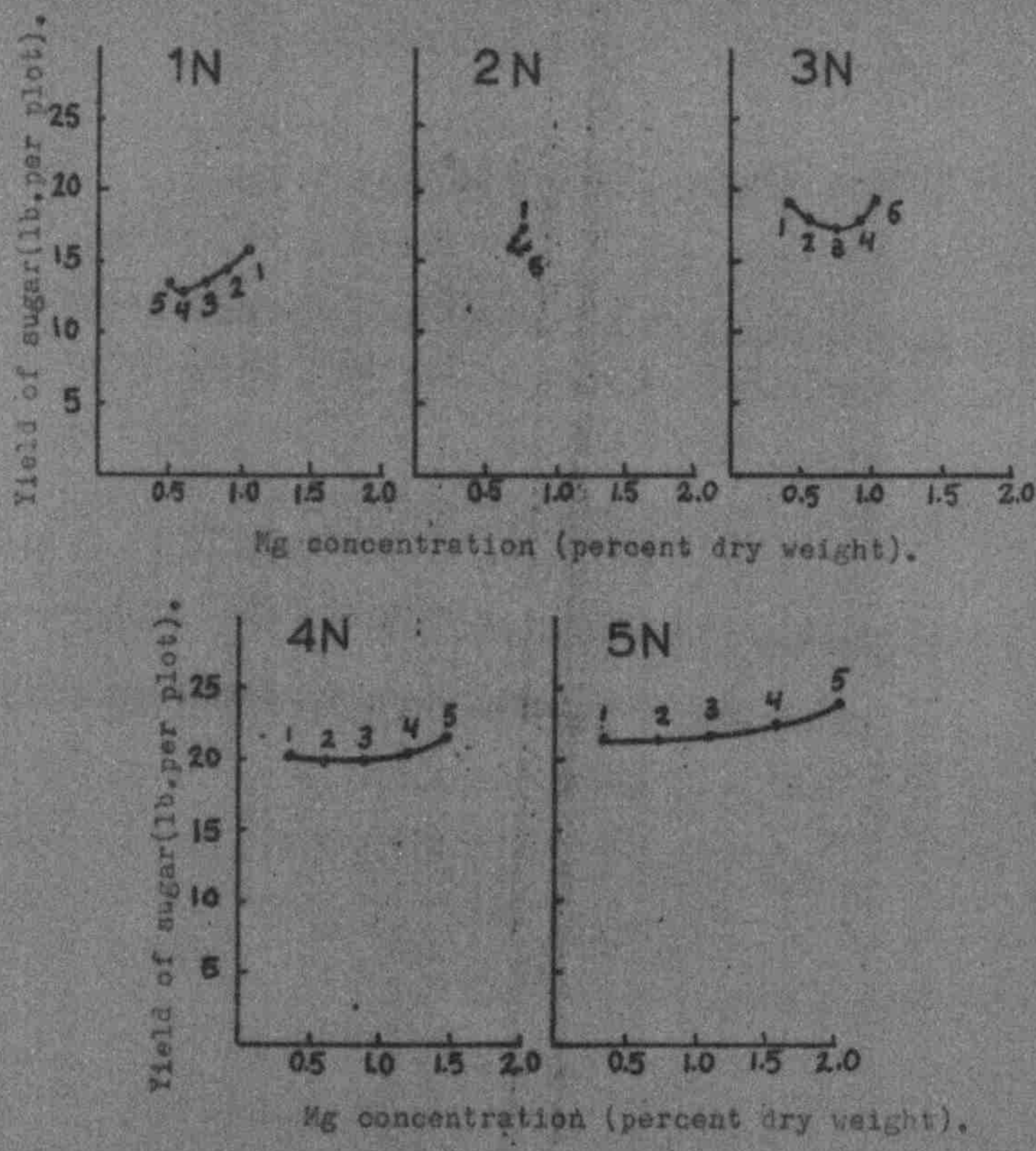

Figure 37. Relationship between yield of sugar (lb. per plot) and Mg concentration (percent dry weight) as affected by addition of different levels of N and P with K, Mg and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of P added. Level of N was held constant for each graph.

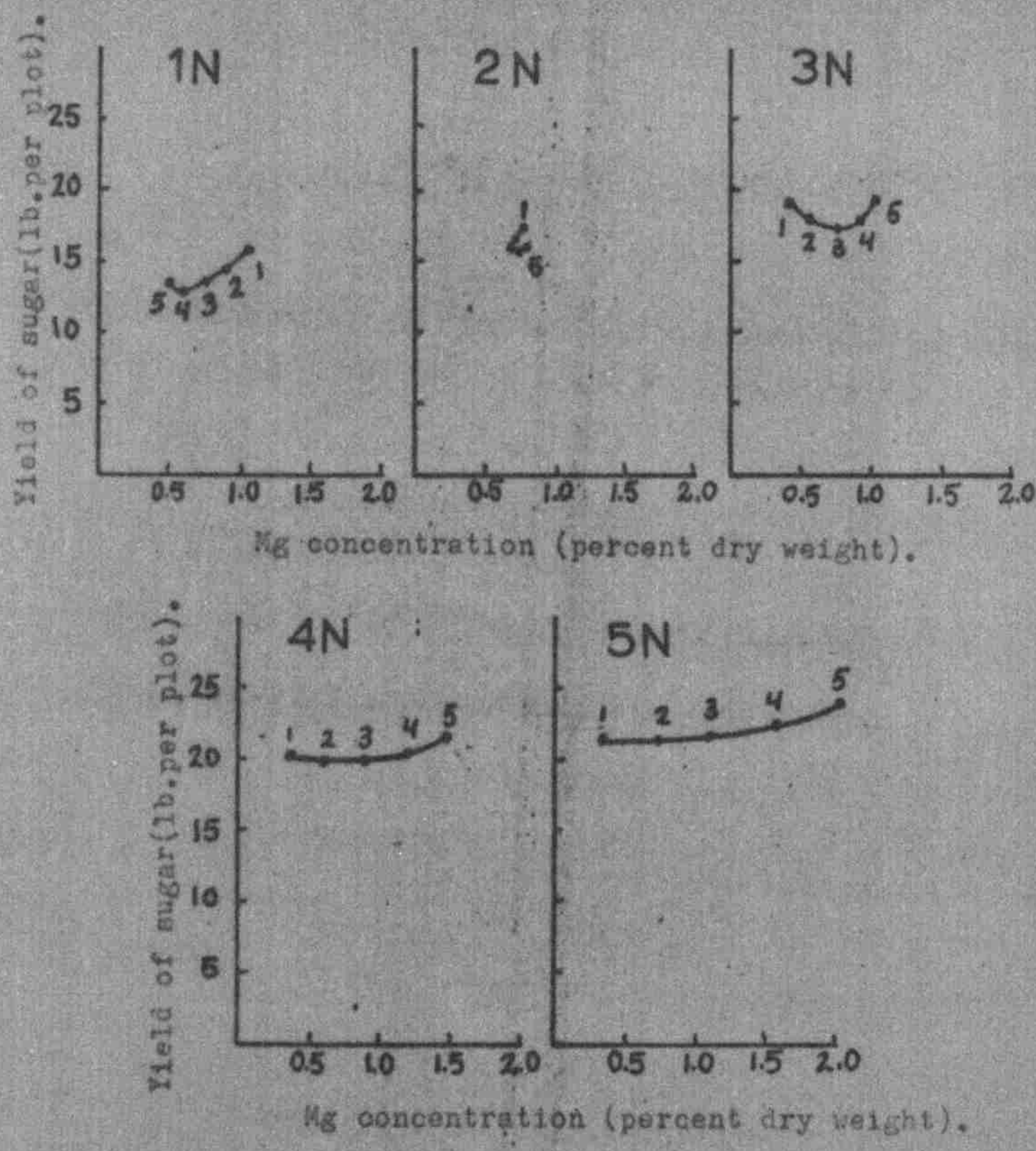

Figure 37. Relationship between yield of sugar (lb. per plot) and Mg concentration (percent dry weight) as affected by addition of different levels of N and P with K, Mg and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of P added. Level of N was held constant for each graph.

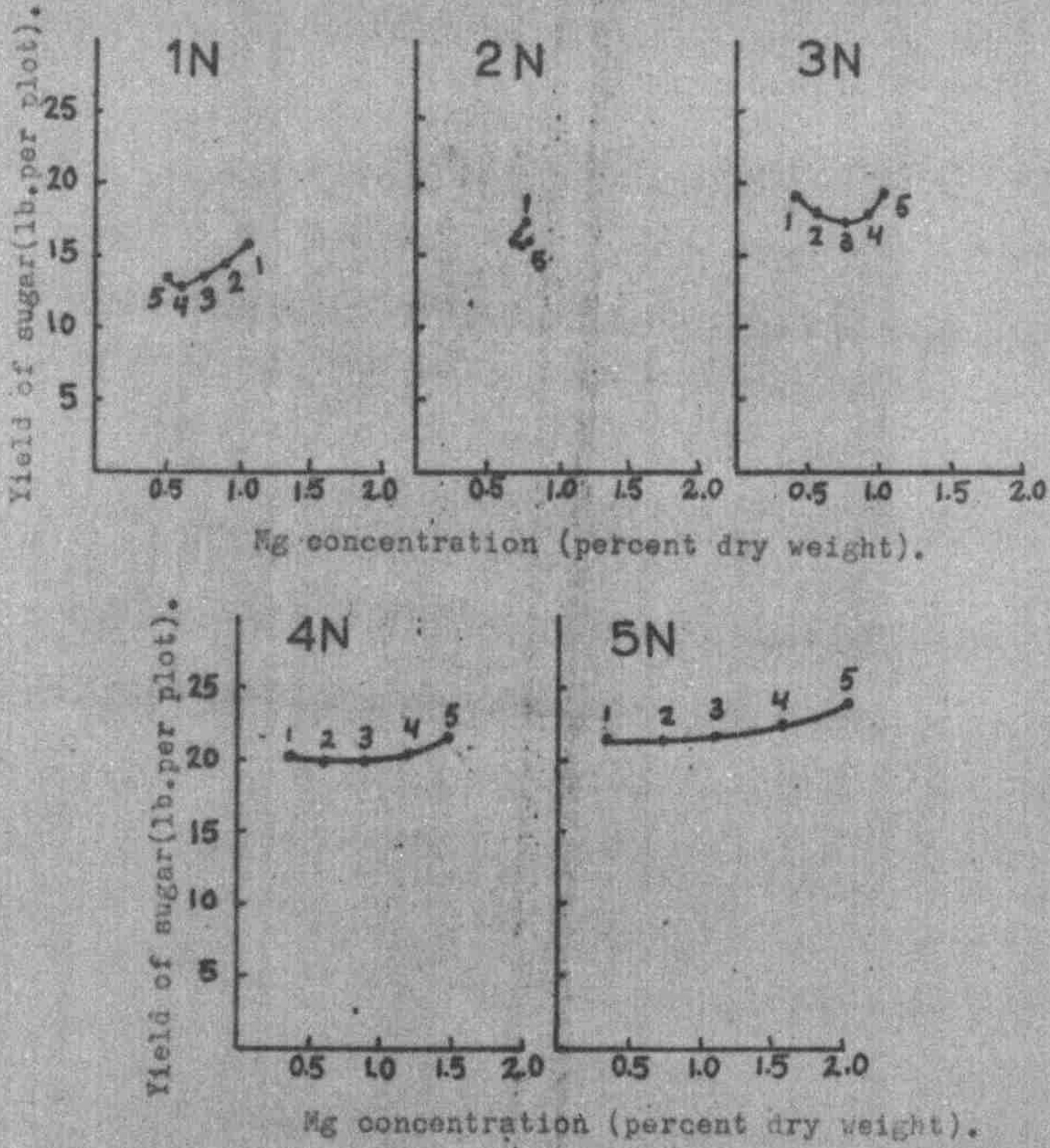

Figure 37. Relationship between yield of sugar (lb. per plot) and Mg concentration (percent dry weight) as affected by addition of different levels of N and P with K, Mg and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of P added. Level of N was held constant for each graph.

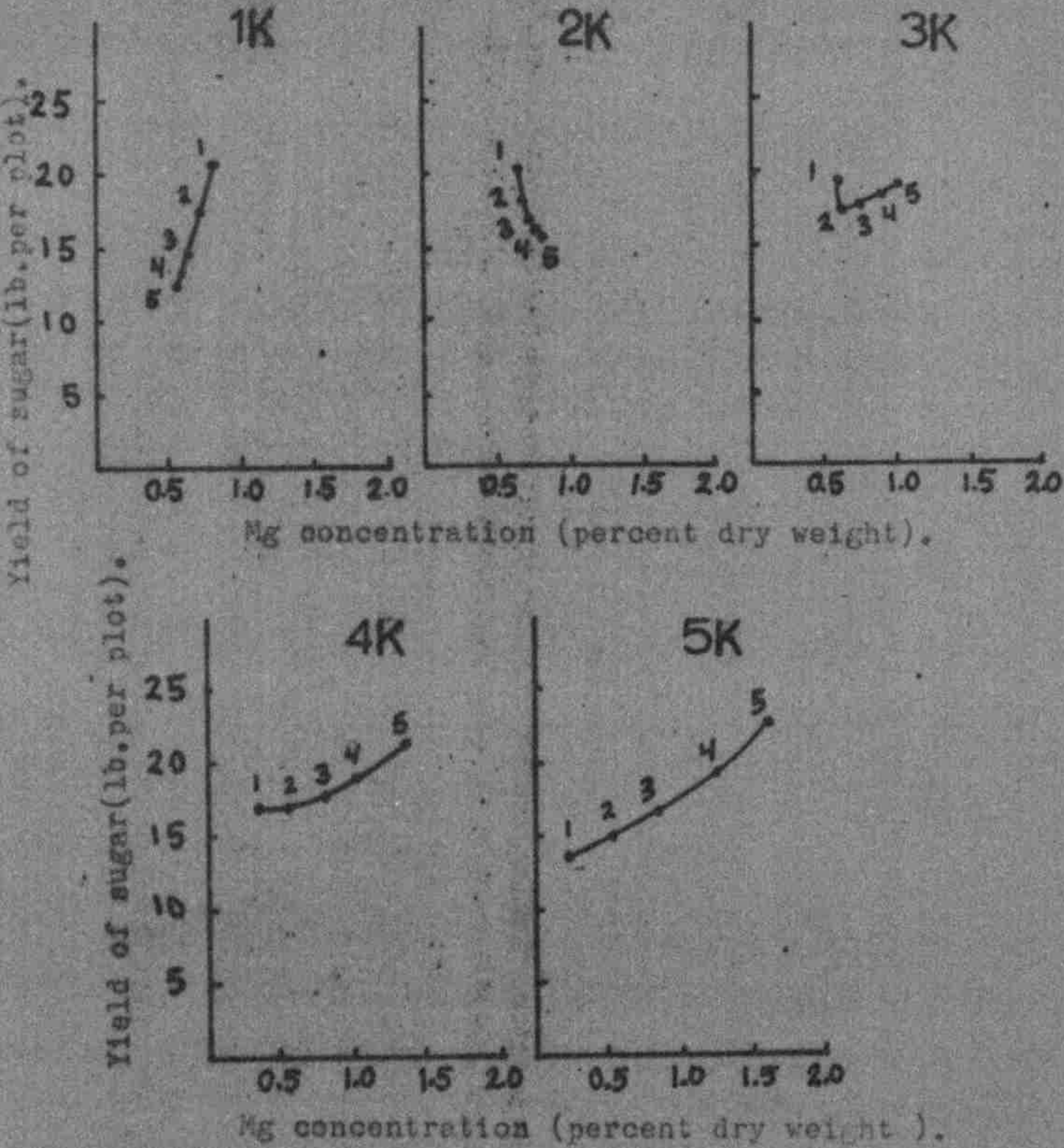

Figure 38. Relationship between yield of sugar (lb. per plot) and Mg concentration (percent dry weight) as affected by addition of different levels of P and K with N, Mg and Na held constant at the middle of five levels (Table 1). Numbers at points refer to the levels of P added. Level of K was held constant each graph.

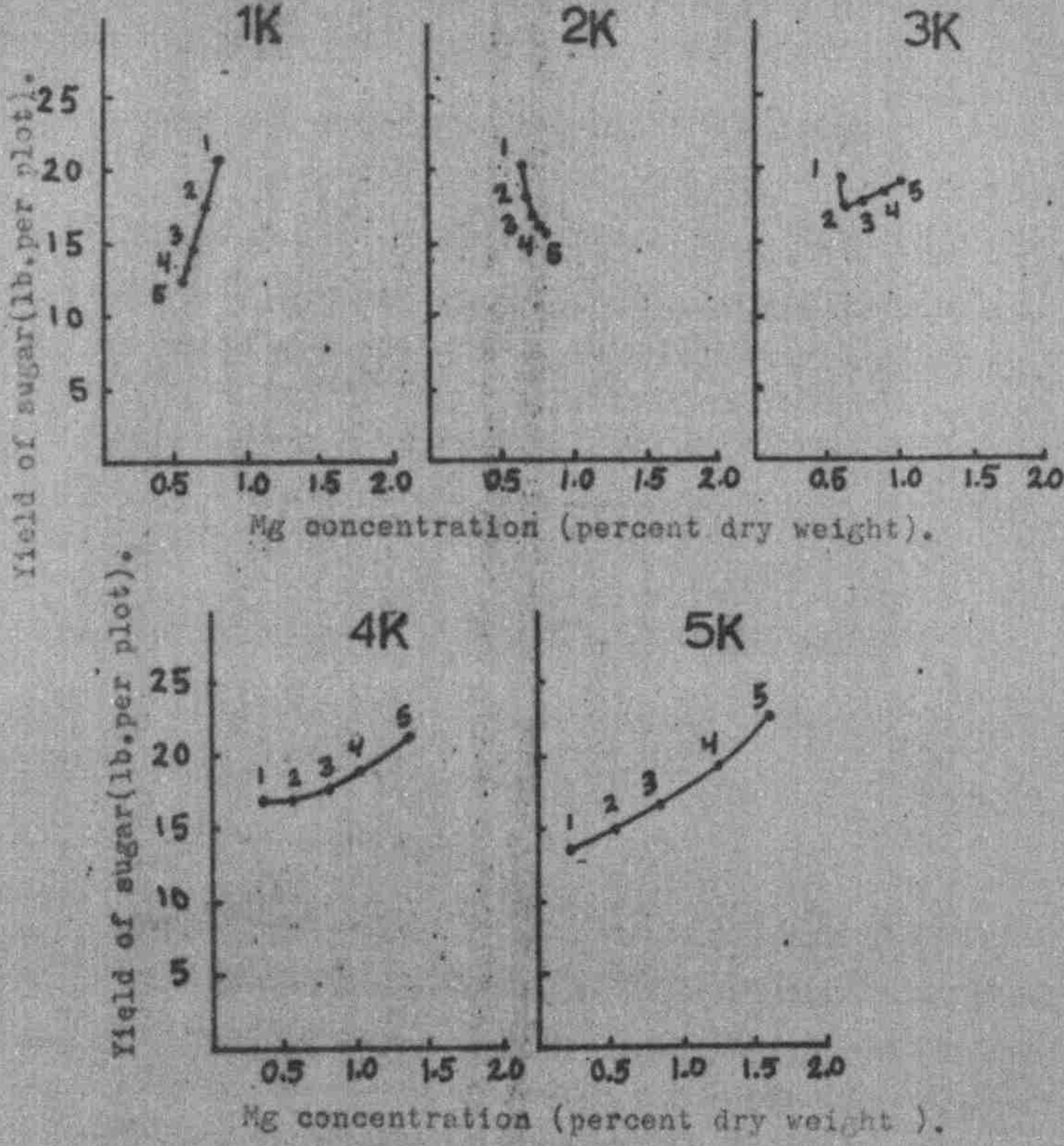

Figure 38. Relationship between yield of sugar Lb. per plot) and Mg concentration (percent dry weight) as affected by addition of different levels of P and K with N, Mg and Na held constant at the middle of five levels (Table 1). Numbers at points refer to the levels of P added. Level of K was held constant each graph.

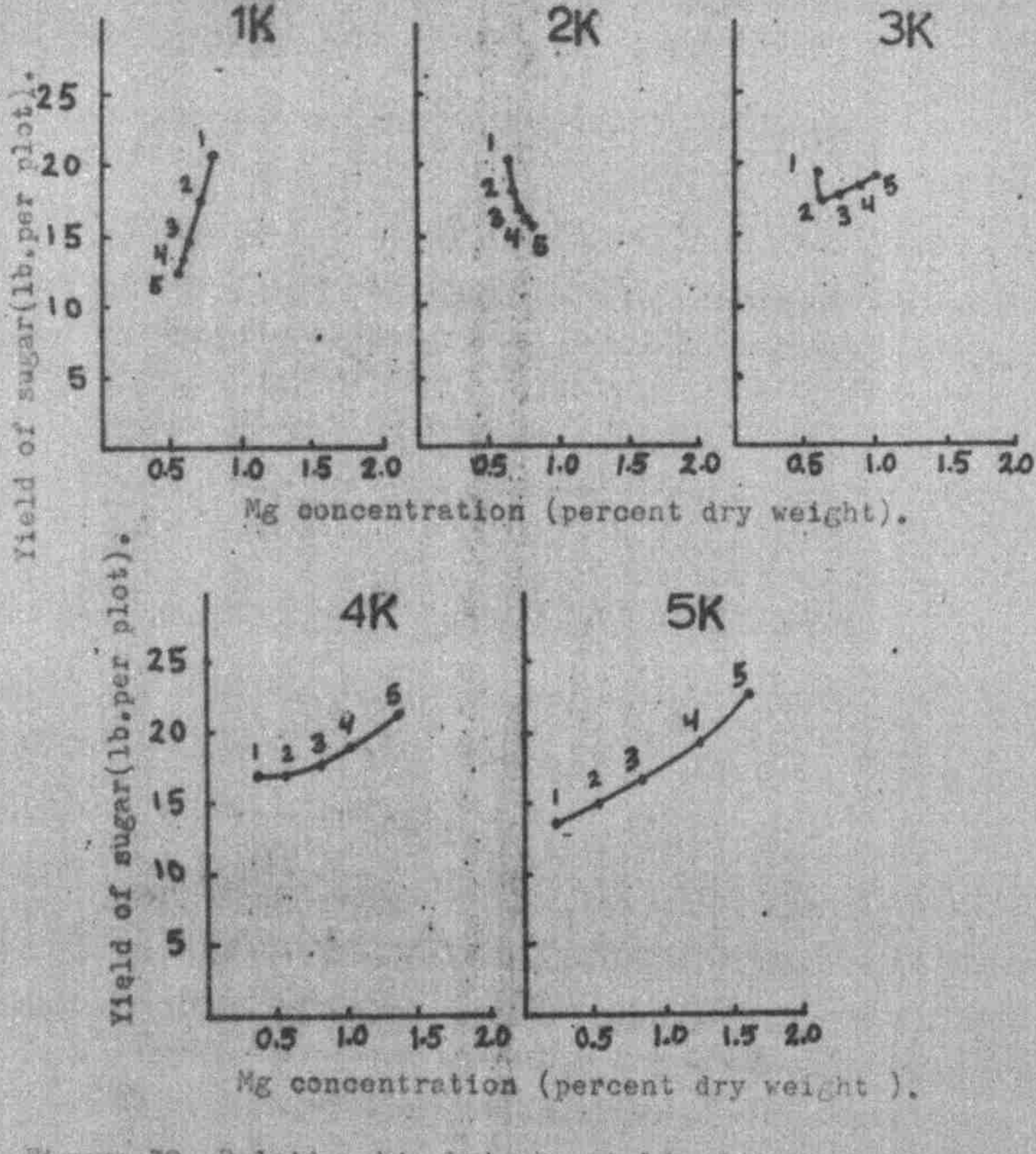

Figure 38. Relationship between yield of sugar (lb. per plot) and Mg concentration (percent dry weight) as affected by addition of different levels of P and K with N, Mg and Na held constant at the middle of five levels (Table 1). Numbers at points refer to the levels of P added. Level of K was held constant each graph.

(Fig. 39) that at low levels of P, the Mg concentration, as well as yield of sugar, was depressed with increasing K applications. As the P level was increased the tendency for K application was to increase both Mg content and yield of sugar. It was observed that high yields of sugar (Fig. 38 and 39) were obtained when both P and K were high or low, whereas the minimum yield was obtained if one element was at the high rate while the other was low. A high yield of sugar was associated with high Mg concentration. The critical Mg concentration (Fig. 39) was observed to range from 0.6-1.5 percent. The magnitude of this critical level was increased with the P level indicating that at a low level of P less Mg was needed whereas at high levels of P more Mg was needed for maximum yield.

The relationship between yield of sugar and Mg concentration as affected by the Na-Mg interaction (Fig. 40 and 41) indicated that high yields of sugar were obtained when either Mg or Na was at the high level while the other element was kept low. Maximum yield of sugar was correlated with low Mg concentrations. Increasing either Mg or Na at a low level of the other depressed the Mg content and the yield of sugar was increased. On the other hand, increasing one element at high levels of the other resulted in a depression of the yield of sugar while the Mg concentration was increased. In all cases a negative correlation between yield of sugar and Mg concentration was observed.

Sodium Concentration of Beet Tops

The correlation coefficient between actual Na concentrations and

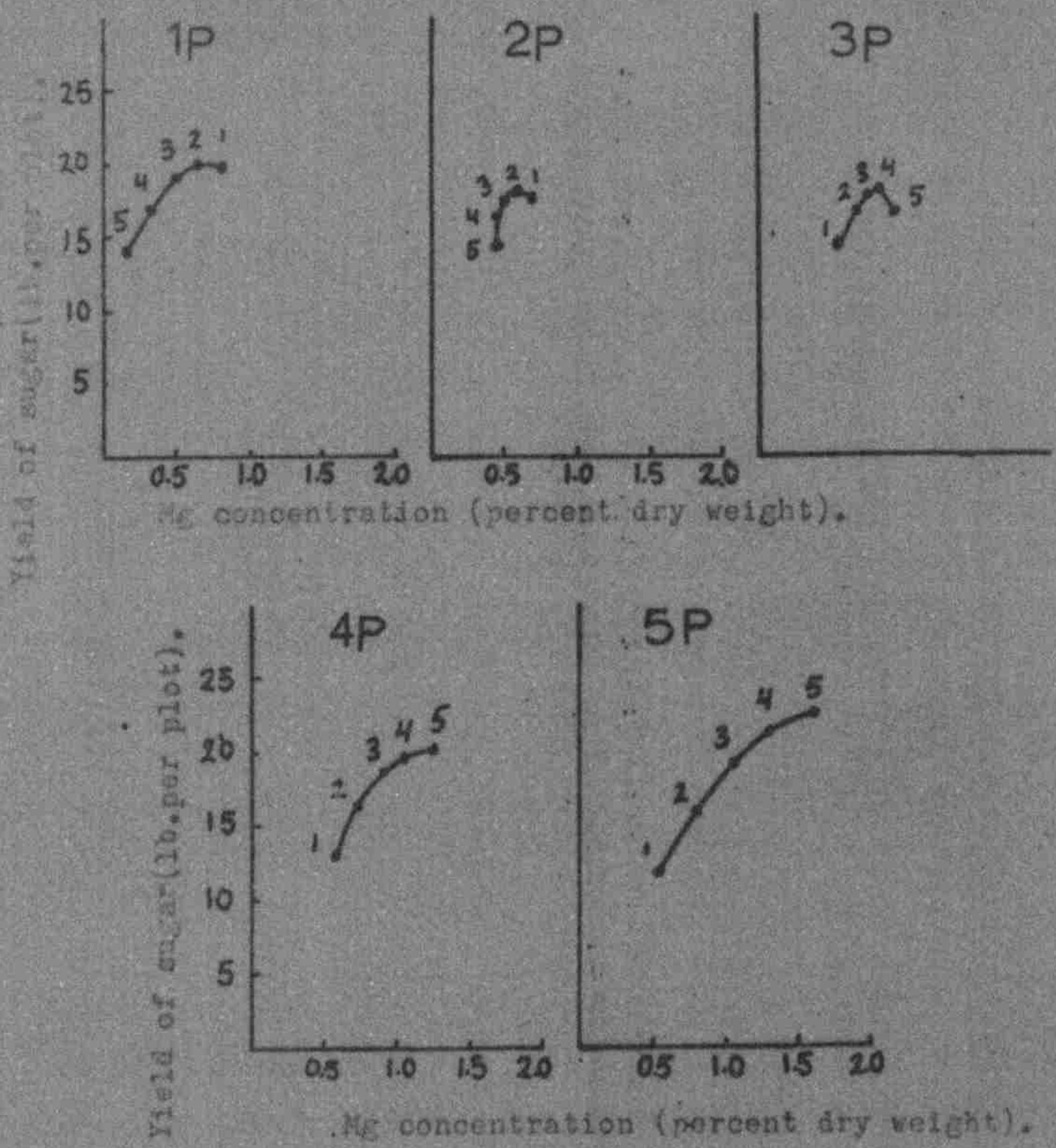

Figure 39. Relationship between yield of sugar (lb. per plot) and Mg concentration (percent dry weight) as affected by addition of different levels of P and K with N, Mg and Na held constant at the middle of five levels (Table 1). Numbers at points refer to the levels of K added. Level of P was held constant for each graph.

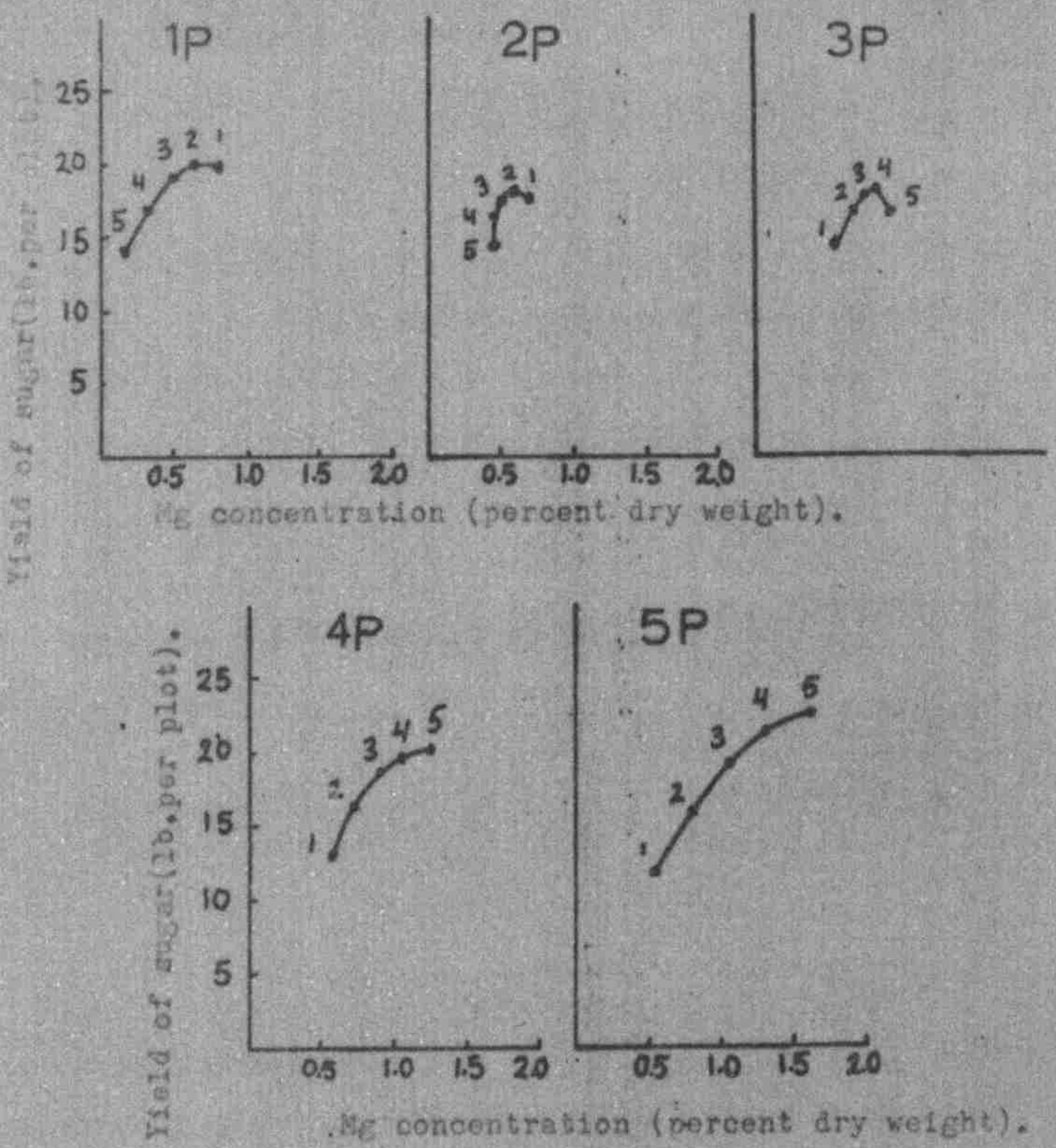

Figure 39. Relationship between yield of sugar (lb. per plot) and Mg concentration (percent dry weight) as affected by addition of different levels of P and K with N, Mg and Na held constant at the middle of five levels (Table 1). Numbers at points refer to the levels of K added. Level of P was held constant for each graph.

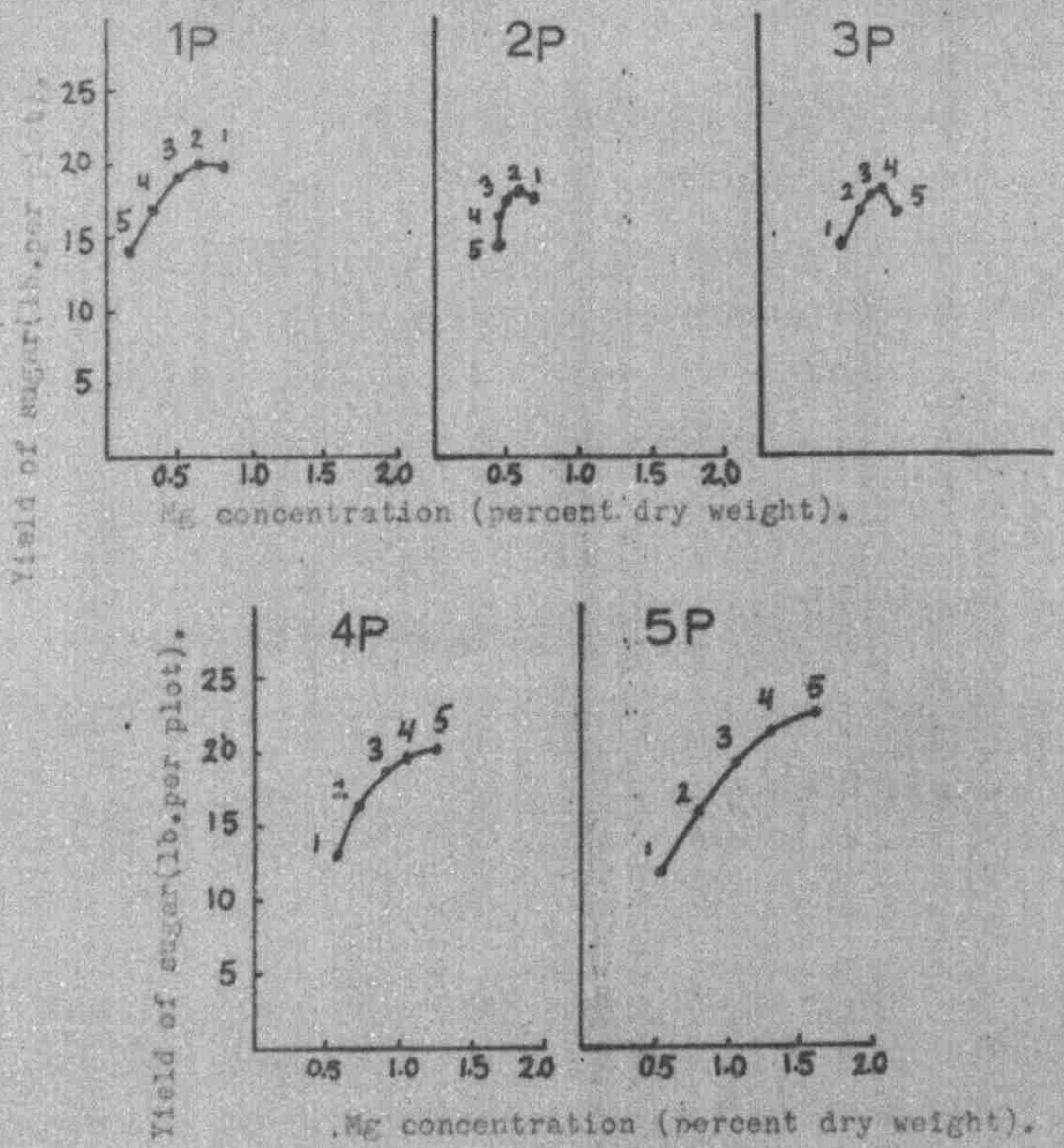

Figure 39. Relationship between yield of sugar (lb. per plot) and Mg concentration (percent dry weight) as affected by addition of different levels of P and K with N, Mg and Na held constant at the middle of five levels (Table 1). Numbers at points refer to the levels of K added. Level of P was held constant for each graph.

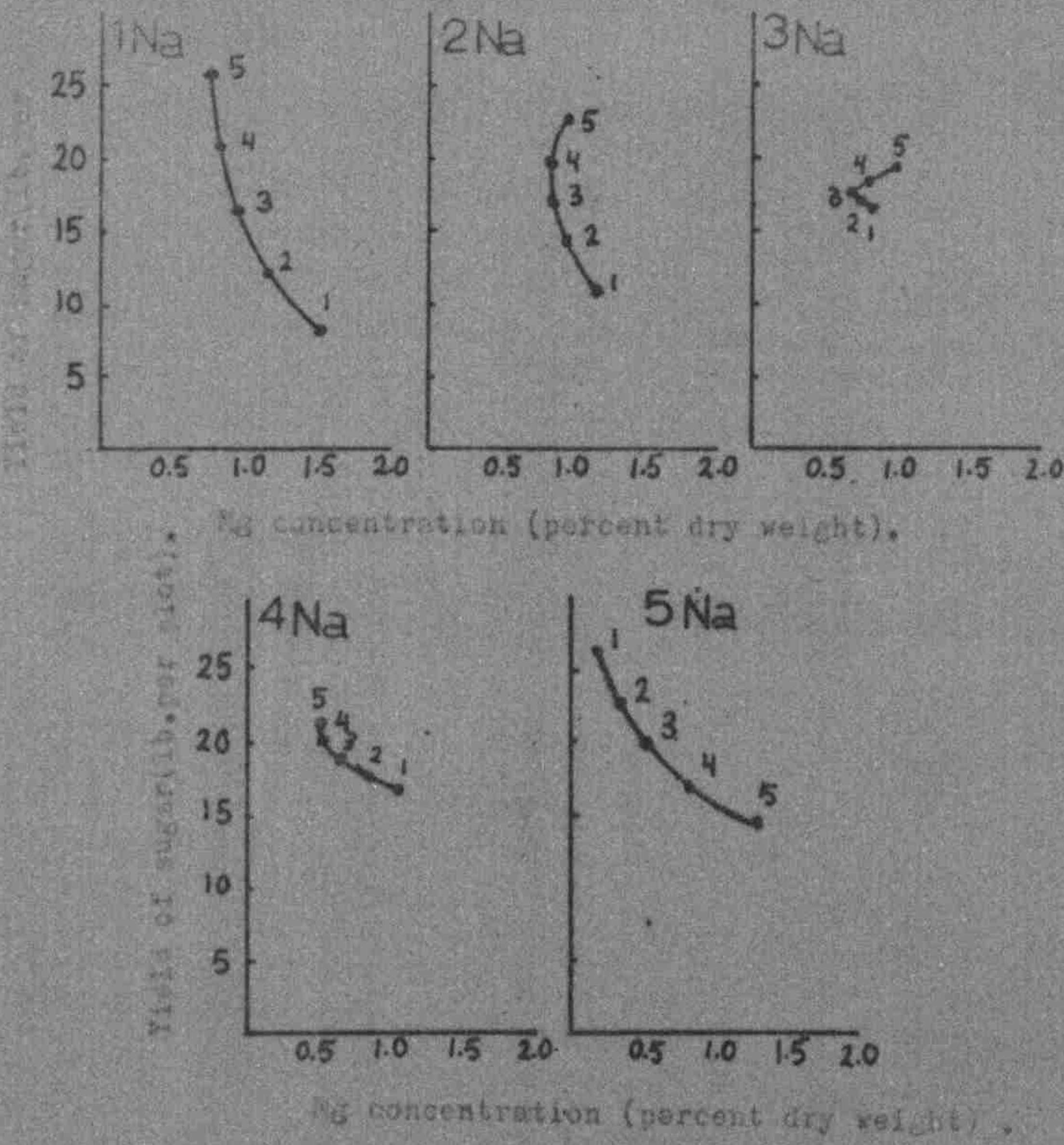

Figure 4b. Relationship between yield of sugar (lb. per plot) and Mg concentration (percent dry weight as effected by addition of different levels of Na and Mg with N, P and K held constant at the middle of the five levels (Table 1). Numbers at points refer to levels of Mg added. Level of Na was held constant for each graph.

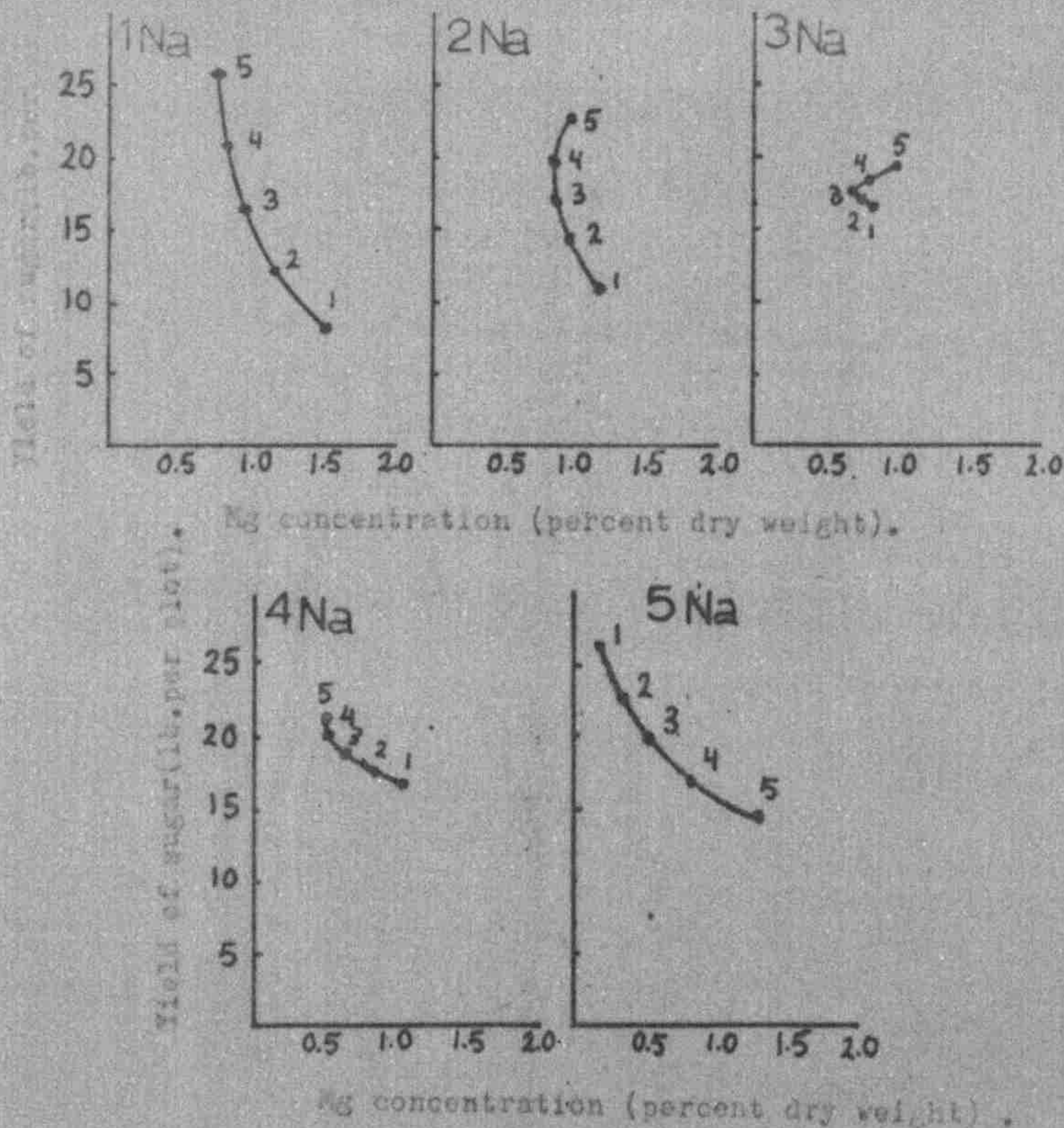

Figure 45. Relationship between yield of sugar (lb. per plot) and Mg concentration (percent dry weight as effected by addition of different levels of Na and Mg with N, P and K held constant at the middle of the five levels (Table 1). Numbers at points refer to levels of Mg added. Level of Na was held constant for each graph.

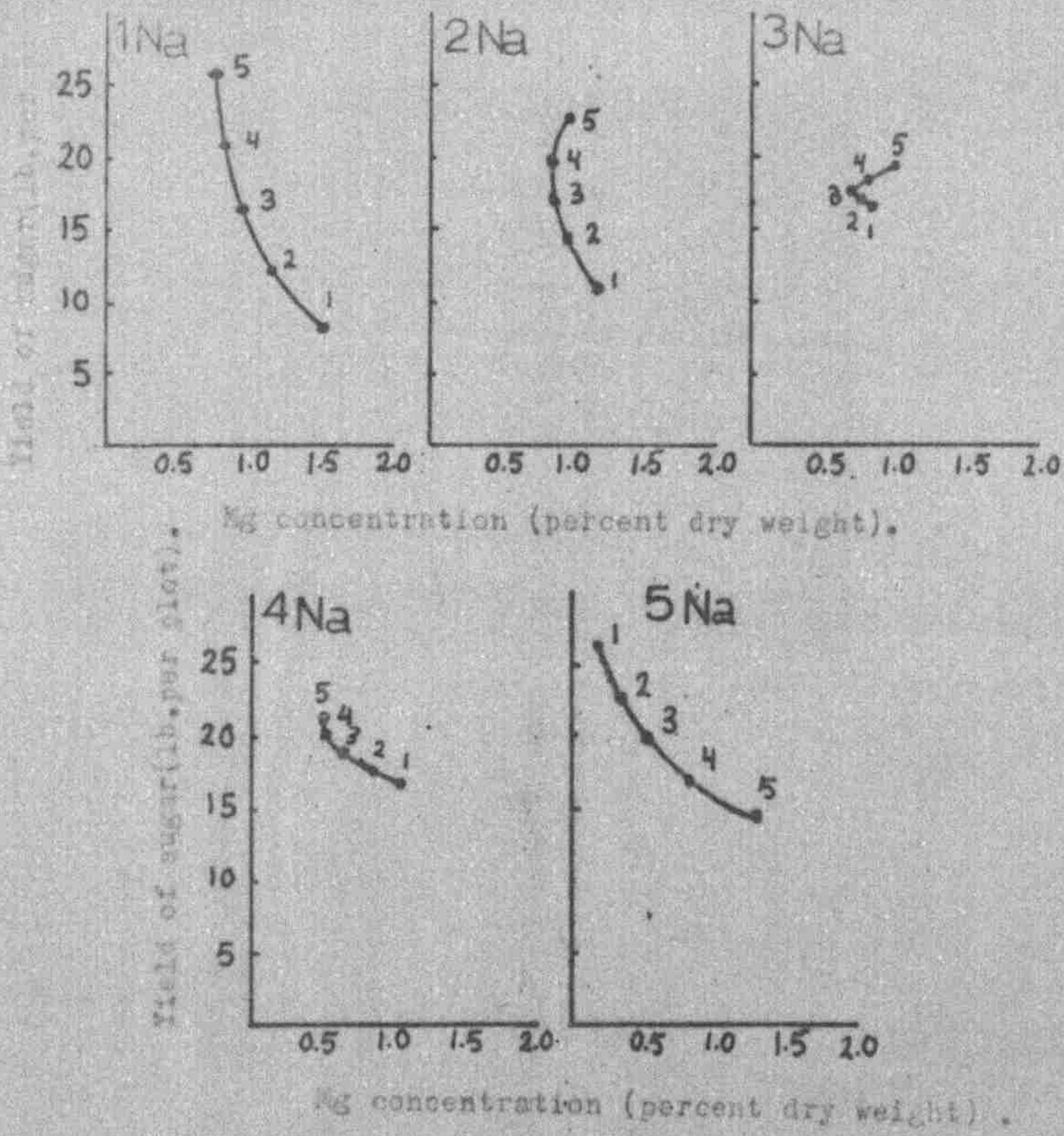

Figure 4c. Relationship between yield of sugar (lb. per plot) and Mg concentration (percent dry weight as effected by addition of different levels of Na and Mg with N, P and K held constant at the middle of the five levels (Table 1). Numbers at points refer to levels of Mg added. Level of Na was held constant for each graph.

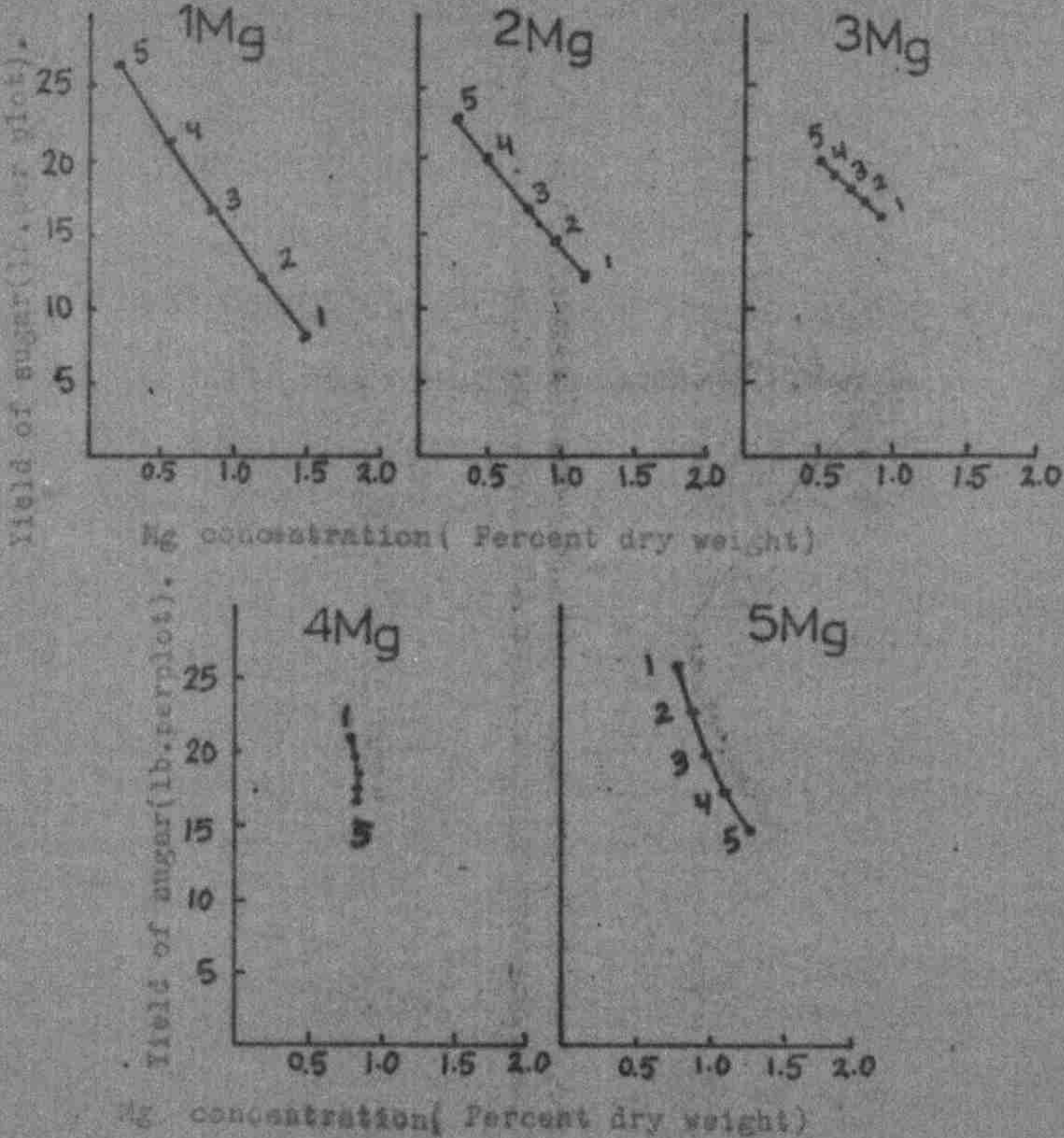

Figure 41. Relationship between yield of sugar(lb. per plot) and Mg concetration (percent dry weight) as effected by addition of different levels of Mg and Na with N, P and K held constant at the middle of the five levels (table 1). Numbers at points refer to levels of Na added. Level of Mg was held constant for each graph.

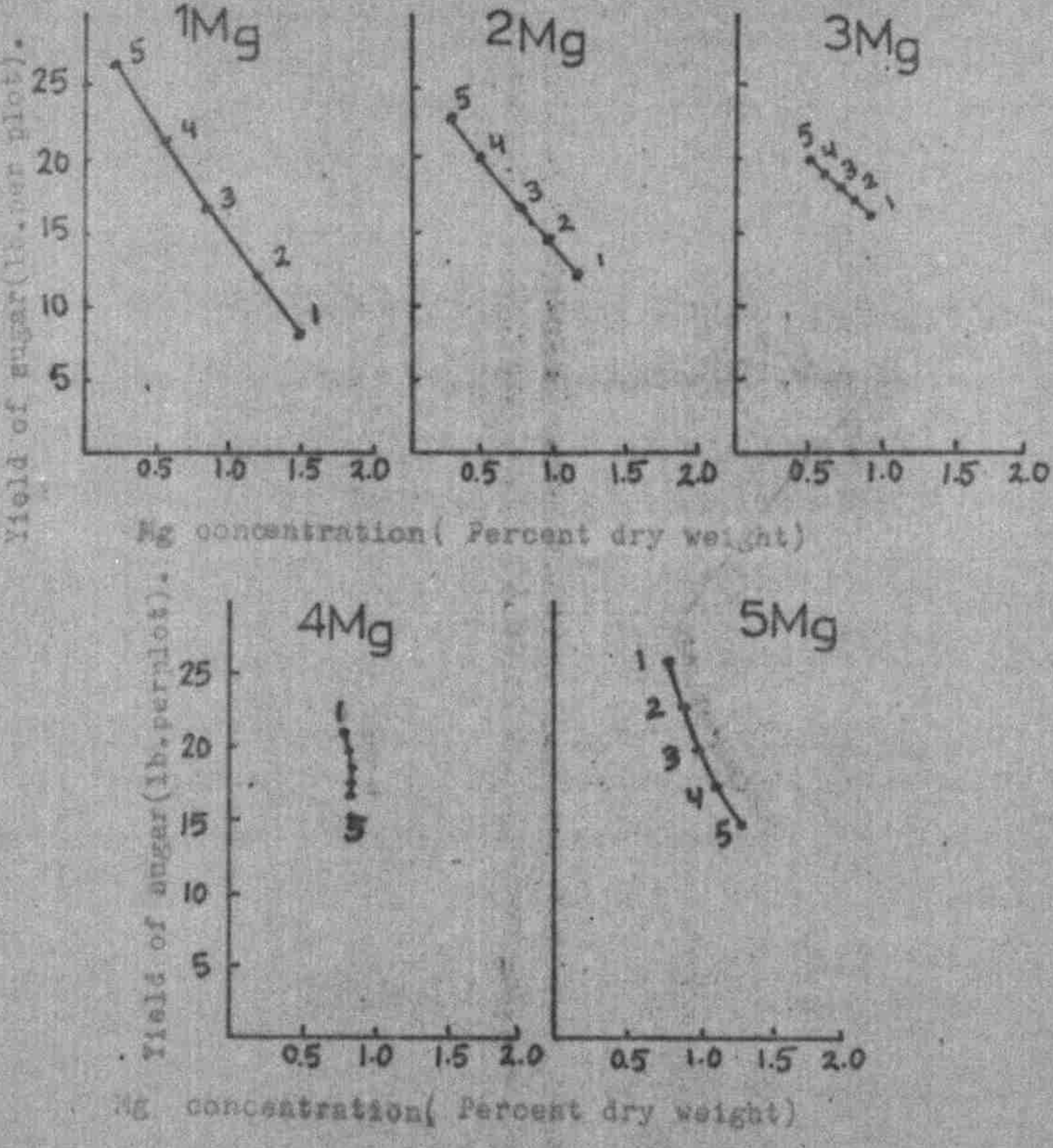

Figure 41. Relationship between yield of sugar(lb. per plot) and Mg concetration (percent dry weight) as affected by addition of different levels of Mg and Na with N, P and K held constant at the middle of the five levels (table 1). Numbers at points refer to levels of Na added. Level of Mg was held constant for each graph.

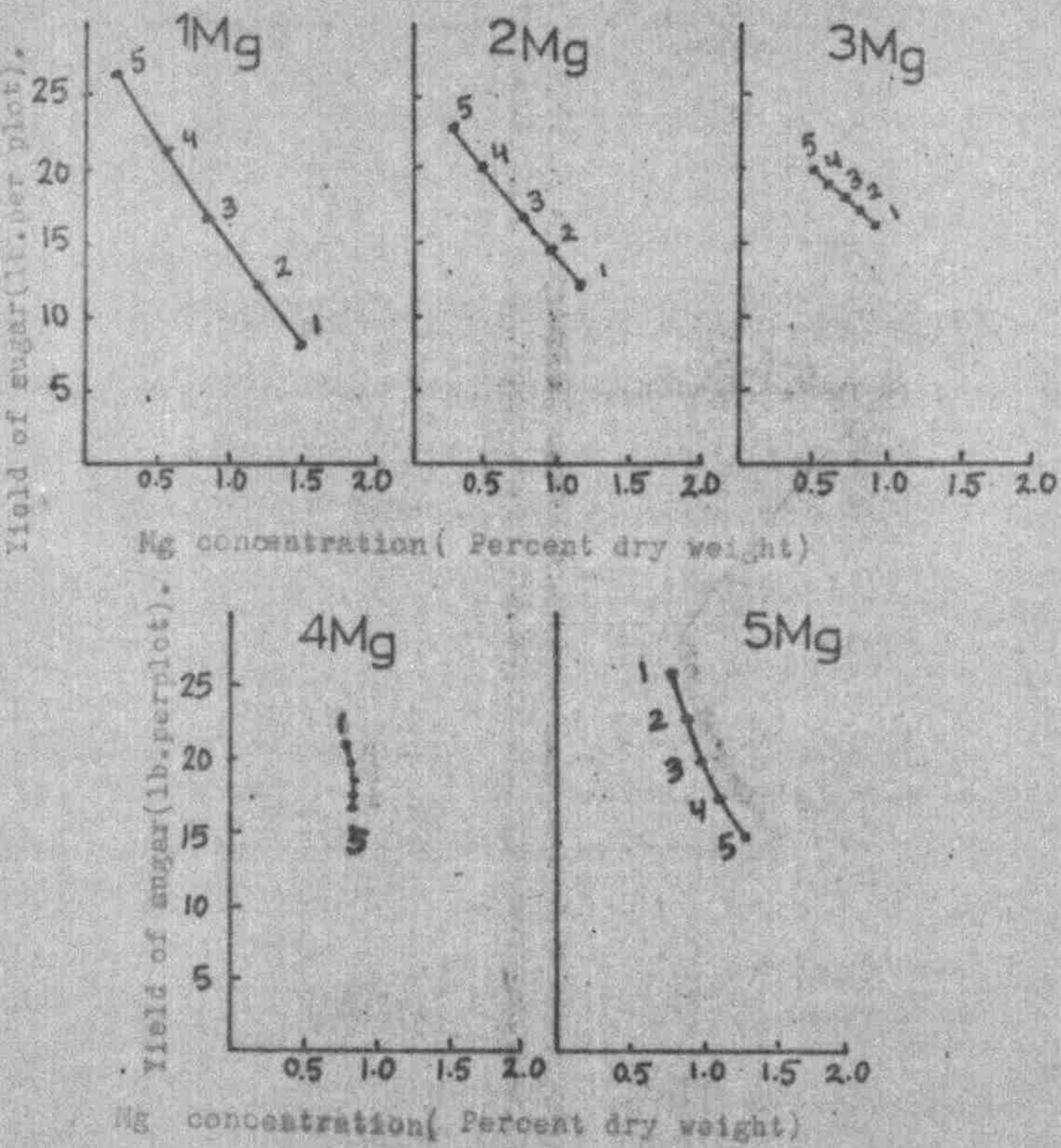

Figure 41. Relationship between yield of sugar(lb. per plot) and Mg concetration (percent dry weight) as affected by addition of different levels of Mg and Na with N, P and K held constant at the middle of the five levels (table 1). Numbers at points refer to levels of Na added. Level of Mg was held constant for each graph.

concentrations calculated from the regression equation (Table 27) was 0.814 indicating a close fit of the regression equation with the actual data.

The analysis of variance for Na concentration (Table 28) indicated that both linear and quadratic effects were not significant. The lack of fit term was not significant indicating no need for a higher order equation.

Examination of the individual regression coefficients for Na concentration (Table 29) indicated that none of the coefficients were statistically significant. All linear effects were positive in sign with N having the greatest effect followed by Mg and then Na. While not statistically significant, it seemed desirable to examine the Mg-N and Mg-Na interactions in order to determine the connection between yield of sugar and Na concentration of beet leaves. Examination of the relationships between yield of sugar and Na concentration of beet leaves as affected by the Mg-N interaction indicated that when the N supply was held constant (Fig. 42), increasing the Mg levels at the low levels of N resulted in a luxury Na consumption without any increase in yield of sugar. As the N level was raised to the 3N level, the Mg application slightly increased the yield of sugar and considerably increased the Na concentration. At higher levels of N, Mg application depressed the Na concentration and increased the yield of sugar. The same tendency was observed for the effect of N application on Na concentration at each of five levels of Mg (Fig. 43). The concentration of Na at the highest yield of sugar decreased from about 4.0 percent at low Mg

Table 28. Observed Na concentration of beet tops (percent dry weight) as affected by various levels of N, P, K, Mg and Na. Sodium concentrations for the same treatments calculated from the regression equation are given. Correlation of actual Na concentrations with calculated Na concentrations was 0.814.

Treatment levels N	P	K	Mg	Na	Actual Na concentration percent	Calculated concentration percent
2	2	2	2	4	1.374	1.561
4	2	2	2	2	2.655	2.439
2	4	2	2	2	2.205	2.151
4	4	2	2	4	3.064	3.002
2	2	4	2	2	1.747	1.514
4	2	4	2	4	3.366	3.357
2	4	4	2	4	2.063	2.241
4	4	4	2	2	3.534	3.239
2	2	2	4	2	3.021	2.925
4	2	2	4	4	3.204	3.115
2	4	2	4	4	3.348	3.889
4	4	2	4	2	2.942	2.637
2	2	4	4	4	2.915	2.995
4	2	4	4	2	3.091	3.042
2	4	4	4	2	2.456	2.225
4	4	4	4	4	3.306	3.151
5	3	3	3	3	2.715	3.296
1	3	3	3	3	2.401	2.184
3	5	3	3	3	2.388	2.118
3	1	3	3	3	2.145	1.778
3	3	5	3	3	2.501	2.782
3	3	1	3	3	2.633	2.714
3	3	3	5	3	2.728	3.100
3	3	3	1	3	2.228	2.220
3	3	3	3	5	3.780	3.480
3	3	3	3	1	2.089	2.752
3	3	3	3	3	3.127	2.496
3	3	3	3	3	2.119	2.496
3	3	3	3	3	2.708	2.496
3	3	3	3	3	1.583	2.496
3	3	3	3	3	1.959	2.496
3	3	3	3	3	2.843	2.496

Table 29. Analysis of variance for Na concentration of beet tops (percent dry weight).

Source	d. f.	S. S.	M. S.	F value
Linear effect	5	3.988	0.798	2.267
Quadratic effect	15	4.034	0.268	0.761
Lack of fit	6	0.764	0.127	0.361
Experimental error	5	1.760	0.352	
Total	31	10.546		

Table 30. Regression coefficients (b) and their standard errors (s_b) for Na concentration of beet tops (percent dry weight).

Coefficient		b	s_b
Mean	b_0	2.596	± 0.246
N	b_1	+ 0.278	± 0.120
P	b_2	+ 0.085	"
K	b_3	+ 0.017	"
Mg	b_4	+ 0.220	"
Na	b_5	+ 0.182	"
N^2	b_{11}	+ 0.061	± 0.109
P^2	b_{22}	- 0.137	"
K^2	b_{33}	+ 0.063	"
Mg^2	b_{44}	+ 0.041	"
Na^2	b_{55}	+ 0.155	"
N-P	b_{12}	- 0.030	± 0.148
N-K	b_{13}	+ 0.137	"
N-Mg	b_{14}	- 0.277	"
N-Na	b_{15}	+ 0.022	"
P-K	b_{23}	- 0.067	"
P-Mg	b_{24}	- 0.119	"
P-Na	b_{25}	+ 0.019	"
K-Mg	b_{34}	- 0.149	"
K-Na	b_{35}	+ 0.058	"
Mg-Na	b_{45}	+ 0.096	"

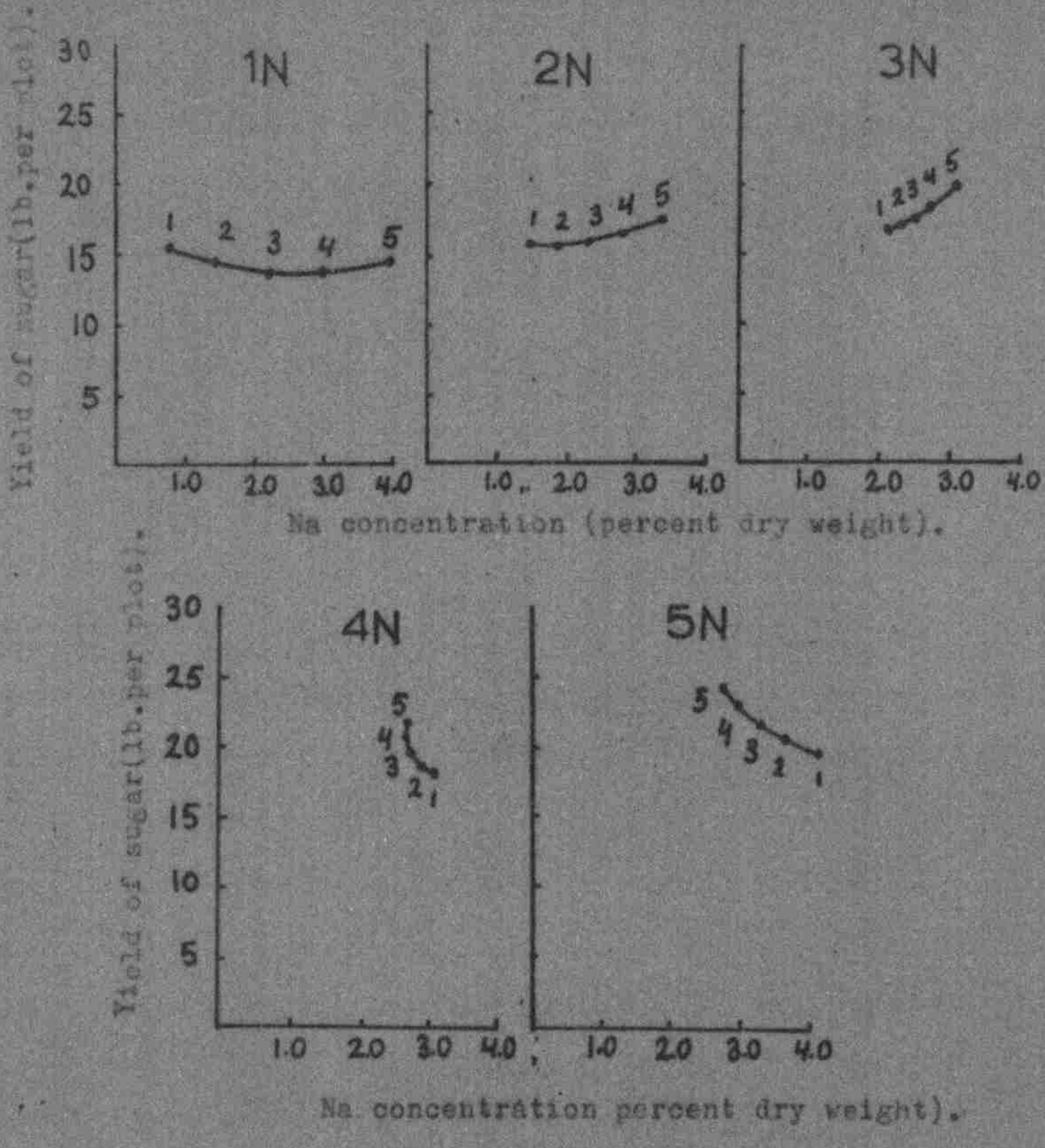

Figure 42. Relationship between yield of sugar (lb. per plot) and Na concentration (percent dry weight) as affected by addition of different levels of N and Mg with P, K and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of Mg added. Level of N was held constant for each graph.

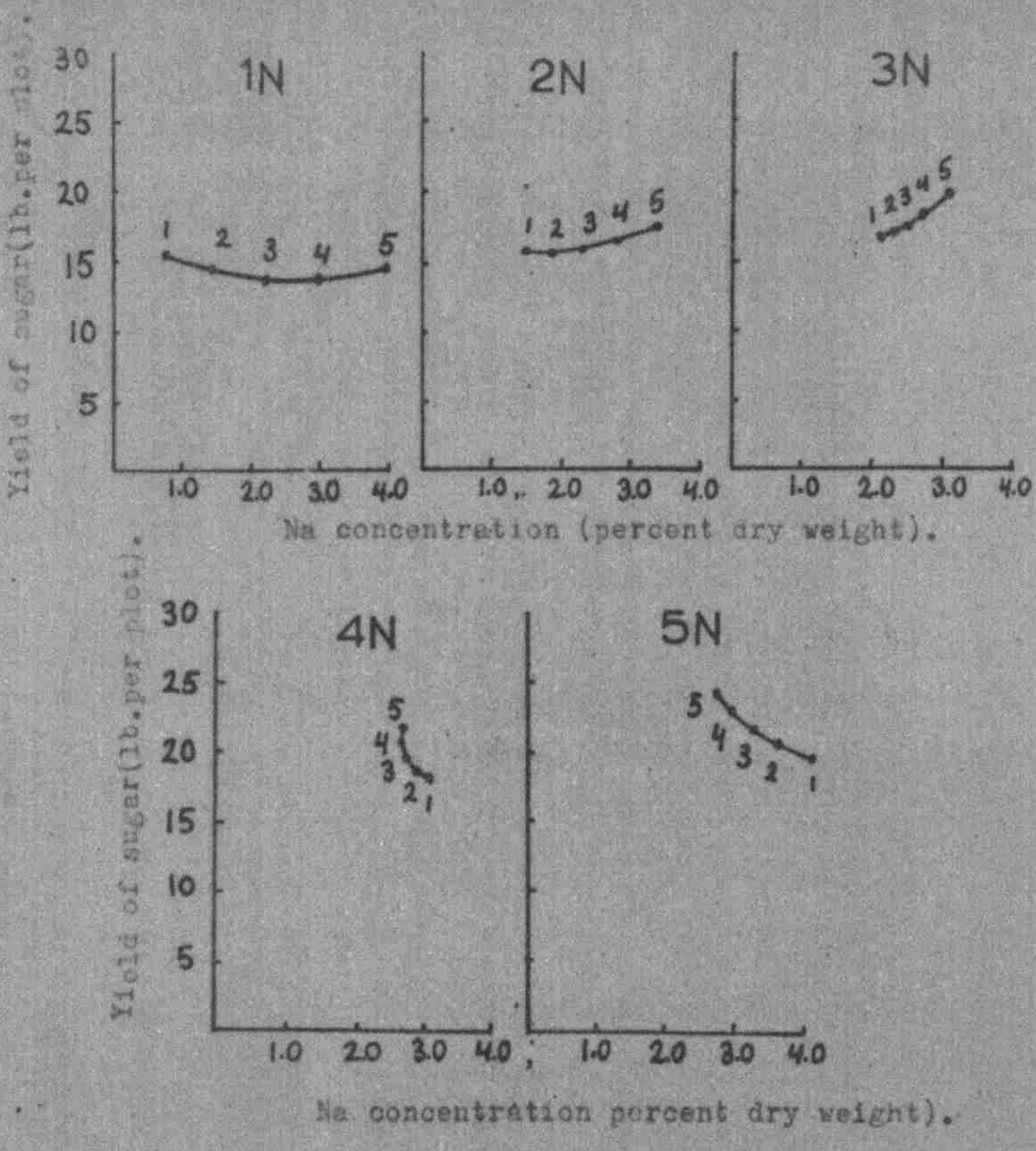

Figure 42. Relationship between yield of sugar (lb. per plot) and Na concentration (percent dry weight) as affected by addition of different levels of N and Mg with P, K and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of Mg added. Level of N was held constant for each graph.

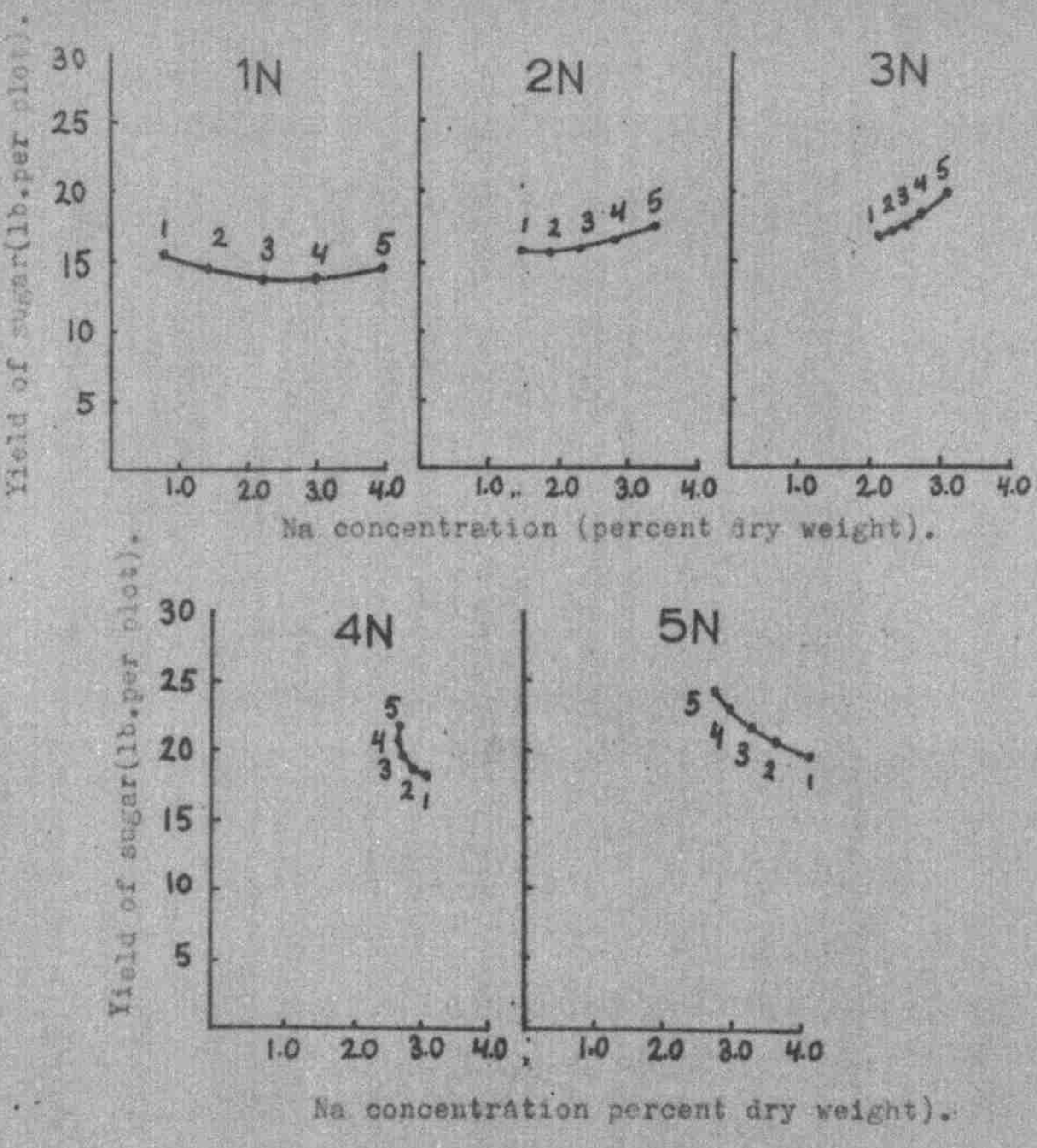

Figure 42. Relationship between yield of sugar (lb. per plot) and Na concentration (percent dry weight) as affected by addition of different levels of N and Mg with P, K and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of Mg added. Level of N was held constant for each graph.

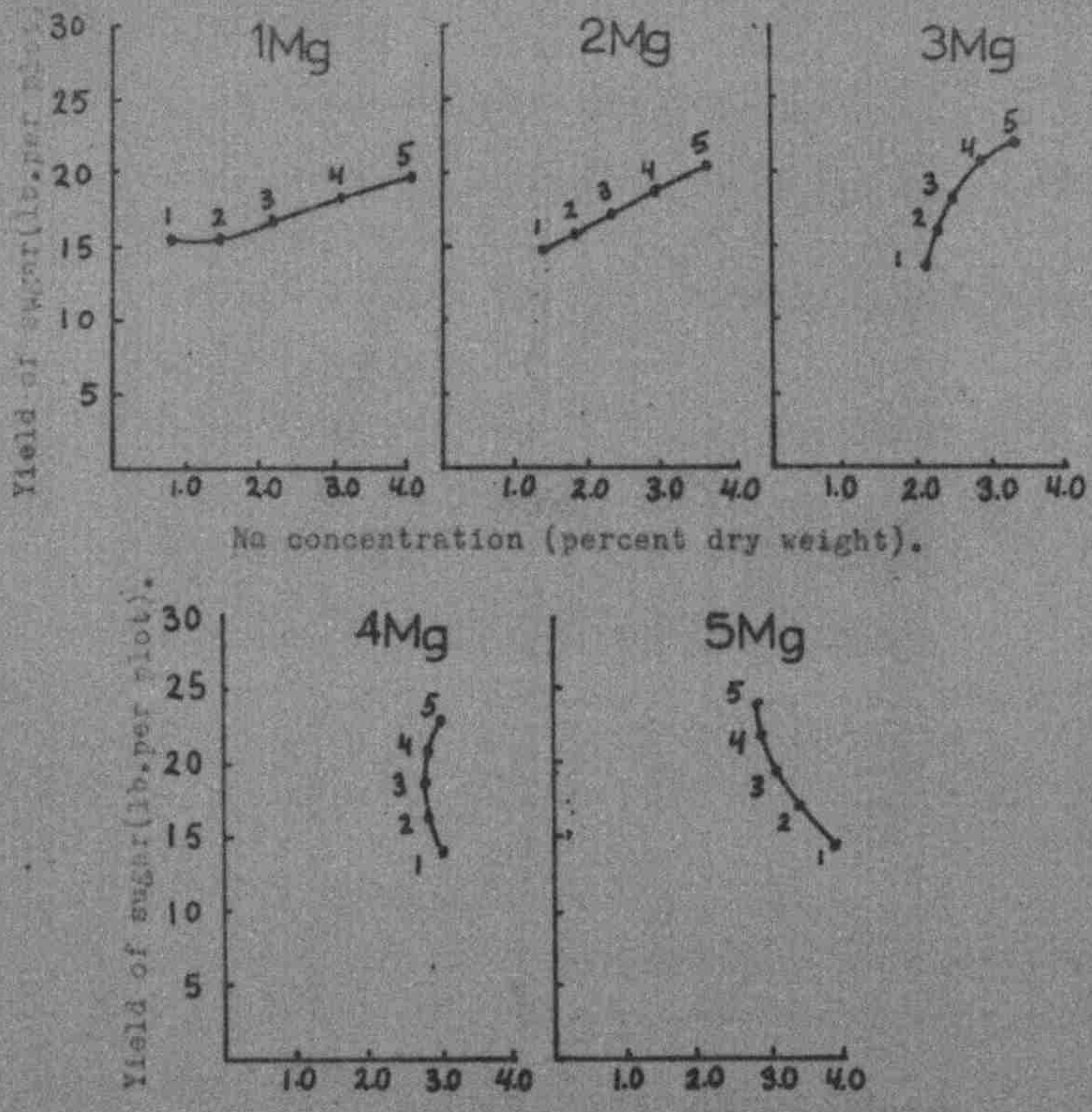

Figure 43. Relationship between yield of sugar (lb. per plot) and Na concentration (percent dry weight) as affected by addition of different levels of N and Mg with P, K and Na held constant at the middle of five levels (table 1). Numbers at points refer to the levels of N added . Level of Mg was held constant for each graph.

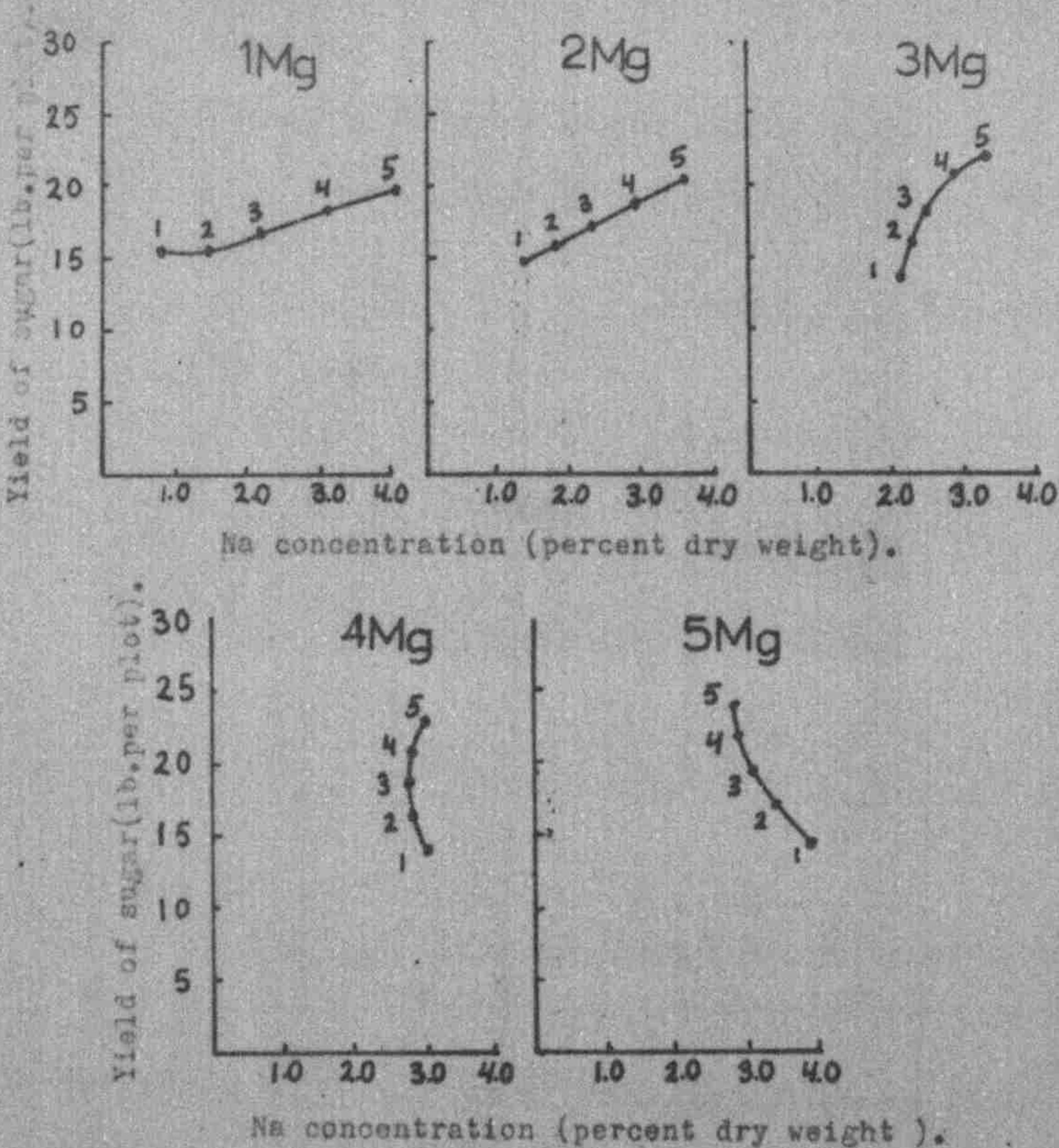

Figure 43. Relationship between yield of sugar (lb. per plot) and Na concentration (percent dry weight) as affected by addition of different levels of N and Mg with P, K and Na held constant at the middle of five levels (table 1). Numbers at points refer to the levels of N added . Level of Mg was held constant for each graph.

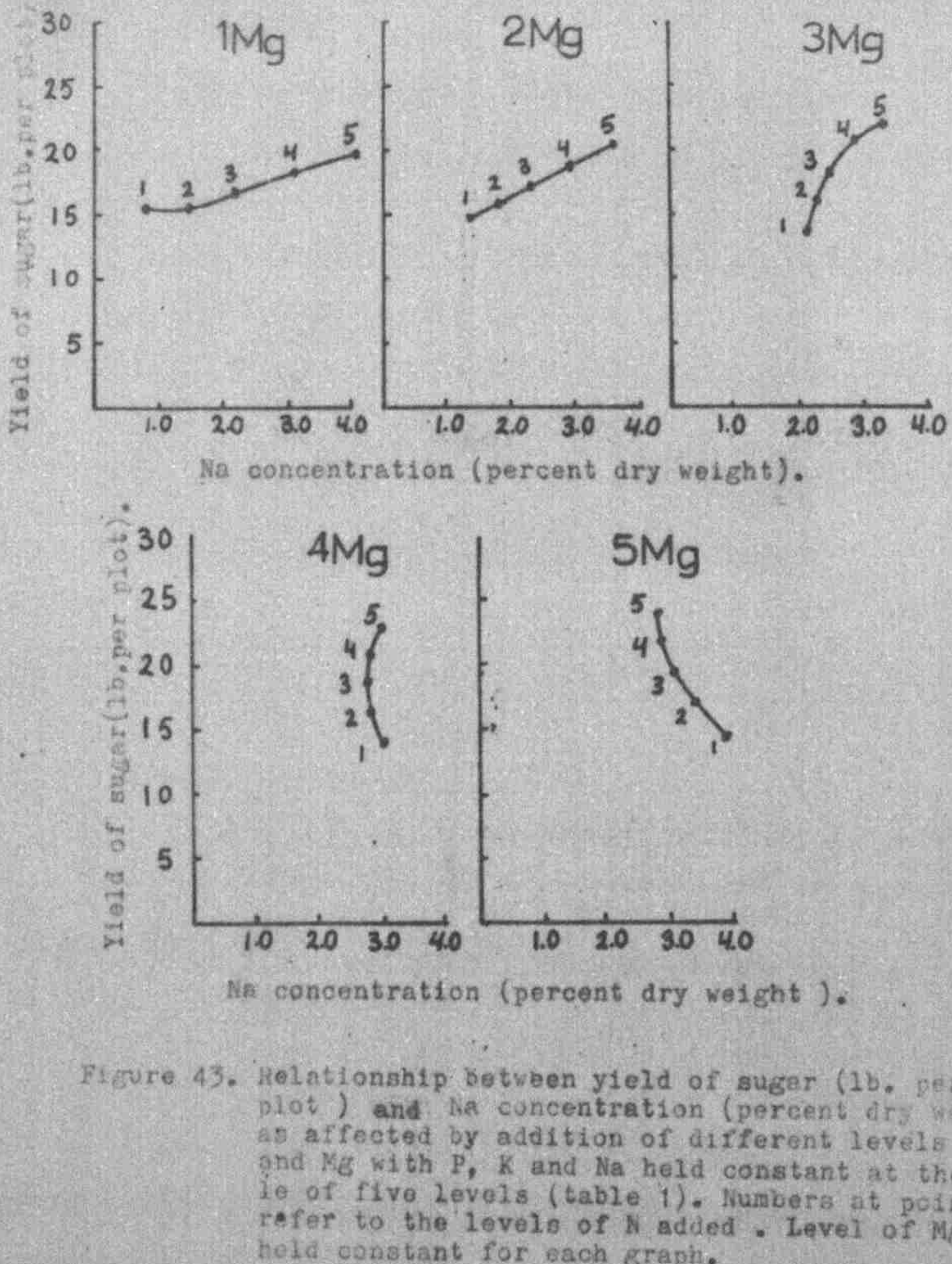

Figure 43. Relationship between yield of sugar (lb. per plot) and Na concentration (percent dry weight) as affected by addition of different levels of N and Mg with P, K and Na held constant at the middle of five levels (table 1). Numbers at points refer to the levels of N added . Level of Mg was held constant for each graph.

levels to about 3.0 percent at the high Mg level indicating that a balance existed between Mg and Na in the leaves.

Examination of the Na concentration and yield of sugar relationship as affected by the Mg-Na interaction (Fig. 44) indicated that increasing the Na rate at a low level of Mg considerably increased the yield of sugar while the Na concentration was not seriously affected. At high levels of Mg, the Na application tended to increase the Na concentration while the yield of sugar was depressed. When the Na level was kept constant (Fig. 45) the tendency for Mg application at low level of Na was to increase the yield of sugar without affecting the Na concentration. However, at high levels of Na, the Mg application considerably depressed the yield of sugar while the Na concentration was increased. In general (Fig. 44 and 45), the yield of sugar was not definitely related to the Na concentration of the leaves.

Calcium Concentration of Beet Tops

The correlation coefficient between actual Ca concentrations and Ca concentrations calculated from the regression equation (Table 30) was 0.570 indicating an incomplete fit of the regression equation to the actual data.

The analysis of variance for Ca concentration (Table 31) indicated that both linear and quadratic effects were not significant. The lack of fit term was also not significant indicating no need for higher order equation.

Examination of the regression coefficients (Table 32) indicated

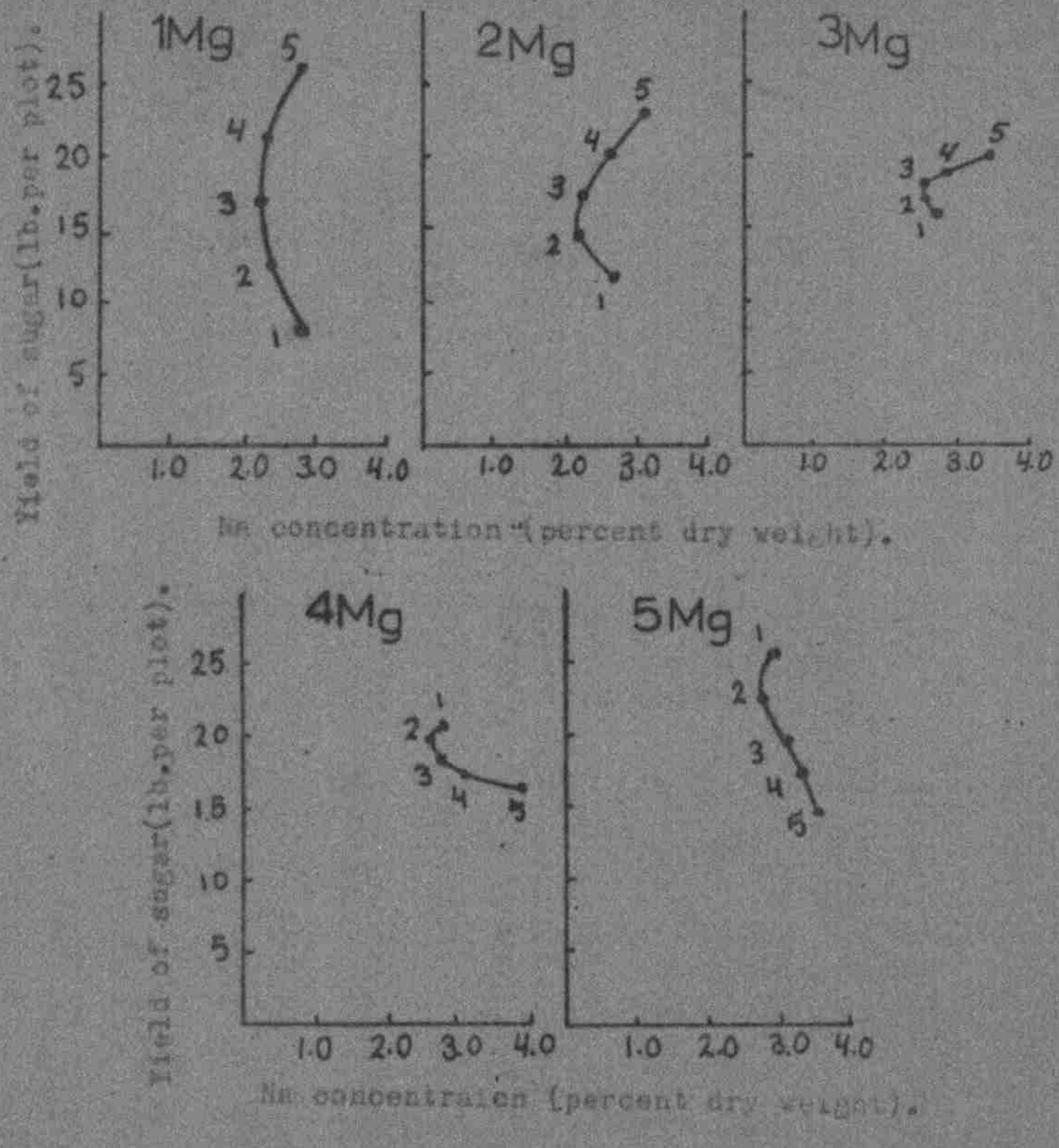

Figure 44. Relationship between yield of sugar (lb. per plot)and Na concentration (percent dry weight) as affected by addition of different levels of Mg and Na with the levels of N, P and K held constant at the middle of five levels (Table 1). Numbers of points refer to the levels of Na added. Level of Mg was held constant for each graph.

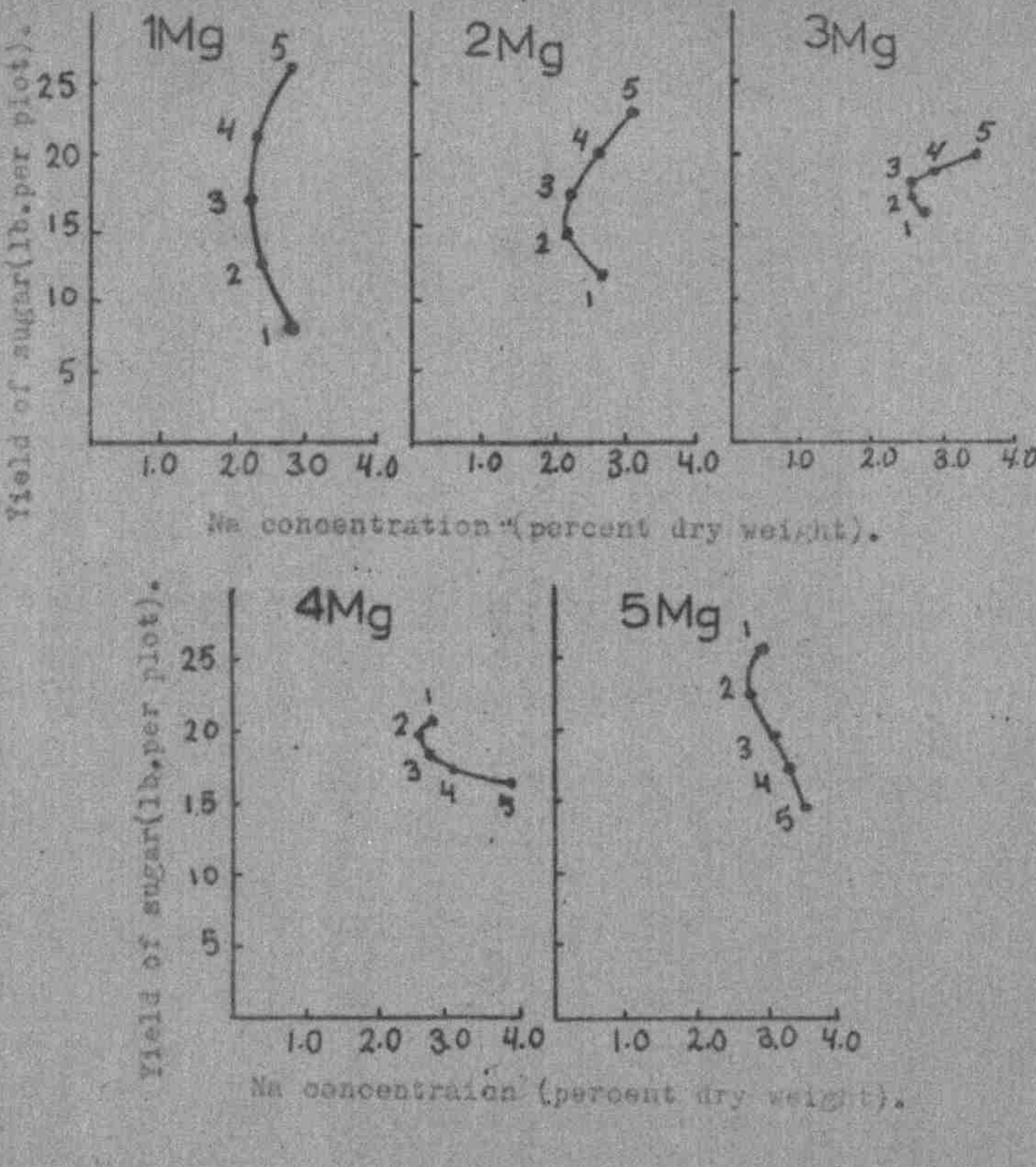

Figure 44. Relationship between yield of sugar (lb. per plot)and Na concentration (percent dry weight) as affected by addition of different levels of Mg and Na with the levels of N, P and K held constant at the middle of five levels (Table 1). Numbers at points refer to the levels of Na added. Level of Mg was held constant for each graph.

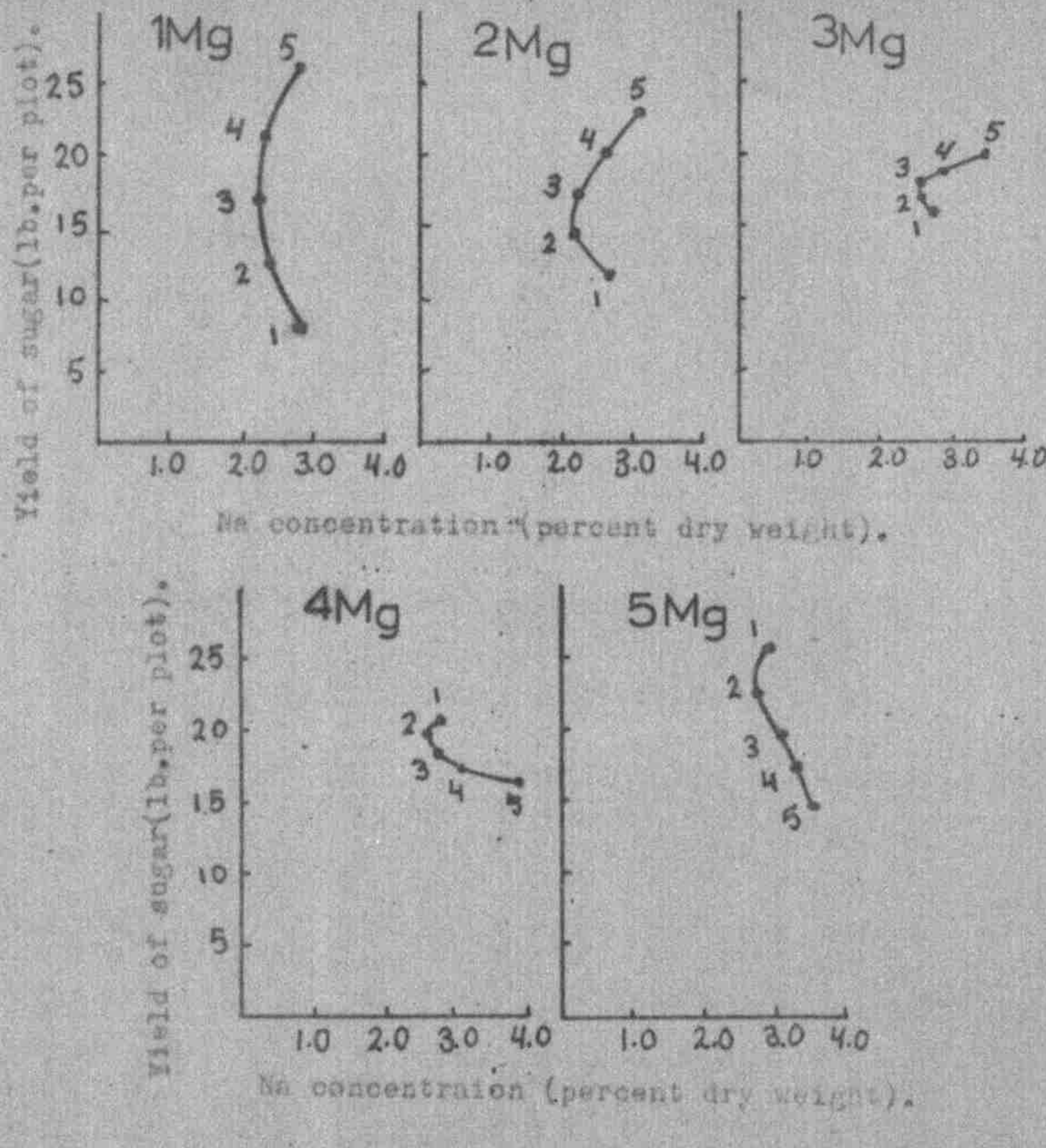

Figure 44. Relationship between yield of sugar (lb. per plot)and Na concentration (percent dry weight) as affected by addition of different levels of Mg and Na with the levels of N, P and K held constant at the middle of five levels (Table 1). Numbers at points refer to the levels of Na added. Level of Mg was held constant for each graph.

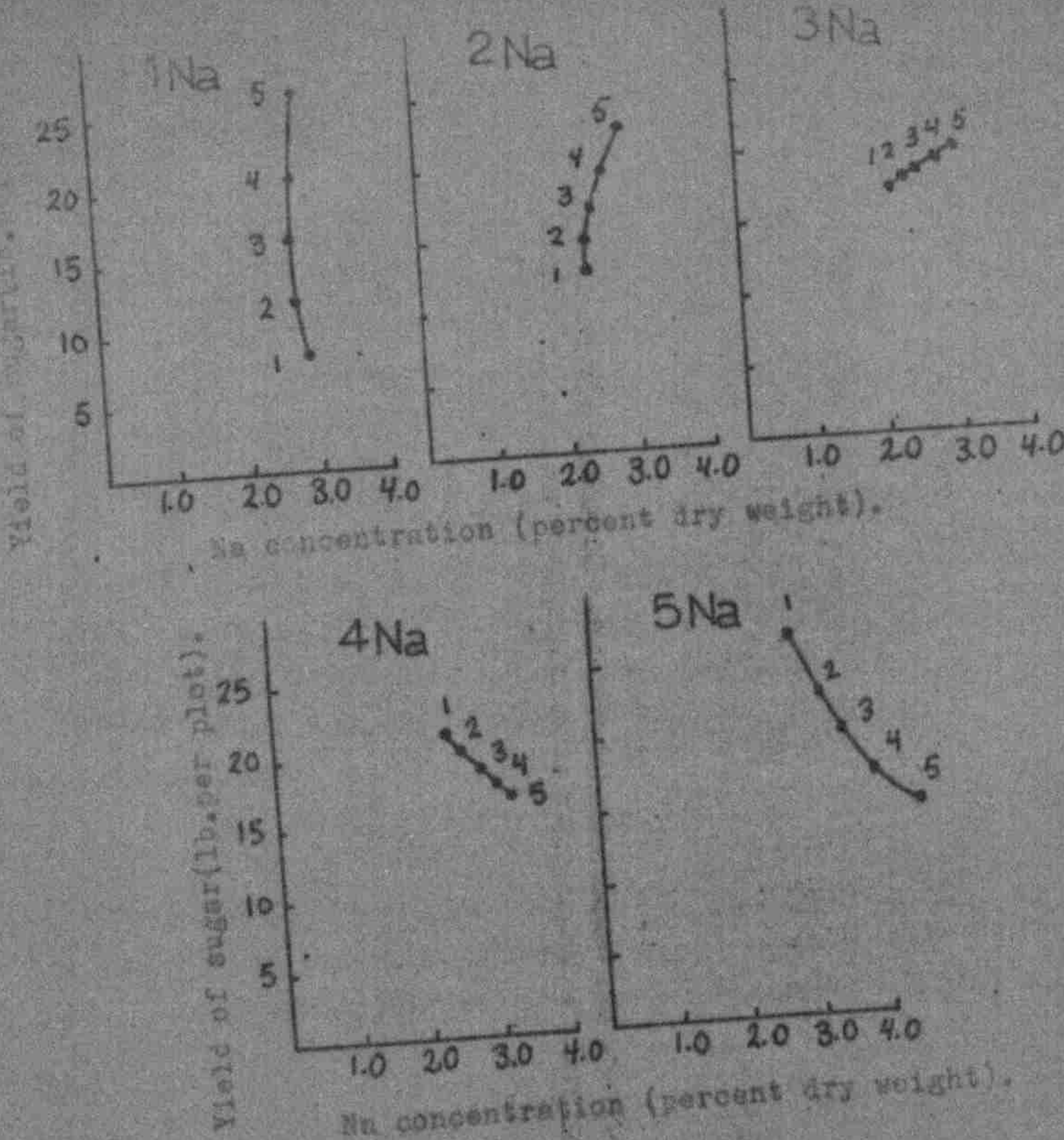

Figure 43. Relationship between yield of sugar (lb. per plot) and Na concentration (percent dry weight) as affected by addition of different levels of Mg and Na with the levels of N, P and K held constant at the middle of five levels (Table 1). Numbers of points refer to levels of Na added. Level of Mg was held constant for each graph.

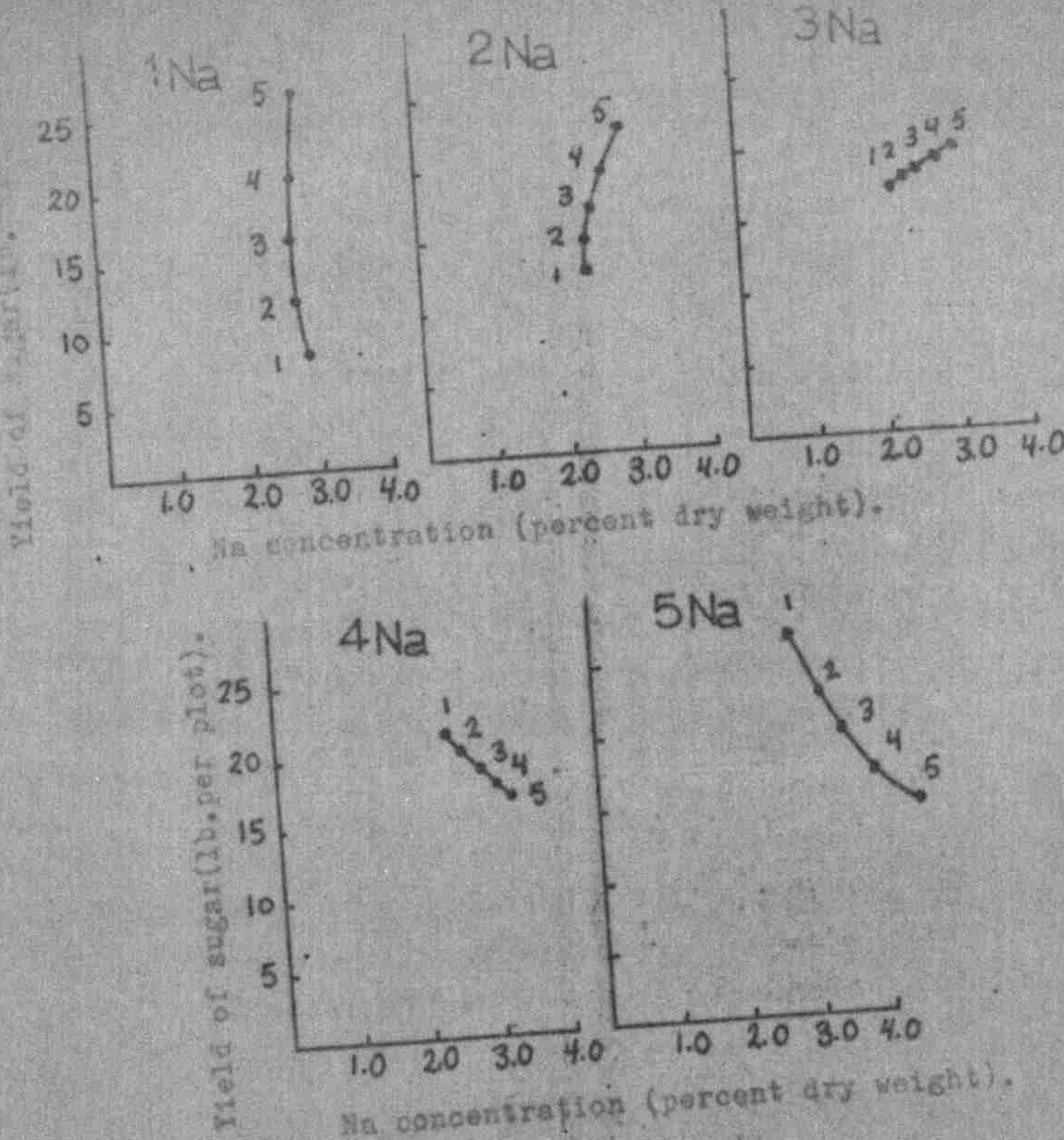

Figure 45. Relationship between yield of sugar (lb. per plot) and Na concentration (percent dry weight) as affected by addition of different levels of Mg and Na with the levels of N, P and K held constant at the middle of five levels (Table 1). Numbers at points refer to levels of Na added. Level of Mg was held constant for each graph.

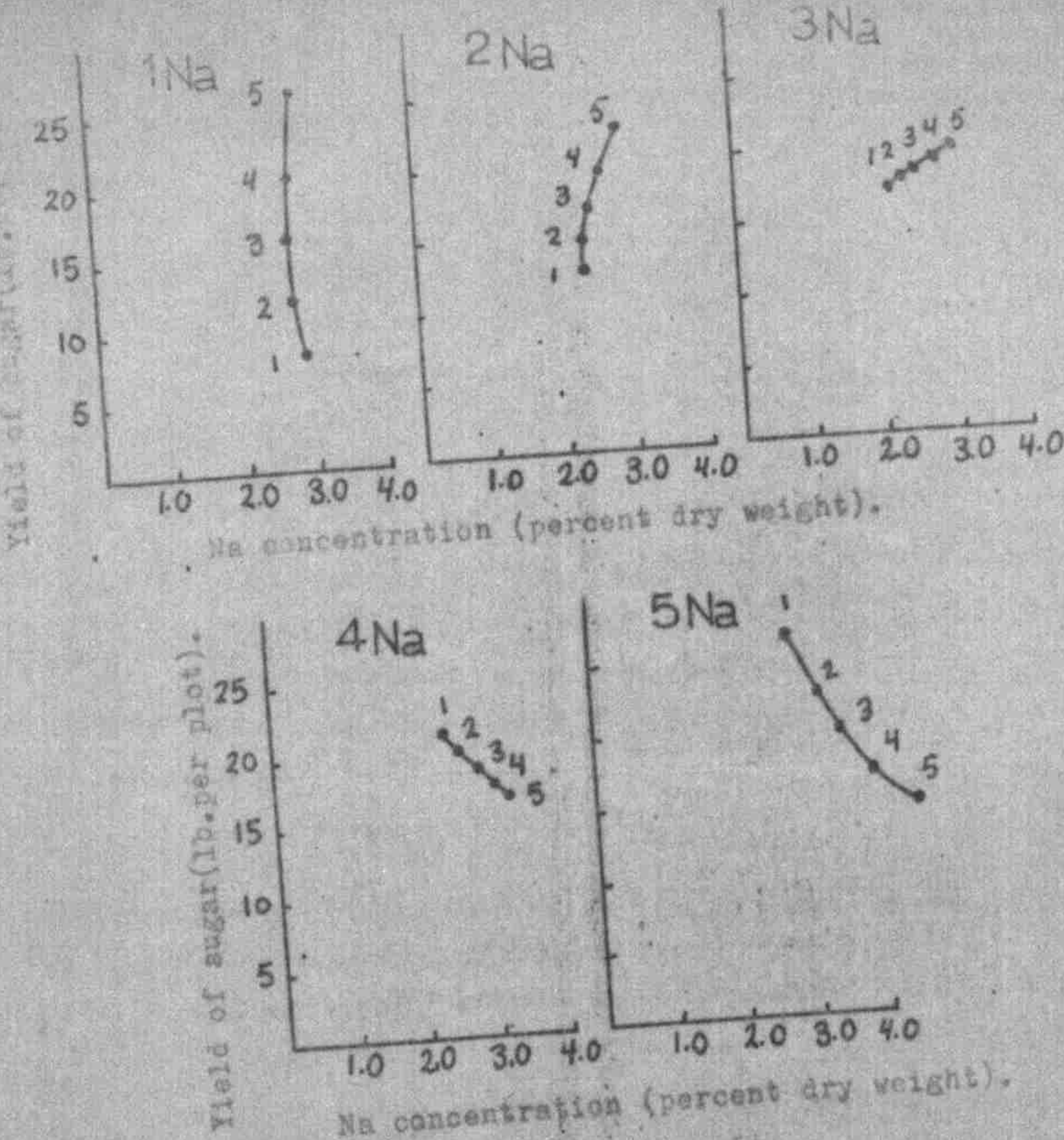

Figure 45. Relationship between yield of sugar (lb. per plot) and Na concentration (percent dry weight) as affected by addition of different levels of Mg and Na with the levels of N, P and K held constant at the middle of five levels (Table 1). Numbers at points refer to levels of Na added. Level of Mg was held constant for each graph.

Table 31. Observed Ca concentration of beet tops (percent dry weight) as affected by various levels of N, P, K, Mg and Na. Calcium concentrations for the same treatments calculated from the regression equation are given. Correlation of actual Ca concentrations with calculated Ca concentrations was 0.570.

Treatment levels N	P	K	Mg	Na	Actual Ca concentration percent	Calculated Ca concentration percent
2	2	2	2	4	1.54	1.66
4	2	2	2	2	2.02	1.96
2	4	2	2	2	2.00	1.97
4	4	2	2	4	1.36	1.25
2	2	4	2	2	1.52	1.58
4	2	4	2	4	1.62	1.70
2	4	4	2	4	1.00	1.11
4	4	4	2	2	1.83	1.66
2	2	2	4	2	1.83	1.88
4	2	2	4	4	1.47	1.55
2	4	2	4	4	1.43	1.53
4	4	2	4	2	1.38	1.21
2	2	4	4	4	1.58	1.78
4	2	4	4	2	1.64	1.67
2	4	4	4	2	1.38	1.14
4	4	4	4	4	1.26	1.13
5	3	3	3	3	1.44	1.35
1	3	3	3	3	1.83	1.53
3	5	3	3	3	1.48	1.64
3	1	3	3	3	2.49	2.24
3	3	5	3	3	1.66	1.53
3	3	1	3	3	1.69	1.74
3	3	3	5	3	1.47	1.35
3	3	3	1	3	1.47	1.50
3	3	3	3	5	1.50	1.41
3	3	3	3	1	1.80	1.80
3	3	3	3	3	1.95	1.76
3	3	3	3	3	1.73	1.76
3	3	3	3	3	2.07	1.76
3	3	3	3	3	1.56	1.76
3	3	3	3	3	1.67	1.76
3	3	3	3	3	1.58	1.76

Table 32. Analysis of variance for Ca concentration (percent dry weight).

Source	d. f.	S. S.	M. S.	F value
Linear effect	5	0.92	0.1840	4.18
Quadratic effect	15	1.00	0.0667	1.51
Lack of fit	6	0.51	0.0850	1.72
Experimental error	5	0.22	0.0440	
Total	31	2.65		

Table 33. Regression coefficients (b) and their standard errors (s_b) for Ca concentration of beet tops (percent dry weight).

Coefficient		b	s_b
Mean	b_0	1.765	± 0.087
N	b_1	- 0.045	± 0.043
P	b_2	- 0.150 *	"
K	b_3	- 0.052	"
Mg	b_4	- 0.038	"
Na	b_5	- 0.097	"
N^2	b_{11}	- 0.080	± 0.039
P^2	b_{22}	+ 0.045	"
K^2	b_{33}	- 0.032	"
Mg^2	b_{44}	- 0.084	"
Na^2	b_{55}	- 0.039	"
N-P	b_{12}	- 0.042	± 0.052
N-K	b_{13}	+ 0.090	"
N-Mg	b_{14}	- 0.077	"
N-Na	b_{15}	+ 0.001	"
P-K	b_{23}	- 0.012	"
P-Mg	b_{24}	- 0.035	"
P-Na	b_{25}	- 0.046	"
K-Mg	b_{34}	+ 0.044	"
K-Na	b_{35}	+ 0.032	"
Mg-Na	b_{45}	+ 0.085	"

* Significant at odds of 19:1

Table 33. Regression coefficients (b) and their standard errors (s_b) for Ca concentration of beet tops (percent dry weight).

Coefficient		b	s_b
Mean	b_0	1.765	± 0.087
N	b_1	- 0.045	± 0.043
P	b_2	- 0.150 *	"
K	b_3	- 0.052	"
Mg	b_4	- 0.038	"
Na	b_5	- 0.097	"
N^2	b_{11}	- 0.080	± 0.039
P^2	b_{22}	+ 0.045	"
K^2	b_{33}	- 0.032	"
Mg^2	b_{44}	- 0.084	"
Na^2	b_{55}	- 0.039	"
N-P	b_{12}	- 0.042	± 0.052
N-K	b_{13}	+ 0.090	"
N-Mg	b_{14}	- 0.077	"
N-Na	b_{15}	+ 0.001	"
P-K	b_{23}	- 0.012	"
P-Mg	b_{24}	- 0.035	"
P-Na	b_{25}	- 0.046	"
K-Mg	b_{34}	+ 0.044	"
K-Na	b_{35}	+ 0.032	"
Mg-Na	b_{45}	+ 0.085	"

* Significant at odds of 19:1

that all linear effects were negative in sign. The negative effect of P was significant. Although none of the quadratic effects were found to be significant, the Mg-Na and N-K positive interactions were the greatest in magnitude and were examined further.

The relationship determined between Ca content of beets tops and yield of sugar as affected by the Mg-Na interaction indicated (Fig. 46) that at low levels of Mg, the Ca concentration of beet leaves decreased with increasing Na applications, whereas at high Mg levels, the Ca concentration was increased with increasing Na applications. The yield of sugar was negatively correlated with Ca concentration. When the Na level was kept constant (Fig. 47) the tendency was for the first increments of Mg to increase the Ca concentration while further increments of Mg depressed it. In general the yield of sugar was negatively correlated with the Ca content. As expected, under the conditions of the experiment (calcareous soil) where the Ca supply was abundant (Table 3), the application of other cations depressed the uptake of Ca (Fig. 46, 47, and 48) and consequently counterbalanced the injurious effect of an abundant Ca supply. The negative correlation between yield of sugar and Ca concentration was evidence for this hypothesis.

Examination of the effect of the N-K interaction on the Ca concentration of leaves in relation to yield of sugar revealed (Fig. 48) that when N was kept constant, K application considerably depressed the Ca concentration at low levels of N and increased it at high levels

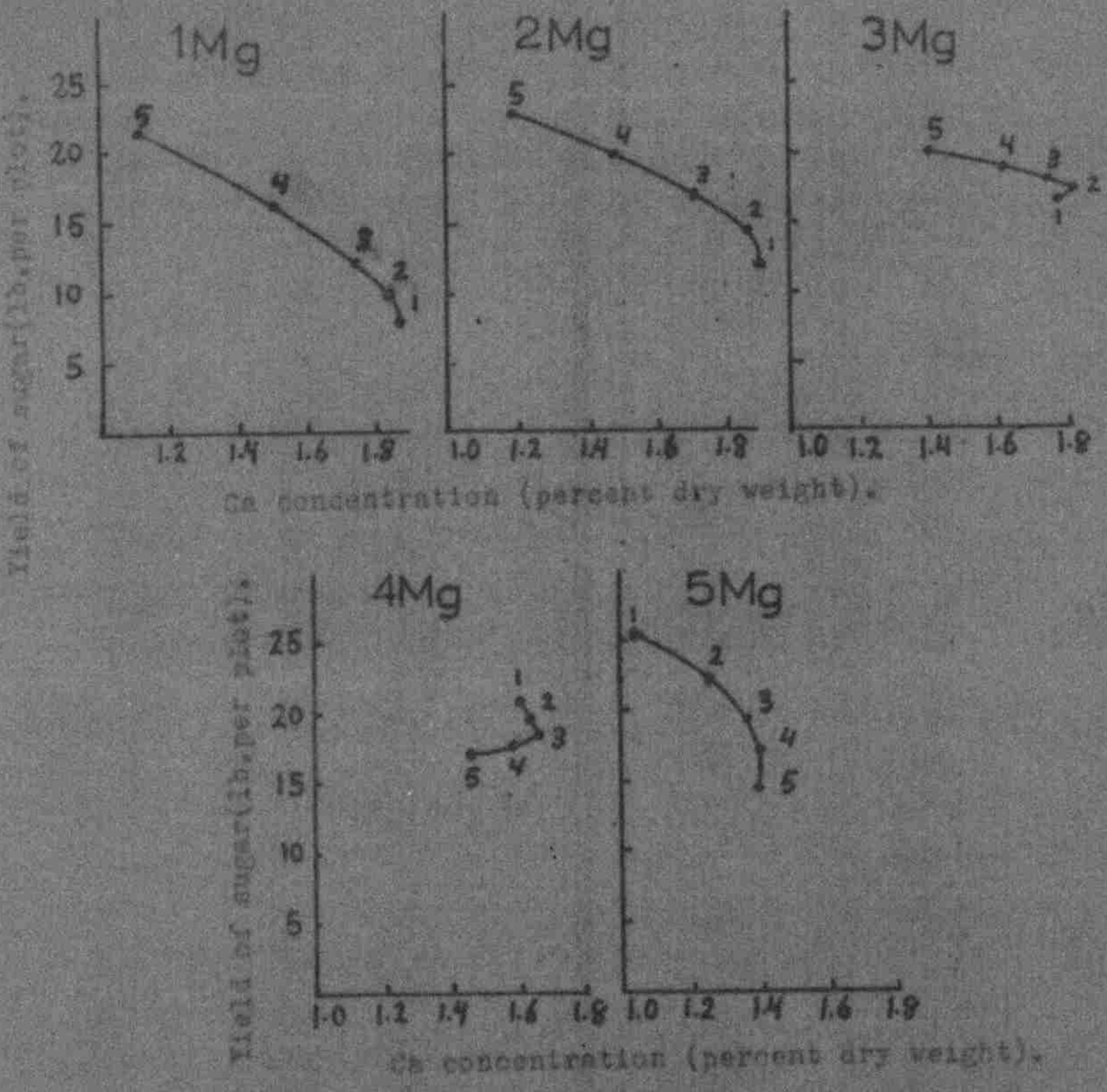

Figure 46. Relationship between yield of sugar (lb. per plot) and Ca concentration (percent dry weight) as affected by addition of different levels of Mg and Na with the levels of N, P and K held constant at the middle of five levels (Table 1). Numbers at points refer to level of Na added. Level of Mg was held constant for each graph.

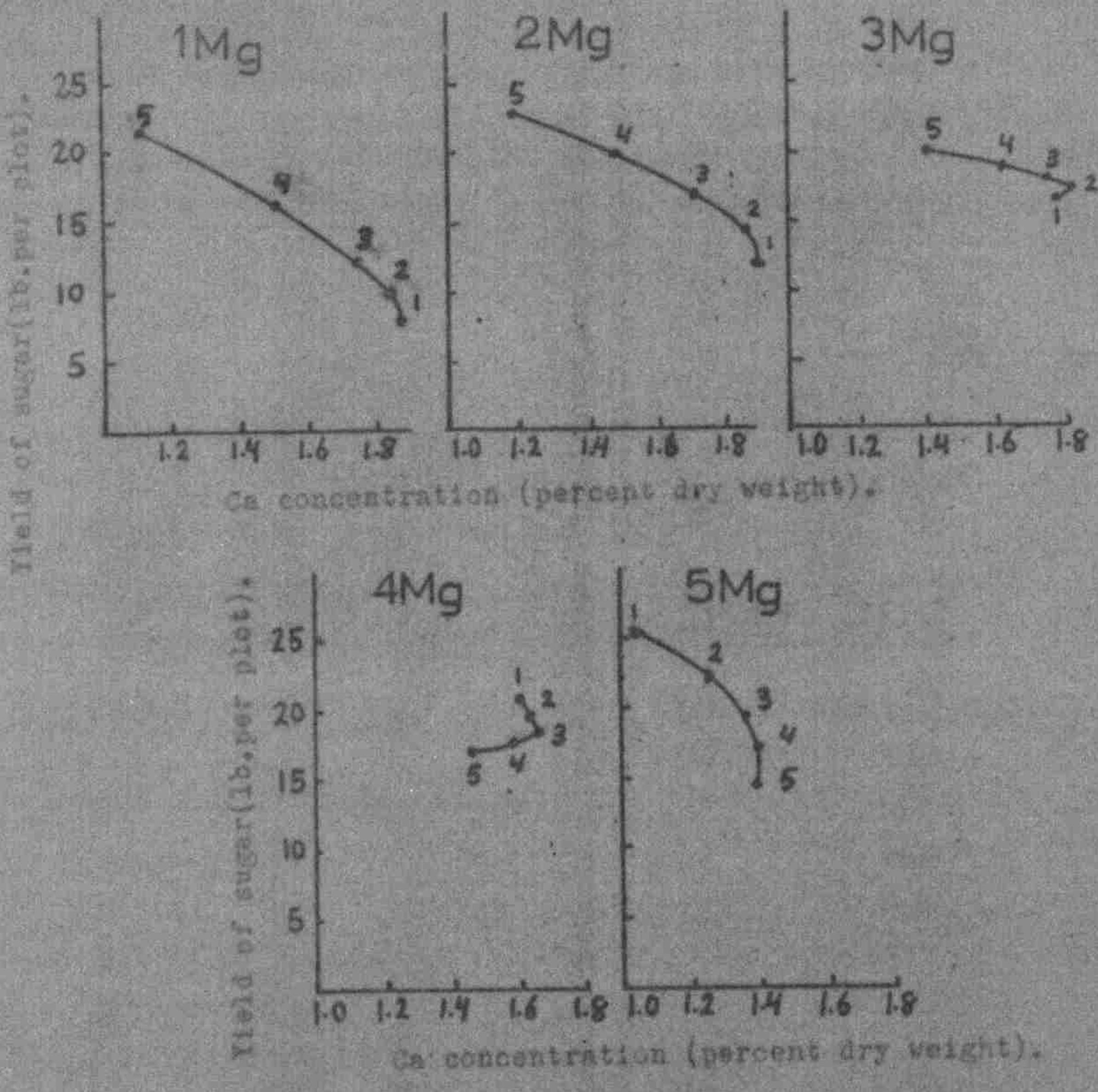

Figure 46. Relationship between yield of sugar (lb. per plot) and Ca concentration (percent dry weight) as affected by addition of different levels of Mg and Na with the levels of N, P and K held constant at the middle of five levels (Table 1). Numbers at points refer to level of Na added. Level of Mg was held constant for each graph.

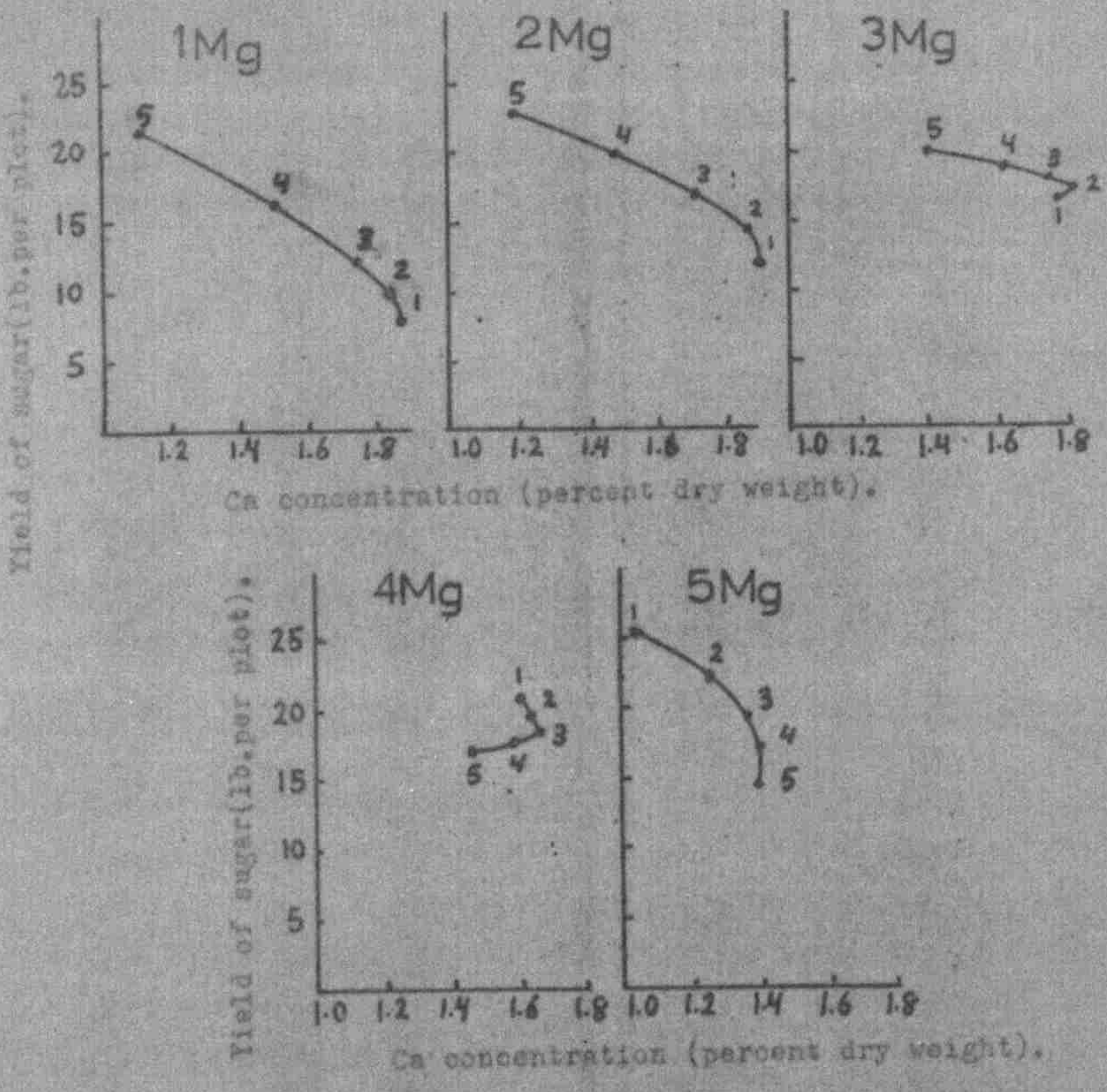

Figure 46. Relationship between yield of sugar (lb. per plot) and Ca concentration (percent dry weight) as affected by addition of different levels of Mg and Na with the levels of N, P and K held constant at the middle of five levels (Table 1). Numbers at points refer to level of Na added. Level of Mg was held constant for each graph.

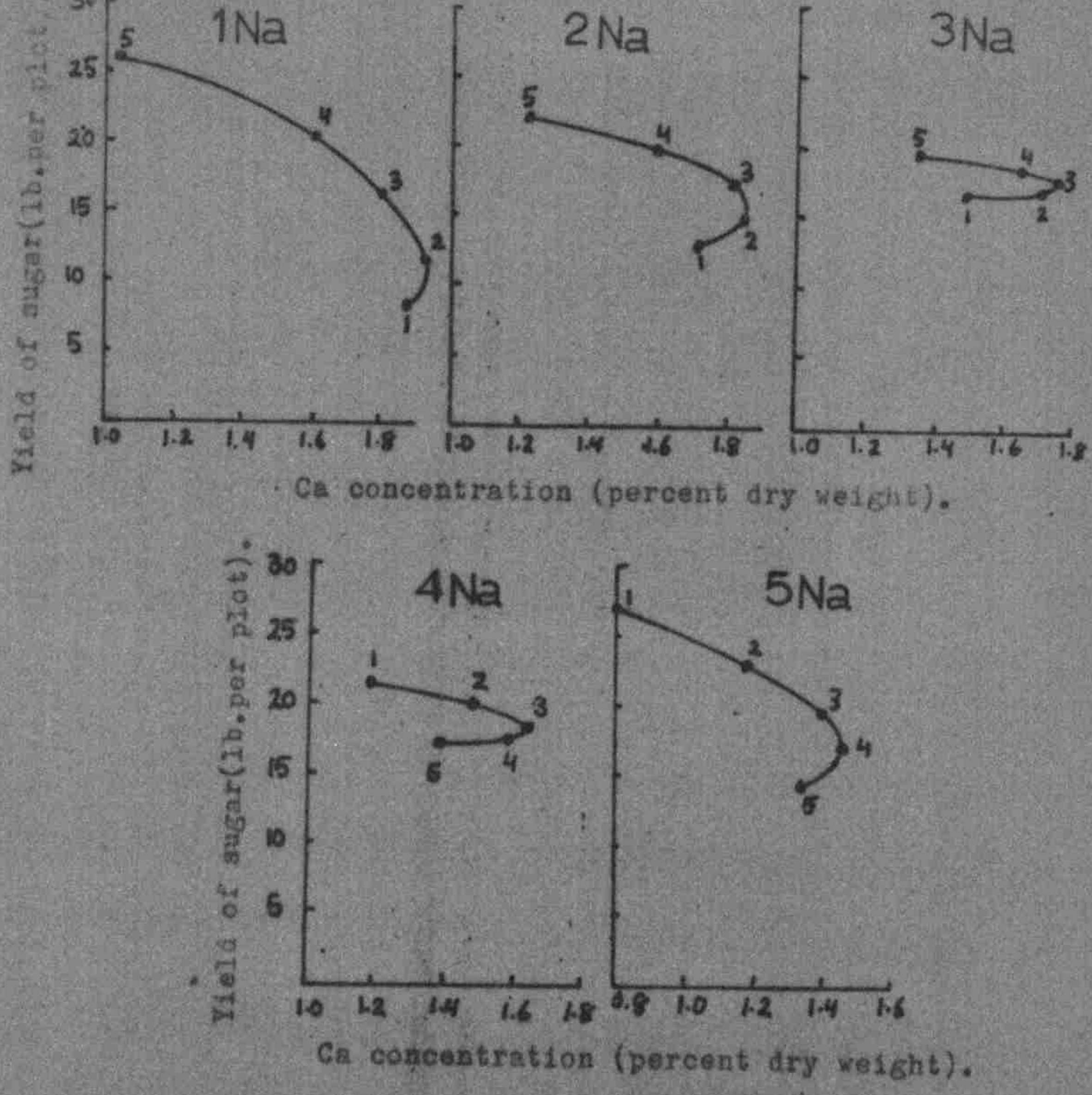

Figure 47. Relationship between yield of sugar (lb. per plot)and Ca concentraion (percent dry weight) as affected by addition of different levels of Mg and Na with the levels of N, P and K held constant at the middle of five levels (Table 1). Numbers at points refer to the levels of Mg added. Level of Na was held constant for each graph.

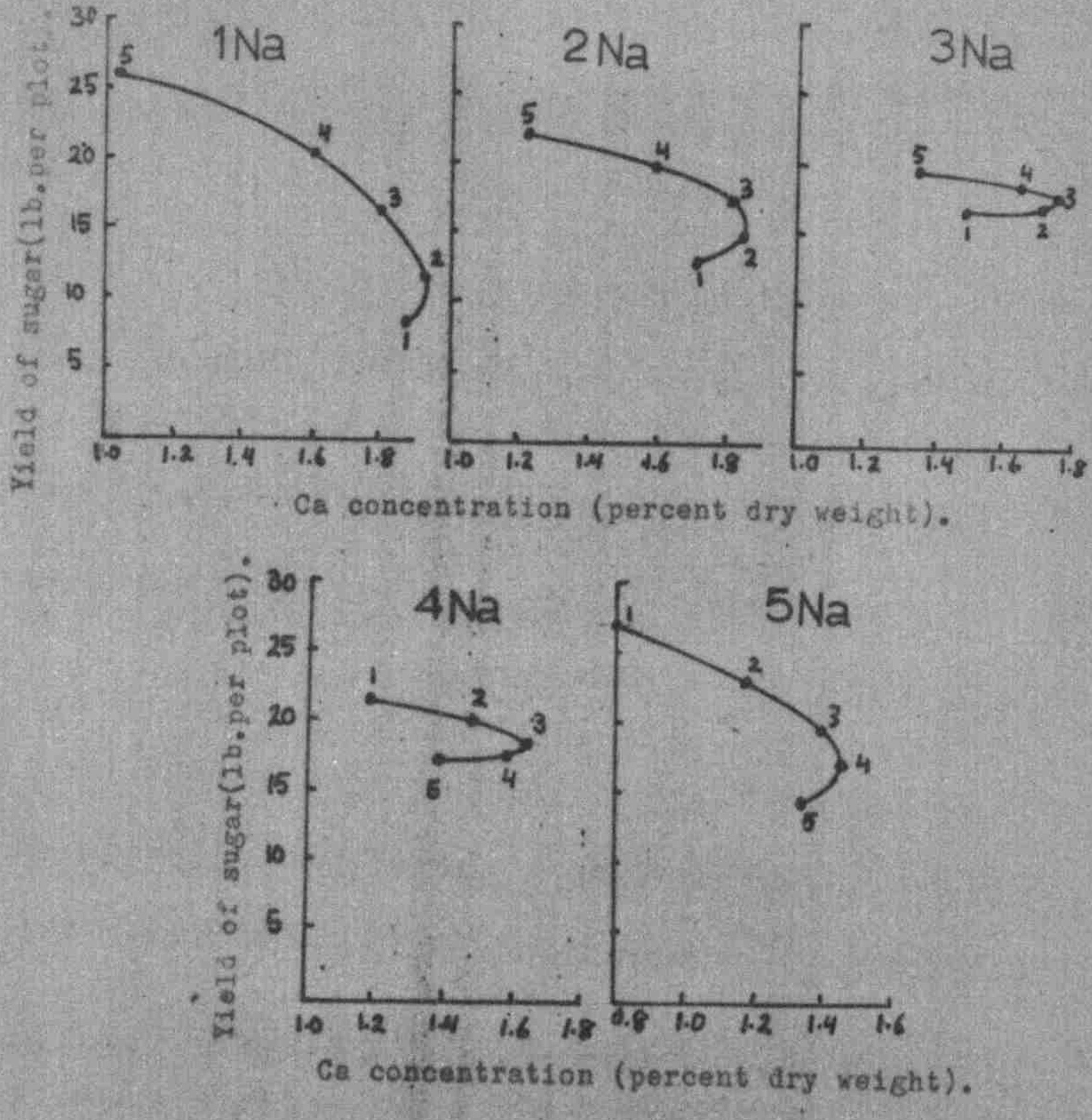

Figure 47. Relationship between yield of sugar (lb. per plot)and Ca concentraion (percent dry weight) as affected by addition of different levels of Mg and Na with the levels of N, P and K held constant at the middle of five levels (Table 1). Numbers at points refer to the levels of Mg added. Level of Na was held constant for each graph.

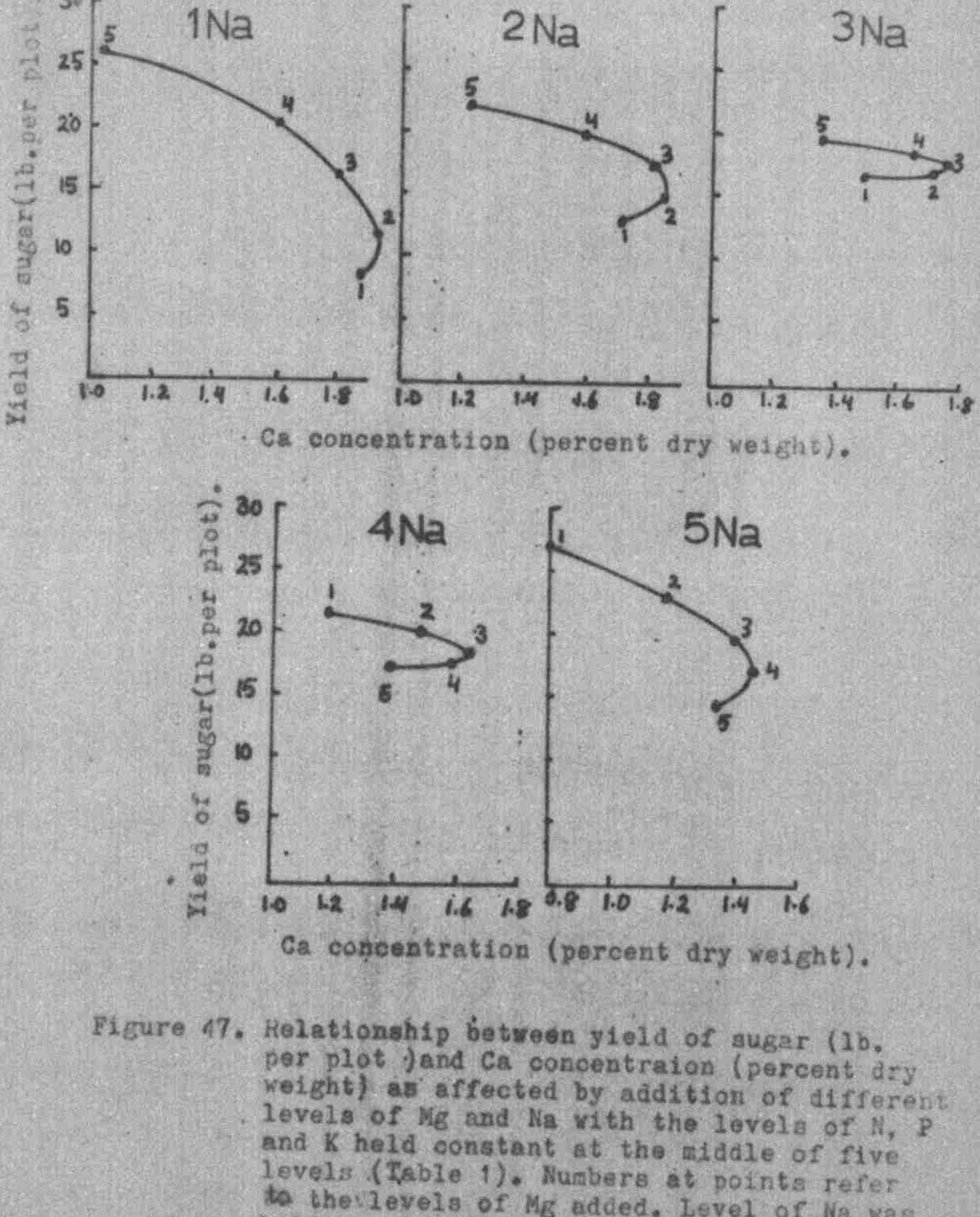

Figure 47. Relationship between yield of sugar (lb. per plot)and Ca concentraion (percent dry weight) as affected by addition of different levels of Mg and Na with the levels of N, P and K held constant at the middle of five levels (Table 1). Numbers at points refer to the levels of Mg added. Level of Na was held constant for each graph.

of N. Yield of sugar was increased with the first 3 increment of K and remained constant or decreased for further K increments. A possible critical level ranging from 1.4-1.6 percent for Ca concentration was observed (Fig. 48). When the K level was held constant, the Ca concentration was increased (Fig. 49) with increasing N application at low levels of K. However, at a high level of K the tendency was for Ca concentration to be decreased with increasing N application. In general, the yield of sugar decreased with increasing Ca concentration but at the high level of K, the yield increased with increasing Ca concentration.

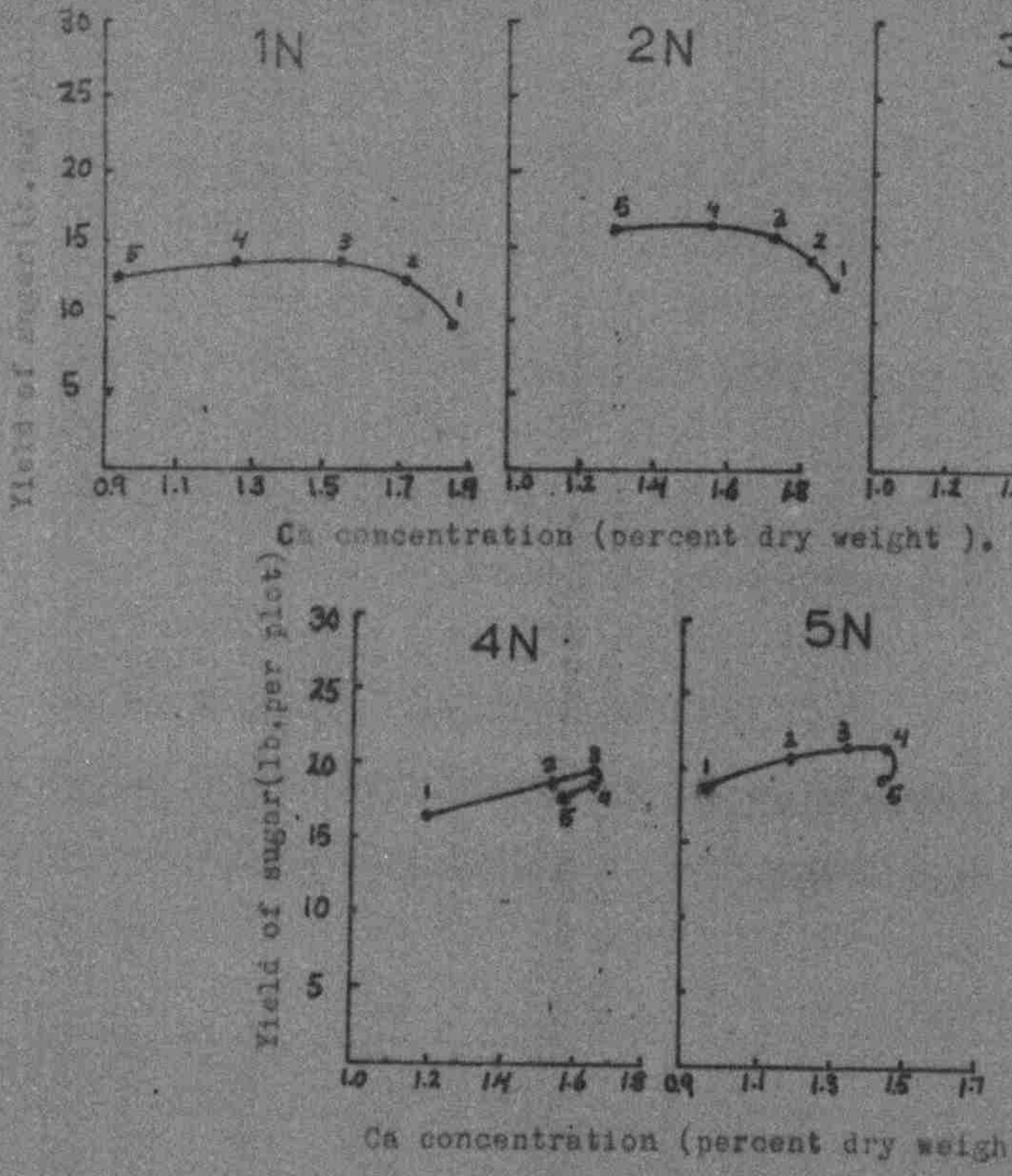

Figure 48. Relationship between yield of sugar (lb. per plot) and Ca concentration(percent dry weight) as affected by addition of different levels of N and K with the levels of P, Mg and Na held constant at the middle of five levels (Table 1). Numbers at points refer to the level of K added . Level of N was held constant for each graph.

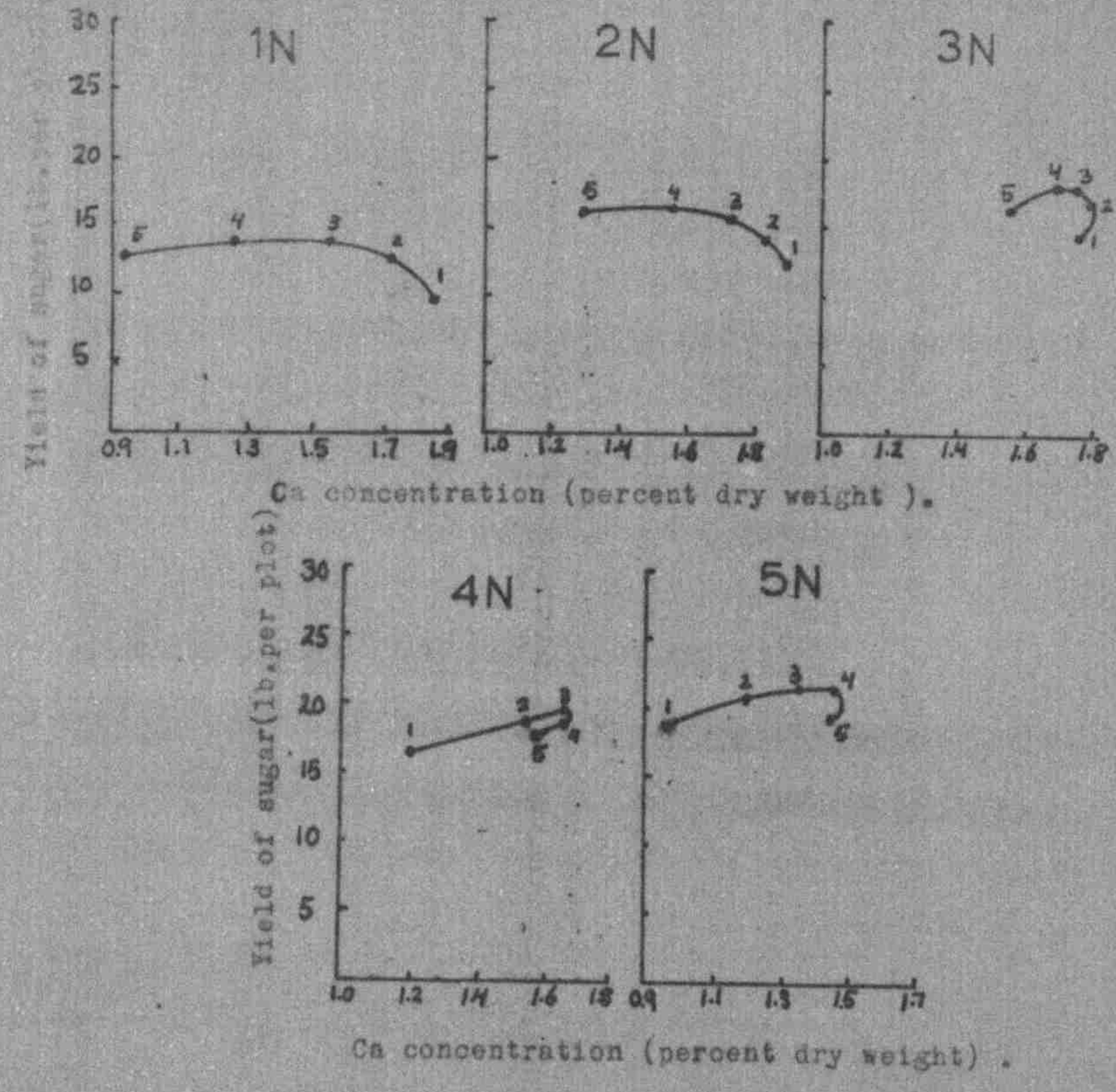

Figure 48. Relationship between yield of sugar (lb. per plot) and Ca concentration(percent dry weight) as affected by addition of different levels of N and K with the levels of P,Mg and Na held constant at the middle of five levels (Table 1). Numbers at points refer to the level of K added . Level of N was held constant for each graph.

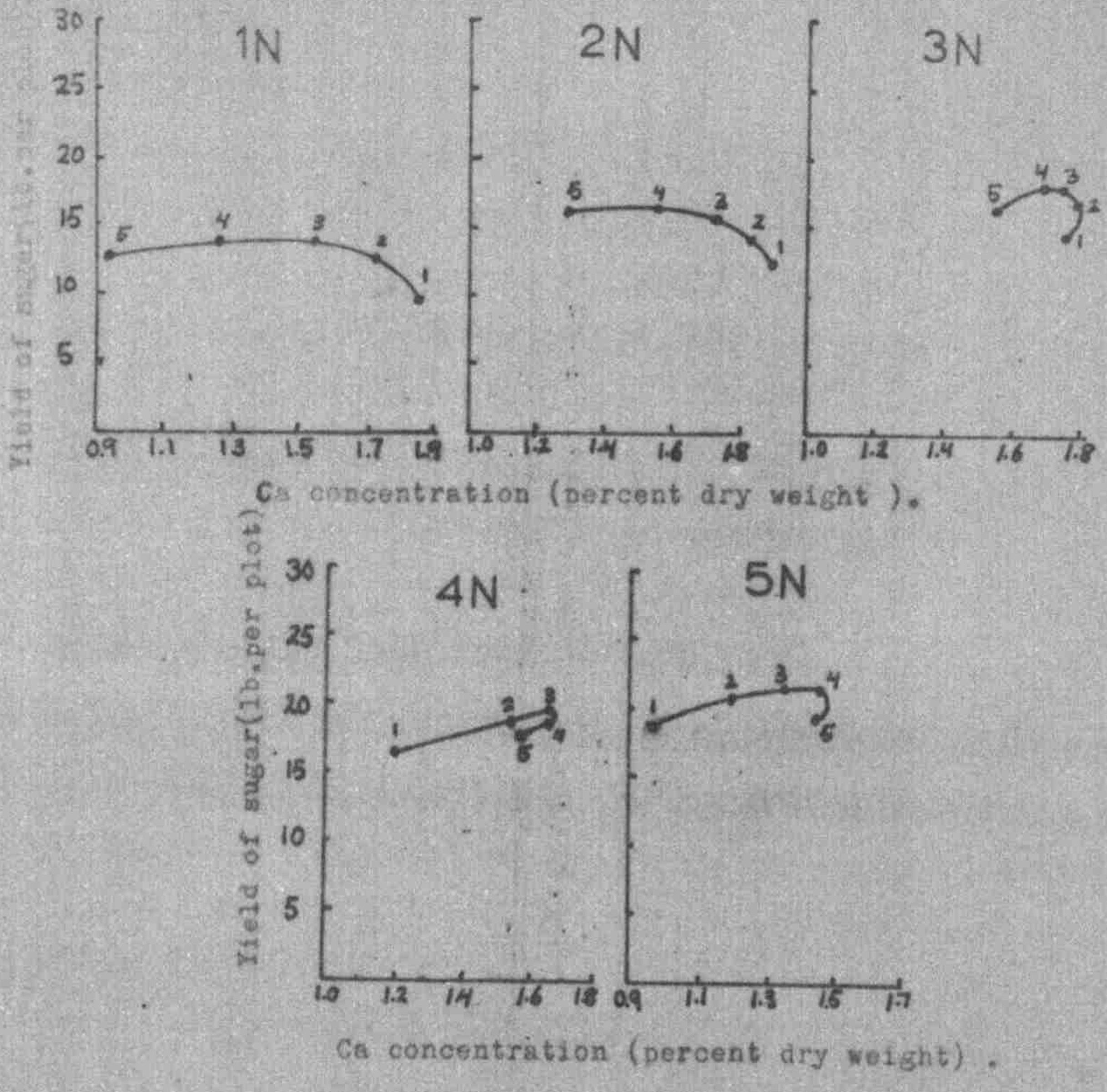

Figure 48. Relationship between yield of sugar (lb. per plot) and Ca concentration(percent dry weight) as affected by addition of different levels of N and K with the levels of P,Mg and Na held constant at the middle of five levels (Table 1). Numbers at points refer to the level of K added . Level of N was held constant for each graph.

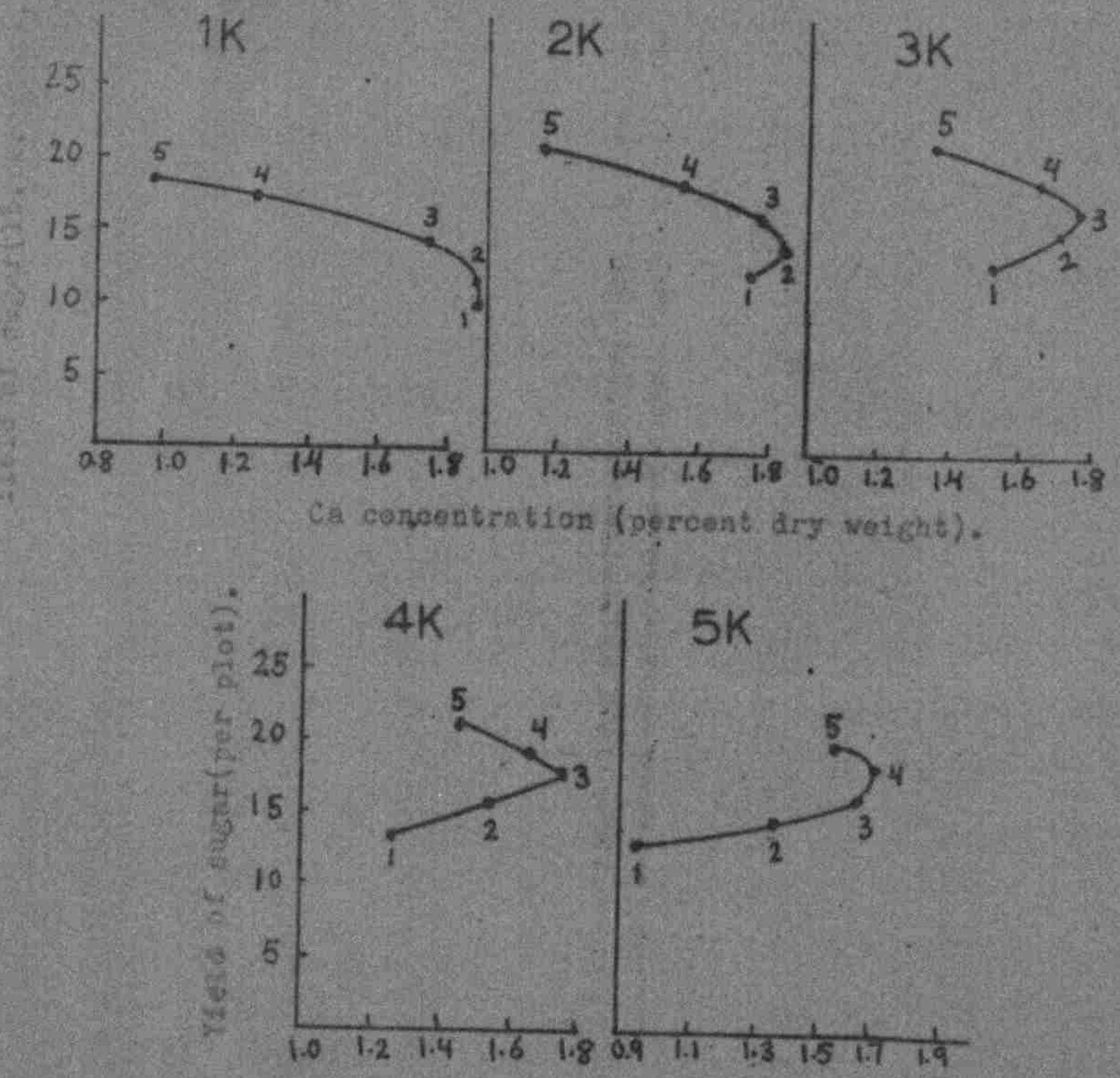

Figure 49. Relationship between yield of sugar (lb. per plot) and Ca concentration (percent dry weight) as affected by addition of different levels of N and K with the levels of P, Mg and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of N added. Level of K was held constant for each graph.

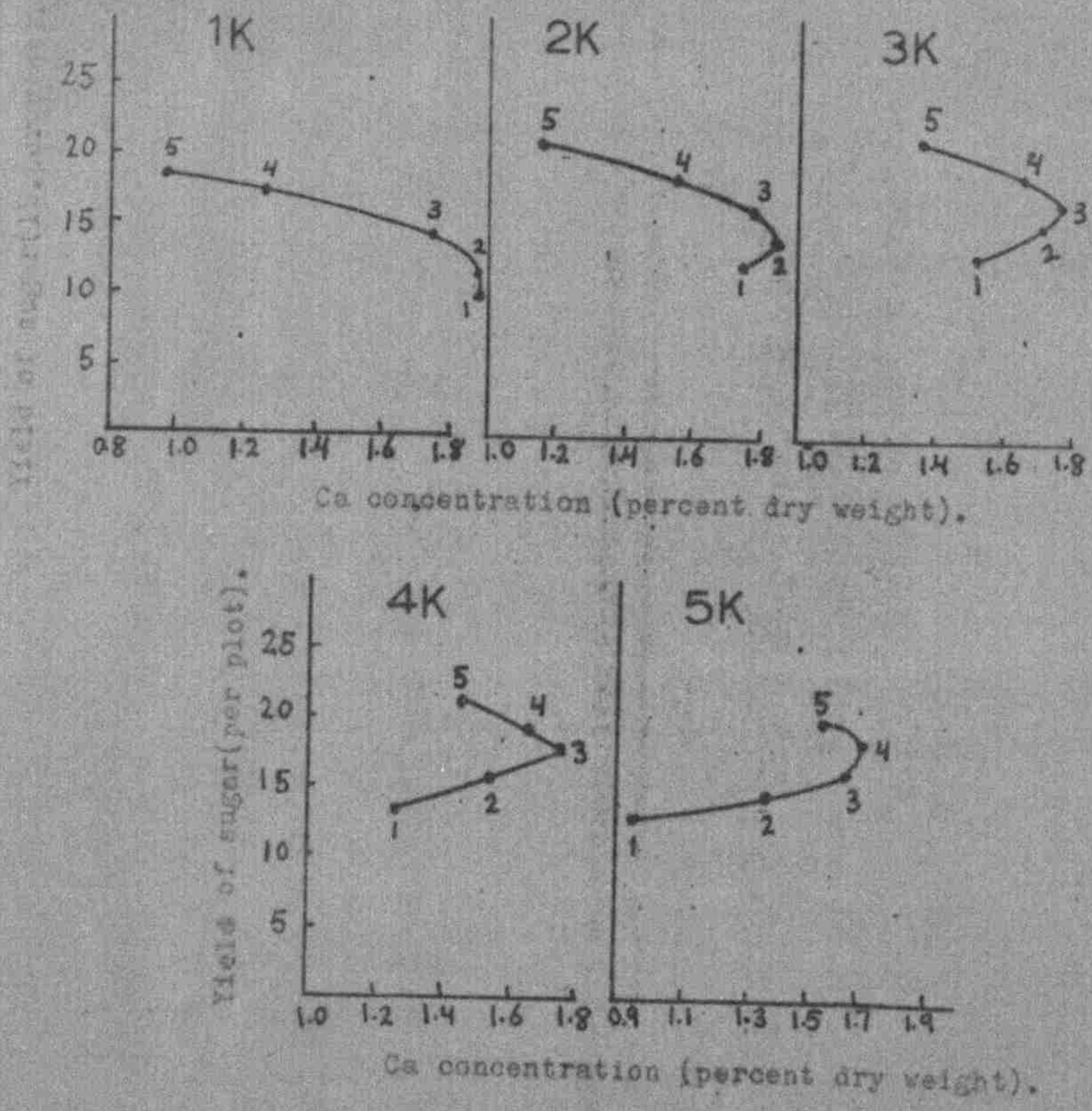

Figure 49. Relationship between yield of sugar (lb. per plot) and Ca concentration (percent dry weight) as affected by addition of different levels of N and K with the levels of P, Mg and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of N added. Level of K was held constant for each graph.

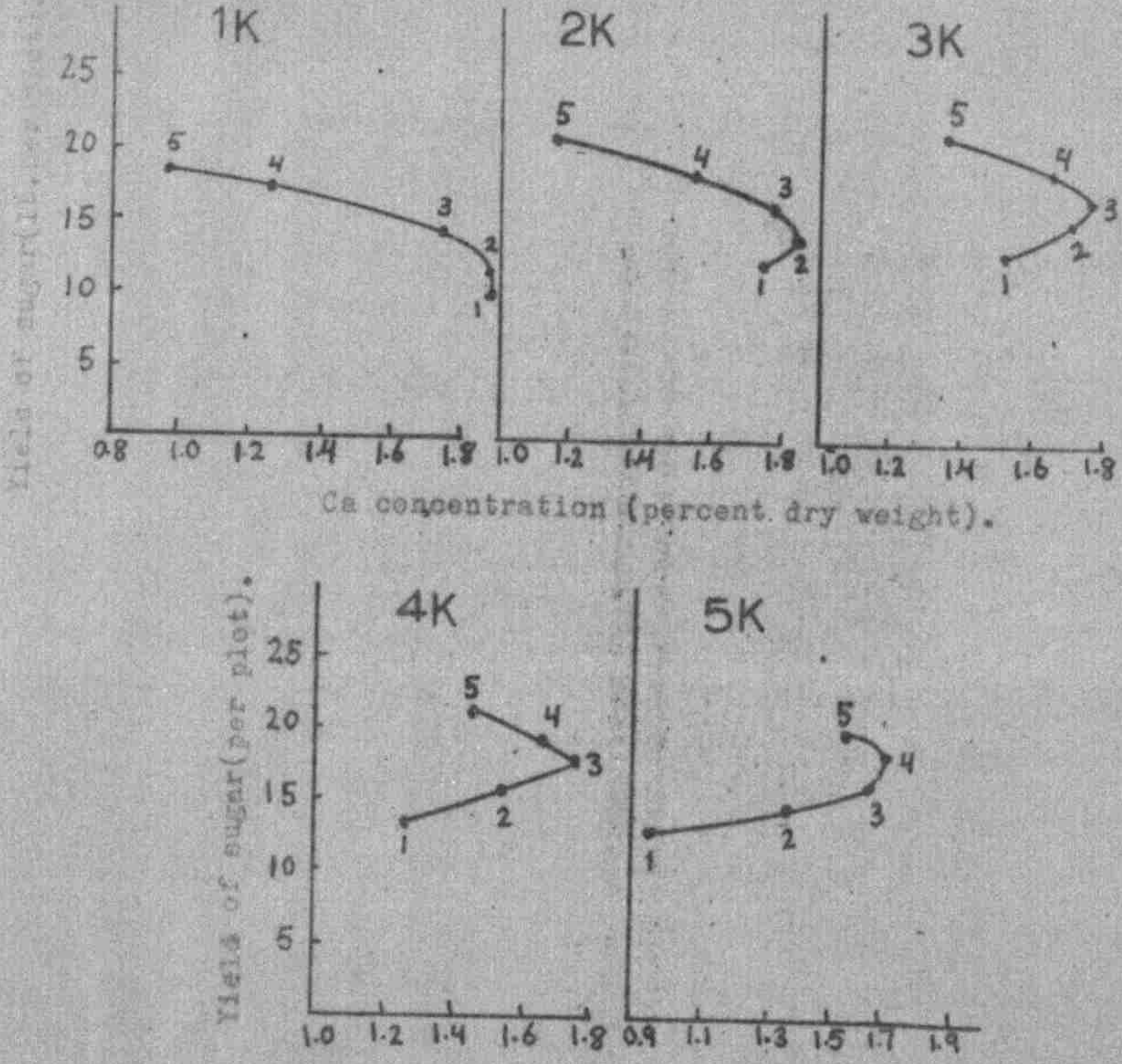

Figure 49. Relationship between yield of sugar (lb. per plot) and Ca concentration (percent dry weight) as affected by addition of different levels of N and K with the levels of P, Mg and Na held constant at the middle of five levels (Table 1). Numbers at points refer to levels of N added. Level of K was held constant for each graph.

SUMMARY AND CONCLUSIONS

The objective of this investigation was to study the effects and interrelationships of the macronutrient elements N, P, K, Mg and Na on the growth and composition of sugar beets. Also, it was believed that information on the elemental composition of the sugar beet leaves would help in the interpretation of the yield response to those elements.

A central composite, rotatable, incomplete factorial design was used in a field experiment conducted at the A.U.B. Farm in the Central Beka'a plain (calcareous soil) involving 5 variables (N, P, K, Mg and Na) each at 5 levels of application ranging from a low level (possible deficiency) to a high level (possible excess). The design required 27 treatments one of which was repeated 6 times. Leaf samples were collected during the growing season and the concentration of N, P, K, Mg, Na and Ca determined.

The sugar beets were harvested, the leaves and roots separated and the fresh weight was recorded for each. Representative samples of the roots were collected for the determination of sugar percentage. The surface soil of the experimental plot was sampled before fertilizers were applied and the physical and chemical properties were determined.

The actual data obtained for root weight, weight of tops, percentage of sugar, yield of total sugar and the concentration of macronutrients studied were used to develop quadratic regression equations of the type:

$$Y = b_o + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{44}X_4^2 + b_{55}X_5^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 + b_5X_1X_5 + b_{23}X_2X_3 + b_{24}X_2X_4 + b_{25}X_2X_5 + b_{34}X_3X_4 + b_{35}X_3X_5 + b_{45}X_4X_5.$$

Where b = regression coefficient, X_1 = coded level of N, X_2 = coded level of P, X_3 = coded level of K, X_4 = coded level of Mg and X_5 - coded level of Na.

The regression equations were used to determine the nature of the response surfaces for the effects of interactions between elements.

Analysis of variance for yields and concentration of nutrients in the leaves indicated that the linear and quadratic effects generally accounted for most of the treatment variability. Therefore, it was not considered necessary to use cubic or higher order terms in the regression equation. When the theoretical yields or concentrations of element in the leaves calculated from the regression equation were compared to the actual data, correlation coefficients ranging from 0.413 to 0.996 were obtained indicating a close fit of the regression equation to the actual data in most cases.

The results and conclusions of this study are summarized as follows:

1. The results of soil analysis indicated that the soil was calcareous (19.5 percent calcium carbonate) and had a low supply of N and a medium supply of available P. The cation exchange capacity was high and the exchangable Ca was abundant. However, the exchangable

K, Mg and Na would be considered adequate for most crops.

2. The yield of roots was significantly increased by N and to a somewhat lesser extent by Na. The Mg-Na interaction was highly significant and complementary indicating that an increase in the application of one element decreased the requirement for the other.

3. The yield of sugar beet tops was significantly increased by application of N and, to a lesser extent, Na. There was a highly significant antagonistic interaction between N and P indicating that when the application of one was increased the requirement for the other was increased. The Na-N and Na-P interactions were significant and antagonistic while the significant Na-Mg interaction was complementary.

4. The percent sucrose was not significantly affected by the application of macronutrients except for the N-P interaction which was significant and antagonistic indicating that an increase in the application of one increased the amount of the other needed for high percentage of sugar.

5. The yield of sugar was considerably affected by the elements studied. Nitrogen and Na had a highly significant positive effect and Mg and K a significant positive effect on the yield of sugar. The Mg-Na interaction was complementary and highly significant as was the somewhat smaller K-Mg interaction. The K-Na interaction was significant and also complementary. Thus, there were significant complementary interactions between the three cations varied indicating that some of

their functions, at least, were interchangeable. The P-K interaction was antagonistic and highly significant while the antagonistic N-Na interaction was significant. The P-Na interaction was significant and complementary.

6. The highly significant response of yield of sugar to N application was increased when the level of P, K, Mg or Na was individually increased. The response to P was very slight but was increased when the N or K level was individually increased or the Mg or Na level was individually decreased. The significant yield of sugar response to K was greater when the P level was high or the Mg or Na level was low. The significant yield of sugar response to Mg was increased when the N level was increased or the P, K, or Na level was individually decreased. The highly significant yield of sugar response to Na was considerably increased when the N level was increased or the P, K or Mg level was individually decreased.

7. The concentration of N in beet tops was significantly increased by increasing levels of P. The highly significant N-Na interaction was complementary in effect on the concentration of N indicating that the effect of Na in increasing the yield of beets may be partially due to an increased uptake of N. The significant N-P and P-Mg interactions had an antagonistic effect on the concentration of N while the significant K-Mg and Mg-Na interactions were complementary. No definite critical level of N in the leaves could be established since the point of highest yield depended on the balance among all the applied nutrients.

8. The application of P had a highly significant positive effect on the concentrations of P. Applications of Na, K, and Mg were found to decrease the P concentration. The K effect was significant whereas the Mg and Na effects were highly significant. The significant K-Mg interaction was complementary in effect on the P concentration. No definite critical level of P was established since high yields were obtained at high and low P concentrations depending on the supply of other nutrients applied.

9. The K concentration of leaves was decreased by the significant effect of N application and the highly significant effect of Na application. No definite relationship between K concentration and yield of sugar was determined as high yields were obtained at both low and high K concentrations. The significant K-Mg interaction was complementary in its effect.

10. The Mg concentration was increased by the highly significant N and P effects, whereas it was decreased by the highly significant Na effect. The application of Mg also significantly increased the Mg concentration. The highly significant N-P, P-K and Mg-Na interactions were found to be antagonistic, whereas the highly significant N-Na interaction was complementary in its effect on the Mg concentration of sugar beet leaves. The antagonistic N-K interaction was significant and the antagonistic N-Mg, P-Mg, P-Na and K-Na effects were highly significant. No definite Mg critical level could be established since the high yield occurred at Mg concentrations in a range between 0.7-1.3 percent.

11. No definite critical level of Na concentration in leaves was established. However, in general, it was found that high yield of sugar was obtained at a high Na concentration. None of the linear or quadratic effects of macronutrients were found to be statistically significant, but the tendency for all the variables was to increase the Na concentration of sugar beet leaves.

12. The Ca concentration was significantly decreased by the application of P. None of the other linear and quadratic effects were statistically significant. However, all of the elements that were varied tended to decrease the Ca concentration. Since the application of cations depressed the Ca content and since the higher yields were associated with the lower concentrations of Ca in sugar beet leaves it was concluded that part of the response to K, Mg or Na might be due to the depressing effect of those elements on Ca uptake from calcareous soils.

13. The maximum possible theoretical yield of sugar, under the conditions of this experiment and excluding levels of the variables outside the levels used, was found to be about 33.1 lb. per plot obtained from the combination 5N, 1P., 3K, 1Mg and 5Na. This would be a yield of about 8.3 tons of sugar per acre or about 40 tons of beet roots per acre. Using local prices for sugar beets and fertilizers, it was concluded that the following combination would have given the approximate maximum profitable yield of sugar:

4.5 N (about 330 lb. of N/acre)

0 P_2O_5

2 K_2O (about 30 lb. of K_2O/acre)

0 Mg

5 Na (about 540 lb. of Na/acre)

14. This study proved that the yield of sugar beets could be considerably influenced by macronutrient fertilization and that the interactions between those elements was, in some cases, more significant than the individual effects indicating that it is not the absolute amount of fertilizer which determines the yield but the balance among all nutrients applied.

15. This study also emphasized the importance of Na in sugar beet production and suggested that more study is needed in regard to the role of Na in sugar beet nutrition.

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