A STUDY OF SOME RELATIONSHIPS AMONG THE RESULTS OF SOIL AND TISSUE TESTS, FERTILIZER TREATMENTS, AND YIELDS OF SEVERAL CROPS GROWN ON ORGANIC SOIL

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John C. Shickluna

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THESIS

This is to certify that the

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John C. Shickluna

AN ABSTRACT

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A STUDY OF SOME RELATIONSHIPS AMONG THE RESULTS OF SOIL AND TISSUE TESTS, FERTILIZER TREATMENTS, AND YIELDS OF SEVERAL CROPS GROWN ON ORGANIC SOIL

by John C. Shickluna

Investigations involving the effect of rate and placement of fertilizers and Na-K interactions on soil test values, crop yields, and plant composition with several crops were undertaken at the Muck Experimental Farm in Clinton County, Michigan. The soil was classified as a Houghton Muck containing 85 per cent organic matter and having a pH of 6.3.

The experiment involving the rate and placement of fertilizers has shown that the method of fertilizer placement did not significantly affect the yield of carrots, table beets, broccoli, or cauliflower. However, higher yields of late-planted cauliflower were obtained where the fertilizer was placed in a band below or to one side of the seed. An increase of 30 to 40 per cent in onion yields can be expected if the fertilizer is applied in a band 2 inches below the seed, rather than in bands 7 inches apart and 3-1/2 inches deep with a grain drill. The maximum yields of the crops studied were related to the residual soil P and K levels and supplemental fertilizer applications.

Less extractable soil K was obtained from samples taken in the spring than in the fall. Time of sampling, however,

did not materially affect the amount of extractable soil P.

The fertilizer ratio experiment has shown that high yields of onions can be obtained with residual soil P and K levels of 20 and 250 to 300 pounds per acre (0.018$\underline{N}$ CH_3COOH extractable), respectively when supplemented with a starter fertilizer containing 50, 10, and 20 pounds of N, P_2O_5, and K_2O, respectively. Also, the effect of residual N was reflected in onion yields. It was further shown that the same yield of onions could be obtained with different combinations of N, P, and K.

The water extractable N, P, and K analysis of the onion tissue showed that it is important to select tissue at a time when it will best correlate with plant needs. An increase in the water extractable P content of onion tissue resulted with soil applications of N as urea and ammonium nitrate.

In the case of celery, it appeared doubtful that much increase in yield would be expected from additional amounts of P and K where the soil tests were around 35 pounds of P and 700 to 800 pounds of K per acre (0.018$\underline{N}$$CH_3COOH$ extractable).

The data from the fertilizer rate experiment showed that the same yield of sweet corn could be obtained over a wide range of residual soil P and K levels. Although there was no relationship between the amount of water extractable P, K, Ca, Mg, Mn, and Na in the green corn tissue and the yield of sweet corn, there was an indicated trend that as the applied K increased the water extractable K in the green tissue increased and the Na decreased. Increased applications of soil K also resulted in an increase in water extractable Mn in the green tissue.

Good correlations were obtained between K uptake, the amount of K_2O applied, and the yield of broccoli, celery, and sweet corn employing the following method for the measurement of K uptake by the plant:

Pounds of K obtained in the spring sampling	+	Pounds of K applied as fertilizer	-	Pounds of K obtained in the fall sampling	=	K uptake

A comparison of extracting solutions showed that the inclusion of the flouride ion into the extracting solution increased the extraction of soil P. Increased amounts of soil P were also obtained by increasing the extractant to soil ratio.

An experiment involving the sodium-potassium interactions of sugar beets showed that sodium appeared to be effective in substituting for K at low levels of soil K. As the per cent K in sugar beet tops increased the per cent Na and Mg decreased. The maximum yield of sugar beet roots occurred where the beet petioles contained 7000 parts per million of water extractable K.

Good correlations were obtained between soil K (0.018N CH_3COOH extractable), water extractable K in the green tissue, total K uptake and the yield of sugar beet roots.

The extracting solution employing 0.018 N CH_3COOH was shown to be a valuable tool in predicting yield response of sugar beets to applied soil K. Also, the large loss of soil K, due to crop removal, indicated the need for annual soil tests to determine fertilization recommendations for sugar beets.

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To My Wife

This thesis is affectionately dedicated to my wife whose unfailing interest in the work was a constant source of encouragement and inspiration throughout its duration.

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INTRODUCTION

The intensive cropping practices in use today have emphasized the need for soil tests and tissue tests as aids in determining fertilizer needs.

Although soil testing and tissue testing are by no means new tools in diagnosing plant needs, great advances have been made in correlating these tests with crop yields.

The problems in correlating a chemical test with the growth and yield response of a living mass of protoplasm are readily apparent. The growth of any plant or animal is affected by many factors that are interrelated and complex. It is important, therefore, that one becomes thoroughly familiar with the agronomic characteristics of a plant before a logical and practical interpretation of soil test results are made.

Chemical soil tests give us practically no information about the variability of different plant species or of those factors affecting plant growth which are common to soils, such as drainage, water supply, physical condition, tillage methods, and soil temperature. Therefore, the results of the chemical testing of soils do not always correlate with plant growth or the response of plants to fertilization.

Correlation of soil and plant tissue tests with crop response is highest when all the factors of plant growth other than nutrients, approach the optimal situation.

Plant tissue tests are chemical analyses of the plant sap or sap extracts and represent very largely the nutrients not already combined in plant tissue at the time the test is made.(41) Tissue tests should be used as a supplemental diagnostic tool in determining how to maintain optimum plant performance in any given environment. The principal objectives of determining the nutrient status of plants has been stated as follows (36): first, to aid in determining the nutrient-supplying power of the soil; second, to aid in determining the effect of treatment on the nutrient supply in the plant; third, to study the relationship between the nutrient status of the plant and crop performance as an aid in predicting fertilizer requirements; and fourth, to help lay the foundation for approaching new problems or for surveying unknown regions to determine where critical plant nutritional experimentation should be conducted.

Organic soils constitute important potential soil reserves for the nation. Of the 4-1/2 to 5 million acres of organic soils in Michigan, an area equal in size to the State of New Jersey and representing approximately one acre in eight, probably less than five per cent is farmed. However, they represent an important economic part of agricultural production for the state. Likewise, a large proportion of the organic soils located in Wisconsin and Minnesota have not been reclaimed.(14) This investigation was initiated and carried out at the Michigan State University, Muck

Experimental Farm in Clinton County, to study the relationship between soil tests, the amount of applied nitrogen, phosphorus and potassium and the uptake of these elements by the plant and their effect on crop yields.

REVIEW OF LITERATURE

The literature pertaining to the correlation of soil tests and tissue tests with crop yields on organic soils is somewhat limited.

Bigger's (5) work with a Houghton muck in Michigan showed a highly significant correlation between the amount of phosphorus applied and the amount of phosphorus extracted from the soil by the following chemical reagents: 0.025N HCl + 0.03N NH_4F, 0.1N HCl + 0.03N NH_4F, 0.135N HCl and 0.018N CH_3COOH. The correlation coefficients for these reagents were 0.943, 0.986, 0.915, and 0.967, respectively. He also found that the amount of potassium applied per acre showed a highly significant correlation with the amount of potassium extracted from the soil by any one of the following reagents: 23 per cent $NaNO_3$, 0.135N HCl and 0.018N CH_3COOH. The correlation coefficient for these reagents were 0.640, 0.667, and 0.671, respectively. His work with green sugar beet and peppermint tissues revealed a seasonal variation in the composition of water extractable nitrate-nitrogen, phosphorus and potassium. The yields from these two crops correlated better with green tissue tests than with soil tests. Dawson (16), using sodium acetate-acetic acid solution buffered to pH 4.8 found the average potassium content of cultivated peat soils in New York to be 760 $\pm$ 650 pounds per acre; and the average phosphorus content to be 200 $\pm$ 210 pounds per acre. He estimated the safe level of soil test potassium at not less than 250 nor more than 350 pounds per acre; and the level of soil test phosphorus at not less than 50 pounds per acre. Dawson concluded that when a peat soil was fertilized with potassium at a constant rate per acre per year, the available potassium content of the soil, as measured by soil-test methods, adjusted itself within 3 to 5 years to the rate of fertilization and remained constant until the fertilizer practice was changed again. A similar situation occurred for phosphorus providing the content of soil-test iron plus aluminum was less than 100 pounds per acre. When the iron and aluminum content exceeded 200 pounds per acre, the soil-test phosphorus was found to be 50 pounds or less per acre. The importance of the relationship between the iron plus aluminum content and the available phosphorus composition of peat soils was emphasized.

Forsee (25) at the Everglades Experiment Station in Florida working with an Okeelanta peaty muck and using celery as the indicator crop found distilled water was preferable to 0.5 N CH_3COOH as an extractant for soil phosphorus determinations. A significant relationship existed between the water soluble phosphorus and the amount of phosphorus applied to the soil. The same was true for potassium soluble in 0.5 N CH_3COOH. The maximum yield for celery grown on Okeelanta peaty muck was associated with 250 pounds of acid soluble potassium and 30 pounds of water soluble phosphorus per acre.

Many investigators (7,64,8) have compared a variety of soil extractants on mineral soils and correlated the "available" phosphorus and potassium obtained by these extractants with crop yields. The results obtained by most workers have generally favored Bray's adsorbed phosphorus test (0.025 N HCl + 0.03 N NH_4F). The work of Bigger (5) also showed that Bray's adsorbed phosphorus test showed a highly significant correlation between the amount of phosphorus applied and the amount of phosphorus extracted from an organic soil.

Lawton and his co-workers (40), working with a mineral soil, attempted to correlate the response of legume hay to both phosphorus and potassium fertilization with the chemically measured available forms of these two elements. These investigators used the methods of Spurway (65), Bray (8), and Peech and English (52). They were unable to find any high degree of linear correlation between crop response and soil test value with either phosphorus or potassium. Similarly the correlation between plant growth response as measured upon percentage basis and exchangeable potassium did not appear significant.

The work of Smith (64) showed that the use of any of the methods of Bray on a mineral soil provided a considerably clearer picture of phosphorus availability because the inclusion of fluoride in the extracting solution enabled the adsorbed phosphorus in the soil to be removed. An extracting ratio of one part soil to fifty parts of solution was more desirable for adsorbed phosphorus studies than the narrow ratio of one part soil to ten parts of solution.

In contrast to the previous methods of soil extraction, Filman and co-workers (22) adopted a mechanical press for the removal of extracts from organic soils in Canada. Solutes expressed by pressure from the organic soils appeared to represent the nutrients available to the growing crops where methods used for mineral soils had failed to do so. These investigators reported evidence of mass movements of solutes in both horizontal and vertical directions in the organic soil.

According to Hester (31) if a knowledge of the composition of the soil solution that influences plant growth is desired, then a dilute chemical extractant is satisfactory. However, if the supplying power of the soil for a period of time is the information sought, perhaps the stronger extracting reagents are preferable.

Eid, <u>et al</u>. (21) have reported that at a soil temperature of 20°C, the availability of soil phosphorus to corn plants was related to the inorganic phosphorus extracted by 0.025 <u>N</u> HCl + 0.03 <u>N</u> NH_4F solution. At this temperature the organic phosphorus fraction, based on a 1 per cent K_2CO_3 extracting solution had no appreciable effect. However, when the soil temperature was increased to 35°C. both the inorganic and organic phosphorus fractions were significantly related to the amount of plant-available phosphorus, but the variation in plant-available phosphorus was better explained by the organic phosphorus fraction than by the inorganic fraction.

This can be accounted for on the basis that at the high soil temperature the organic phosphorus fraction underwent relatively rapid mineralization and the mineralized phosphorus served as a source of supply for the crop. At the low soil temperature the organic phosphorus mineralization was limited and the crop was, therefore, dependent on the phosphorus orginally present in the inorganic form.

Kelly and Midgley (35) have proposed the mechanism of phosphate fixation to be the same with hydrated sesquioides as with finely ground kaolin. In both, fixation represents a physiochemical anion exchange equilibrium whereby phosphate ions replace exposed hydroxyl ions from the colloidal materials.

The increase in pH of a colloidal system caused by phosphate fixation is taken as evidence that such an exchange of anions takes place. Furthermore, the removal of active iron and aluminum greatly reduced the capacity of soils to fix phosphate.

Silicate and fluoride ions are capable of replacing hydroxyl ions, as evidenced by pH changes. The beneficial effect of silica on plant growth may possibly be due to its ability to remove fixed phosphate or to replace the hydroxyl ions and thus decrease phosphate fixation.

Larsen, et al., stated (39) that when organic soils are first drained and placed under cultivation, a relatively high percentage of applied phosphorus is available for plant growth. However, as these soils are cultivated for longer periods, a much smaller percentage of the applied phosphorus is available. The efficiency of uptake of applied phosphorus by plants gradually diminishes as organic soils become more decomposed. Two opposing factors function in the absorption of phosphorus by organic soils. Humic acid tends to prevent the absorption of phosphorus by the organic soil. In contrast the additions of iron and/or aluminum greatly increase the capacity of the soil to absorb phosphorus. The comparison of the humic acid contents of a cultivated and virgin muck by Larsen and his co-workers (39) showed the former to possess three times the amount of humic acid as the latter. On this basis one would expect the cultivated muck to have less fixation capacity. However, the sesquioxide content of the cultivated muck was fourteen times greater than that of the virgin soil. The increase in iron and aluminum masked the influence of the increase in humic acid content.

Furthermore, it has been suggested that the sesquioxide content tends to increase continuously with age as a result of subsidence or mineralization, while the humic acid content tends to reach an equilibrium. Aging, which results in increased quantities of iron and aluminum then is primarily responsible for the increase in phosphorus fixation.

Additional information by Larsen, et al., (37) has added support to this hypothesis. Where a virgin and cultivated muck soil were extracted with distilled water a decrease in the ratio of soil to water resulted in an increase in the phosphorus concentration of the virgin soil as compared to a decrease in the phosphorus concentration in the cultivated soil. This indicates that only a small part of the phosphorus was held in an insoluble form in the case of the virgin muck. The reverse of this occurred in case of the cultivated muck soil.

The effect of other compounds arising from the decomposition of organic residues on phosphorus availability may be due to a combination of many factors. For example, Bear (4), has suggested that the humus extracts from soils increase the solubility of phosphorus resulting from (a) the formation of phospho-humic complexes that are more easily assimilable by plants; (b) anion replacement of the phosplate by the humate ion; (c) the coating of the sesquioxide particles by humus forming a protective cover and thus reducing the phosphate-fixing capacity of the soil; and (d) that certain organic anions arising from the decomposition of organic matter form stable complexes with iron and aluminum thus preventing their reaction with phosphorus. These complex ions release phosphorus previously fixed by iron and aluminum by the same mechanism.

Paul (51) has suggested that the inorganic alkali-soluble phosphorus (phosphorus removed from the soil by digestion with 0.25 N NaOH) consists largely of phosphates of iron and aluminum and that the inorganic alkali-soluble and the exchangeable phosphorus fractions may be regarded as equivalent to one another. He also pointed out that the organic alkali soluble (total phosphorus-inorganic alkali soluble phosphorus) and the inorganic alkali soluble forms of phosphorus are appreciable in both cultivated and virgin organic soils, contributing between them more than 70 per cent of the total phosphorus of the soils. The virgin soil contained a larger amount of inorganic alkali-soluble and organic alkali-soluble fractions than did the cultivated soil. The significantly greater yield increase of sweet potatoes obtained on the virgin soil was attributed to the greater percentage of these two forms of phosphorus in the virgin soil. It is suggested that the organic phosphorus fraction and the inorganic alkali soluble forms, the latter mainly as iron phosphate, are available to plants and that in the cropping of organic soils these two fractions were considerably reduced.

Brown (10) using natural iron and aluminum phosphate obtained beet yields about 75 per cent of that resulting from the addition of superphosphate. Scarseth and Tidmore (60), on the other hand, obtained yields of sorghum from soils receiving iron phosphate of around 24 per cent relative to superphosphate. Bray (8) has pointed out that when the flouride methods of soil extraction have been applied to soils receiving applications of superphosphate, the assumption that the added superphosphate is practically all fixed in unavailable forms is not substantiated by the results. Rather, much of the phosphate added is adsorbed on the colloidal complex in a form which is less soluble than in the original superphosphate but which is still rapidly soluble.

Some workers (1,49) have suggested that soil organic constituents may be important as anion exchangers. Aderikhin (1) found that humus sorbed phosphate ions from monocalcium phosphate, whereas Doughty (20) found that soil organic matter did not play an important part in fixing phosphates. Mortland (49) showed that anion exchange resins sorb and exchange anions through free amino groups. He also showed that polyamino organic soil complexes and polyamino clay complexes exhibit anion sorption and exchange as shown in the following reaction, although they may be of minor importance:

$$H^+ - Clay^- + Excess\ H_2PO_4^-\ (^+NH_3\text{-}R\text{-}NH_3^+)\ H_2PO_4 \rightarrow H_3PO_4 + Clay^-\ (^+NH_3\text{-}R\text{-}NH_3^+)\ H_2PO_4^-$$

The work of Dean and Rubins (17) has shown that the phosphorus which accumulates in acid soils as a result of intensive fertilization is for the most part, relatively insoluble in dilute solutions of the strong mineral acids but can be readily replaced from soils by solutions containing certain anions. The majority of the common procedures for evaluating the phosphorus fertility status of soils are based on solubility rather than on anion exchange reactions. Thus, much of the phosphorus which has accumulated in fertilized soils is not considered when evaluating the phosphorus fertility. It has been suggested by these workers that the absorbed phosphorus should be considered when chemical data are used in the diagnosis of phosphate deficiency in soils.

They stated that most of the applied phosphorus occurs as exchangeable phosphorus in acid soils, whereas in slightly alkaline soils containing a small amount of calcium carbonate the phosphorus occurs mostly as salts of divalent bases (the calcium phosphates). Dean and Rubins (17) suggested the transition zone to be in the neighborhood of pH 6.0 and pointed out that the exchangeable phosphorus fraction is important in those soils of pH less than 6.0.

Lawton and Davis (43) noted that the phosphorus content of plants grown on organic soils was progressively depressed by successive increments of $CaCo_3$. They attributed this decrease in per cent plant phosphorus caused by liming to a decrease in the proportion of $H_2PO_4^-$ to $HPO_4^=$ ions in the soil solution.

In contrast to studies on fixation, Larsen, _et al_. (38), conducted investigations on the leaching of applied labeled phosphorus in organic and mineral soils. After 15 inches of water were leached through the soil columns, phosphate retention appeared closely correlated to the sesquioxide content of the soils and the apparent degree of decomposition. When labeled phosphate was mixed into the surface 2 inches of a 14-inch column of a virgin soil, 60 and 80 per cent appeared in the leachate from 15 and 30 inches of water, respectively. Lesser amounts of phosphorus appeared in the leachate from soils with greater sesquioxide contents and longer drainage histories while no phosphate was leached from the mineral soil or from the organic soil which had been drained for 15 or more years.

The mechanism of potassium availability, as far as organic soils are concerned, appears to be less complex than that of phosphorus. Soil scientists have tried for many years to develop chemical tests for ascertaining the potassium requirements of different soils for the production of various crops. It is probable that one of the factors contributing to the failure of chemical tests is the capacity of different soils to supply plants with different amounts of potassium from non-exchangeable forms. Stewart and Volk (66) pointed out that considerable potassium (an average of 2/3 of the potassium used by plants) comes from forms that were non-exchangeable at the beginning of the test, and the amount of non-exchangeable potassium removed from the different soils varied between 39 and 87 per cent of the total amount of potassium consumed by plants.

Levine and Joffe (45) have suggested several mechanisms of potassium fixation, such as the reaction of potassium with "so-called" silicates to form difficulty soluble muscovite; or the migration of potassium from the surface of a colloid into the interior of the crystal. They postulated the possibility of potassium being fixed between the layers of the expanding and contracting c-axis of layer lattice minerals. They pointed out when montmorillonite layers are collapsed by heating to temperatures of about 550° C., the ability of montmorillonite to fix potassium diminished to the vanishing point. In general, with the decreasing ability of montmorillonite to swell reversibly, there was a decrease in the ability of the mineral to fix potassium.

It is unlikely that any appreciable quantity of potassium is fixed by the organic material comprising a muck or peat soil.

Jones (34) concluded that the humus colloids possess a very low fixing power for potassium. Likewise, Joffe and Levine (33) and Joffe and Kolodny (32) reported that organic matter did not fix potassium in a non-exchangeable form. The fact that potassium occurs in plants almost solely as soluble inorganic salts (48) is indicative of its free nature in organic material. Russell (59) reported that mulches increased the amount of exchangeable potassium in the soil and that potassium appeared to be the only mineral element showing a strong downward percolation.

Garmon (27) has shown that the relative rates of leaching of the different K salts were rather insignificant. He stated that the percentage K retained from an application of a K salt appeared to depend upon the amount of salt applied, the base saturation, and the base exchange capacity of the soil. Higher exchange capacities, increased K retention.

The work of McCool (47) has shown that organic soils with a very low ash content, 10 per cent or less, were found to possess a very small capacity to fix potassium, but their capacity increased with their mineral content.

Cook (11) has reported that efficient management of fertilizers is the art of feeding the plant rather than the soil. Broadcasting and mixing soluble phosphates with soil or spraying solutions on the soil surface result in maximum fixation and least efficienty as far as the immediate crop is concerned. That is because maximum contact is provided between the particles of fertilizers and the hydrated oxides which are a part of the soil and with which the phosphate ions readily combine.

Placing the phosphate in bands beside the rows of seeds is a more efficient way to apply them both as to crop yields and the percentage of the phosphorus the plants take up.

Lawton, et al. (42) showed that soluble phosphorus moves rapidly out of fertilizer granules but moves slowly away from the granules. The result is a highly concentrated spherical zone of soluble phosphorus around a granule as long as the soil is not disturbed. Roots may then penetrate that sphere and feed readily on the phosphorus in the soluble form.

Robertson and his co-workers (58) have shown that the young corn plant has a high preference for the phosphorus applied in a band at planting time. As the plant developed it depended more and more on the soil phosphorus. The degree to which the plant utilized the fertilizer was not directly proportional to the amount applied. When 20 pounds of phosphorus was applied per acre, 3.3 pounds was recovered in the aboveground part of the plant, whereas when four times as much was applied only twice as much was recovered. The rapid decline in the plants' intake of applied phosphorus from the fertilizer, which occurred irrespective of the amount applied, may be caused by one or more of the following factors: (a) chemical or biological fixation or both of the applied phosphorus, which becomes less available to the crop as the season progresses; (b) the fertilizer band is no longer a favorable medium for nutrient adsorption because, for example, dehydration of the fertilization zone through root action or normal soil drying; (c) the fertilizer band applied at planting near the seed was in a zone occupied only by cutinized nonadsorptive roots during the latter part of the growing season; and (d) the phosphorus needs of the plant are satisfied by absorption from the soil through its much enlarged root system, irrespective of any localized areas of high nutrient concentration.

Cook and his co-workers (12), have pointed out that when granular or pulverant fertilizer was banded in the soil, the uptake by plants of fertilizer phosphorus increased with an increase in the degree of water solubility of the fertilizer. Yields also increased with an increase in the percentage of the fertilizer phosphorus in the soluble form. For maximum uptake of phosphorus and top yields, fertilizers applied in bands should have at least 40 per cent of the phosphorus in water soluble form. On the other hand, fertilizers which contain no water soluble phosphorus should be thoroughly mixed with the soil and they should be pulverant rather than granular.

Fertilizer placement work or methods of applying fertilizer in Michigan (15) have shown that if the fertility level in the soil is high enough, particulary of phosphorus, that 150 pounds of 5-20-10 starter fertilizer at planting time is sufficient for early development of the crop and for final yield. It was stressed that some fertilizer at planting time is necessary to get the crop off to an early start, even though at high fertility levels this stimulation of early growth may not be reflected in increased yield at harvest time.

Other workers (56) have shown the first corn feeder roots grow downward at a 45-degree angle. These feeder roots soon reach the starter fertilizer if it has been placed properly, that is--in a band 2 inches to one side and 2 inches below the level of the seed. This promotes early vigorous growth of the corn seedling and avoids the possibility of fertilizer salts coming in contact with the germinating seed. Their work has also shown that a corn plant can obtain maximum efficiency from a single band of properly placed fertilizer. It is not necessary to have starter fertilizer banded on both sides of the seed at planting time.

It has been reported (53) that the corn plant produces almost half its total weight during one month of the growing season (in Ohio this occurred between July 20 and August 19); and that a 100 bushel corn corp (including total weight of above ground dry matter) required 143 pounds of N, 69 pounds of P, and 118 pounds of K per acre. It is obvious that if high yields are to be produced, the soil must be able to supply large amounts of plant food to the corn crop during the period of rapid growth.

Soil fertility investigations for several crops under field and greenhouse conditions have been carried out by Forsee, et al. (26), on a new Everglades peat soil in Florida. The soil received 75 pounds of copper sulfate per acre and had the following residual soil tests: water soluble phosphorus, 8.4 pounds per acre; dilute acid soluble potassium, 58 pounds per acre; pH, 5.37. His findings with the various crops investigated are summarized as follows:

Broccoli: A fall planting of early green sprouting broccoli responded to applications of potash. Yields of plots where one-half the fertilizer was applied broadcast and one-half side-dressed, or where one-half was applied in the row and one-half side-dressed, were not appreciably different from those obtained where all the fertilizer was broadcast. Maximum yields of broccoli may be obtained on new Everglades peat soil when the water-soluble phosphorus level in the soil is approximately 8 pounds per acre and the dilute acid-soluble level is approximately 125 pounds per acre.

Sweet Corn: A spring planting of Golden Security and F-M cross varieties responded well to potash applications. Fertilizer applications up to 80 pounds of K_2O per acre increased the yield of unhusked marketable corn as much as 200 per cent, increased length and diameter of ears and decreased length of unfilled tips. However, no yield response was obtained to applications of phosphorus. There were no differences between broadcast and band methods of application.

In another experiment a spring planting of sweet corn on old, well-decomposed Everglades peat soil with a pH of 5.50, a water soluble phosphorus level of 5.2 pounds per acre and a dilute acid-soluble potassium level of 127 pounds per acre responded to phosphate applications up to 72 pounds of P_2O_5 per acre. The phosphorus applications increased the yield of unhusked marketable corn as much as 100 per cent, decreased slightly the length of ears, increased the diameter of the ears, and decreased the length of unfilled tips. Low soil phosphorus levels resulted in significantly lower stands. No yield responses were obtained to applications of potash at this soil test level of K.

Placing all the fertilizer in the row at planting also resulted in poor stands as well as decreased yields. Yields were significantly lower on plots receiving one-half of the phosphate at planting with the other half applied one month later. Side-dressed applications of nitrate-nitrogen had no effect on yields.

These fertility experiments with sweet corn indicated that maximum yields of good quality corn may be obtained from broadcast applications of phosphorus and potassium in such amounts as to give a soil test level of 10 pounds per acre of water-soluble phosphorus and 125 pounds per acre of dilute-acid soluble K.

Davis and his co-workers (13) in a fertilizer placement experiment on an organic soil found that fertilizer placement caused yields of onions and spinach to vary as much as 103 and 50 per cent, respectively. The results from this experiment indicated that fertilizers for these two crops should preferably be placed in a band 2 to 3 inches below the seed level.

They also concluded that quantities of fertilizer in excess of 800 pounds of a 5-10-20 per acre should either be drilled in ahead of planting, broadcast on the surface, or plowed under. It was further concluded that the amount of fertilizer that could be safely applied in a band 2-inches below the seed depends on the amount of moisture in the seedbed at planting time, the row spacing, and the performance of the fertilizer applicator in maintaining the desired depth of 2-inches below the seed throughout all of the planting area.

Shear (62) has stated that at any level of nutritional intensity there exists a nutritional balance at which "optimum" growth for that intensity level will result. This means that at any given level of nutritional intensity, provided all nutrient elements are in proper balance, it is possible to obtain plants that appear normal in every respect and in which all metabolic processes are qualitatively normal. Maximum growth and yield, however, result only when the proper balance of nutrient elements occurs in combination with their optimum intensity. Thus, it is possible to have plants lacking symptoms of malnutrition, yet varying over a wide range in growth, or yield, or both. Under conditions of optimum balance, whether nutritional intensity is high or low, any critical change in the accumulation of one or more elements not accompanied by appropriate changes in all of the other nutrient elements will result in an unbalanced nutrition. This will be reflected first in decreased growth and later, if the unbalance is intensified, in additional reduction in growth or yields, or in the appearance of leaf symptoms, or in all three ways.

Magistad (46), on reviewing the literature, has reported that heavy applications of soluble fertilizers often increase the salt concentration of the soil solution to a degree injurious to plant growth, especially on sandy soils. Fertilizer applications of 1200 pounds per acre on Norfolk sandy loam were reported to have increased the osomotic pressure of the displaced soil solution to about 14 atmospheres.

It has been reported (46,57,38,2) that when the concentration of the soil solution is increased, the osmotic pressure gradient is decreased and water absorption goes on at a slower rate. Magistad (46) in his review suggested why a reduction in water intake decreases plant growth. These include salting out of cellular proteins, shrinkage of cell contents from the cell wall, and irreversibility of hydration of the cell contents.

Haas (28) has reported that excessive NaCl or KCl decreased the magnesium content of plants and their chlorophyll content. He also suggested that an application of 100 pounds or less of chlorides per acre may seriously interfere with carbohydrate metabolism in tobacco plants by disturbing the amylolytic activity in the leaf, resulting in excessive starch accumulation in the leaves. Younts and Musgrave (72) have reported that corn growth was depressed at a chloride rate between 45 and 90 pounds per acre (60 to 120 pounds K_2O as KCl) when row applied, with maturity being delayed by a somewhat lower chloride rate. Field experiments indicated that broadcasting the KCl alleviated the high chloride effect.

These same workers (73) have shown the total nitrogen uptake by corn was depressed by high rates of chloride. This effect was primarily associated with nitrate-nitrogen. Also, the absorption of chloride was directly related to the amount applied. Haas (28) has also reported that increased salts in the medium were associated with decreases in the percentages of nitrate-nitrogen and protein nitrogen in the plants.

York (71) has shown the addition of KCl and NaCl greatly increased the manganese content of corn and sudan grass. Bolle-Jones (6) showed that an increased K supply increased the concentration of manganese in the stems and petioles of potato plants. He also suggested that one of the functions of K was to increase the mobility of manganese within the plant.

Hartwell and Pember, as reported by Harmer and Benne (29), concluded that apparently certain of the uses of K, with some plants at least, may be performed by sodium, although there are certain principal functions of K which cannot be performed by any other element. If the amount of K is insufficient for the performance of these exclusive functions, probably maximum growth cannot be secured with any amount of sodium which may be added. Perhaps one of the more exclusive functions of K, in respect to sodium, is the necessity of adequate K in the plant for nitrogen to be made into proteins. It has been reported (54) with low K, protein formation is retarded, nitrates are not changed into proteins quite as fast or completely, and ammonia forms of nitrogen accumulate.

Scarseth (61) has suggested that since only the nutrient that enters the plant is effective in feeding the crop, it is important to know whether or not the plant is absorbing the nutrient. The failure of the plant to obtain the nutrient may depend upon many factors, such as, movement of the nutrient to the surface out of reach of the roots, leaching, fixation, poor root development, or deficient aeration and toxic root zones.

Tissue tests indicate the presence or absence of these nutrients in the conducting tissues of the plant in soluble, unassimilated form. When the intent is to ascertain the first limiting nutrient growth factor it seems important to differentiate between nutrients that have been assimilated and those that are unassimilated and still in the role of a raw material. It is for this reason the conducting-tissue parts are cut instead of crushed or ground. The test does not show nutrients that have been assimilated into organic compounds.

The plant is a dynamic system growing out of an equally dynamic soil. Conditions of nutrition vary within the plant with the state of growth, root development, and formation of the seed or fruiting body. Soil conditions also vary in regard to moisture, fertilizer placement, aeration, organic matter content, temperature, and other factors. Therefore, variations in the soluble nutrients in a plant at various stages of growth are to be expected. Nevertheless, if the nutritional status within the plant is determined frequently during the growing period, information regarding the factors of nutrition that are limiting at any particular period is obtained.(61)

Lawton (41) suggested the best program for diagnosis of chemical problems in soil fertility includes the integrated use of various diagnostic techniques, such as tissue testing, soil testing, and foliar symptoms.

EXPERIMENT I

RATE AND PLACEMENT OF FERTILIZERS

Crops: Carrots, Table Beets, Onions, Broccoli, and Cauliflower

Procedure

The field work of this investigation, and the ones to follow, was carried out at the Muck Experimental Farm in Clinton County, Michigan. The soil was classified as a Houghton Muck containing 85 per cent organic matter and having a pH of approximately 6.3.

Three fertilizer placement and rate experiments were initiated in 1949. Chantenay carrots, Detroit Dark Red table beets, and Downing Yellow Globe onions were grown. The fertilizer treatments are shown in Tables 1 and 2. The treatments in beet and carrot series were replicated four times and the onion series six times. They were maintained on the same area during the 4-year period.

Soil samples from all plots were made up of 10 cores from the 0 to 6-inch layer. Each sample was screened through a 2mm. sieve and dried at room temperature.

The carrot and table beet plots were sampled in May, 1952. They were tested for extractable P and K using 0.018 N CH_3COOH extractant and a 1:4 soil to extractant ratio by volume. The onion plots were sampled in September 1951, May 1952, and

May 1953 to determine the effect that time of sampling and annual application of fertilizers had on amounts of available soil P and K. Yields of the various crops were determined.

Broccoli (var. Green Sprouting Green Mountain) was planted in 1955 and 1956 on the area where onions were previously grown (Table 3). All treatments were replicated three times and a 5-10-20 fertilizer containing 3/4 per cent manganese was the basic fertilizer used. Fifty pounds of borax per acre was broadcast on all plots.

The plots were sampled in the spring and fall of 1955 and 1956, respectively. The soil P was extracted by 0.025 N HCl + 0.03 N NH_4F (Bray P_1) and by 0.018 N CH_3COOH (Spurway Active), and the soil K was extracted by 0.018 N CH_3COOH as shown in Table 3. The soil to extractant ratio was 1:4 by volume.

This same area was planted to cauliflower (var. Snowball) in 1957 and 1958 having received the same annual rates of fertilizer and the same methods of fertilizer placement as the broccoli and onion experiments. All treatments were replicated three times and received applications of boron and manganese at the rate of 3 and 10 pounds per acre, respectively.

The plots were sampled in the spring of 1957 and were tested for extractable P and K. The soil P and K was extracted by 0.018 N CH_3COOH having a soil to extractant ratio of 1:4; soil P was also determined by extracting with 0.025 N HCl + 0.03 N NH_4F at soil to extractant ratios of 1:4 and 1:16.

The extractable P was determined by a colormetric method using the ammonium-molybdate-hydrochloric acid solution proposed by Dickman and Bray (19) and 1-ammino, 2-napthol, 4-sulphonic acid reducing agent developed by Fiske and Subbarow (24).

The extractable K was determined with a photoelectric colorimeter using a red filter (wavelength of 650 mu) and employing a sodium cobalti-nitrite procedure involving the use of 95 per cent ethyl alcohol.

The uptake of K by broccoli was measured by determining the amount of potassium in the spring and fall on all plots using 0.018 N CH_3COOH as the extracting solution, and including the amount of K applied per acre as fertilizer. On this basis the following relationship was used as a measure of the uptake of K by the plant:

Pounds of K obtained in the spring sampling	+	Pounds of K applied to the soil	-	Pounds of K obtained in the fall sampling	=	K uptake by the plant

Results and Discussion

Data in Table 1 show that rates of fertilizer application were reflected in the soil tests. Highest tests for P and K were obtained from the plots receiving the greatest amounts of fertilizer. However, no significant increases in yield of either carrots or beets resulted from any of the treatments.

Placement of fertilizer did not significantly affect the total yield. However, when a serious infestation of "black root" occurred, better stands of beets were obtained on plots

TABLE 1

THE INFLUENCE OF FERTILIZER TREATMENT ON THE YIELD OF CARROTS AND TABLE BEETS AND THE AMOUNT OF EXTRACTABLE SOIL PHOSPHORUS AND POTASSIUM, 1952

Pounds 0-10-30 per acre	Placement	Pounds per acre*				Tons per acre*	
		P		K			
		Carrots	Table beets	Carrots	Table beets	Carrots	Table beets
400	1" below seed	10	10	102	137	33.1	27.0
800	1" below seed	12	13	123	137	33.8	29.6
800	2" below seed	14	11	121	125	34.8	28.4
800	3" below seed	11	14	125	197	34.6	28.6
800	Drilled in**	13	13	119	151	35.0	28.4
800	1" to side and 2" below seed	11	10	163	137	34.6	27.8
800	Drilled in }	15	19	246	354	34.6	27.6
800	3" below seed }						
L.S.D.*** (5% level)		4.6	4.1	68.5	96.0	N.S.	N.S.

*Averages of four replications. Soil sampled May 1952.
**Fertilizer applied in 7-inch bands, 3-1/2-inches deep.
***L.S.D. refers to least significant difference between means at the 5% level.

where the fertilizer was applied by the single band method rather than with a grain drill in 7-inch parallel bands. A soil test of 10 pounds of P and 100 pounds of K per acre supplemented with an application of 400 pounds of 0-10-30 per acre annually was sufficient to produce high yields of either crop.

The data in Table 2 show the influence of fertilizer placement on the yield of onions. The yields were significantly higher on plots where part or all of the fertilizer was placed in a band below the seed, or in a band 1 inch to the side and 2 inches below the seed, than they were on plots where the fertilizer was placed with the grain drill in bands 7 inches apart and 3-1/2 inches deep.

Significant differences obtained between placement treatments for both the P and K tests were not consistent and probably should be ascribed to sampling error. However, in 1951 and 1953, those plots receiving 400 pounds of fertilizer placed 1 inch below the seed and an additional 400 pounds side dressed generally gave significantly higher P and K tests than those receiving other methods of placement. Conversely, in 1952, plots receiving this same method of placement gave significantly lower K tests than those receiving some of the other methods.

The significantly higher P and K tests obtained by this method of placement in 1951 and 1953 may possibly be attributed to larger residual amounts of these elements in the soil. This might be due, in part, to the later date of application

TABLE 2

THE INFLUENCE OF FERTILIZER TREATMENT ON THE YIELD OF ONIONS AND AMOUNT OF EXTRACTABLE SOIL PHOSPHORUS AND POTASSIUM, 1951, 1952, and 1953

Pounds* per acre	Placement	Pounds per acre**						Number of 50-pound bags per acre	
		P			K				
		1951	1952	1953	1951	1952	1953	1951	1952
400	Drilled in	14	14	11	276	265	215	162	249
400	1" below seed	14	11	11	308	164	168	320	502
600	1" below seed	15	16	11	339	309	207	381	499
800	1" below seed	18	16	12	487	270	276	492	563
800	2" below seed	18	14	12	400	272	207	524	572
800	3" below seed	19	15	10	392	319	200	577	512
800	1" side and 2" below seed	14	18	11	375	282	231	498	487
800	Drilled in	17	18	11	395	291	230	313	399
800 800	Drilled in 3" below seed	28	23	14	375	413	259	625	652
400 400	1" below seed Drilled in	18	13	16	356	316	260	425	583
400 400	1" below seed Side dressed	21	16	19	581	228	320	438	532
L.S.D.	(5% level)	4.5	5.5	3.6	124	47.8	45.4	90	112

*4-10-20 applied in 1951 and 5-10-20 in 1952.

**Soil test and yield data are averages of six replications. Soils sampled in September 1951 and May 1952 and 1953.

of "side-dress" fertilizer, or to the fact that fewer nutrients were removed because of lower crop yields.

By comparing treatments which involved the same methods of placement, the data indicate that 1951 yields increased directly with rate of fertilizer application.

The residual soil P and K also increased when more fertilizer was applied. The amount of extractable P in the plots receiving 1,600 pounds of fertilizer per acre was significantly higher than in any other plots in 1951. Similar results were obtained in 1952 except where 800 pounds of 5-10-20 was applied 1 inch to the side and 2 inches below the seed or where the fertilizer was drilled in. The same degree of significance, however, did not apply to the extractable soil K but a general increase in K was observed with increased rates of fertilizer application.

The highest yields were obtained in 1951 and 1952 on the plots receiving 800 pounds of fertilizer per acre placed 3 inches below the seed and 800 pounds per acre drilled in. Yields resulting from this treatment were significantly higher than all the other treatments in 1951 except where 800 pounds of fertilizer per acre was placed 3 inches below the seed. In 1952, significantly higher yields were produced on plots receiving this treatment except where 800 pounds of fertilizer per acre was placed 1 inch below the seed, 2 inches below the seed, and where 400 pounds was placed 1 inch below the seed and 400 pounds was drilled in.

Onions required a higher level of soil P and K for high yields than did carrots or table beets. Where the soil test was about 15 pounds of P and 200 pounds of K per acre, the onion crop required 800 pounds of 4-10-20 or 5-10-20 per acre annually to produce high yields.

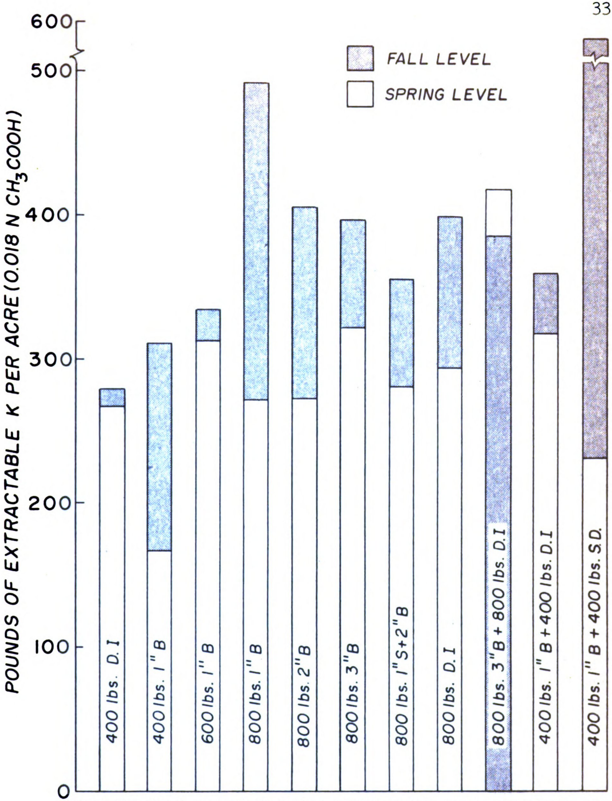
Time of sampling is important in interpreting soil test results. In general, less extractable K was obtained from samples taken in the spring than in the fall as shown in Table 2 and Figure I. In all cases except one, the soils sampled in the fall of 1951 had higher amounts of extractable K than did those sampled in the spring of 1952 and 1953. Time of sampling did not materially affect the amount of soil P. There was no accumulation of P or K from 1951 to 1953 inclusive, even at the higher fertility levels.

From the data shown in Table 2 and Figure I as much as 60 per cent of elemental K was lost from the 0-6 inch layer between fall and spring sampling dates. Probably the displaced K was lost in the drainage water and/or removed from the surface layer and subsequently deposited at some lower depth in the profile.

Similar results were reported by Bigger (5). He found that the applied K was leached from the surface layer and moved down to the lower depths.

These results suggest that fall applications of K on organic soils can lead to serious losses of K. Likewise, it would be inadvisable to attempt to build up residual K to extremely high levels on these soils.

As shown in Table 3, there was no significant difference in yields of broccoli in 1955 or 1956, regardless of the rate



METHODS AND RATES OF APPLICATION OF A 5-10-20 FERTILIZER

Figure 1. A comparison of the extractable soil potassium obtained in the fall versus spring sampling by various methods of fertilizer placement.

TABLE 3

THE INFLUENCE OF FERTILIZER TREATMENT ON THE YIELD OF BROCCOLI AND ON THE AMOUNT OF EXTRACTABLE SOIL PHOSPHORUS AND POTASSIUM, 1955 AND 1956

	Pounds per acre*			Pounds per acre						Tons broccoli per acre*	
	P			K							
	1955	1956		1955			1956				
Soil Treatment**	Spring	Spring		Spring	Fall	K*** Uptake	Spring	Fall	K Uptake	1955	1956
400 drilled in	11	24	10	144	79	132	53	52	67	3.3	2.4
400 1" below seed	11	30	8	171	93	145	40	30	76	3.8	2.7
600 1" below seed	15	29	10	144	83	161	52	40	112	3.6	2.7
800 1" below seed	18	31	13	179	96	216	52	43	142	3.1	2.5
800 2" below seed	14	32	13	142	128	147	66	74	125	3.1	2.3
800 3" below seed	18	34	11	137	100	170	70	53	150	3.7	2.4
800 1" side and 2 below seed	17	34	10	148	161	120	61	30	164	3.5	2.4
800 drilled in	15	33	12	144	107	170	69	74	128	3.2	2.4
800 3" below seed, 800 drilled in	37	57	23	245	299	213	156	279	144	3.5	2.5
400 1" below seed, 400 drilled in	19	30	10	163	99	197	61	71	123	3.5	2.2
400 1" below seed, 400 side dressed	18	29	11	169	118	184	76	104	105	3.7	2.4
L.S.D. (5% level)	6	11	6	50	45	--	54	N.S.	--	N.S.	N.S.

*Averages of three replications. Soil K extracted with $0.018\underline{N}CH_3COOH$; soil P extracted with $0.018\underline{N}CH_3COOH$ in 1955 and with $0.025\underline{N}$ HCl+$0.03\underline{N}NH_4F$ and $0.018\underline{N}CH_3COOH$ in 1956.

**5-10-20 was the basic fertilizer applied.

***Pounds Soil K obtained in spring sampling + Pounds K applied - Pounds Soil K obtained in fall sampling = K uptake of fertilizer applied or the method of fertilizer placement. However, the highest yields in 1955 and 1956 were obtained where 400 pounds of a 5-10-20 fertilizer was placed in a band 1 inch below the seed. The residual P and K levels for this treatment in the spring of 1955 and 1956, based on extracting the soil with 0.018 N CH_3COOH were 11 and 8 pounds per acre of P and 171 and 40 pounds of K per acre, respectively. The residual P test in the spring of 1956 employing 0.025 N NCl + 0.03 N NH_4F as the extracting solution was 30 pounds per acre.

These data are in close agreement with those of Forsee (26). He reported that maximum yields of broccoli were obtained where 100 pounds of K_2O per acre was applied broadcast and the water-soluble P level in the soil was 8 pounds per acre and the acid soluble K level was 125 pounds per acre.

The lower yields of broccoli in 1956 appeared to be related to the lower fertility level, particularly in the case of K.

The ratio of P extracted by 0.025 N HCl + 0.03 N NH_4F relative to 0.018 N CH_3COOH in the spring of 1956 was 2.8:1.

It is apparent from the K data that there was a fairly consistent decrease in K both between spring and fall samplings and between the 1955 and 1956 sampling dates. The decrease in soil K between the spring and fall samplings of 1955 and 1956 can likely be attributed to crop removal, whereas the decrease in soil K between the fall of 1955 and the spring of 1956, is primarily due to leaching.

The relationships between K uptake, the pounds of K_2O applied, and the yield of broccoli and the response of

broccoli to a 5-10-20 fertilizer are shown in Tables 3 and 4.

There was a high degree of linear correlation between K uptake by broccoli, as measured by soil tests, and the pounds of K_2O applied 1 inch below the seed both in 1955 and 1956. The correlation coefficients for this relationship in 1955 and 1956 were 0.994 and 0.999, respectively. The correlation coefficient of 0.999 obtained in 1956 was significant at the 5 per cent level. The value obtained in 1955 was not statistically significant.

The over-all correlation coefficients for K uptake versus pounds of K_2O applied, regardless of method of fertilizer placement for 1955 and 1956 were 0.765 and 0.786, respectively. Both values were significant at the 1 per cent level.

Many workers have supported the theory that the chemical fixation of K by the organic matter fraction of the soil is negligible (32,33,34). The work of McCool (47) showed that organic soils with a very low ash content, 10 per cent or less, were found to possess a very small capacity to fix K, but their capacity increased with their mineral content.

The soil used in this study had a pH of 6.3 and contained 85 per cent organic matter (63). The 15 per cent mineral material in this soil undoubtedly contained a large quantity of soil bases and had little influence on the chemical fixation or release of K. This is indicated by the correlation coefficients obtained between K uptake by broccoli and the pounds of K_2O applied (Table 4). These data also support the theory of other workers (32,33,34,48,47) that the humus colloids posses a very low fixing power for K.

TABLE 4

RELATIONSHIPS BETWEEN K UPTAKE, AS MEASURED BY SOIL TESTS, THE YIELD OF BROCCOLI, AND THE AMOUNT OF K_2O AND 5-10-20 FERTILIZER APPLIED IN 1955 AND 1956

Relationship	Line of Best Fit	σ_e	r
Pounds K_2O (1" below seed) vs. K uptake, 1955	$\hat{Y} = 66.5 + 1.063x$	15.9	0.997
Pounds K_2O (1" below seed) vs. K uptake, 1956	$\hat{Y} = 11.9 + 0.988x$	2.16	0.999*
Pounds K_2O (regardless of placement) vs. K uptake, 1955	$\hat{Y} = 120.8 + 0.474x$	26.5	0.765**
Pounds K_2O (regardless of placement) vs. K uptake, 1956	$\hat{Y} = 83.2 + 0.425x$	22.2	0.786**
Yield vs. pounds of 5-10-20 fertilizer (1" below seed), 1955	$\hat{Y} = 4.6 - 0.009x$	0.12	-0.971
Yield vs. pounds of 5-10-20 fertilizer (1" below seed), 1956	$\hat{Y} = 2.9 - 0.003x$	0.08	-0.866
K uptake vs. yield (fertilizer placed 1" below seed), 1955	$\hat{Y} = 5.1 - 0.008x$	0.01	-0.999*
K uptake vs. yield (fertilizer placed 1" below seed), 1956	$\hat{Y} = 3.0 - 0.003x$	0.10	-0.847

*Significant at 5 per cent level.
**Significant at 1 per cent level.

As shown in Tables 3 and 4, the yield of broccoli decreased with increased rates of applied P_2O_5 and K_2O beyond the 40 and 80 pound application rate, respectively, where the fertilizer was placed 1 inch below the seed. The correlation coefficients for these data in 1955 and 1956 were -0.971 and -0.866, respectively. Neither value was statistically significant.

A similar relationship is shown in Table 4 between K uptake and the yield of broccoli. The negative correlation coefficients of -0.999 and -0.847 for 1955 and 1956, respectively, are indicative of the inverse relationship that existed between K uptake and the yield of broccoli.

The uptake of K, as determined by soil tests, may not necessarily indicate the actual K taken up by the plant. A loss of soil K between the spring and fall samplings, as a result of leaching, would be considered as K uptake as determined by this method.

If available K is considered as exchangeable plus water soluble K, then it is apparent that the extracting solution employing 0.018<u>N</u> CH_3COOH is measuring only a fraction of the available K. The work of Bigger (5) has shown that the exchangeable K of a Houghton muck soil, as determined by extracting the soil with 23 per cent $NaNO_3$ was approximately 1-1/2 times greater than that obtained from the same soil using 0.018<u>N</u> CH_3COOH as the soil extractant. It is also possible that successive soil extractions with 0.018<u>N</u> CH_3COOH and/or longer extraction periods would more closely approximate

the available soil K. It is possible, therefore, that larger uptake values for K would have been obtained had the exchangeable fraction of soil K been determined.

On this basis the K uptake values, based upon soil tests as used in this discussion, and the ones to follow, should be considered as relative rather than absolute uptake measurements.

The effect of rate and placement of fertilizer on the yield of cauliflower and on the amount of extractable soil P and K is shown in Table 5.

The yield of cauliflower obtained in 1957 was considerably lower than that of 1958. The difference in yield may be partially attributed to the difference in date of planting. The 1957 crop was planted on June 13, and the 1958 crop, May 10.

The plots from all treatments in 1957 gave significantly higher yields over those plots where 400 pounds of 5-10-20 was drilled in bands 7-1/2 inches apart and 3 inches deep with a grain drill. The next lowest yield was obtained from plots where 800 pounds of the fertilizer was drilled in. The highest yield of cauliflower in 1957 was obtained from the plots receiving 800 pounds of 5-10-20 placed 2 inches below the seed. The plots from this treatment, however, did not give significantly higher yields than those receiving 800 pounds of 5-10-20 placed 1 inch below the seed. However, these yields (800 pounds 5-10-20, 2 inches below seed) were significantly higher than those from plots receiving the 400 or 600 pound application rate placed 1 inch below the seed and/or where 800 pounds was placed 3 inches below the seed.

TABLE 5

THE INFLUENCE OF FERTILIZER TREATMENT ON THE YIELD OF CAULIFLOWER AND ON THE AMOUNT OF EXTRACTABLE SOIL PHOSPHORUS AND POTASSIUM, 1957 AND 1958

	Pounds per acre					
	P			K		
	$0.018\underline{N}CH_3COOH$	$0.025\underline{N}NCl + 0.03NNH_4F$		$0.018NCH_3COOH$	Cwt. per acre	
Soil treatment*	1:4**	1:4	1:16	1:4	1957	1958
400 drilled in	9	21	48	76	55	232
400 1" below seed	8	18	29	30	124	285
600 1" below seed	7	17	32	36	139	240
800 1" below seed	10	20	30	43	166	313
800 2" below seed	8	22	34	53	177	303
800 3" below seed	12	24	34	59	135	285
800 1" side and 2" below seed	7	20	28	53	161	308
800 drilled in	11	24	47	67	104	300
800 3" below seed, 800 drilled in	10	28	30	82	141	284
400 1" below seed, 400 drilled in	9	21	35	52	151	313
400 1" below seed, 400 side dressed	10	24	29	71	---	239
L.S.D. (5% level)	N.S.	N.S.	N.S.	N.S.	29	N.S.

*5-10-20 fertilizer applied. All plots received the equivalent of 3 pounds of boron and 10 pounds of manganese per acre. Soil sampled in Spring, 1957.

**Refers to soil to extractant ratio.

A similar situation resulted where 800 pounds was drilled in, or where a split application of 800 pounds was placed 3 inches below the seed and 800 pounds was drilled in.

Plots receiving the 800 pound application rate placed 3 inches below the seed gave significantly higher yields than those where 800 pounds was drilled in, although it was inferior to those treatments receiving the same amount of fertilizer placed 1 inch below the seed. Similarly, the plots receiving the 800 pound rate placed 1 inch to the side and 2 inches below the seed gave significantly higher yields than those where 800 pounds was drilled in or where only 400 pounds was placed 1 inch below the seed. Both the plots from the treatment receiving 800 pounds placed 3 inches below the seed, plus 800 pounds drilled in and the treatment where only half these rates were applied produced significantly higher yields than where the 800 pounds of 5-10-20 was drilled in.

The fact that higher yields of cauliflower were obtained in 1957 from plots where either all or part of the fertilizer was placed in a band below or to one side of the seed, as compared to the drilled in method of fertilizer placement, emphasizes the importance of band placement of fertilizer on the yield of late planted crops.

The methods of fertilizer placement, rather than the level of P and K appeared to be responsible for the difference in yields of cauliflower obtained from the different treatments in 1957. This is apparent since there was no significant difference in the amounts of extractable P or K between plots receiving the various soil treatments.

No significant difference occurred in the yield of cauliflower due to treatment in 1958.

The extractable soil P and K data in Table 5 were quite variable. However, a general trend of increased levels of soil P and K resulted with increased applications of these elements to the soil.

The higher soil P and K levels obtained from the plots where 400 pounds of 5-10-20 was drilled in as compared to the other methods of fertilizer placement may possibly be ascribed to sampling errors.

During seasons of high fertilizer response a soil test of 8 pounds of P obtained by the 0.018N CH_3COOH soil extractant or 22 and 34 pounds employing 0.025N HCl + 0.03 N NH_4F as the extracting solution at soil to extractant ratios of 1:4 and 1:16, respectively, and 50 pounds of K per acre supplemented with an application of 800 pounds of 5-10-20 per acre annually placed approximately 2 inches below the seed, was sufficient to produce high yields of cauliflower.

The ratios of P removed by 0.025 N NCl + 0.03 N NH_4F at soil to extractant ratios of 1:4 and 1:16 relative to that removed by extracting the soil with 0.018 N_3CH COOH at a soil to extractant ratio of 1:4, were 2.4:1 and 3.7:1, respectively.

EXPERIMENT II

FERTILIZER RATIO EXPERIMENT

Crops: Onions and Celery

Procedure

A fertilizer ratio experiment was initiated in 1952. Downing's Yellow Globe onions was the crop grown. Annual applications of nutrients equivalent to those in 1,000 pounds of one of the following fertilizers were made on quadruplicate plots in 1952 and 1953: 0-20-10, 5-20-10, 10-20-10, 0-20-20, 5-20-20, 10-20-20, 0-20-30, 5-20-30, 10-20-30, 0-10-30, 5-10-30, and 10-10-30. These fertilizer treatments were repeated on one-half of each plot in 1954. (From 1940 to 1951 this area had received 1,000 pounds of 0-10-30 fertilizer every year.)

A starter fertilizer containing 50 pounds of N, 10 pounds of P_2O_5, and 20 pounds of K_2O was applied to the remaining half of each plot. The fertilizers were applied at planting time in a band 2 inches below the seed. The amounts of N, P_2O_5, and K_2O applied are shown in Table 6.

The soils from the plots receiving the various treatments were sampled in September 1953 and May 1954. The samples were made up of 10 cores from the 0- to 6 inch layer of an 11 x 60 foot plot. Each sample was screened (2 mm. sive) and dried at room temperature.

Green tissue tests were made on the onion leaves on July 16 and August 1. The object was to determine the relationships between the quantity of applied N, P, and K, the uptake of these elements by the plants, and the yield of onion bulbs.

The leaves from 10 onions were selected per plot for green tissue analysis. The samples were kept cold by means of dry ice until the extractions were completed, as outlined by Bigger, et al. (5).

The water soluble N was determined colormetrically by using 10 per cent brucine in chloroform. The water soluble P and K were determined by the methods previously mentioned for determining soil P and K.

Sampling errors were determined for soil and green tissue tests.

The soils from the same onion experiment were again sampled in the spring of 1955 and analyzed for available P and K employing 0.018 N CH_3COOH as the extracting solution at a soil to extractant ratio of 1:4. The yields from the plots receiving the various treatments were determined.

Green tissue samples were collected on July 18, 1955 and water extractable P and K were determined as previously outlined. The results are shown in Tables 7, 8, 9, and 10, and Figures 5, 6, 7, 8, and 9.

A K rate experiment (0, 400, 800, and 1200 pounds K_2O per acre) with Utah 10B celery was started in 1953. Two hundred pounds of P_2O_5 were applied in 1953 and again in 1954, on one-half of each of the plots. The other half of each plot was unfertilized in 1954. Fifty pounds of borax per acre was used annually on all plots. The results are shown in Tables 11, 12, 13, and 14, and Figures 11, 12, and 13.

Another celery experiment was initiated in 1955 to determine the relationship between available soil K, total K in the plant tissue, and the yield of celery.

The air dried celery tissue was finely ground and extracted with neutral normal ammonium acetate containing lithium chloride as the internal standard. The K contained in the filtrate was evaluated flame photometrically (50).

The experimental area was previously fertilized with 2000 pounds of 0-10-30 per acre, annually, from 1941 to 1952, inclusive. Applications of nutrients equivalent to those in 2000 pounds of 0-10-0, 0-10-20, 0-10-40, and 0-10-60 fertilizers were made on one-half of each plot. The remaining half of each plot received no fertilizer application. All treatments were replicated three times and the results are shown in Table 15 and Figures 14 to 18, inclusive.

Results and Discussion

Rates of fertilizer application in the onion experiment were reflected in the soil tests, as shown in Table 6. Less extractable K was obtained from samples taken in the spring than in the fall. The time of sampling did not materially affect the amount of extractable P.

The fertilizers did not significantly affect the yield of onions in 1953. However, in 1954, the plots receiving 100

TABLE 6

THE INFLUENCE OF FERTILIZER TREATMENT ON THE YIELD OF ONIONS AND ON THE AMOUNT OF EXTRACTABLE SOIL PHOSPHORUS AND POTASSIUM, 1953 AND 1954

Pounds per acre annually, 1952, 1953, 1954	Soil tests*				Number of 50-pound bags per acre*		
	Pounds per acre						
	P		K				
$N-P_2O_5-K_2O$	Sept. 1953	May 1954	Sept. 1953	May 1954	1953	1954**	1954***
0-200-100	21	18	282	171	1130	785	806
50-200-100	21	23	296	187	1134	811	843
100-200-100	24	20	267	179	1123	868	880
0-200-200	27	21	301	236	1060	776	830
50-200-200	20	22	276	267	1101	782	806
100-200-200	15	22	280	225	1123	795	947
0-200-300	20	23	375	302	1057	728	863
50-200-300	26	20	357	264	1085	748	930
100-200-300	24	22	299	304	1088	756	950
0-100-300	15	15	309	287	960	849	920
50-100-300	14	15	288	289	1060	787	934
100-100-300	16	17	318	294	1011	927	932
L.S.D. (5% level)	10.0	4.6	84.3	43.5	N.S.	120	N.S.

*Average of four replications. Soils sampled in September 1953 and May 1954. Tissue samples taken on July 16 and August 1, 1954.

**Yield from plots receiving 1,000 pounds of fertilizer per acre.

***Yield from plots receiving only a starter fertilizer containing 50 pounds N, 10 pounds P_2O_5, and 20 pounds K_2O.

pounds N, 100 pounds P_2O_5, and 300 pounds K_2O per acre yielded more than did any of the other treatments and in most cases the differences were significant.

The plots receiving only the starter fertilizer, 50, 10, and 20 pounds per acre of N, P_2O_5, and K_2O, respectively, produced higher yields in 1954 in every case than did those plots receiving the basic fertilizers without the starter. It is evident from these data that the residual N, P, and K were sufficient to produce high yields in 1954 when only a starter fertilizer was used.

Figure 2 shows that on July 16 the water extractable N in the leaves of the onions increased directly with the amount of N applied. There appeared to be a relationship between the amount of N in the onion leaves and the yield of bulbs although the relationship did not exist with onions sampled on August 1.

It is important to select tissue for sampling at a time when the N, P, and K will best correlate with plant needs.

Figure 3 shows that the water extractable P in the onion leaves sampled on July 16 did not entirely reflect the increased soil P, but in every case except one it was related to the yield of bulbs. This relationship did not exist with the onions sampled on August 1. There was less concentration of P in the onion tissue sampled on August 1 than in that sampled on July 16. This same relationship existed between the two tissue sampling dates receiving the starter fertilizer.

The data in Figure 4 show no relationship between the amount of K in the onion leaves and the yield of bulbs.

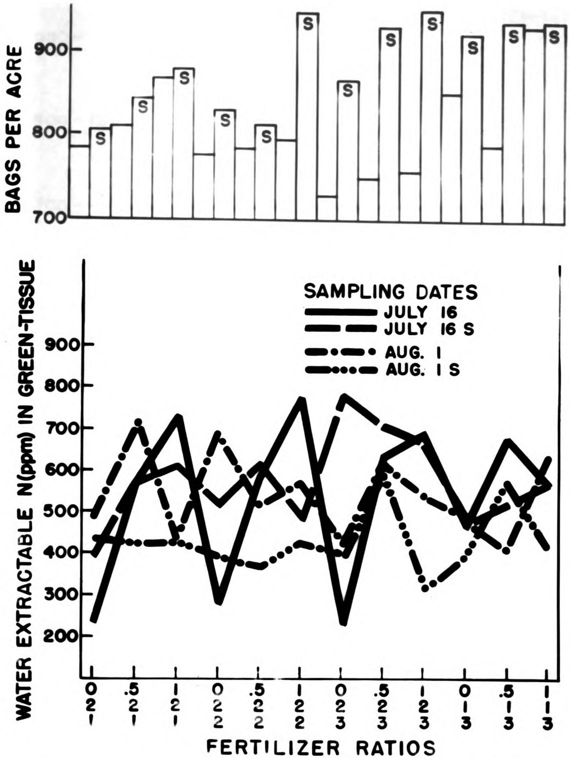


Figure 2. The effect of fertilizer treatment on the amount of nitrogen in the leaves of onions and the yield of bulbs.

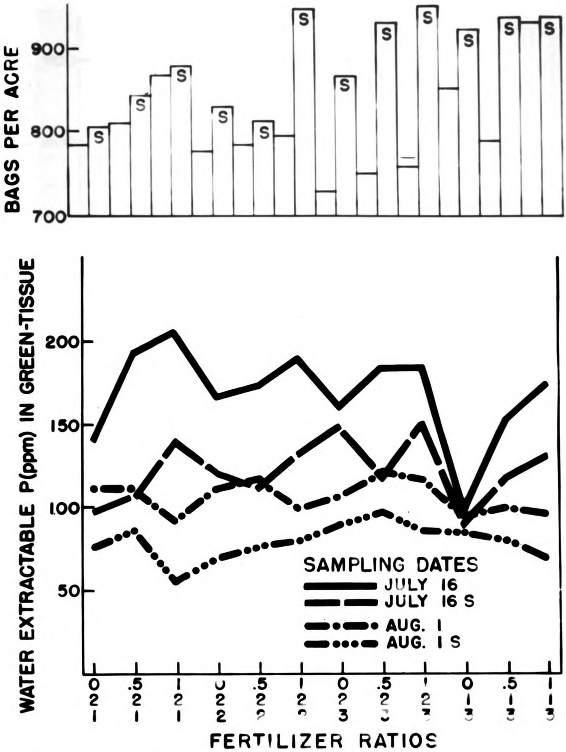


Figure 3. The effect of fertilizer treatment on the amount of phosphorus in the leaves of onions and the yield of bulbs.

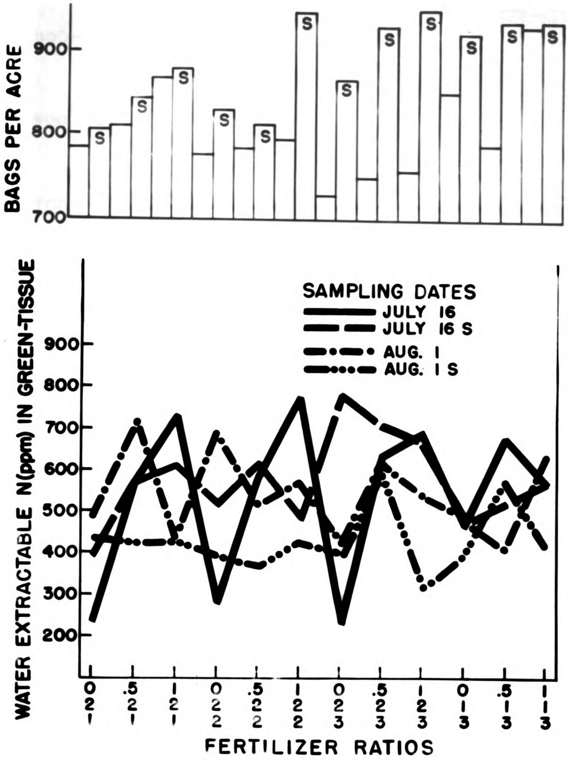


Figure 2. The effect of fertilizer treatment on the amount of nitrogen in the leaves of onions and the yield of bulbs.

Likewise, the applied soil K was not reflected in the leaves of the onion tissue. Generally there was more water extractable K in the onion tissue sampled on August 1 than in the onion tissue sampled on July 16. The reverse relationship occurred for the water extractable N and P, as shown in Figures 2 and 3, respectively.

The soil and tissue test results and the 1955 onion yield data are shown in Table 7. The "fertilized half" of the plots resulted in higher yields than the half receiving starter fertilizer (50 pounds N, 10 pounds P_2O_5, and 20 pounds K_2O per acre). To simplify the discussion the plots which received the initial treatments annually are designated as the "fertilized half" of the plot.

No significant interactions between P and K or between N, P, and K were obtained on the "fertilized half" of the plots or on the plots receiving the starter fertilizer. There was, however, a significant difference in the yield of onions between rates of N at the 1 per cent level on both the "fertilized half" of the plots and on those receiving the starter fertilizer (Tables 8 and 9).

The relationship between the yield of onions and the residual soil K at three levels of N on the plots receiving the starter fertilizer is shown in Figure 5.

Where no nitrogen was applied the previous year (1954), the yield increased directly with an increase in available K up to approximately 180 pounds of K per acre. A decrease in yield resulted when the available K increased beyond this amount.

TABLE 7

THE INFLUENCE OF FERTILIZER TREATMENT ON THE YIELD OF ONIONS, ON THE AMOUNT OF EXTRACTABLE SOIL P AND K, AND THE P AND K IN THE GREEN TISSUE, 1955

Pounds per acre annually since 1952	Pounds per acre		PPM in green tissue*		Number of 50-pound bags per acre
	P	K	P	K	
0-200-100(S)**	22	136	65	1150	596
0-200-100(F)	24	177	98	1400	771
50-200-100(S)	22	165	98	1000	701
50-200-100(F)	26	153	120	1650	838
100-200-100(S)	23	146	-	-	749
100-200-100(F)	23	158	174	1150	872
0-200-200(S)	25	173	-	-	742
0-200-200(F)	28	222	135	1800	811
50-200-200(S)	26	184	66	1250	711
50-200-200(F)	30	212	80	1800	806
100-200-200(S)	25	204	144	1150	775
100-200-200(F)	31	217	135	2150	839
0-200-300(S)	23	225	78	1950	673
0-200-300(F)	24	254	145	2000	730
50-200-300(S)	23	219	80	1500	784
50-200-300(F)	26	258	98	2250	852
100-200-300(S)	23	218	90	1650	739
100-300-300(F)	25	286	75	2100	861
0-100-300(S)	17	236	35	1750	671
0-100-300(F)	22	336	66	2150	785
50-100-300(S)	22	213	42	1950	746
50-100-300(F)	23	271	90	2750	790
100-100-300(S)	21	201	127	2300	803
100-100-300(F)	28	304	184	2500	837
L.S.D.(5%level)(S)	6.2	51.2	-	-	101.7
L.S.D.(5%level)(F)	7.8	56.8	-	-	93.0

*Green tissue sampled on July 18, 1955.

**(F) refers to plots receiving 1,000 pounds of fertilizer per acre.
(S) refers to plots receiving starter fertilizer containing 50 pounds N, 10 pounds P_2O_5, and 20 pounds K_2O per acre.

TABLE 8

THE INFLUENCE OF FERTILIZER TREATMENT ON THE YIELD OF ONIONS FROM THE PLOTS RECEIVING THE STARTER FERTILIZER AT THREE LEVELS OF NITROGEN WHICH HAD BEEN APPLIED IN 1954

Pounds applied per acre in 1954			Pounds per acre		Number of 50-pound bags per acre
N	P_2O_5	K_2O	P	K	
0	200	100	22	136	596
50	200	100	22	165	701
100	200	100	23	146	749
0	200	200	25	173	742
50	200	200	26	184	711
100	200	200	25	204	775
0	200	300	23	225	673
50	200	300	23	219	784
100	200	300	23	218	739
L.S.D. (5% level)	-	-	6.2	51.5	101.7
Average for Nitrogen Levels					
0	-	-	-	-	670
50	-	-	-	-	732
100	-	-	-	-	754
L.S.D. (5% level)	-	-	-	-	51.0

TABLE 9

THE INFLUENCE OF FERTILIZER TREATMENT ON THE YIELD OF ONIONS FROM THE "FERTILIZED HALF" OF THE PLOTS AT THREE LEVELS OF NITROGEN AND THREE LEVELS OF POTASH, 1955

Pounds applied per acre in 1955			Pounds per acre		Number of 50-pound bags per acre
N	P_2O_5	K_2O	P	K	
0	200	100	24	177	771
50	200	100	26	153	838
100	200	100	23	158	872
0	200	200	28	222	811
50	200	200	30	212	806
100	200	200	31	217	839
0	200	300	24	254	730
50	200	300	26	258	852
100	200	300	25	286	861
L.S.D. (5% level)	-	-	7.9	56.8	96.0
Average for Nitrogen Levels					
0	-	-	-	-	771
50	-	-	-	-	832
100	-	-	-	-	857
L.S.D. (5% level)	-	-	-	-	46.4

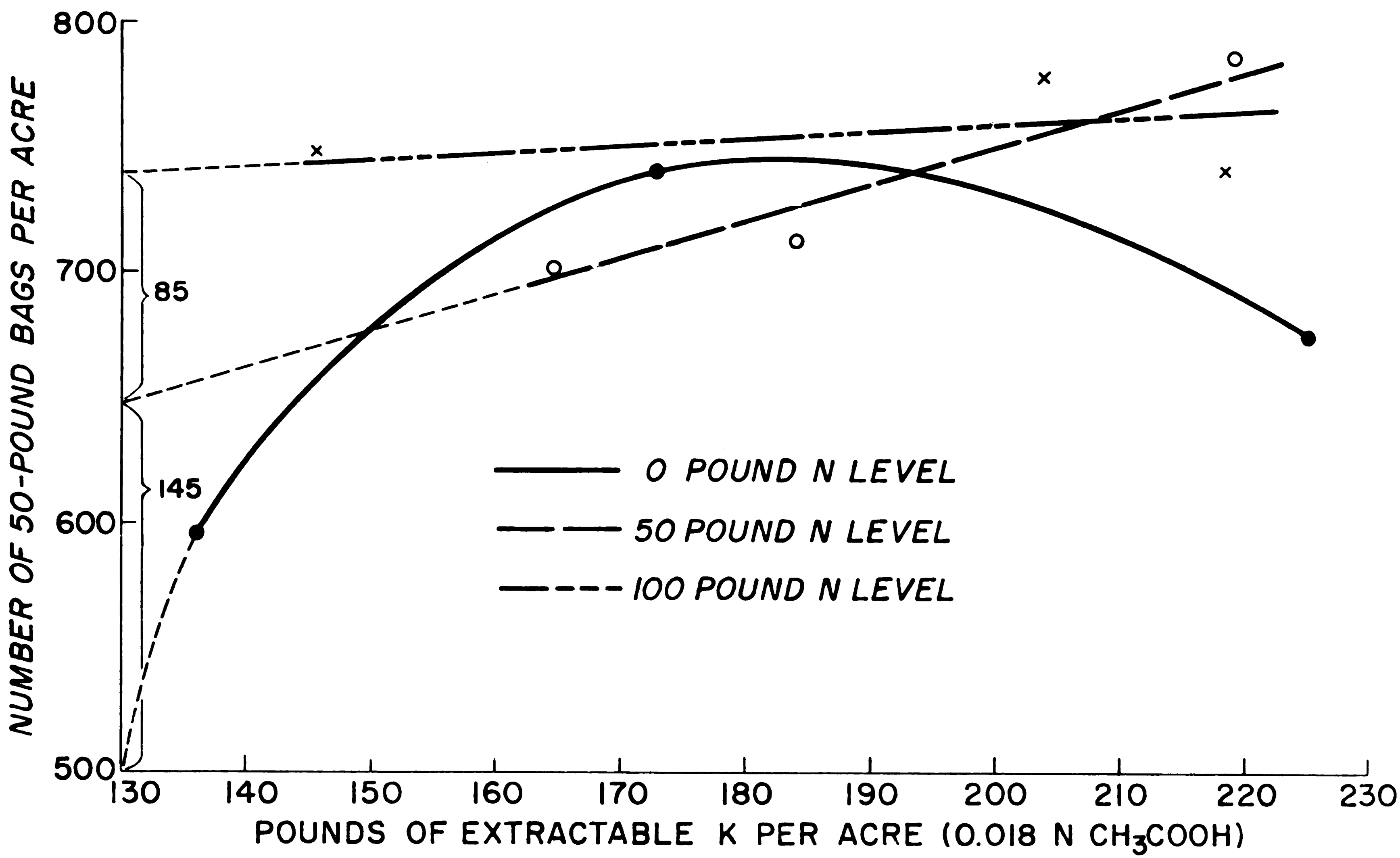


Figure 5. The relationship between the yield of onions in 1955 and residual soil potassium at three levels of nitrogen applied in 1954.

The yield of onions obtained from the plots receiving no N in 1954 was 500 fifty pound bags per acre. The available soil P and K, as indicated by extracting the soil with 0.018N CH_3COOH, were 22 and 130 pounds per acre, respectively. Where 50 pounds of N was applied per acre at the same level of soil K, the yield of onions was increased by 145 fifty pound bags per acre. These values were obtained by extrapolating the yield response curves for the 0-N and 50 pound N treatments back to the "Y" axis. Since there was no significant difference in the level of available soil P the increase in yield may be ascribed to the 50 pounds of applied N per acre.

There was a positive linear yield response between the 50 pounds of applied N and increased levels of soil K. The yield response curves for the 0 pound N treatment and the 50 pound N treatment intersected at approximately 151 and 192 pounds of available soil K per acre. It is apparent that the same yield of onions can be obtained with different combinations of N, P, and K. From these data approximately 23 pounds of P and 192 pounds of K per acre are capable of producing the same yield of onions as when supplemented with an additional 50 pounds of N. The initial response to N occurred at the lower level of available K. The price of the various carriers of N, P, and K may determine what combination of these three elements would be used in order to obtain optimum yields.

Extrapolation of the 100 pound N treatment back to the "Y" axis indicated that high yields of onions were initially obtained at the lower levels of available soil K. However, the yield did not increase to any extent with increased soil K.

The residual effect from the application of 100 pounds of N per acre in 1954, increased the yield of onions in 1955 by 85 fifty pound bags per acre over the 50 pound N application and by 230 fifty pound bags per acre over the 0 pound N treatment at a level of approximately 22 pounds of P and 130 pounds of K per acre.

The yield response curves for the 50 and 100 pound nitrogen treatments intersected at around 207 pounds of available K per acre.

It appears from these data that the same yield of onions can be obtained with different combinations of N, P, and K even at the higher nitrogen levels. Approximately 23 pounds of P and 210 pounds of K per acre and the residual N remaining from a 50 pound application of N the previous year are capable of producing the same yield of onions as the treatment receiving 100 pounds of N the previous year.

These data show that the residual N (N applied the previous year) affected the yield of onions even though 50 pounds of N was applied in the starter fertilizer.

A similar relationship is shown in Figure 6, in contrast to the effects of residual N, P, and K the data in Table 9 and Figure 6, show the relationship between the yield of onions and available soil K at three levels of applied N and K. The yield of onions obtained on the "fertilized half" of the plots in 1955 were consistently higher than those

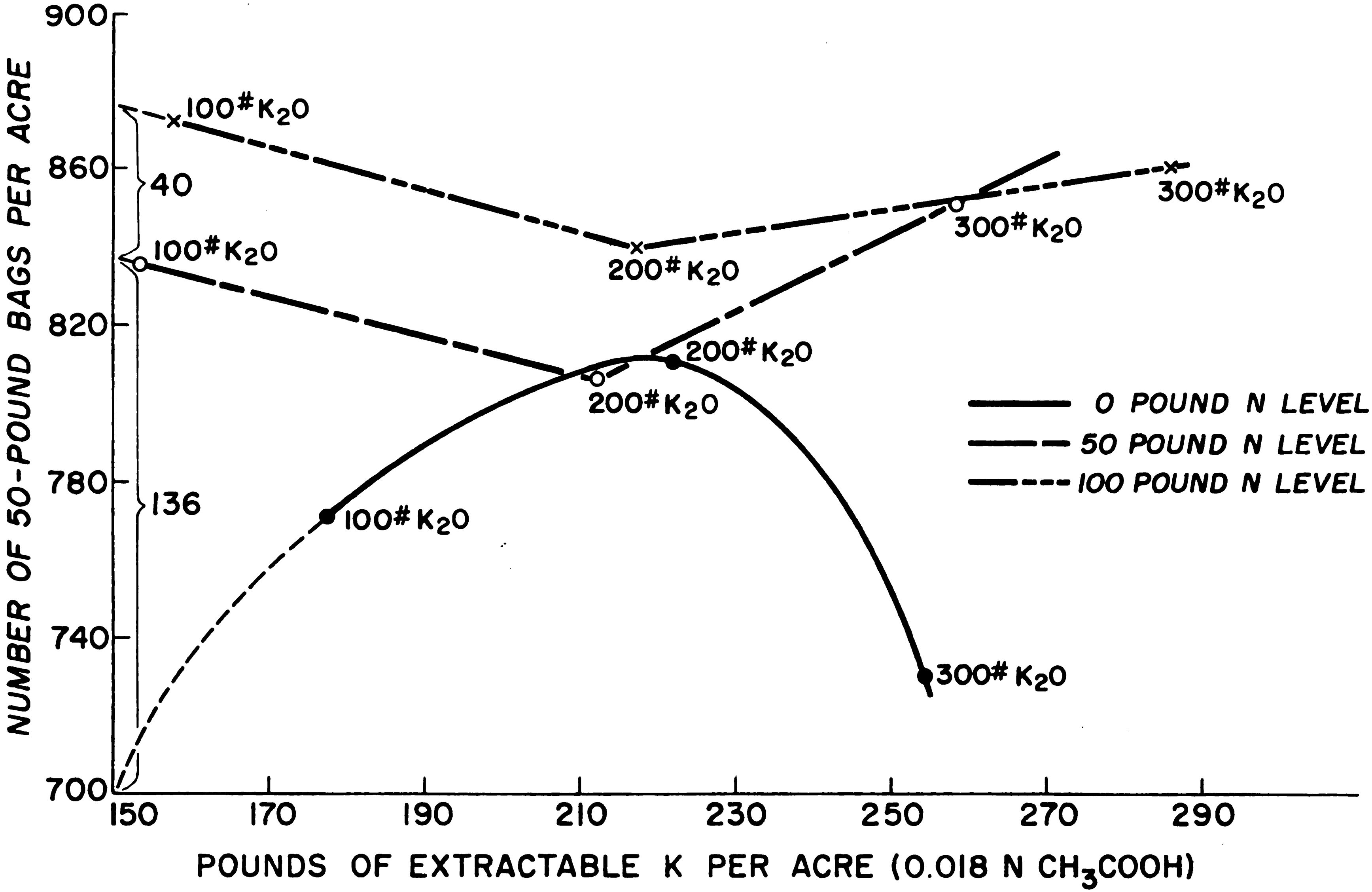


Figure 6. The relationship between the yield of onions and extractable soil potassium at three levels of nitrogen and potash.

receiving starter fertilizer, consisting of 50 pounds of N, 10 pounds P_2O_5, and 20 pounds K_2O per acre. This is shown in Tables 8 and 9 and Figures 5 and 6.

The general shape of the yield response curves on the plots receiving the 0, 50, and 100 pound N treatments and the 200 and 100, 200, 300 pounds per acre of P_2O_5 and K_2O, respectively, were similar to those receiving the starter fertilizer only.

The yield of onions from the plots receiving no N increased directly with an increase in available K up to approximately 220 pounds of available K per acre. The sudden decrease in yield as shown in Figure 6 may have been due to an unbalanced condition in the plant.

Walsh and Clarke (69) have shown a K induced Mg deficiency of tomatoes. Excessive K fertilization resulted in depressed growth and yield together with symptoms typical of Mg deficiency, the severity of the disorder depending upon the degree of unbalance between the concentration of K and Mg in the leaves. York (71) has shown that K greatly reduced absorption of other major cations, particularly Ca and Mg. The decrease in onion yields at the higher K levels may possibly be explained on this basis. Wallace (68) has reported that Mg deficiency in acid soils of the Netherlands is much increased by adding K salts and still more by adding N as an ammonium compound, probably from the standpoint of NH_4 being a competing ion. In this experiment the nitrogen was supplied as a combination of urea and ammonium nitrate which may have complimented the K in decreasing the uptake of Mg by the onion plants at the 100 pound N treatment. It is possible NH_4 and K antagonism on the uptake of Mg and/or an insufficient supply of available P or K at such high N levels were responsible for limiting the yield of onions at the 100 pound N treatment. The former hypothesis has been supported by Bear (3). He showed the absorption of N in the NH_4 form resulted in a reduction in the K + Ca + Mg + Na content of plants.

A comparison of the yield response of onions from the plots receiving the starter fertilizer relative to those receiving applied N at three levels of application, where 100 and 300 pounds per acre of P_2O_5 and K_2O were applied, respectively, is shown in Table 10 and Figure 7.

There was a positive linear yield response with increasing levels of N on both the plots receiving the starter fertilizer and on the "fertilized half" of the plots. The yield of onions was increased on the plots receiving the starter fertilizer, from 671 fifty pound bags per acre to 803 fifty pound bags per acre where no N and 100 pounds of N, respectively, had been applied the previous year. The soil P and K levels on these plots ranged from 17 to 22 and from 201 to 236 pounds per acre, respectively. There was no significant difference in either the P or K soil test values.

The yield of onions on the "fertilized half" of the plot receiving no N was 785 fifty pound bags per acre, and increased linearly to 837 fifty pound bags per acre where 100 pounds of N had been applied annually. The "fertilized half" received 100 pounds of P_2O_5 and 300 pounds K_2O per acre. There was no significant difference in soil P between N treatments; however,

TABLE 10

A COMPARISON IN THE RESPONSE OF ONIONS TO RESIDUAL NITROGEN AND APPLIED NITROGEN WHERE 100 AND 300 POUNDS PER ACRE OF P_2O_5 AND K_2O WERE APPLIED RESPECTIVELY TO THE "FERTILIZED HALF" OF THE PLOTS, 1955

Initial N level in pounds per acre	Soil tests pounds per acre		Number of 50-pound bags per acre (S)	Soil tests pounds per acre		Number of 50-pound bags per acre (F)
	$P_{(S)}$*	$K_{(S)}$		$P_{(F)}$**	$K_{(F)}$	
0	17	236	671	22	336	785
50	22	213	746	23	271	790
100	21	201	803	28	304	837
L.S.D. (5% level)	6.2	51.5	101.7	7.8	56.8	N.S.

*(S) refers to plots receiving starter fertilizer in 1954 and 1955, plus 100 pounds of P_2O_5 and 300 pounds K_2O in 1952 and 1953.

** (F) refers to plots receiving 100 pounds of P_2O_5 and 300 pounds of K_2O annually since 1952 the 0 pound N treatment had a significantly greater amount of soil K than did the 50 pound N treatment, as shown in Table 10.

The increase in yield obtained on the "fertilized half" of the plots relative to the plots receiving the starter fertilizer on the 0 pound N treatments, appeared to be due to the higher level of residual soil K plus the 100 and 300 pounds of applied P_2O_5 and K_2O per acre.

The magnitude in yield differences between the two N response curves decreased as the residual N in the unfertilized half of the plots increased. At the 100 pound N level the difference in yield between the "fertilized half" of the plots and those receiving the starter fertilizer, amounted to 34 fifty pound bags per acre as compared to 114 fifty pound bags at the 0 pound N level.

The residual soil P and K values were 21 and 201 pounds per acre, respectively, as obtained by extracting the soil with 0.018<u>N</u> CH_3COOH on half of the plots receiving the starter fertilizer, consisting of 50 pounds of N, 10 pounds P_2O_5, and 20 pounds K_2O per acre at planting time.

These data indicate high yields of onions were obtained from various combinations of N, P, and K.

In general, soil test levels of 20 pounds of P and 200 pounds of K per acre, using 0.018 <u>N</u> CH_3COOH as the soil extractant, will produce maximum yields under these conditions when supplemented with a starter fertilizer at planting time, consisting of 50 pounds of N, 10 pounds of P_2O_5, and 20 pounds of K_2O per acre.

The relationship between the amount of water extractable P in green onion tissue in 1955, and the amount of residual and applied N is shown in Table 7 and Figure 8.

In general, the amount of water extractable P in the green onion tissue increased with increased soil nitrogen. The amount of P in the onion tissue from the "fertilized half" of the plots was greater than that contained in the tissue from the plots receiving the starter fertilizer only. However, the amount of water extractable P in the tissues from the "fertilized half" of the plots at the higher nitrogen levels did not increase to as large a degree as the P in the tissue from the plots receiving the starter fertilizer. The correlation coefficients relating the amount of water extractable P in the green tissue and the amount of applied soil N for the "fertilized" and unfertilized half of the plots, were 0.343 and 0.727, respectively. The correlation coefficient for the latter was significant at the 5 per cent level, as shown in Figure 8.

Bear (3) has pointed out that the absorption of N as NH_4, rather than as NO_3, tends to increase the uptake of P by the plant and, at the same time, tends to lower the intake of other mineral cations. This explanation may be used to explain the increase in water extractable P from the onion tissue receiving the higher applications of N, since the N was applied as urea and ammonium nitrate.

As shown in Figure 9, there was a positive linear relationship between available soil K and the amount of K in

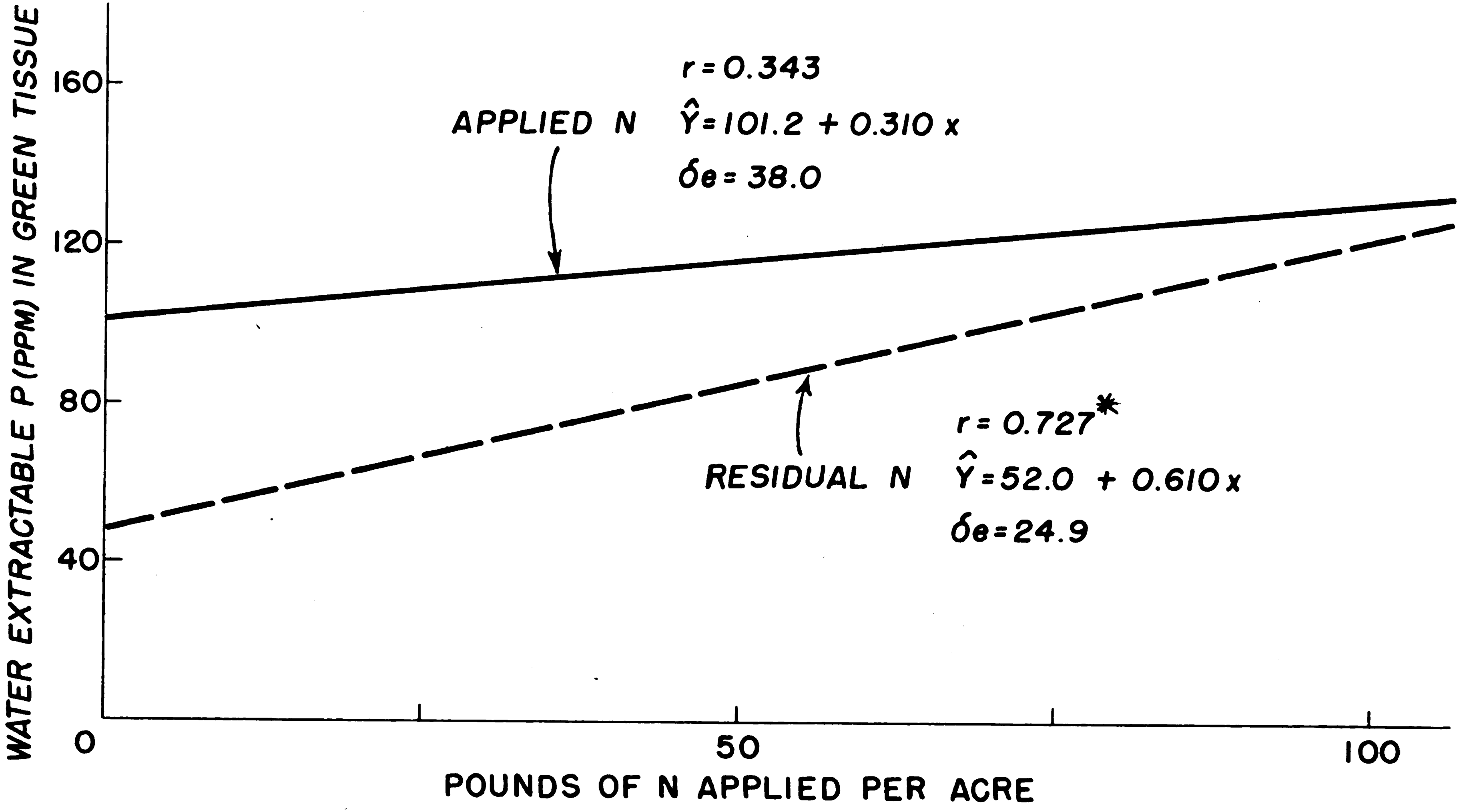


Figure 8. The relationship between residual and applied soil nitrogen and the water extractable phosphorus content of green onion tissue, 1955.

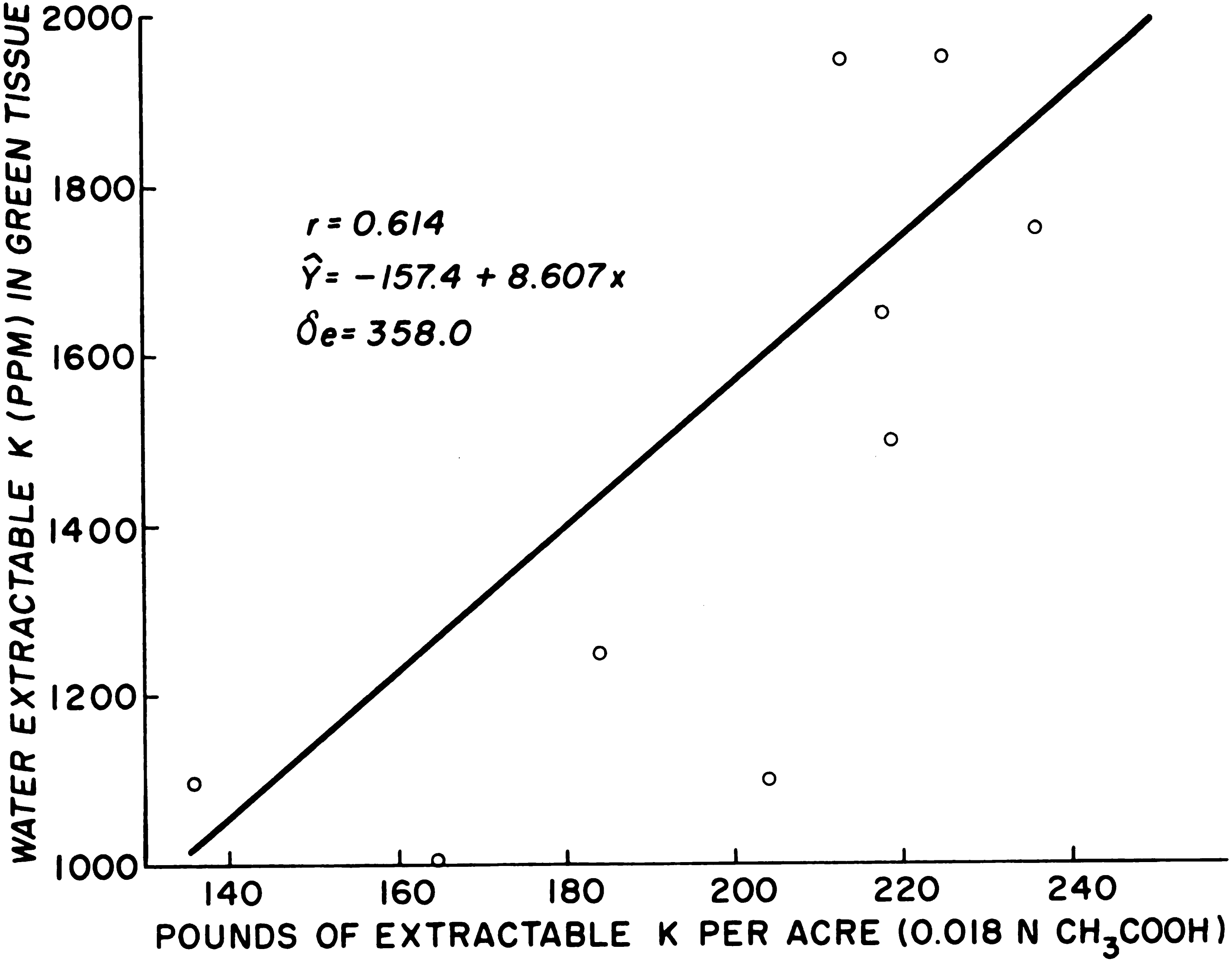


Figure 9. The relationship between extractable soil potassium and the water extractable potassium content of green onion tissue, 1955.

green onion tissue. The correlation coefficient for this relationship was 0.614.

There was no significant relationship between the yield of onions and the water soluble K in the green tissues, as evidenced by the r value for this relationship of 0.294.

Table 11 shows the influence of fertilizer treatment on the yield of the celery and on the amount of soil P and K. The soil tests reflected the increased rates of K application. The highest tests for extractable soil K were obtained from plots which received the most potash fertilizer; the lowest tests were on soil not treated with potash. The range where fertilizer was applied in 1954 was from 1267 to 157 pounds per acre.

Yield differences were not significant, but lower yields were obtained from plots which did not receive potash. In each case, the half plots fertilized in 1954 yielded more than the half not fertilized since 1953.

On comparing the amount of soil K obtained in May, before fertilization, and the amount obtained in September, after fertilization and crop removal, the data show that in two cases there was a small accumulation of soil K. Where 800 pounds of K_2O were applied in May, the residual soil K was less after the crop had been harvested which indicates this amount was used by the crop and/or was lost through leaching. This will be discussed under K uptake studies by celery.

On the unfertilized plots, the residual soil K was less in every case after crop removal. The highest yields

TABLE 11

THE INFLUENCE OF FERTILIZER TREATMENT ON THE YIELD OF CELERY AND THE AMOUNT OF EXTRACTABLE SOIL PHOSPHORUS AND POTASSIUM, 1954

Pounds per acre $N - P_2O_5 - K_2O$	Pounds per acre*						Tons per acre*			ΔY***
	P			K			Fertilized		No fertilizer	
	May 24	Sept. 24		May 24	Sept. 24					
		F**	0		F	0	1953	1954	1954	
50-200-0	29	33	27	231	157	155	49.6	46.5	46.4	0.1
50-200-400	33	33	28	332	502	321	53.3	51.9	43.4	8.5
50-200-800	39	45	33	768	698	393	50.5	60.0	54.5	5.5
50-200-1200	39	47	35	1005	1267	685	46.8	57.2	53.2	4.0
L.S.D. (5% level)	-	-	-	-	-	-	N.S.	N.S.	N.S.	-

*Averages of four replications.

**"F" refers to the fertilized half of the plot in 1954 and "0" to the unfertilized half.

*** $\Delta Y = Yf + r - Y r$ (col. 9 - col. 10) on the fertilized plots in 1954 were obtained where 800 pounds of K_2O was applied per acre and the spring soil test showed 768 pounds of soil K per acre. The residual soil K, after crop removal, was 698 pounds per acre.

The highest yields on the plots not fertilized in 1954 were obtained where the spring soil test showed 768 pounds K per acre and the residual soil K, after crop removal, was 393 pounds per acre.

The variation in the soil extractable P on the fertilized plots, before and after fertilization, was from 29 to 39 and 33 to 47 pounds per acre, respectively. The extractable P in the unfertilized plots varied from 27 to 35 pounds per acre.

It is doubtful that much increase in yield of celery can be expected from additional amounts of P and K where the soil tests are 30 to 35 pounds of P and 700 to 800 pounds of K per acre.

To determine the error of sampling involved in the experiments previously described, soil samples were taken from 76 plots at the Muck Experimental Farm that had received a uniform fertilizer treatment for a 14 year period. The extractable soil P and K were determined. The standard deviations from the mean were 10 ± 0.3 and 161 ± 2.4 for the extractable soil P and K, respectively.

From one to 10 onion plants were taken at random from one plot of the onion fertilizer placement experiment and the water extractable N, P, and K determined. The standard deviations from the mean were 563 ± 16.7, 60.5 ± 4.1, and 3504 ± 21 for the N, P, and K, respectively.

These data show that the error of sampling for both the soil and plant tissue was low. Probably five onion plants per plot would be sufficient to obtain a representative sample.

The following relationship was used to determine the response of celery in the above experiment, to various levels of potash:

$$\Delta Y = Yf + r - Yr$$

where, ΔY = the adjusted yield or the yield response of celery to applied potash

$Yf + r$ = the yield obtained from the fertilized half of the plot.

Yr = the yield obtained from the unfertilized or residual half of the plot.

The relationship between the yield response of celery to four levels of potash, as determined by the above method, is shown in Table 11 and Figure 10.

The largest yield response (8.5 tons of celery per acre) was obtained from the 400 pound application rate where the available soil K was 332 pounds per acre. Additional increments of applied potash (800 and 1200 pounds per acre) resulted in a decreased yield response as the available soil K increased.

The correlation coefficient for this curvilinear (quadratic) relationship was 0.433.

The uptake of K by celery (Table 12 and Figure 11) was measured by determining the amount of extractable K in the spring and fall samplings, using 0.018 N CH_3COOH as the soil extractant and including the amount of K applied per acre as fertilizer. This may be expressed as follows:

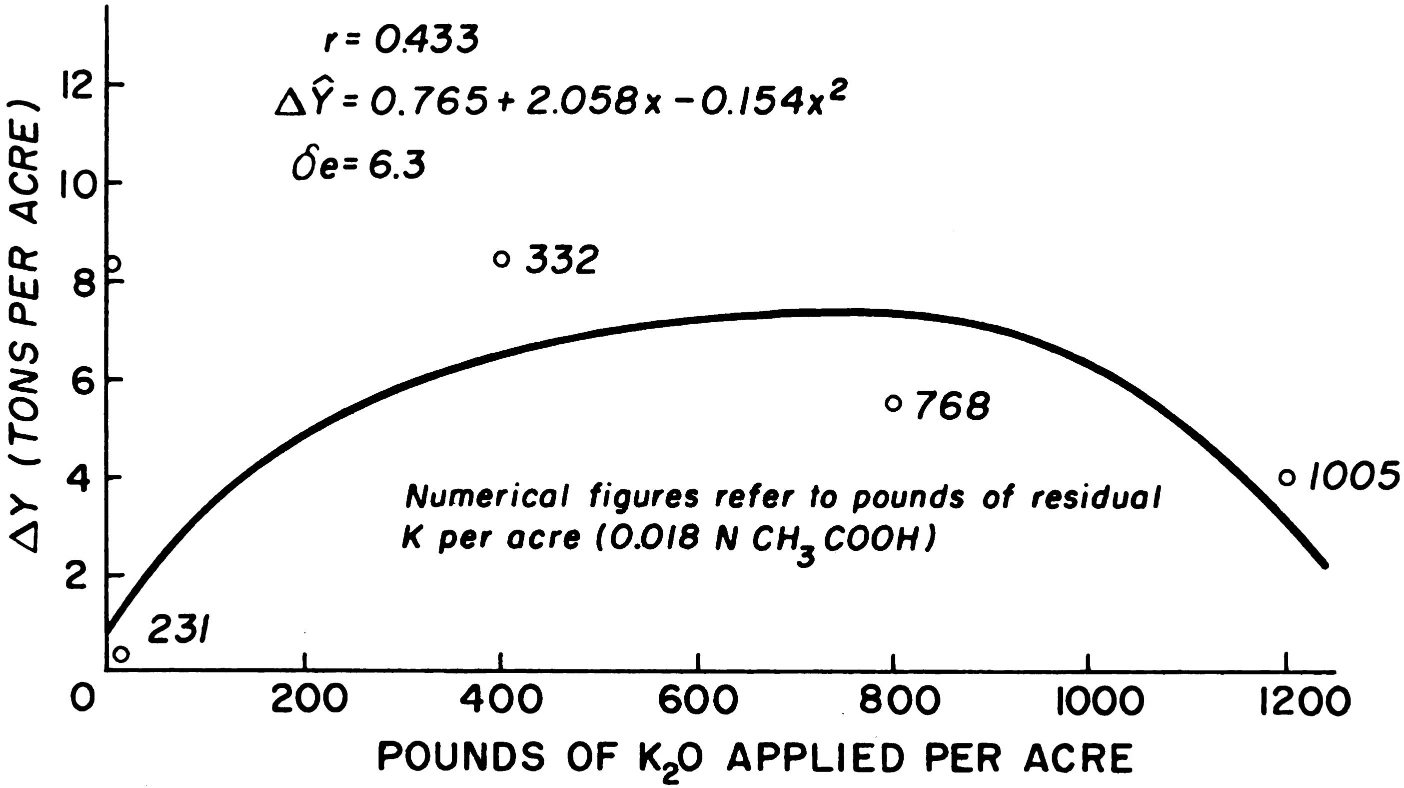


Figure 10. The adjusted yield response (ΔY) of celery to applied potash, 1954.

TABLE 12

THE RELATIONSHIP BETWEEN THE AMOUNT OF RESIDUAL SOIL POTASSIUM, THE AMOUNT OF POTASSIUM APPLIED AND THE UPTAKE OF POTASSIUM BY CELERY AND ITS EFFECT ON YIELD, 1954

Pounds K_2O applied per acre	Pounds K per acre				Tons per acre	Per cent increase in yield
	Spring	Applied	Fall	Uptake		
0	231	0	157	74	46.5	0
400	332	333	502	163	51.9	11.6
800	768	666	698	762	60.0	29.5
1200	1005	1000	1267	738	57.2	23.0

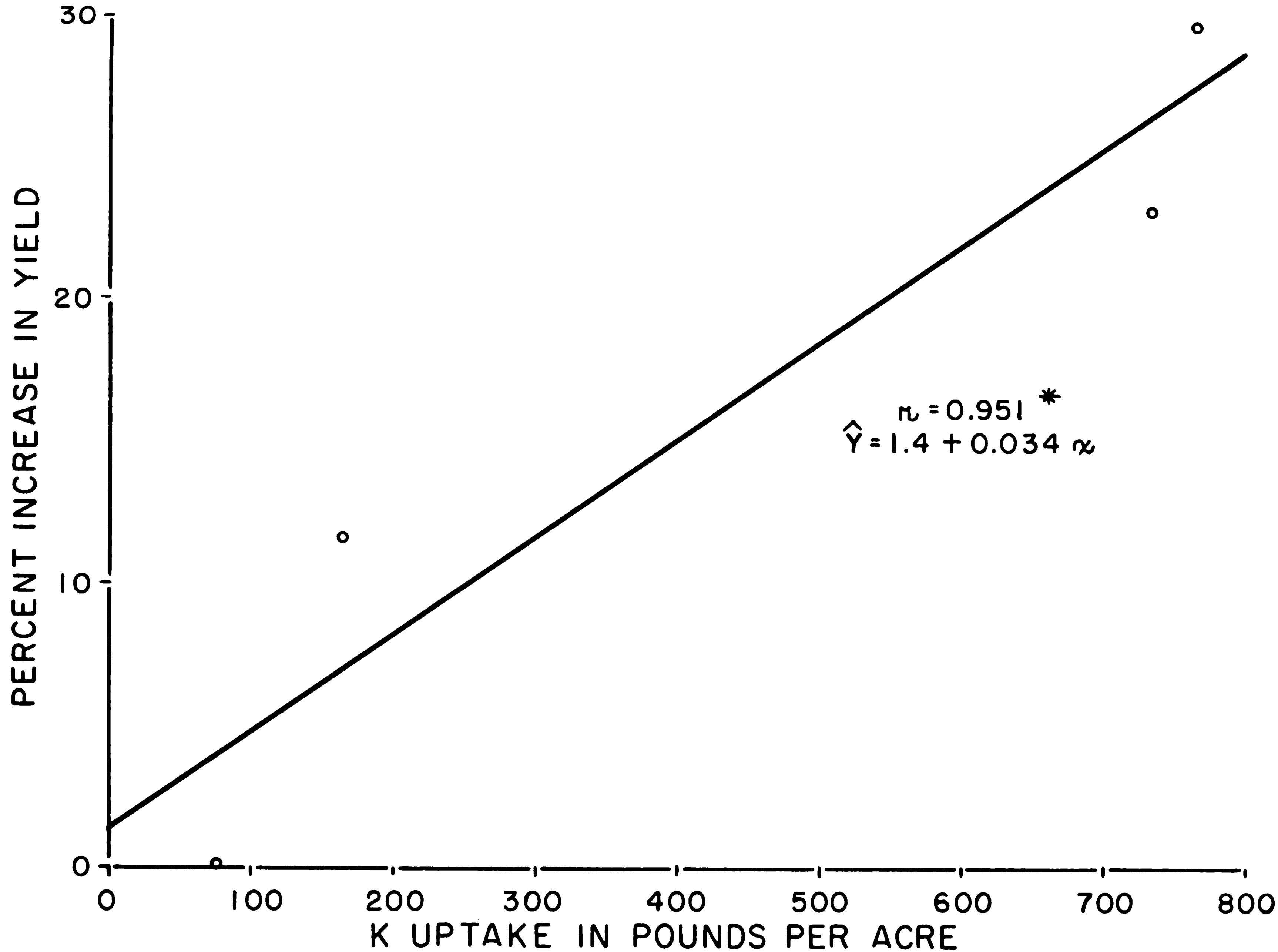


Figure 11. The relationship between potassium uptake on the fertilized plots and the yield of celery, 1954.

Pounds of K obtained in the spring sampling + Pounds of K applied to the soil - Pounds of K obtained in the fall sampling = K uptake by celery

As shown in Figure 11, there was a positive relationship between the per cent increase in the yield of celery and the uptake of K. The linear r value for this relationship was 0.951 and was significant at the 5 per cent level.

The decrease in the yield of celery where 1200 pounds of potash was applied per acre may be explained from the data presented in Table 12 and the relationship between K uptake and per cent increase in the yield of celery shown in Figure 11.

As shown in Table 12, the uptake of K by celery on the plots receiving 1200 pounds per acre of potash and having a residual soil test of 1005 pounds of K per acre, was 34 pounds less than the uptake of K by celery on those plots receiving 800 pounds per acre of potash and having a residual soil test level of 768 pounds of K per acre.

The relationship between the amount of residual soil K and the uptake of K by celery grown on the unfertilized half of the plots is shown in Table 13 and Figure 12. The uptake of K by celery was determined by obtaining the difference between the spring and fall soil test values for K. As shown in Figure 12, there was a positive linear correlation between the K uptake values by celery from the unfertilized half of the plots as measured by soil tests, and the yield of celery. The r value for this relationship was 0.982, which was significant at the 5 per cent level.

TABLE 13

THE RELATIONSHIP BETWEEN THE AMOUNT OF RESIDUAL SOIL POTASSIUM AND THE UPTAKE OF POTASSIUM BY CELERY AND ITS EFFECT ON YIELD, 1954

Pounds K_2O applied per acre in 1953	Pounds K per acre			Tons per acre
	Spring	Fall	Uptake	
0	231	155	76	46.4
400	332	321	11	43.4
800	768	393	375	54.5
1200	1005	685	320	53.2

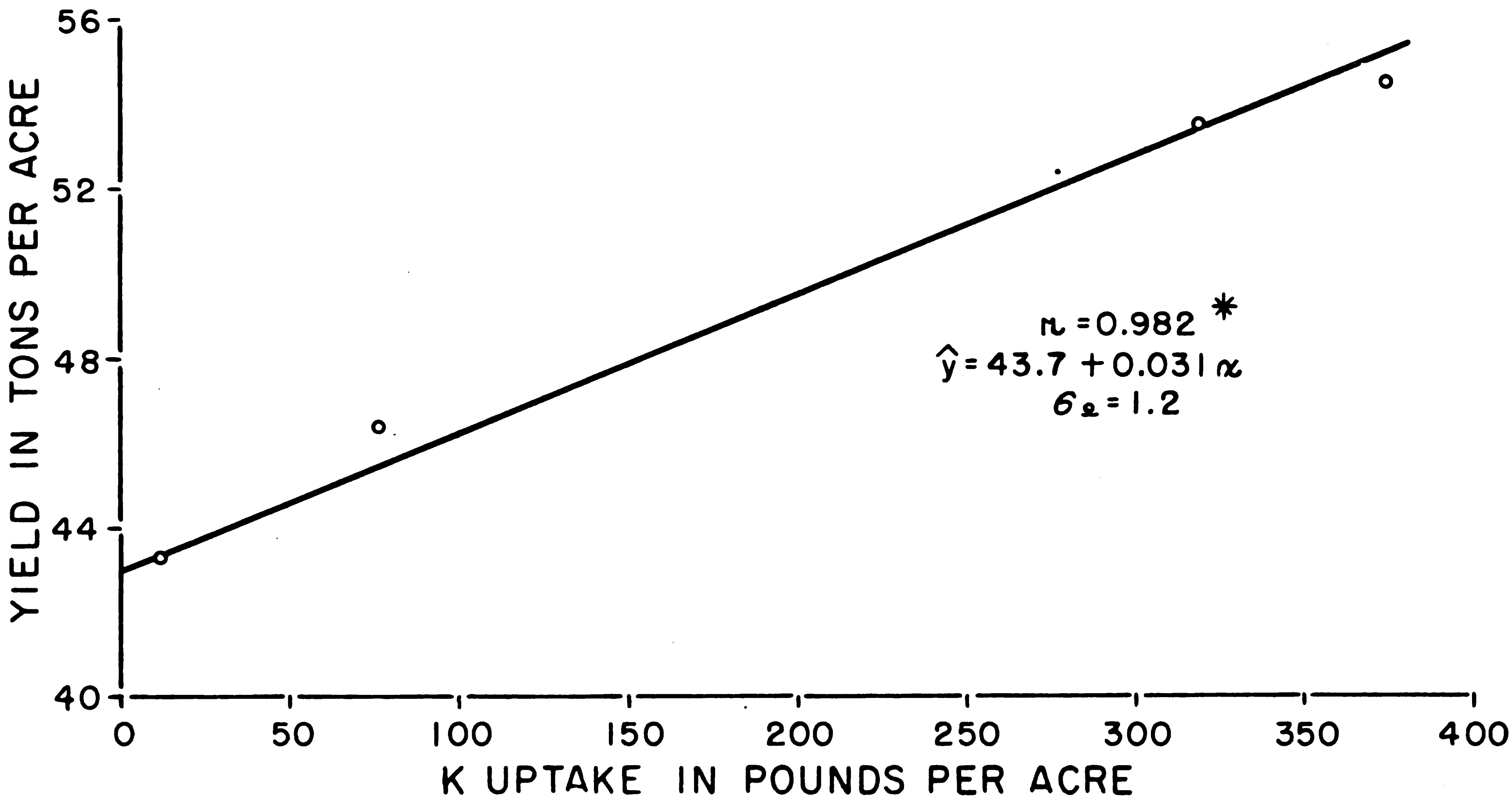


Figure 12. The relationship between potassium uptake on the unfertilized plots and the yield of celery, 1954.

The per cent K and the pounds of K removed by celery in 1955, as determined by plant analysis, and its effect upon yield is shown in Table 14.

As shown in Figure 13, there was a positive linear correlation between K uptake (plant analysis) and the yield of celery on the fertilized half of the plots. The linear correlation coefficient for this relationship was 0.865, which was significant at the 1 per cent level as compared to 0.653 for the same relationship on the unfertilized half of the plots which was significant at the 5 per cent level (Figure 14). The low yields obtained from all treatments'is a result of the late transplanting date of June 27.

A comparison of data in Tables 12, 13, and 14 show that there was a relationship between the uptake of K by celery as measured by soil tests and K uptake, as determined by chemical analysis of plant tissue.

As shown in Table 14, the above ground portion of a 31 ton celery crop removed 330 pounds of K per acre, as determined by chemical analysis of the plant material. The K removed by 60 tons of celery per acre as measured by soil tests was 762 pounds per acre, as shown in Table 12. However, there appears to be a wide range of K uptake values over which good yields of celery may be obtained. For example, a 46 ton celery crop removed 74 pounds of K per acre, whereas a 60 ton crop removed 762 pounds of K per acre, as determined by soil tests. If we assume none of the K was leached

TABLE 14

THE RELATIONSHIP BETWEEN EXTRACTABLE SOIL POTASSIUM, PER CENT POTASSIUM IN THE TISSUE, POTASSIUM UPTAKE, AND THE YIELD OF CELERY, 1955

Treatment*	Per cent K in crop	Pounds K removed by crop**	Pounds K per acre***	Tons per acre
0-10-0(F)****	2.98	98	157	22.6
0-10-0	3.57	127	161	24.5
0-10-20(F)	6.00	230	259	26.3
0-10-20	3.95	145	209	25.3
0-10-40(F)	7.28	330	295	31.1
0-10-40	5.87	244	259	28.6
0-10-60(F)	7.71	304	657	27.1
0-10-60	6.04	224	319	25.5

*Fertilizers applied at the rate of 2000 pounds per acre. This area was previously fertilized with 2000 pounds of 0-10-30 per acre annually from 1941 to 1952.

**Calculated as follows:
Yields(tons per acre) x 2000 (to convert tons to pounds) x per cent K in tissue x per cent dry matter.
e. g. 22.56 x 2000 x .0298 x .0728 = 97.88

***Soils extracted with 0.018$\underline{N}$ CH_3COOH at a soil to extractant ratio of 1:4.

****(F) refers to the fertilized half of the plots.

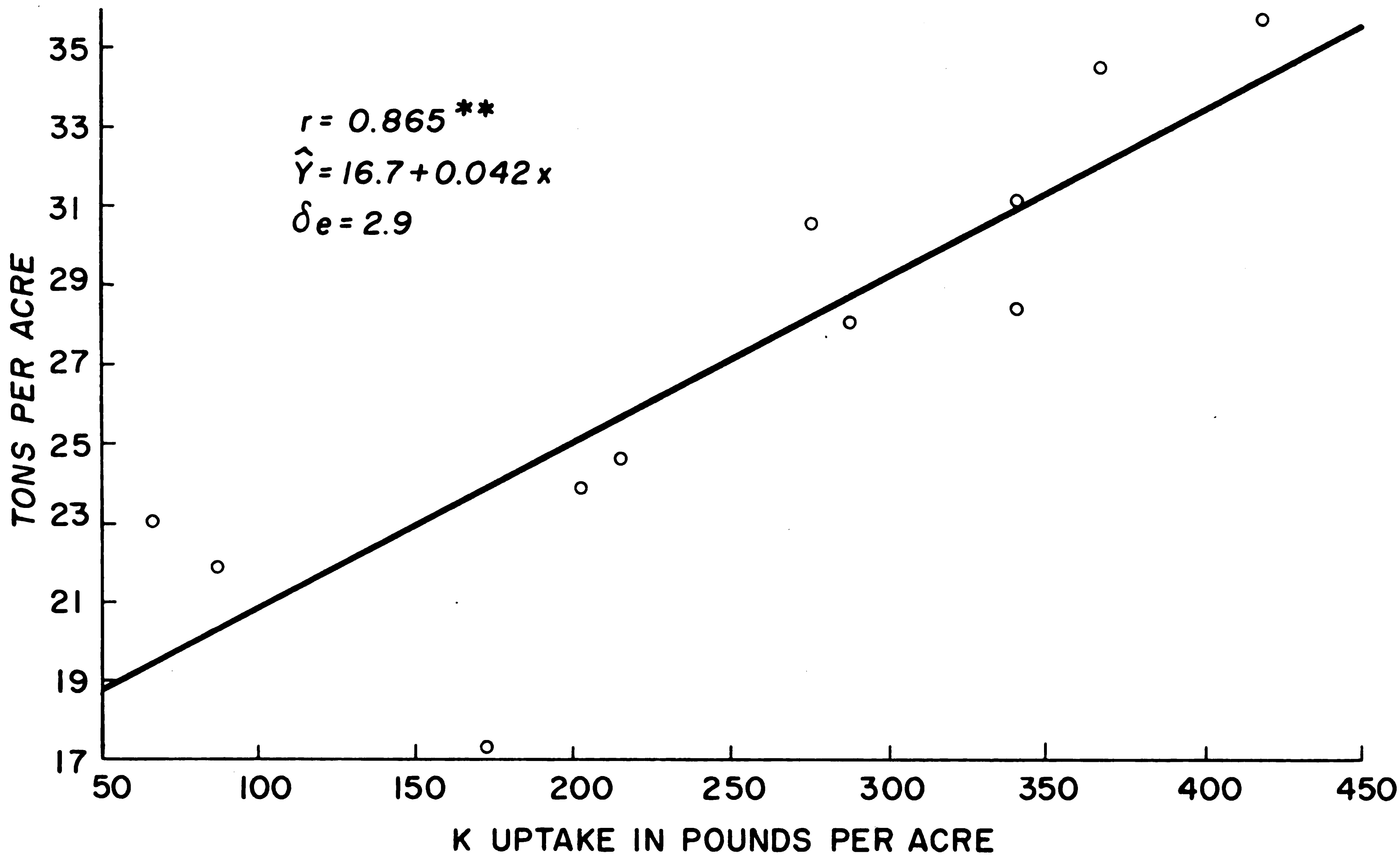


Figure 13. The relationship between K uptake (plant analysis) on the fertilized half of the plots and the yield of celery, 1955.

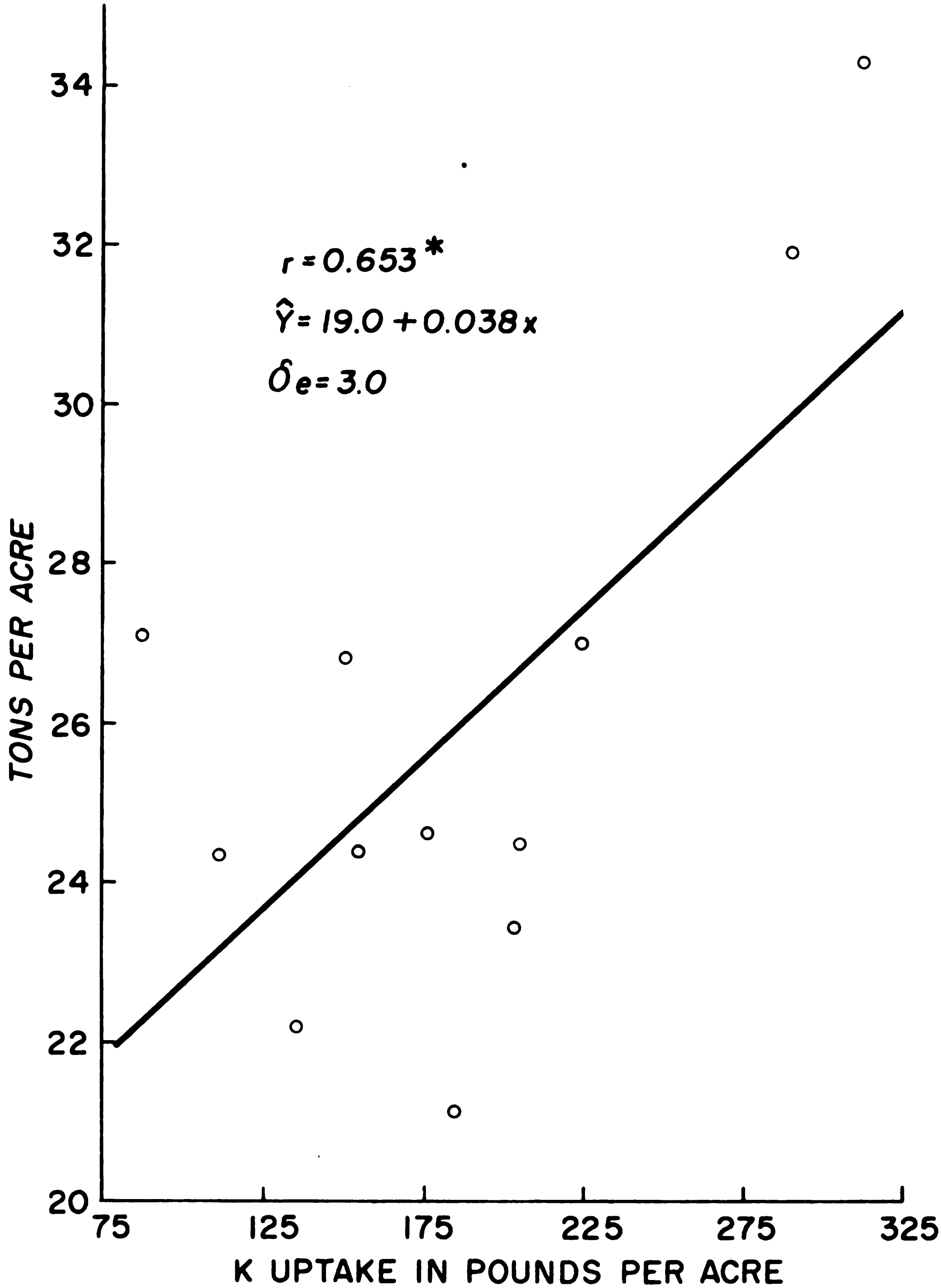


Figure 14. The relationship between K uptake (plant analysis) on the unfertilized half of the plots and the yield of celery, 1955.

from the plots and that the entire 762 pounds of K was utilized by the plant, then it would appear that luxury consumption occurred on these plots having a high residual soil test and receiving a large application of potash.

The data in Table 14 also show considerable variation in K uptake, as measured by plant analysis, with no significant difference in yield between potash treatments. York (71) has pointed out that the absorption of K is primarily a function of the available supply of this element in the soil.

The curvilinear relationship between K uptake by celery, as measured by plant analysis and the pounds of potash applied, is shown in Figure 15. Both the linear and curvilinear correlation coefficients were significant at the 1 per cent level. Increased uptake values for K are reflected with increased rates of potash up to the 800 pound per acre application. The maximum uptake of K actually occurred where the equivalent of 975 pounds of K_2O was applied. The 1200 pound application of potash failed to increase the uptake of K by celery.

The positive linear relationships obtained for the combined mean values from the fertilized and unfertilized half of the plots, between the yield of celery and K uptake, as determined by plant analysis and per cent K in the tissue, are shown in Figures 16 and 17, respectively. The r value for the former relationship was 0.712 and that of the latter was 0.793. Both values were significant at the 5 per cent level.

Similar relationships between the yield and uptake of K by celery for the fertilized and unfertilized plots taken

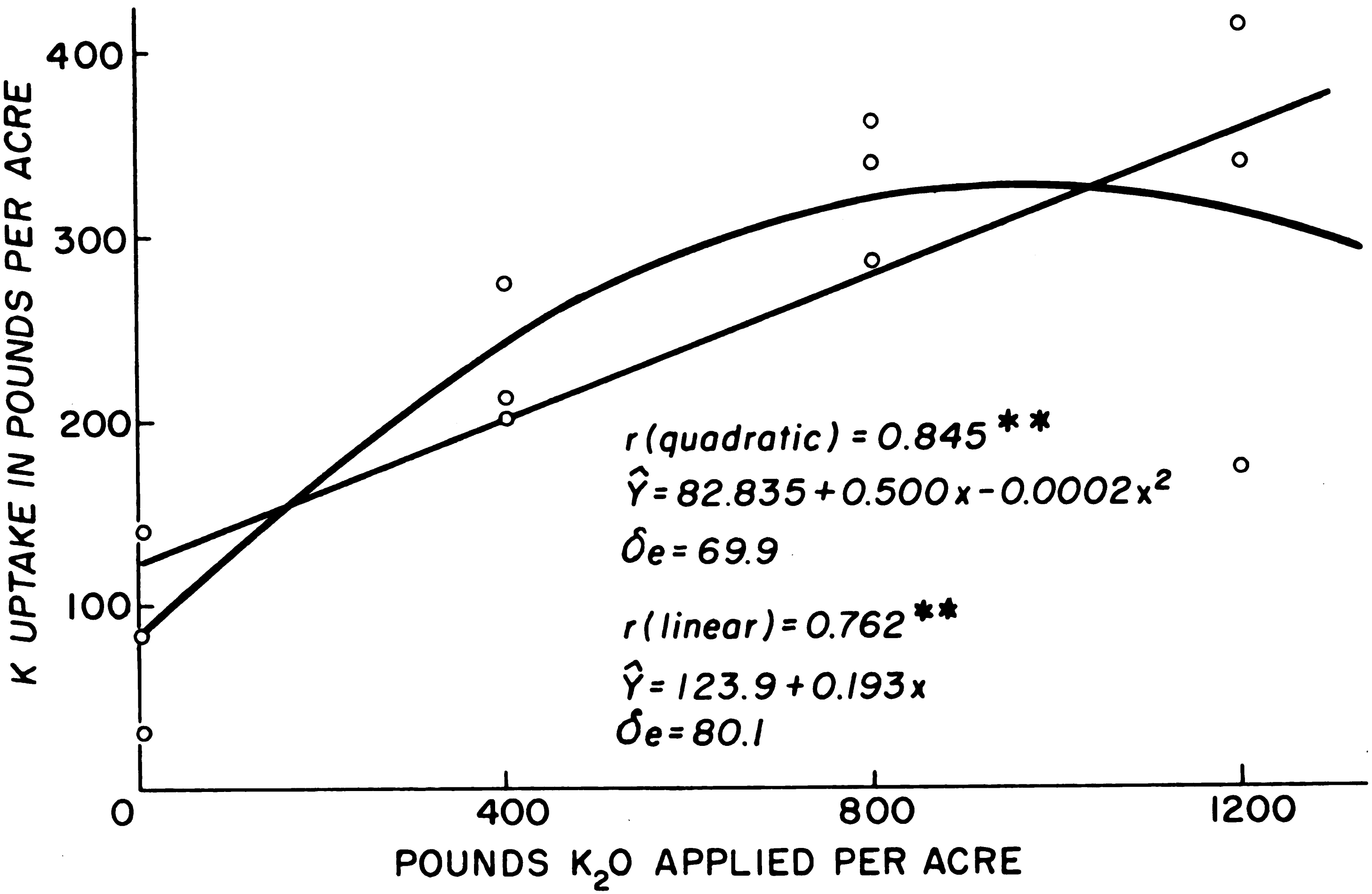


Figure 15. The relationship between K uptake (plant analysis) by celery and the pounds of potash applied, 1955.

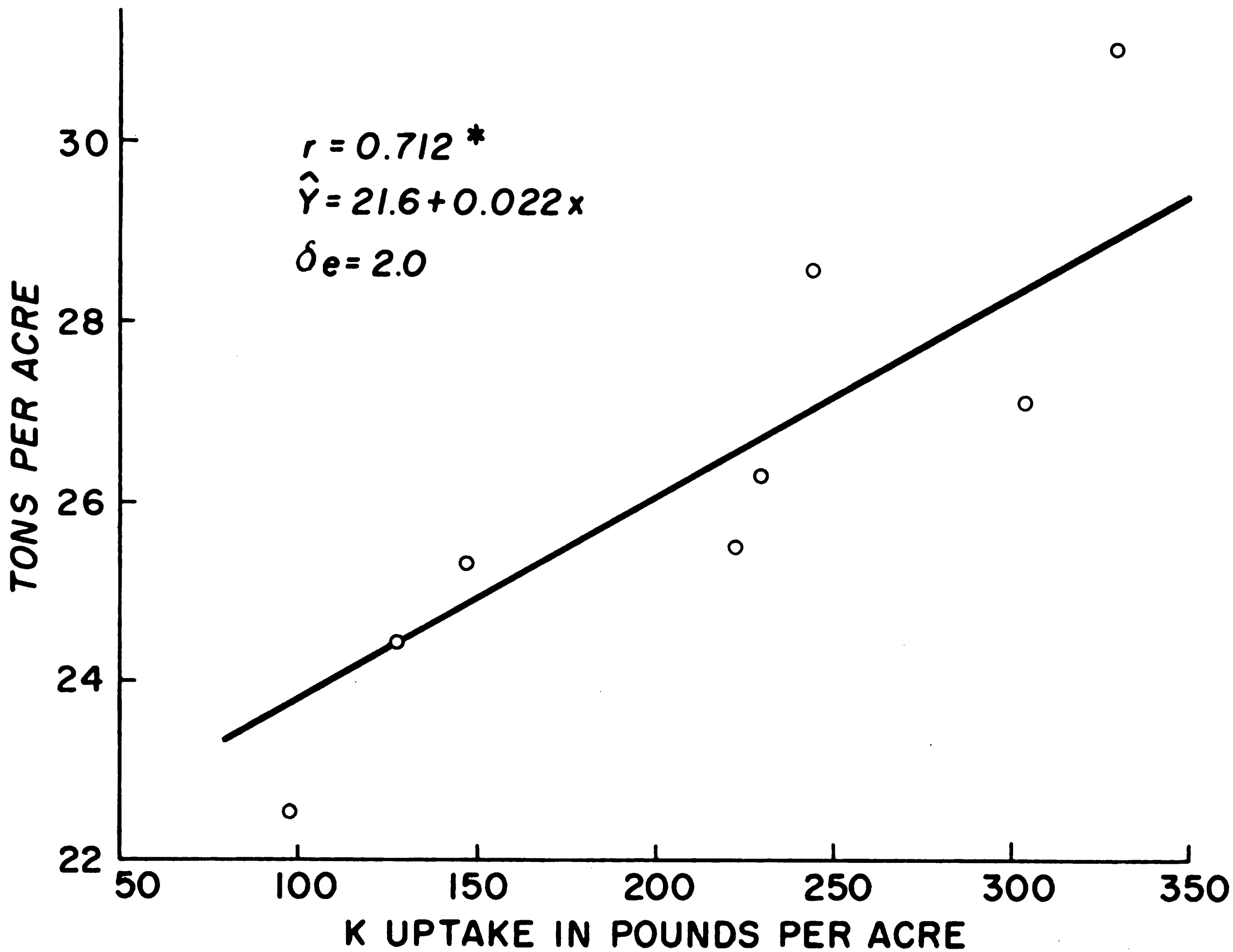


Figure 16. The relationship between K uptake (plant tissue analysis) on the fertilized and unfertilized plots and the yield of celery, 1955.

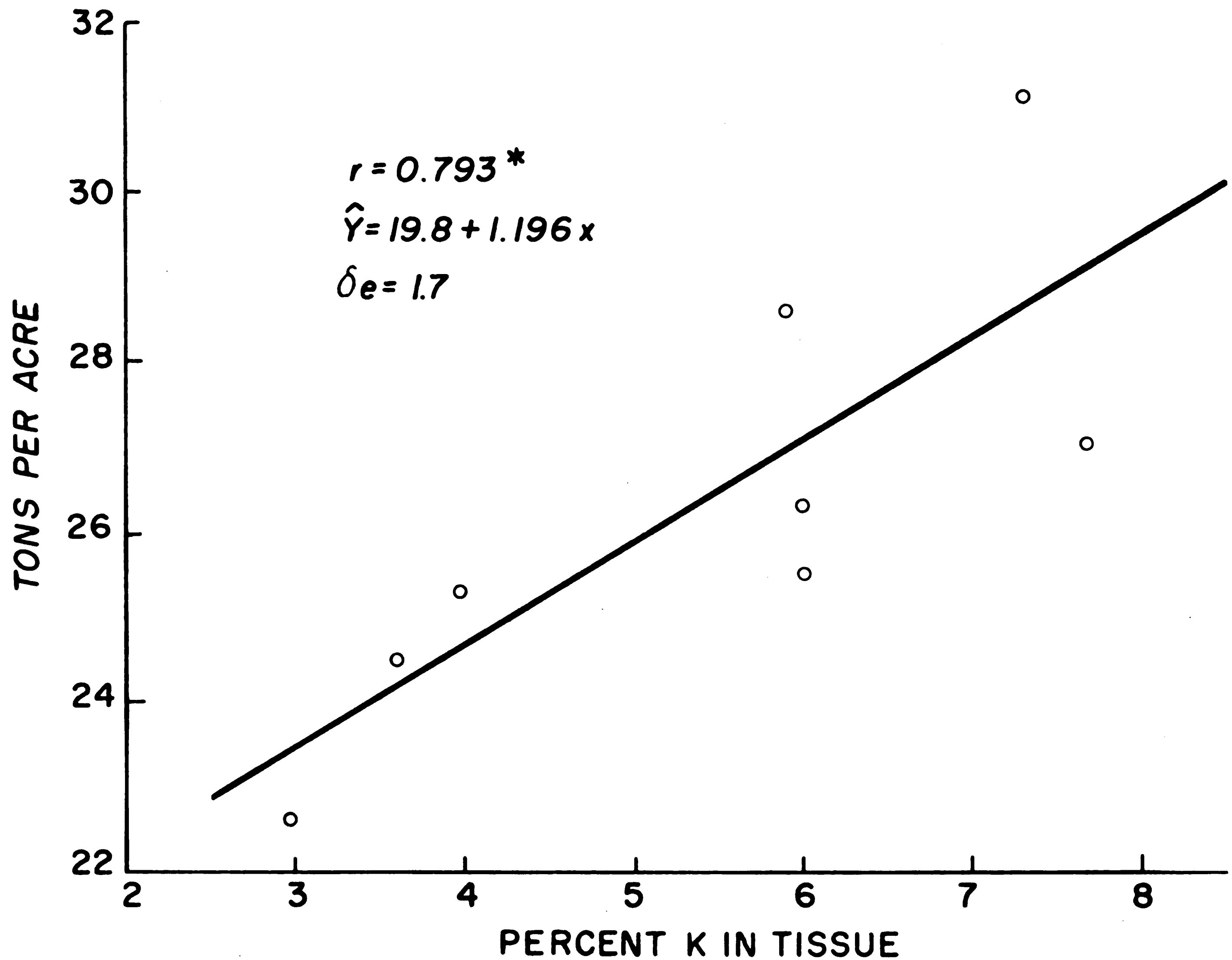


Figure 17. The relationship between per cent potassium in the tissue and the yield of celery, 1955.

individually are shown in Figures 13 and 14, respectively. There was less variability in the data from the fertilized plots. This is shown by the respective r values of 0.653, as compared to 0.865 for the fertilized plots.

A correlation coefficient of 0.455 was obtained between the yield of celery and residual soil K, as extracted by 0.018 N CH_3COOH (Figure 18).

These data indicate that plant uptake measurements of K, when supplemented with a soil test taken in the spring, are valuable tools in determining the additional amount of K that must be added as fertilizer to obtain good yields of celery.

Potassium uptake values as determined by soil tests showed that 51.9 tons of celery were obtained where 163 pounds of K per acre was removed by the crop and 60 tons per acre, or 29.5 per cent increase, was obtained where 762 pounds of K per acre was removed. Luxury consumption and/or leaching of K may be factors to be considered for celery.

Similar variations in K uptake by celery were obtained in 1955 with no significant difference in yield where the K uptake values were determined by plant analysis. Celery yields of 22.6 and 26.3 tons per acre, respectively, were obtained when K uptake values were 98 and 230 pounds per acre.

These data indicate that comparable yields of celery can be obtained over a wide range of K levels.

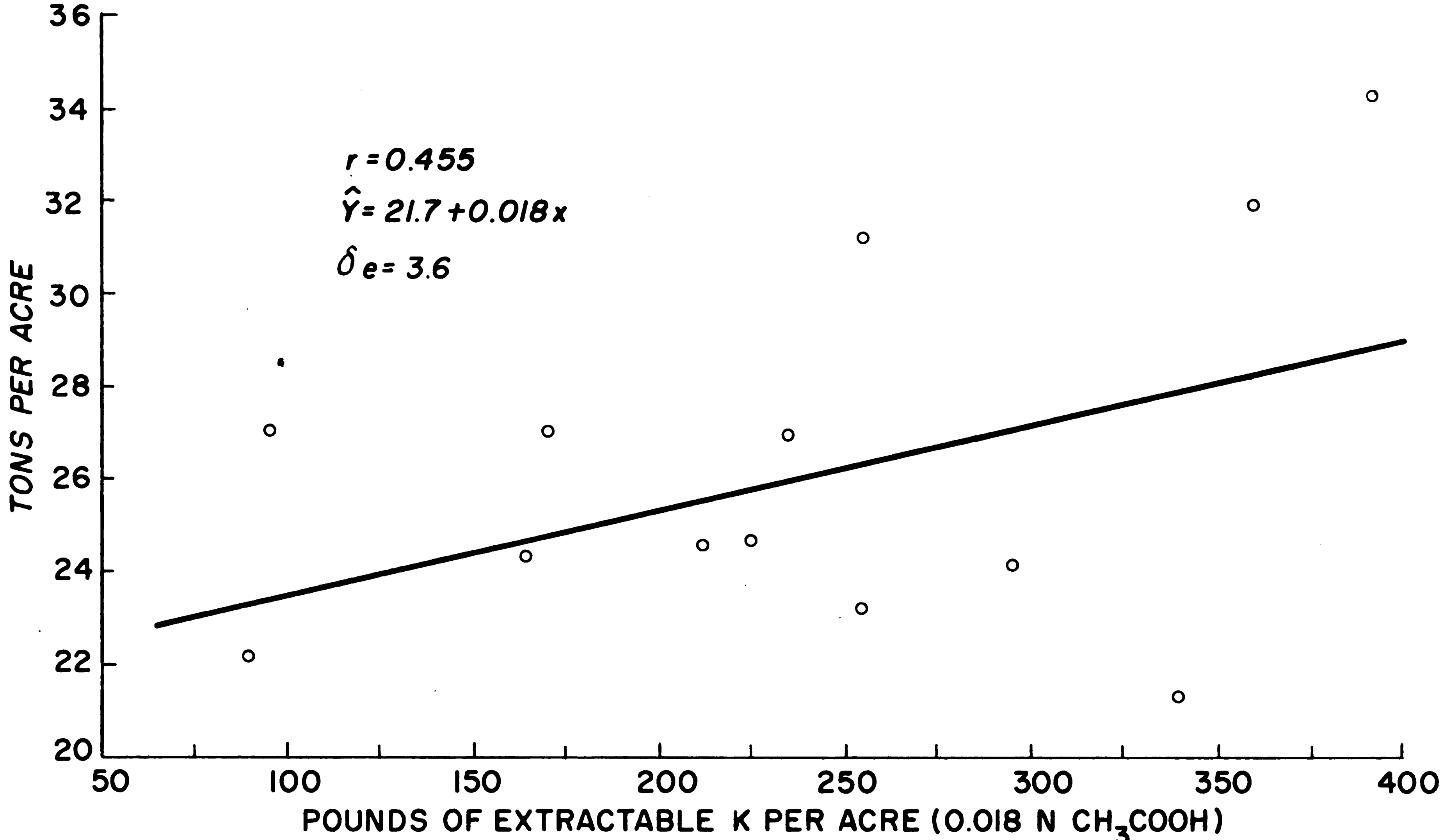


Figure 18. The relationship between extractable soil potassium on the unfertilized plots and the yield of celery, 1955.

EXPERIMENT III

INFLUENCE OF FERTILIZER RATES ON SOIL TEST VALUES AND PLANT COMPOSITION

Crop: Sweet Corn

Procedure

A fertilizer rate experiment with sweet corn was initiated in 1951. Annual broadcast applications of an 0-10-30 fertilizer were applied in 1951, 1952, 1953, and 1954, and on one-half of the plots in 1955 and 1956. The fertilizer rates employed were 750, 1500, 2250, and 3000 pounds per acre.

Variety Carmel Cross was planted on June 3, 1955 and Ferry's Hybrid 78822 was planted on June 15, 1956 and harvested on August 18 and September 12, respectively. All treatments were replicated three times. Size of plots was 11 x 25 feet.

The soil samples taken in 1955 were extracted with 0.018 N CH_3COOH at a soil to extractant ratio of 1:4 and the P and K were determined by the methods previously described. The soils sampled in 1956 were extracted by means of 0.025 N HCl + 0.03 N NH_4F at soil to extractant ratios of 1:4 and 1:16, 0.018 N CH_3COOH at a soil to extractant ratio of 1:4, and by 0.018 N CH_3COOH + 0.03 N NaF at soil extranctant ratios of 1:4 and 1:16 to determine the relationship between the extracting solution employed and P status of the soil.

The corn tissue was sampled on July 28, 1955. Composite tissue samples were composed of ten leaf sheaths per plot taken from the third leaf. The water extractable P, K, Ca, Mg, Na, and Mn were determined. The water soluble P was determined by the method previously described for the determination of soil P. The K, Ca, Mg, and Na were determined on a Beckman Model DU Spectrophotometer with a flame attachment at wavelengths of 766.5, 422.7, 285.2, and 589.3 mu, respectively. Manganese was determined in the water soluble extract by the periodate method proposed by Willard and Greathouse (70). A wavelength of 530 mu was employed.

Results and Discussion

As shown in Table 15 the amounts of soil P and K, extracted by means of 0.018 N CH_3COOH, increased with increased application of these elements to the soil. The low K tests obtained in the spring sampling, 1956 (Table 16), as opposed to the high tests obtained in the fall of 1955 (Table 15) from the fertilized half of the plots, suggests a considerable loss of K due to leaching. These data confirm those obtained in Experiment I where large losses of K were attributed to leaching. It would be inadvisable to attempt to build up residual K to extremely high levels on these soils.

No significant difference was obtained in the yield of sweet corn and the various soil treatments employed. The highest yield, however, was obtained from the plots receiving,

TABLE 15

THE INFLUENCE OF FERTILIZER TREATMENT ON THE EXTRACTABLE PHOSPHORUS AND POTASSIUM CONTENT OF THE SOIL, THE CHEMICAL COMPOSITION (WATER EXTRACTABLE) OF THE GREEN TISSUE AND THE YIELD OF SWEET CORN, 1955

Pounds of 0-10-30 per acre	Pounds per acre			Parts per million in green tissue						Tons per acre**
	P	K								
	S*	S	F	P	K	Ca	Mg	Na	Mn	
750(f)***	9	156	267	560	5000	67	23	213	43	5.8
750(0)	12	190	127	512	5100	67	22	187	43	5.4
1500(f)	14	223	346	528	5333	67	18	183	50	5.4
1500(0)	14	248	201	500	4933	60	23	230	60	5.6
2250(f)	15	260	741	464	4833	57	22	210	47	6.1
2250(0)	15	328	273	452	5400	67	25	183	43	5.8
3000(f)	23	393	1006	440	5500	67	23	227	57	6.4
3000(0)	20	340	--	556	5333	60	17	187	50	5.8
L.S.D. (5% level)	3.5	112.1	227.7	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

*S = samples taken in the spring; F = samples taken in the fall.
**Yield data based on weight of unhusked ears.
***(f) = fertilized half of plot; (0) = unfertilized half of plot.

TABLE 16

THE RELATIONSHIP BETWEEN POTASSIUM UPTAKE AND THE YIELD OF SWEET CORN, 1956

Pounds of 0-10-30 per acre	Pounds K per acre				
	Spring	Applied	Fall	Uptake	Tons per acre
750	254	188	165	314	6.4
750	247	188	182	290	6.9
750	103	188	178	150	3.8
1500	178	375	480	148	5.6
1500	220	375	503	167	5.8
1500	192	375	474	168	4.2
2250	391	563	741	325	7.0
2250	316	563	516	475	2.7
2250	302	563	804	173	5.8
3000	426	750	825	501	3.8
3000	439	750	935	404	5.9
3000	480	750	1008	372	6.3

3000 pounds of 0-10-30 fertilizer per acre and having residual soil P and K levels of 23 and 393 pounds per acre, respectively. It is doubtful, however, that these high rates of fertilization could be justified relative to the small yield increase obtained from their application.

From these data approximately the same yield of sweet corn can be obtained over a wide range of residual soil P and K levels, since approximately the same yield was obtained from residual soil P tests of 12 and 20 pounds per acre, and 190 and 340 pounds of K per acre. Current fertilizer recommendations for sweet corn grown on muck soils in Michigan (23) suggest that no additional P and K need be applied to the soil when the soil tests indicate 20 pounds or more of P and 240 pounds or more of K per acre.

The mean K uptake values for sweet corn on the fertilized half of the plot, as determined by soil tests, were 77, 82, 137, and 252 pounds per acre; their respective yields were 5.8, 6.1, 6.4, and 5.4 tons per acre. These data show the yield increased as the uptake of K increased to 137 pounds per acre. A decrease in yield resulted as the K uptake increased beyond this value. However, there was considerable variation in plot data in regards to K uptake.

A curvilinear (quadratic) relationship existed in 1956 between K uptake, as determined by soil tests, and the yield of sweet corn. The correlation coefficient for this relationship was 0.832 and was significant at the 1 per cent level (Figure 19 and Table 16). The maximum yield of 7 tons per

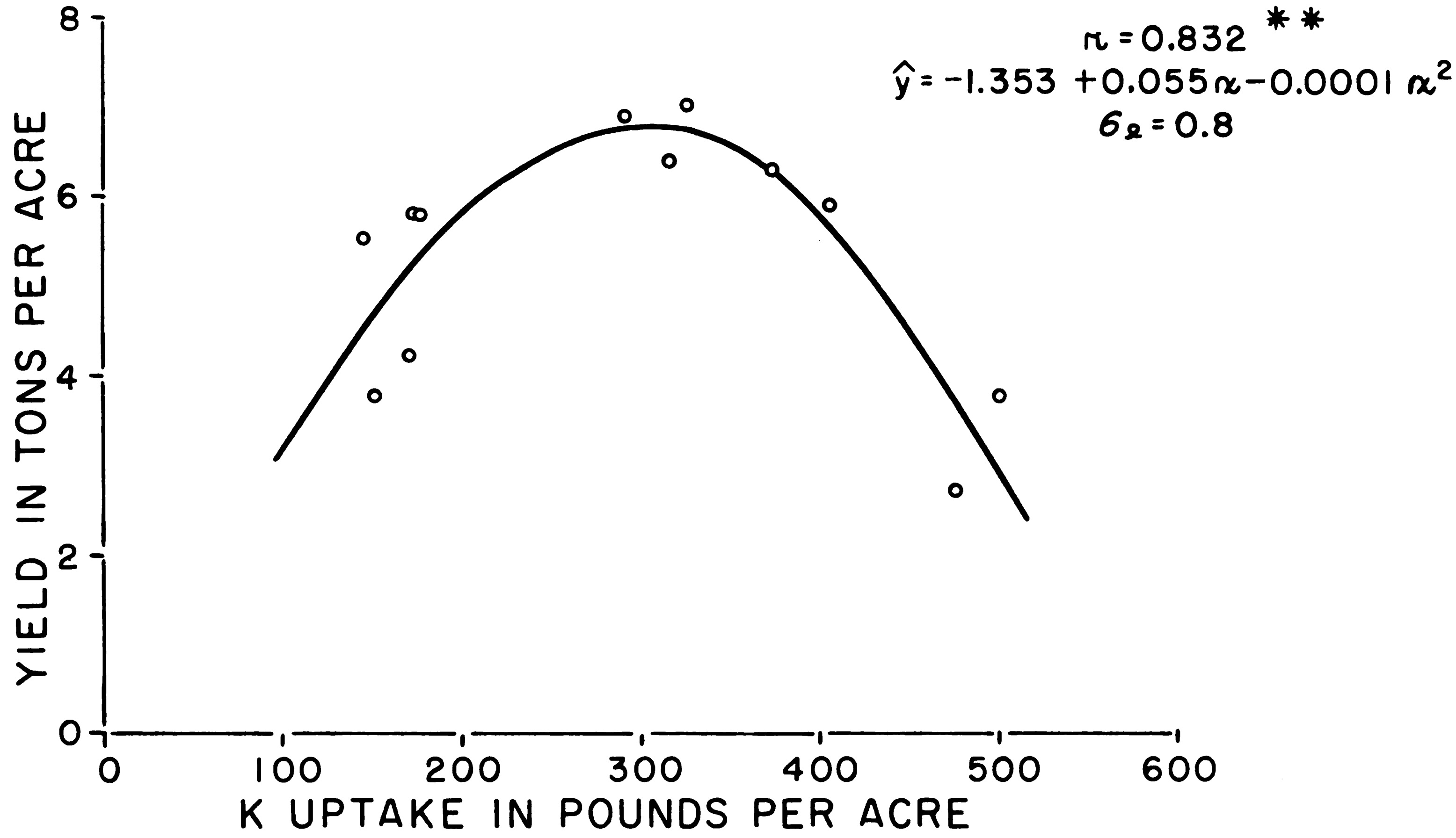


Figure 19. The relationship between potassium uptake and the yield of sweet corn, 1956.

acre was obtained at a K uptake value of 325 pounds per acre, and the available soil P in the spring sampling was 34 and 73 pounds per acre, as indicated by the Spurway Active (0.018 N CH_3COOH) and Bray P_1 (0.025 N HCl + 0.03 N NH_4F) soil extracting solutions at a soil to extractant ratio of 1:4, respectively. The higher rates of applied K were generally reflected in higher plant uptake values for K. The highest K uptake value of 501 pounds per acre was obtained from the plots receiving 750 pounds of applied K per acre; and the sweet corn from the plots receiving 188 pounds of K per acre reflected the least amount of K taken up by the plant, 150 pounds per acre.

The decrease in yield obtained with higher uptake of K suggests a possible unbalanced nutritional condition within the plant. The high amount of available K may have inhibited the uptake of calcium and magnesium although no deficiency symptoms were observed.

During the season from June 1 to August 15, the respective railfall for 1955 and 1956 was 12.5 and 9.8 inches. In general, a much more even distribution of rainfall occurred in 1956, while a particularly heavy railfall occurred in the last half of July in 1955. This might suggest the possibility that the uptake of K by sweet corn was inhibited due to poor aeration created by excessive soil moisture.

The relationship between pounds of available soil K per acre (0.018 N CH_3COOH extractable) on the unfertilized half of the plots in the spring of 1956 and the yield of sweet corn is shown in Figure 20. The correlation coefficient for this relationship was 0.515. Although this coefficient was not statistically significant at the 5 per cent level, the general trend that existed between increased soil K and increased yields of sweet corn emphasizes the importance of soil tests in reflecting yield response. It is possible that this coefficient would have been significant had there been a greater number of values involved in the correlation.

Correlation coefficients of -0.285 and 0.696 were obtained for the relationship relating the pounds of soil P extracted by the Spurway Active (0.018 N CH_3COOH) and Bray P_1 (0.025 N HCl + 0.03 N NH_4F) tests and yield of sweet corn from the unfertilized half of the plots (Figures 21 and 22). The latter relationship was statistically significant at the 5 per cent level.

The extracting solution employing 0.018 N CH_3COOH showed no significant relationship between soil P and the yield of sweet corn, since the negative correlation coefficient was not significant. The extracting solution employing 0.025 N HCl + 0.03 N NH_4F, however, indicated a positive linear relationship between soil P and the yield of sweet corn. These data may be interpreted that the adsorbed forms of P extracted by 0.025 N HCl + 0.03 N NH_4F are available to the plant and are an important source of P for plants grown on organic soils.

As shown in Table 17, no significant linear relationships were obtained between the following:

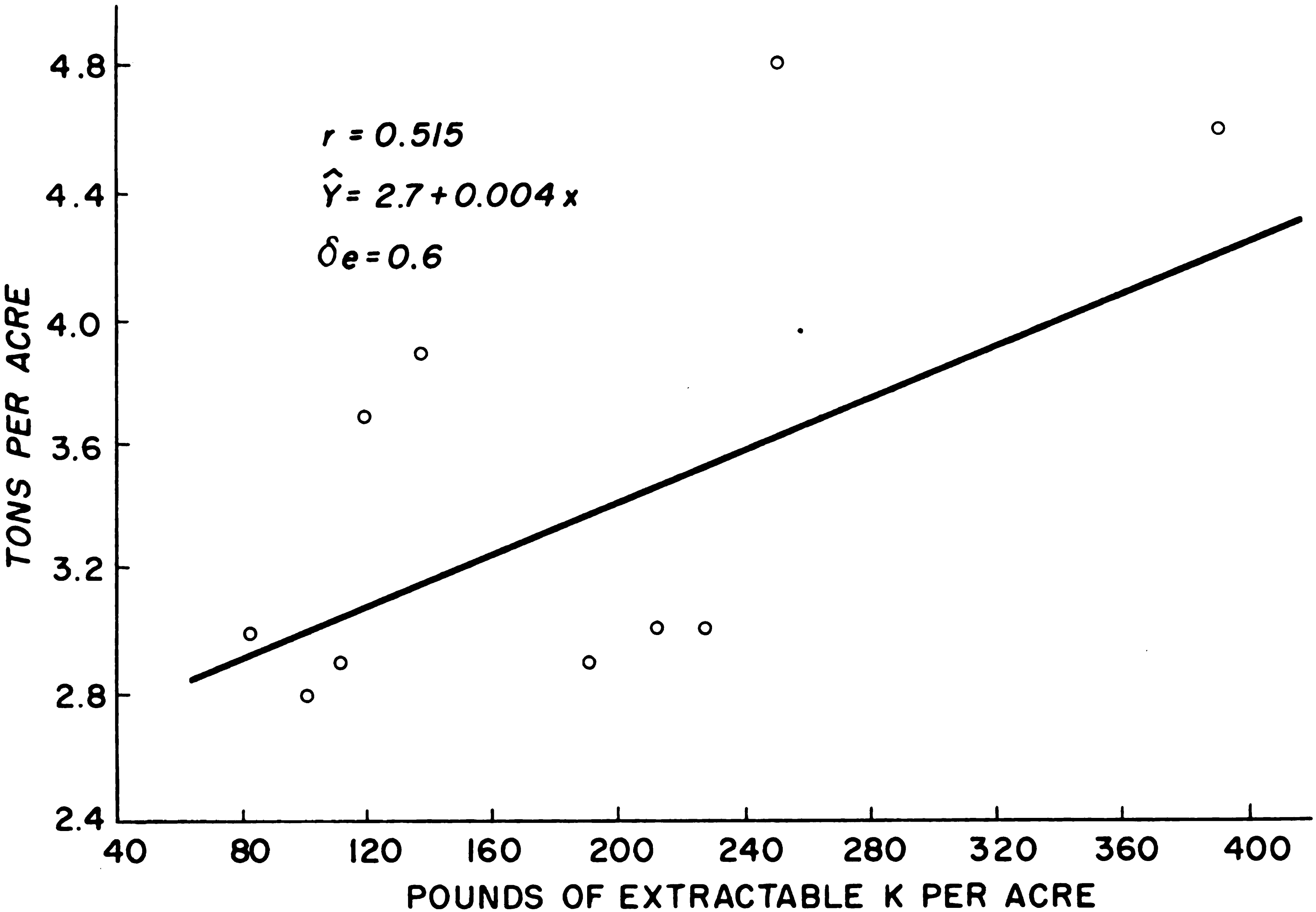


Figure 20. The relationship between extractable soil potassium on the unfertilized plots and the yield of sweet corn, 1956.

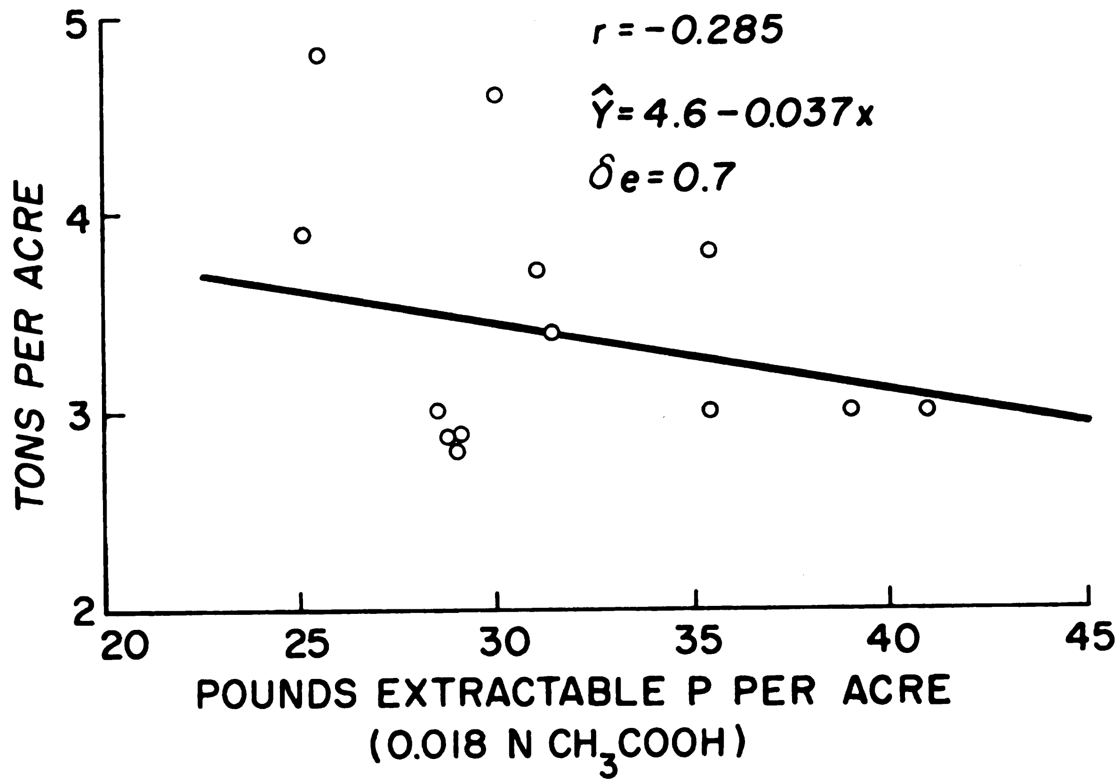


Figure 21. The relationship between extractable soil phosphorus (0.018 N CH_3 COOH) and the yield of sweet corn, 1956.

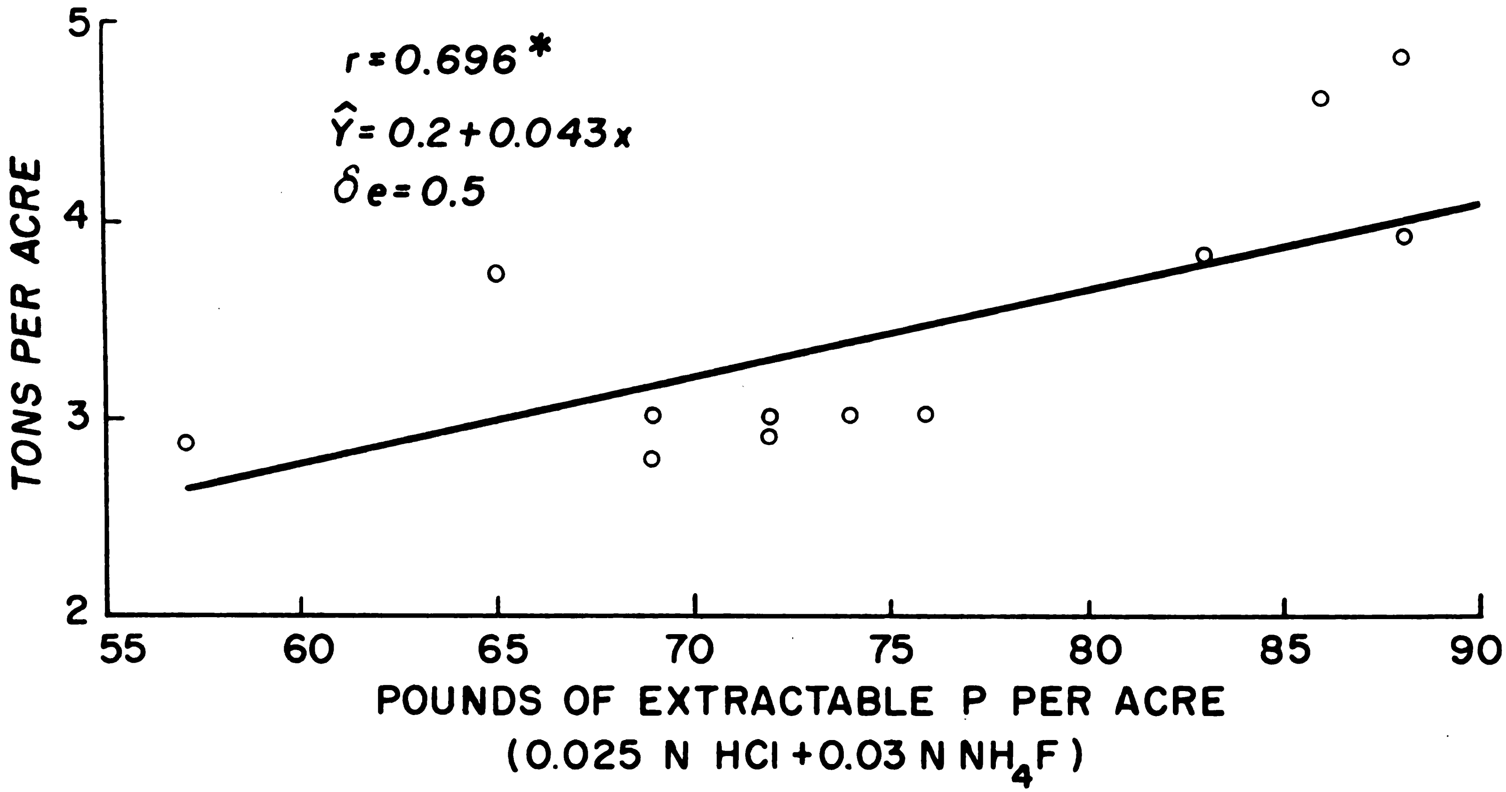


Figure 22. The relationship between extractable soil phosphorus (0.025 N HCl + 0.03 N NH_4F) and the yield of sweet corn, 1956.

TABLE 17

WATER EXTRACTABLE PHOSPHORUS, POTASSIUM, CALCIUM MAGNESIUM, MAGNANESE, AND SODIUM RELATIONSHIPS OF GREEN CORN TISSUE, 1955

Relationship	Prediction equation	σ_e	r
Pounds P_2O_5 applied vs. p.p.m. of P in tissue.	$Y = 604.0 - 0.653x$	421.8	-0.363
Pounds K_2O applied vs. p.p.m. of K in tissue.	$Y = -1810.4 + 0.453x$	748.8	0.511
Pounds K_2O applied vs. p.p.m. of Mn in tissue.	$Y = 40.0 + 0.016x$	10.4	0.395
Pounds K_2O applied vs. p.p.m. of Na tissue.	$Y = 221.7 - 0.047x$	29.3	-0.407

1. Pounds of P_2O_5 applied versus parts per million of P in the green tissue.
2. Pounds K_2O applied versus parts per million of K in the green tissue.
3. Pounds K_2O applied versus parts per million of Mn in the green tissue.
4. Pounds of K_2O applied versus parts per million of Na in the green tissue.

However, there was an indicated trend that as the applied K was increased the water extractable K in the green tissue increased and the Na decreased. The increase in water extractable Mn with increased rates of applied K agreed with the findings of York (71) and Bolle-Jones (6).

A comparison was made on the soil samples taken in the fall between the types of extractant employed and the amount of soil P extracted.

As shown in Table 18, significant correlations were obtained between all comparisons with extractants and soil to extractant ratios.

The descending order of magnitude which the various solutions extracted the soil P was as follows:

Bray P_1 (1:16) > Spurway Active + 0.03 N NaF (1:16) > Bray P_1 (1:4) > Spurway Active + 0.03 N NaF (1:4) > Spurway Active (1:4). The descending order of magnitude of correlation obtained between the extracting solutions employed, based on the correlation coefficients obtained (Table 18), were as follows:

TABLE 18

CORRELATION OF EXTRACTIOUS OF SOIL PHOSPHORUS BY VARIOUS SOLUTIONS

Comparison	Linear regression equation	σ_e	r	Ratio of P extracted
Bray P_1(1:4) vs. Spurway Active (1:4)	$\hat{Y} = 4.0 + 0.485x$	7.8	0.768**	1.8:1
Bray P_1(1:16) vs. Spurway Active (1:4)	$\hat{Y} = -3.1 + 0.247x$	6.7	0.836**	4.6:1
Bray P_1(1:16) vs. Bray P_1 (1:4)	$\hat{Y} = 50.8 + 1.638x$	26.3	0.768**	2.3:1
Bray P_1(1:4) vs. Spurway Active + 0.03 N Na F (1:4)	$\hat{Y} = 17.6 + 0.604x$	19.6	0.510*	1.2:1
Spurway Active + 0.03 N Na F (1:16) vs. Bray P_1(1:4)	$\hat{Y} = 76.1 + 0.887x$	32.0	0.471*	2:1
Bray P_1(1:16) vs. Spurway Active + 0.03 N Na F (1:4)	$\hat{Y} = -9.5 + 0.420x$	14.9	0.757**	2.8:1
Bray P_1(1:16) vs. Spurway Active + 0.03 N NaF (1:16)	$\hat{Y} = 46.2 + 0.557x$	28.2	0.630**	1.2:1
Spurway Active + 0.03N NaF (1:4) vs. Spurway Active (1:4)	$\hat{Y} = 11.1 + 1.285x$	16.6	0.685**	1.5:1
Spurway Active + 0.03 N NaF (1:16) vs. Spurway Active (1:4)	$\hat{Y} = 56.4 + 2.164x$	25.0	0.725**	3.7:1
Spurway Active + 0.03N NaF (1:16) vs. Spurway Active + 0.03 N NaF (1:4)	$\hat{Y} = 90.7 + 0.783x$	31.6	0.492*	2.3:1

*Significant at the 5 per cent level.
**Significant at the 1 per cent level.

Bray P_1 (1:16) vs. Spurway Active (1:4) > Bray P_1 (1:4) vs. Spurway Active (1:4) and Bray P_1 (1:16) vs. Bray P_1 (1:4) > Bray P_1 (1:16) vs. Spurway Active + 0.03 N Na F (1:4) > Spurway Active + 0.03 N NaF (1:16) vs. Spurway Active (1:4) > Spurway Active + 0.03 N NaF (1:4) vs. Spurway Active (1:4) > Bray P_1 (1:16) vs. Spurway Active + 0.03 N NaF (1:16) > Bray P_1 (1:4) vs. Spurway Active + 0.03 N NaF (1:4) > Spurway Active + 0.03 N NaF (1:16) vs. Spurway Active + 0.03 N NaF (1:4) > Spurway Active + 0.03 N NaF (1:16) vs. Bray P_1 (1:4).

As shown in Table 18, the inclusion of the flouride ion into the CH_3COOH increased the extraction of P from the soil. Increasing the soil to extractant ratio also increased the extraction of soil P.

The Bray P_1 (0.025 N HCl + 0.03 N NH_4F) extracting solution appears satisfactory and is currently being used in Michigan for the extraction of soil P (soil to extractant ratio of 1:8) on both organic and mineral soils.

EXPERIMENT IV

SODIUM-POTASSIUM INTERACTIONS

Crop: Sugar Beets

Procedure

An investigation involving the response of crops to salt (NaCl) at varying rates of potash was established in 1951.

The original experimental plot design consisted of a randomized block which was later split, thus permitting half of the plot to receive an application of 500 pounds of salt (NaCl) per acre; the other half of the plot received no salt. Both the salt treated plots and the plots receiving no salt received an application of 1000 pounds per acre of the following fertilizers: 0-10-10, 0-10-20, 0-10-30, and 0-10-60. These rates were equivalent to 100, 200, 300, and 600 pounds of potash per acre. Celery and table beets were grown on these plots from 1951 through 1954.

In 1955 these plots were again split thus permitting the following treatments: residual K, residual K plus 500 pounds of salt, K alone, and K plus 500 pounds of salt. The plots were cropped with sugar beets (var. U. S. 400) for two consecutive years. All treatments were replicated four times. Plots were 11-1/2 feet by 26-1/2 feet in size. The fertilizer was applied with a grain drill and all treatments received the equivalent of 40 pounds (13.6 per cent) fertilizer borate per acre.

The soils were sampled on May 17, 1955 before the second split was initiated. Soil P and K were extracted by means of 0.018 N CH_3COOH at a soil to extractant ratio of 1:4. The green sugar beet tissue was sampled on August 24, 1955 and analyzed for water soluble Na and K. The method previously described for the extraction of these elements in corn was employed, and the quantitative determinations of Na and K were carried out on a Beckman Model DU Spectrophotometer with a flame attachment at wavelengths of 589.3 and 766.5, respectively.

The air dried sugar beet tops and roots were finely ground and extracted with neutral normal ammonium acetate containing lithium chloride as the internal standard. The K and Na in the filtrate were evaluated flame photometrically. Magnesium was precipitated as $MgNH_4PO_4$, ignited to $Mg_2P_4O_7$ and evaluated gravimetrically, subsequent to the removal of Ca by repeated precipitations with $(NH_4)_2C_2O_4$.

The soils were again sampled in May of 1956, and analyzed for available Na and K, employing 0.018 N CH_3COOH as the soil extractant at a soil to solution ratio of 1:4. The chemical procedure employed for the evaluation of these elements was the same as that previously described for their evaluation in green sugar beet tissue.

In 1955 and 1956, planting dates were May 20 and June 2, respectively, and they were harvested on November 8, 1955 and November 7, 1956.

Results and Discussion

The effect of applications of Na (NaCl) and K (KCl) and the interactions of Na and K on the yield of sugar beet roots for 1955 and 1956 are shown in Tables 19 and 20, and in Figures 23 and 24, respectively. Uniform levels of P were maintained across all plots in the experiment as shown in Table 21.

The highest yield of sugar beet roots in 1955, 25.1 tons per acre, was obtained from the plots which had a residual soil test of 298 pounds of K, and which had received 500 pounds of NaCl per acre. The next highest yield of 23.5 tons per acre was obtained from the plots receiving 1000 pounds of 0-10-60 per acre, where the residual soil K was 212 pounds. As shown in Figures 23 and 24, with one exception, both in 1955 and 1956, the plots receiving the combination of salt plus fertilizer out-yielded all others. In 1955 the application of 500 pounds of NaCl per acre on the residual plots, which had previously been fertilized with 1000 pounds of 0-10-60 fertilizer per acre, was sufficient to produce high yields of beets when the residual K test was 298 pounds per acre. In 1956, however, the soil K test on these same plots was only 111 pounds per acre and an application of 1000 pounds of 0-10-60 per acre produced higher yields than either the 500 pound NaCl treatment, or where 500 pounds of NaCl plus 1000 pounds of 0-10-60 were applied. The order of magnitude of the fertilizer ratios producing the greatest yield in 1955 and 1956, when applied at the rate of 1000 pounds per acre were as follows: 0-10-60 > 0-10-30 > 0-10-20 > 0-10-10.

TABLE 19

THE YIELD RESPONSE OF SUGAR BEETS TO SALT (NaCl) ON PLOTS CONTAINING VARIOUS LEVELS OF EXTRACTABLE SOIL POTASSIUM, 1955

Pounds of extractable soil K per acre on salt treated plus fertilized half of plots	Yield of sugar beets in tons per acre		
	Half of plot receiving NaCl plus K (Y_{s+f})	Half of plot receiving K only (Y_f)	Yield response to NaCl (ΔY)
264	20.8	23.5	- 2.7
312	25.3	25.8	- 0.5
272	22.6	22.9	- 0.3
346	23.1	21.9	1.2
126	17.8	23.1	5.3
150	22.1	19.9	2.2
168	25.2	20.8	4.4
156	23.9	19.1	4.8
112	22.4	18.6	3.8
112	21.9	19.1	2.8
104	19.1	17.7	1.4
116	23.4	19.5	3.9
84	20.1	9.0	11.1
90	18.5	13.9	4.6
84	18.5	15.4	3.1
104	10.0	16.8	- 6.8

TABLE 20

THE YIELD RESPONSE OF SUGAR BEETS TO SALT (NaCl) ON PLOTS CONTAINING VARIOUS LEVELS OF EXTRACTABLE SOIL POTASSIUM, 1956

Pounds of extractable soil K per acre on salt treated plus fertilized half of plots	Yield of sugar beets in tons per acre		
	Half of plot receiving NaCl plus K ($Y_s + f$)	Half of plot receiving K only (Y_f)	Yield response to NaCl (ΔY)
137	12.2	13.7	- 1.5
110	10.4	10.4	0.0
275	12.8	13.4	- 0.6
27	12.3	11.9	0.4
31	11.6	11.4	0.2
192	11.7	11.2	0.5
48	11.3	11.5	- 0.2
17	13.7	10.5	3.2
17	11.6	11.2	0.4
13	11.5	10.0	1.5
17	9.9	8.5	1.4
10	10.4	9.0	1.4

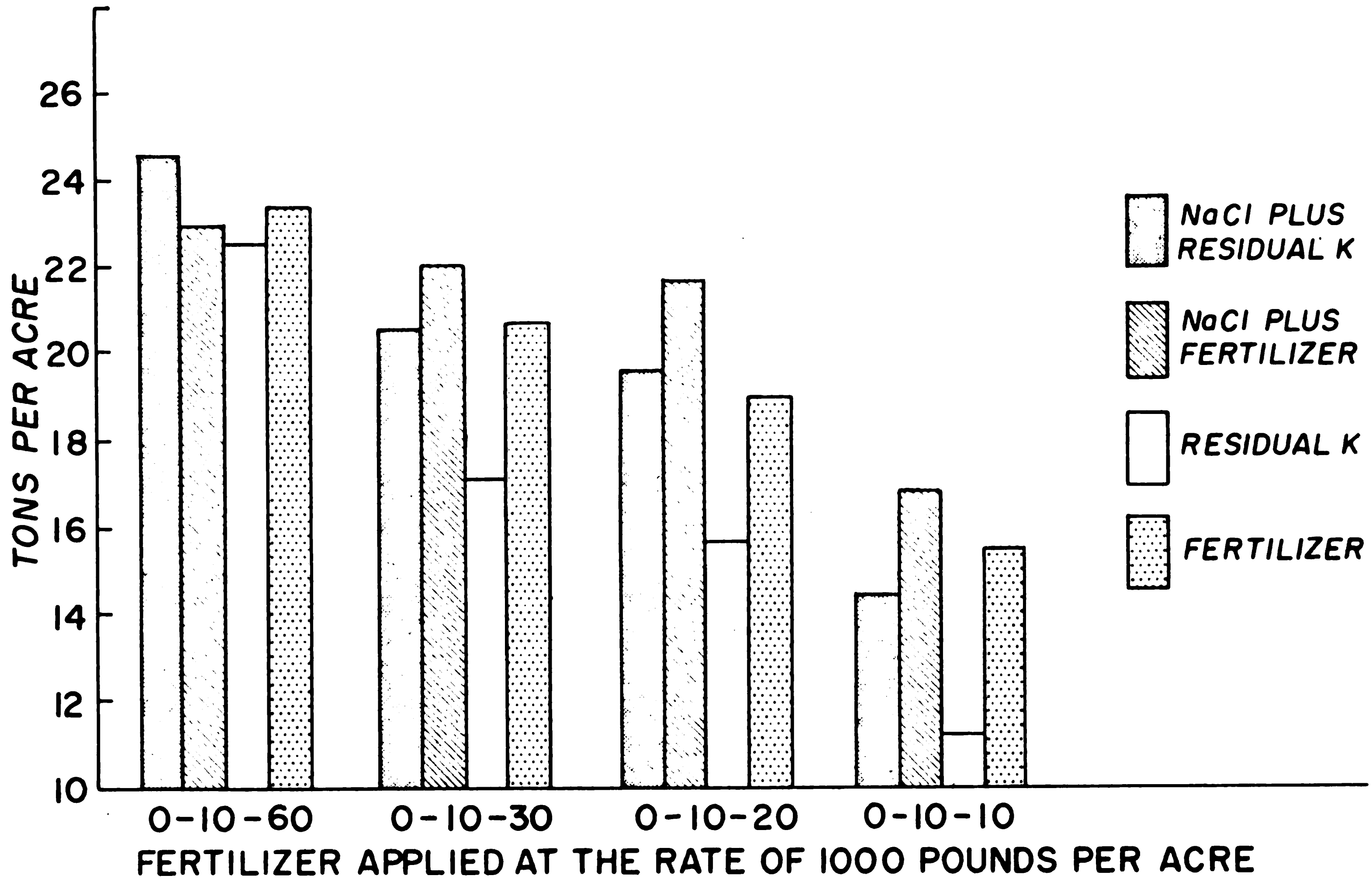


Figure 23. The effect of salt (NaCl) and the interaction of salt (NaCl) and potassium on the yield of sugar beets, 1955.

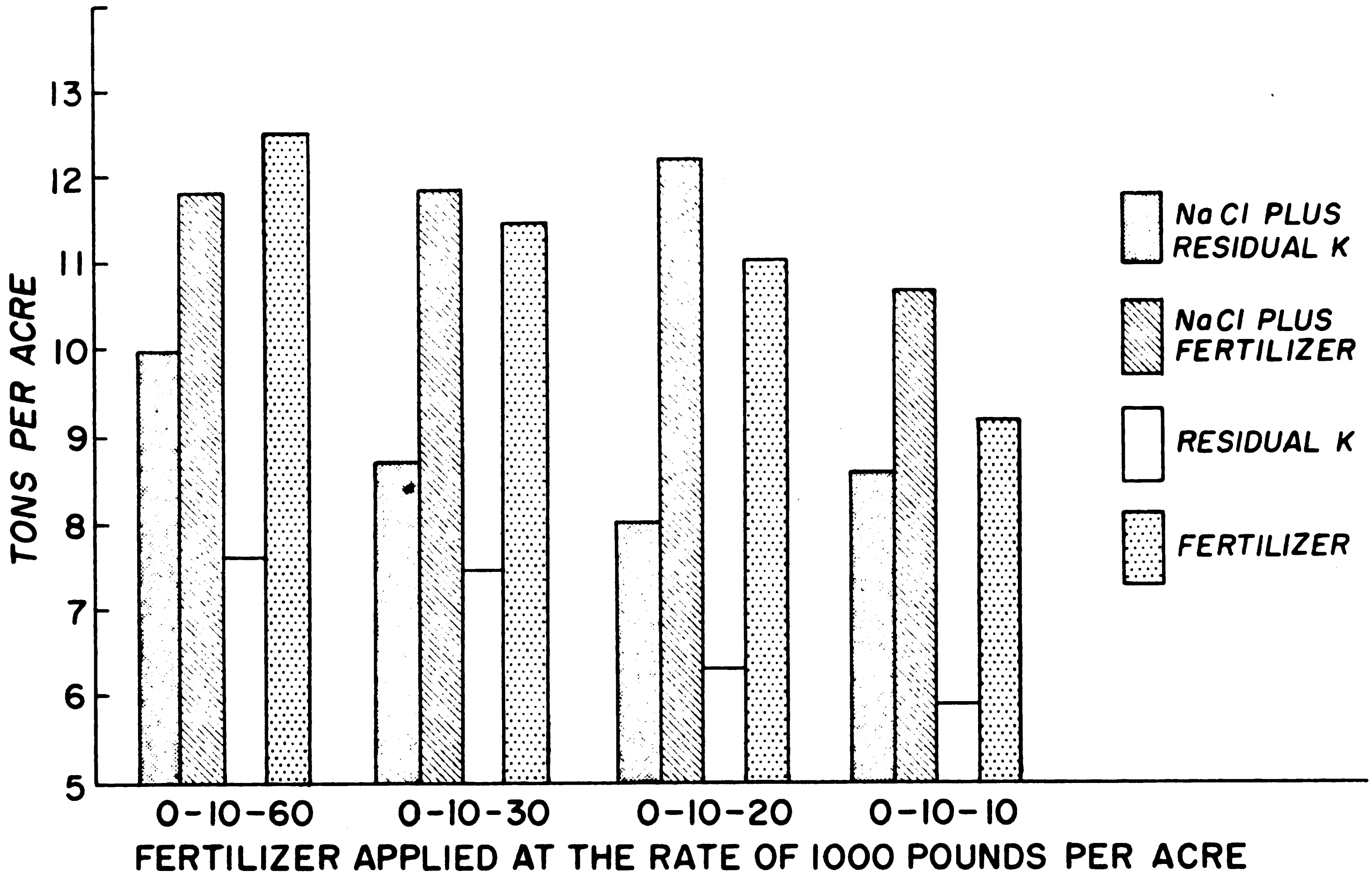


Figure 24. The effect of salt (NaCl) and the interaction of salt (NaCl) and potassium on the yield of sugar beets, 1956.

TABLE 21

THE EFFECT OF RATES OF APPLICATION OF KCl AND NaCl ON THE AMOUNT OF EXTRACTABLE SOIL PHOSPHORUS AND POTASSIUM, THE YIELD OF SUGAR BEET ROOTS AND TOPS, AND THE AMOUNT OF POTASSIUM REMOVED PER ACRE, 1955

	Pounds per acre		Per cent K		Pounds K removed per acre*			Tons per acre **	
Treatment	P	K	Roots	Tops	Roots	Tops	Total	Roots	Tops
Residual plots									
0-10-60 + s***	27	298	2.46	5.72	273	269	542	25.1	15.9
0-10-30 + s	25	150	2.27	4.03	207	183	390	20.6	15.3
0-10-20 + s	27	111	0.91	3.80	79	177	256	19.4	15.7
0-10-10 + s	25	91	0.98	4.06	63	174	237	14.4	14.5
0-10-60	27	212	3.42	4.77	341	225	566	22.5	15.9
0-10-30	26	155	0.79	4.05	60	187	247	17.2	15.6
0-10-20	25	113	1.48	2.92	96	131	227	14.6	15.1
0-10-10	27	91	2.29	2.87	115	108	223	11.3	12.7
Fertilized plots									
0-10-60 + s	27	298	2.75	6.32	280	228	508	23.0	12.2
0-10-30 + s	25	150	2.23	5.04	220	230	450	22.3	15.4
0-10-20 + s	27	111	2.21	5.15	212	197	409	21.7	12.9
0-10-10 + s	25	91	1.01	2.28	75	94	169	16.8	13.9
0-10-60	27	212	2.97	6.46	309	279	588	23.5	14.6
0-10-30	26	155	2.33	5.39	214	228	442	20.7	14.3
0-10-20	25	113	1.54	4.72	128	203	331	18.7	14.5
0-10-10	27	91	1.21	3.21	74	135	209	13.8	14.2

*Calculated as follows: Yield (tons per acre) x 2000 (to convert to pounds) x per cent K in tissue x per cent dry matter.
Per cent dry weight of roots = 22.14.
Per cent dry weight of tops = 14.80

**Averages of four replications.

***S = 500 pounds of NaCl applied per acre.

In every case, both in 1955 and 1956, the residual plots which had received 500 pounds of NaCl gave higher yields of sugar beets than the plots receiving no fertilizer or salt application.

The yields were very similar in 1955 from the plots receiving 500 pounds of NaCl and those which had received 1000 pounds of the specific fertilizer (no salt). However, in 1956 the plots receiving 1000 pounds of fertilizer gave higher yields than the plots receiving only 500 pounds of NaCl. This yield difference appeared to be the result of the difference in residual soil K. In 1955 the residual soil K levels from the various plots were such that when supplemented with 500 pounds of NaCl they gave higher yields than those plots receiving 1000 pounds of 0-10-30, 0-10-20, or 0-10-10 per acre. In 1956, however, subsequent to the harvest of the 1955 sugar beet crop, the residual K was of such a low level, as shown in Table 20, that the application of 500 pounds of NaCl was not sufficient to produce yields comparable to those obtained from 1000 pounds of the various fertilizers employed.

These data appear to substantiate the findings of other workers (29, 71) where Na has been shown to be effective in overcoming K deficiency; and also that Na is apparently able to substitute for part of the K. These data also show that the response to Na is related to the amount of K applied and/or the residual level of soil K. At lower levels of K a greater response to NaCl was obtained.

These data show that good yields of sugar beets were obtained where the residual soil P and K levels were around 27 and 300 pounds per acre (0.018 N CH_3COOH extractable) when supplemented with 500 pounds of NaCl per acre. However, from the practical standpoint some starter fertilizer should be used.

The data in Figure 25 show the K level of the soil in the spring of 1955 and the K level in the spring of 1956, following a one year cropping with sugar beets. The loss of K from the unfertilized soil in 1955 as a result of cropping is apparent. The highest soil test level dropped from 300 pounds of K per acre to around 117 pounds. This large loss of K indicates the need for annual soil tests to determine fertilization recommendations for sugar beets.

The relationship between residual soil K (K extracted with 0.018 N CH_3COOH) from the plots receiving no applied K or Na and the yields of sugar beet roots for 1955 and 1956 is shown in Figures 26 and 27, respectively. A positive linear relationship was obtained between available soil K and the yield of sugar beet roots in 1955. The linear correlation coefficient of 0.866 for the 1955 data was statistically significant at the 1 per cent level, whereas the linear correlation coefficient of 0.301 and curvilinear correlation coefficient of 0.530 obtained for this relationship in 1956 were not statistically significant. Note the much lower yields obtained in 1955 than in 1956, which suggests the differential seasonal relationships.

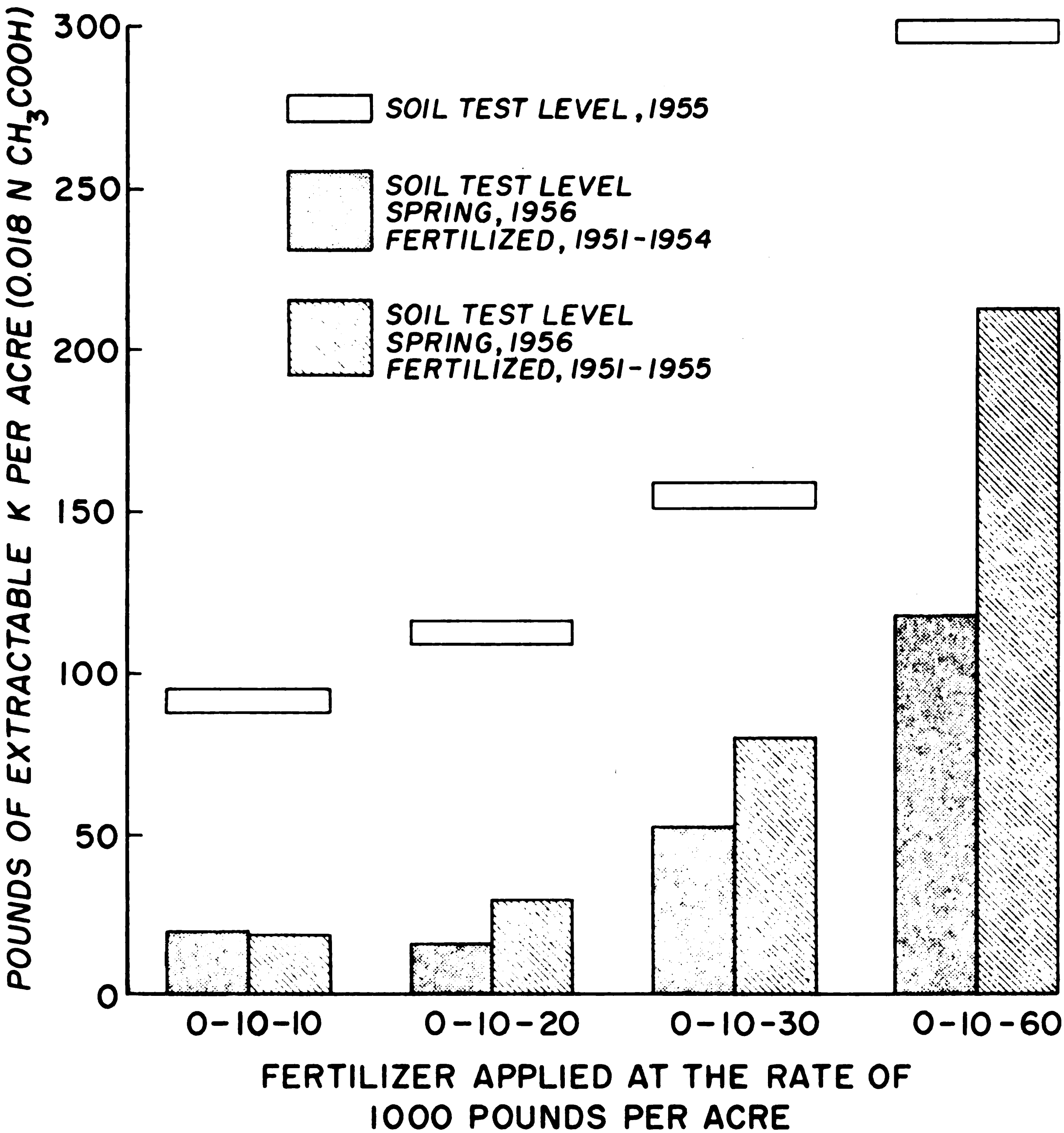


Figure 25. Soil potassium levels as related to fertilizer application and crop removal, 1955 and 1956.

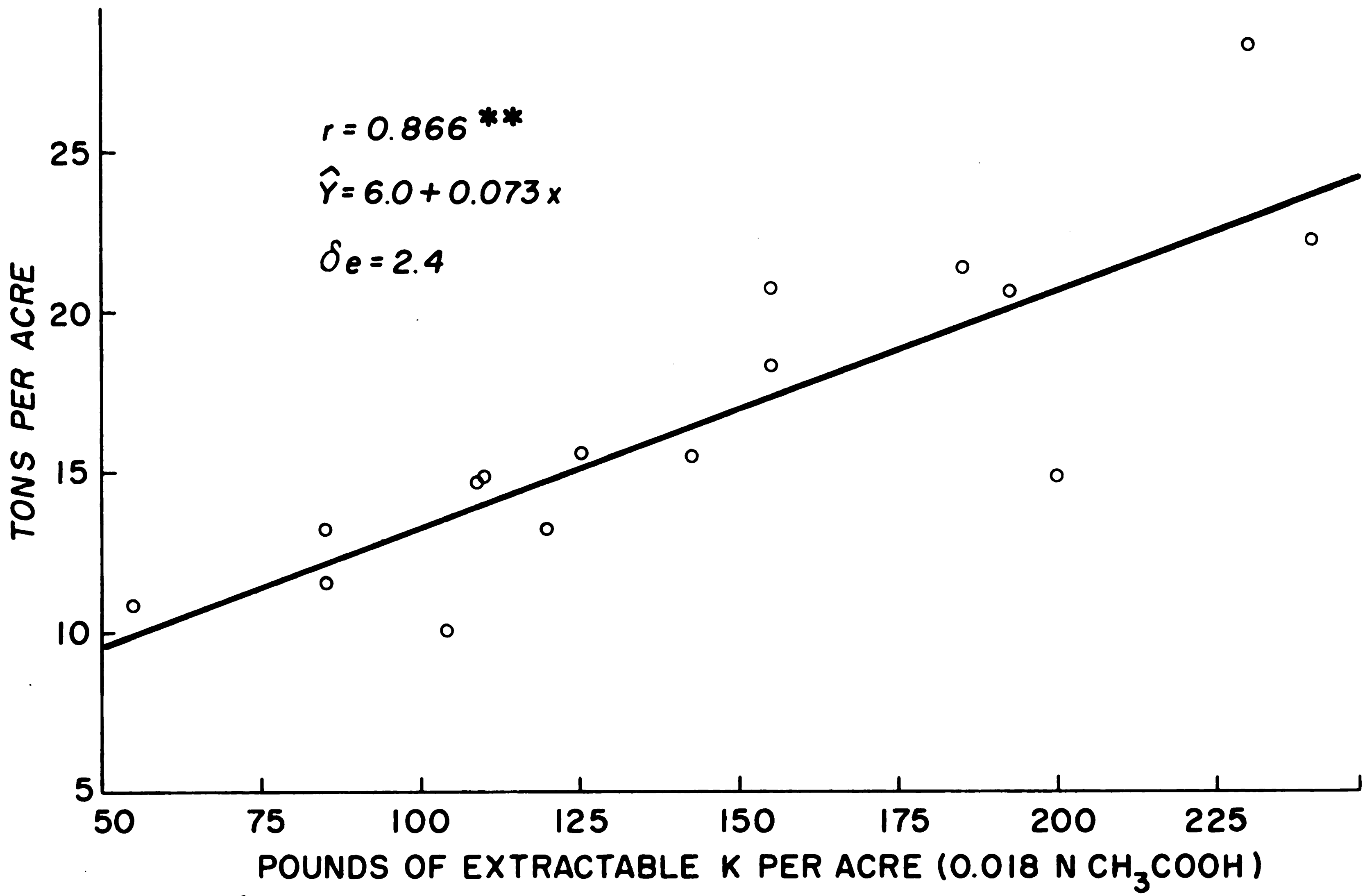


Figure 26. The relationship between extractable soil potassium and the yield of sugar beet roots, 1955.

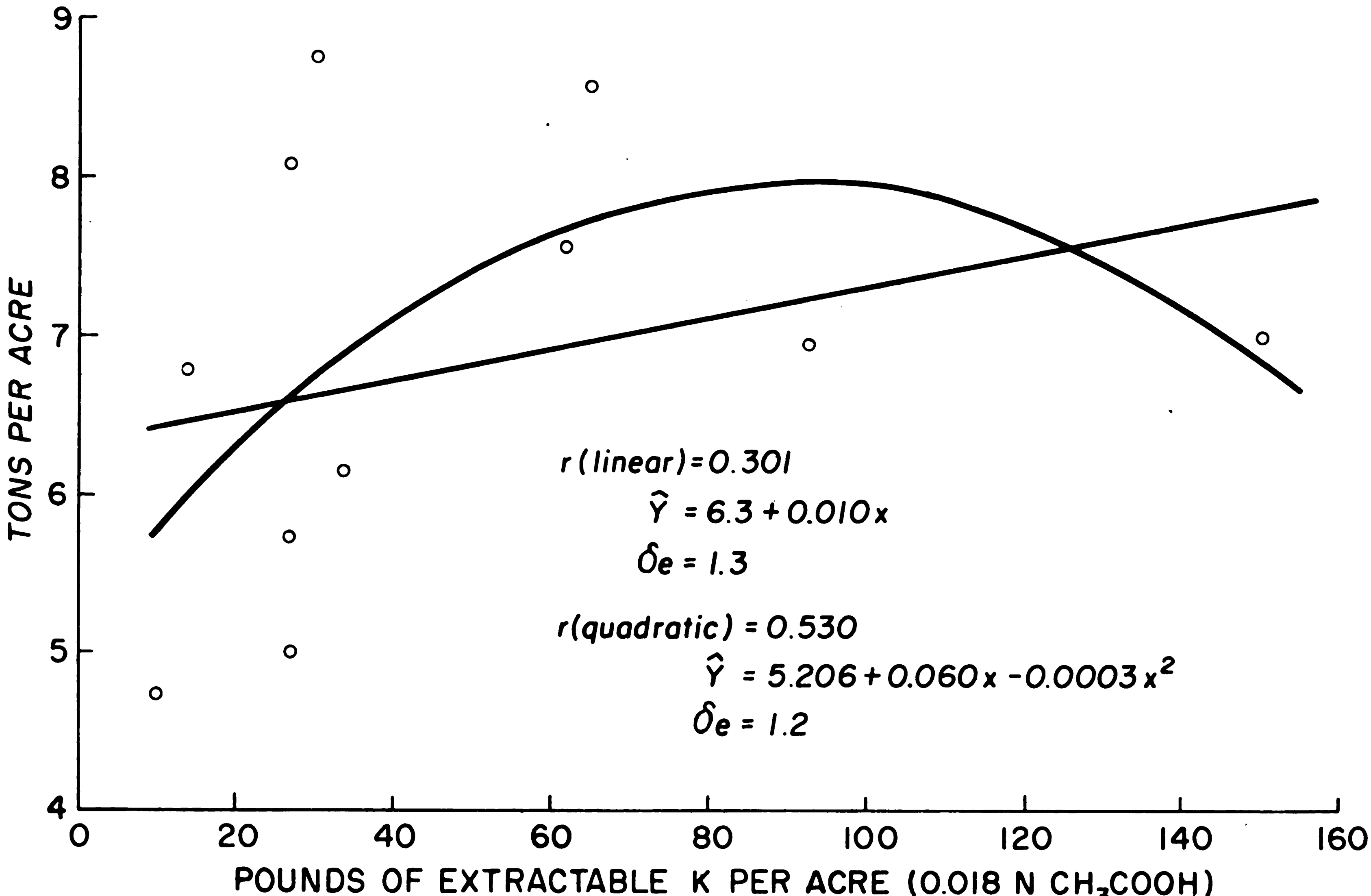


Figure 27. The relationship between extractable soil potassium and the yield of sugar beet roots, 1956.

As shown in Figure 26, the yield of sugar beets increased linearly with available K and yields of 22.1 tons per acre were obtained where the available soil K was approximately 240 pounds per acre and the available soil P was 27 pounds per acre as indicated by extracting the soil with 0.018 N CH_3COOH.

It is apparent from the regression line for this relationship (Figure 26) that higher levels of available soil K might have resulted in higher yields of sugar beets, providing the other growth factors were not limiting. It is also evident, from the correlation coefficient obtained, that the extracting solution employing 0.018 N CH_3COOH is a valuable tool in predicting yield response of sugar beets relative to available soil K, providing good representative soil samples have been submitted for testing.

The yield response of sugar beets (ΔY) in 1955 and 1956 to 500 pounds of NaCl on plots containing various amounts of residual soil K is shown in Tables 19 and 20 and Figures 28 and 29, respectively. The data for this relationship were obtained as follows:

$$\Delta Y = Y_{s+f} - Y_f$$

where, ΔY = yield response of sugar beets to applied salt (NaCl) at various levels of soil K.

Y_{s+f} = the yield obtained from the half plots receiving salt (NaCl) plus K.

Y_f = the yield obtained from the half plots receiving K only.

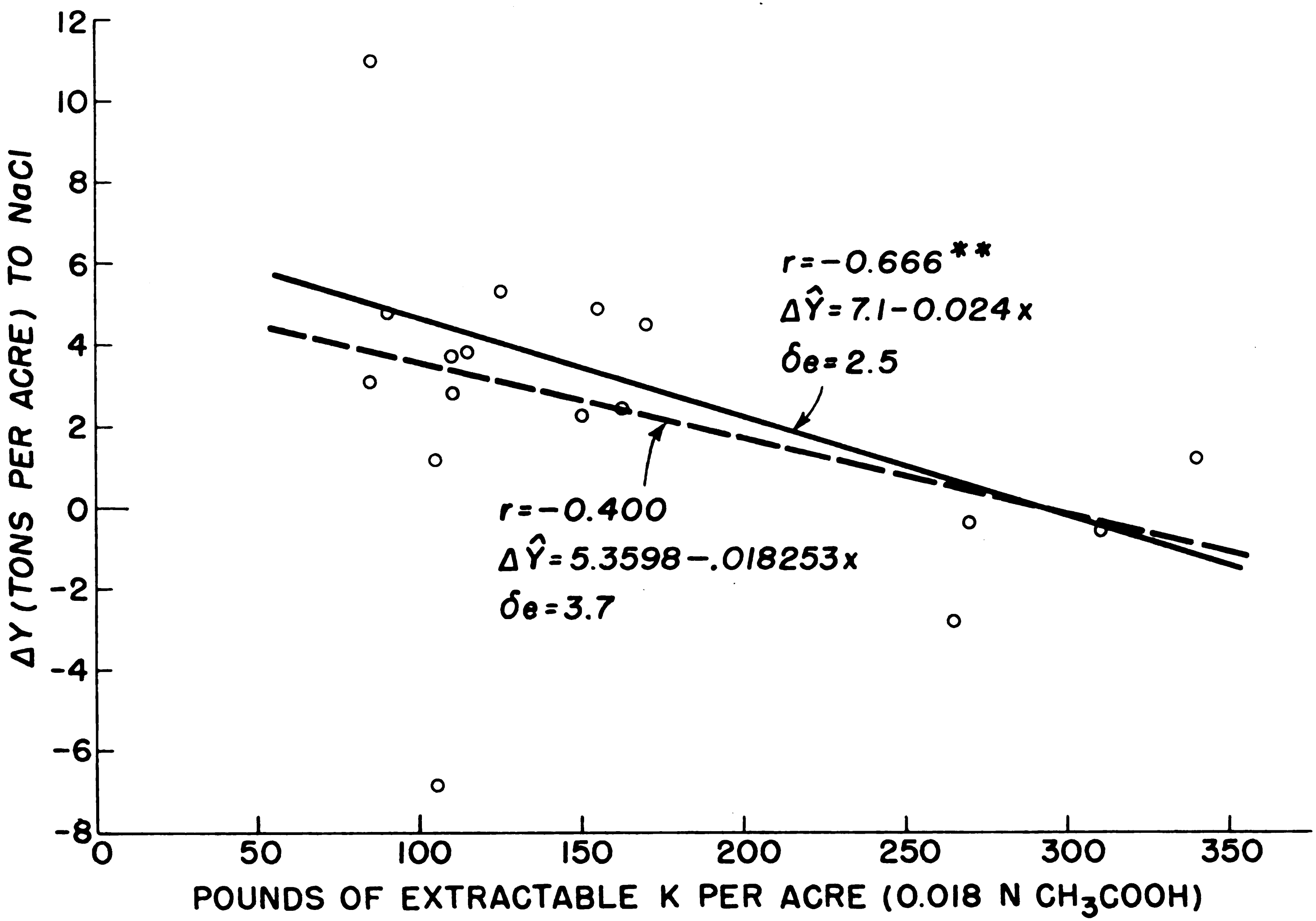


Figure 28. The adjusted yield response (ΔY) of sugar beet roots to salt (NaCl) at varying levels of soil potassium, 1955.

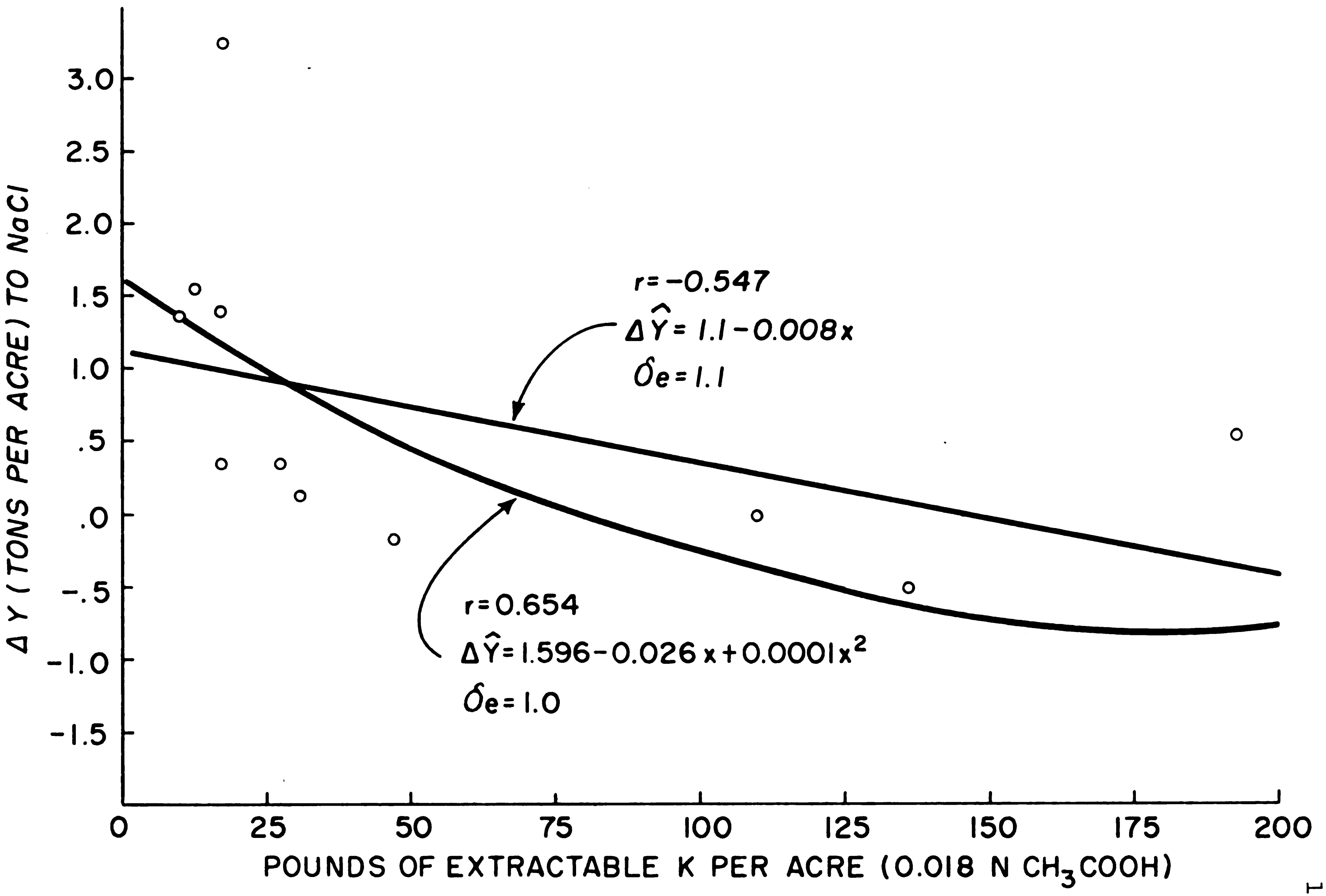


Figure 29. The adjusted yield response (ΔY) of sugar beet roots to salt (NaCl) at varying levels of soil potassium, 1956.

An inverse relationship existed between the yield response of sugar beets to NaCl and increased levels of soil K both in 1955 and 1956. A correlation coefficient of -0.666, which was significant at the 1 per cent level, was obtained for this relationship, in 1955 when the ΔY value of -6.8 was eliminated from the correlation, and -0.400 when this value was included. The ΔY value of -6.8 does not conform to the other values and it appears that an error may have occurred in processing these data.

As shown in Figure 29, a linear correlation coefficient of -0.547 and a curvilinear correlation coefficient of 0.654 were obtained for this relationship in 1956.

These data suggest that Na is capable of substituting for part of the K required by sugar beets, particularly at the lower levels of available soil K. Whether the element assists in the functions of K in the matabolic processes of the plant, or whether it has, in certain plants, functions that it alone can best fulfill, is a question yet to be answered (30).

Timm (67) has shown that a substitution of Na for K, in the nutrition of sugar beets, occurred in soils with a low initial exchangeable K content treated with 100 pounds of potash. Lehr (44) has suggested that in the event of a K shortage, most of the Na went to the foliage, where it set free a certain quantity of K for use in other parts of the plant. This situation was not apparent in these data (Table 21).

As shown in Table 22, there was a trend toward lower levels of extractable Na from the residual plots which had received no fertilizer application other than 500 pounds of NaCl per acre as compared to the plots receiving both fertilizer and NaCl. These data tend to indicate the larger uptake of Na by sugar beets in the absence of less available soil K.

The relationship between water soluble Na and K in green sugar beet petioles and soil treatment in 1955 is shown in Table 23 and Figures 30, 31, and 32.

In general, green tissue obtained from the plots receiving 500 pounds of NaCl contained the greatest amount of water soluble Na.

The decreasing order of magnitude of water soluble Na contained in the green petioles from the plots receiving the various fertilizer treatments was as follows: NaCl only $>$ NaCl plus fertilizer $>$ residual Na and K $>$ fertilizer (K_2O) only.

The amount of Na obtained in the green petioles was fairly constant both from the plots receiving 1000 pounds of the various fertilizers, and also from the residual plots. However, the tissue from the plots receiving 500 pounds of NaCl, and those from the plots receiving the NaCl plus 1000 pounds of 0-10-60, 0-10-30, 0-10-20, and 0-10-10 generally contained larger amounts of Na where the least amount of K was applied.

As shown in Figure 31, the application of 500 pounds of NaCl per acre to the plots receiving no K (residual plots)

TABLE 22

THE POUNDS OF EXTRACTABLE SOIL POTASSIUM AND SODIUM PER ACRE AND THE YIELD OF SUGAR BEET ROOTS, 1956

Treatment	Pounds per acre*		Tons per acre
	K	Na	
Residual plots			
0-10-60 + s**	111	268	9.9
0-10-30 + s	48	313	8.7
0-10-20 + s	16	257	8.0
0-10-10 + s	24	226	8.6
0-10-60	119	117	7.6
0-10-30	52	135	7.4
0-10-20	16	120	6.3
0-10-10	21	104	5.8
Fertilized plots			
0-10-60 + s	181	312	11.8
0-10-30 + s	97	323	11.8
0-10-20 + s	25	121	12.2
0-10-10 + s	14	238	10.6
0-10-60	214	134	12.5
0-10-30	84	130	11.5
0-10-20	31	122	11.1
0-10-10	18	101	9.2

*Soils sampled in May, 1956

**s = 500 pounds of NaCl applied per acre.

TABLE 23

THE AMOUNT OF WATER SOLUBLE POTASSIUM AND SODIUM IN GREEN SUGAR BEET TISSUE AS RELATED TO SOIL TREATMENT, 1955

	Parts per million in tissue							
	Salt only*		Salt + F		Residual		F	
Treatment	K	Na	K	Na	K	Na	K	Na
0-10-60	4100	1940	4625	1930	4750	1320	5650	1235
0-10-30	2650	3540	3700	3410	2800	1830	3275	1380
0-10-20	1575	3560	2750	3210	1975	1540	2850	1550
0-10-10	1375	2665	1600	4280	1350	1650	1650	1180

*Salt only = 500 pounds of NaCl applied per acre annually since 1951.

Salt + F = 500 pounds of NaCl plus 1000 pounds of designated fertilizer applied per acre since 1951.

Residual = No salt (NaCl) ever applied and no fertilizer applied since 1954.

F = 1000 pounds of designated fertilizer applied per acre since 1951.

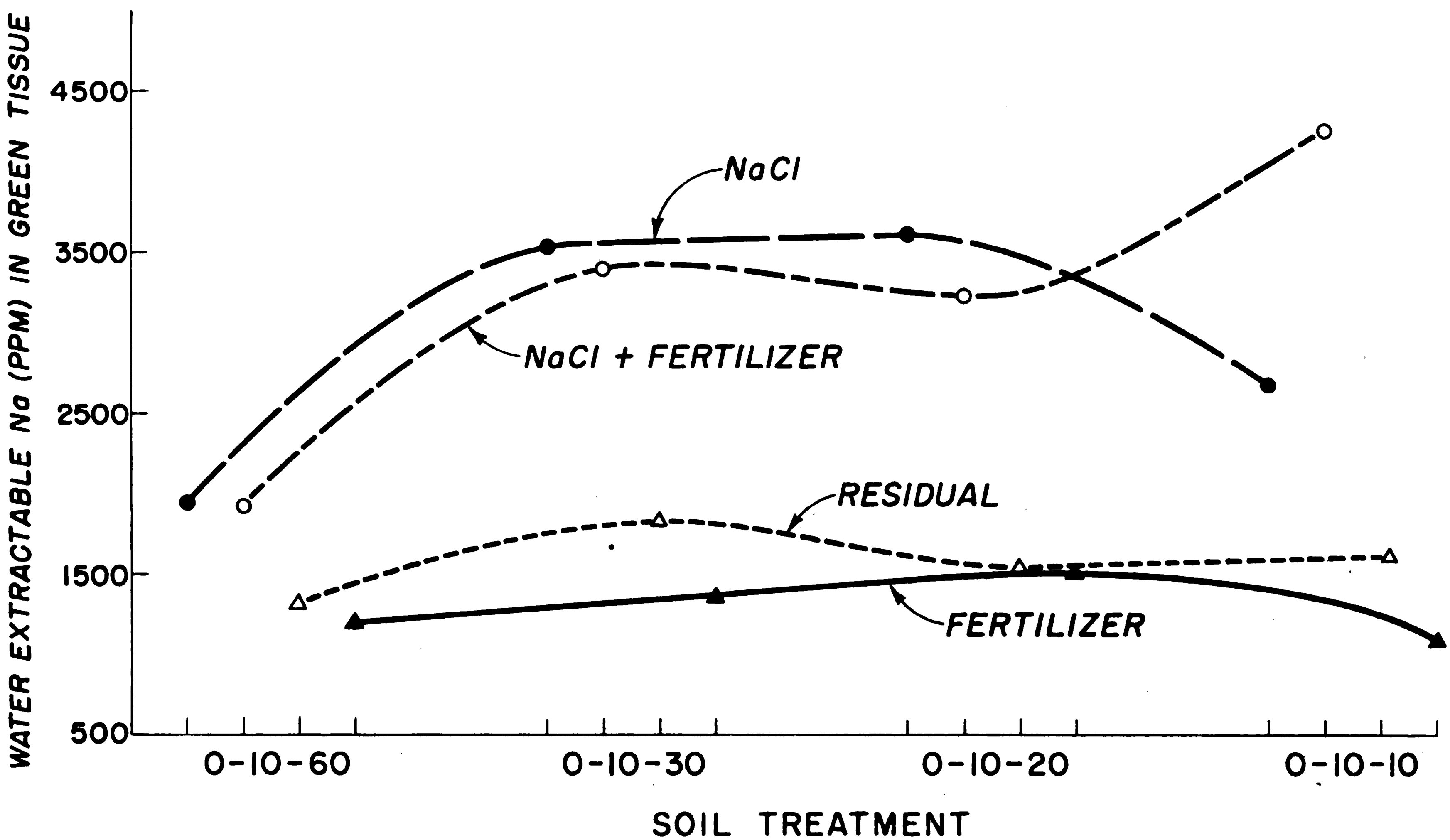


Figure 30. The relationship between the water extractable sodium content of green sugar beet tissue and soil treatment, 1955.

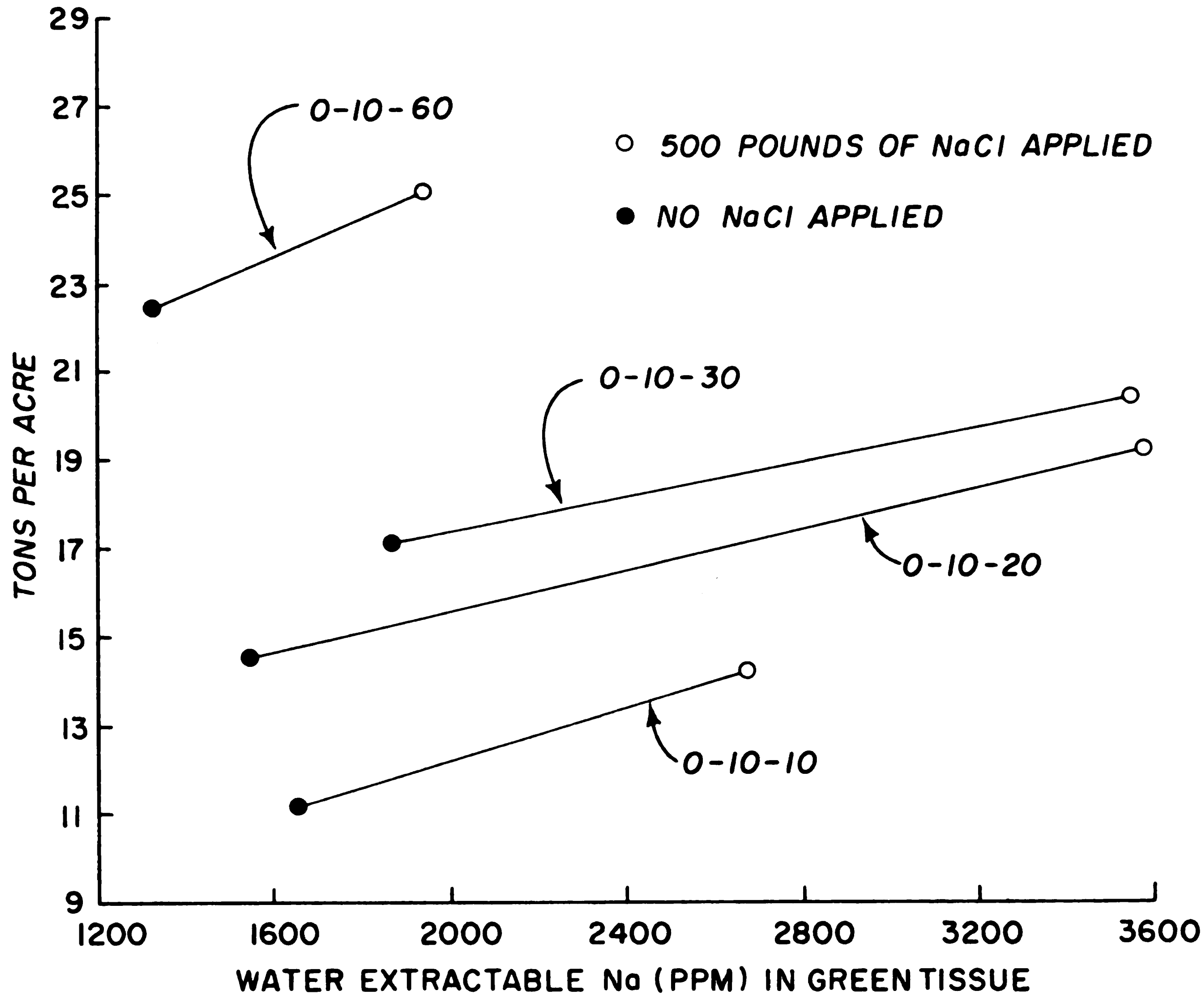


Figure 31. The relationship between the water extractable sodium content of green sugar beet tissue and the yield of sugar beet roots from the residual potassium plots where no salt (NaCl) and 500 pounds of salt (NaCl) were applied per acre, 1955.

increased the yield of sugar beets in every case over those containing residual K only. Also, the amount of Na in the green petioles was highest from those plots receiving NaCl.

The largest amount of K (5650 parts per million) was obtained in the tissue from the plots receiving 1000 pounds of 0-10-60 per acre; the least amount (1350 parts per million) was obtained in the tissue from the residual plots which had previously been fertilized with 1000 pounds of 0-10-10 per acre (Table 23).

The decreasing order of magnitude of K contained in the green tissue within treatments was as follows:

0-10-60: F > 0 > Salt + F > salt only

0-10-30: Salt + F > F > 0 > salt only

0-10-20: F > Salt + F > 0 > salt only

0-10-10: F > Salt + F > salt only > 0

Where, salt only = 500 pounds NaCl applied per acre.

salt + F = 500 pounds NaCl plus 1000 pounds of the designated fertilizer.

0 = No NaCl or fertilizer applied (residual).

F = 1000 pounds of the designated fertilizer applied per acre.

These data show that the uptake of K by the plant was related to the amount of available soil K, and to the amount of K and Na applied. In every case, except one (0-10-10 treatment), the least amount of K was taken up by the plants from the plots which had received 500 pounds of NaCl only per acre. The lower uptake of K by these treatments, however, was compensated for by a larger uptake of Na (Table 23).

A high degree of correlation was obtained between the K contained in the green sugar beet petioles and the yield of sugar beet roots, as shown in Figure 32. The following relationships were significant at the 1 per cent level: (1) parts per million of K in the petioles versus the yield of sugar beet roots obtained from the residual plots, (2) parts per million of K in the petioles on the plots receiving K versus the yield of sugar beet roots, (3) parts per million of K in the petioles from the combined values obtained from the residual and fertilized plots versus their respective yield values. The respective correlation coefficients for these relationships were 0.623, 0.801, and 0.830.

A curvilinear relationship was obtained where the K in the green tissue obtained from the plots receiving applied K was plotted against the yield obtained from the respective plots. The correlation coefficient for this relationship was 0.849, and significant at the 1 per cent level as shown in Figure 32. From this relationship the calculated maximum yield of sugar beets should occur when the beet petioles contain approximately 7000 parts per million of water soluble K.

These data indicate the importance of tissue testing as a diagnostic tool in determining the K requirement of sugar beets.

The relationships between extractable soil K on the unfertilized plots, extracted by 0.018 N CH_3COOH, and the K

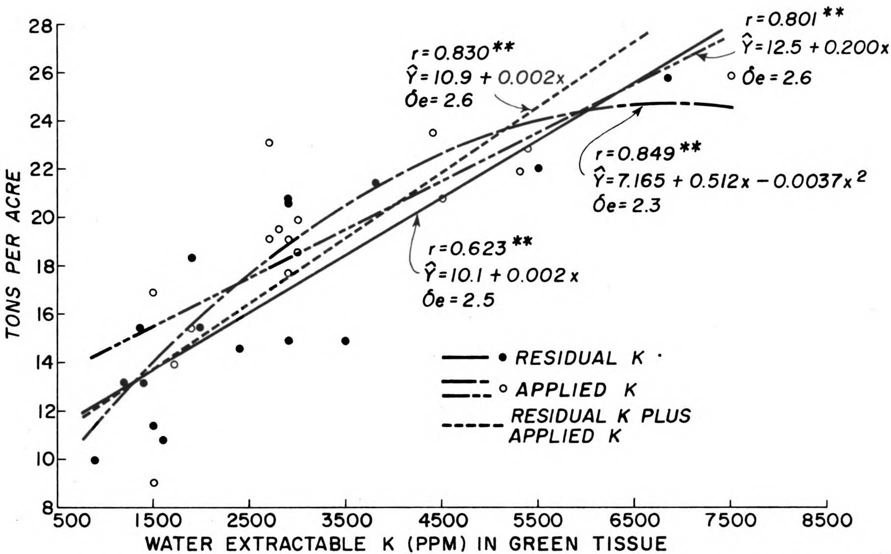


Figure 32. The relationship between the yield of sugar beet roots and the water extractable potassium content of the green tissue, August 24, 1955.

removed by sugar beet tops and that removed by the tops plus the roots in 1955 are shown in Figures 33 and 34, respectively. The respective linear correlation coefficients for these relationships were 0.898 and 0.885; both r values were significant at the 1 per cent level.

The per cent K in the sugar beet tops was significantly related to the extractable soil K (significant at the 1 per cent level) as indicated by the correlation coefficient of 0.891 (Figure 35). Although the r value of 0.665 obtained for the relationship of extractable soil K versus the per cent K in the sugar beet roots, as shown in Figure 35, was not statistically significant, a definite trend existed between increased K in the root tissue with increased levels of extractable soil K.

The per cent K in the sugar beet tops reflected the yield of sugar beet roots with a high degree of accuracy as indicated by the correlation coefficient of 0.881, which was significant at the 1 per cent level (Figure 36). An r value of 0.447, however, was obtained for the relationship between the yield of roots and per cent in the root tissue.

It is apparent from these data that the K contained in the sugar beet tops is a better indicator of yield response than the K contained in the root tissue. These data also emphasize the importance of an ample supply of available soil K if good yields of sugar beets are to be obtained. As shown in Figure 37, and Table 21, a sugar beet crop (tops plus roots) yielding 25.1 tons per acre, removed 542 pounds of soil K per acre.

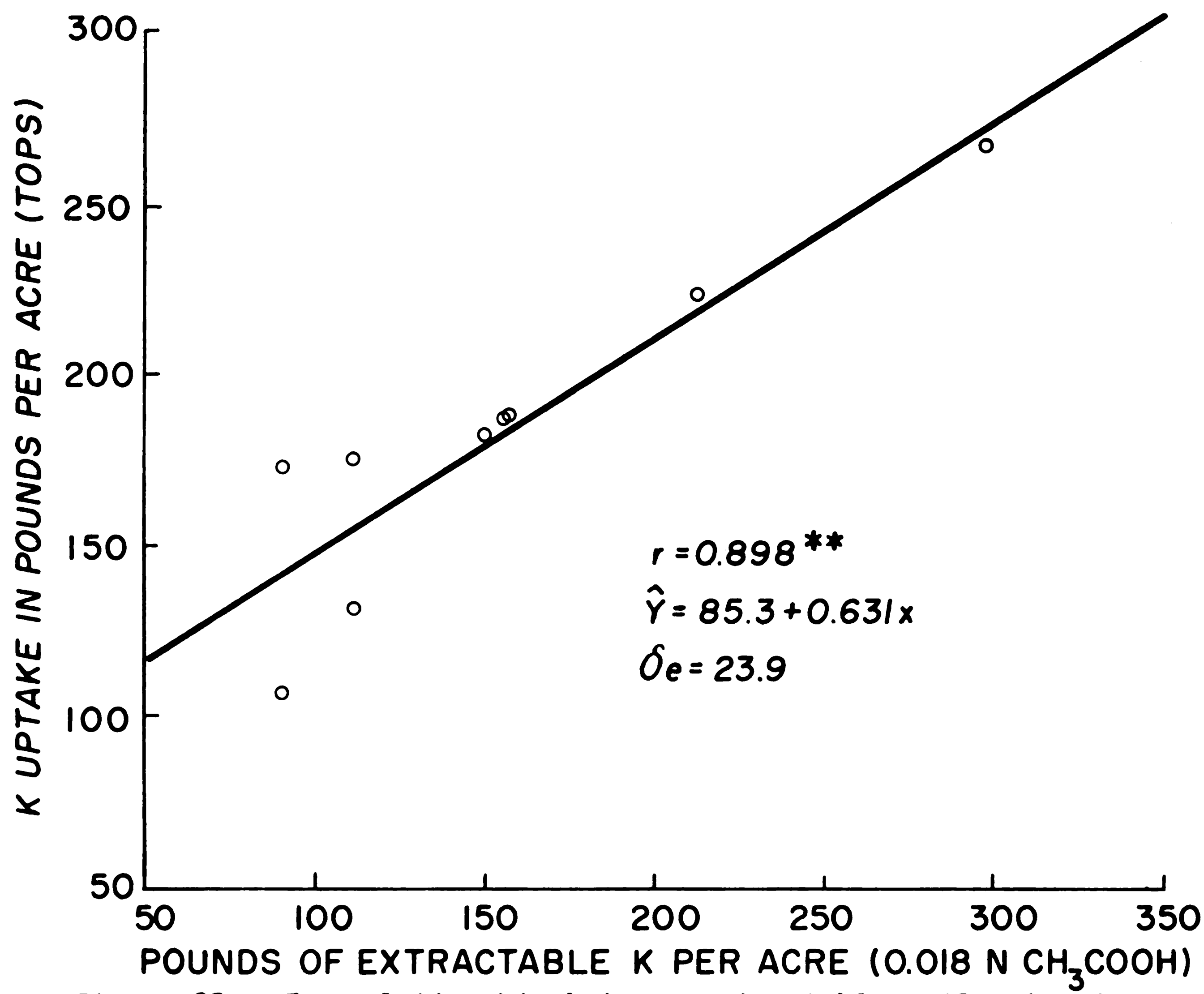


Figure 33. The relationship between extractable soil potassium and the uptake of K by sugar beet tops, 1955.

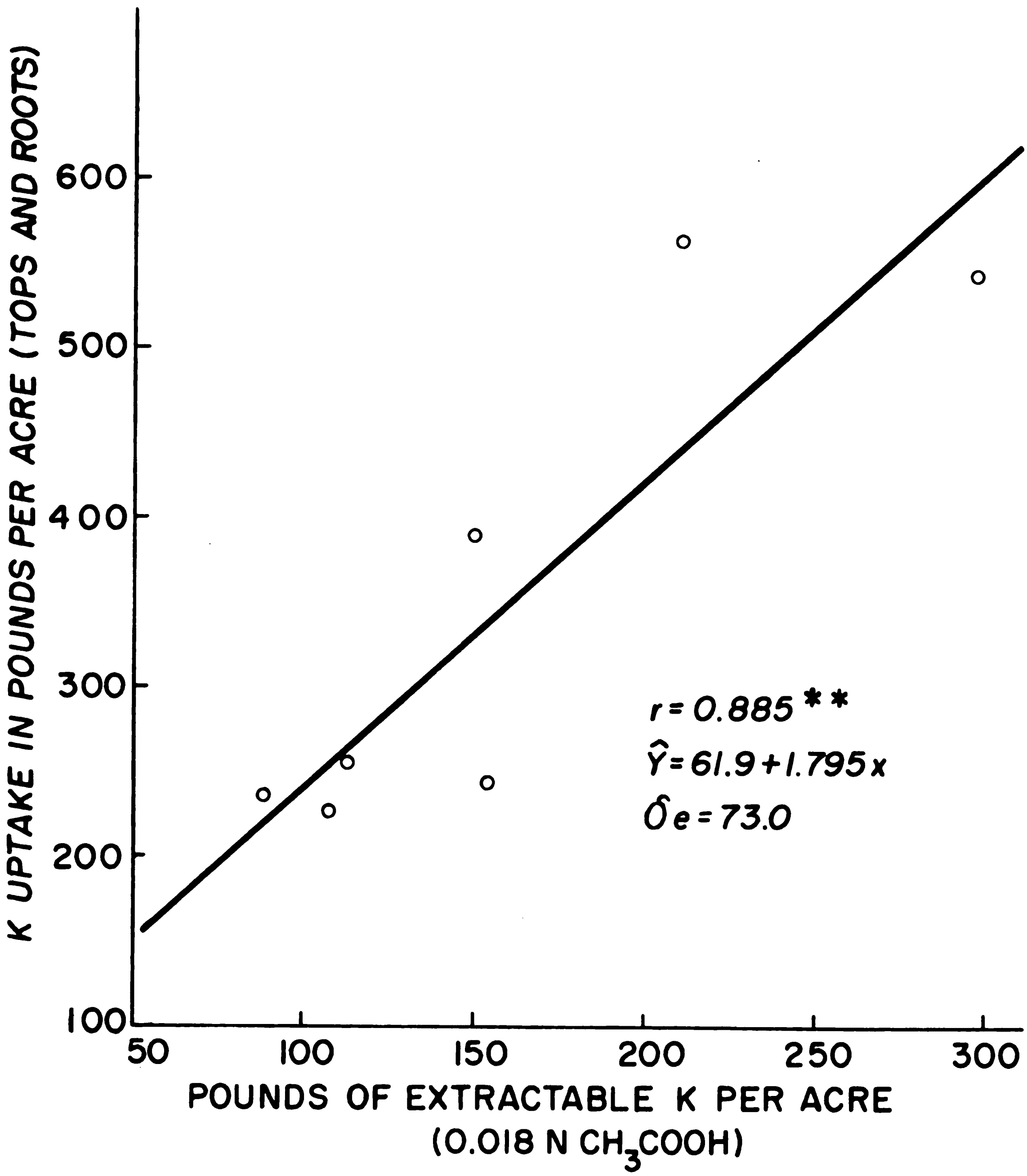


Figure 34. The relationship between extractable soil potassium and total potassium uptake (tops+roots) by sugar beets, 1955.

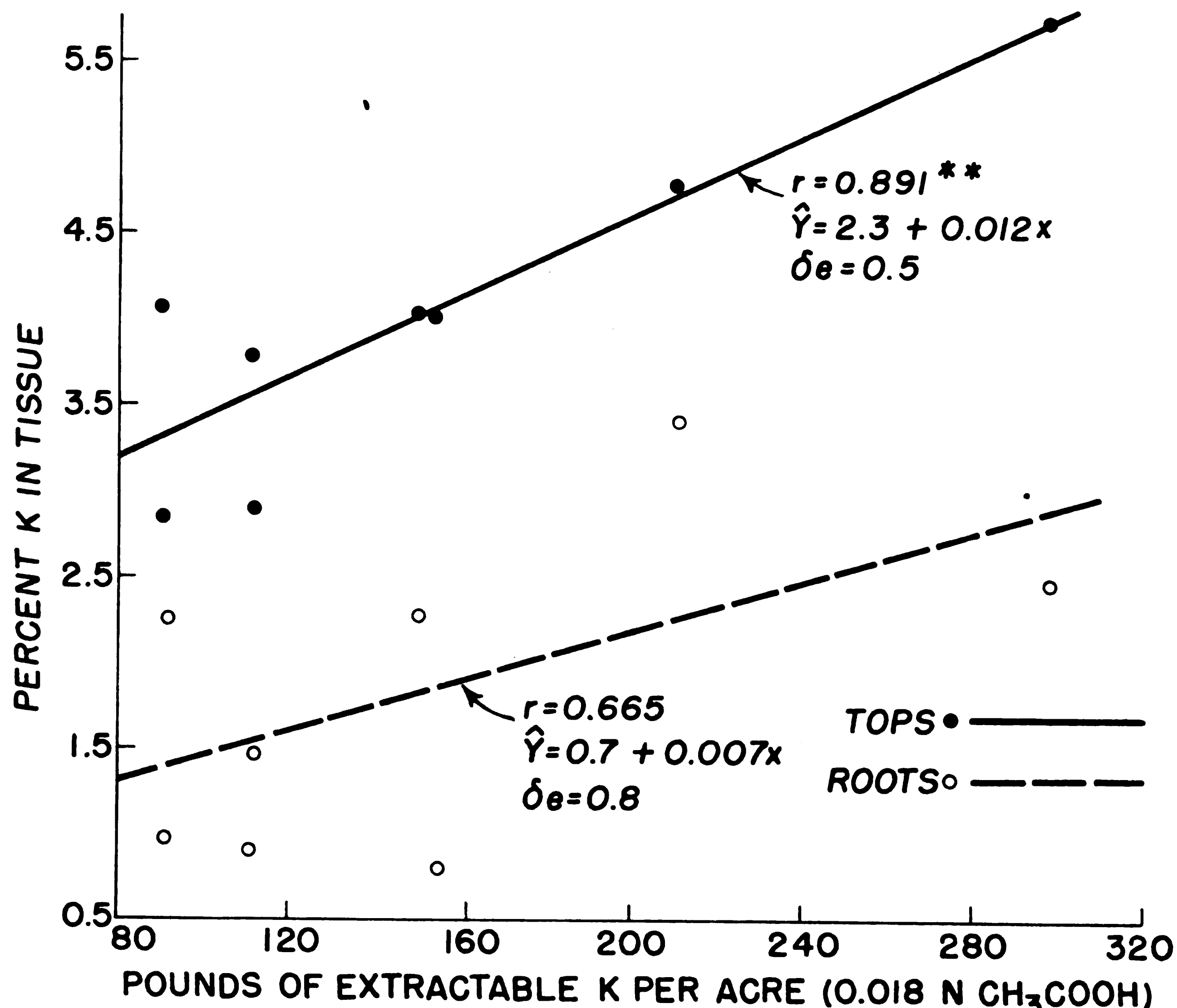


Figure 35. The relationship between extractable soil potassium and the per cent potassium in sugar beet tissue, 1955.

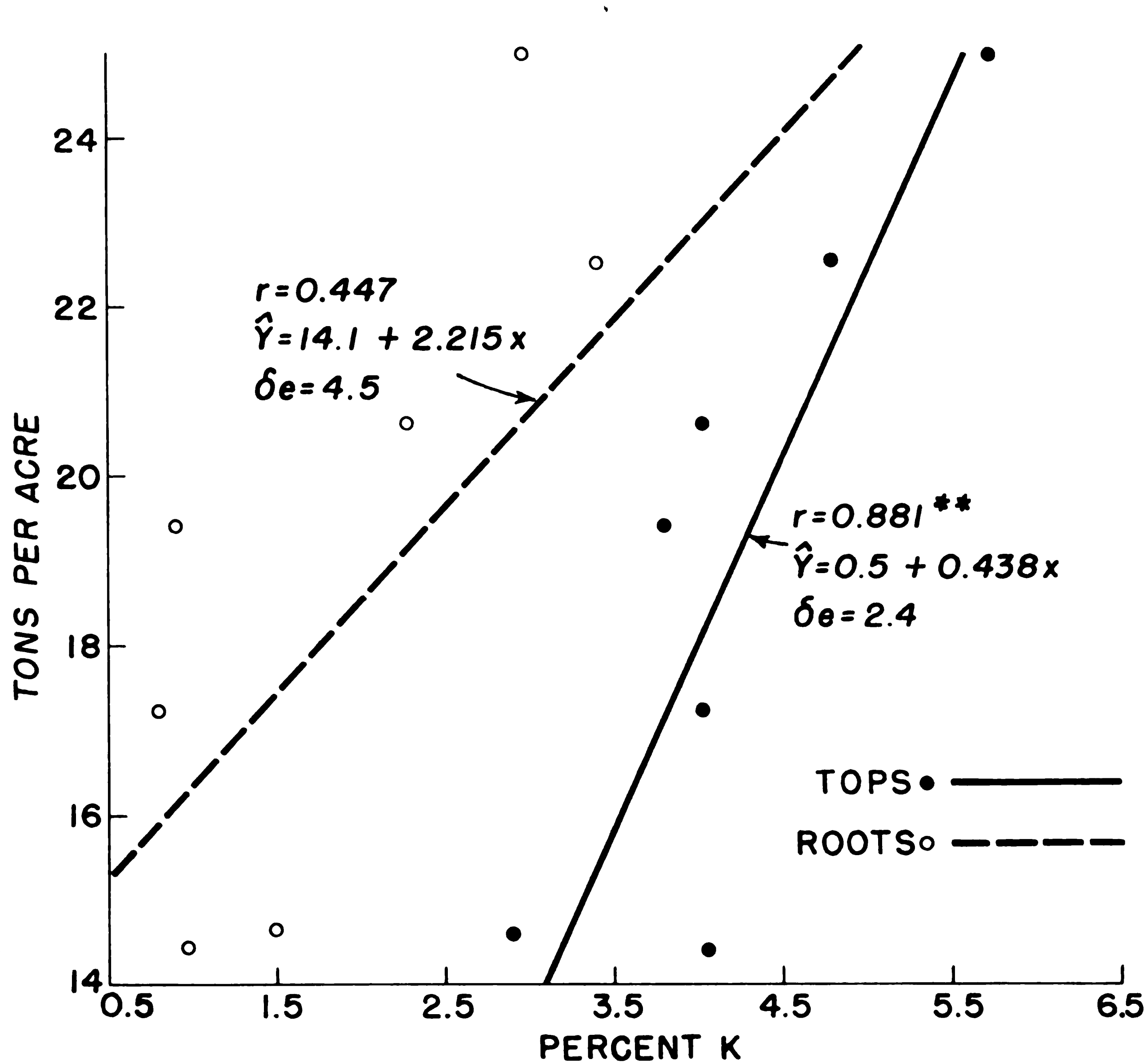


Figure 36. The relationship between the yield of sugar beet roots and the per cent potassium in the sugar beet tops and roots, 1955.

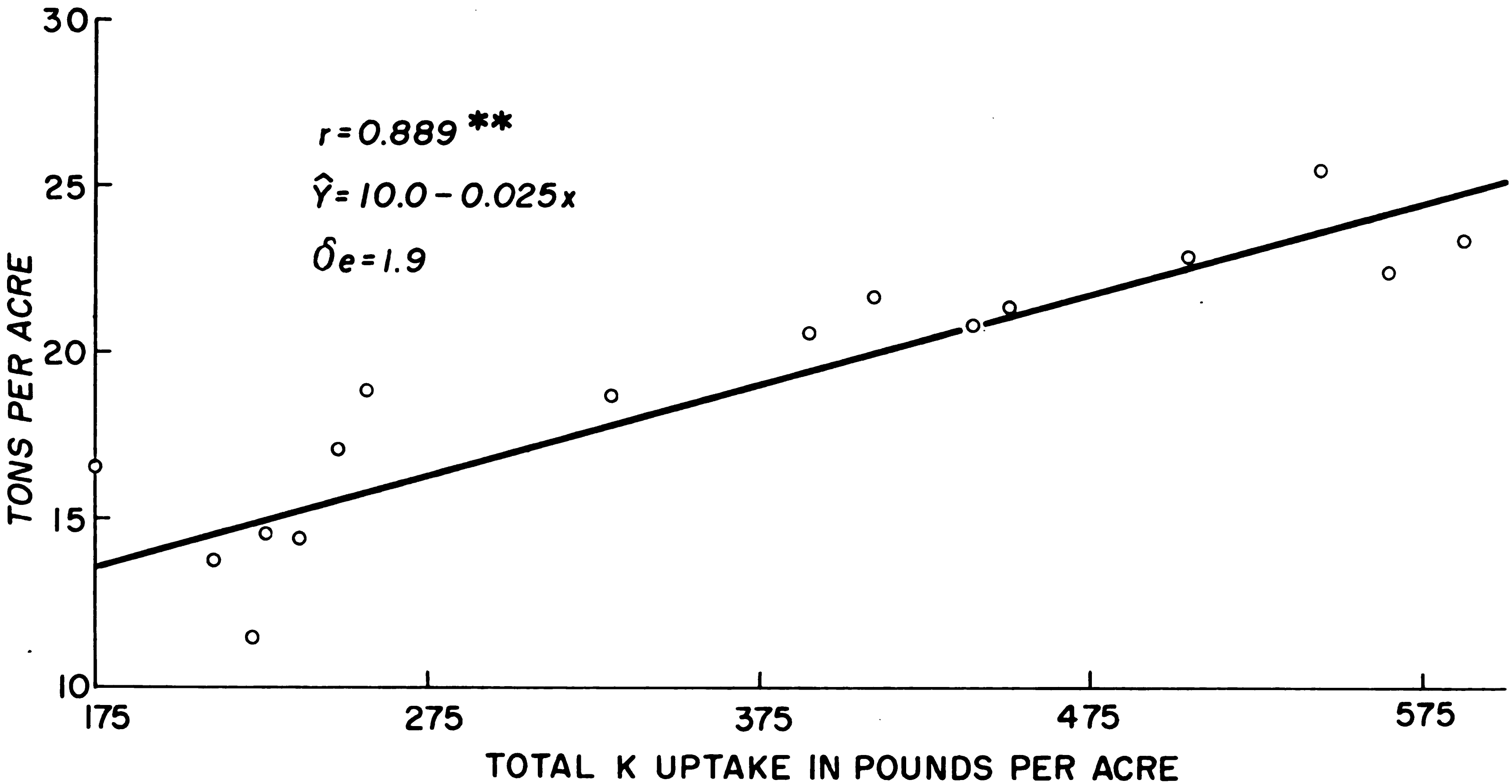


Figure 37. The relationship between the yield of sugar beet roots and total potassium uptake (tops + roots), 1955.

A high degree of linear correlation existed between the water extractable K obtained from the petioles of green sugar beet tissue and the pounds of K removed in the tops (Figure 38). The correlation coefficient for this relationship was 0.808 and was significant at the 5 per cent level.

The fact that a high degree of correlation was obtained between both the amount of water extractable K in the green sugar beet petioles and in the pounds of K removed by the sugar beet tops (Figure 38), and between the yield of sugar beet roots (Figure 32) emphasizes the importance of green tissue testing in maintaining optimum amounts of soil K and for diagnosing K deficiency in sugar beet tissue.

These data also show that 0.018 $\underline{N}$ CH_3COOH reflects the amount of soil K available to the plant with a high degree of accuracy (Figures 33, 34, and 35), and is a valuable tool in determining the amount of available soil K and in predicting K needs for good growth.

The relationship between the per cent Na in sugar beet tops relative to the per cent K in the tops of the sugar beet tissue is shown in Figure 39. The negative correlation coefficient of -0.732 obtained for the relationship (significant at the 5 per cent level) is indicative of the inverse relationship that existed between these two elements. As the per cent K in the tops increased, the per cent Na decreased and vice versa.

A similar relationship existed between the per cent K present in sugar beet tops relative to the per cent Mg in the

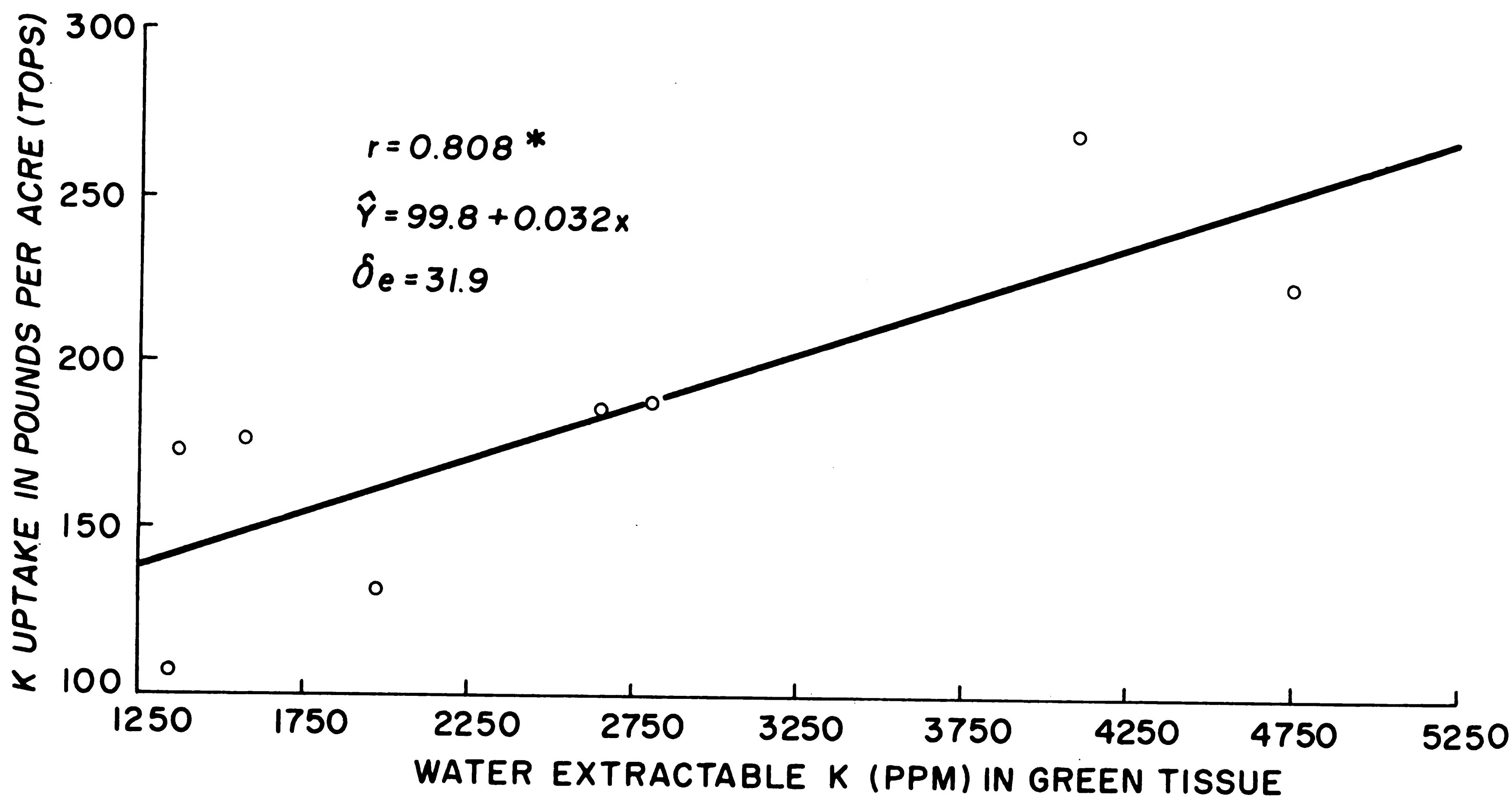


Figure 38. The relationship between the water extractable potassium content of green sugar beet tissue and the pounds of K removed by sugar beet tops, 1955.

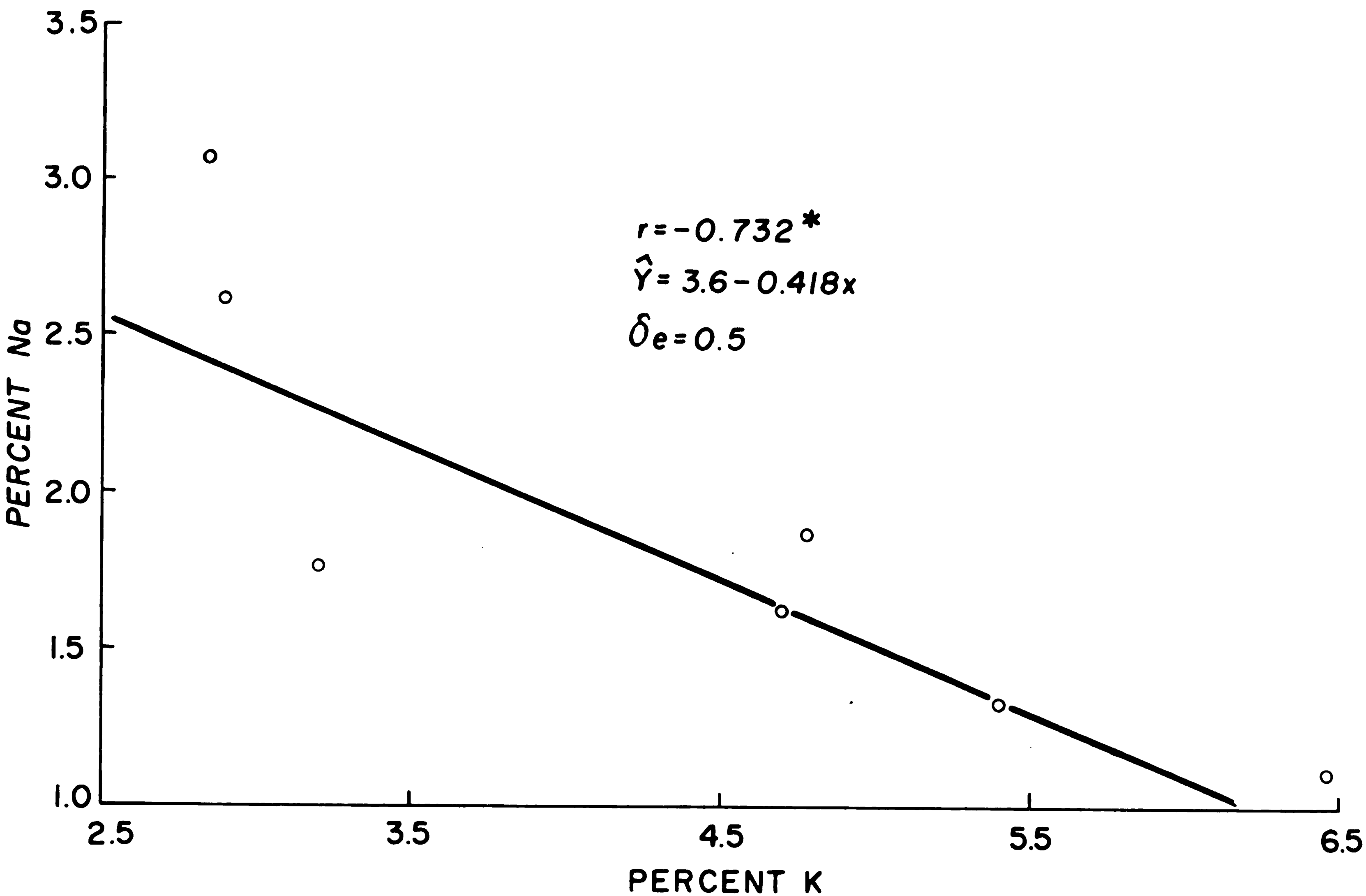


Figure 39. The relationship between per cent potassium and sodium in sugar beet tops, 1955.

tissue. As shown in Figure 40, an inverse relationship existed between the presence of these two elements in the sugar beet tops. An increase in the per cent K in the tops resulted in a decrease in the per cent Mg and vice versa. The negative correlation coefficient of -0.515 obtained for this relationship was statistically significant at the 5 per cent level.

There was no apparent relationship between the per cent K and the per cent Mg in sugar beet roots. The r value obtained for this relationship was 0.258, and was not statistically significant.

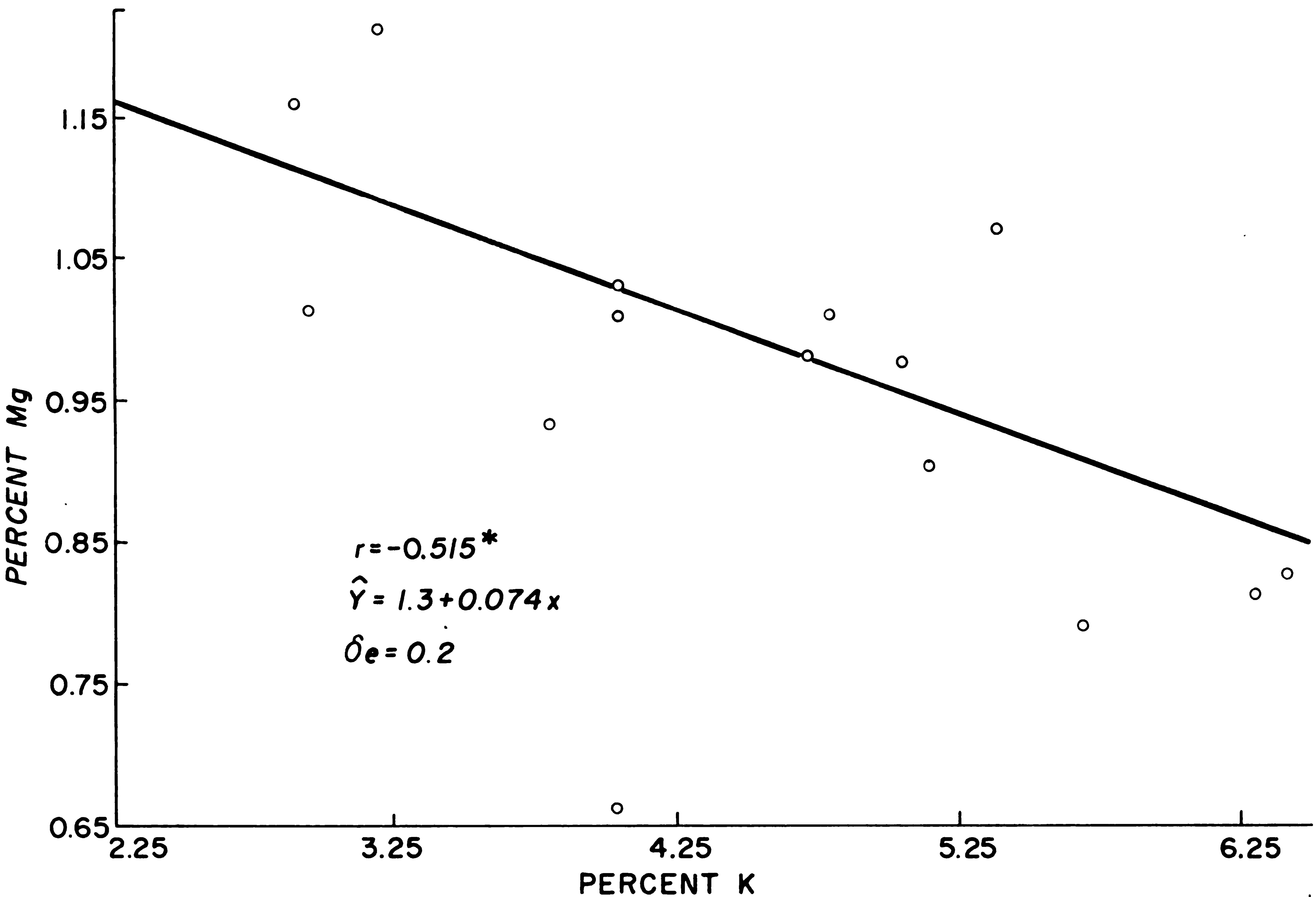


Figure 40. The relationship between per cent potassium and magnesium in sugar beet tops, 1955.

SUMMARY AND CONCLUSIONS

EXPERIMENT I: RATE AND PLACEMENT OF FERTILIZERS

Crops: Carrots, Table Beets, Onions, Broccoli, and Cauliflower

A study was made to determine the relationship between soil tests, the rate and method of placement of nitrogen, phosphorus and potassium, the uptake of these elements by the plant, and the effect on crop yields.

The uptake of K by broccoli was measured by soil tests employing 0.018 N CH_3COOH as the extracting solution for the removal of soil K.

1. Carrots and Table Beets. Method of fertilizer placement did not significantly affect the yield of carrots or table beets. A soil test of 10 pounds of P and 100 pounds of K (0.018 N CH_3COOH extractable) per acre supplemented with an application of 400 pounds of 0-10-30 per acre annually is sufficient to produce high yields of either crop.

Onions. An increase of 30 to 40 per cent in onion yields can be expected if the fertilizer is applied in a band 2 inches below the seed rather than with a grain drill in 7-inch parallel bands. Good yields of onions were obtained by this method of fertilizer placement where the soil test was about 15 pounds of P and 200 pounds of K per acre (0.018 N CH_3COOH extractable) and supplemented annually with 800 pounds of 5-10-20 per acre.

Broccoli. There was no significant difference in the yield of broccoli regardless of the method of fertilizer placement. Residual P and K levels of around 25 and 140 pounds per acre, respectively (0.018 N CH_3COOH extractable), produced good yields of broccoli when supplemented with 400 pounds of a 5-10-20 fertilizer.

Cauliflower. No significant difference in the yield of cauliflower was obtained as a result of fertilizer placement in 1958. However, higher yields of late-planted cauliflower were obtained in 1957 where the fertilizer was placed in a band below or to one side of the seed rather than with a grain drill in 7-inch parallel bands.

A soil test of 10 pounds of P (0.018 N CH_3COOH extractable) or 20 and 30 pounds by the Bray P_1 test (0.025 N HCl + 0.03 N NH_4F extractable) at soil to solution ratios of 1:4 and 1:16, respectively, and 43 pounds of K per acre supplemented with 800 pounds of 5-10-20 per acre was sufficient to produce good yields of cauliflower.

2. Time of sampling is important in interpreting soil test results. In general, less extractable K was obtained from samples taken in the spring than in the fall. Time of sampling did not materially affect the amount of extractable soil P.

It is inadvisable, therefore, to make fall applications of K on organic soils or to attemtp to build up residual K levels on such soils.

3. The Bray P_1 soil extracting solution (0.025 N NCl + 0.03 N NH_4F) at soil to solution ratios of 1:14 and 1:16 removed 2.4 and 3.7 times as much soil P, respectively, as the Spurway Active extracting solution (0.018 N CH_3COOH) at a soil to solution ratio of 1:4.

4. Good correlations were obtained between K uptake, the amount of K_2O applied, and the yield of broccoli employing the following method for the measurement of K uptake by the plant:

Pounds of K obtained in the spring sampling	+	Pounds of K applied as fertilizer	-	Pounds of K obtained in the fall sampling	=	K uptake

5. It is possible that excessive precipitation may give K uptake values as measured by soil tests in excess of that actually taken up by the plant.

6. These data tend to substantiate the findings of other workers in that organic matter has a low fixing power for K.

EXPERIMENT II: FERTILIZER RATIO EXPERIMENT

Crops: Onions and Celery

A study was initiated to determine the effect of residual N, P, and K on the yield of onions and celery and the response of these crops to soil applications of the above three elements.

Green tissue tests were made on the onion leaves and a total chemical analysis was carried out on the celery tissue to determine the relationships between the quantity of applied

N, P, and K, the uptake of these elements by the plant, and the yield of onions and celery.

The uptake of K by celery was also measured by soil tests employing 0.018 N CH_3COOH as the extracting solution for the removal of soil K.

1. High yields of onions were obtained where the residual soil P and K levels were around 20 and 250 to 300 pounds per acre, respectively (0.018 N CH_3COOH extractable), when supplemented with a starter fertilizer containing 50, 10, and 20 pounds of N, P_2O_5, and K_2O, respectively.

Less extractable soil K was obtained from samples taken in the spring than in the fall, as previously shown, and the time of sampling did not materially affect the amount of extractable P.

2. The effect of residual nitrogen was reflected in the yield of onions even though 50 pounds of N was applied with the starter fertilizer. An increase of 145 and 230 fifty pound bags of onions per acre was obtained where 50 and 100 pounds of N, respectively, was applied the previous year.

The same yield of onions was obtained with different combinations of N, P, and K.

3. The water extractable N and P from the leaves of onions sampled on July 16, 1954 was related to the amount of these elements applied to the soil and to the yield of bulbs. This relationship did not exist with the water extractable K. However, in 1955 the water soluble K contained in the green

tissue increased with increased extractable soil K but was not related to the yield of bulbs.

4. Applications of N as urea and ammonium nitrate increased the water extractable P obtained from the green onion tissue.

5. Statistically significant correlation coefficients were obtained for the relationship between K uptake, as measured by soil tests and plant analysis, and the yield of celery. Good relationships were obtained for the amount of K removed by celery as determined by the two methods employed for the measurement of K uptake.

6. It appears doubtful that much increase in the yield of celery can be expected from additional amounts of P and K where the soil tests are around 35 pounds of P and 700 to 800 pounds of K per acre.

Large applications of K_2O reduced the yield of celery where the soils were high (1000 pounds K per acre) in residual soil K.

EXPERIMENT III: FERTILIZER RATE EXPERIMENT

Crop: Sweet Corn

A fertilizer rate experiment with sweet corn was initiated in 1951. Annual broadcast applications of an 0-10-30 fertilizer were applied in 1951, 1952, 1953, and 1954, and on one-half of the plots in 1955 and 1956. The fertilizer rates employed were 750, 1500, 2250, and 3000 pounds per acre.

The soils were sampled in 1955 and 1956 and various soil extracting solutions at different soil to solution ratios were employed to determine the relative amount of P removed from the soil by the various solutions. The available soil K was obtained by extracting the soil with 0.018 N CH_3COOH.

The green corn tissue was sampled in July, 1955, and the water extractable P, K, Ca, Mg, Na, and Mn were determined.

1. No significant difference was obtained in the yield of sweet corn and the various soil treatments employed.

The same yield of sweet corn was obtained over a wide range of residual soil P and K levels. Approximately the same yield was obtained from residual soil P tests of 12 and 20 pounds per acre and 190 and 340 pounds of K per acre (0.018 N CH_3COOH extractable).

2. There was no relationship between the amount of water extractable P, K, Ca, Mg, Mn, and Na in the green corn tissue and the yield of sweet corn.

However, there was an indicated trend that as the applied K was increased, the water extractable K in the green tissue increased and the Na decreased. Increased applications of soil K also resulted in an increase in water extractable Mn in the green tissue.

3. A statistically significant curvilinear relationship was obtained between K uptake by the plant as measured by the soil tests, and the yield of sweet corn in 1956. Potassium uptake values also reflected K treatments applied to the soil.

The maximum yield of 7 tons per acre was obtained at a K uptake value of 325 pounds per acre and the available soil P was 34 and 73 pounds as obtained by extracting the soil with a 0.018 N CH_3COOH and 0.025 N HCl + 0.03 N NH_4F at soil to solution ratios of 1:4, respectively.

In 1955, the maximum yield of 6.4 tons per acre was obtained where the K uptake value was 137 pounds per acre. The lower K uptake values in 1955 may possibly be attributed to the excessive rainfall which occurred in the latter part of July when the corn was actively taking up K.

4. The extracting solutions employing 0.025 N NCl + 0.03 N NH_4F and 0.018 N CH_3COOH at soil to solution ratios of 1:16 and 1:4, respectively, showed the highest degree of correlation relative to the amount of P removed from the soil.

The descending order of magnitude which the various solutions extracted soil P was as follows:
0.025 N HCl + 0.03 N NH_4F (1:16) > 0.018 N CH_3COOH + 0.03 N NaF (1:16) > 0.025 N HCl + 0.03 N NH_4F (1:4) > 0.018 N CH_3COOH + 0.03 N NaF (1:4) > 0.018 N CH_3COOH (1:4).

EXPERIMENT IV: SODIUM-POTASSIUM INTERACTIONS

Crop: Sugar Beets

The effect of applications of Na, as NaCl, and K, as KCl, and the interactions of Na and K on the yield of sugar beets was studied. The soils were sampled and P, K, and Na determined by extracting the soil with 0.018 N CH_3COOH. Green sugar beet tissue (petioles) was sampled in August, 1955 and water soluble Na and K determined. Total K, Na, and Mg were determined in the sugar beet tops and roots and the yield, in tons per acre, determined.

1. Good yields of sugar beet roots were obtained where the residual soil P and K tests were approximately 27 and 300 pounds per acre, respectively, when supplemented with 500 pounds of NaCl per acre.

2. A sugar beet crop yielding 25.1 tons of roots and 15.9 tons of tops per acre removed 543 pounds of soil K per acre.

3. Sodium appeared to be effective in substituting for K at low levels of soil K.

4. An inverse relationship existed between the yield response of sugar beets to NaCl and increased levels of soil K.

5. Statistically significant correlations were obtained between soil K (0.018 $\underline{N}$ CH_3COOH extractable), water extractable K in the green tissue, total K uptake and the yield of sugar beet roots.

6. The K contained in sugar beet tops was a better indicator of yield response to K than the K contained in the root tissue.

7. An inverse relationship existed between the per cent K and Na and K and Mg in sugar beet tops.

8. The maximum yield of sugar beets occurred where the beet petioles contained 7000 parts per million of water extractable K.

9. The extracting solution employing 0.018 $\underline{N}$ CH_3COOH is a valuable tool in predicting yield response of sugar beets

to applied soil K. Also, the large loss of soil K, due to crop removal, indicates the need for annual soil tests to determine fertilization recommendations for sugar beets.

LITERATURE CITED

1. Aderikhin, P. G. Role of Colloids in P_2O_5 absorption by soils. Pedology 9:550-554. 1946.

2. Ayers, A.D., and R. B. Campbell. Freezing point of water in a soil as related to salt and moisture contents of the soil. Soil Sci. 72:201-205. 1951.

3. Bear, F. E. Cation and anion relationships in plants and their bearing on crop quality. Agron. Jour. 42: 176-178. 1950.

4. ______. Chemistry of the Soil. Reinhold Pub. Corp., New York. 373 pp. 1955.

5. Bigger, T. C., J. F. Davis, and K. Lawton. The behavior of applied phosphorus and potassium in organic soil as indicated by soil tests and the relationship between soil tests, green-tissue tests, and crop yields. Soil Sci. Soc. Amer. Proc. 17:279-283. 1953.

6. Bolle-Jones, E. W. The effect of varied nutrient levels on the concentration and distribution of manganese within the potato plant. Plant and Soil 6:45-60. 1955.

7. Bray, R. H., and S. R. Dickman. Adsorbed phosphates in soil and their relation to crop responses. Soil Sci. Soc. Amer. Proc. 6:32-320. 1941.

8. ______. Rapid tests for measuring and differentiating between the adsorbed and acid soluble forms of phosphate in soils. Ill. Agr. Expt. Sta. Agron. Dept. Pamphlet, Ag. 1028. 1942.

9. ______, and L. T. Kurtz. Determination of total, organic and available forms of phosphorus in soils. Soil Sci. 59:39-45. 1945.

10. Brown, R. J. An improved sodium acetate buffer method for the determination of plant available phosphate and its application to irrigated Rocky Mountain Soils. Soil Sci. Soc. Amer. Proc. 2:185-195. 1937.

11. Cook, R. L., and W. C. Hulburt. Applying fertilizers. Yearbook of Agriculture, U. S. Dept. Agr., Washington. 216-229. 1957.

12. ______, K. Lawton, L. S. Robertson, and C. M. Hansen. Phosphorus solubility, particle size and placement as related to the uptake of fertilizer phosphorus and crop yields. Commercial Fertilizer and Plant Food Industry, June, 1957.

13. Davis, J. F., W. C. Hulburt, C. M. Hansen, and L. N. Shepherd. The effect of fertilizer placement on the yield of onions and spinach grown on an organic soil. Mich. Agr. Expt. Sta. Quart. Bul. 39:25-35. 1956.

14. ______, and R. E. Lucas. Organic soils, their formation, distribution, utilization, and management. Mich. Agr. Expt. Sta. Spec. Bul. 425. 155 pp. 1959.

15. ______. Unpublished data. Mich. Agr. Expt. Sta., Soil Sci. Dept.

16. Dawson, J. E. Application of soil test methods to peat soils. Unpublished data. New York Agr. Expt. Sta., Soil Sci. Dept.

17. Dean, L. A., and E. J. Rubins. Anion exchange in soils: I. Exchangeable phosphorus and the anion-exchange capacity. Soil Sci. 63:377-387. 1947.

18. ______. Anion exchange in soils: III. Applicability to problems of soil fertility. Soil Sci. 63:399-406. 1947.

19. Dickman, S. R., and R. H. Bray. Colormetric determination of phosphate. Ind. and Eng. Chem. Anal. Ed. 12:665-668. 1940.

20. Doughty, J. L. Phosphate fixation in soils, particularly as influenced by organic matter. Soil Sci. 40:191-202. 1935.

21. Eid, M. T., C. A. Black, and O. Kempthorne. Importance of soil organic and inorganic phosphorus to plant growth at low and high soil temperatures. Soil Sci. 71:361-370. 1951.

22. Filman, C. C., et al. "A 5000-acre water garden?" Better Crops with plant food, XXXII, No. 4:15-18. 1948.

23. Fertilizer recommendations for Michigan crops. 10th rev. ed. Mich. Agr. Expt. Sta. Ext. Bul. 159. 47 pp. 1957.

24. Fiske, C. H., and V. Subbarow. The colormetric determination of phosphorus. Jour. Biol. Chem. 66:375-400. 1925.

25. Forsee, W. T., Jr. The place of soil and tissue testing in evaluating fertility levels under Everglades conditions. Soil Sci. Soc. Amer. Proc. 15:297-299. 1950.

26. _______, E. A. Wolf, and W. A. Hill. Soil fertility investigations under field and greenhouse conditions. Flor. Agr. Expt. Sta. Reports. State Project 86:180-183. 1950-1952.

27. Gammon, N., Jr. The role of major bases in Florida Soils. Flor. Agr. Expt. Sta. Project 598:131-132. 1956.

28. Haas, A. R. C. Influence of chlorine on plants. Soil Sci. 60:53-61. 1945.

29. Harmer, P. M., and E. J. Benne. Sodium as a crop nutrient. Soil Sci. 60:137-148. 1945.

30. _______, E. J. Benne, W. M. Laughlin, and C. Key. Factors affecting crop response to sodium applied as common salt on Michigan muck soil. Soil Sci. 76:1-17. 1953.

31. Hester, J. B. A study of the availability of phosphorus and potash and their influence upon vegetable crop production and fertilizer practices on coastal plain soils. Soil Sci. Soc. Amer. Proc. 1:233-242. 1936.

32. Joffe, J. S., and L. Kolodny. The distribution and fixation of potassium in the profile of brown podzolic soils and sandy podzols. Soil Sci. Soc. Amer. Proc. 2:239-241. 1938.

33. _______, and A. K. Levine. Fixation of potassium in relation to exchange capacities of soils: III. Factors contributing to the fixation process. Soil Sci. 63:241-247. 1947.

34. Jones, U. S. Availability of humate potassium. Soil Sci. Soc. Amer. Proc. 12:373-378. 1947.

35. Kelly, J. B., and A. R. Midgley. Phosphate fixation--an exchange of phosphate and hydroxyl ions. Soil Sci. 55: 167-175. 1943.

36. Krantz, B. A., W. L. Nelson, and L. F. Burkhart. Plant-tissue tests as a tool in agronomic research. Diagnostic Techniques for soils and crops. The Amer. Potash Inst., Washington, D. C. 308 pp. 1948.

37. Larsen, J. E., G. F. Warren, and R. Langston. Studies of phosphorus availability in organic soils. Soil Sci. Soc. Amer. Proc. 22:336-339. 1958.

38. _______, R. Langston, and G. F. Warren. Studies on the leaching of applied labeled phosphorus in organic soils. Soil Sci. Soc. Amer. Proc. 22:558-560. 1958.

39. _______, G. F. Warren, and R. Langston. Effect of iron, aluminum and humic acid on phosphorus fixation by organic soils. Soil Sci. Sco. Amer. Proc. 23:438-440. 1959.

40. Lawton, K., L. S. Robertson, R. L. Cook, and P. J. Rood. A study of the correlation between rapid soil tests and response of legume hay to phosphorus and potassium fertilization on some Michigan soils. Soil Sci. Soc. Amer. Proc. 12:353-358. 1947.

41. _______, L. S. Robertson, R. L. Cook, and P. J. Rood. Diagnostic techniques used in soil fertility studies. Mich. Agr. Expt. Sta. Quart. Bul. 34:466-471. 1952.

42. _______, C. Apostolakis, R. L. Cook, and W. L. Hill. Influence of particle size, water solubility and placement of fertilizers on the nutrient value of phosphorus in mixed fertilizers. Soil Sci. 82:465-476. 1956.

43. _______, and J. F. Davis. The effect of liming on the utilization of soil and fertilizer phosphorus by several crops grown on organic soils. Soil Sci. Soc. Amer. Proc. 20:522-526. 1956.

44. Lehr, J. J. Importance of sodium for plant nutrition. Soil Sci. 52:237-244. 1941.

45. Levine, A. K., and J. S. Joffe. Fixation of potassium in relation to exchange capacity of soils: V. Mechanism of fixation. Soil Sci. 63:407-415. 1947.

46. Magistad, D. C. Plant growth relations on saline and alkali soils. The Botanical Rev. 11:181-215. 1945.

47. McCool, M. M. Peat and muck soils. Fixation of fertilizers. Mich. Agr. Expt. Sta. Quart. Bul. 3:126-127. 1921.

48. Meyer, B. S., and D. B. Anderson. Plant Physiology. 2nd ed. D. Van Nostrand Co., Inc., New York. 784 pp. 1952.

49. Mortland, M. M., and J. E. Giesking. Anion sorption and exchange by amine-clay complexes. Soil Sci. 68:391-397. 1949.

50. Official and tentative methods of analysis, 7th ed. Assoc. Official Agr. Chem., Washington, D. C. 1950.

51. Paul, H. Phosphorus status of peat soils in British Guiana. Soil Sci. 77:87-93. 1954.

52. Peech, M., and L. English. Rapid microchemical soil tests. Soil Sci. 57:167-195. 1944.

53. Plant food your corn absorbs during different periods of growth. The Amer. Potash Inst., Inc., Washington, D. C. Folder D-59. 1959.

54. Potash News Letter. The Amer. Potash Inst. 1959.

55. Prince, A. L., M. Zimmerman, and F. E. Bear. The magnesia supplying power of 20 New Jersey soils. Soil Sci. 63:69-78. 1947.

56. Principles of growing corn. Cornell Recommends for field crops. N. Y. State College of Agr., 1960.

57. Richards, R. L. Diagnosis and improvement of saline and alkali soils. U. S. Dept. Agr., Washington. Handbook No. 60. 1954.

58. Robertson, W. K., P. M. Smith, A. J. Ohlrogge, and D. M. Kinch. Phosphorus utilization by corn as affected by placement and nitrogen and potassium fertilization. Soil Sci. 77:219-226. 1954.

59. Russel, E. W. Soil conditions and plant growth. 8th ed. Longmans, Green, and Co., Ltd., New York. 635 pp. 1950.

60. Scarseth, G. D., and J. W. Tidmore. The fixation of phosphates by clays. Jour. Amer. Soc. Agron. 26:152-162. 1934.

61. _______. Plant tissue testing in diagnosis of the nutritional status of growing plants. Soil Sci. 55: 113-120. 1943.

62. Shear, C. B., H. L. Crane, and A. T. Myers. Nutrient element balance: A fundamental concept in plant nutrition. Amer. Soc. Hort. Sci. 47:239-248. 1946.

63. Shepherd, L. N., J. C. Shickluna, and J. F. Davis. The sodium-potassium nutrition of sugar beets. Jour. of the A.S.S.B.T. X: 603-608. 1959.

64. Smith, F. W. A study of the availability of native and added phosphorus in several Michigan soils as measured by chemical analysis and plant growth response. PhD thesis, Michigan State University, 146 pp. 1949.

65. Spurway, C. H., and K. Lawton. Soil testing--a practical system of soil fertility diagnosis. Mich. Agr. Expt. Sta. Tech. Bul. 132 (revised). 39 pp. 1949.

66. Stewart, E. H., and N. J. Volk. Relation between potash in soils and that extracted by plants. Soil Sci. 61: 125-130. 1946.

67. Timm, H. Effect of potassium and sodium on the yield and chemical composition of sugar beets and table beets grown on four organic soils. M.S. thesis, Michigan State University, 42 pp. 1952.

68. Wallace, T. Trace elements in plant physiology. Botanica Co., Waltham, Mass. 141 pp. 1950.

69. Walsh, T., and E. J. Clark. A further study of chlorosis of tomatoes with particular reference to potassium-magnesium relationships. Proc. Roy. Irish Acad. 50(B) 245-263. 1945.

70. Willard, H. H., and L. H. Greathouse. The colormetric determination of manganese by oxidation with periodate. Jour. Amer. Chem. Soc. 12:141-142. 1917.

71. York, E. T., Jr. Influence of lime and potassium on yield and cation composition of plants. Soil Sci. 77: 53-63. 1954.

72. Younts, S. E., and R. B. Musgrave. Growth, maturity, and yield of corn as affected by chloride in potassium fertilization. Agron. Jour. 50:423-426. 1958.

73. _______. Chemical composition, nutrient uptake, and stalk rot incidence of corn as affected by chloride in potassium fertilizer. Agron. Jour. 50:426-430. 1958.