

1936

# Chemical investigations of the effect of fertilizer ratios and green manures on yields and composition of crops and the organic matter in Norfolk sand

James Edward Adams  
*Iowa State College*

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CHEMICAL INVESTIGATIONS OF THE EFFECT OF FERTILIZER  
RATIOS AND GREEN MANURES ON YIELDS AND COMPOSITION  
OF CROPS AND THE ORGANIC MATTER IN NORFOLK SAND

BY

James Edward Adams

A Thesis Submitted to the Graduate Faculty  
for the Degree of

DOCTOR OF PHILOSOPHY

Major Subject Soil Chemistry

**Approved:**

Signature was redacted for privacy.

**In charge of Major work:**

Signature was redacted for privacy.

**Head of Major Department**

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**Dean of Graduate College**

Iowa State College

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#### ACKNOWLEDGMENT

Acknowledgment is made to the Officials of the Bureau of Plant Industry who have kindly allowed these data to be presented as a thesis to Iowa State College; to Dr. J. J. Skinner, who formulated the basic outline of the work and has been officially responsible for it; to Drs. W. M. Quattlebaum Jr. and E. M. Roller, and Messrs. H. M. Boggs and A. B. Bowen who were associated in the work for variable lengths of time; to Messrs. A. S. Laird, R. B. Carr, and A. Carns, who, as representatives of the Office of Forage Crops and Diseases, have helped to conduct the plat work; and to the Officials of the South Carolina Experiment Station who have co-operated in many ways.

The kindly and sustained interest of Drs. Norman A. Clark and P. E. Brown has been a stimulation during the several years of endeavor represented by this thesis. Dr. Clark has extended a commendable professional courtesy in allowing these data to be presented in lieu of a problem which would have received his personal supervision; his criticism of this work has been very helpful, and is appreciated.

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## INTRODUCTION

The evaluation of soils in terms of their potential agricultural value has assumed considerable importance in recent years. Sandy soils vary greatly in fertility; their widespread occurrence in the United States, even in regions of fertile soils, stresses the necessity for information with regard to their agricultural capacity.

The coarser-textured sandy soils are usually of low fertility; many factors are frequently involved, and this statement is to be modified according to the derivation of the particular soil, the nature of the subsoil, natural drainage, and extrinsic factors. These soils are responsive to good management, but their low capacity to hold moisture limits their productiveness. It is generally conceded that the improvement of the organic matter supply helps to improve this condition, and to increase the nitrogen supply which is usually quite low. The need for additions of phosphate, lime and potash is variable.

Soils of similar texture and derivation have many properties and problems in common; variations of these are generally of degree rather than kind. This is exemplified by the soils of the sand-hill area of South Carolina which is a portion of the region extending from

south-central North Carolina into Alabama. It lies between the Coastal Plains and the Piedmont Regions, and marks the old shore of the Atlantic Ocean. The portion which lies in South Carolina comprises approximately ten per cent of the area of the state. The area, to a considerable extent, was covered originally with longleaf pine. Deforestation resulted in a very different cover so that at present there is a mixture of dwarf oak, sedge and other plants generally adapted to a soil of coarse and open texture, and of low available and potential fertility. The cultivated areas are used principally for the production of corn and cotton. In recent years small areas have been used for peaches, grapes, dewberries, and to a smaller extent, asparagus.

The soils of the sand-hill region are principally of the Norfolk and related series. A considerable variation in texture is to be found, ranging from coarse sand to sandy loams, with a like variation in fertility. The production of crops without the use of fertilizers is hazardous. These soils are responsive to good management and with the proper amount of rainfall, well distributed, will produce beyond expectation. The open texture militates against a high potential fertility. Practices which are instrumental in combating leaching, and those helping to improve moisture conditions, are of utmost

importance. The maintenance and the improvement of the quality of the organic matter would appear to be a logical approach to the problem. Although the need for all the more common plant-food elements is distinct, any system must be based upon the addition and conservation of nitrogen, the element lost in greatest quantities by leaching. The soil approximates the conditions of "sand cultures" with many of the factors of plant nutrition beyond control.

This investigation deals with the effect of fertilizer practices and crop management on the quantity and quality of the crops produced on Norfolk sand. The residues of the crops are used to determine their relative effects on the quantity and quality of the organic matter, and the pH of the soil.

A GREEN MANURE-FERTILIZER STUDY WITH A  
ROTATION OF LEGUMES, CORN AND COTTON

Organic matter is the component which differentiates soil from inert, disintegrated rock material. The functions of this material in microbial and plant life are many and varied. Although this work deals with a limited phase of the relations of organic matter to soil fertility, associated functions are briefly reviewed.

Literature Cited

The Symposia on Soil Deterioration (151), Soil Organic Matter (152) and Soil Organic Matter and Green Manuring (153), which were held during the years 1926, 1927, and 1929, respectively, have done much to focus attention upon the pertinent relations of organic matter to soils and crops. Its effects are both physical and chemical. Page (111) points out that the tendency to draw conclusions from inconclusive evidence has been greater in this than any other phase of soil work, as it leads one into the more difficult phases of organic and physical chemistry. In that work organic matter is discussed as existing in the soil in two forms: (a) "humus matter", or the dark-colored component of high molecular weight and colloidal in nature; and (b) "non-humic matter" which is made up of

colorless substances, mostly soluble, and the undecomposed, refractive portions of plant and microbial remains. This is a theoretical separation and not completely attainable in the laboratory. The humic portion is an acidoid belonging in the same category as clay acids. It is pointed out that up to the present time there is no definite evidence that any of the preparations made from this fraction can be classified as chemical individuals, even though it can be fractionated into groups with well-defined properties. The investigation of the non-humic fraction has been more fruitful, the "brilliant work" of Schreiner and co-workers being cited.

It is the gel-like humic matter which affects the physical properties of the soil. Page (110) concludes that one of the principal actions of the gel is to act as a buffer, using the term in its broadest sense, thus serving as a stabilizer; it thereby reduces markedly the variations in the responses of soils. Russell (120) states that as much as twenty per cent of organic matter will reduce other soil factors to a minimum. The presence of the gel also increases the water-holding capacity, improves the tilth, increases the pore space, and helps to regulate the availability of plant nutrients. Alway and Neller (8) compared plats of widely different organic matter content which

carried cultivated crops; they found that the water-holding capacity of only the upper layer of the soil was affected. This effect was noticeable in wet but not in dry seasons. There was little effect upon productivity. Baver (13) found that the plasticity and mechanical structure of soils are affected by this component, and that it constitutes a large portion of the exchange complex of the surfaces of soil. This latter fact is emphasized by McGeorge (96) who found a definite correlation between the organic matter and exchange values of soil. Brown and O'Neal (24) found that the color of dark-brown to black soils is associated with a relatively high carbon and nitrogen content. Lipman and Waynick (87) give in detail the effects of a change of climate upon some of these properties. The color may be darkened or lightened; the hygroscopic and moisture equivalents, which are associated with the water-holding capacity, may be changed; and the destruction of the non-humic fraction may be accelerated.

Keen (81) in summarizing the physical effects of organic matter states: "Direct study of the material apart from the soil, of which it forms an intimate part, is not possible at present, and its physical properties must be inferred from direct observations on the soil itself."

The chemical nature of the organic fraction of the soil has claimed the attention of investigators since the early

part of the nineteenth century. This early work was summarized in 1909 by Schreiner and Shorey (127) who pointed out the discordant results which had been obtained. They (128) isolated some twenty organic compounds which by their nature indicated a complex parent source. A very complete survey of the literature was made in 1926 by Waksman (161).

The equilibrium between the various factors affecting soil fertility is described by Schreiner (126) as being dynamic rather than static. This equilibrium under virgin-soil conditions tends toward the up-building of soil. The effect of cultivation is to establish a new equilibrium which is accompanied by the destruction of organic matter. Inasmuch as the organic matter is the source of energy for micro-organic life, and of nitrogen for plant growth, the conditions affecting its decomposition are of much importance. Soil organisms may compete with plants for available nitrogen as shown by Doryland (39); this is a normal process in the metabolism of the organism. The ratio of carbon to nitrogen in the plant material, the type of organism involved in the decomposition, and the reaction (pH), as well as the carbon-nitrogen ratio of the soil itself are factors which determine the nitrogen balance during and at the end of the decomposition.

Waksman (160) lists fungi, actinomycetes, bacteria and possibly protozoa as the organisms active in the decomposition of organic matter. In acid soils the action of the fungi predominates, while under alkaline conditions, that of bacteria. The energy requirement of the fungi is the greater. A plant material containing 2.5 to 3.0 per cent nitrogen, such as alfalfa, will be decomposed by fungi with the liberation of little or no free ammonia. With the same material under favorable conditions the metabolic needs of bacteria will be met and they will liberate considerable quantities of nitrogen as ammonia, this being subsequently oxidized to the nitrate form. A nitrogen content greater than that mentioned results in an increased liberation of ammonia, the amount being greater for the bacteria than for fungi. These conditions hold for soils in which the carbon-nitrogen ratio is comparatively narrow; i.e., 10:1 to 12:1. If the soil ratio is wide, the nitrogen liberated from materials containing a large percentage of nitrogen will be utilized to accompany the energy needs of the organism, with a depletion of the nitrogen which otherwise would be available to plants. Russell (120) states that nitrogen can appear in the nitrate form only when the ratio is 12:1. These statements apparently apply to the processes within the body of the organic matter, for if



organic material of a high-nitrogen content were intimately mixed with soil of a wide ratio no free nitrate would be found until the entire mass was reduced to the stated ratio. An intimate mixture of organic matter and soil is not attained in field practice.) Thom and Smith (156) found that the increased micro-biological activity due to turned and mulched materials was confined to the materials themselves, without greatly affecting or being affected by the surrounding soil. Thom and Humfeld (155) studied the decomposition of roots and found an increase in the numbers of organisms in the soil adjacent to the roots, but much larger numbers were present on the roots themselves. The root material resisted much change of the pH value. The total variation was from pH 6.0 to pH 7.5; in acid soil the root material was more alkaline than the soil, and in alkaline soil more acid. In view of this it would seem that it would be impractical to postulate exact conditions for the decomposition of organic materials. That the ratio of the organic matter in the soil may enter into the situation is indicated for some soils, but it would seem to be an influence depending upon the infiltration of the products of decomposition into the surrounding soil. Brown and Allison (23) called attention to the increased interest attached to the carbon-nitrogen ratio. They

considered a narrow ratio to be an indication of the lack of fresh organic matter, and a ratio of 12:1, or above, a more satisfactory condition for the production of soluble plant food.

Anderson and Byers (9) found a wide variation in the carbon-nitrogen ratios of the great soil groups, and also within most of the groups. The ratio decreased in general with the depth of the soil. The variation in the ratio indicated an essential difference in the composition of the organic matter of soils. A more constant ratio was found in the soils where it is narrow. Waksman and Hutchings (162) stress this point, showing that podsol soils are characterized by a high cellulose, a high hemicellulose, and a low protein content. The carbon-nitrogen ratio is wide; it varies from 41.7:1 for a heath podsol, to 22.5:1 for a Michigan podsol. A soil group with a ratio of 10:1 contains organic matter of high lignin and protein content. Leighty and Shorey (85) found a wide variation in the ratio in a study of one hundred and seventy-six samples of soil from twelve states; the range was from 3.5:1 to 35.1:1, with a limited number lying beyond the range of 7.1:1 to 15.1:1. They considered a ratio of 20:1 as conducive to micro-organic activity, while a 10:1 ratio represents an advanced stage of

decomposition.

Jenny (76) stated that in the Great Plains there seems to be a narrowing of the ratio with an increase in temperature, the amount of organic matter bearing an inverse relation to the temperature. The factors (77) which control soil formation, listed in order of decreasing importance, are: (1) climate, (2) vegetation, and (3) topography and materials. Dhar and Mukherji (58) found the ratio in a temperate climate to be lower than under tropical conditions; they concluded that the ratio is not entirely dependent upon microbial activity.

Fraps (48) found a variation in the ratio of Texas soils of 2 to 59; Issac (75) for South African soils, 11.2 to 22.9; Issac and Gershili (74) for semi-arid soils, 5.0 to 15.1; and McLean (99) for 50 British soils, 6.5 to 15.5, with a variation from 2 to 25 for foreign soils. The fallacy of attempting to calculate the percentage of carbon from the nitrogen content of the soil, as has been so frequently suggested, was pointed out by Leighty and Shorey, and Anderson and Byers.

Sievers and Holtz (137) give data to show that cropping reduces the ratio. Jordan (79), working with an irrigated soil, found that alfalfa grown for two years widened the ratio, but at the end of the experiment the ratio returned

to that of the virgin soil. There was a decrease in the carbon and nitrogen of the soil during the first period, and an increase at the end of the experiment. Calculations of the ratio from data given by: (a) Mooers (104) show a slight widening during twenty years with a rotation management; and (b) from those of Shutt (136), very little change in cases where there were gains in carbon and nitrogen, or losses, under prairie conditions. Under irrigation, the data of Shutt show that more appreciable changes in the ratio take place; there were cases of a widening of the ratio as well as a narrowing. From observations of Oveson and Powers (109) cases of both increases and decreases occur, but the changes are comparatively small under a wide variety of treatments. The data of Powers and Lewis (118), who obtained marked increases in carbon and nitrogen under irrigated conditions, show no variation. Data by Snider <sup>1/</sup>, supplementing those given in (143), show that lime has had more effect than various fertilizer treatments in a sixteen-year test. Moderate quantities of lime show a slight but consistent decrease in the ratio,

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<sup>1/</sup> Data, supplementing that given in the literature cited, were kindly furnished by Dr. H. J. Snider, Assistant Chief, Soil Experiment Fields, Illinois Agricultural Experiment Station. Soil analyses for November, 1932, and for 1916, allow a sixteen-year study to be quoted.

while heavier applications have produced a slight, but equally consistent increase in the ratio. There have been decreases in both carbon and nitrogen during the sixteen years.

Salter (122), using a soil with a ratio of 13.3:1, studied the changes in materials of varying carbon-nitrogen ratios. Those with ratios wider than 10:1 caused losses of organic matter from the soil, but with ratios less than 10:1 there was a conservation of carbon. There was a rapid convergence, even though the original ratios varied from 15:1 to 5:1, so that the value of approximately all the ratios at the end of one month approached 10:1. A ratio of 1:1 for material at the beginning of the experiment was changed to 6:1 in twelve months. A wide ratio in the original material decreased nitrate-nitrogen, while a narrow ratio favored nitrate formation. Jensen (78), using wheat straw, leguminous materials, manure, and fungus mycelium, with ratios varying from 84.1 to 10.2:1, found that a ratio above 25.9:1 limited nitrate formation. The conclusion was reached that the carbon-nitrogen ratio exerted as profound an influence as the pH of the medium. The effect of materials of varying carbon-nitrogen ratios on nitrate formation has been investigated by Blair and Prince (17, 19), Hutchings and Martin (71), Jensen (78), McKinley (98),

Conrad (32), Murray (105), Starkey (145), Sturgis (150), and others. The general conclusion is that the nitrate-nitrogen content is depressed by a wide carbon-nitrogen ratio. Collison and Conn (30) attributed a part of the effect of straw to the presence of toxic substances. Brown and Allison (23) consider that there is little influence exerted by the ratio on nitrification. It was found that nitrification of legumes was greater than that of manures, but the rate of ammonification was less. Hutchings and Martin (71) accelerated the decomposition of wide-ratio materials by the addition of available nitrogen, which is in accord with the work of Starkey (145), Sturgis (150), and others. Bell (15), using Norfolk sand, found that manure and cowpeas produced accumulations of nitrates. Some legumes and Natal grass depressed nitrates for varying periods of time.

A soil may be well supplied with nitrogen, and of a fairly low ratio, and still the nitrogen will be comparatively unavailable as reported by Bizzell (16). The average ratio  $\frac{1}{/}$  for this Volusia soil is 10.3:1. McKibbin (97) has reported carbon and nitrogen data for

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$\frac{1}{/}$  The ratio varies from 8.8 to 12.1:1. This information was furnished through correspondence with Dr. J. A. Bizzell.

three long-cultivated, upland-podsol soils of Quebec which were considered the least fertile of the soils reported. Calculations of the ratio from the data presented give values of 13.5 for two soils, and 15.3 for the third. Nitrate-nitrogen during the growing season is reported as usually inadequate. Further calculations give ratios as follows: (1) for relatively fertile soils, 15.8; (2) for the "brown earths of intermediate fertility", 12.7; (3) for upland podsols, 17.8, and (4) for lowland podsols, 21.9:1; the last was considered the least fertile. These data would indicate that a soil may be infertile when associated with either a medium or wide ratio, and also when the total supply of nitrogen is abundant.

Potter and Benton (116) show that materials of a wide ratio applied to soils produce an organic residue lower in nitrogen than that from legumes or manure. Comparatively large amounts of phosphorus may be present in the organic form; soil organic matter from legumes is higher in phosphorus content than that from non-legumes.

Data are available regarding the effect of cropping upon the organic matter content of the soil, in addition to the citations made. DeTurk (37) states that the acceleration of the oxidative processes of the soil, with the consequent decline in organic matter, is one of the

important effects of bringing the soil under the plow. Also, it is that portion of the organic matter undergoing decomposition, rather than the residuum, which affects crop yields; this is a restatement of the dynamic conception. A fair correlation was obtained between organic carbon and crop yields. Salter and Green (123) found that organic carbon and organic nitrogen were highly and positively correlated with total crop production. Crops vary considerably in their effects upon soil organic matter; corn is least effective for conservation while hay is very effective. Carr (26) found a close correlation between the humus content of soil and the growth of corn.

That the nitrogen of organic materials can be utilized by plants has been shown by Schreiner and Skinner (130), and by Hutchinson and Miller (72).

It has been indicated that both pH and the carbon-nitrogen ratio influence markedly the decomposition processes in soil. Starkey (146), after an exhaustive search of the literature, states that the growth of higher plants affects the soil population, and that marked increases in the numbers of certain organisms frequently occur. Aberson et al. (1) state that the acidity of sands is due to humic acid and that this has great influence upon the development of lower organisms. Conner (31) attributes the acidity of



humid soils to the leaching of bases and their removal by crops, and to the decay of the organic matter and hydrolysis of minerals. Hester (64) shows that more organic matter is leached from Norfolk sand as the pH changes from 5.5 to 7.0.

Hill (67) in 1919 found an initial increase in acidity when rye was turned under but recovery was rapid. Soybeans, buckwheat and red clover developed no marked acidity in a five-year test. It was concluded that the use of green manures tends toward an alkaline rather than an acid condition. Potter and Snyder (117) list green manures and manure as conservers of lime. Sackett et al. (121) show that both leguminous and non-leguminous materials lowered the pH of a soil well supplied with calcium carbonate. Stephenson (147) used a wide variety of organic materials and concluded that they decreased the acidity. White (166) reports a temporary decrease in acidity, due to the turning of manure, and air-dry and fresh leguminous and non-leguminous material, which was followed by an increase. It is generally conceded that the air-drying of material delays decomposition. White et al. (168) found a close correlation between reaction, respiratory capacity, and the decomposition of organic matter. Apparently the results to be obtained depend upon the conditions under which a study

is conducted.

Bottomley (20, 21), working with extracts of peat and the by-products of nitrogen-fixing organisms, obtained increased growth of Lemna major and other water plants. This work introduced the conception of plant accessories, called "auximones", thought to be analogous to vitamins in animal nutrition, but Clark and Koller (27) obtained satisfactory growth of the same plant in mineral nutrients comparable to that in solutions containing soil.

Lemna has been grown under sterile conditions (28) in a purely inorganic medium. Under these conditions the use of a manure extract and other organic materials either had no effect or even, in some cases, suppressed growth. The use of manure extract under non-sterile conditions results in a stimulated rate of reproduction. It is amply demonstrated that "auximones" are not essential to growth and reproduction.

It is not considered that toxicity due to organic compounds is a factor in Norfolk sand. The conditions to be observed for the prevention and elimination of toxic materials, as outlined by Schreiner (125), are either inherent or easily attained in this soil.

The soils of the sand-hill areas contain charcoal due to the prevalent practice of "burning over" during the

spring season. Heyward and Barnette (65) and Greene (57) have found this practice to be beneficial under more heavily forested conditions. The former studied protected and burned areas in eighteen widely scattered sections of the southeast, two of which were in the Coastal Plains of South Carolina. The changed cover caused an increase in the nitrogen content of the soil as great as fifteen per cent. The burning increased directly the exchangeable calcium as much as one hundred and one per cent, and decreased the acidity. Greene found a sixty per cent increase in organic matter and a fifty per cent increase in nitrogen, following eight years of burning. The amount of forage produced was doubled. Charcoal in these soils contributes to the wide carbon-nitrogen ratio and must be taken into consideration when absolute quantities of carbon are discussed. However, changes in the carbon content of the soil, induced by management and other factors, should give reliable information.

Another factor which contributes to the wide ratio of sand-hill soils is the type of vegetation which predominates following deforestation. The cover is essentially low in nitrogen. The rapid leaching of the nitrogen as soon as it is made available has resulted in an equilibrium that is quite stable. Nitrogen added in the form of

leguminous materials, manures, or as inorganic fertilizers is probably used to a great extent in the destruction of this reserve of low-nitrogen material; i.e., hemicellulose and cellulose, as shown by Waksman and Hutchings (162).

Williams et al. (169) rate the lighter Norfolk soils of the lower Piedmont and upper Coastal Plains with a value of 1 to 7, the best soils of North Carolina having a value of ten. The particular value assigned depends upon the crop to be grown and the fertilizer used. It is thought that the factors influencing the fertility of the Norfolk soils of the sand-hill area differ in degree rather than in nature from those of the Coastal Plains. Skinner (138) has found that cotton grown on Norfolk fine sandy loam responds best to a fertilizer of a 5:8:2 ratio, while on Norfolk sandy loam the ratio averaged 6 to 7 per cent nitrogen; 6-8 of  $P_2O_5$ ; and 1 to 3 per cent of  $K_2O$ . Relatively greater amounts of nitrogen increased the yields of corn. Eighteen to thirty pounds of nitrogen (139) in addition to the basic application is recommended for the lighter sandy soils. The source of nitrogen used in the fertilizer affects the yields of cotton. Skinner and Buie (140) obtained best results with a fertilizer having two-thirds of the nitrogen derived from nitrate of soda, and one-third from sulphate of ammonia. This was superior to

having one-half derived from an organic source. On the sand-hill phase of Norfolk fine sand, Skinner and Williams, et al. (142) have found that marked increases in yields of early cotton were obtained from fertilizers which contained organic nitrogen, and it appeared that the lighter soils should receive nitrogen in the slowly available form.

The use of a continuous cover in a pecan grove by Skinner and Demaree (141) increased the organic matter content of Norfolk soils very appreciably in spite of the many factors working toward a decrease. Stokes et al. (149) compared the relative efficiencies of crotonaria, velvet beans and cowpeas as measured by citrus growth. Crotonaria was the only green manure which increased the nitrogen content of the soil; it also produced the greatest growth response on Norfolk medium fine sand.

Pieters and McKee (115) suggested that under some conditions a smaller quantity of organic matter may be equally as beneficial as a larger amount, depending upon the capacity of the following crop to utilize the nitrogen.

Funchess, in 1935, (52) states that although the highest recorded yields of corn are those of the South: "It is probably true that the relatively low yields of all farm crops in the South are due more to a deficiency of available plant nutrients than to any single factor"; and

further: "The deficiency of nitrogen is greater from a relative stand point". As cited from the field tests, the value of nitrogen, both in mineral form and from legumes, is striking.

A program for the improvement of the Norfolk sand would seem to be concerned principally with factors controlling the increase in the quantity and quality of organic matter. This would appear to be the proper approach toward improved moisture conditions, and a more labile nitrogen content. There are indications that organic materials serve as an efficient source of nitrogen. The increasing cost of organic nitrogen when derived from either concentrates or plant residues, however, makes desirable a study, under a rational cropping and fertilizer system, of the extent to which organic materials can be replaced by mineral sources of nitrogen.

#### Experimental

The area of Norfolk sand used was cleared in 1919 <sup>1/</sup>. It was cropped to corn during the years 1920, 1921, and 1927, the last season mentioned being the first year it was under the supervision of the state of South Carolina.

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<sup>1/</sup> History of area furnished by Mr. J. A. Riley, Superintendent, Sandhill Experiment Station, Columbia, S. C.

Cotton was grown from 1922 to 1926, inclusive. The corn was fertilized with four hundred pounds of a 4-8-4 fertilizer, and side-dressed with one hundred pounds of nitrate of soda per acre. The cotton received eight hundred pounds of fertilizer of the same formula, and the same amount of nitrate of soda as for the corn.

Twenty-four plats (1/20 acre), as shown in Figure 1, have been used in a rotation of legumes, corn and cotton. The diagram shows the relative positions of the plats at the beginning of the rotation in 1929, and again in 1932 at the beginning of the second round. The plats are arranged in six tiers of four each, the tiers being paired, as they have the same crop on the same section of each of the two tiers, during any one year. The tiers are lettered from A to F, inclusive. Series 1 receives soybeans as the legume crop; Series 2, velvet beans; Series 3, cowpeas; and Series 4, cowpeas which are followed by a winter cover of rye and vetch. The four plats of each series remaining after the legumes are planted are given over to corn and cotton. The twenty-four plats are replicated once.

In 1928, the entire area was cropped to legumes; i. e., Series 1 to soybeans; Series 2 to velvet beans; and Series 3 and 4 to cowpeas, the fertilizer treatments being as indicated. The full crop was turned as a green manure on

Figure 1. Plat diagram of green manure-fertilizer experiment.

F 400# 2-8-4	Soybeans	Velvet Beans	Cowpeas	Cowpeas Rye - Vetch	↑
E 400# 6-8-4	Soybeans	Velvet Beans	Cowpeas	Cowpeas Rye-Vetch	↑
D 400# 2-8-4		Stubble Turned			↑
C 400# 6-8-4		Green Manure Tier			↑
B 800# 2-8-4		Stubble Tier			↑
A 800# 6-8-4		Green Manure Tier			↑
N-P <sub>2</sub> O <sub>5</sub> -K <sub>2</sub> O	1	2	3	4	5 to 8
		Series			



Tiers A, B, E and F, while the stubble was turned on C and D.

In 1929, the first year of the experiment, the legumes grown with the 6-8-4 fertilizer on Tier E were harvested and the stubble turned, while on Tier F the legumes grown with the 2-8-4 were turned as a green manure. Tiers A and B, Series 1 to 4, were cropped to cotton using a 6-8-4 and a 2-8-4 fertilizer, respectively. In like manner Tiers C and D were cropped to corn. With reference to the plat diagram, the rotational direction is from A-B toward E-F and E-F to A-B.

The year 1934 marked the end of the second round of the rotation.

#### Methods

Soil samples were taken in May, 1928, March, 1929, and semi-annually thereafter. Twelve "cores" per plat were taken with a garden trowel and composited. The portion taken from the composite was air-dried, passed through a sieve with 2 mm. openings, and ground in a ball mill to pass an 80-mesh sieve. These ground samples were used in the determination of total carbon and nitrogen. The total carbon was determined by the wet

oxidation method of Adams (2) <sup>1/</sup>, and the nitrogen by the Gunning-Hibbard Method as given in the Official Methods of the Association of Official Agricultural Chemists. The pH values were determined according to the hydrogen-electrode procedure of Synder (144) using the modified Gillespie electrode vessel.

#### Yields Data

Figures 2, 3 and 4 show the growth of soybeans, corn and cotton in 1932. The plats on the left received the 6-8-4 fertilizer, and those on the right the 2-8-4 fertilizer. The row in the center is an unfertilized buffer row.

The average yields for all crops for the first round (1929-1931), the second round (1932-1934) of the rotation, and for the six years are given in Table 1. The average yields for corn and cotton, the indicator crops, are portrayed graphically in Figure 5. The 6-8-4 and stable system has produced yields of all crops greater than those of the 2-8-4 and green manure. The most outstanding increases are those of seed cotton,

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<sup>1/</sup> Dr. W. M. Quattlebaum Jr. should receive equal credit for this method, but due to a ruling of the Company with which he was employed at the time of publication it was thought best to give credit in the manner used.

Table 1. Average yields of crops grown on legume-stubble plate, with 6-8-4 fertilizer, and on green-manure plots with 2-8-4 fertilizer, on Norfolk sand: 1929-1931; 1932-1934; 1929-1934.

Summer Crop and Winter Management	Stubble Turned Plus 6-8-4			Green Manure Turned Plus 2-8-4*		
	Green Hay Tons Per Acre	Corn Bushels Per Acre	Seed Cotton Pounds Per Acre	Green Hay Tons Per Acre	Corn Bushels Per Acre	Seed Cotton Pounds Per Acre
<b>Soybeans:</b>						
<b>Fallow:</b>						
Av. 1929-31	2.15	10.77	437	1.64	8.71	290
Av. 1932-34	2.04	11.61	688	1.53	8.63	375
Av. 1929-34	2.10	11.14	562	1.59	8.77	333
<b>Velvet beans:</b>						
<b>fallow:</b>						
Av. 1929-31	3.68	9.49	368	2.66	8.17	227
Av. 1932-34	3.22	10.72	567	2.40	8.46	306
Av. 1929-34	3.45	10.11	462	2.53	8.32	267
<b>Cowpeas:</b>						
<b>fallow:</b>						
Av. 1929-31	2.09	10.15	370	1.63	7.10	221
Av. 1932-34	2.49	10.94	627	2.20	8.94	322
Av. 1929-34	2.29	10.55	499	1.92	8.02	272
<b>Cowpeas, rye and vetch:</b>						
Av. 1929-31	2.45	11.53	564	1.98	9.22	371
Av. 1932-34	3.06	15.12	915	2.67	11.05	472
Av. 1929-34	2.76	13.53	740	2.33	10.14	422

\* Legumes and corn received 400 pounds per acre; cotton, 800 pounds.

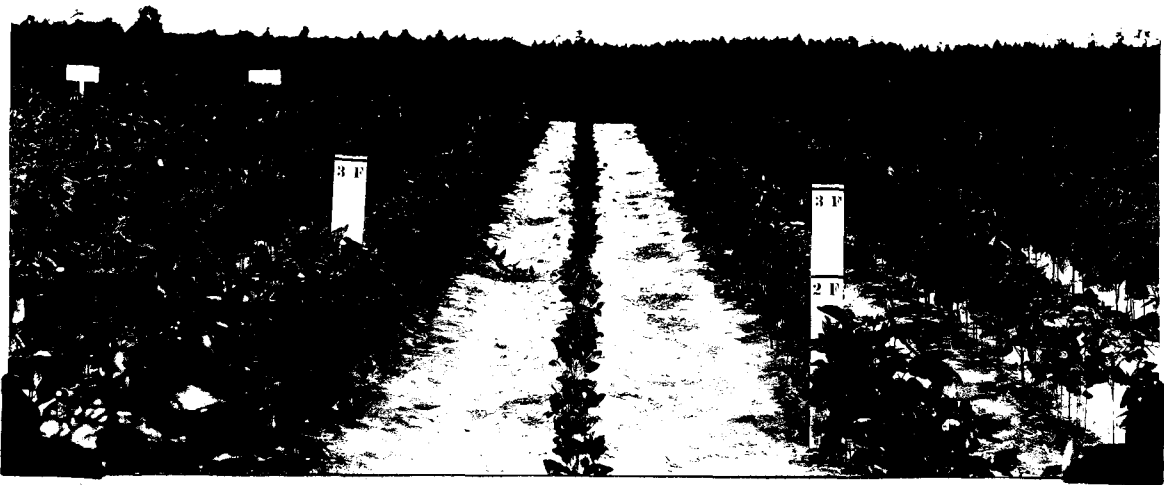


Figure 2. Soybeans on the left grown on stubble plat with 6:8:4 fertilizer; the right, on the green manure plat with 2:8:4 fertilizer. Buffer row in center received no fertilizer treatment.



Figure 3. Corn on the left grown on stubble plus 6:8:4 plat, following cowpeas, rye and vetch. The right is the green manure plus 2:8:4 plat, with the same winter cover crop. An unfertilized buffer row is in the center.



Figure 4. Cotton on the left grown following corn shown in Figure 3. The left is the stubble plus 6:8:4 series of plots, while the right is the green manure plus 2:8:4 series. An unfertilized buffer row is in the center.

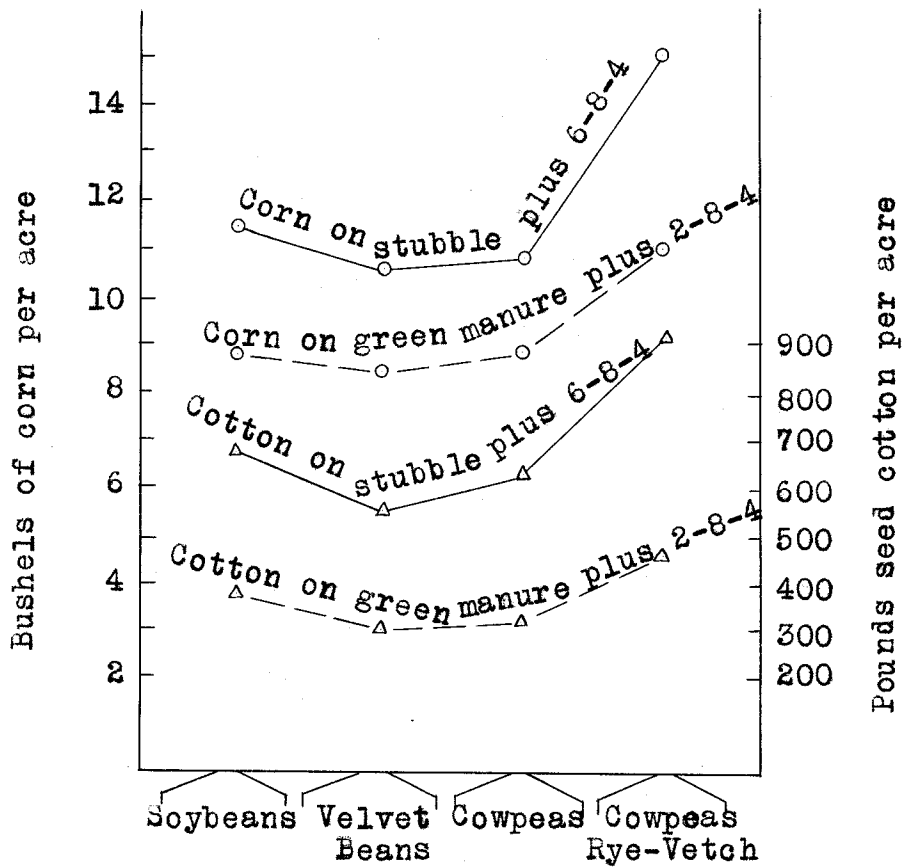


Figure 5. Average yields (1929-1934) of corn and cotton grown on legumes stubble and supplemented with a 6-8-4 fertilizer, as compared with those following legumes are turned as green manures and receiving a 2:8:4 ratio as a supplement.

which are, following: (1) soybeans, 230 pounds; (2) velvet beans, 201 pounds; (3) cowpeas (fallow), 227 pounds; and (4) cowpeas, rye and vetch, 318 pounds per acre per year.

The increases in yields of corn assume more significance, however, when one considers that the corn received only a four hundred-pound application of fertilizer as compared with the eight hundred-pound application made to the cotton. No nitrogen was applied to the side of either crop as is customary in general practice.

The cash value of the crops produced under the 6-8-4 system are appreciably greater than those of the 2-8-4. This is due not only to the increased yields of corn and cotton, but also the hay which is handled as a cash crop. This source of revenue, or of forage, is of importance in farm management. Using a uniform cash-basis for the materials used and for the crops produced, the following increased values, per acre per year, are obtained, following: (1) soybeans, \$5.61; (2) velvet beans, \$7.29; (3) cowpeas, \$5.60; (4) cowpeas, rye and vetch, \$7.82. The comparatively high value of velvet beans in the rotation is due to the yields of hay rather than to unusual increases in the yields of corn and cotton. The use of a winter cover following cowpeas has, however,



slightly more than equalled that value due to increased yields of corn and cotton.

An additional value should be attached to the use of the winter cover as it has been outstanding in the conservation of organic nitrogen, as will be shown.

The pH of all plats decreased from 5.5 to 4.8 during the first round of the rotation, the values given being approximate. An application of hydrated lime to overcome the increased acidity was made at the rate of three hundred pounds per acre each spring of the second round to the two tiers of plats on which the legumes were to be grown. This allowed the full effect of the lime to be exerted upon the legumes rather than upon the corn and cotton. The lime changed the pH from 4.8 to 5.8, approximately. The yield data, therefore, reflect the effect of lime for three years on the legumes; corn, two years; and on cotton, one year only.

The average yields of soybeans and velvet beans decreased during the second round of the rotation. Those of cowpeas, for both winter fallow and winter cover, were increased. Apparently the cowpeas were benefited by the use of hydrated lime, while soybeans and velvet beans were not. It is possible that seasonal effects play a part here, as well as for all comparisons of

yields of the second and first rounds. Corn yields show slight but consistent increases during the second round, for both systems of management, and those of cotton are appreciably greater. The average increase of seed cotton for the second round is 263 pounds per acre for the 6-8-4 and stubble series, and 84 pounds for the 2-8-4 and green manure. It is doubtful if lime influenced the yields of corn and cotton. The largest increases, as well as total yields, were obtained from the cowpea-stubble, rye and vetch plat.

#### Carbon and Nitrogen Data

The presence of charcoal in these soils has already <sup>p. 22</sup> been discussed. The type of vegetation and the coarse texture of the soil, which allows excessive leaching, give rise to organic matter of a wide ratio and low in amount. The soil is analogous to "sand cultures" to which material of a wide carbon-nitrogen ratio has been added. The management supplying the greatest quantity of nitrogen available to the indicator crops should be indicated by increased yields. The data indicate that the extra four per cent of nitrogen in the fertilizer used with the stubble management supplies the greater quantity of available nitrogen.

The carbon and nitrogen data are given in Table 2.

Table 2. Carbon and nitrogen relationships of Norfolk sand, with legume stubble turned and crops grown with a 6-8-4 fertilizer, as compared with legumes turned as green manures and crops grown with a 2-8-4 fertilizer, in a rotation of legumes, corn, and cotton.

Summer Crop and Winter Management	Stubble Turned Plus 6-8-4 fertilizer					
	Total C		Total N		C/N	
	1928	1934	1928	1934	1928	1934
	%	%	%	%		
Soybeans; fallow	0.54	0.40	0.020	0.018	27.0	22.2
Velvet beans; fallow	0.48	0.38	0.020	0.018	24.0	21.1
Cowpeas; fallow	0.52	0.38	0.020	0.019	26.0	20.0
Cowpeas, rye and vetch	0.54	0.43	0.019	0.020	26.8	21.5

Summer Crop and Winter Management	Green Manures Turned Plus 2-8-4 Fertilizer					
	Total C		Total N		C/N	
	1928	1934	1928	1934	1928	1934
	%	%	%	%		
Soybeans; fallow	0.51	0.36	0.020	0.017	25.5	21.2
Velvet beans; fallow	0.50	0.38	0.020	0.018	25.0	21.1
Cowpeas; fallow	0.51	0.38	0.020	0.017	25.5	22.3
Cowpeas, rye and vetch	0.50	0.42	0.019	0.020	26.3	22.1

Leighty and Shorey (85), Anderson and Byers (9), and McLean (99) have shown that the variable carbon-nitrogen ratio of soils makes unreliable the use of a factor to convert organic carbon to organic matter. For this reason, and due to the presence of charcoal in the soil, the term carbon is used except where the term organic matter is applied in the broadest sense.

In the six years of the experiment a very appreciable loss of carbon has occurred on each of the forty-eight plats irrespective of treatments and management; consequently the averages show only losses. These losses represent from sixteen to twenty-seven per cent of the total carbon present at the beginning of the experiment. The use of rye and vetch has resulted in a smaller loss under both systems of management. There are losses of nitrogen on all plats which were left fallow during the winter season; these were slightly greater where the crops were turned as green manures. Cowpeas followed by a winter cover show a slight gain in nitrogen, the gain being the same for the two systems of management.

When winter fallow is practiced, the stubble and 6-8-4 system is slightly superior to the green manure system in regard to the conservation of organic carbon and nitrogen. The two systems are of equal value when a winter

cover is used.

There has been a considerable decrease in the carbon-nitrogen ratio for each of the 48 plats. Figure 6 depicts the change in the ratio obtained as an average of all plats (24) on which the 6-8-4 and stubble management was used, as compared with the 2-8-4 and green manure plats (24), irrespective of the crops grown. The data give a direct comparison of the effect of each of the systems upon the ratio for the years 1928 to 1934, and show that there is no appreciable difference due to management. It is thought that the increased yields of corn and cotton during the second round of the rotation are associated, in a general way, with the decreased ratios. The reduction in ratio should result in a greater supply of nitrogen available for plant growth. The rate at which the ratio is decreasing indicates that some years will probably elapse before an optimum ratio will be established.

Appreciable decreases in the ratio have been effected in lysimeter tanks where manure has been used with a summer crop of pearl millet and a mixed winter cover of rye, barley and vetch. The crops have been clipped to simulate grazing conditions and have received moderate applications of commercial fertilizers. This combined

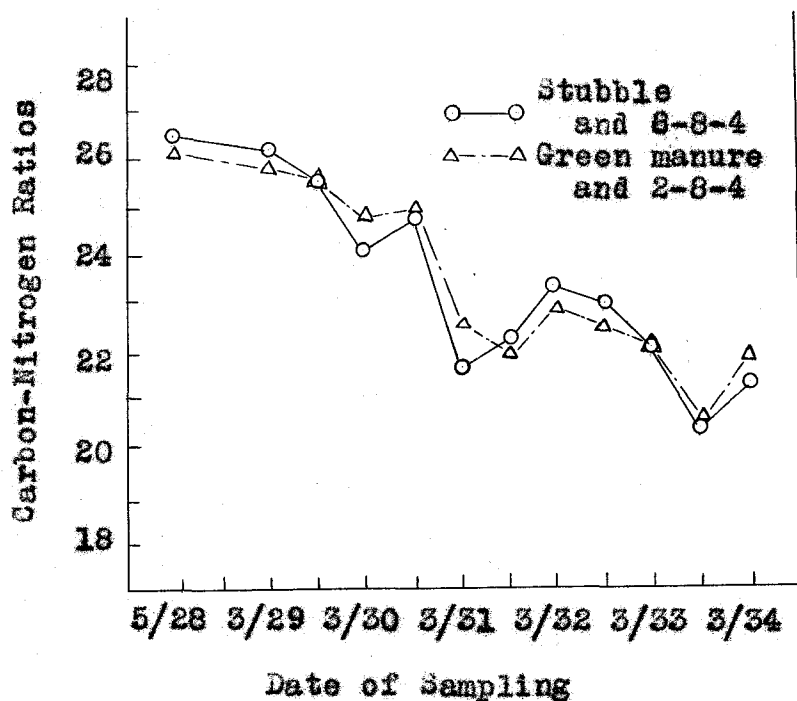


Figure 6. Change in carbon-nitrogen ratios for average of all plats of the 6-8-4 and stubble series vs. 2-8-4 and green manuring series, for original samples of May, 1928, to samples of March, 1934. Intermediate dates represent samples taken during October of the preceding year indicated.

treatment has resulted in an increase in the carbon and nitrogen of the soil which has been accompanied by a decrease in the ratio of the two. Although the amount of total nitrogen added has been beyond that encountered in ordinary fertilizer practice, there still exists a decided tendency toward nitrogen starvation, especially with the summer crop. It is interesting to note that a reduction in the ratio can be accomplished at the same time the organic matter content of the soil is increased. If the same ratio can be established at two different levels of organic matter content then the true effects of the organic matter on soil problems may be obtained.

#### Nitrate-Nitrogen Data

Determinations of the nitrate-nitrogen for the plots throughout the summer season of each year, for which tables are not given, showed a low average content. Figure 7 depicts the average nitrate-nitrogen content during 1933 for the 6-8-4 and the 2-8-4 combinations; these have been calculated in the same way as the carbon-nitrogen ratios. The 1933 season was chosen because leaching was not pronounced. Experience during other seasons has shown that the differences exhibited are minimized greatly when excessive rainfall occurs. The generally increased supply of available nitrogen due to

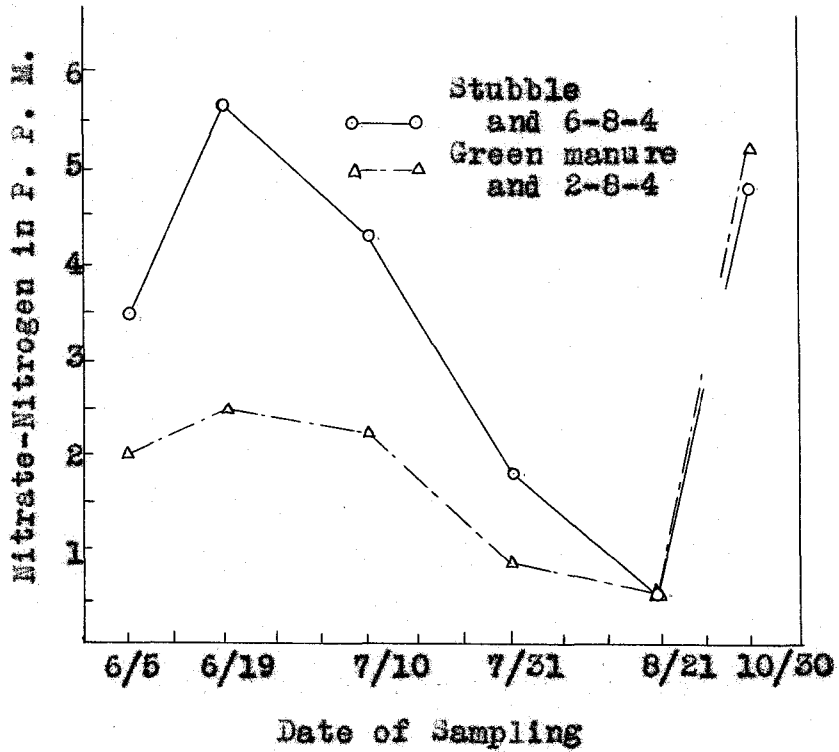


Figure 7. Nitrate-nitrogen in soil of 6-8-4 and stubble plots vs. 2-8-4 and green manure plots during 1933. Last half of fertilizer applied June 15. Stubble and green manures turned August 18.



the use of the 6-8-4 fertilizer has produced larger average yields of all crops.

#### Residual Carbon and Yields

Salter and Green (123), and White (167), have found that the yields of crops are correlated with the organic matter content of the soil. Figure 8 presents the relations between the carbon content of the plats at the end of the second round of the rotation and the average yields of corn and cotton for the particular plat. Each plat is treated separately. Tabular data are not given. The relations are masked by the influence of the nitrogen of the fertilizer, but there is a loose correlation between yields and carbon content; it is somewhat better for the green manure and 2-8-4 system than for the stubble and 6-8-4.

#### Conclusions

A comparison has been made of legumes stubble with the full crops turned as green manures when used in a rotation with corn and cotton. Crops grown on stubble plats received a fertilizer of a 6:8:4 ratio, while those grown on the green manure plats received a 2:8:4 fertilizer. From data obtained on the Norfolk sand, under the conditions of the experiment, the following conclusions are drawn:

- (1) A 6:8:4 fertilizer applied to crops, with the

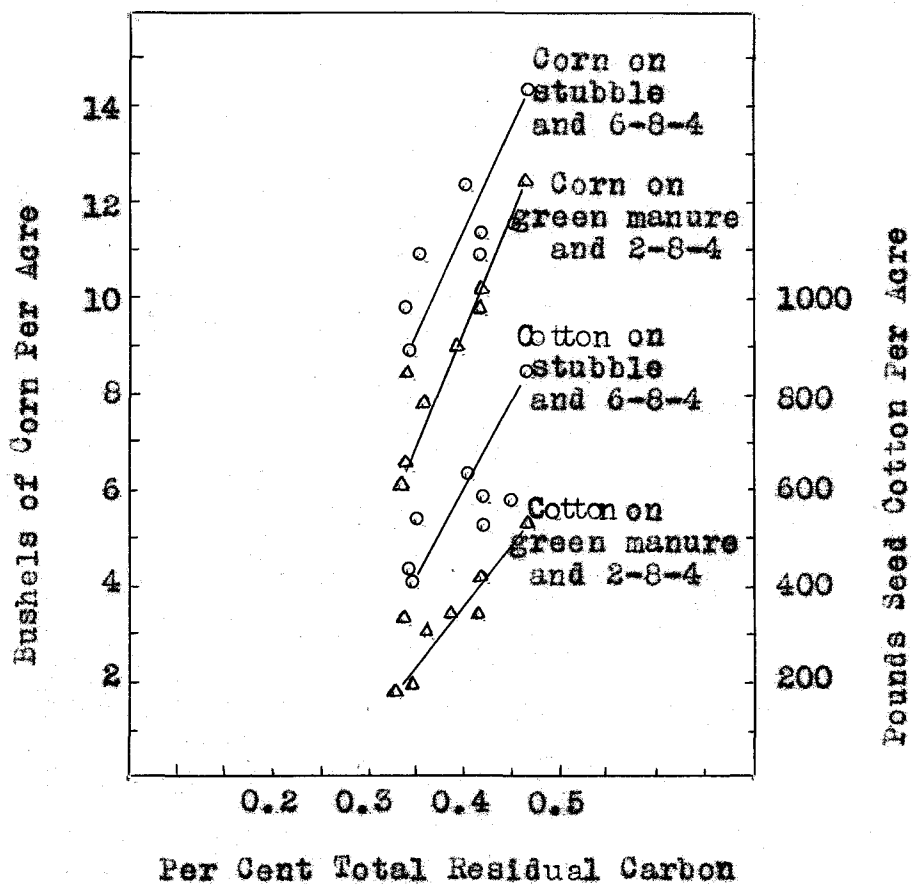


Figure 8. Relation of yields of corn and cotton, to residual total carbon content of plots, when grown on legume stubble and supplemented with 6-8-4 fertilizer, as compared with legumes turned as green manure and fertilized with 2-8-4.

stubble of soybeans, velvet beans, and cowpeas turned, produced larger yields than a 2:8:4 fertilizer supplementing the same crops used as green manures, all plats being left fallow during the winter.

(2) The use of a winter cover of rye and vetch, following either cowpea stubble or cowpeas turned, has increased the yields of the succeeding crops; i.e., corn and cotton. The yields are appreciably greater than following winter fallow. The cowpea stubble-winter cover-6:8:4 combination has produced the highest average yields of all crops.

(3) The use of the stubble and 6:8:4 combination results in a slightly greater conservation of carbon and nitrogen than does the green manure and 2-8-4. The two systems are practically of equal efficiency where a winter cover follows both cowpea-stubble and cowpeas turned as a green manure.

(4) Yields of corn and cotton are but loosely associated with the carbon content of the soil at the end of the second round of the rotation. This correlation becomes less apparent when increased quantities of nitrogen are applied in the form of commercial fertilizer.

(5) There has been a considerable reduction in the

carbon-nitrogen ratio of the soil. This is thought to be associated with an increase in the availability of the nitrogen present.

(6) Yields are influenced more by the nitrogen of the fertilizer than by the management of the legumes.

(7) A winter cover of rye and vetch plays an important part in obtaining the greatest effect from legume residues.

When winter fallow is used, the 6:8:4-stubble system is superior to the 2:8:4-green manure system in the following respects: (a) greater yields of legumes, corn, and cotton are produced, and (b) a slightly better conservation of carbon and nitrogen is attained. The systems are essentially of equal value when a winter cover crop of rye and vetch follows the legume residues. The winter cover apparently is of greater value in the conservation of organic matter than is the summer legume. Both systems have effected a marked reduction in the carbon-nitrogen ratio of the Norfolk sand. A larger cash return accompanies the use of the 6:8:4-stubble system.

THE EFFECT OF FERTILIZER RATIOS ON THE  
YIELD AND COMPOSITION OF SOYBEAN HAY

The data which have been presented indicate that a system of fertilization and crop management can be employed for the Norfolk sand which allows the use of the summer legume as a forage crop rather than as a green manure. This system apparently increases the capacity of this soil for crop production. It is desirable that the forage which is made available be of good quality. It is reasonable to assume that fertilizers will affect the composition of the plant to a greater extent on a sandy soil than on one of heavier texture.

Literature Cited

The effect of fertilizers upon the quality of crops has been of much interest in recent years. The survey (106) entitled "American Fertilizer Practices" led to a resume of the literature by Hartwell (62), in 1932. In the former work, 75.2 per cent of the farmers interviewed stated that fertilizers improved the market quality of crops and 54.7 per cent agreed that fertilizers improved the feeding quality.

Maynard (94) gives an excellent review of the literature on the relation of mineral deficiencies to the

diseases and abnormal growth of animals. He concludes that the troubles due to mineral deficiencies can be remedied by fertilizing the crops to be fed, and by proper supplementary feeding of the animals.

The growing importance of soybeans for both forage and seed purposes is shown by Warburton (164), who cites an increase in the acreage devoted to the crop from 150,000 acres in 1907 to 5,500,000 acres in 1935.

Russell (120) states that the air supply, water supply, temperature, injurious factors, and the supply of nutrients are the factors which influence plant growth. The plant may be affected as to its rate of growth, in its composition at various stages of growth, in the character or habit of growth, or in yield. The many factors which influence the nutrition of plants explain the reason for the many discrepancies encountered in the work which has been done.

The investigations dealing with the nutrition of plants can be classified broadly according to the medium in which the plants have been grown; i. e., solution cultures, sand cultures, and soils. Each medium has its advantages. Solution and sand cultures allow working conditions to be controlled, while field studies allow an interpretation of results only if they are continued

for a period of years in order to obtain the average effects of all factors. Miller (101) states that nutrient solution studies are preferable to soil studies, but also points out the necessity for controlling the conditions under which the work is done. Bakke and Erdmann (43) found that wheat plants exhibit a different nutrient requirement when grown in water cultures as compared with sand cultures. Miller (101) points out the difficulty of applying results obtained from such studies to soils.

The number of elements conceded to be needed by chlorophyll-bearing plants for normal growth has been increased within recent years. Thatcher (154) lists carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, potassium, calcium, magnesium, and iron as the elements necessary for a plant to reach maturity. It is pointed out that nearly all the elements functioning in plant nutrition appear in the first four Series of the Periodic Table. The elements are classified by groups, according to their primary functions in the plant, but with some overlapping due to multiple functions. The various headings are: (1) energy exchange elements, (2) energy storers, (3) translocation regulators, (4) oxidation-reduction regulators, and (5) those whose functions are as yet unknown.

In 1927, Cooper and Wilson (35) found good agreement between the electrode potentials of the elements and their absorption by plants. A classification of plants can be made on this basis. Some common legumes, such as alfalfa and sweet clover, belong to the class requiring the elements of high voltage, and cotton is an example of an important crop belonging to the class adapted to poor soils where elements of lower voltage predominate. More recently (36) it has been stated that plants requiring high-potential elements; i. e., potassium and calcium, in large amounts are capable of synthesizing organic compounds which can supply large amounts of energy. The reverse is likewise true. Cooper (33) states that large amounts of metallic elements below calcium in the electromotive series are not to be found in plants grown on non-saline soils. Analyses of thirty-four samples of pasture grasses give an average content as follows: K<sub>2</sub>O, 1.33 per cent; CaO, 0.22 per cent; and MgO, 0.14 per cent. The absorption of strong ions may limit that of weak ions, even of essential elements such as magnesium, manganese, and iron. Legumes contain more Ca than K while the reverse is true for cereals. The quality of radiant energy utilized by the plant may control the absorption of ions.



Thomas (157) explains a preponderance of cations or anions in a plant on the basis of the nature of the electric charge residing on the roots. In "normal soils"; i.e., those of pH 5.5 to 7.0, the roots are negatively charged which results in an abundant absorption of positive ions, and the order of absorption is that of the Hofmeister lyotropic series; the order of decreasing absorption for the most important positive ions being H, K, Na, Mg, and Ca; the order for the anions is: NO<sub>3</sub>, Cl, PO<sub>4</sub>, and SO<sub>4</sub>. The series does not hold beyond the range indicated. Below a pH value of 5.5 the anions are absorbed to a greater extent than cations due to a positive charge on the roots. This would explain the variable results of investigations with ammonium sulphate and nitrate of soda.

The citations offered emphasize the complexity of the processes of plant nutrition. Apparently the results obtained are specific only under the conditions pertaining to the particular experiment, and an application of the results can be made to other conditions only in a very general way.

The nutrition of a leguminous plant is further complicated by its ability to obtain nitrogen through symbiotic relations. The many factors influencing

nodulation in turn affect the relation of nitrogen fertilizers to the plant, and secondarily the absorption of other elements. Albrecht (3, 4) and Albrecht and Horner (6) find the function of calcium is that of a plant nutrient rather than for the control of reaction, and that it is more important in nodulation than is the control of the pH. Lipman and Blair (90) found that liming increased nodulation ten times, and that the yields of seed and hay, and the nitrogen content of the hay were increased in this way. That sulphur stimulates nodulation has been demonstrated by Miller (102), Rudolfs (119), Neller (107), and others. Stewart (148) attributes the effect of sulphur to an increased availability of the phosphorus of the soil. Helz and Whiting (63) found that potassium and phosphorus increased the nodulation of soybeans, and Allison (7) points out that the carbohydrate supply of the plant also has an effect; if the supply in the roots is low, due to rapid growth induced by nitrogen fertilizers, then inoculation is retarded. This explains the inhibitory effect of an abundance of available nitrogen in the soil as recorded by many workers. Under some conditions a nitrogenous fertilizer may increase nodulation; this was shown by Hartwell (60) who obtained positive results with sodium nitrate, and by Giöbel (56) who

also secured increases with combined nitrogen. Fred and Graul (50) found small amounts of nitrates beneficial, but larger amounts were considered harmful.

The nitrogen content of soybean hay is materially increased by nodulation as demonstrated by Lipman and Blair (90), Fred (49), Fred and Graul (51), Walker and Brown (165), and others. It varies with age of the plant as found by Albrecht and Allison (5), Austin (10), and Brmann (45), but there is some question as to which stage of maturity represents the highest nitrogen content. The effect due to liming is amply demonstrated and is generally associated with increased nodulation, although the effect may be a direct one.

Lipman and Blair (88) obtained increased yields of dry matter with applications of nitrogen but the per cent of nitrogen in the hay was not greatly influenced. Soluble phosphates (89) increased the nitrogen content; potash was without effect. Fellers (46) states that it is not economical to apply nitrogen to soybeans even though there is an increase in the protein content. Phosphates and potash are beneficial for the production of forage. Ginsberg (55) shows that an unbalanced nutrient medium results in an increased absorption of calcium with a decreased intake of nitrogen. Janssen

and Bartholomew (75) report that a high nitrogen content is associated with a low potassium content of the cowpea plant. Kelly (82) in a review of researches on fertilization indicates that the application of nitrogen fertilizers may be of benefit to legumes. An increased nitrogen content is associated with nitrogen fertilization by MacTaggart (92), although the percentage was not influenced as much as the total nitrogen produced by the crop. Potassium decreased the nitrogen content while phosphorus increased it markedly. In a statistical treatment of results obtained with mangolds, Kalamaker (80) found a close correlation between nitrogen and potassium, the response from one being dependent upon the other. Austin (10) found that the influence of fertilizer treatment upon the soybean plant varied with the type of soil; on one soil type all treatments increased the nitrogen content of the soybean plant. In general, the soil type influenced the composition of the hay more than did the fertilizer treatment. Kornfeld (83) found that phosphates tended to overcome the effect of inoculation upon the soybean plant.

Cockefair (29), in discussing the role of phosphorus in plant nutrition, lists five functions proposed in recent years: (1) the reduction of nitrates in the roots,

(2) as an aid in the synthesis of starch, (3) control of respiration, (4) nuclear division, and (5) selective adsorption. There is a definite linkage with the hexose sugars; thus it functions in the energy changes of the plant.

Using magnesium in common with all treatments, Austin found that sulphur reduced the phosphorus content of soybean hay while the addition of potassium, or potassium and nitrogen, increased the content appreciably. Blair and Prince (18) obtained an increased phosphorus content of mixed hay by a phosphate application. Summarizing various experiments, they concluded that phosphorus fertilization had but little effect upon the phosphorus content of crops. Bisenmenger (42) states that magnesium and phosphorus availability are closely associated. Phosphates increased nodulation and the protein content of soybeans, as shown by Fellers (46) who obtained increased hay yields with various combinations of phosphorus, nitrogen and potassium. Hartwell (61) has shown that applications of phosphorus to the soil result in an increased concentration of the element in the juices of plants. Hoagland (69) and Parker (113) conclude that a very low concentration of phosphorus will suffice for plant growth if the supply is continuous. Parker (112)

has shown that the concentration of carbon dioxide in the soil may influence the intake of this element. Hartwell (60) states that soybeans have a relatively high feeding power for phosphorus and a high feeding power for potassium. Brown and Skinner (22) found a correlation between the citric acid-soluble phosphorus in soils and the yields of crops.

Mitchell et al. (103), in 1928, found no increase in the P<sub>2</sub>O<sub>5</sub> content of soybean hay with a fertilizer containing four per cent P<sub>2</sub>O<sub>5</sub> but obtained an increase when the fertilizer contained ten per cent.

The presence of calcium in superphosphate complicates the study of the effect of this material on plant growth. The relation of calcium to nodulation and nutrition and the effect of lime has been pointed out. Thatcher classifies calcium as one of the translocation regulators; it takes part in the synthesis of fats and proteins and helps to control rates of reactions and permeability. Burrell (25) cites the tendency of roots to lose the epidermis when the element is deficient, and also the tendency for nitrate accumulation, indicating that it plays a part in the reduction of nitrates in the plant. This latter point is also pointed out by Nightingale et al. (108). Dunne (40) states that calcium is not

Indispensable in the buffer system of the plant, as potassium can function in its place. Fonder (47) finds that calcium controls the amount of potassium absorbed. A high concentration of sodium will decrease both potassium and calcium in the plant, according to Hoegland (68). Parker and Truog (114) found a close relation between the calcium and the nitrogen content of plants. Plant acids found in protein formation were thought to increase the need for calcium. Shedd (134) obtained distinct increases in the calcium content of soybeans and other crops with various calcium-bearing materials, as did Wyatt (172) who used dolomite. Willis (170) lists calcium as the most important minor element inasmuch as it counter-balances the effects of excessive amounts of the ammonium and magnesium ions in addition to its own physiological function. It reduces the absorption of chlorine. Willis et al. (171) state that there is abundant evidence to show that assimilation of phosphorus is dependent upon the calcium or magnesium supply, this having been set forth by Truog (159).

The calcium-phosphorus ratio in forage has received a large amount of attention in studies of animal nutrition. Hart et al. (59) found that a lack of palatability of range forage was associated with an increase in the ratio.

and this was due to an increase in the calcium content and a decrease in the phosphorus content. Eckles et al. (41) associated mineral deficiency symptoms with a wide ratio in alfalfa, timothy and prairie hay; this was due to a low phosphorus content. Bonemeal as a supplement overcame the resulting depraved appetite. Evans (45) found a low ash content associated with calcium deficiency in the skeletons of young pigs. The calcium-phosphorus ratio in the bones was practically the same for normal and deficient animals. Mineral deficiencies in range cattle have been corrected by Schmidt (124) by supplemental feeding. From data given by Mitchell et al. (103), it can be shown that increasing amounts of phosphorus in the fertilizer cause a decrease of both the CaO and P<sub>2</sub>O<sub>5</sub> content of oats, and also causes a reduction in the CaO:P<sub>2</sub>O<sub>5</sub> ratio; with soybeans, however, they are accompanied by increases of both CaO and P<sub>2</sub>O<sub>5</sub>, with the ratio remaining the same. Variations in the ratio for soybeans range from 1.84 to 4.03, by some calculations made from the data given; this depended upon the variety, and the location at which they were grown.

Magnuson (93) has found that the amount of P<sub>2</sub>O<sub>5</sub> in the blood of range cattle is a reflection of the P<sub>2</sub>O<sub>5</sub> content of the feeds consumed.

Lipman (86) reviewed critically the question of the



existence of an optimum calcium-magnesium ratio for plants and concluded that there was little or no evidence to support the theory.

The variation in the potassium content of plants is quite wide, and much evidence has accumulated to show that the concentration within the plant depends to a great extent upon the amount supplied in the soil. "Luxury consumption" of potassium by plants is described as an important physiological function by Bartholomew and Janssen (12); it serves as a safeguard against a possible deficiency during the later stages of growth. It exists in plants almost entirely in the water soluble form. Cooper (35) points out that cereals usually are higher in potassium than calcium while the reverse is true for legumes. A high potassium content may seriously affect animals as indicated by Cooper and Wilson (36). Potassium functions in the formation of starch and protein, and is active in preventing disease (25); it may replace calcium as a component of the buffer system (40). Its exact function in carbohydrate synthesis has not, however, been established experimentally (82). The nitrogen content of soybeans may be increased by potassium fertilization (92). Schuster (132) reports a hastening of the maturity of soybeans due to the potash in manure. Potassium is deemed

necessary for the production of crops of quality (62).

There is an inverse relationship between the calcium and potassium contents of plants. This is described by Fonder (47) as a physiological balance, and is supported by the work of Dunne (40), and others. Hoagland (70) points out that magnesium is also involved in this relation; there is also a reciprocal relation between light and potassium.

Potash deficiency is a problem of increasing importance in some sections of the United States and abroad. Cooper (34), McMurtry (100), and Kornfeld (84) have described the symptoms induced by a deficiency of this element for a wide variety of crops. Liming reduced the availability of the potash in the soil, as shown by MacIntire et al. (91). Gilbert et al. (54) created a manganese deficiency by liming a soil to neutrality; the addition of a manganese salt to overcome the manganese deficiency in turn induced a potash deficiency.

The crops grown on the sand-hill phase of Norfolk sand develop symptoms of potash, magnesium, and calcium deficiencies under special conditions of rainfall and fertilizer treatment. The existence of a magnesium deficiency on a related but more fertile area at the

Sandhill Station was established by Mr. J. H. Hunter<sup>1/</sup>, working under the direction of Dr. T. S. Buie. Subsequent investigations by Dr. H. P. Cooper, and his associates of the South Carolina Experiment Station, have done much to make the station outstanding in that line of work in the Southeast.

The effect of the fertilizers upon the composition of soybean hay and seed is complicated by the turning of the crops as green manures. It was desirable that a study be made of the effect of the soybean plants, produced with different ratios, upon the organic matter and the pH of the soil. The literature resume, as given for the green manure-fertilizer experiment, is pertinent to this phase of the work.

1. The triangle system of fertilizer study.

The triangle system, as applied to fertilizer investigations by Schreiner and Skinner (129) (elaborated upon in 131), is of particular value in pioneer investigations. It has been used by Tottingham (158), Shive (135), Harris (58), McCall (95), Bear (14), and others. A favorable critical review

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<sup>1/</sup> Work done in 1929 to 1930. Now a member of the staff of the Soil Fertility Station, Soil Fertility Investigations, Bureau of Plant Industry, Austin, Texas.

has been made by Espino (44). Hibbard (66) concluded that the triangular system is inadequate as an aid in determining the best nutrient ratio for wheat, oats, and corn grown in soil cultures.

A triangular diagram is shown in Figure 9. The apices of the equilateral triangle represent a fertilizer containing one element only; i.e., nitrogen, phosphoric anhydride, or potassium oxide. Each side is divided into five equal parts with lines connecting the points of the three sides. The eighteen points and three apices are numbered giving a total of 21. This is called a twenty-one point triangle and represents as many fertilizer ratios. In this experiment the total amount of plant food is fifteen per cent. Thus the apices starting with P<sub>2</sub>O<sub>5</sub> represent the 0:15:0, 0:0:15, and 15:0:0 ratios. As one proceeds from the P<sub>2</sub>O<sub>5</sub> apex (No. 1) each successive parallel line represents a decrease of three per cent in the P<sub>2</sub>O<sub>5</sub> content, but an increase of the same percentage for nitrogen and potash. Flats 2 and 3 contain twelve per cent P<sub>2</sub>O<sub>5</sub>; 4, 5 and 6 contain 9 per cent, and so on. The base lines consequently represent a mixture of P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O with varying quantities of the two, but no nitrogen. The side of

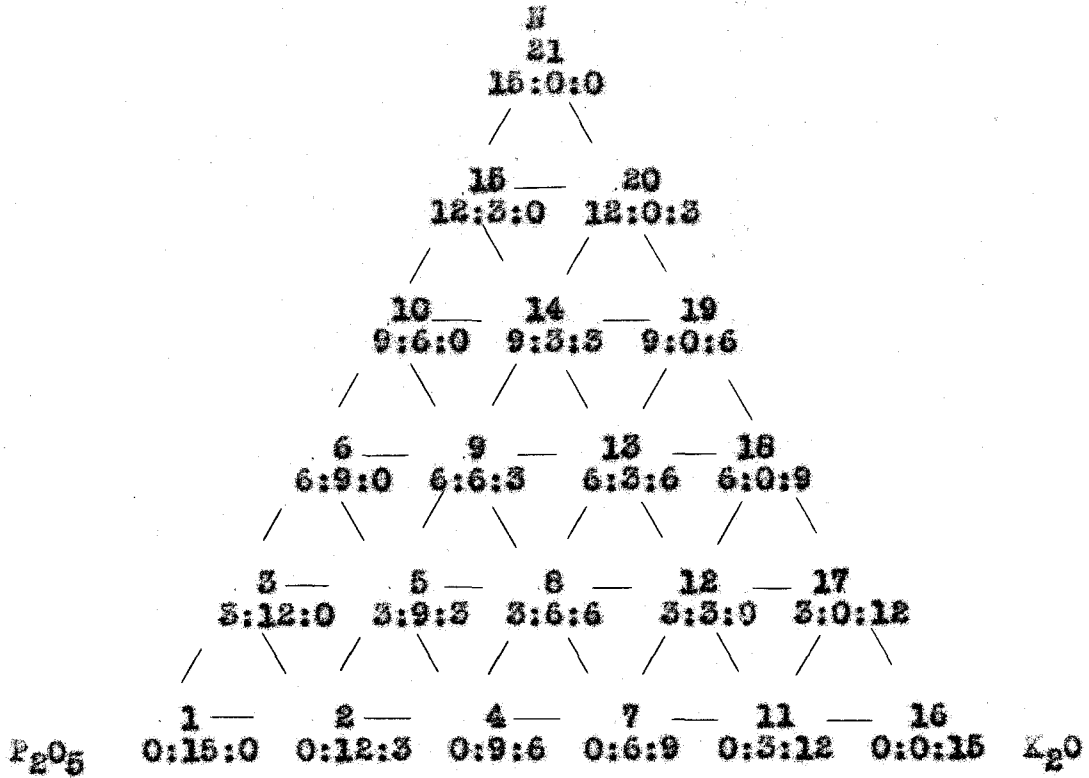


Figure 9. Triangle giving the twenty-one fertilizer ratios, of fifteen per cent plant food, as used in the experiment.

the triangle opposite the  $K_2O$  apex gives ratios of only  $P_2O_5$  and nitrogen, and that opposite the  $P_2O_5$ , a mixture of nitrogen and  $K_2O$ . The points of intersection inside the triangle represent ratios containing all three of the elements; e.g., No. 5 represents a 3:9:3 ratio; No. 14, a 9:3:3; and No. 12, a 3:3:9. Figure 9 gives the number of the "plat" and corresponding ratio.

\* presentation of data by means of the triangular diagram allows one to follow variations in yields or changes in composition due to small variations in the ratio. By averaging the data from plats along a particular line, one obtains an average value attributable to the percentage of plant food represented. Both methods will be used in this treatment.

### Experimental

#### 1. Plat outline.

Figure 10 is the plat diagram. Each plat receiving a particular fertilizer treatment is 435 feet long and nine feet wide. The area is divided into three sections so that each fertilizer treatment and the checks are represented in each section. The plants grown on the central section furnished samples for

Figure 10. Plat diagram of triangle fertilizer experiment with soybeans.

1	0-15-0	<p>Section A Seed threshed and hay returned to the plat.</p> <p>Section B Samples of hay taken for analy- sis. Turned as green manure.</p> <p>Section C Hay removed and stubble turned.</p>
2	0-12-3	
3	3-12-0	
4	0-9-6	
5	3-9-3	
6	6-9-0	
7	0-6-9	
8	3-6-6	
9	6-6-3	
10	9-6-0	
CK-1	0-0-0	
11	0-3-12	
12	3-3-9	
13	6-3-6	
14	9-3-3	
15	12-3-0	
16	0-0-15	
17	3-0-12	
18	6-0-9	
19	9-0-6	
20	12-0-3	
21	15-0-0	
CK-2	0-0-0	

N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O

analysis, and the crops were turned as a green manure. This was done each year when the plants were in the late bloom and early pod stage. At the same time Section B was handled, the hay was removed from an end-section and the stubble turned. The plants on the other end-section were allowed to mature, were cut, the seed threshed and the threshed hay returned to the proper plot. Samples of seed were preserved for analysis, nitrogen and oil being determined.

## 2. Methods.

The 1928 crop was grown for yields only but the management of the crops was as indicated. Soil samples were taken semi-annually starting in the spring of 1929, and were analyzed for total carbon, nitrogen, and the pH value determined; the methods used are those outlined in the green manure-fertilizer experiment.

The hay samples were analyzed by the methods of the Association of Official Agricultural Chemists, except for potash which was determined according to Treadwell and Hall, Vol. II (Seventh Edition, 1928), pages 64 to 66.

## Discussion

A study of the quality of a forage is necessarily associated with the quantity factor. The production of



quality may be accompanied by a reduction in yield such as to render it prohibitive. Yield data are of value in indicating the plant-food elements which are lacking in the soil. It is reasonable to assume that a rational program would be to strive for a balance between quantity and quality of forage plants.

1. Yields data.

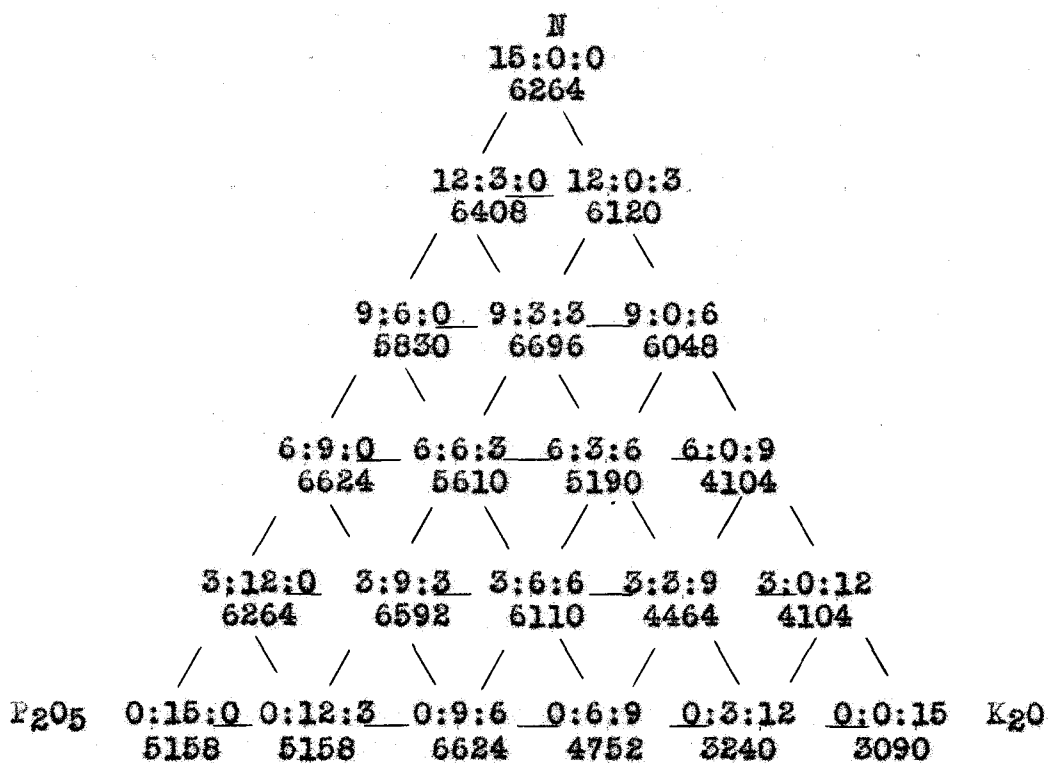
The yields of hay are given in Table 3 for each year of the period 1928 to 1933. The average yields for the six years are also included.

During the first season the 9:3:3 ratio produced the highest yield; in 1929, the 6:3:6 ratio; in 1930, 1931, and 1932, the 3:9:3; and in 1933, the 0:12:3 ratio. The yields, in general, were lowered from attacks of *Sclerotium rolfsii*. They are shown graphically in Figures 11 to 16, inclusive.

The average yields are given by means of the triangle, in Figure 17. It is thought that these averages should be discussed rather than the yearly data, except to point out the general tendency toward an increased need for phosphate with a decreased need for potash. Moisture has been a limiting factor in forage production from 1930 to 1933, owing to sub-normal rainfall during those years. The largest

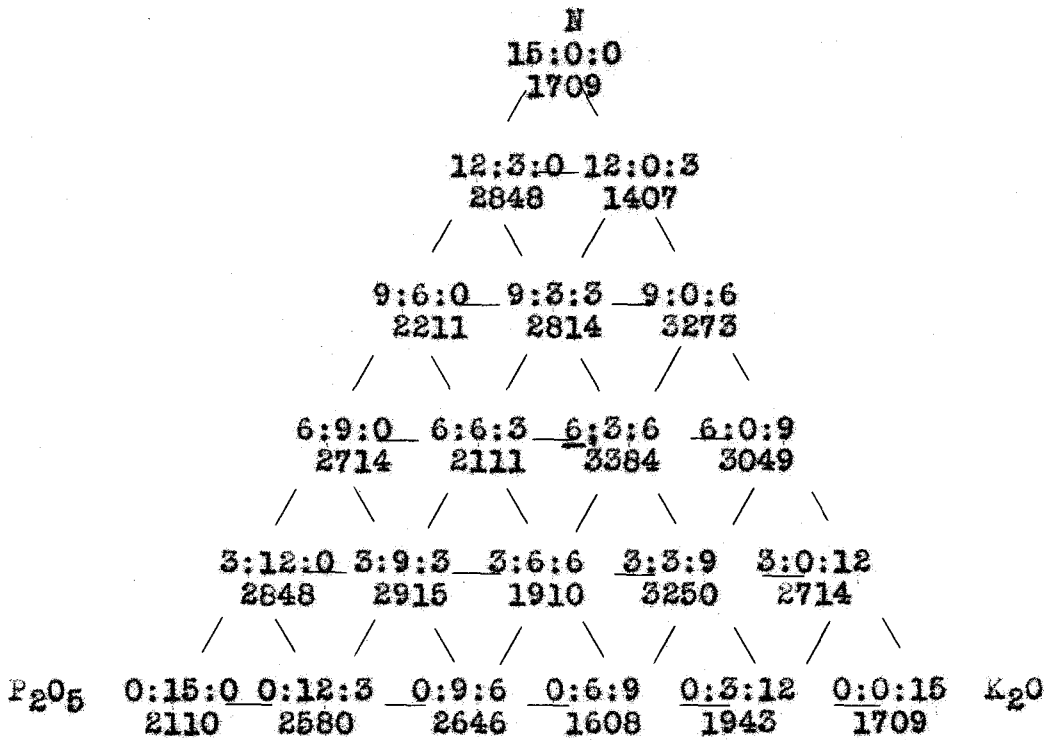
Table 3. Yearly and average yields of hay produced on Norfolk sand with incomplete and complete fertilizers for the period 1928 to 1933. Data obtained from Section B.

Plat	N-P <sub>2</sub> O <sub>5</sub> -K <sub>2</sub> O	1928 Lbs./A	1929 Lbs./A	1930 Lbs./A	1931 Lbs./A	1932 Lbs./A	1933 Lbs./A	Av. Lbs./A
1	0-15-0	5158	2110	972	1040	1072	940	1882
2	0-12-3	5158	2580	1224	1600	2472	2620	2609
3	3-12-0	6264	2848	1620	2140	2412	2160	2907
4	0-9-6	6624	2646	1404	1680	1742	1900	2666
5	3-9-3	6532	2915	1944	2580	2613	1980	3094
6	6-9-0	6624	2714	1584	2280	2077	1540	2803
7	0-6-9	4752	1608	1152	1140	871	940	1744
8	3-6-6	6110	1910	1296	1500	1843	1820	2412
9	6-6-3	5610	2111	1764	1840	2178	2060	2594
10	9-6-0	5830	2211	1548	1880	2010	1100	2430
11	0-3-12	3240	1943	396	980	670	540	1295
12	3-3-9	4464	3250	1260	1780	1809	1800	2394
13	6-3-6	5190	3384	1620	2480	2546	2260	2914
14	9-3-3	6696	2814	1692	2380	2412	1860	2976
15	12-3-0	6408	2848	1872	2320	2312	1280	2840
16	0-0-15	3090	1709	288	880	570	380	1153
17	3-0-12	4104	2714	540	1200	972	720	1708
18	6-0-9	4104	3049	1116	2040	1742	1320	2229
19	9-0-6	6048	3273	1440	2200	2178	1520	2777
20	12-0-3	6120	1407	936	2000	21	1040	1921
21	15-0-0	6264	1709	576	1340	9	220	1686
Av. of Checks	0-0-0	2556	1156	194	300	74	310	765



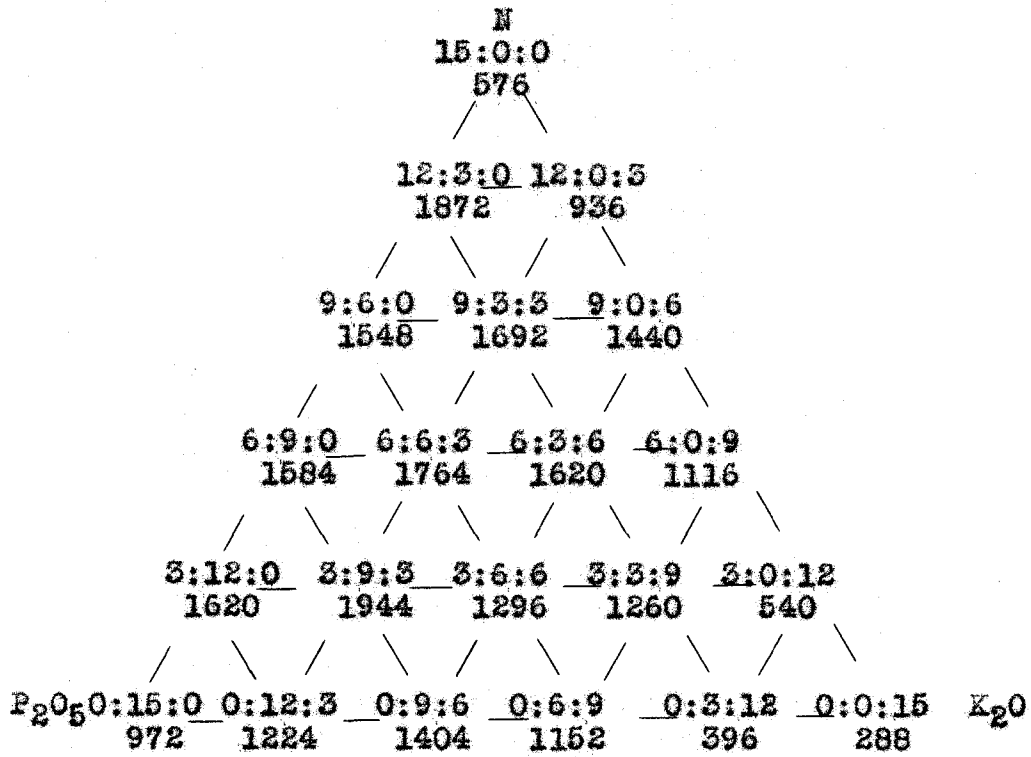
Average of checks = 2556

Figure 11. Yields of soybean hay in pounds per acre produced on Norfolk sand for the year 1928. Data are for section B.



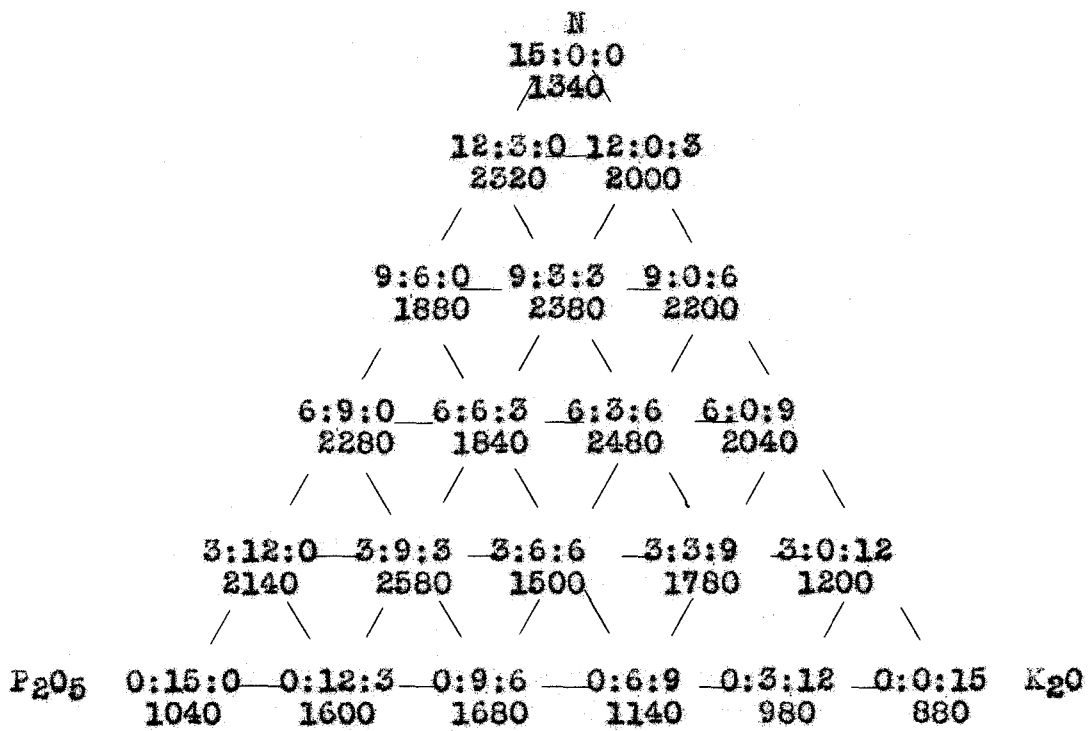
Average of checks = 1156

Figure 12. Yields of soybean hay, in pounds per acre, on Norfolk sand for the year 1929. Data are for Section B.



Average of checks = 194

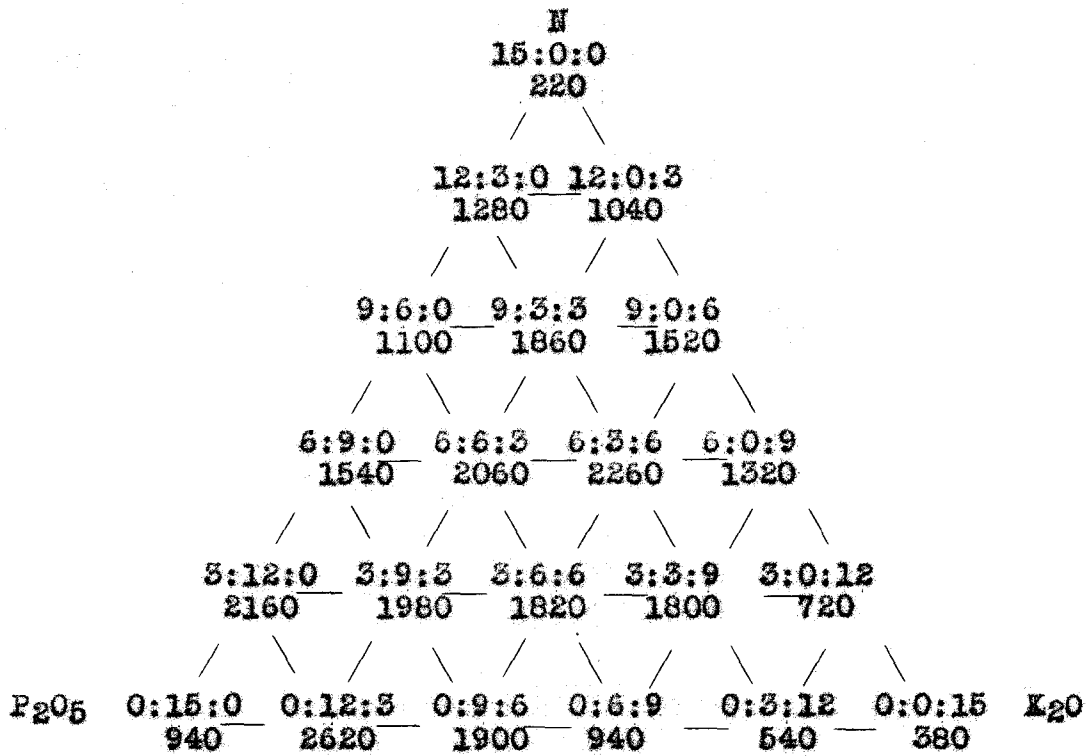
Figure 13. Yields of soybean hay, in pounds per acre, produced on Norfolk sand for the year 1930. Data are for section B.



Average of checks = 300

Figure 14. Yields of soybean hay, in pounds per acre, produced on Norfolk sand for the year 1931. Data are for Section B.

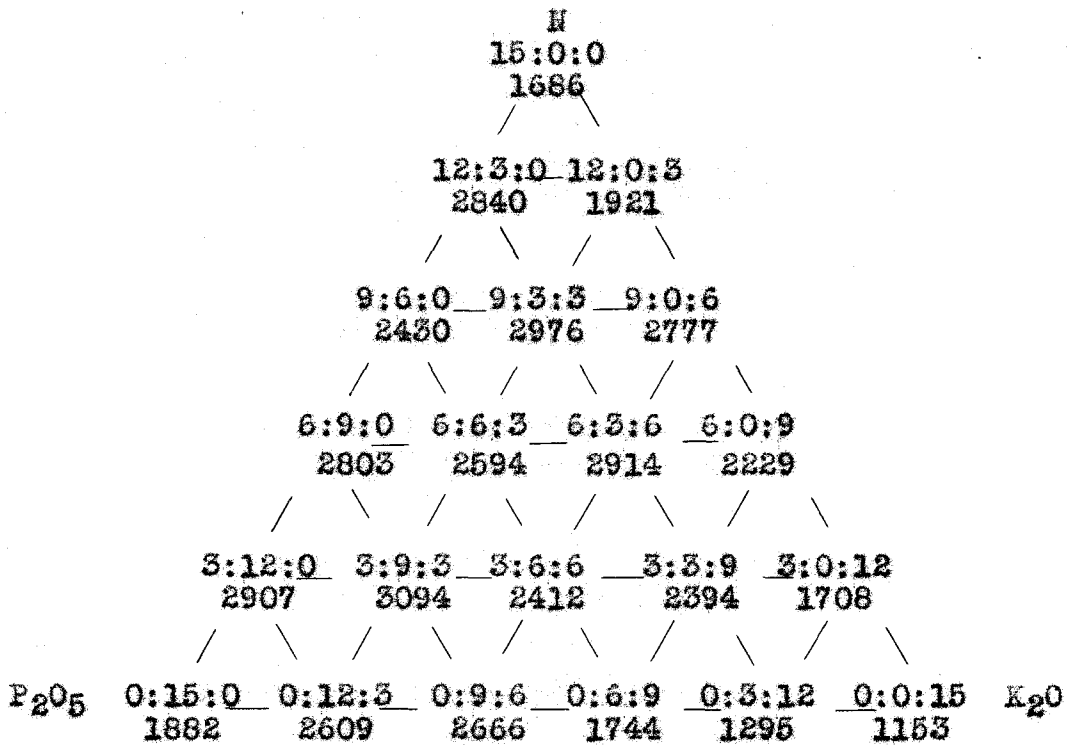




Average of checks = 310

Figure 16. Yields of soybean hay, in pounds per acre, produced on Norfolk sand for the year 1933. Data are for Section B.





Average of checks = 765

Figure 17. Average yields of soybean hay, in pounds per acre, produced on Norfolk sand for the period 1928 to 1933, inclusive. Data are for section B.

average yield for the six years has been produced on the 3:9:3 plat; the next highest has been from the use of the 9:3:3 ratio, with the 6:3:6 and 3:12:0 ratios of equal standing.

The most definite reflection of the effect of the fertilizers used upon the yields, as depicted in Figure 17, is shown with those containing no nitrogen or a small amount of this element. If one follows the base line of the triangle from the 0:0:15 ratio to the left, or along the three per cent nitrogen line, starting with the 3:0:12 ratio, it is seen that increased yields are obtained until the 0:12:3 and 3:9:3 ratios are reached; i.e., the three per cent potash line. This indicates that, when the nitrogen content of the fertilizer is held constant, a decrease in  $K_2O$  accompanied by an increase in  $P_2O_5$  in the fertilizer results in larger yields. With mixtures of nitrogen and potash only, the yields converge upon the 9:0:6 ratio. When the  $P_2O_5$  content is held at three per cent the convergence is toward the 9:3:3 ratio; at six per cent the direction is toward the 6:6:3; and at nine per cent  $P_2O_5$  the yields converge upon the 3:9:3 ratio. These data point toward a ratio low in potash for maximum production of forage.

For mixtures containing nine per cent potash the high yielding plat was the 3:3:9; for six per cent, 6:3:6; for three per cent, 3:9:3; and for 0 per cent potash, the best ratio is the 3:12:0. This last ratio ranked third with the 6:3:6 for yield and was only slightly inferior to the 3:9:3 and 9:3:3 ratios.

The triangular analysis of the average yield of hay is given in Table 4. When the yields are averaged according to the percentage of the element in the fertilizer; i.e., 15, 12, 9, 6, 3 or 0 per cent, which includes both complete and incomplete ratios, it is seen that the ratio indicated for highest yields is 9:9:6 or 9:9:3. When reduced to the fifteen per cent basis this becomes a 5.6:5.6:3.7 or 5.6:5.6:2.9. This ratio is a little higher in nitrogen and potash, and lower in phosphoric acid than that obtained by averaging the four highest-yielding ratios used in the experiment.

That the need for phosphorus is greatest, with nitrogen and potash following in the order given, is shown by the yields of 3094, 2976, and 2394 pounds, respectively, for the 3:9:3, 9:3:3, and 3:3:9 ratios.

The average yield for all the complete fertilizers is 2731 pounds as compared with 765 pounds for the average of the checks. The greatly diminished yields

Table 4. Yields of soybean hay, seed and oil in pounds per acre, produced on Norfolk sand by incomplete and complete fertilizers; also averages according to the percentage of a particular fertilizer ingredient. Data are for the period 1928 to 1933.

Effect of:	Plats Averaged	Average Yields			
		Pounds Per Acre			
		Hay	Seed	Oil	
Per Cent:					
	15	21	1686	128	23.00
	12	15, 20	2381	181	33.10
	9	10, 14, 19	2728	178	31.66
Nitrogen	6	6, 9, 13, 18	2635	171	29.10
	3	3, 5, 8, 12, 17	2504	169	29.62
	0	1, 2, 4, 7, 11, 16	1892	154	26.70
	15	1	1882	107	18.40
	12	2, 3	2758	194	32.95
Phosphoric	9	4, 5, 6	2855	187	32.00
Acid	6	7, 8, 9, 10	2295	179	31.60
	3	11, 12, 13, 14, 15	2483	158	27.96
	0	16, 17, 18, 19, 20, 21	1912	153	27.66
	15	16	1153	137	24.60
	12	11, 17	1502	130	23.20
Potash	9	7, 12, 18	2122	154	27.30
	6	4, 8, 13, 19	2692	175	30.60
	3	2, 5, 9, 14, 20	2639	198	34.88
	0	1, 3, 6, 10, 15, 21	2425	155	27.11
Complete Mixtures:					
High N	9-3-3	14	2976	196	34.60
High P <sub>2</sub> O <sub>5</sub>	3-9-3	5	3097	205	35.20
High K <sub>2</sub> O	3-3-9	12	2394	139	24.60
All Complete		5, 8, 9, 12, 13, 14	2731	180	31.58
N	6	9, 13	2754	181	31.65
	3	5, 8, 12	2634	175	30.53
P <sub>2</sub> O <sub>5</sub>	6	8, 9	2503	187	32.90
	3	12, 13, 14	2761	168	29.83
K <sub>2</sub> O	6	8, 13	2663	174	30.55
	3	5, 9, 14	2889	198	34.60
Av. of Checks	0-0-0		765	60	10.40

of the checks during the last four years of the experiment indicate that the native fertility, which originally was very low, has been further depleted even though the crop has been turned as a green manure each year. The growth of soybeans on the central check plat in 1932, the lowest yield for any of the six years, is shown in Figure 18, and is to be compared with the 3:9:3 plat in Figure 19.

The yields for the 3:9:3, 9:3:3 and 3:12:0 plats are given graphically in Figure 20. There is no indication that the use of the incomplete ratio, 3:12:0, has resulted in a decreased fertility of the soil.

## 2. Composition of hay.

The hay samples were analyzed for nitrogen, phosphorus, potassium, calcium, the mixed oxides of iron and aluminum, magnesium, sulphur, manganese and the soluble ash. Average data are given for the first four elements for four years, and for the remainder for three years. These data, and the form in which the analyses are reported, are given in Tables 5 and 6. It is thought that only average data should be given as the differences due to seasonal variations would only serve to confuse the presentation.



Figure 18. Central check plot of Section A, in 1932. The 0:3:12 plat is on the left and the 9:6:0 on the right. The plats are three rows wide.



Figure 19. The central three rows are of the 3:9:3 plat. On the left is the 6:9:0 plat, and on the right the 0:9:6.

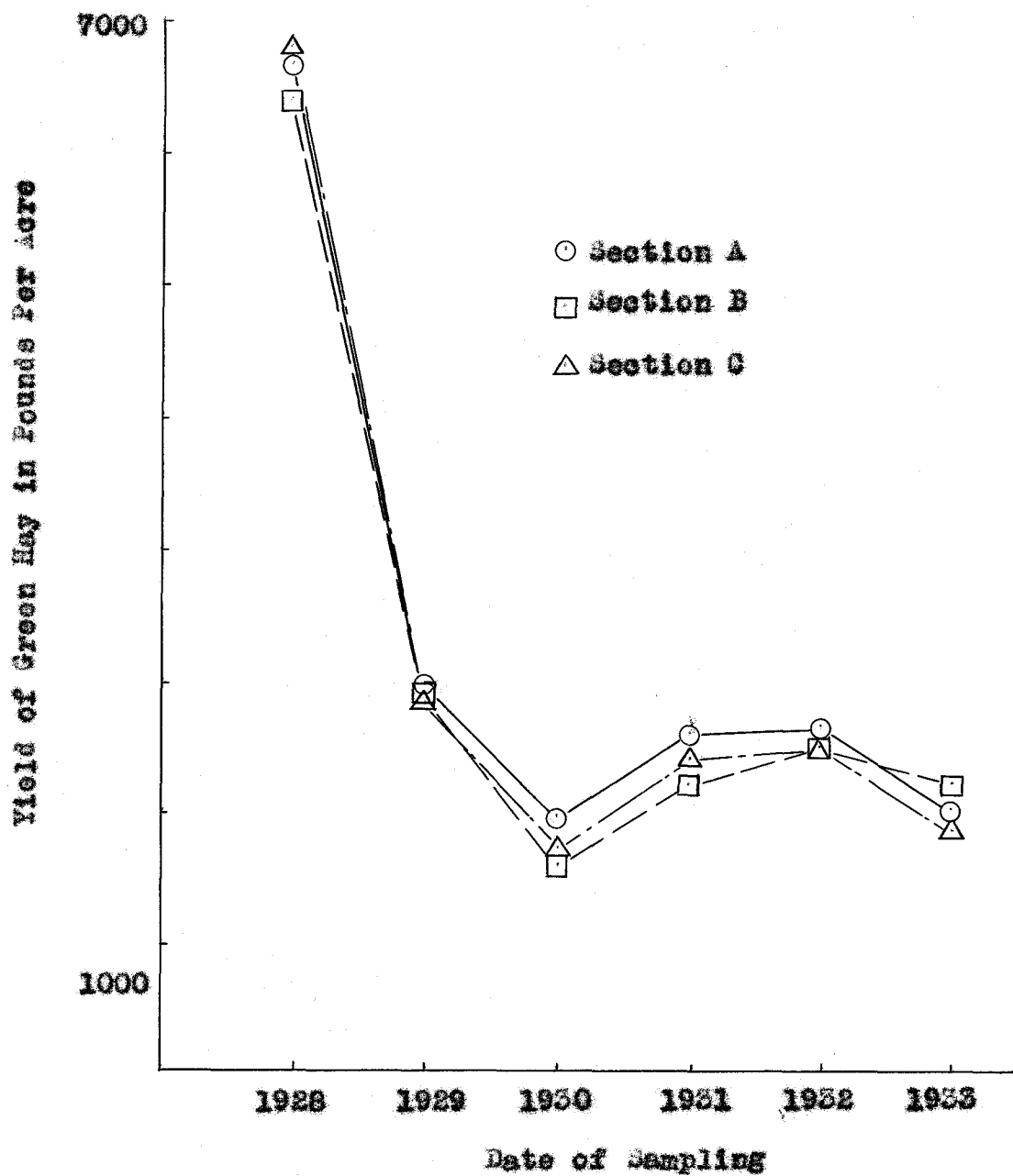


Figure 20. Yields for 3-9-3, 3-12-0 and 9-5-3 plats, Section B, for period 1928 to 1933.



Table 5. Average yields of soybean hay, and the nitrogen, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O, and CaO content as produced with incomplete and complete fertilizers on Norfolk sand.

No.	Fertilizer Formula	Yield Green Hay Lbs./A	Composition of Hay - Air Dry Basis					
			Av. H <sub>2</sub> O %	Av. N %	Av. P <sub>2</sub> O <sub>5</sub> %	Av. K <sub>2</sub> O %	Av. CaO %	1950-53
	N-P <sub>2</sub> O <sub>5</sub> -K <sub>2</sub> O	1928-53	1950-53	1950-53	1950-53	1950-53	1950-53	1950-53
1	0-15-0	1882	5.29	2.25	0.58	0.66	2.13	
2	0-12-3	2609	5.70	2.10	0.59	0.82	2.01	
3	3-12-0	2907	4.86	2.41	0.59	0.70	1.97	
4	0-9-6	2666	4.57	2.07	0.64	1.42	1.78	
5	3-9-5	3094	5.10	1.90	0.62	1.15	1.87	
6	6-9-0	2803	5.29	2.12	0.53	0.70	1.87	
7	0-6-9	1744	4.72	2.05	0.66	2.13	1.49	
8	3-6-6	2412	4.93	1.88	0.59	1.59	1.44	
9	6-6-3	2594	4.86	2.03	0.57	1.14	1.50	
10	9-6-0	2430	4.50	2.01	0.58	0.72	1.63	
11	0-3-12	1295	4.91	1.93	0.66	2.28	1.12	
12	3-3-9	2394	5.27	1.72	0.59	1.85	1.14	
13	6-3-6	2914	5.31	1.60	0.53	1.46	1.13	
14	9-3-3	2976	5.69	1.72	0.54	1.14	1.15	
15	12-3-0	2840	4.85	2.06	0.52	0.88	1.31	
16	0-0-15	1153	4.89	1.66	0.61	2.23	0.98	
17	3-0-12	1708	5.11	1.63	0.62	2.23	1.01	
18	6-0-9	2329	4.45	1.62	0.55	1.93	0.94	
19	9-0-6	2777	5.54	1.46	0.49	1.43	1.09	
20	12-0-3	1921	5.41	2.01	0.48	1.25	1.04	
21	15-0-0	1686	5.30	2.08	0.45	1.10	1.25	
Ok. Av.	0-0-0	765	4.75	2.02	0.57	0.99	1.77	

\* Moisture content of air-dried material at 65° C. in vacuum.

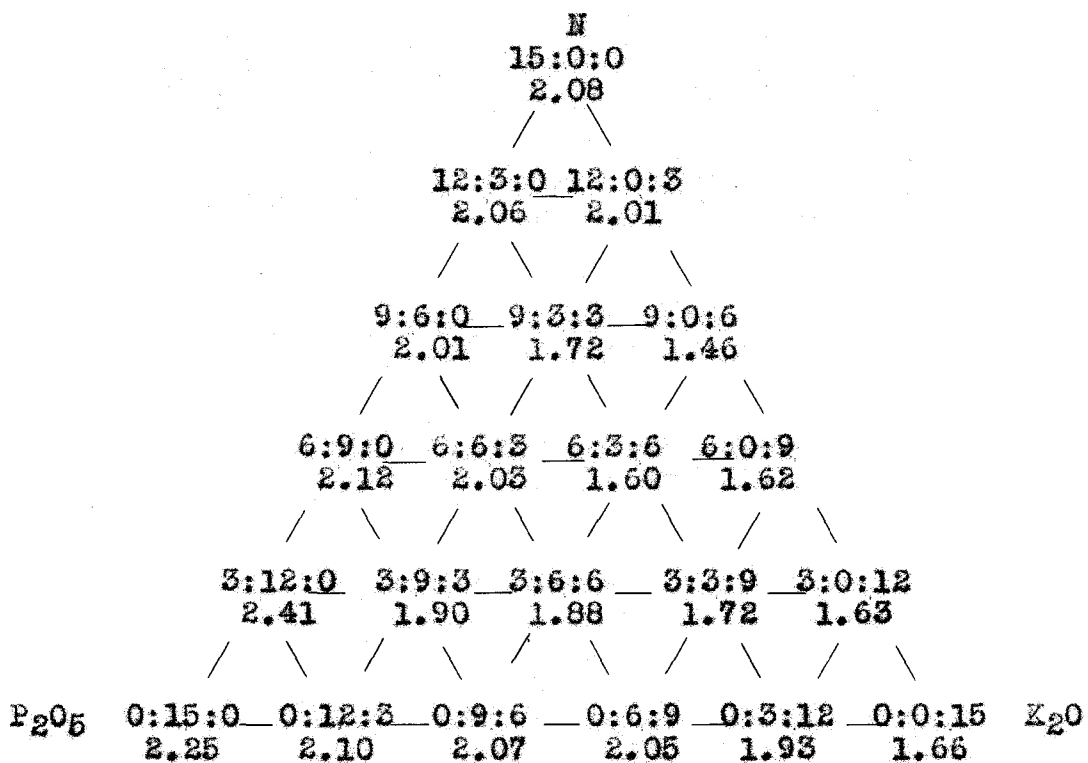
Table 6. Soluble ash, R2O3, Mn3O4, SO4, and MgO content of the hay, as produced with incomplete and complete fertilizers on Norfolk sand, for the years 1930, 1932 and 1933.

No.	Fertilizer Formula	Composition of Hay - Air-Dry Basis							
		Av. H2O %	Av. Soluble Ash %	Av. R2O3 %	Av. Mn3O4 %	Av. SO4 %	Av. MgO %		
1	0-15-0	6.26	5.81	0.21	0.10	0.78	0.39		
2	0-12-3	5.90	4.45	0.38	0.09	0.87	0.46		
3	3-12-0	5.38	4.79	0.33	0.10	0.77	0.38		
4	9-9-6	5.21	5.16	0.21	0.10	0.92	0.42		
5	3-9-3	6.48	4.91	0.16	0.07	0.98	0.37		
6	6-9-0	5.55	4.50	0.25	0.07	0.81	0.36		
7	0-6-9	5.10	4.90	0.19	0.08	1.14	0.36		
8	3-6-6	4.74	5.10	0.13	0.08	0.92	0.35		
9	6-6-3	4.74	4.45	0.17	0.09	0.79	0.40		
10	9-6-0	4.84	4.44	0.15	0.08	0.66	0.40		
11	0-3-12	5.13	5.77	0.21	0.08	0.88	0.36		
12	3-3-9	5.52	5.21	0.14	0.07	0.92	0.40		
13	6-3-6	5.25	4.78	0.11	0.07	0.86	0.38		
14	9-3-3	5.84	4.16	0.12	0.07	0.69	0.41		
15	12-3-0	5.32	4.19	0.17	0.08	0.62	0.43		
16	0-0-15	4.96	5.67	0.25	0.09	0.95	0.44		
17	3-0-12	5.30	5.52	0.17	0.08	0.93	0.40		
18	6-0-9	5.13	4.69	0.18	0.08	0.83	0.36		
19	9-0-6	5.42	4.45	0.18	0.06	0.75	0.44		
20	12-0-3	5.47	3.93	0.25	0.07	0.45	0.44		
21	15-0-0	5.45	4.04	0.25	0.07	0.56	0.52		
OK. Av.	0-0-0	5.08	4.89	0.30	0.09	0.47	0.60		

\* Moisture content of air-dried material at 65° C. in vacuum.

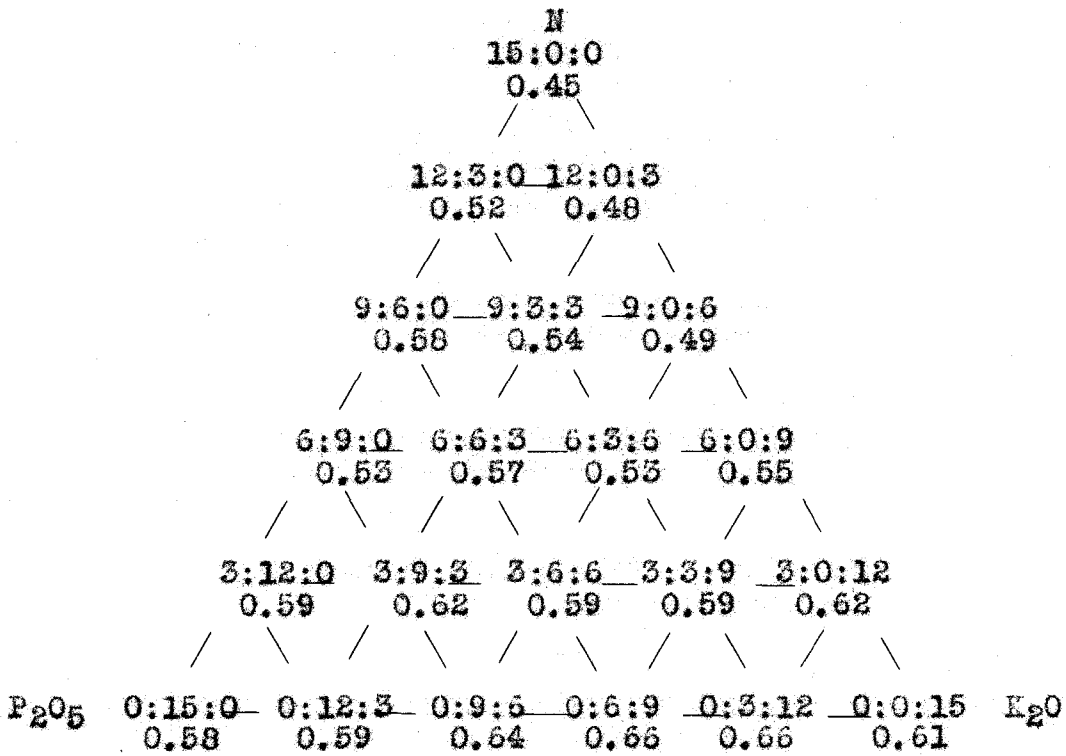
These data are best presented graphically by means of the triangle. Those of nitrogen are given in Figure 21, of  $P_2O_5$  in Figure 22, of  $K_2O$  in Figure 23, and of  $CaO$  in Figure 24.

a. Nitrogen content. An inspection of Figure 21 shows that the nitrogen content of the soybean plant has been influenced appreciably by the fertilizer used; the total variation is from 1.46 per cent to 2.41 per cent, the former being produced with a 9:0:6 fertilizer and the latter with a 3:12:0 fertilizer. As given in Table 3, the 3:9:3 ratio produced an average of 3094 pounds green material (619.4 pounds dry weight) per acre; the 9:3:3 ratio, 2976 pounds (595.2 pounds); and the 3:12:0, 2907 pounds (581.4 pounds). Using the nitrogen contents given in Figure 21, the weights of nitrogen per acre recovered in the hay, respectively, are: (1) 11.8 pounds for the 3:9:3; (2) 10.2 pounds for the 9:3:3; and (3) 14.0 pounds for the 3:12:0 ratio. The amounts of nitrogen applied in the fertilizers were: (1) 12 pounds in the 3:9:3, (2) 36 pounds in the 9:3:3, and (3) 12 pounds in the 3:12:0 ratio. Only in the last case does the amount of nitrogen recovered in the hay exceed that applied in the



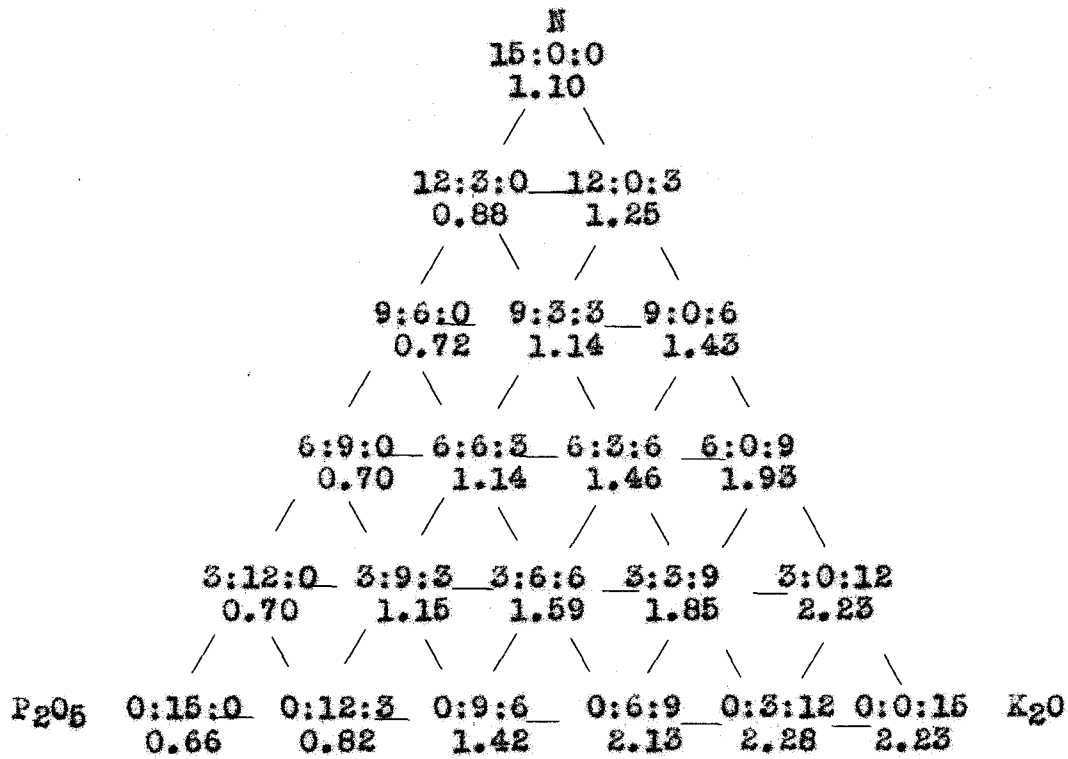
Average of checks = 2.02

Figure 21. Average per cent of nitrogen in air-dried soybean hay as produced on Norfolk sand for the period 1930 to 1933.



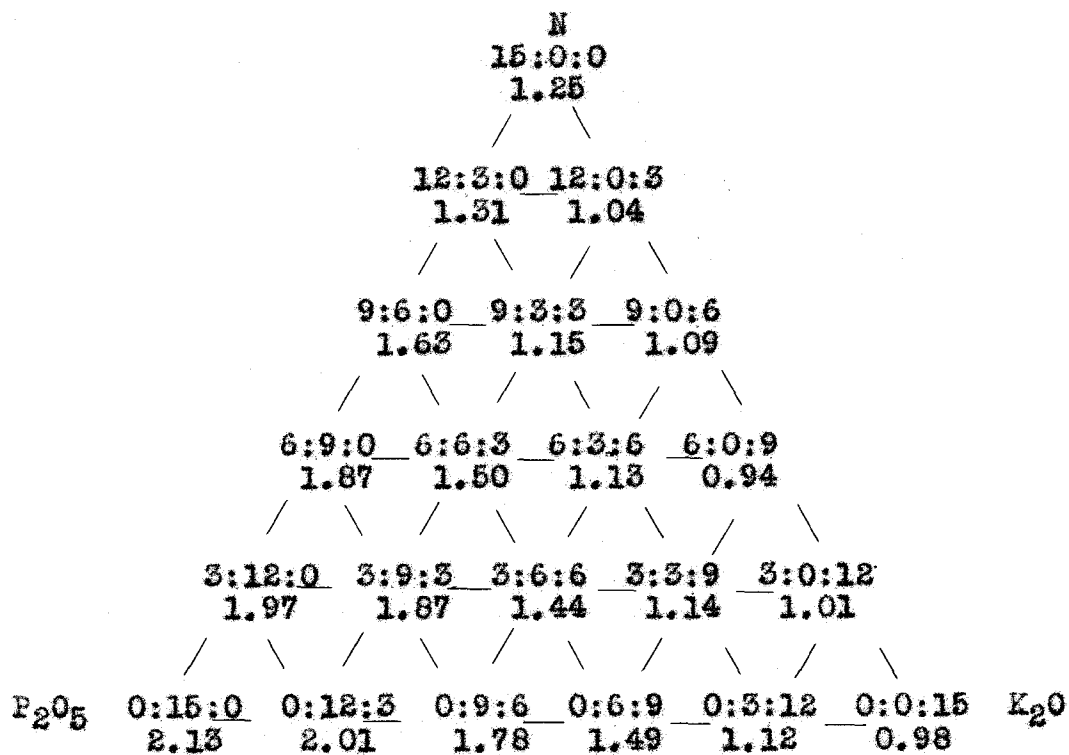
Average of checks = 0.57

Figure 22. Average per cent of P<sub>2</sub>O<sub>5</sub> in air-dried soybean hay, as produced on Norfolk sand, for period 1930 to 1933.



Average of checks = 0.99

Figure 23. Average per cent K<sub>2</sub>O in air-dried soybean hay, as produced on Norfolk sand, for the period 1930 to 1933.



Average of checks = 1.77

Figure 24. Average per cent of CaO in air-dried soybean hay, as produced on Norfolk sand, for the period 1930 to 1933.

fertilizer.

That inoculation influences both the nitrogen content and the total nitrogen recovered per acre has been pointed out in the literature cited. The beans used for planting were inoculated for this experiment and examination each year showed the presence of nodules. It is debatable whether the high-nitrogen content of the 3:12:0 samples was due to an increased fixing power of the organisms as induced by this combination of nitrogen and phosphorus, or directly to the plant-food elements.

That the nitrogen content can be interpreted as a reflection of the fertilizer used is apparent from an inspection of Figure 21. When the nitrogen in the fertilizer is held constant at 0 or 3 per cent, and the potash and phosphate contents varied, it is found that an increase in the nitrogen content is obtained as the decrease in the potash of the ratio is accompanied by an increase in the phosphate content. The variation, with ratios containing only potash and phosphate, is from 1.66 to 2.25 per cent. With the nitrogen of the fertilizer held at three per cent, the percentage of nitrogen in the air-dried material is 1.63 for the 3:0:12 ratio, and increases



steadily to 2.41 with the 3:12:0 ratio. A discontinuity develops when the nitrogen content is held at six per cent. A slight decrease, from 1.62 to 1.50 per cent, takes place when the potash of the fertilizer is reduced from 9 to 6, and the P2O5 is increased from 0 to 3 per cent. The order observed in the 0 and 3 per cent nitrogen lines is restored when the 6:6:3 ratio is reached, and the percentage of nitrogen for the 6:9:0 ratio is greater than for the 6:6:3. This continuity holds along the 9 and 12 per cent lines.

The variation in the nitrogen content of the hay resulting from a variation in the nitrogen and potash, with the phosphate held constant in the fertilizer, lacks continuity as in the case of the 6 per cent nitrogen line. Starting with the N-K2O line at the 9:0:6 ratio, one obtains an increase in the percentage of nitrogen by using the 12:0:3 and 15:0:0 ratios. These increases are due, presumably, to increased amounts of nitrogen in the fertilizer. This may be due, however, to the phosphorus or calcium contained in the cottonseed meal used as a source of one-third of the nitrogen, but other data do not substantiate this idea. This

possibility is inferred from the consideration of the effect of phosphate when the amount of  $K_2O$  is reduced, with the nitrogen held constant at 0, 3, 9, or 12 per cent. Again the nitrogen content increases as the field is shifted from the 9:0:6 ratio to the 0:0:15 ratio. When the  $P_2O_5$  in the fertilizer is held constant, and the amounts of  $K_2O$  and nitrogen vary inversely, there is distinct evidence that the nitrogen exerts its effect when the potash content is below six per cent. This line of demarcation bisects the triangle starting between the 12:0:3 and 9:0:6 ratios and extending toward the base line to a point between the 0:12:3 and 0:9:6 ratios; i.e., between the six and three per cent potash lines. When the amount of potash is three per cent or less, increases in the nitrogen of the fertilizer result in an increased nitrogen content, except at the six per cent  $P_2O_5$  line, while amounts of potash, six per cent or greater, cause increases in the nitrogen content of the hay.

When the potash content of the fertilizer is held constant at 12, 9, or 6 per cent, with the nitrogen and  $P_2O_5$  contents of the fertilizer varying inversely, an increase in the amount of phosphate

applied causes an increase in the nitrogen of the forage produced. There is a break in this continuity when there is three per cent or no  $K_2O$  in the ratio, the break occurring on the nine and three per cent nitrogen lines, respectively.

The shift from a 9:3:3 to a 12:0:3 ratio, or from a 9:6:0 to the 15:0:0, results in an increase in the nitrogen of the hay; however, with the shift from the 9:3:3 to the 0:12:3 ratio, it is the increase in the phosphate used which causes an increase in the nitrogen content. This is also true when the change is from the 9:6:0 toward the 0:15:0, a break occurring at the 3:12:0 ratio.

The analysis of the data according to the percentage of the element in the fertilizer that is held constant is given in Table 7. There are two indications in regard to the amount of nitrogen to be used in the fertilizer - an increase in the nitrogen of the forage occurs starting with nine and increasing in the fifteen per cent mixtures, and an increase going from 9 to 0 per cent is obtained.

The indication for a  $P_2O_5$  content of the fertilizer to the extent of twelve or fifteen

Table 7. Percentages of nitrogen, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O and CaO in soybean hay produced on Norfolk sand by incomplete and complete fertilizers; with averages according to the percentage of a particular fertilizer ingredient. Data are for the period 1930 to 1933.

Effect of:	Plats Averaged	Hay - Air-Dry Basis				
		N %	P <sub>2</sub> O <sub>5</sub> %	K <sub>2</sub> O %	CaO %	
Per Cent:						
Nitrogen	15	21	2.08	0.45	1.10	1.25
	12	15, 20	2.04	0.50	1.07	1.18
	9	10, 14, 19	1.73	0.54	1.10	1.29
	6	6, 9, 13, 18	1.84	0.57	1.56	1.36
	3	3, 5, 8, 12, 17	1.91	0.60	1.50	1.49
	0	1, 2, 4, 7, 11, 16	2.01	0.62	1.59	1.59
Phosphoric Acid	15	1	2.25	0.58	0.66	2.13
	12	2, 3	2.26	0.59	0.76	1.99
	9	4, 5, 6	2.03	0.60	1.09	1.84
	6	7, 8, 9, 10	1.99	0.60	1.40	1.52
	3	11, 12, 13, 14, 15	1.81	0.57	1.52	1.17
	0	16, 17, 18, 19, 20, 21	1.74	0.53	1.70	1.05
Potash	15	16	1.66	0.61	2.23	0.98
	12	11, 17	1.78	0.64	2.26	1.07
	9	7, 12, 18	1.80	0.60	1.97	1.19
	6	4, 8, 13, 19	1.75	0.56	1.48	1.36
	3	2, 5, 9, 14, 20	1.95	0.56	1.10	1.51
	0	1, 3, 6, 10, 15, 21	2.17	0.54	0.79	1.69
Complete Mixtures:						
High N	9-3-3	14	1.72	0.54	1.14	1.15
High P <sub>2</sub> O <sub>5</sub>	3-9-3	5	1.90	0.62	1.15	1.87
High K <sub>2</sub> O	3-3-9	12	1.72	0.59	1.85	1.14
All Complete		5, 8, 9, 12, 13, 14	1.81	0.57	1.39	1.37
N	6	9, 13	1.82	0.55	1.30	1.32
	3	5, 8, 12	1.83	0.60	1.53	1.48
P <sub>2</sub> O <sub>5</sub>	6	8, 9	1.96	0.58	1.37	1.47
	3	12, 13, 14	1.68	0.55	1.48	1.14
K <sub>2</sub> O	6	8, 13	1.74	0.56	1.53	1.29
	3	5, 9, 14	1.88	0.58	1.14	1.51
Av. of Checks	0-0-0		2.02	0.57	0.99	1.76

per cent, for the production of forage of a high-nitrogen content, is quite definite. A low content of potash in the fertilizer is also indicated.

Although the exact average of the samples produced by fertilizers containing no potash is higher than for those of three or six per cent  $K_2O$  content, it is to be pointed out that the yields for the latter two as given in Table 4 are somewhat higher.

A comparison of the nitrogen contents of the hay as produced by the 9:3:3, 3:9:3, and 3:3:9 ratios shows 1.72, 1.90, and 1.72 per cent, respectively. This would indicate that a larger per cent of phosphate with perhaps equal quantities of nitrogen and  $K_2O$  would be most efficient. This is borne out by the content produced by the 3:9:3 ratio; i.e., 1.90 per cent.

b. Phosphoric acid content. The triangle presentation of the  $P_2O_5$  content of the hay samples is made as Figure 22. By comparison of these data with those for average yields, as given in Figure 17, it will be seen that a close inverse relationship exists between the  $P_2O_5$  contents and yields. Inasmuch as the yields of all fertilized plats are greatly in excess of the unfertilized checks, it appears that

the  $P_2O_5$  content may be considered as a true reflection of the fertilizer treatment for the particular plot.

The  $P_2O_5$  content of the hay varies inversely with the amount of superphosphate applied, when no nitrogen is used in the fertilizer. This indicates a direct relation with potash, which is again brought out when no phosphate is used. An increased  $P_2O_5$  content accompanies the shift from the 15:0:0 or 0:15:0 to the 0:0:15 ratio.

When the nitrogen content of the fertilizer is held constant at three per cent, there is no particular regularity in the change of the  $P_2O_5$  content. This irregularity is again apparent for the ratios containing six per cent, but when the nitrogen is held constant at nine per cent a definite trend develops. This holds for the ratios with twelve per cent nitrogen; there is an increase in the  $P_2O_5$  content of the forage going from the 9:0:6 to 9:6:0, and from the 12:0:3 to 12:3:0 ratios. The addition of phosphate to a high-nitrogen ratio which contains either six or three per cent of potash results in a forage of increased  $P_2O_5$  content.

Potash, rather than nitrogen, dominates the

absorption of phosphoric acid by the plant when no phosphate is present in the fertilizer. The change from the 15:0:0 to 0:0:15 ratio produces an increase from 0.45 to 0.61 per cent  $P_2O_5$ , showing a maximum of 0.62 with the 3:0:12 ratio. The supremacy is not so consistent when the ratios containing three per cent  $P_2O_5$  are considered, but nevertheless there is a definite increase as one shifts from the 12:3:0 to the 0:3:12 ratio, the figures rising from 0.52 to 0.66 per cent of  $P_2O_5$  in the hay. There is an apparent discontinuity with ratios containing six per cent  $P_2O_5$ , analogous to that of the preceding series, with the indication that nitrogen has exerted a slight effect. With the twelve per cent  $P_2O_5$  ratios, potash again dominates; it is to be concluded that potash has more influence than nitrogen on the  $P_2O_5$  content of soybean hay when the phosphate in the fertilizer is held constant.

There is a distinct and consistent effect of the phosphate of the fertilizer on the  $P_2O_5$  content of the samples when the amount of potash is held constant; the content is increased by an increased amount of phosphate.

The average data, with the three elements held

constant at the six different levels, are given in Table 7. These indicate that a mixture of potash and phosphate, with no nitrogen added, should produce a forage of highest  $P_2O_5$  content. The ratios indicated are the 0:6:12 and 0:9:12. The 0:6:12, when reduced to the fifteen per cent basis, becomes a 0:5:10 ratio, and lies between the 0:6:9 and 0:3:12 ratios both of which have given 0.66 per cent  $P_2O_5$ . This content is the maximum that has been obtained.

- c. Potassium oxide content. The potassium oxide contents of the forage samples are given in Table 5, and set forth in the triangle form in Figure 23.

The variation in the  $K_2O$  content is from 0.66 to 2.28 per cent. Due to the inverse relationship of  $CaO$  and  $K_2O$  in plant nutrition, the relative amounts of  $CaSO_4$ , carried by the superphosphate, and of  $K_2SO_4$  should be kept in mind. The per cent of  $K_2O$  varies directly with the amount of sulphate of potash in the fertilizer and indirectly with the amount of superphosphate used.

When no nitrogen is used, and the ratio is varied in regular order from 0:15:0 to 0:0:15, the variation in  $K_2O$  content is from the minimum to the maximum. The maximum, however, is not obtained with



the 0:0:15 ratio but with the 0:3:12 there being a slight drop from the 0:3:12 to the 0:15:0 ratio. This lack of continuity disappears when the nitrogen content is held at successively higher levels. The  $K_2O$  content starts at a higher level with each succeeding increase of nitrogen, which also means a steady decrease of phosphate in the ratio. It ends, however, for each higher nitrogen level with a value below the maximum for the ratios of lower nitrogen content.

Samples produced by ratios of nitrogen and potassium sulphate only, contain an amount of  $K_2O$  in keeping with the amount of the sulphate applied. This is true for each of the phosphate levels; i.e., 0, 3, 6, 9 and 12 per cent. The rate at which the  $K_2O$  content increases with a decrease in the phosphate content of the fertilizer is of interest. The average increases are as follows: (1) from 15 to 12 per cent  $P_2O_5$ , 0.10; (2) 12 to 9 per cent, 0.33; (3) 9 to 6, 0.31; (4) 6 to 3, 0.12; and (5) from 3 to 0 per cent, 0.18 per cent  $K_2O$ . The rate of increase is not regular for the value rises as the  $P_2O_5$  is reduced to 12 per cent and then tapers off at the 3 per cent level; it increases again

when no phosphate is used.

The effect of the decrease of phosphate becomes more apparent when the potash of the fertilizer is held constant. The change from the 0:15:0 ratio to the 15:0:0 results in an increase in the  $K_2O$  content. This relation holds on the three per cent potash line for only the two extremes; i.e., the 0:12:3 and 12:0:3 ratios, as the complete fertilizers are very uniform in content. The direction of the increase is reversed when the potash content is at the six per cent level. The increase in the  $K_2O$  content of the hay is regular from the 9:0:6 to the 3:6:6 ratio, but decreases as nitrogen is entirely eliminated from the fertilizer. The 3:3:9 ratio is the point of focus at the nine per cent level. These data indicate that the effect of the phosphate is masked at the low potash levels but becomes evident at the higher levels. The necessity for some phosphorus for the maximum assimilation of potassium is indicated by the content produced by the 0:3:12 ratio.

The average data given in Table 7 show that the highest  $K_2O$  content can be expected from the application of sulphate of potash alone. The need for

phosphate is not indicated due to the limited range within which the effect is exerted.

- d. Calcium oxide content. The highest calcium oxide content of the hay is obtained with the 0:15:0 ratio, which carries the largest amount of superphosphate in the fertilizer. The lowest content is produced by the 6:0:9 ratio. These data are set forth in Table 5, and Figure 24.

The inverse relation of the CaO and K<sub>2</sub>O contents may be observed by comparing Figure 23 with 24. The CaO content varies with the amount of superphosphate used when nitrogen is not present in the fertilizer. A change from the 0:0:15 to 0:15:0 ratio results in a continuous increase from 0.98 to 2.13 per cent CaO. This continuity is apparent at all nitrogen levels. The actual CaO content becomes less as the amount of nitrogen in the ratio is increased and the superphosphate, as represented by P<sub>2</sub>O<sub>5</sub>, is decreased.

When the K<sub>2</sub>O content of the fertilizer is held constant, the CaO content of the hay is in proportion to the amount of phosphate used. This holds for all ratios at all potash levels. Mixtures of nitrogen and potash only, give data for

which there is no apparent regularity. The 15:0:0 ratio, however, has an appreciably higher content than the 0:0:15 ratio. With three per cent of  $P_2O_5$  in the ratio, there develops a continuity starting with the 6:5:6 ratio and extending to the 12:5:0 ratio. This continues at the six per cent  $P_2O_5$  level, extending from the 3:6:6 to the 9:6:0 ratio; there is also an increase in the CaO content in the opposite direction; i.e., from the 3:6:6 ratio to the 0:6:9. At the nine per cent level, an increase is obtained from the 0:9:6 to the 6:9:0 ratio. The direction is reversed when there is twelve per cent  $P_2O_5$  in the ratio.

The 0:15:0 ratio is indicated for a maximum calcium oxide content by the average data in Table 4, and this is the ratio which has actually produced the maximum content.

e. Averages relative to nitrogen, phosphoric acid, potassium oxide, and calcium oxide contents produced by fertilizers high in nitrogen, phosphate, and potash. Figure 25 presents data for nitrogen,  $P_2O_5$ ,  $K_2O$  and CaO which have been obtained by averaging the contents produced by fertilizers containing 15, 12 and 9 per cent of

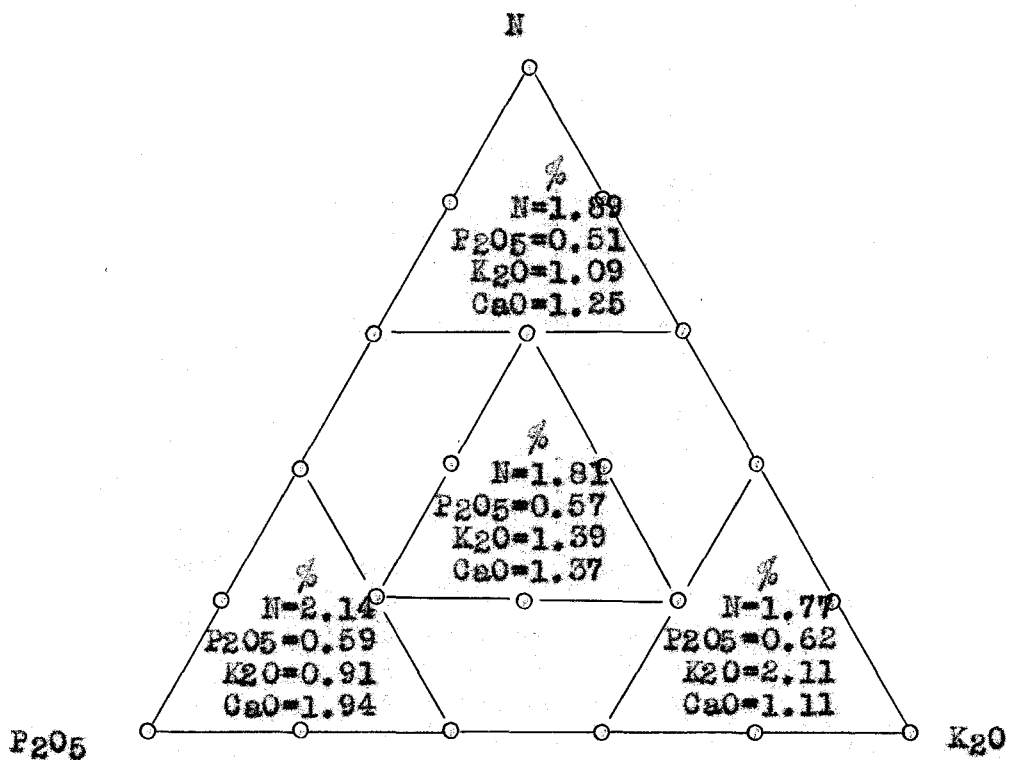


Figure 25. Average nitrogen, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O, and CaO contents of air-dried soybean hay, as produced on Norfolk sand by high-nitrogen, phosphate, and potash fertilizers, and by all complete fertilizers.

nitrogen, phosphoric acid, and potash, respectively. The central triangle represents the averages for the six complete fertilizers. There is one complete ratio in each of the three corner averages; i.e., the average at the  $P_2O_5$  apex contains the 3:9:3 ratio; that of the nitrogen apex, the 9:3:3; and of the  $K_2O$ , the 3:3:9.

The highest average  $K_2O$  content of the forage samples is obtained with the fertilizers of high-potash content. The order of decreasing content is: (1) high-potash fertilizers, (2) complete, (3) high-nitrogen, and (4) high-phosphate.

The order for a decreasing  $P_2O_5$  content of the hay is: (1) high- $K_2O$  ratios, (2) high-phosphate, (3) complete, and (4) high-nitrogen.

For the production of a forage of a high-nitrogen content, the average of the high-phosphate fertilizers ranks first; the high-nitrogen is second; complete fertilizers, third; and the high-potash average is fourth.

The order for a decreasing calcium oxide content of soybean hay is as follows: (1) high-phosphate ratios, (2) complete fertilizers, (3) high-nitrogen, and (4) high-potash ratios.

The data which have been cited indicate that sulphate of potash, in conjunction with superphosphate, controls the K<sub>2</sub>O content of soybean hay produced on Norfolk sand. This combination in general controls the P<sub>2</sub>O<sub>5</sub> content. The superphosphate used in association with nitrogen supplied as a mixture of nitrate of soda, sulphate of ammonia and cottonseed meal, controls the nitrogen content of the plant. Superphosphate controls the CaO content with a reverse effect exerted by the sulphate of potash.

Complete fertilizers tend to equalize the more extreme results of the ratios in which a particular material is present in larger amounts in the fertilizer.

The nutrition of the soybean plant involves a balance between the three main plant-food elements. The associations are involved but it appears that potassium, as furnished by potassium sulphate, is the key element. It influences the K<sub>2</sub>O and P<sub>2</sub>O<sub>5</sub> contents of the plant. The phosphate content of the fertilizer, in turn, enhances the quantity of nitrogen in the hay. There is an indication that the calcium of the superphosphate enters into the nitrogen picture; a high-calcium content is

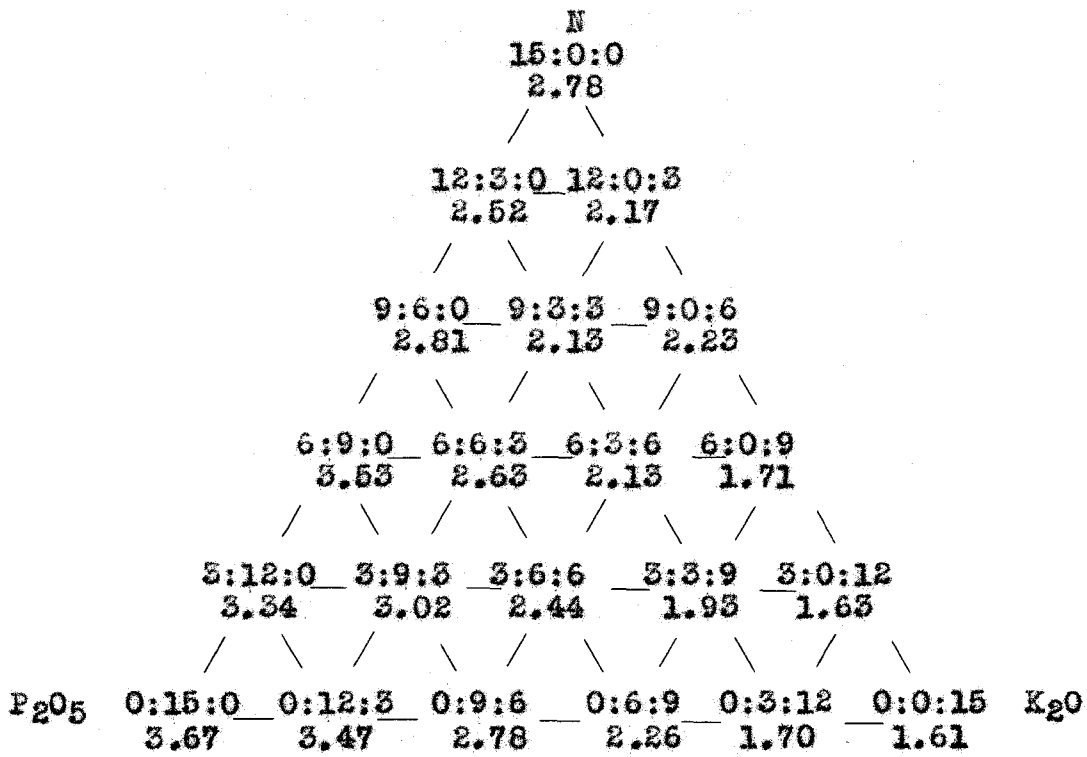
associated with a high concentration of nitrogen in the plant.

- f. The CaO:P<sub>2</sub>O<sub>5</sub> ratio. The CaO:P<sub>2</sub>O<sub>5</sub> ratio in feeds is considered of importance in animal nutrition. The optimum value is approximately 2:1. The ratios given in Figure 26 show a very large variation; the lowest is 1.61 and the highest is 3.67. The large CaO content does away with some of the apparent irregularities observed in the P<sub>2</sub>O<sub>5</sub> data, with the result that the trends for an increase of the ratio are essentially those given for the CaO content of the hay.

It is worthy of note that the 9:3:3 ratio, which ranked well in regard to yields, is one of the three which contain CaO and P<sub>2</sub>O<sub>5</sub> in a ratio approximately that desired for optimum nutrition. The amount of phosphate required as a supplement to reduce the ratio to the desired value is much less in the case of the 9:3:3 than for the 3:9:3.

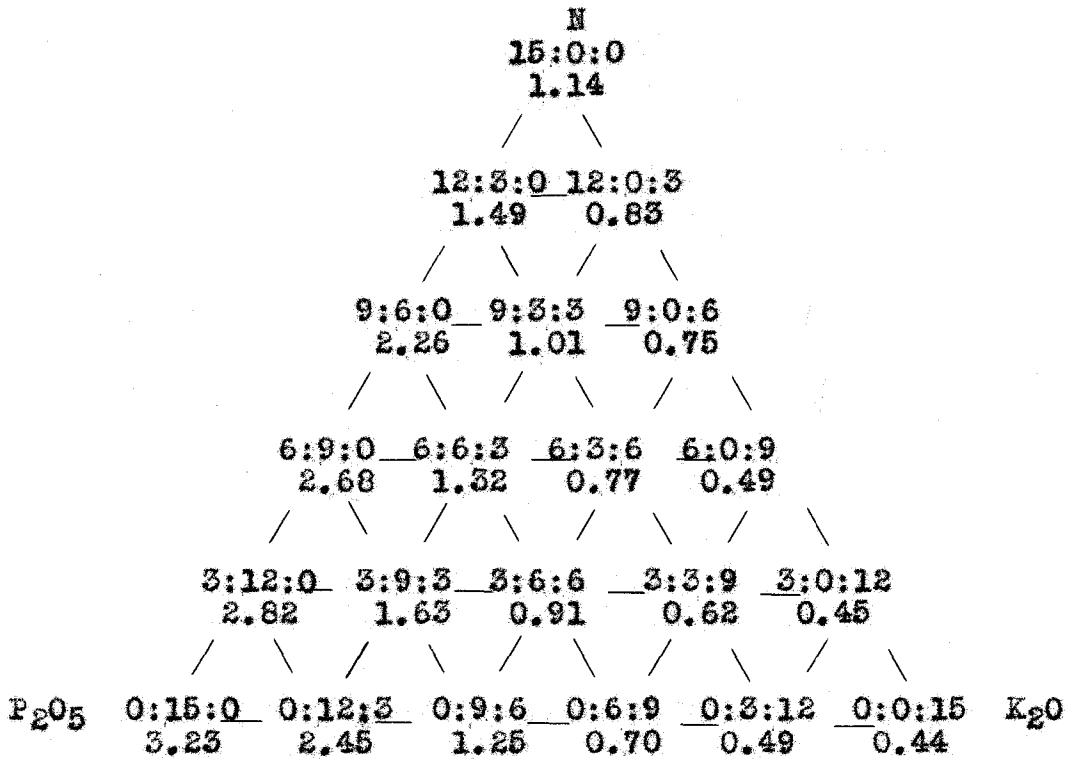
- g. The CaO:K<sub>2</sub>O ratio. The relation of CaO to K<sub>2</sub>O in the hay is depicted in Figure 27 as the CaO:K<sub>2</sub>O ratio. It is the one case in which the changes in content induced by the fertilizer are in perfect order. The variation in the ratio is considerably





Average of checks = 3.11

Figure 26. Average of CaO:P<sub>2</sub>O<sub>5</sub> ratio of air-dried soybean hay, as produced on Norfolk sand, for the period 1930 to 1933.



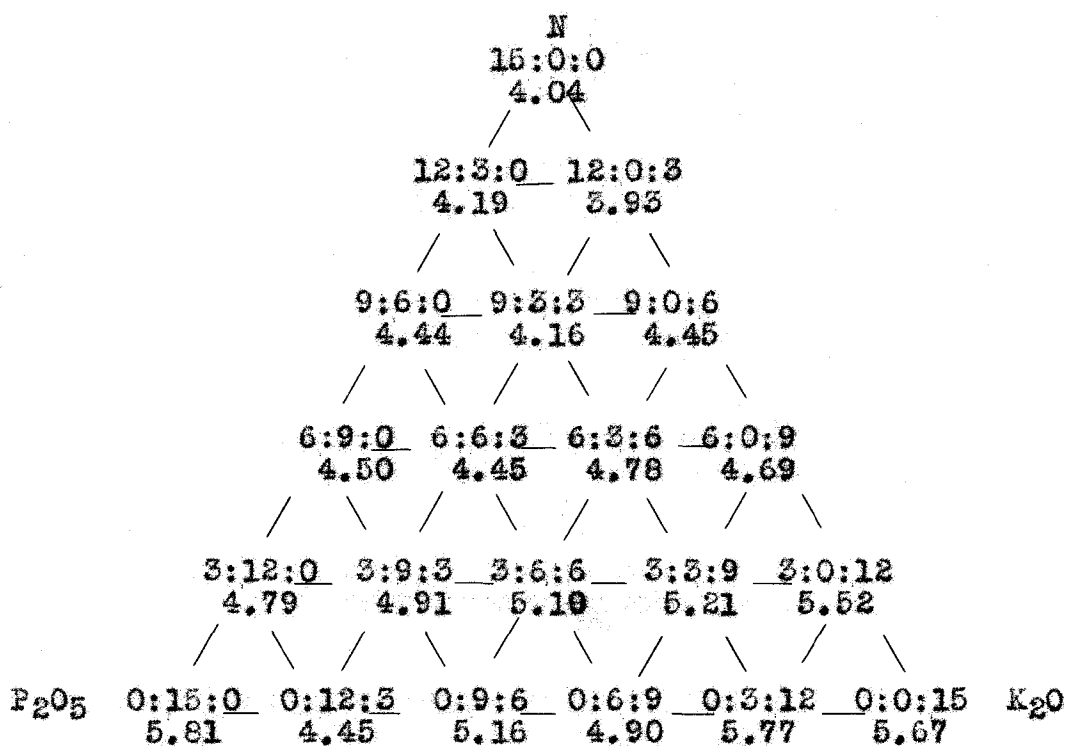
Average of checks = 1.79

Figure 27. Average CaO:K<sub>2</sub>O ratios for air-dried soybean hay, as produced on Norfolk sand, for the period 1930 to 1933.

increased, inasmuch as the CaO content is in proportion to the amount of superphosphate used, and the K<sub>2</sub>O is in proportion to the sulphate of potash. The CaO:K<sub>2</sub>O ratio of the forage produced by the 9-3-3 fertilizer is 1.01:1. This is accompanied by a CaO: P<sub>2</sub>O<sub>5</sub> ratio of 2.13:1. The 3:9:3 fertilizer, which gave slightly greater yields than the 9:3:3, produced a forage with values of 3.02:1 and 1.63:1 for the CaO:P<sub>2</sub>O<sub>5</sub> and CaO:K<sub>2</sub>O ratios. The use of the 3:12:0 fertilizer resulted in ratios of 3.34:1 and 2.82:1. The CaO:P<sub>2</sub>O<sub>5</sub> ratio is entirely too wide for proper nutrition in the case of either the 3:9:3 or 3:12:0 ratios.

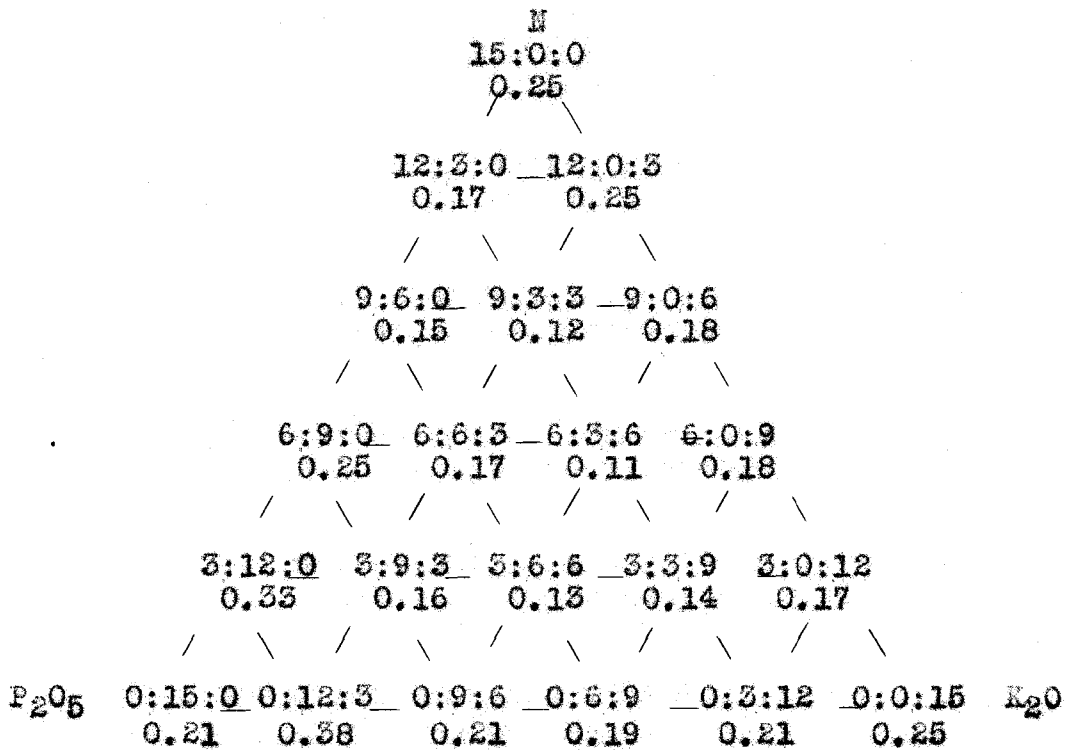
h. Soluble ash, R<sub>2</sub>O<sub>3</sub>, Mn<sub>3</sub>O<sub>4</sub>, sulphur and MgO contents.

The soluble ash, R<sub>2</sub>O<sub>3</sub>, Mn<sub>3</sub>O<sub>4</sub>, sulphur and MgO contents of forage produced by the twenty-one fertilizer ratios are given in Table 6. These data are averages for the years 1930, 1932 and 1933. They are presented by means of the triangle, as follows: (1) soluble ash, Figure 28; (2) R<sub>2</sub>O<sub>3</sub>, Figure 29; (3) Mn<sub>3</sub>O<sub>4</sub>, Figure 30; (4) sulphur as SO<sub>4</sub>, Figure 31; and (5) MgO in Figure 32. These are given individually so that one can follow the



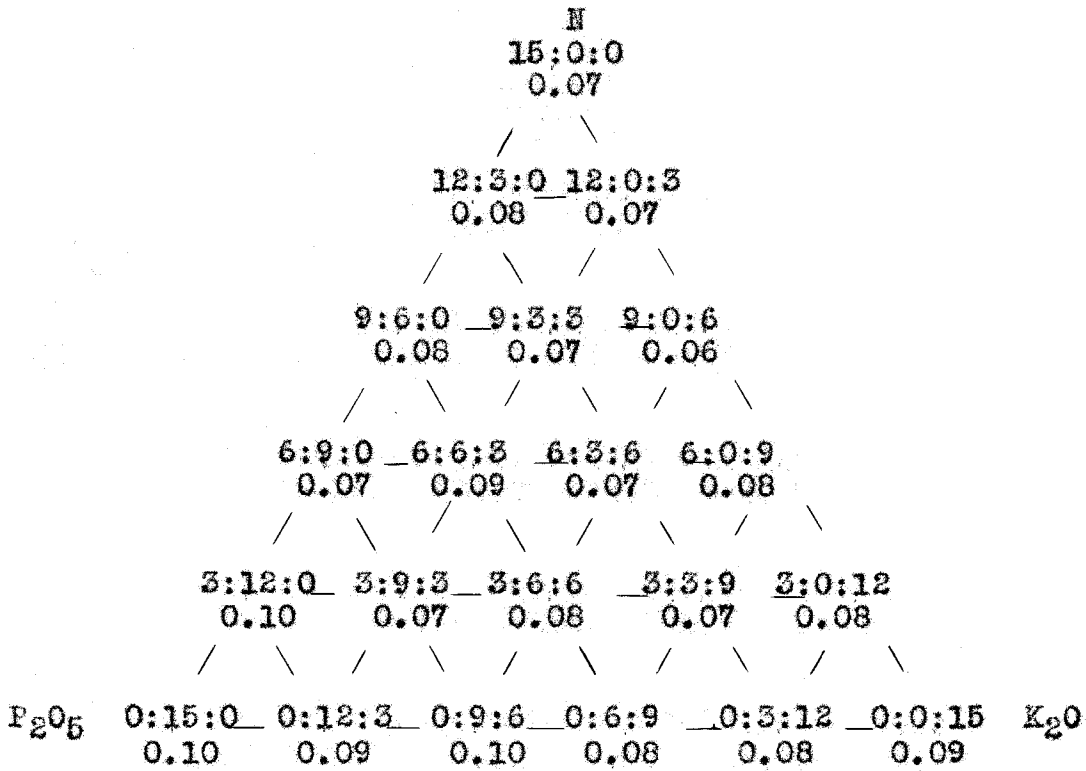
Average of checks = 4.89

Figure 28. Average per cent of soluble ash in air-dried soybean hay, as produced on Norfolk sand, for the years 1930, 1932 and 1933.



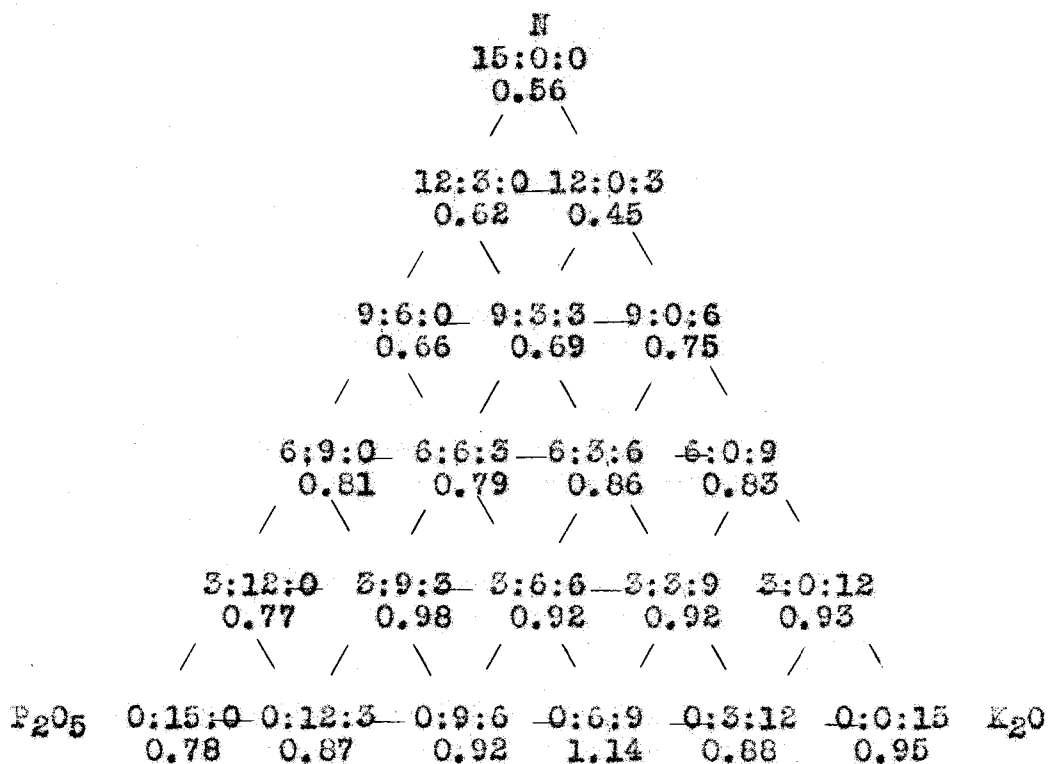
Average of checks = .30

Figure 29. Average per cent of R<sub>2</sub>O<sub>3</sub> in air-dried soybean hay, as produced on Norfolk sand, for the years 1930, 1932 and 1933.



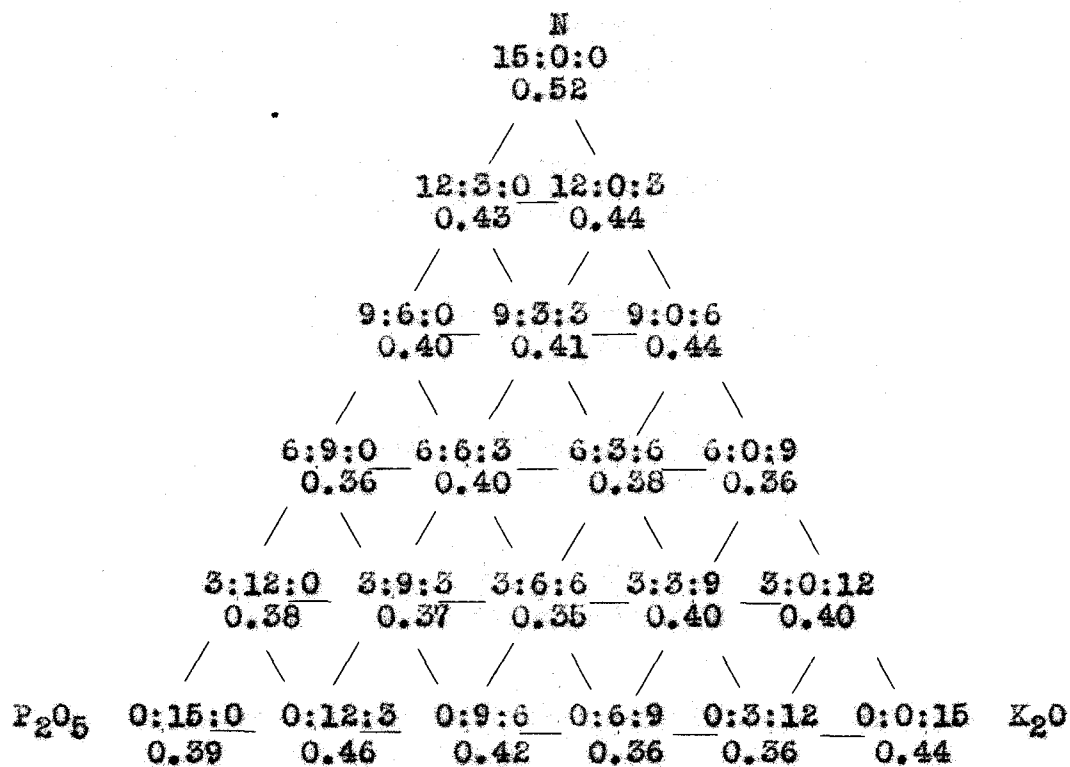
Average of checks = 0.09

Figure 30. Average per cent of MgO<sub>4</sub> in air-dried soybean hay, as produced on Norfolk sand, for the years 1930, 1932 and 1933.



Average of checks = 0.47

Figure 31. Average SO<sub>4</sub> content of air-dried soybean hay, as produced on Norfolk sand, for the years 1930, 1932 and 1933.



Average of checks = 0.60

Figure 32. Average MgO Content of air-dried soybean hay, as produced on Norfolk sand, during the years 1930, 1932 and 1933.



content of the particular material as produced by a variation of the fertilizer ratio.

Although there are some rather definite trends to be observed, the main objective can be reached by averaging these data for the high-phosphate, the high-potash, the high-nitrogen, and the complete fertilizers. For those other than the complete, the fertilizers of 15, 12 and 9 per cent of the particular element or oxide are averaged. Their relative positions in the large triangle are indicated by the smaller ones. These are shown as Figure 33.

The soluble ash of the forage is materially affected by the fertilizer treatment. The highest average ash content is that of the high-potash ratios; the next is from the high-phosphate; and the lowest from the high-nitrogen ratios.

The  $R_2O_3$  and  $Mn_3O_4$  contents are highest in the high-phosphate area of the triangle. The former is considerably larger in that area than in the other two, both of which have equal values. The  $Mn_3O_4$  content shows a gradual increase from the nitrogen to the potash and then to the phosphate apex.

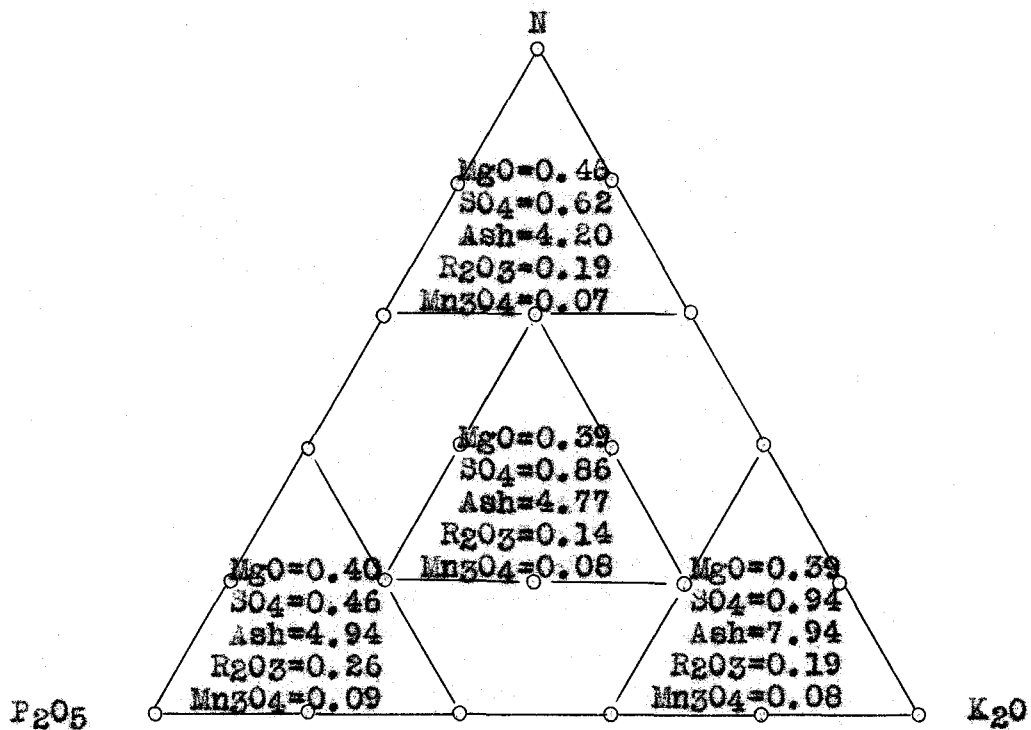


Figure 33. Average MgO, SO<sub>4</sub>, soluble ash, R<sub>2</sub>O<sub>3</sub> and Mn<sub>3</sub>O<sub>4</sub> contents of air-dried soybean hay, as produced on Norfolk sand, for the years 1930, 1932 and 1933.

It is apparent that the sulphate of potash influences the sulphur content of the forage more than does the calcium sulphate of the superphosphate. There is some indication that the sulphur in the hay is not present entirely as protein sulphur. A comparison of Figures 25 and 33 shows that the highest average nitrogen content is produced in the phosphate apex, which also gives the lowest sulphate content. This indicates an inverse rather than a direct relation. The nitrogen apex gives intermediate values in both cases. Inasmuch as the high-nitrogen fertilizers contain sulphate of ammonia to the extent of one-third of the total nitrogen, and these produce a sulphate content intermediate in value, it would appear that the sulphate content, like  $K_2O$ , is influenced by the amount available in the soil.

The magnesium content is expressed as  $MgO$  and is of much interest due to the prevalence of magnesium deficiency on Norfolk sand during seasons in which leaching rains occur. The chief source of magnesium in the fertilizer is the cottonseed meal which is used to furnish nitrogen to the extent of one-third of the total. The crops grown in the green

manure-fertilizer experiment (the photographs are given as Figures 2, 3 and 4) have shown striking differences; those grown with the 2:8:4 fertilizer have displayed the symptoms of the deficiency to a much greater extent than in the case of the 6:8:4. The amount of sulphate applied in the phosphate and sulphate of potash has been the same for both plats, consequently any difference in the retardation or decrease in the development of the deficiency would seem to have been due to the magnesium content of the cottonseed meal. It will be seen from Figure 33 that the average MgO content of samples from the high-phosphate and high-potash plats is essentially the same, but that of the high-nitrogen plats is considerably greater. This is thought to be a reflection of the magnesium applied in the cottonseed meal.

Figures 34 and 35 show cotton and corn leaves which display pronounced symptoms of the magnesium deficiency. The use of fertilizer materials which produce magnesium salts of high solubility increase the tendency toward the development of a deficiency of magnesium in Norfolk sand.

The average contents of soluble ash, MgO, sulphate,



Figure 34. Cotton leaves which show the pattern developed due to a deficiency of magnesium.



Figure 35. Corn leaves showing the typical striping caused by a deficiency of magnesium.

$Mn_3O_4$ , and  $R_2O_3$ , as influenced by the percentage of the element in the fertilizer, are given in Table 8.

The soluble-ash content varies inversely with the nitrogen content of the fertilizer, and directly with the phosphate and potash contents. The high-potash ratio, 3:3:9, produces a greater content than does the high-phosphate; i.e., the 3:9:3 ratio. These data are corroborated by those for the ratios containing 6 and 3 per cent, respectively, of nitrogen,  $P_2O_5$  and  $K_2O$ .

The magnesium content of the hay is influenced more by the nitrogen-bearing materials of the fertilizer than by the phosphate or potash. This influence is not brought out well by a comparison of the data for the 9:3:3, 3:9:3, and 3:3:9 ratios, for the nitrogen content has to be as great as twelve per cent to show appreciable differences.

The sulphate content of the hay varies inversely with the nitrogen applied in the fertilizer. The average of the contents produced by the high-potash ratios, as shown in Figure 35, is greater than for that of the high-phosphate. However, the 3:9:3 ratio induces a content of sulphate which is greater than that given by the 3:3:9.

Table 8. Composition of soybean hay produced by complete and incomplete fertilizers on Norfolk sand, and average data based upon the percentages of the elements used. Data are for the years 1930, 1932 and 1933.

Effect of:	Plats Averaged	Hay - Air-Dry Basis					
		Sol. Ash	MgO	SO <sub>4</sub>	Mn <sub>2</sub> O <sub>4</sub>	R <sub>2</sub> O <sub>3</sub>	
		%	%	%	%	%	
Per Cent:							
Nitrogen	15 12 9 6 3 0 15 12 9 6 3 0 15 12 9 6 3 0	21 15,20 10,14,19 6,9,13,18 3,5,8,12,17 1,2,4,7,11,16 1 2,3 4,5,6 7,8,9,10 11,12,13,14,15 16,17,18,19,20,21 16 11,17 7,12,18 4,8,13,19 2,5,9,14,20 1,3,6,10,15,21	4.04 4.06 4.35 4.61 5.11 5.29 5.81 4.62 4.86 4.72 4.82 4.72 5.67 5.65 4.93 4.87 4.38 4.63	0.52 0.44 0.42 0.38 0.38 0.41 0.39 0.42 0.38 0.38 0.40 0.43 0.44 0.38 0.37 0.40 0.42 0.41	0.56 0.54 0.70 0.82 0.91 0.92 0.78 0.82 0.90 0.88 0.80 0.75 0.95 0.91 0.96 0.86 0.76 0.70	0.070 0.075 0.070 0.077 0.080 0.090 0.100 0.095 0.080 0.083 0.074 0.075 0.090 0.080 0.077 0.078 0.078 0.083	0.25 0.21 0.15 0.18 0.19 0.24 0.21 0.36 0.21 0.16 0.15 0.21 0.25 0.19 0.17 0.16 0.22 0.23
Phosphoric Acid	15 12 9 6 3 0 15 12 9 6 3 0	14 5 12 5,8,9,12,13,14 9,13 5,8,12 8,9 12,13,14 8,13 5,9,14	4.16 4.91 5.21 4.77 4.62 5.07 4.78 4.72 4.94 4.51	0.41 0.37 0.40 0.39 0.39 0.37 0.38 0.40 0.37 0.39	0.69 0.98 0.92 0.86 0.83 0.94 0.86 0.82 0.89 0.82	0.070 0.070 0.070 0.075 0.080 0.073 0.085 0.070 0.075 0.077	0.12 0.16 0.14 0.14 0.14 0.14 0.15 0.12 0.12 0.15
Potash	15 12 9 6 3 0	14 5 12 5,8,9,12,13,14 9,13 5,8,12 8,9 12,13,14 8,13 5,9,14	4.16 4.91 5.21 4.77 4.62 5.07 4.78 4.72 4.94 4.51	0.41 0.37 0.40 0.39 0.39 0.37 0.38 0.40 0.37 0.39	0.69 0.98 0.92 0.86 0.83 0.94 0.86 0.82 0.89 0.82	0.070 0.070 0.070 0.075 0.080 0.073 0.085 0.070 0.075 0.077	0.12 0.16 0.14 0.14 0.14 0.14 0.15 0.12 0.12 0.15
Complete Mixtures:							
High N	9-3-3	14	4.16	0.41	0.69	0.070	0.12
High P <sub>2</sub> O <sub>5</sub>	3-9-3	5	4.91	0.37	0.98	0.070	0.16
High K <sub>2</sub> O	3-3-9	12	5.21	0.40	0.92	0.070	0.14
All Complete		5,8,9,12,13,14	4.77	0.39	0.86	0.075	0.14
N	6	9,13	4.62	0.39	0.83	0.080	0.14
	3	5,8,12	5.07	0.37	0.94	0.073	0.14
P <sub>2</sub> O <sub>5</sub>	6	8,9	4.78	0.38	0.86	0.085	0.15
	3	12,13,14	4.72	0.40	0.82	0.070	0.12
K <sub>2</sub> O	6	8,13	4.94	0.37	0.89	0.075	0.12
	3	5,9,14	4.51	0.39	0.82	0.077	0.15
Av. of Checks	0-0-0		4.89	0.60	0.47	0.090	0.30



The manganese content is influenced by phosphate and potash more than by the nitrogen content of the fertilizer; the differences are rather small in all cases. No symptoms of manganese deficiency have been observed on this soil. A revision of this experiment instituted in 1934, however, showed a considerable response to an application of seventy-five pounds of  $MnSO_4$  per acre in the case of certain plats, with decreased yields in the case of other treatments.

The  $R_2O_3$  content of the forage is larger for the high-phosphate than for the nitrogen or potash ratios. These data show that the content can be varied appreciably.

#### Conclusions

The data which have been obtained on Norfolk sand show that the composition of soybean hay can be influenced materially by the fertilizer used. The triangle system has been of much value in interpreting the changes induced by relatively small variations in the fertilizer ratio. It is evident that the involved relation of the various plant-food elements allows incorrect interpretations to be made unless the effects are studied simultaneously.

The study of twenty-one fertilizer ratios on Norfolk

sand (which approaches the conditions of sand culture, except that field conditions prevail) indicates that potassium is the "key element" in the nutrition of soybeans. The following relations, as obtained under the conditions of this experiment, appear to be pertinent:

(1) The potash content of the hay is in proportion to the amount of potash furnished to the soil by the sulphate of potash. Under some conditions the phosphate aids in the assimilation.

(2) The  $P_2O_5$  content is a reflection of the potash and superphosphate contents of the fertilizer, with the effect of the former dominating.

(3) The nitrogen content varies directly with the amount of phosphate in the fertilizer. When only the high-phosphate and high-nitrogen ratios are considered, there is an apparent direct relation between the  $P_2O_5$  content of the fertilizer and the nitrogen content of the hay. Inasmuch as the greatest  $P_2O_5$  content is produced by the high-potash ratios, it would appear that the nitrogen content is more directly affected by the calcium content of the fertilizer, and in turn by the calcium oxide content of the plant. The order for a high CaO content, from highest to lowest, is: (a) high-phosphate,

(b) high-nitrogen, and (c) high-potash ratios; this is also the order for the nitrogen content of the forage.

(4) The  $\text{CaO}:\text{P}_2\text{O}_5$  ratio can be varied widely by the fertilizer used. A value approaching the optimum ratio (for feeds) of 2:1 is attained only within a limited range; i.e., by the use of the 9:3:3, 6:3:6, and 3:3:9 ratios. The six-year average of yields of hay obtained with the 9:3:3 was second to the 3:9:3 average. Some sacrifice in yield and nitrogen and phosphate contents had to be made in order to approach an optimum  $\text{CaO}:\text{P}_2\text{O}_5$  ratio.

(5) The  $\text{CaO}:\text{K}_2\text{O}$  ratio indicates a physiological balance in the plant. The perfect inverse relation of these two elements is strikingly illustrated.

(6) The highest individual soluble-ash content is produced by the 0:15:0 ratio. The average of the high-potash ratios, however, is greater than that of the high-phosphate, with the nitrogen ratios of lowest average content.

(7) The magnesium content, expressed as  $\text{MgO}$ , is thought to be a reflection of the amount of cottonseed meal used as one of the sources of nitrogen.

(8) The percentage of manganese contained in the forage can be influenced but slightly by fertilizers

compounded from ordinary materials. The phosphatic fertilizers induce a higher content than is obtained by the use of the potash or nitrogen ratios. This is true also for the  $R_2O_3$  content.

There is evidence which points to an opportunity for the production of forage of wide variation in composition for nutritional studies with animals, and for the study of the effect of fertilizers on forage crops in general.

THE EFFECT OF FERTILIZER RATIOS ON THE  
YIELD AND COMPOSITION OF SOYBEAN SEED

The soybean plant serves a dual purpose in that it is used as a forage and producer of seed; the acreage used for the latter purpose has increased appreciably during the last 25 years. The seed serves as a source of protein and oil; both of these are of commercial importance. The relation of fertilizers to the yield, and oil and protein content should be considered; this experiment was outlined with these points in mind.

Literature Cited

Schuster and Graham (132) studied the variation in the oil content of soybeans; they found that single elements and a complete fertilizer had no effect. Statistical treatment of the data gave a very significant decrease when a combination of nitrogen and phosphorus was used on unlimed soil, also with phosphorus and potassium, and with nitrogen and potassium. Lime decreased the oil content of beans produced on unfertilized soil but not where fertilizer was used. A decrease in the oil content was usually associated with an increase in the protein content. Schuster (132) found a large percentage of immature beans when potassium was not used. Nitrate of

soda did not favor yield or maturity.

Webster and Kiltz (165) studied the seasonal variation in the oil and protein contents of different varieties, giving four- and five-year averages; a considerable variation in composition was found. The protein and oil content varied inversely. Variations in oil content as great as 3.24 per cent and in protein as great as 12.5 per cent were found in the same variety grown at different locations.

Fellers (46) obtained a decrease of three per cent in the oil content of soybeans due to inoculation; this was accompanied by an increase in protein of seven per cent. Phosphorus and nitrate of soda increased the protein content. Potassium affected oil and protein but slightly. Various combinations of nitrogen, phosphorus and potassium increased yields of both hay and seed. Calcium sulphate applied in large amounts increased the oil content.

Garner et al. (53) state that conditions conducive to carbohydrate formation are necessary during the maturation period for the production of oil. Different varieties show marked differences in oil content. The conclusion is drawn that climate is a more important factor than soil type, and that, within reasonable limits, the relative fertility of the soil is of minor importance in influencing

the oil content of soybeans.

Kornfeld (84) found that fertilizers increased the protein content and decreased the oil content of soybeans. This general relation holds for the investigations which have been cited.

#### Experimental

The plots used are those described in Section II.

#### Discussion

##### 1. Yields data.

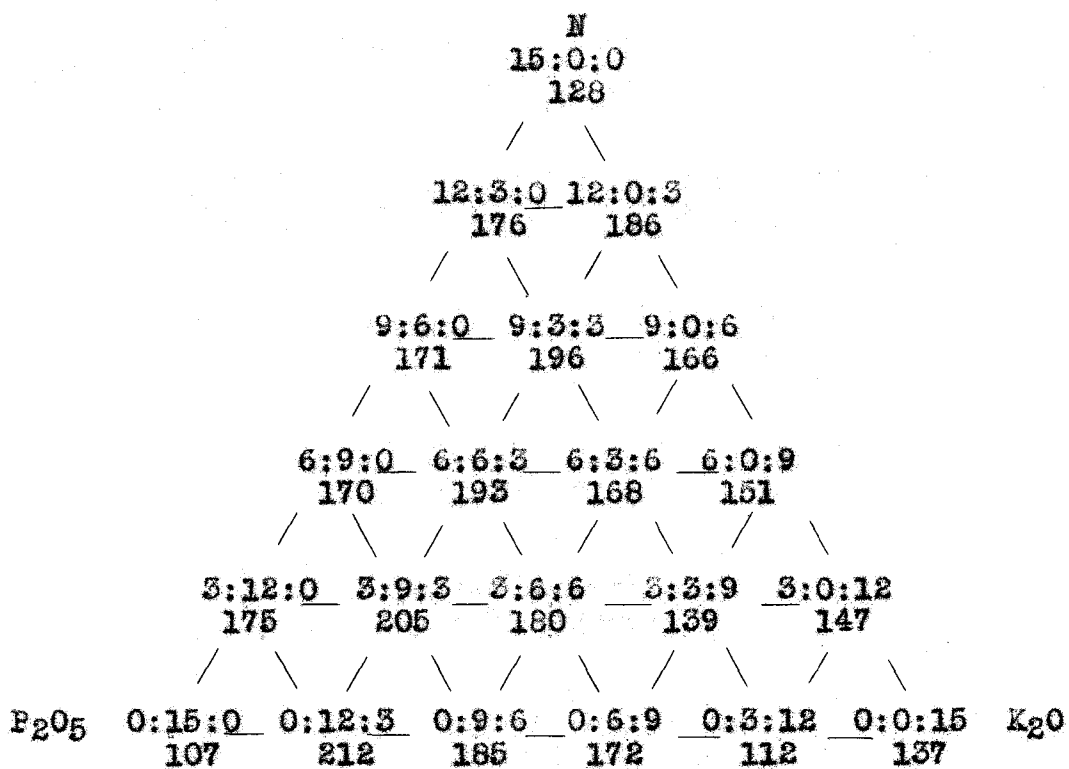
The yields of soybean seed for the years 1928 to 1933, inclusive, and the average yields for the six-year period are given in Table 9. These average data show that the 0:12:3 ratio has produced the largest yield, and this is followed in order by the 3:9:3 and 9:3:3 ratios. The use of a combination bean, the Biloxi, has resulted in low yields of both hay and seed.

Figure 36 presents the average yields of seed by means of the triangle. The variation in yields, due to variable fertilizer ratios, is from 107 to 212 pounds per acre. The highest yields are along the line representing the ratios containing three per cent of potash. As the phosphate content of the fertilizer increases along this line there is a small increase in the yield of beans.

Table 9. Yields of soybean seed, in pounds per acre, produced on Norfolk sand by incomplete and complete fertilizers, and average data for the period 1928 to 1935.

Plot	N-P <sub>2</sub> O <sub>5</sub> -K <sub>2</sub> O	1928	1929	1930	1931	1932	1933	1935	Av.
		Lbs./A	Lbs./A	Lbs./A	Lbs./A	Lbs./A	Lbs./A	Lbs./A	Lbs./A
1	0-15-0	133	222	85	59	76	65	107	
2	0-12-3	111	310	243	74	247	285	212	
3	3-12-0	126	245	220	82	211	167	175	
4	0-9-6	133	308	243	49	167	212	185	
5	3-9-3	144	314	270	84	207	211	205	
6	6-9-0	118	243	228	84	199	148	170	
7	0-6-9	108	333	198	74	138	182	172	
8	3-6-6	79	273	227	75	214	214	180	
9	6-6-3	90	260	272	82	237	214	193	
10	9-6-0	90	218	247	127	196	146	171	
11	0-3-12	72	132	175	72	102	117	112	
12	3-3-9	90	151	216	74	139	163	139	
13	6-3-6	90	216	255	97	185	167	168	
14	9-3-3	97	218	288	94	265	211	196	
15	12-3-0	79	189	252	125	221	191	176	
16	0-0-15	90	218	211	72	130	99	137	
17	3-0-12	108	268	180	79	127	121	147	
18	6-0-9	97	218	232	77	155	129	151	
19	9-0-6	79	193	252	94	220	159	166	
20	12-0-3	90	176	301	112	264	173	186	
21	15-0-0	97	122	245	103	140	59	128	
Av. of									
Checks	0-0-0	63	111	74	37	44	29	60	





Average of checks = 60

Figure 36. Average yields of soybean seed, in pounds per acre, as produced on Norfolk sand, for the period 1928 to 1933.

Figure 37 shows the average yields of the high-phosphate, high-nitrogen and high-potash ratios. The yields are 176, 171 and 143 pounds per acre, respectively. The average for all the complete fertilizers is 180 pounds.

The yields, averaged according to the percentage of a particular element in the ratio, are given in Table 10. These data indicate a 12:12:3 ratio for the production of soybean seed on Norfolk sand. This becomes a 6.7:6.7:1.6 ratio when reduced to a fifteen per cent basis. It is not in accord with the general conception for such a low amount of potash to be indicated for seed production. The highest yield, as has been mentioned, has been from the 0:12:3 plat with the 3:9:3 ranking second. The latter yield is only slightly superior to that of the 9:3:3 plat, but is considerably above that of the 3:3:9.

## 2. Composition of seed.

Tables 11 and 12 give the percentages of nitrogen and oil in the seed for each year of the experiment, and also the averages for the five years.

a. Nitrogen content. The average nitrogen content of the seed is presented by means of the triangle as Figure 38. Mixtures of only phosphate and potash

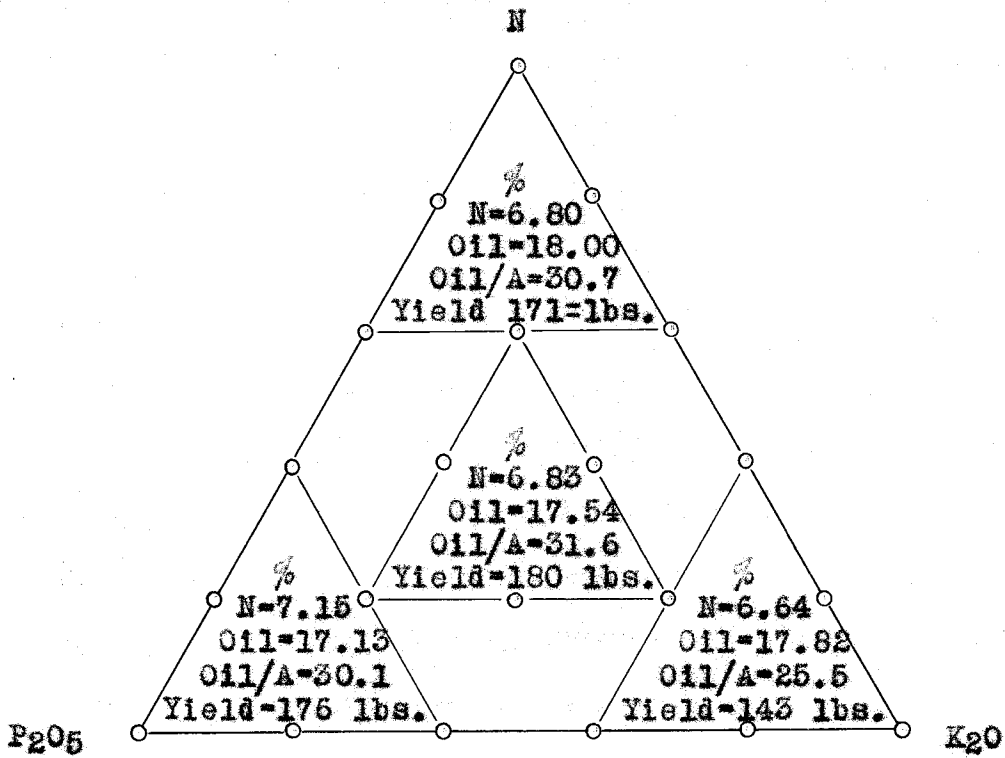


Figure 37. Average per cent of nitrogen and oil, and yields of seed and oil in pounds per acre, as produced on Norfolk sand for the period of 1928 to 1933 for yields and 1929 to 1933 for the percentage composition.

Table 10. Yields of soybean seed and oil and composition of seed produced on Norfolk sand with complete and incomplete fertilizers, with average data based upon the percentages of the elements used. Data are for the period 1928 to 1933.

Effect of:	Plats Averaged	Soybean Seed		Oil lbs./A	
		Yields lbs./A	%		
Per Cent:					
Nitrogen	21 15, 20 10, 14, 19 6, 9, 13, 18 3, 5, 8, 12, 17 1, 2, 4, 7, 11, 16 1 2, 3 4, 5, 6 7, 8, 9, 10 11, 12, 13, 14, 15 16, 17, 18, 19, 20, 21 16 11, 17 7, 12, 18 4, 8, 13, 19 2, 5, 9, 14, 20 1, 3, 6, 10, 15, 21	128 181 178 171 169 154 107 194 187 179 158 153 137 130 154 175 198 155	6.88 6.73 6.82 6.84 6.88 6.90 7.19 7.24 7.07 6.87 6.72 6.66 6.56 6.53 6.74 6.82 6.91 7.04	17.95 18.27 17.84 17.60 17.54 17.39 17.19 17.07 17.16 17.65 17.68 18.11 17.94 17.88 17.74 17.55 17.61 17.55	23.0 33.1 31.7 30.0 29.6 26.7 18.4 33.0 32.0 31.6 28.0 27.7 24.6 23.2 27.3 30.6 35.0 27.1
Phosphoric Acid	14 5 12 5, 8, 9, 12, 13, 14 9, 13 5, 8, 12 8, 9 12, 13, 14 8, 13 5, 9, 12	196 206 159 180 161 175 187 168 174 198	6.83 7.02 6.74 6.83 6.79 6.87 6.85 6.76 6.78 6.90	17.63 17.17 17.70 17.54 17.53 17.52 17.65 17.59 17.57 17.47	34.6 35.2 24.6 31.6 31.7 30.5 32.9 29.8 30.6 34.6
Potash	14 5 12 5, 8, 9, 12, 13, 14 9, 13 5, 8, 12 8, 9 12, 13, 14 8, 13 5, 9, 12	60	6.85	17.37	10.4
Complete Mixtures:					
High N	9-3-3				
High P <sub>2</sub> O <sub>5</sub>	3-9-3				
High K <sub>2</sub> O	3-3-9				
All Complete N	6				
P <sub>2</sub> O <sub>5</sub>	3				
K <sub>2</sub> O	6				
AV. of Checks	0-0-0				



Table 12. Average per cent of oil in soybean seed, as produced on Norfolk sand, for the period 1929 to 1933.

Flat	N-P <sub>2</sub> O <sub>5</sub> -K <sub>2</sub> O	Per Cent of Oil					Av.
		1929	1930	1931	1932	1933	
1	0-15-0	17.65	17.31	17.90	16.65	16.45	17.19
2	0-12-3	17.20	17.49	17.41	16.64	16.11	16.97
3	3-12-0	17.50	17.25	17.82	16.77	16.47	17.16
4	0-9-6	17.40	17.45	17.00	16.31	15.97	16.83
5	3-9-3	17.79	17.88	17.64	16.22	16.30	17.17
6	6-9-0	18.23	17.76	18.00	16.07	17.34	17.48
7	0-6-9	18.54	18.70	17.98	16.25	16.76	17.65
8	3-6-6	18.50	18.62	17.96	16.47	16.88	17.69
9	6-6-3	18.42	18.43	17.79	16.49	16.93	17.61
10	9-6-0	17.86	17.96	17.88	17.21	17.33	17.65
11	0-3-12	18.22	18.18	17.94	17.20	17.28	17.76
12	3-3-9	18.00	18.79	17.75	16.60	17.36	17.70
13	6-3-6	18.80	17.59	17.64	16.58	16.57	17.44
14	9-3-3	18.50	18.02	17.69	16.56	17.39	17.63
15	12-3-0	18.78	18.38	17.65	17.57	16.93	17.86
16	0-0-15	18.78	18.15	17.98	17.72	17.08	17.94
17	3-0-12	18.98	18.51	17.84	17.10	17.55	18.00
18	6-0-9	19.01	18.72	17.35	17.14	17.14	17.87
19	9-0-6	19.08	18.62	17.67	18.01	17.83	18.24
20	12-0-3	19.05	18.54	18.39	19.12	18.23	18.67
21	15-0-0	18.67	17.86	17.95	17.42	17.84	17.95
Ck. 1	0-0-0	18.21	18.31	17.55	16.19	16.63	17.38
Ck. 2	0-0-0	18.20	18.05	17.28	16.64	16.64	17.36
Av. Cks.							17.37

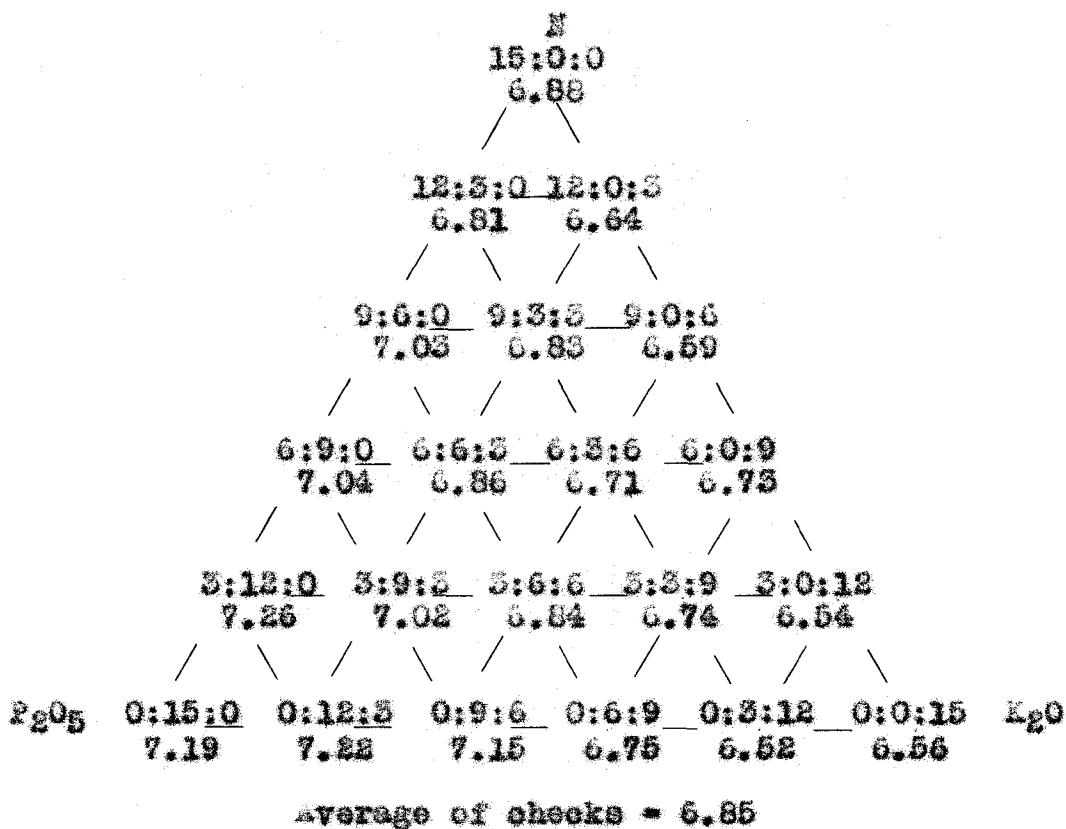


Figure 38. Average per cent of nitrogen in soybean seed, as produced on Norfolk sand, for the period 1929 to 1933.

produce a nitrogen content ranging from 6.52 to 7.22 per cent; the 0:0:15 and 0:15:0 ratios give 6.56 and 7.19 per cent, respectively. There is a tendency toward an increase in the nitrogen of the seed when the phosphate content of the fertilizer is increased at the expense of the potash. This is more pronounced when the nitrogen of the ratio is held constant at three per cent; there is a gradual increase in the nitrogen content from the 3:0:12 to the 3:12:0 ratio. With nitrogen held at six per cent in the ratio, the continuity is evident from the 6:3:6 to the 6:9:0 ratio. The trend is the same at the 9 and 12 per cent levels.

When the phosphate in the fertilizer is held constant at the three lower levels; i.e., at 0, 3 and 6 per cent, an increase in nitrogen, with potash decreasing in the ratio, produces a general increase in the nitrogen content of the seed. There is a split trend at the nine per cent level as there is a slight increase from the 3:9:3 to the 6:9:0 ratio, and a larger increase from the 3:9:3 to the 0:9:6 ratio. This latter case, and the increases from the 0:3:12 and 3:0:12 ratios to the 0:0:15, are the instances in which an



increase in the potash content of the fertilizer causes an increase in the nitrogen content of the seed.

The highest nitrogen content is in seed produced by the 3:12:0 ratio. This was true also for the hay. Collins <sup>1/</sup> has found that the ratio which produces a high-nitrogen content in cotton seed also produces the same in the plant.

Holding potash constant at all levels results in an increase in the nitrogen of the seed when the phosphate of the ratio is increased. This is true, in general, for mixtures of two or more fertilizer ingredients.

The average nitrogen contents produced by the ratios high in phosphate, nitrogen and potash are given in Figure 37. The content is 7.15, 6.80 and 6.64 per cent, respectively. These data are in agreement with those for the nitrogen content of the hay samples, as given in Figure 21, and the relations postulated in that discussion are

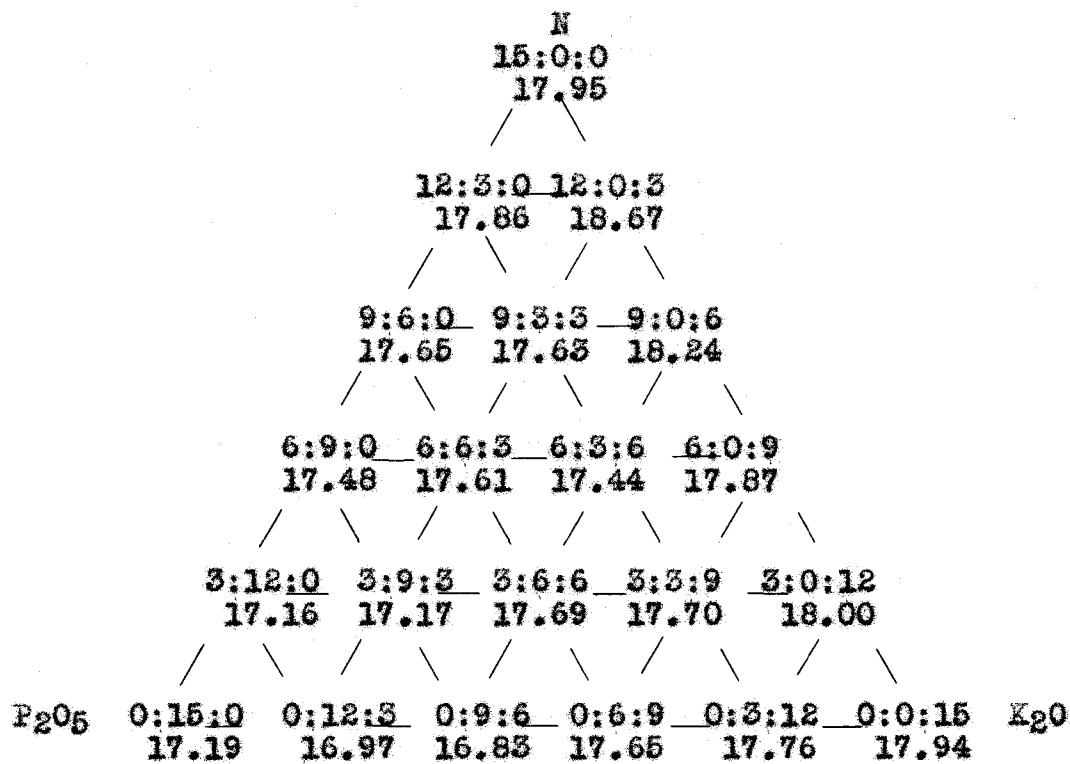
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<sup>1/</sup> From unpublished data obtained by Dr. E. R. Collins of the Soil Fertility Station, Bureau of Plant Industry, Austin, Texas; present location - North Carolina Experiment Station.

pertinent here. The phosphate content of the fertilizer is more effective in influencing the nitrogen content of the seed than the nitrogen of the fertilizer, and nitrogen more than the potash.

The averages given in Table 10 indicate a ratio high in phosphate and low in potash for the production of seed of high-nitrogen content. The complete high-nitrogen ratio (9:3:3) gives a value less than that of the 3:9:3, but greater than that of the 3:3:9 ratio. These values are 6.83, 7.02 and 6.74 per cent, respectively.

- b. Oil content. The oil contents of the soybean seed are given in Table 12 for each year of the experiment (1929-1933), together with the average for the five years. The five-year averages are shown graphically in Figure 39. The highest oil content is that produced by the 12:0:3 ratio. It is interesting to note that the highest nitrogen content came from the 3:12:0 ratio, inasmuch as an inverse relation between the nitrogen and oil content usually exists for a particular sample. The variations in the oil content are not as great as have been reported for varieties, or for the seasonal variation for the same variety. These



Average of checks = 17.37

Figure 39. Average per cent of oil in soybean seed, as produced on Norfolk sand, for the period 1929 to 1933.

averages, however, should have considerable weight because of the number of seasons involved.

When the nitrogen of the fertilizer is held constant, there is a tendency for the oil content to increase with an increase in the amount of potash in the fertilizer, especially when the potash content is fairly high. This tendency is greater when the nitrogen in the fertilizer is low in amount. The trend for the mixtures of phosphate and potash varies; the 0:9:6 ratio is the focal point. As the change is made from the 0:9:6 to the 0:15:0 ratio, there is an increase in the oil content which is also true when going from the 0:9:6 to the 0:0:15 ratio; the increase, however, is entirely in proportion to the increase in potash at the three per cent nitrogen level. The trend is again divided at the six and nine per cent levels, but is in favor of the potash at the twelve per cent nitrogen level.

The most definite trends are to be observed when potash is held constant. A decrease in the phosphate content of the fertilizer accompanied by an increase in the nitrogen results in a higher oil content; this is true for all potash levels.

The relative effects of fertilizers of high-phosphate, high-nitrogen and high-potash content are shown by the data given in Figure 37. The average oil content of the high-nitrogen ratios is 18.00 per cent; of high-phosphate, 17.13; and of high-potash, 17.82 per cent. This would indicate that some difference in the oil content of soybeans can be expected as a result of fertilizer treatment.

The nitrogen-oil ratio is 0.42:1 for the high-phosphate plats, 0.37 for the high-potash, and 0.38 for the high-nitrogen ratios.

- c. Average relative nitrogen and oil contents produced by high-nitrogen, phosphate and potash ratios. The averages obtained in Table 10 indicate that a fertilizer containing twelve per cent nitrogen, fifteen per cent potash, and no phosphate can be expected to produce the highest percentage of oil. When reduced to a fifteen per cent basis, this becomes a 6.6:0:8.4 ratio. The ratios approaching this value did not, however, give as large an oil content as that of the 3:0:12 ratio. A comparison of the contents for the 9:3:3, 3:9:3, and 3:3:9 ratios shows that the 3:3:9 is

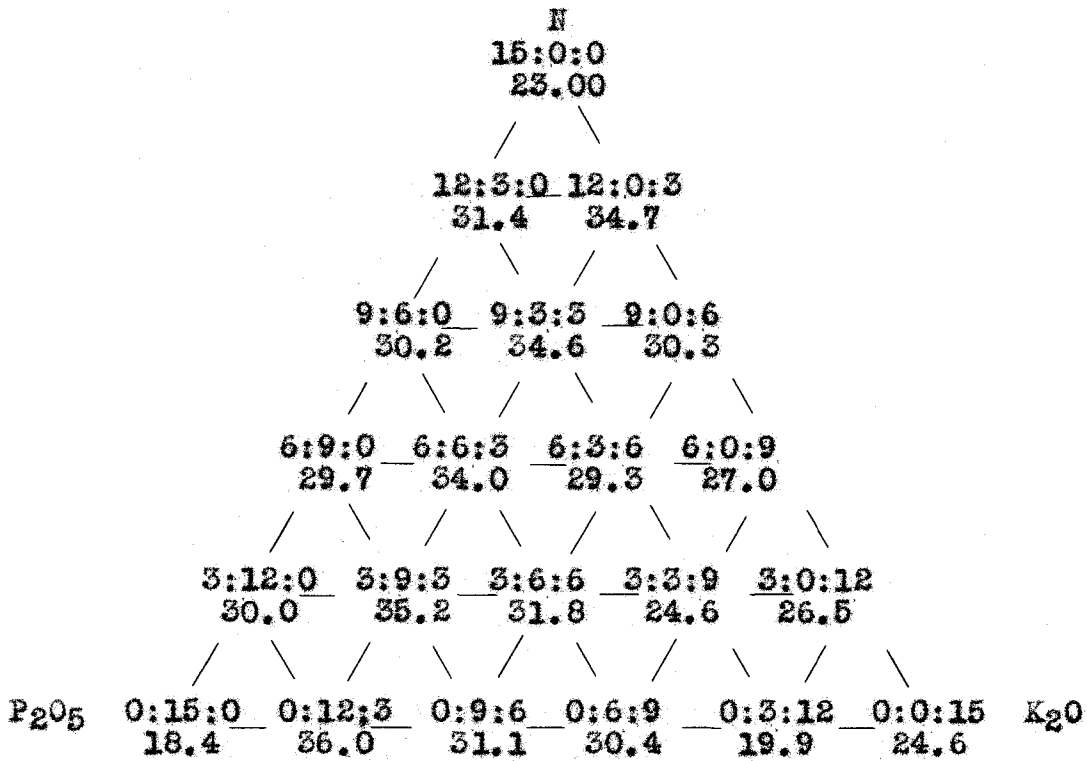
slightly superior, with the 9:3:3 and 3:9:3 in the order given. The data as a whole point to a definite need for nitrogen and potash with little or no need for phosphate for the production of a high percentage of oil.

The average production of oil, in pounds per acre, for which a table is not given, is shown in Figure 40. The largest production is that of the 0:12:3 ratio while the other ratios of the three per cent potash level are but slightly less. The averages given in Figure 37 show that for production, in terms of pounds per acre, the need is for nitrogen and phosphate rather than for nitrogen and potash. The averages given in Table 10 support this conclusion.

#### Conclusions

The yields of soybean seed have been low throughout the experiment. The data are of interest inasmuch as they indicate the effects to be obtained from fertilizers of various ratios, when used on Norfolk sand.

The need for potash for the production of seed is low, as for the production of hay. Little nitrogen is required but a definite need for phosphate is shown. The data show, however, that if a comparison were made of



Average of checks = 10.4

Figure 40. Average yield of oil, in pounds per acre, from soybean seed produced on Norfolk sand for the period 1929 to 1933.

high-phosphate and high-nitrogen ratios little difference in yields of seed could be expected.

The factors which control the nitrogen content of soybean hay also operate for the seed. High-phosphate ratios produce a higher content than high-nitrogen, and the high-potash ratios produce the lowest content.

The same fertilizer ratio cannot be used for both oil content and oil production. Nitrogen and potash, with little or no phosphate, favor a high oil content. Nitrogen and phosphate, with a small amount of potash, are indicated for production.



THE EFFECT OF FERTILIZER RATIOS AND CROP  
MANAGEMENT ON THE RELATION OF CARBON AND  
NITROGEN, AND THE pH OF NORFOLK SAND

The effects of the fertilizer treatments and crop managements on the soil used in the rotation experiment are accentuated by some of the less rational treatments used in the production of soybean forage. The continued use of fertilizers of varying ratios and the diversified crop management have modified the original fertility and other properties of the Norfolk sand. This phase of the experiment which follows was formulated to obtain information: (1) in regard to the capacity of this soil to retain added organic matter, (2) the effect of these residues on the relation of carbon and nitrogen, and (3) to study the combined residual effect on the soil of the residues and fertilizers, under different systems of crop management.

Literature Cited

The resume given in the green manure and fertilizer study is applicable here.

Experimental

Attention is again called to Figure 10. The area was divided into three sections for the soil studies and these were designated as A, B and C. The seed from the

21 plats of Section A were allowed to mature, threshed, the hay returned to the plat on which it was produced and disced in sufficiently to prevent blowing. Section B received the crop as a green manure, while the hay was removed from C, at the same time it was turned on B, and the stubble turned. These variations in management allow a comparison to be made of their effects upon the soil organic matter and the pH. The crops were grown with the 21 fertilizer ratios already discussed and on two unfertilized checks for each system of management.

#### Discussion

The gains or losses of carbon or nitrogen, and the change in pH are given in Table 13. This method of presentation is preferable to the statement of actual values. The changes in the carbon-nitrogen ratio are given only in triangle form.

#### 1. Carbon and nitrogen relation.

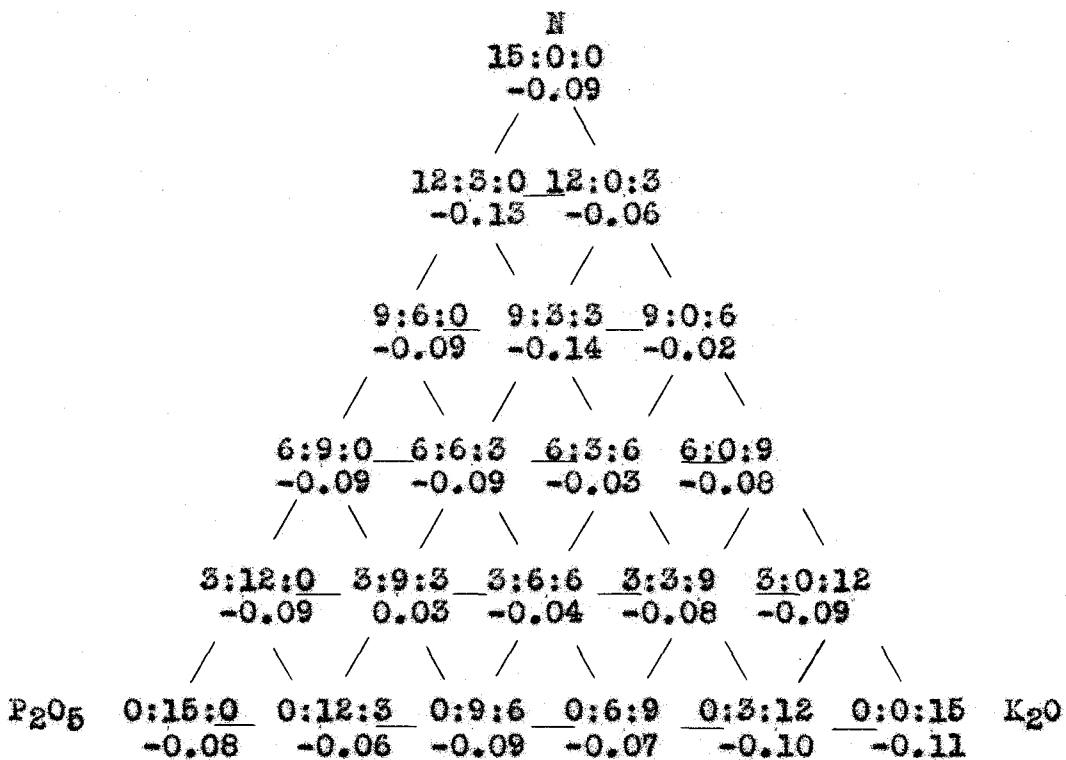
These differences in carbon content, which are assumed to be differences in the organic fraction rather than charcoal, are depicted by Figures 41, 42, and 43 for Sections A, B and C, respectively. They represent the change between the samples of March, 1929, to March, 1934. There is but one gain registered; it is the 3:9:3 plat of Section A. The

Table 13 (Part 1). Gain or loss of organic carbon and nitrogen and change in the pH as influenced by the fertilizer treatment and crop management used on Norfolk sand.

	Plat N-P <sub>2</sub> O <sub>5</sub> -K <sub>2</sub> O	Org.C.	Org.N.	pH	Plat N-P <sub>2</sub> O <sub>5</sub> -K <sub>2</sub> O	Org.C.	Org.N.	pH	
1A	0-15-0	-0.08	0.001	-0.94	8A	5-6-6	-0.04	0.002	-0.89
B		-0.08	0.002	-0.90	B		-0.10	0.002	-1.16
C		-0.13	-0.002	-0.56	C		-0.10	0.000	-1.18
2A	0-12-3	-0.06	0.000	-1.11	9A	6-6-3	-0.09	0.002	-0.46
B		-0.07	0.004	-0.91	B		-0.08	0.003	-0.48
C		-0.07	-0.004	-0.14	C		-0.11	0.000	-0.63
3A	3-12-0	-0.09	0.001	-0.68	10A	9-6-0	-0.09	0.001	-0.56
B		-0.07	0.004	-0.64	B		-0.07	0.002	-0.39
C		-0.10	-0.004	-0.46	C		-0.14	0.000	-0.49
4A	0-9-6	-0.09	-0.001	-0.59	11A	0-3-12	-0.10	-0.001	-0.82
B		-0.06	0.002	-0.57	B		-0.11	0.000	-0.29
C		-0.10	-0.003	-0.47	C		-0.11	-0.002	-0.22
5A	3-9-3	0.03	0.002	-0.64	12A	3-3-9	-0.08	0.001	-0.67
B		-0.11	0.003	-0.33	B		-0.13	-0.002	-0.46
C		-0.03	-0.003	-0.21	C		-0.16	-0.003	-0.19
6A	6-9-0	-0.09	-0.002	-1.08	13A	6-3-6	-0.03	0.003	-0.56
B		-0.06	0.006	-1.26	B		-0.12	0.002	-0.33
C		-0.16	-0.004	-1.08	C		-0.13	0.000	-0.05
7A	0-6-9	-0.07	0.001	-1.08	14A	9-3-3	-0.14	0.002	-0.44
B		-0.17	0.001	-1.20	B		-0.14	0.000	-0.38
C		-0.19	-0.003	-0.84	C		-0.11	0.001	-0.09

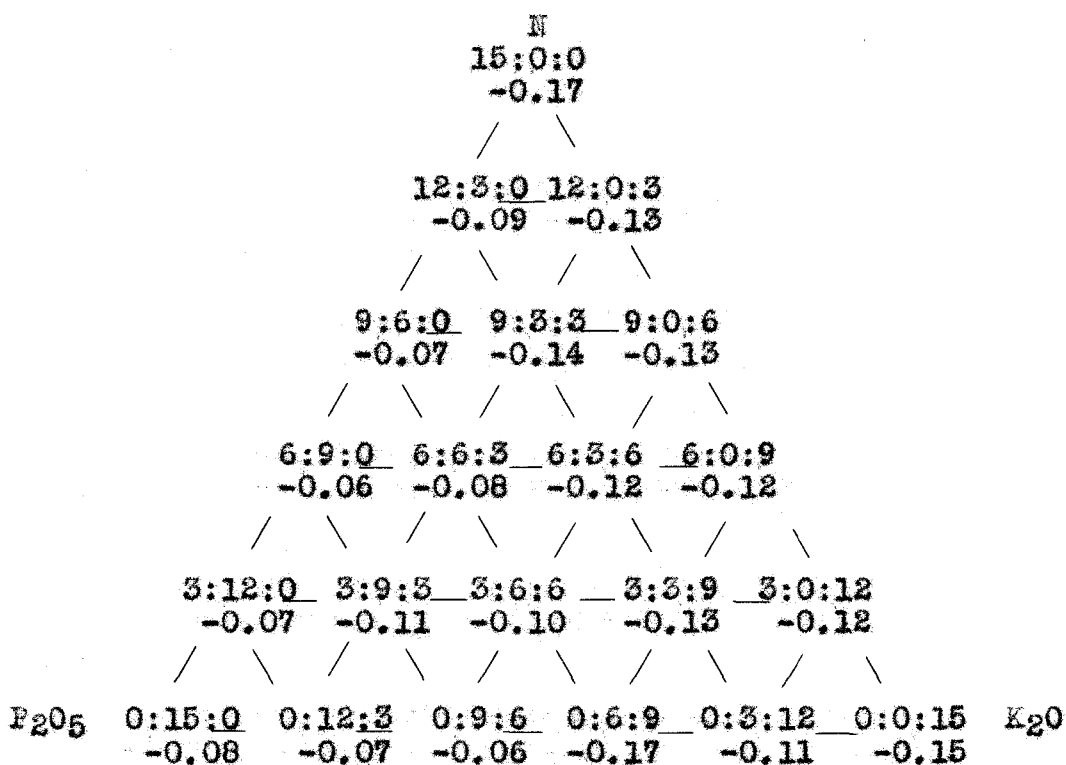
Table 15. (Part 2). Gain or loss of organic carbon and nitrogen and change in the pH as influenced by the fertilizer treatment and crop management used on Norfolk sand.

Plot N-P205-K90		Org.C.	Org.N.	pH		Plot N-P205-K20		Org.C.	Org.N.	pH
15A	12-3-0	-0.13	0.003	-0.78	20A	12-0-5	-0.06	0.003	-0.27	
B		-0.09	0.001	-0.51	B		-0.13	-0.003	-0.39	
C		-0.15	-0.002	-0.55	C		-0.15	-0.004	-0.33	
16A	0-0-15	-0.11	-0.001	-0.59	21A	15-0-0	-0.09	0.003	-0.55	
B		-0.15	-0.002	-0.27	B		-0.17	-0.002	-0.14	
C		-0.10	-0.003	-0.20	C		-0.09	-0.004	-0.55	
17A	3-0-12	-0.09	0.003	-0.76	21A	0-0-0	-0.20	-0.004	-0.17	
B		-0.12	0.000	-0.29	B		-0.09	-0.001	-1.00	
C		-0.15	-0.002	-0.46	C		-0.07	-0.002	-1.02	
18A	6-0-9	-0.08	0.002	0.09	21A	0-0-0	-0.20	0.000	-0.15	
B		-0.12	0.000	0.22	B		-0.18	-0.003	-0.30	
C		-0.12	-0.004	0.00	C		-0.19	-0.004	-0.01	
19A	9-0-6	-0.02	0.002	0.04						
B		-0.15	-0.001	0.15						
C		-0.08	-0.002	-0.48						



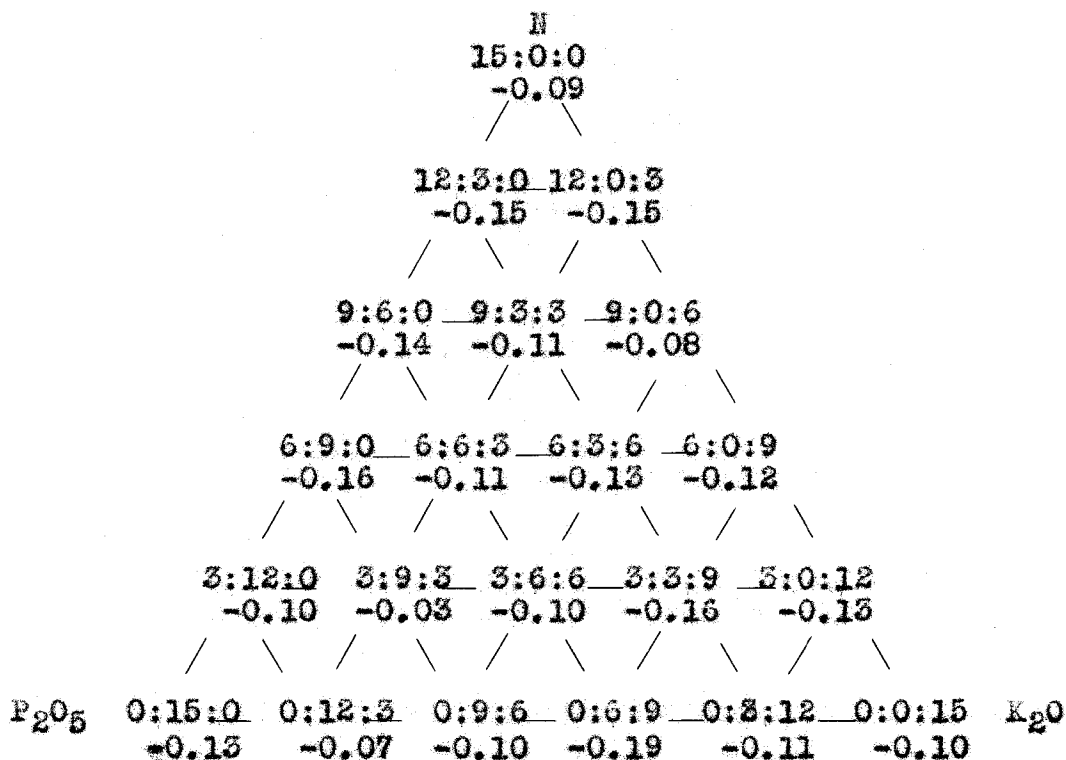
Average of checks = -0.20

Figure 41. Section A - Gain or loss in the percentage of organic carbon in Norfolk sand from March, 1929, to March, 1934. Mature hay turned.



Average of checks = -0.14

Figure 42. Section B - Gain or loss of organic carbon in Norfolk sand from March, 1929, to March, 1934. Crop turned as green manure.



Average of checks = -0.08

Figure 43. Section C - Loss in the percentage of organic carbon in Norfolk sand from March, 1929, to March of 1934. Hay removed from plat and stubble turned.

lack of outstanding trends in the change in the carbon content induced by the factors concerned makes Figure 44 particularly useful.

The nitrogen data are given in Figures 45, 46, 47 and 48.

The changes in the carbon-nitrogen ratio are given in triangular form as Figures 49, 50, 51 and 52.

The carbon and nitrogen data are summarized in Table 14 for discussion and are taken from Figures 44, 48 and 52. These average data show that large losses of organic carbon occurred during the 6 years of the experiment. The gain of the 3:9:3 ratio of Section A is masked by the losses for the other high-phosphate plats. All check plats show losses of both carbon and nitrogen, as well as all plats of Section C where only the stubble was turned. There is considerable variation in the amount to which the ratio has decreased; this decrease is accentuated if the loss of carbon has been accompanied by a gain in nitrogen.

The high-nitrogen ratios have produced an average gain of 0.002 per cent nitrogen on Section A, but losses have occurred on Sections B and C. There was neither gain nor loss for the high-phosphate fertilizers



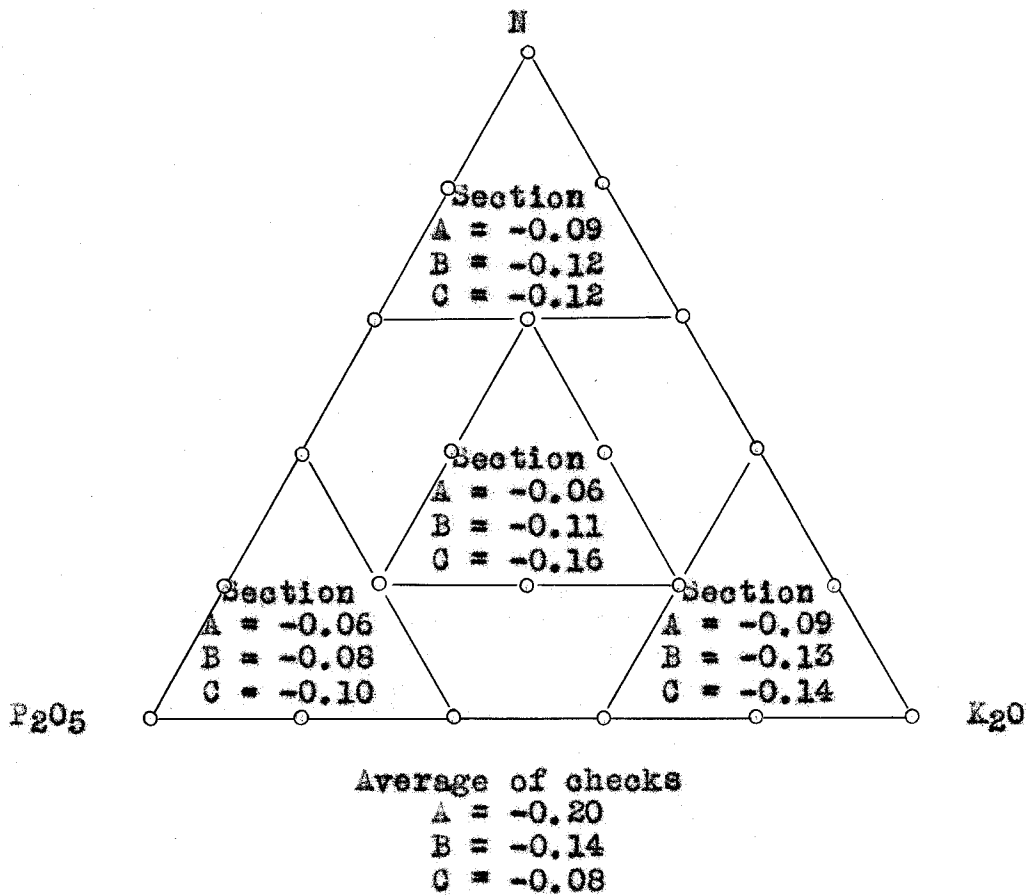
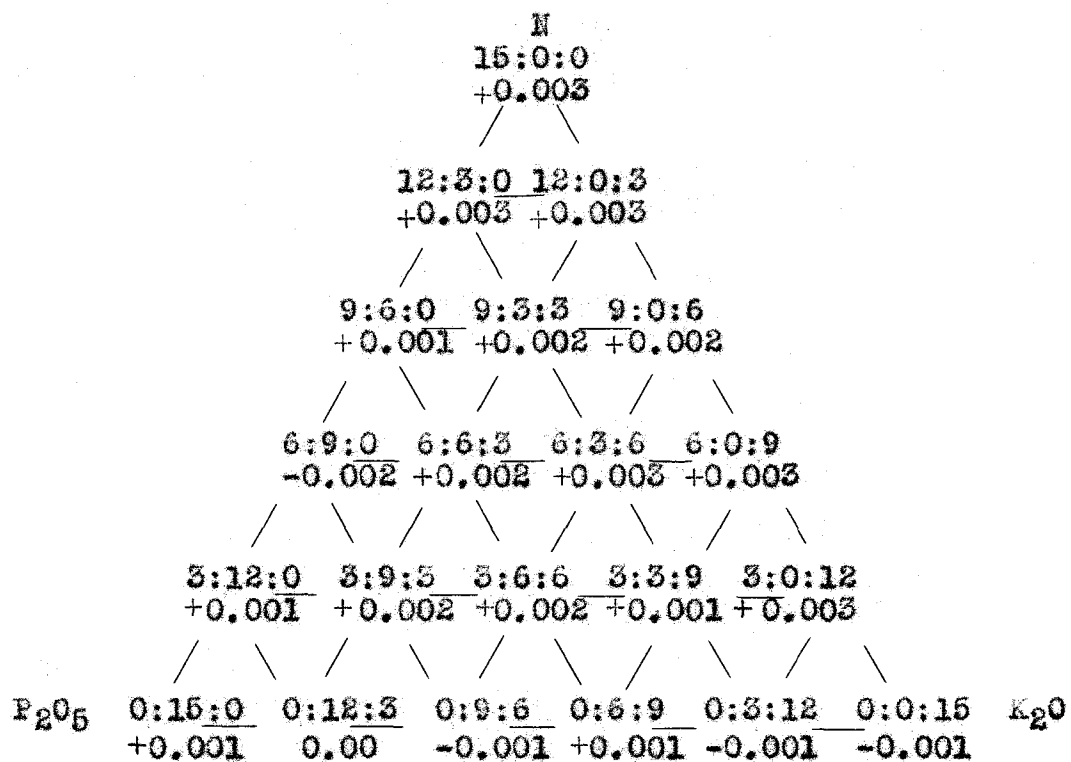
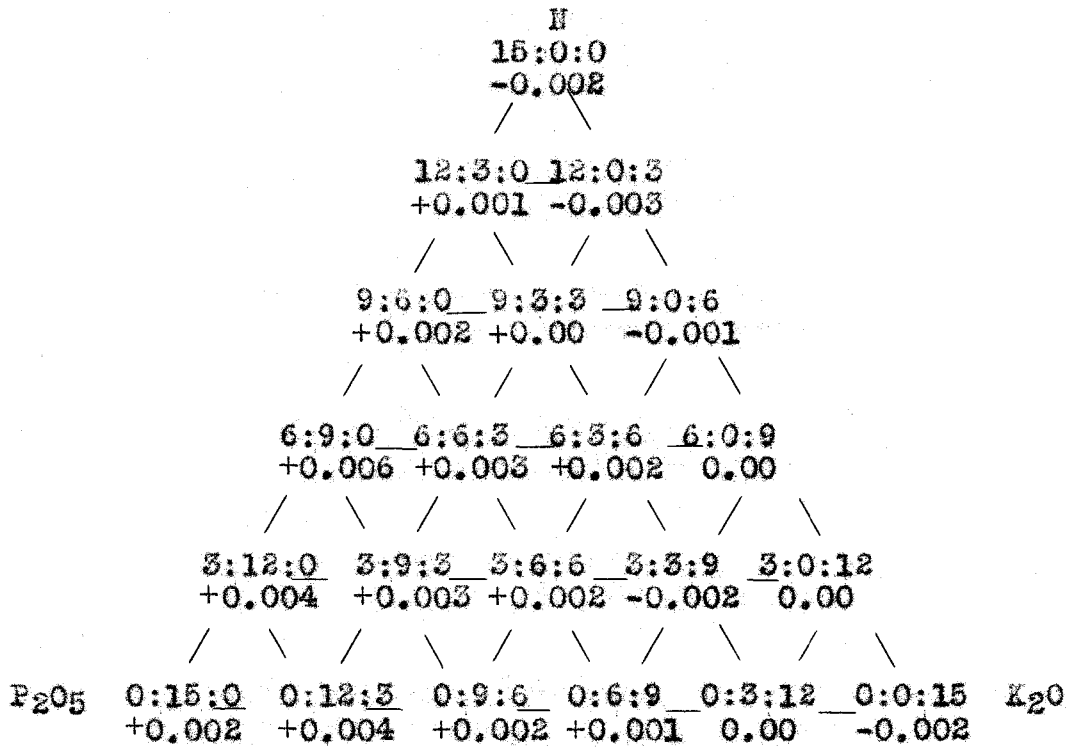


Figure 44. Average loss in the percentage of organic carbon from Norfolk sand, for sections A, B and C resulting from the use of high-nitrogen, high-phosphate, high-potash, and complete fertilizers under the three systems of crop management, for the period 1929 to 1934.



Average of the checks = -0.002

Figure 45, Section A. Gain or loss in the percentage of organic nitrogen in Norfolk sand from March, 1929, to March of 1934. Mature hay turned.



Average of checks = -0.002

Figure 46, Section B. Gain or loss in the percentage of organic nitrogen in Norfolk sand for the period March, 1929, to March of 1934. Crop turned as green manure.

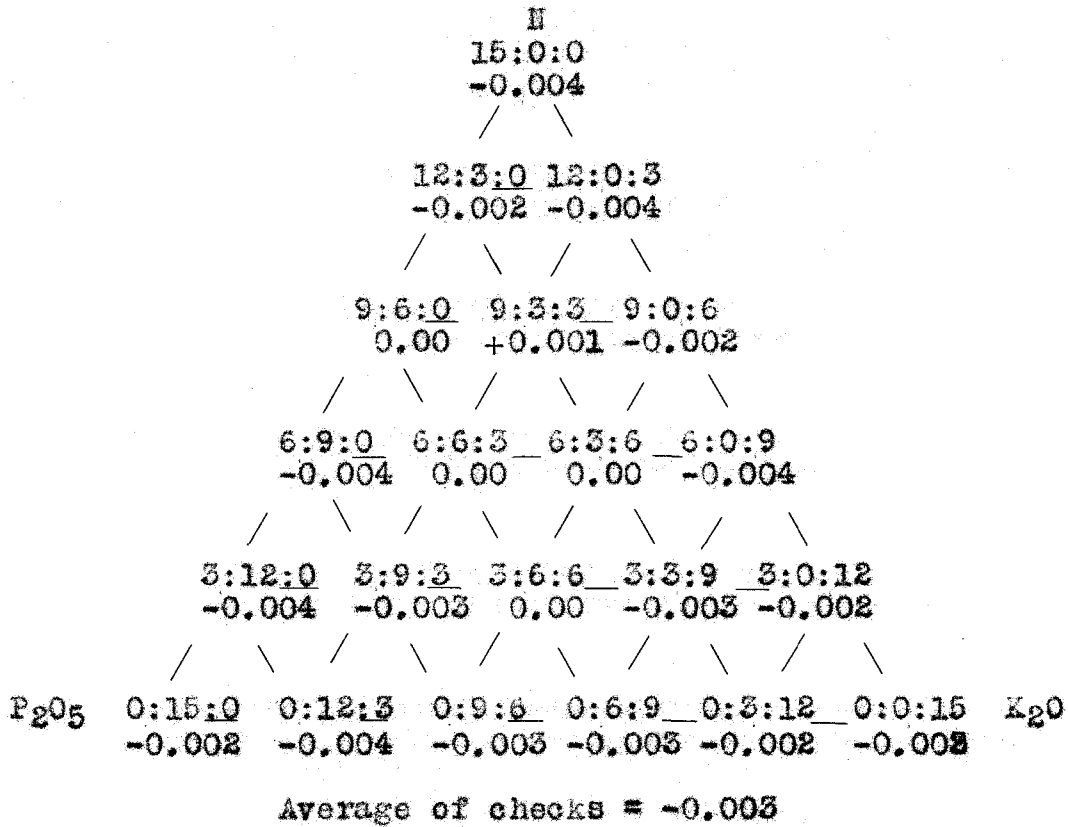


Figure 47. Section C. Gain or loss in the percentage of organic nitrogen in Norfolk sand for the period March, 1929, to March of 1934. Hay removed and stubble turned.

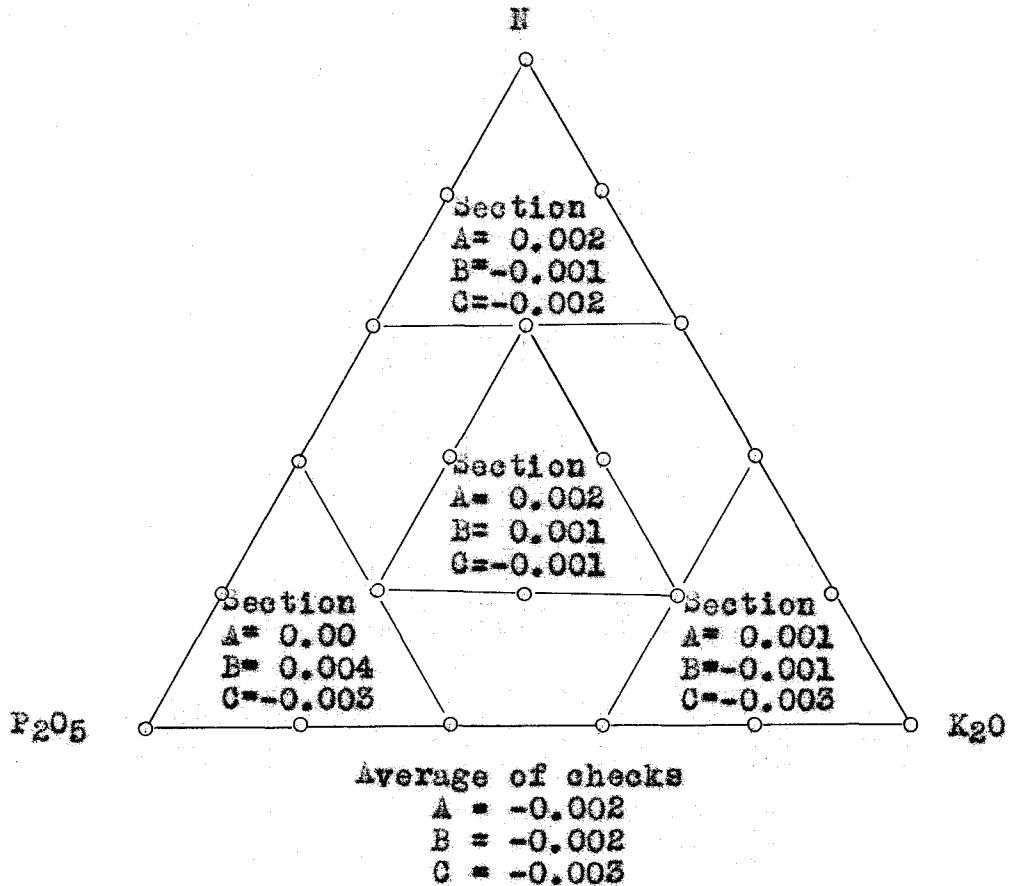


Figure 48. Average gain or loss in the percentage of organic nitrogen on Norfolk sand for Sections A, B and C resulting from the use of high-nitrogen, high-phosphate, high-potash and complete fertilizers under the three systems of crop management, for the period 1929 to 1934.

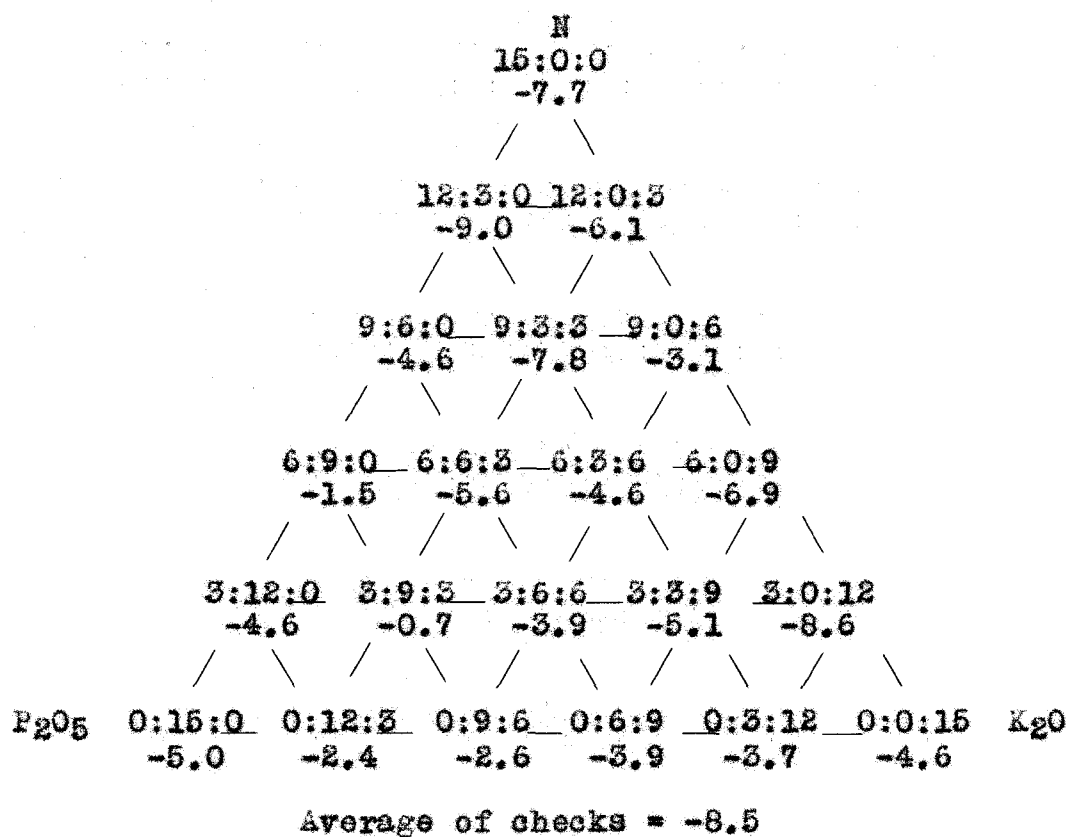


Figure 49. Section A. Reduction in the carbon-nitrogen ratio of Norfolk sand, during the period March, 1929, to March of 1934. Mature hay turned.

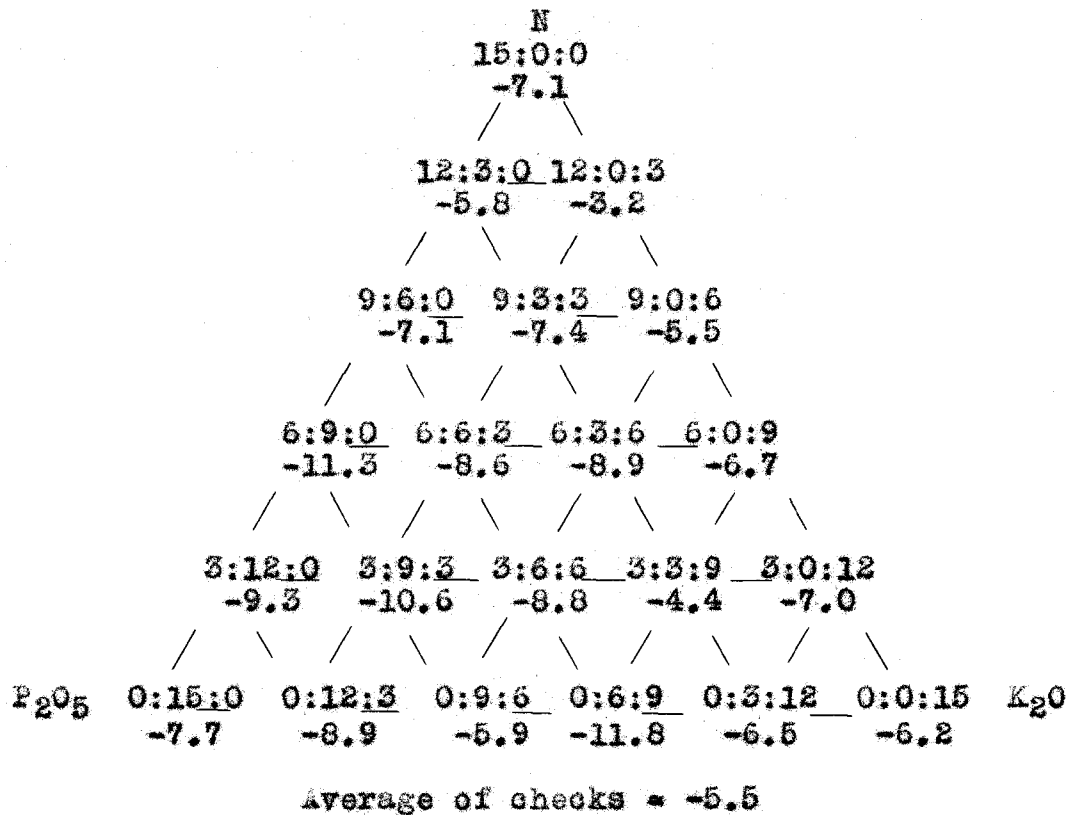
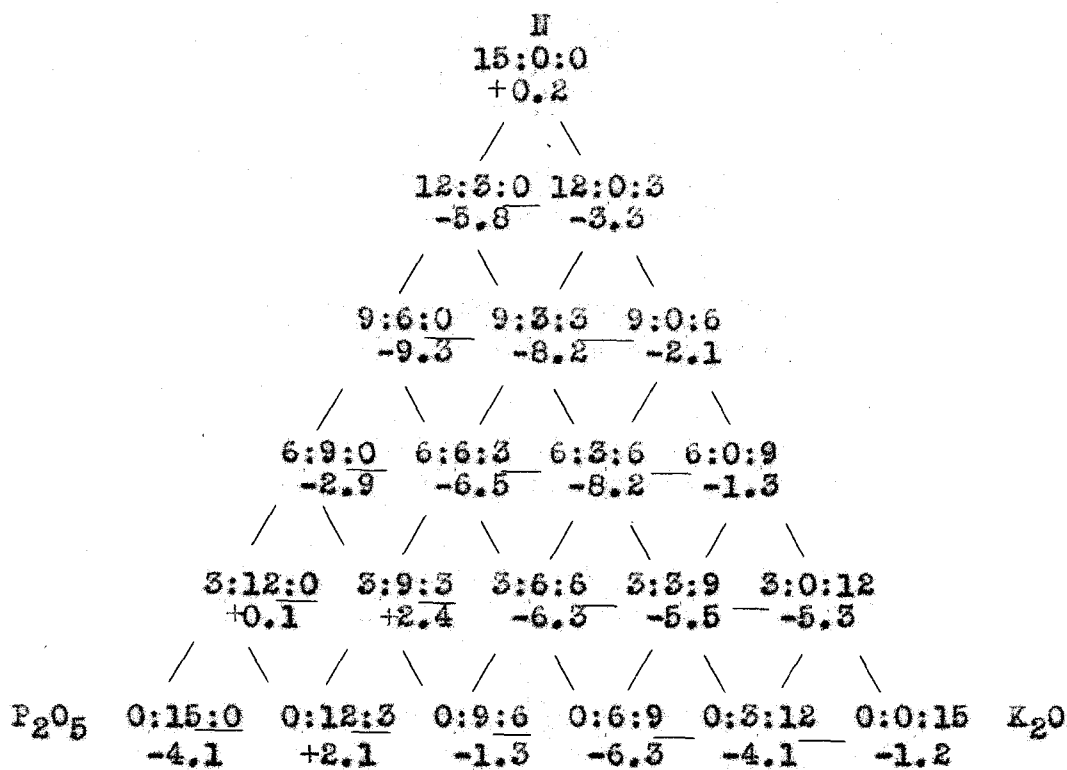


Figure 50, Section B. Reduction in the carbon-nitrogen ratio of Norfolk sand, during the period of March, 1929, to March, 1934. Crop turned as green manure.



Average of checks = -0.2

Figure 51, Section C. Increase or reduction in the carbon-nitrogen ratio of Norfolk sand for the period March, 1929, to March, 1934. Hay removed and stubble returned.



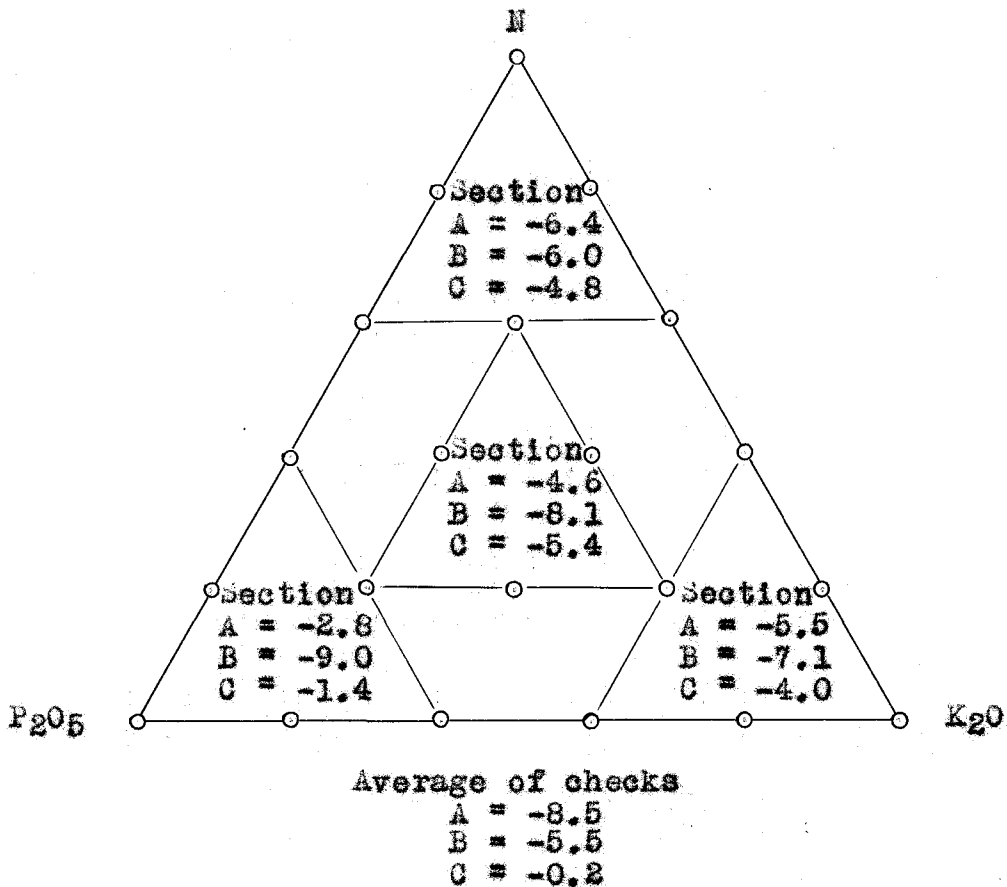


Figure 52. Average reduction in the carbon-nitrogen ratio of Norfolk sand for Sections A, B and C resulting from the use of high-nitrogen, high-phosphate, high-potash and complete fertilizers under the three systems of management, for the period 1929 to 1934.

Table 14. Average increase or decreases in organic carbon and nitrogen, and in the carbon-nitrogen ratio for Norfolk sand, for the period 1929 to 1934.

Fertilizers Used	Section A		Section B		Section C	
	C %	N %	C %	N %	C %	N %
High Nitrogen 15, 12, 9 %	-0.09	0.002	-0.12	-0.001	-0.12	-0.002
High Phosphate 15, 12, 9 %	-0.06	0.000	-0.08	0.004	-0.10	-0.003
High Potash 15, 12, 9 %	-0.09	0.001	-0.12	-0.001	-0.14	-0.003
Complete	-0.06	0.002	-0.11	0.001	-0.16	-0.001
Checks (av.) No Fertilizer	-0.20	-0.002	-0.14	-0.002	-0.08	-0.003

on A, but there has been a loss on C. The largest gain of organic nitrogen registered was obtained with high-phosphate fertilizers on B where the green manure was turned. The averages for the high-potash fertilizers are in accord with those of the high-nitrogen; both have shown gains on A and losses on Section B. Those of the complete ratios show a gain for both Sections A and B.

Particular emphasis can be placed upon the gain of organic nitrogen produced by the high-phosphate ratios on Section B. It will be seen from Figure 46 that this average gain of 0.004 per cent is equal to that of the 12:3:0 and 0:12:3 ratios. The greatest individual gain, however, is for the 9:6:0 ratio which registers a 0.006 per cent increase in nitrogen. These increases are associated with high-nitrogen and calcium contents of the forage produced on these plats.

The importance of calcium becomes more distinct when one considers the photograph (1932) presented as Figure 53. The barren space outlined by soybean plants is the portion of Section C which received fertilizers containing little or no superphosphate. Considerable difficulty was experienced early in the

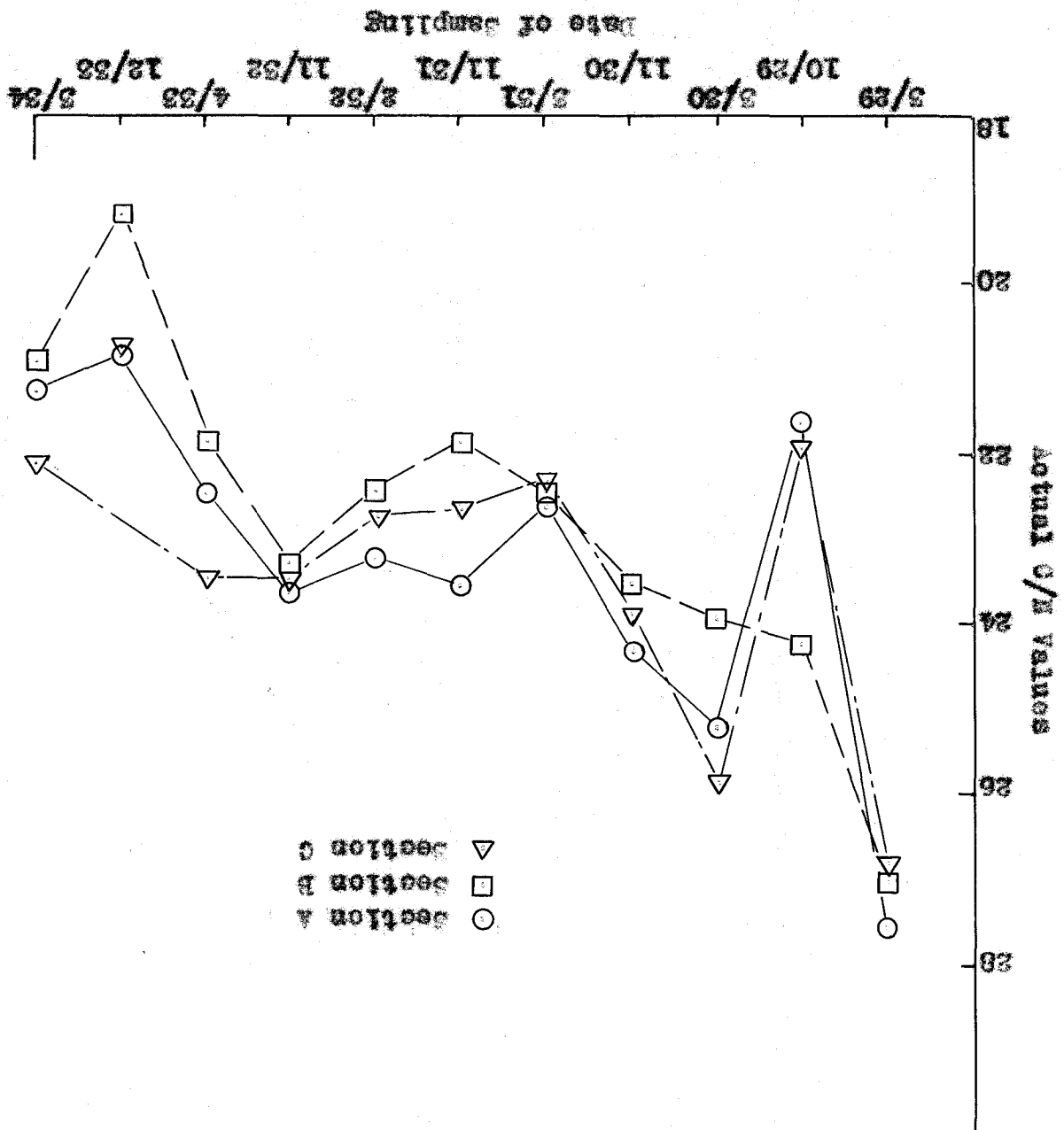


Figure 53. Photograph taken in May, 1932, of an area in Section C which had received fertilizers carrying little or no superphosphate. The dying of the seedling soybean plants was thought to be due to a calcium deficiency induced by the removal of the hay during the period 1928 to 1930.

experiment in obtaining a stand on these plats. The conclusion was drawn that the failure was due to a calcium deficiency which had developed incident to the removal of the hay, and to the lack of calcium in the fertilizer. This deficiency developed within the period 1928 to 1931.

The wide variation in the carbon-nitrogen ratios at different dates of sampling is illustrated by Figures 54 and 55. The original uniformity of the ratios, for all three sections for the plats which received the high-nitrogen fertilizers (Figure 54), would allow a direct comparison of actual ratios to be made. There is such a spread between the ratios of A, B and C for the high-phosphate plats (Figure 55), at the beginning of the experiment, that a direct comparison of ratios at the various dates of sampling would hardly be valid. For this reason, the numerical differences between the ratios of the samples of March, 1929, and those of a particular spring season are given. By confining the graphs to samples taken during the spring season of each year, the curves are much smoother, easier to follow, and bring out differences as well as if semi-annual variations are considered. These differences are shown for the high-nitrogen plats (an average of

Figure 64. Changes in the average carbon:nitrogen ratio of the high-nitrogen plots under the three systems of crop management, from March, 1929, to March of 1934.



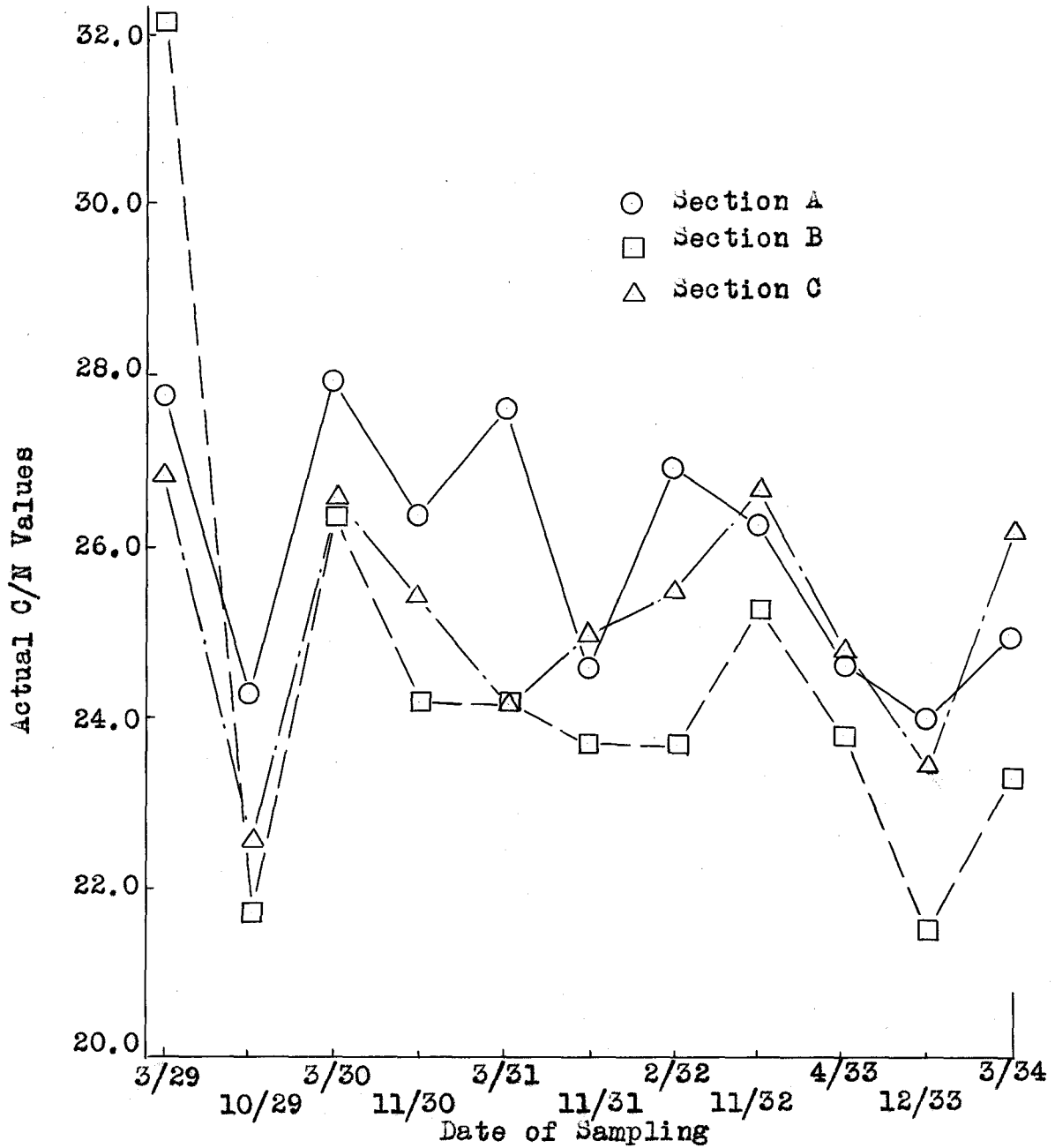


Figure 55. Change in the average carbon:nitrogen ratio of the high-phosphate plats under the three systems of crop management from March, 1929, to March, 1934.

the plats receiving fertilizers containing 15, 12 and 9 per cent of nitrogen; a total of six plats) in Figure 56. Those for the high-phosphate are shown in Figure 57 and of the high-potash plats in Figure 58. The check plats are given as Figure 59. As all graphs are on the same scale, the relative vertical positions give the proportionate decrease due to a particular fertilizer treatment.

It is shown in Figure 56 that the reduction of the ratio by the high-nitrogen fertilizers has been practically the same for all three sections, and the change has been rather gradual. The most abrupt change was during the period of March, 1930, to March, 1931.

The changes on the high-potash plats, as given in Figure 58, have been at approximately the same rate as on the nitrogen plats. The decrease between March of 1929 and 1930 was quite large for Sections B and C, but it was delayed until the succeeding year for the mature hay of A. There is a tendency for Section C to revert to a higher carbon-nitrogen ratio level.

The check plats are given as Figure 59. It is to be recalled that very meager crops have been produced on these plats since 1931. The rate of decrease for Section A seems to have been greatly accelerated since



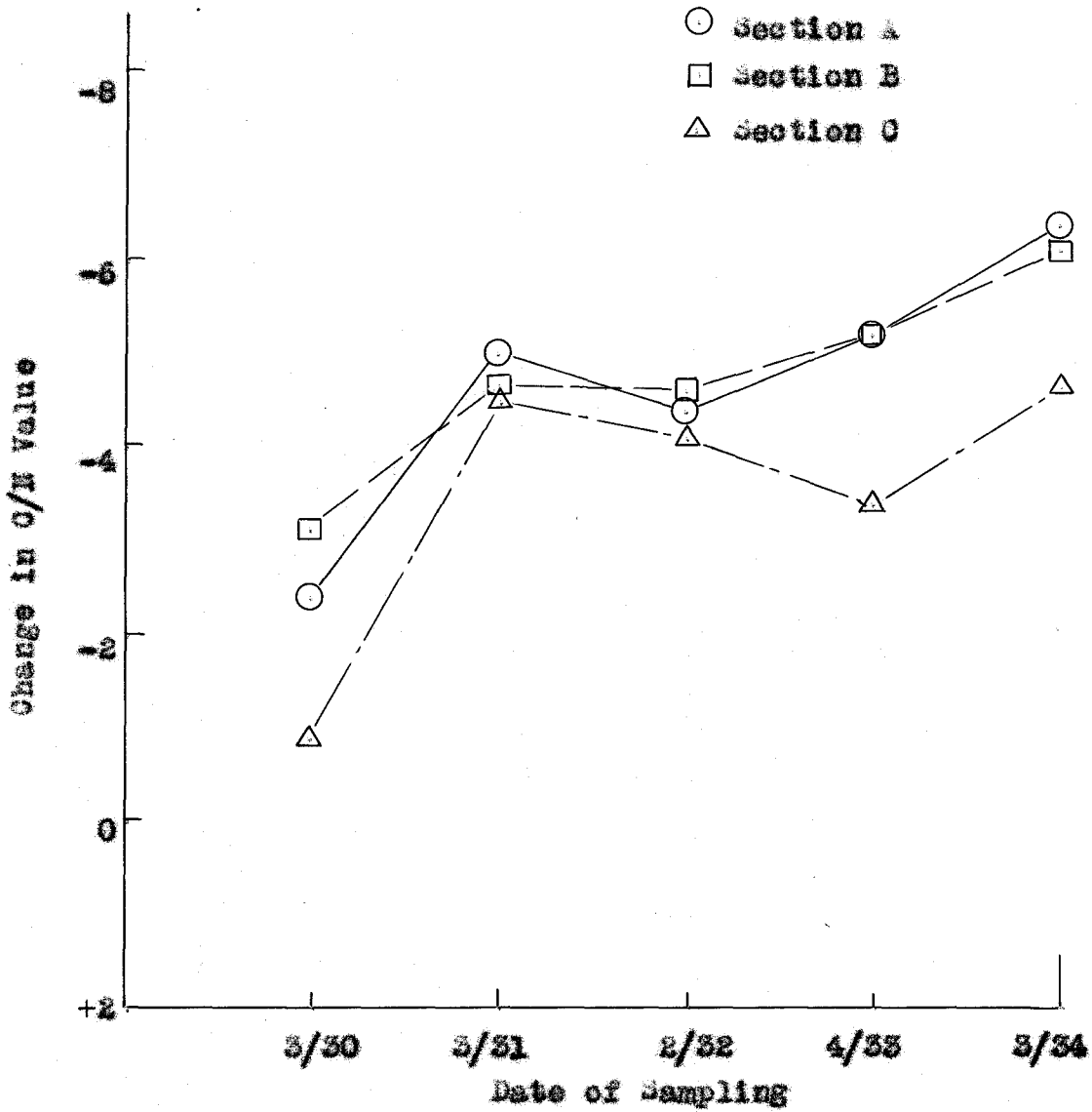


Figure 56. Reduction in the average carbon:nitrogen ratio of the high-nitrogen plants for samples taken in the spring of each year from March, 1929, to March, 1934.

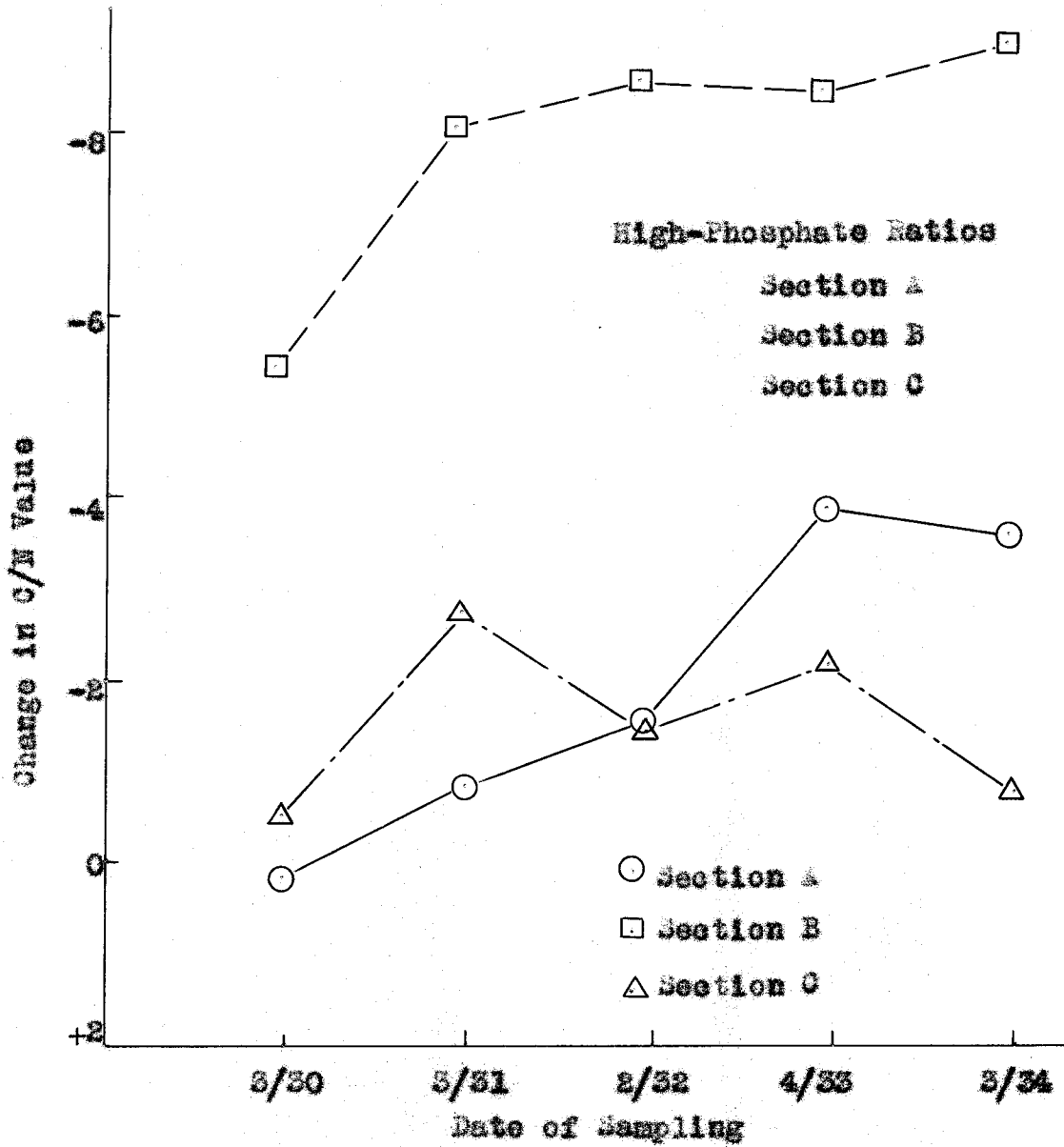


Figure 57. Reduction in the average carbon:nitrogen ratio of the high-phosphate plats for yearly samples taken from March, 1930, to March, 1934.

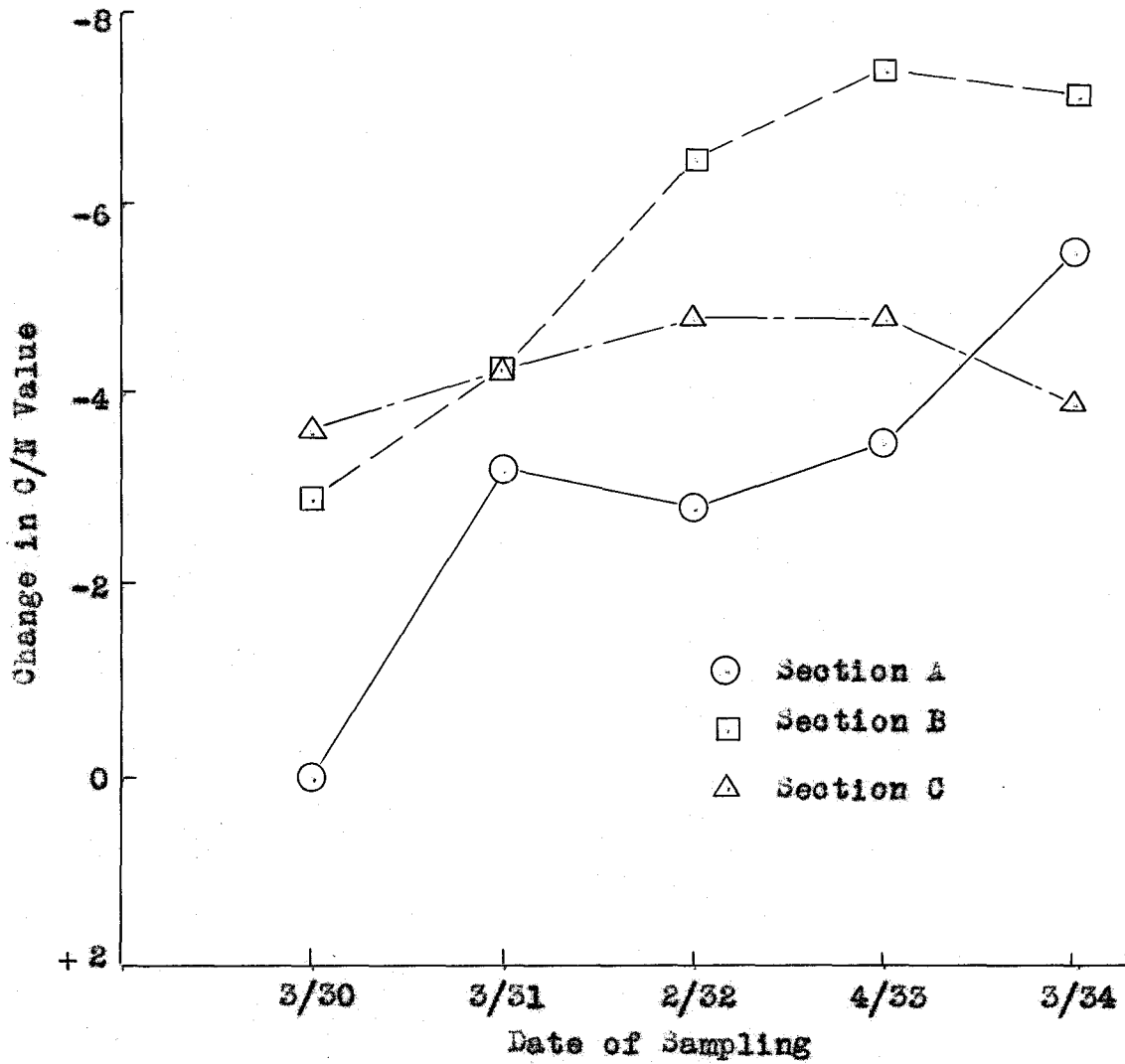


Figure 58. Reduction in the average carbon:nitrogen ratio of the high-potash plats for yearly samples taken from March, 1929, to March, 1934.

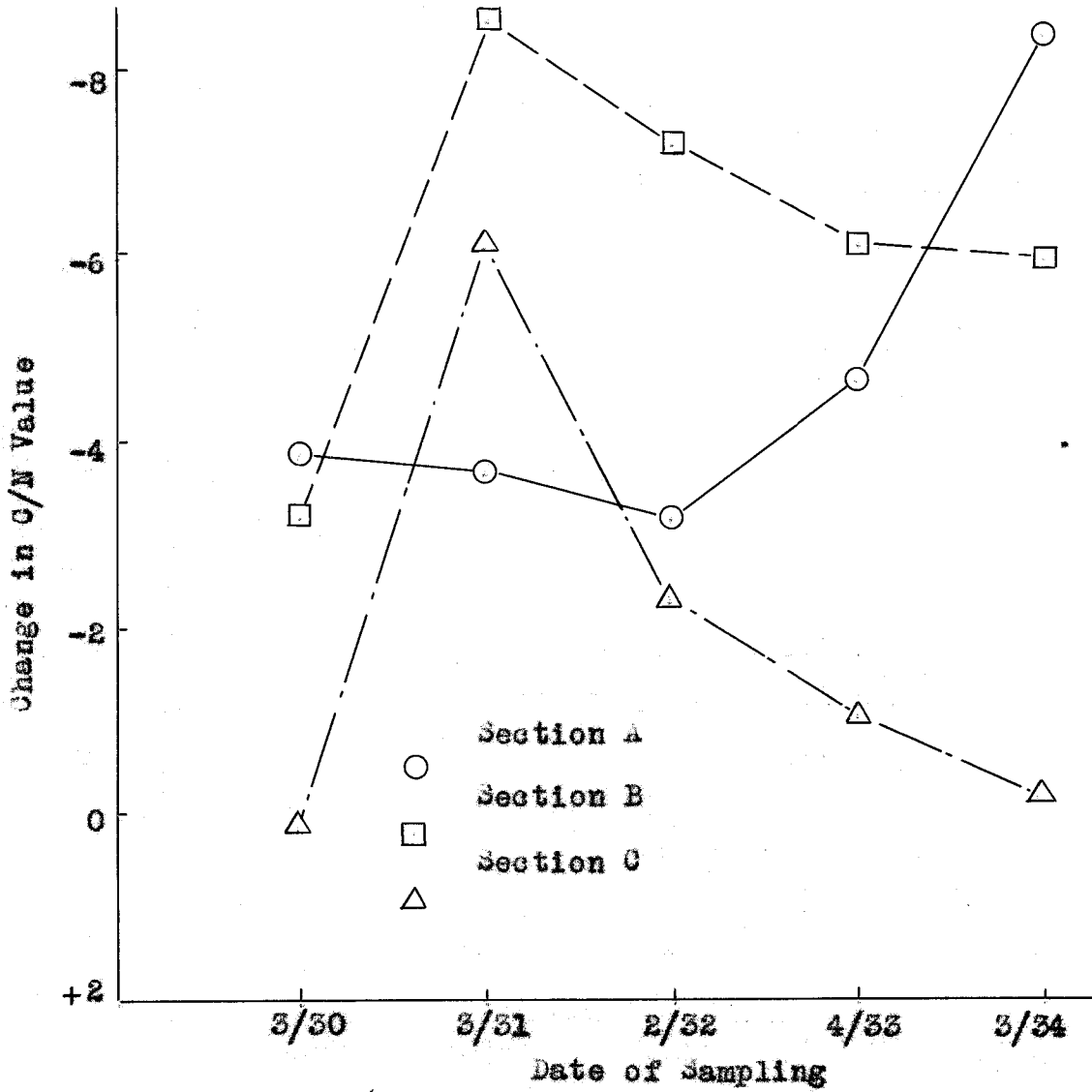


Figure 59. Gain or reduction of the average carbon: nitrogen ratio of the check plats for yearly samples taken from March, 1929, to March, 1934.

March, 1932, and has been greater than for B, which constitutes the green manure plats. Section C has nearly reverted to the original carbon-nitrogen ratio.

The greatest change in the carbon-nitrogen ratio is exhibited in Figure 57 by the high-phosphate plats of Section B, while the change for A is essentially the same as for C. Attention is called to Figure 25 which shows that the hay from these plats of Section B averaged 2.14 and 1.94 per cent of nitrogen and calcium, respectively, while those of the high-nitrogen plats were 1.89 and 1.25; and of the high-potash plats, 1.77 and 1.11. Again it should be pointed out that the changes in the ratio on the check plats is practically of the same magnitude as on other plats which received much greater quantities of nitrogen when the hay crop was turned. Assuming that virtually the same amount of nitrogen was turned for a particular plat of Section A as for B, there is an indication that the turning of the crop of high-nitrogen content as a green manure is very efficacious in reducing the carbon-nitrogen ratio. It is to be observed that the rate of reduction for the period of March, 1930, to March, 1934, is practically the same as for the other sections and for the other fertilizer treatments. The very large reduction in the period 1929 to 1930, and again

from 1930 to 1931, would seem to indicate that there is a portion of the native organic matter which is comparatively readily available as a source of energy for micro-organic life. When this is utilized, the more refractive portion decreases the rate of the reduction of the ratio to a lower value. It would appear that the nitrogen of the hay turned cannot be fully and immediately effective unless the hay is turned into the soil when in the succulent stage of growth.

The comparison of the fertilized plats has been made with respect to each other rather than in regard to the respective checks. The use of unfertilized checks resulted in a meager growth and the crop was virtually a failure, after the first three years, except for a light growth on A.

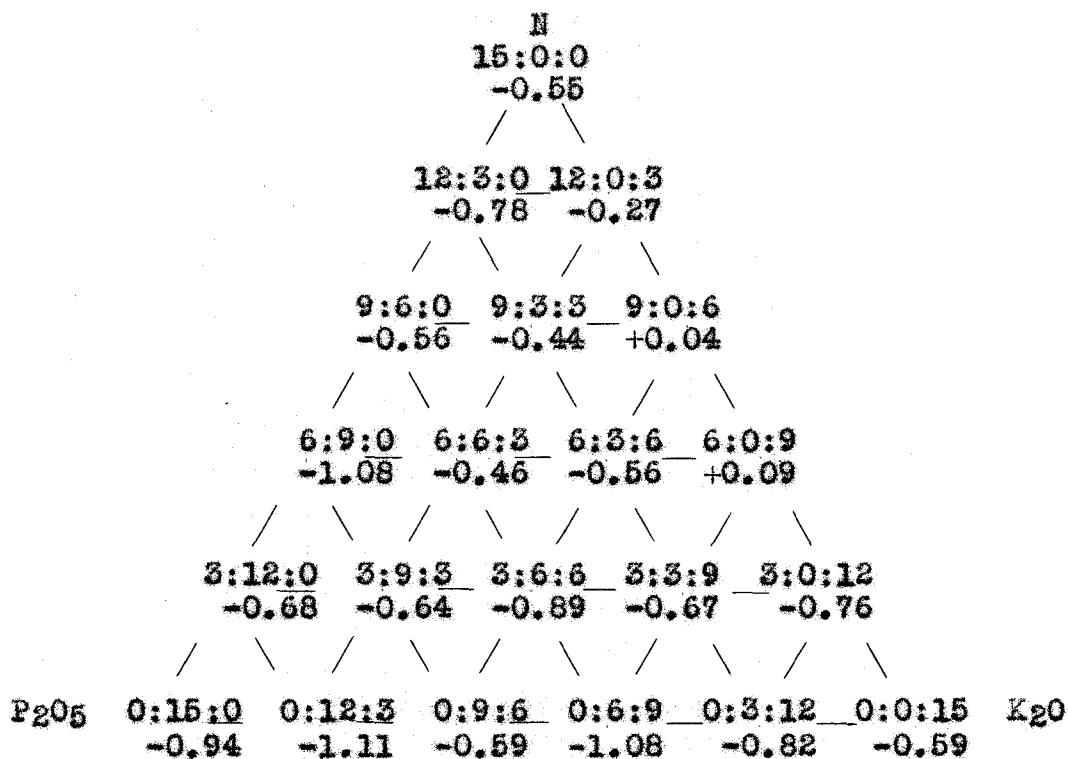
Figure 59 shows that the rates of decline in the carbon-nitrogen ratio of Sections B and C of the check plats are comparable. Following the 1931 sampling there has been a tendency to revert to the original ratio; this is more pronounced for C than for B. This is thought to be in keeping with the cropping management and the very small amounts of leguminous material turned. The tendency toward a decrease in the ratio is apparent for Section A until February of 1932, but since then the

rate has increased appreciably.

2. Data regarding pH.

The change in the pH of each plat is given in Table 13. These data are presented for Section A as Figure 60; for Section B as Figure 61; and for C as Figure 62. Averages as calculated for the other data which have been given are not made, due to the lack of significance to be attached to averages of logarithmic values. Comparisons of the data by means of the figures, or as given in Table 13 will suffice.

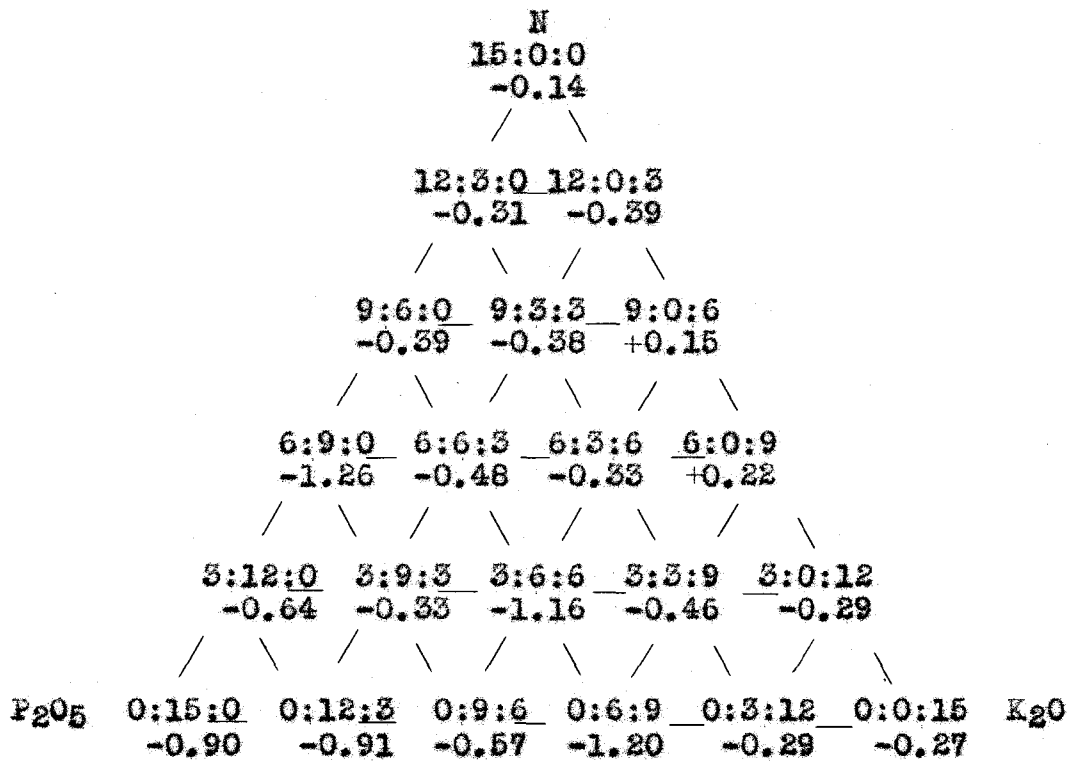
A comparison of the six plats of the high-phosphate area of the triangle shows that for each individual plat the reduction in pH has been greatest on Section A, followed in order by Sections B and C. This order does not hold for all plats in the high-potash area as there has been an increase for the 6:0:9 ratio on Sections A and B with neither increase nor decrease for C. The plat receiving the 9:0:6 fertilizer has also shown an increase for Sections A and B, but there has been a decrease for C. The smallest change in pH has been along the N-K<sub>2</sub>O line, and for the complete fertilizers. The 15:0:0 ratio has induced a smaller increase in acidity on Sections A and B than have the 0:15:0 and 0:0:15 ratios. The 0:0:15 ratio has taken the place



Average of check No. 1 = -0.17  
 Average of check No. 2 = -0.15

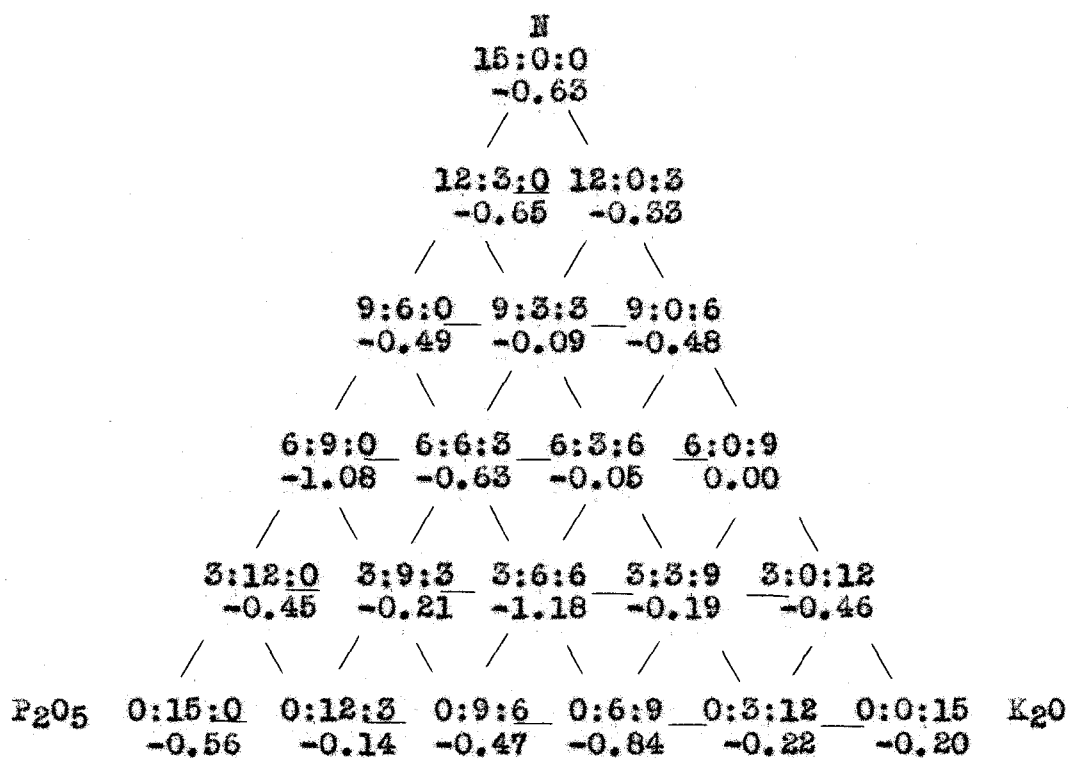
Figure 60, Section A. Changes in the pH of Norfolk sand induced by the fertilizer ratio and crop management used for the period March, 1929, to March of 1934.





Average of check No. 1 = -1.00  
 Average of check No. 2 = -0.30

Figure 61. Section B. Changes in the pH of Norfolk sand induced by the fertilizer ratio and crop management used for the period March, 1929, to March of 1934.



Average of check No. 1 = -1.03  
 Average of check No. 2 = -0.01

Figure 62. Section C. Changes in the pH of Norfolk sand induced by the fertilizer ratio and crop management used for the period March, 1929, to March of 1934.

of the 15:0:0 ratio for Section C.

#### Conclusions

Soybean residues, which have been produced by fertilizers of varying ratios, have been used under three systems of management; i.e., (1) the mature hay was returned to the plat on which it was produced, after the seed were threshed; (2) the crop was turned in the succulent stage of growth; and (3) the hay was removed from the plat, and the stubble turned. The combined effect of fertilizer treatment and crop management on the quantity and quality of the residual soil organic matter, and the pH, was studied. The results obtained on Norfolk sand, under the conditions of the experiment during a six-year study, seem to justify the following conclusions:

(1) There has been a decrease in the quantity of organic carbon on 68 of the 69 sub-plats; the turning of the mature hay produced by the 3:9:3 ratio resulted in the one increase (0.03 per cent).

(2) Both gains and losses of organic nitrogen have occurred. The gains of nitrogen have generally been more numerous on Section A, where the mature hay has been turned, than on B. Losses from Section C have occurred on 21 of 23 plats, with neither gain nor loss on the remaining two plats.

(3) A comparison of the averages of the high-nitrogen, high-phosphate, and high-potash plats brings out the following points: (a) the turning of mature hay produced by either the high-nitrogen or potash ratios has resulted in a slightly better conservation of nitrogen than from the use of the high-phosphate ratios, but the losses of carbon have been somewhat larger; (b) the turning as a green manure of the crop produced by the high-phosphate ratios has resulted in a greater conservation of both nitrogen and carbon than in the case of either the nitrogen or potash ratios, and (c) an average of the complete ratios occupies an intermediate position.

(4) The changes in the relative amounts of carbon and nitrogen (C/N) have varied considerably. When produced with high-phosphate fertilizers and turned in the succulent stage, soybean hay has been very effective in reducing the carbon-nitrogen ratio. This reduction took place early in the history of the experiment, and would seem to indicate that a part of the native organic matter is readily available as a source of energy for micro-organic life. The portion left apparently is not utilized so readily. The rapid and large reduction in the carbon-nitrogen ratio should be conducive to a more labile fertility for Norfolk sand. When incorporated in the mature stage of growth,

this same material does not have an effect of the same magnitude, but there is an indication that the rate of change has become greater during the later years of the experiment. The outstanding change mentioned is for a crop of high-average nitrogen and calcium content.

(5) The effect of the fertilizer ratio and crop management upon the pH of Norfolk sand is variable. The turning of mature hay produced with fertilizers has decreased the pH more than the unfertilized hay. The reverse is generally true for the green manure and stubble managements. Complete fertilizers and those composed of nitrogen and potash have effected the smallest decrease; certain of the latter combinations have actually increased the pH. These changes have taken place on Norfolk sand which has a pH value from 5.2 to 5.5 when the native cover is removed.

## DISCUSSION

Some of the characteristics of the Norfolk sand used in this experiment have been discussed. The desirability of improving the moisture and nitrogen status of the soil by an increase of the organic matter content is in accord with the general principles of soil fertility. The quality of organic matter in a soil of this type is perhaps equally as important as the quantity; the soil texture and climatic conditions would appear to preclude a large increase in quantity, except as the result of an unusual crop-management program.

The wide carbon-nitrogen ratio which exists in this Norfolk sand indicates a condition analagous to a "sand culture" to which material of a wide ratio has been added. The assumption that such a condition exists allows the application of certain general principles which have been evolved from a large number of investigations, as have been cited in the literature resume. The necessity for establishing a narrower ratio would seem to take precedence over that for quantity. A full availability of added fertilizer materials, especially nitrogen, apparently cannot be expected until this reduction has been effected. The findings in the investigations cited

are at variance in that different limits are set for the ratio at which it is considered that the nitrogen is available for plant growth. It is thought that there should be a variance, and that availability depends on the particular soil type, the extent to which the nitrogenous material is mixed with the soil, the moisture content, and probably other factors.

The reductions in the carbon-nitrogen ratio which have occurred in these experiments which have been presented are probably due to a combination of factors; these have taken place where appreciable amounts of legume residues have been turned to the soil. It is possible that cultivation has been a factor, but the change in the ratio on the check area of Section C does not uphold this possibility; practically no residues have been returned to this soil since 1930 and there has been a rapid reversion toward the original carbon-nitrogen ratio. The nitrogen of the fertilizer probably enters into the process. In spite of these complicating factors, it would seem that the rate and amount of the reduction depends to some extent on the composition of the hay as induced by the fertilizer treatment; and the maturity of the plant at the time it is incorporated with the soil.

The pH of the soil has been reduced on most of the plats by the turning of legume residues; some differences

are to be observed due to the condition of the residues when turned. There have been increases in the pH for a limited number of plats receiving green manure, or mature hay, as the case may be. This indicates that the composition of the hay and fertilizer is involved.

The hay and seed data obtained from the studies conducted on Norfolk sand show the extent to which the composition of these plant parts has been affected by the fertilizers used. This soil develops deficiencies of potash, magnesium and calcium under special conditions of rainfall, fertilizer treatment and crop management. It would seem that the influence of the soil should be at a minimum under these conditions; this should allow an accurate reflection of the effect of the treatment, from both the theoretical and practical standpoints. The results obtained might have been altered considerably had a more fertile soil been used.

Potassium has been described as the "key element" in the nutrition of the soybean plant. It has been intimated, however, that calcium may be fully as important. This latter suggestion would do away with an apparent anomaly in that little potash is needed for the production of either soybean hay or seed, yet it appears to be most important when only the three fertilizer ingredients are



recognized. Superphosphate ordinarily contains three-fourths  $\text{CaSO}_4$  and one-fourth phosphate. This warrants a serious consideration of the probable effects of calcium in the nutrition of the soybean plant. Some of the effects are: (1) the  $\text{CaO}$  content is in proportion to the  $\text{CaSO}_4$  applied; (2) the nitrogen content of the forage parallels, generally, the  $\text{CaO}$  content; (3) the potash content is inversely proportional to the  $\text{CaO}$  content which indicates control by the  $\text{CaSO}_4$  applied; and (4) the  $\text{P}_2\text{O}_5$  content is proportional to the  $\text{K}_2\text{O}$  of the fertilizer. This last point would indicate indirect control of the  $\text{P}_2\text{O}_5$  content by the calcium content of the superphosphate. This line of reasoning leaves but little doubt in regard to the classification of calcium as the "key element".

The effects of fertilizer treatment on the composition of soybeans, as cited in the literature resume, represent investigations conducted under a wide range of soil and climatic conditions. Consideration of the data from this viewpoint would allow for a lack of harmony in such studies; for this reason no attempt has been made to reconcile differences which are apparent.

### CONCLUSIONS

The average data obtained on the Norfolk sand, under the conditions of the various experiments, can be interpreted to allow the following conclusions to be drawn:

(1) Larger yields of legumes, corn and cotton have been obtained in the green manure-fertilizer experiment from plats to which legumes stubble was turned and the crops grown with a 6-8-4 fertilizer, as compared with those yields from plats which received the full legume crop as a green manure and a 2:8:4 ratio used as a supplement. These results were obtained under both a winter-fallow and a winter-cover management. The largest yields were obtained by using a winter cover of rye and vetch following the legume stubble and 6-8-4 combination.

(2) The use of the stubble and 6:8:4 combination resulted in a slightly greater conservation of organic carbon and nitrogen than was obtained from the green manure-2:8:4 system, under winter fallow. There was no appreciable difference between the two systems when a winter cover crop was used.

(3) A considerable reduction of the carbon-nitrogen ratio occurred under both systems of management. This is thought to be conducive to a more desirable soil-nitrogen

status.

(4) Yields are apparently influenced more by the nitrogen of the fertilizer than by the management of the legume residues.

(5) The largest average yield of soybean hay was obtained by using a 3-9-3 fertilizer. These data, as a whole, indicate that only a small amount of potash is needed when the total amount of plant food is 15 per cent, and the fertilizer is applied at the rate of 400 pounds per acre.

(6) The quality of a forage is related to its composition, both mineral and organic; the mineral content of the soybean hay was materially influenced by the fertilizer used. The nitrogen content varied from 1.46 to 2.41 per cent; the  $P_2O_5$  content from 0.45 to 0.66; the  $K_2O$ , from 0.66 to 2.28; and the  $CaO$  content ranged from 0.98 to 2.13 per cent. The content of the other ingredients varied to a smaller extent.

(7) The following fundamental relations are indicated: (a) the  $K_2O$  content of the hay is in proportion to the amount of potash applied in the fertilizer; (b) the  $P_2O_5$  content is a reflection of the potash and phosphate used, with the former dominating; (c) the nitrogen varies directly with the superphosphate, and indirectly with the

potash contained in the fertilizer. The contents of soluble ash,  $K_2O_3$ ,  $Mn_3O_4$ , sulphur, and  $MgO$  are also discussed. The effect of the calcium of the fertilizer can be demonstrated as overshadowing that of potash.

(8) The yield of seed can be influenced by the fertilizer treatment; conditions favorable to the production of forage are generally conducive to greater yields of seed.

(9) Fertilizer ratios conducive to the yields of seed have not produced the greater oil content, but have effected the greatest nitrogen content.

(10) The same fertilizer ratios cannot be used for both oil content and production; nitrogen and potash favor a high oil content, while nitrogen and phosphate favor production.

(11) A gain in the organic carbon of the soil was registered on but one of the 69 sub-plats. This was obtained by the use of the 3:9:3 ratio where the mature hay was turned. All other plats suffered losses which were variable, but appreciable.

(12) Both gains and losses of organic nitrogen have occurred. Gains are apparent on more plats of Section A (mature hay turned) than on B (green manure turned); however, where gains have been secured for the same ratio on both sections, that for B is usually the larger. Losses of nitrogen are recorded for 21 of the 23 sub-plats of Section

C, where only the stubble was turned.

(13) The effect of the three systems of management on the carbon and nitrogen status of the soil depends to a large extent on the fertilizer used to produce the plant material. A comparison of the averages of the high-nitrogen, high-phosphate, and high-potash plats seems to indicate the following: (a) the use of mature hay produced by either the nitrogen or potash ratios has resulted in a slightly better conservation of nitrogen than from the phosphate ratios, but the losses of carbon have been somewhat larger; (b) when turned as a green manure, the hay produced by high-phosphate ratios induces a greater conservation of both carbon and nitrogen than that resulting from the use of the residues from the nitrogen and potash plats; and (c) an average of the complete ratios occupy an intermediate position.

(14) The reduction in the carbon-nitrogen ratio has varied in amount depending upon the fertilizer and management used. High-phosphate fertilizers produce a soybean crop of a composition such as to be quite effective in reducing the ratio, if turned in the succulent stage. The hay from these plats is characterized by a high-nitrogen and calcium content.

(15) The effect of the fertilizer ratio and crop

management on the pH of the Norfolk sand is quite variable. The turning of mature hay produced with fertilizers has reduced the value more than has the unfertilized hay. The reverse is true for the green manure and stubble sections. The smallest decrease resulted from the use of complete fertilizers, and those composed of nitrogen and potash; certain of the latter combinations have actually increased the pH, as compared with that of the original soil.

### SUMMARY

The data presented have been obtained from a combined field and laboratory study conducted on Norfolk sand; this type of soil is prevalent throughout the sand-hill region of the Carolinas and Georgia. Investigations concerning the relative efficiencies of fertilizers and crop residues as sources of nitrogen for corn and cotton have been made. These involved a comparison of legumes used as green manures; i.e., soybeans, velvet beans, and cowpeas, with only the stubble turned; a low-nitrogen fertilizer was applied to the crops grown on the green manure plats, while a high-nitrogen ratio was used on the stubble plats. These two systems of management were used in a rotation of legumes, corn and cotton. Winter fallow following cowpeas was compared with a winter cover.

Yields data were obtained, and the carbon and nitrogen status of the soil was determined semi-annually during the two rounds of the three-year rotation.

The foregoing study of the effect of a rational soil management and cropping program on the quantity of the crops produced, and the organic matter content of the soil, was in conjunction with an intensive study of the effect of 21 fertilizers of varying ratio, as dictated

by the triangle system, on the composition (quality) of soybean hay and seed. The use of the residues under the three systems of management; i.e., (1) the turning of the crop as a green manure, (2) the turning of the mature hay after the seed had been removed, and (3) the turning of the stubble, allowed the study of the combined effect of fertilizers and residues on the organic matter and the pH of the soil.

Yields of seed and hay were obtained for the period 1928 to 1933, inclusive. The seed were analyzed for nitrogen and oil during the period 1929 to 1933. The following components of the hay were determined during a four-year period: (1) nitrogen, (2) phosphoric anhydride, (3) potassium oxide, and (4) calcium oxide; soluble ash,  $R_2O_3$ ,  $Mn_2O_4$ , sulphur, and magnesium oxide were determined during a three-year period.

These studies have provided information regarding some fundamental problems associated with a fertility program for the Norfolk sand.



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