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On the Nitrate Accumulation as Affected by Soil Type, Soil Management and Cropping System

Alwyn C. Sessions

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Memorandum

From Chemistry Date, May 3, 1927.

To Dr. Beaumont. (Copy to Miss Hallowell)

Subject: Mr. Sessions' Thesis.

I have just read Sessions' thesis, and am very much pleased with the way he handles his English. He shows marked improvement and the paper is a credit to the college.

One suggestion, - at the end of page 26 he finishes the summary of the literature, and on page 27 he begins the discussion of his work. I think there ought to be a statement incorporated into the text so that the reader will have that change impressed upon him. I was quite at a loss here to know what he was describing. On page 27 I think it would be better if he should say that he is going to describe the methods he used, and give us an idea of what he expects to bring out.

One other thing, - on pages 27, 28, 29, several plots which he uses are described I presume according to experiment station records, but a casual reader like myself would like to have those plots located in reference to the campus. I can see that Mr. Sessions wanted to be scientific and not introduce any local relationships, but any one on the campus reading the paper would like to have them localized in his mind. It is easier to think about them.

On page 71 he states "lower pH". I take it he means lower acidity or higher pH.

Signed, C A Peters

ON THE NITRATE ACCUMULATION AS AFFECTED BY SOIL TYPE, SOIL MANAGEMENT AND CROPPING SYSTEM

BY

Alwyn C. Sessions

Thesis submitted for the degree of

Master of Science

Department of Agronomy

Massachusetts Agricultural College

Amherst

May 1927

CONTENTS

NITRATE ACCUMULATION AS AFFECTED BY SOIL TYPE, SOIL MANAGEMENT AND CROPPING SYSTEM.

Introduction

Due to the important position nitrates hold in plant nutrition and the close relationship which exists between soil nitrates and crop production, the nitrifying power of the soil is today recognized as one of the most important factors affecting its fertility. Thus the role of soil nitrates has become one of the paramount agronomic questions.

The relation of nitrates to plant nutrition early engaged the attention of research workers and throughout the period of existence of agricultural experiment stations the study of this relation has received considerable attention. Field experiments especially have been numerous. Of late years, emphasis has been given the study of factors affecting nitrification under different conditions.

The data here presented add to the present extensive body of knowledge of nitrification under different field conditions. The study embraces some phases of the problem heretofore not given emphasis or consideration.

Scope of Thesis

This investigation deals with the trend of nitrate production and accumulation under the conditions of different soils, methods of soil management and cropping systems, as found on the College Farm and Experiment Station plots. Corn, apple trees and tobacco were the main plants grown. Detailed descriptions of soils and systems of management are given later in connection with each part of the thesis.

Part I deals with the soil from the corn plots in relation to their nitrate content as affected by: 1, topography; 2, soil class and 3, barnyard manure.

Part II is devoted to a consideration of nitrate accumulation in orchard soils as affected by: 1, sod and cultivation with and without a nitrogen fertilizer; 2, straw mulch and 3, fertilizer treatment and tree growth.

Part III embraces a study of nitrate production in tobacco fields as affected by: 1, time of plowing under timothy and rye when used as a cover crop; 2, as affected by fertilizer high in organic and inorganic sources of nitrogen.

Review of Literature

This review includes the work of a few men whose findings pertain to the following topics:

1. The nitrifying power of the soil as an index to its crop producing power.
2. Nitrate accumulation in a soil, supporting plant growth, as an indication of nitrifying power.
3. Nitrate nutrition of the orchard as associated with fruit-bud formation.
4. Fruit-bud formation as affected by rise and fall of soil nitrates.
5. Relationship between crop growth and nitrate accumulation.
6. Optimum moisture requirements for maximum nitrification.
7. Moisture variations as associated with soil type, soil aeration and nitrification.
8. Application of organic matter as affecting nitrification.
9. Temporary depressions in nitrification noted from high applications of barnyard manure.
10. The relation of chemical toxins and bacteria to nitrate depression.
11. Soil reaction as a factor in nitrification.
12. Relation of cultivation to nitrification.
13. Soil types as influencing nitrification.

Relation of Soil Nitrates to Plant Growth.

So important is the nitrate role in plant nutrition that the nitrifying power of a soil is considered a most accurate index to its fertility. Burgess (17)* states, "Nitrification (soil cultural method) is by far the most accurate biological soil test yet perfected for predicting probable fertility. In fact, it is probably the best single test of any description yet developed for ascertaining the comparative crop-producing powers of arable soils. Active nitrification may not be the cause of high fertility, yet those conditions which tend to promote rapid nitrification are very evidently identical with those which tend to give us enhanced crop yields."

Brown (11) (14) found that in every case higher ammonification and nitrification were accompanied with higher crop yields. Fred (31), Murphy (86) and others (99) (71) have noted a similar correlation. Again Brown (12) shows that the bacterial activities involved in the transformation of nitrogenous organic matter in the soil bear a very close relationship to the actual crop yields secured on the same soil.

*Figures in parenthesis refer to literature cited in the bibliography.

Waksmann (121) warns against laying too much stress on the relation of any microbiological process to soil fertility; he emphasises the fact, however, that nitrification studies may yield valuable information for the differentiation of soil fertility.

White (125) called attention to the fact that the absence of nitrates under growing plants is no indication of the inactivity of nitrifying organisms and that the lower nitrates which he received on the alkaline areas were due to the vigorous growth of vegetation, while the higher nitrates on the acid areas represented an accumulation in the absence of growing plants. Thus one of the main functions of cultivation (82) is to keep down weeds which are utilizing the nitrogen.

Lyon and Bizzell (73)reported, "A definite relation is seen in which the crop yields and nitrate content of the soil are shown. The higher yielding plots show a higher accumulation of nitrates before planting than do the lower yielding plots."

Lipman (64),after studying the availability of nitrogenous fertilizers in various California soil types, stated, "For plant growth purposes, therefore, we are reasonably safe in assuming that the problem of nitrogen nutrition is chiefly one of supplying to the root zone enough nitrates at different periods in the life of the plant to increase normal growth."

Lyon et al., (78) working on the effect of soil on apple trees, found greatest growth with greatest applications of nitrate fertilizers and in their later work (77), they report,

"The average growth of plum trees in sod which received 900 pounds or more of sodium nitrates was about twice as great as in those which received no nitrate fertilizer." Lewis and Allen (63) received a marked increase in growth of apple trees, the number of blossoming spurs, the percentage fruit set and the average yield per tree, by the use of nitrogen fertilizer.

The unique position nitrates play in the process of fruit-bud formation and fruit set is of late receiving much attention, and appears to be not alone a question of a liberal supply of nitrates as suggested by Lipman (64) for indications are that a withdrawal of nitrates at proper periods might be beneficial to fruit production. It seems, from the work of Gourley (38), Remy (101), Kirby (60), Chandler (18) and others (3), (129), (79), (19) that optimum conditions for fruit-bud formation would be a liberal supply of nitrogen early in the season, which would stimulate early growth, followed by a rapid decrease in order to check growth and widen the carbon-nitrogen ration. Shaw (106) sums the question of fruit-bud formation and soil nitrates as follows, "In order to get heavy bloom there must be produced quickly in the spring a large spur leaf area but a short period of spur and shoot growth. Assuming a sufficient supply of available carbohydrates in the

tissue, nitrogen seems to be the variable element most often controlling leaf production and growth. It seems, then, that a liberal supply of nitrogen early in the season, but quickly decreasing so as to check growth, might favor fruit-bud formation." He then asks, "May not this condition be secured more often through a sod-nitrate program than by cultivation?" Some of the data presented in this report suggests an affirmative answer to Shaw's question.

From this review, it appears that the nitrifying power of a soil is correlated with its yielding powers and is, therefore, an index to its fertility, but nitrate accumulation under growing crops may or may not be a measure of the soils nitrifying or yielding powers. It seems that the nitrate problem in orchards involves a question of growth stimulation and growth retarding in felation to the trees fruiting processes.

Effect of Plant Growth on Nitrate Formation.

Lyon (71), in studying the relations of higher plants to nitrate formation, found that there was a characteristic relationship between the crop and the nitrate content of the soil. He, with Jensen (54), found that during the active growing period of maize, nitrates were frequently higher under the corn than in the bare cultivated soil. In oat land, the nitrates were never as high as in the uncropped land, yet nitrates were highest under both crops during the period of most rapid growth, or greatest drain on nitrates. Stewart (116),

King (159) and others (301) (71) have noted similar results.

Neller (91) stated, "The oxidation processes in sand cultures, to which organic matter (ground alfalfa hay) was added, was accelerated by growing green plants. All the experimental evidence obtained indicates that growing plants of buckwheat, barley, soybeans and field peas, have a beneficial influence upon oxidation activities in the substrata in which the plants were grown, and suggests a symbiotic relationship between the soil-oxidation organisms and the growing green plant."

"These phenomena are explainable," stated Lyon (71), "on the assumption that nitrification is stimulated by some processes connected with active plant growth."

Stewart and Greaves (115), found soil nitrates to be greatest under maize, followed by potatoes, oats and alfalfa. Brown and MacIntire (9) give the average nitrate accumulation under the following crops as: corn, 55.5 parts per million dry soil; oats, 18.0; wheat, 7.9; and grass, 1.4. In this work, nitrates reached their lowest point first under grass and last under maize.

Lyon and et al., (75) (72), Worington (123), Leather (61), and Russell (104) have all noted a disappearance of nitrogen from soil where plants were growing, which disappearance could not be accounted for by absorption by the plant.

It seems from the work of Lyon and Bizzell and Wilson (75) that the soil nitrates found under the crops are related to the stage of the crop maturity. They stated, "All three experiments show little difference between oats and maize in respect to the extent to which they depress nitrate formation when the plants are allowed to mature, but that the loss began much earlier in the life of the wheat than in the maize plant."

Peckering (98) and Gourley (39) found when sod was used in orchards it greatly reduced the vigor of the trees even when soil moisture was not limited. Hedrick (49) (50) received increased yields when the orchard in sod was put under cultivation and decreased yeilds when the cultivated orchard was seeded to sod.

Gourley and Shunk (40) with Lyon and Bizzell (71) found sod greatly reduced soil nitrates. Chandler (18) in referring to the findings of Stewart (114) which were similar to those of Hendrick states, "It appears that in this orchard the injurious effect of the sod was due entirely to its reduction on the supply of available nitrogen."

Lyon et al (78) in studying the effects of sod on apple trees stated, " There was a disappearance of nitrate nitrogen from the soil of the sod plots which could not be accounted for by its removal in the crops of hay or its incorporation in the roots and stubble, and presumably not by its removal of drainage water."

Nitrate loss was greatest when greatest amounts of sodium nitrate were used. Apparently, part of this transformation is due to the consumption of the nitrate nitrogen by soil organisms whose growth is favored by the sod, with the result that the nitrate nitrogen is converted into other compounds in which form it may be held for some time, and when conditions are favorable for the nitrifying process it may again be converted into nitrate. This statement is substantiated by the fact that while the effects of nitrate treatments on the nitrate content of the soil had largely disappeared by the autumn of 1920, yet the following summer with no additional nitrate fertilizer the yield for the rye cover crop which was allowed to mature, was in proportion to the quantity of nitrates added during the previous years.

The injurious effect of sod was greatly reduced with applications of sodium nitrate as tree growth on the sod plots was greatest where the largest quantity of nitrates were applied, and consequently on those plots where the soil moisture was often least. Since the tree growth was greatest where the soil moisture was least, it is evident that the relatively low moisture under grass was not a very important factor in curtailing growth. On the other hand, the fact that tree growth on the sod plots was greatest where the greatest quantities of nitrate of soda were applied, is evidence that nitrate nitrogen was an important consideration.

In summing the work of these men it appears that at certain stages in the life of some plants (usually during most rapid growth) they seem to possess the power to stimulate nitrification yet in most, if not all cases, soil nitrates are greatly reduced when the plants are allowed to mature. This nitrate depression appears to be manifested earlier and with greater intensity in the case of the grasses than with other farm crops.

Moisture as Affecting Nitrification

The optimum moisture requirements for maximum nitrification vary with the type of soil studied. This accounts for Paterson and Scott (93) placing the optimum at 14 per cent, Lipman (68) at 15 and Guistiniani (37) at 16, while Traaen (120) gives the following relationships which were obtained under controlled laboratory conditions with a temperature of 25° C.

Soil Moisture	Soil Nitrates in 100 g. soil	*Parts per million
5.0%...............	1.9 mg...........	19.00
10.0...............	1.9	19.00
17.5	13.2	132.00
25.0	16.6	166.00
30.0	15.5	155.00

Thus Traaen as did Harris (47) found that greatest nitrification occurred when the soil contained 25 per cent moisture, and that it was only slightly retarded when the moisture percentage reached 30.

*The last column was not included by Traaen.

Lipman and Sharp (65) as well as Greaves and Carter (46) found two maxima of nitrate fixation in relation to soil moisture, one when the moisture percentage was 17.5, this being optimum for aerobes, and one at 22.5 per cent as being most ideal for anaerobes.

Greaves (44) reports, from a study of twenty-two soils, that maximum nitrification and ammonification occurred when the soils contained 60 per cent of their water-holding capacity and that this is near optimum moisture requirements for many of the common field crops (45) (46). Gainey (34) received highest nitrification with soil 70 per cent saturated while Hutchinson and Milligan (52) with Noyes (92) place the optimum at three-eighths saturation, which represents 16 per cent moisture. This would indicate that the latter men worked with a light soil whereas the greater part of Gainey's and Greaves' investigations were done on silt loams.

Paterson (93) as did Munter (83) and Fisher (29) found at the lower limits of soil moisture, less water started nitrification in sand than in clay and at the higher limits of moisture, less water stopped nitrification in sand than in clay. Paterson with Fraps (30) found a rise above optimum more detrimental than an equal of fall below. Noyes and Conner's (92) work showed that soil fully saturated with moisture did not contain nitrates either before or after incubation with ammonium sulphate, and that more mitrates were formed in soil kept one-half saturated than in soils kept one-fourth saturated.

Warmbold (124) found the optimum moisture content of the soil to be 20 per cent. When it fell below 10 per cent, there

was no nitrogen fixed, and in some cases there was a decided loss of nitrogen. Greaves (43) in referring to the work of Deherain (26) states that an insufficient supply of moisture checks both nitrification and nitrogen fixation and this may occur in some soils when the water content has been reduced to but 16.5 per cent. Coleman (21) found nitrification was retarded when the water content was reduced to 10 per cent or increased to 26 per cent.

Lebidjantzer (62(believes the yielding power of a soil is maintained by alternate wetting and drying, and Lyon (70) by freezing and thawing. Both of these factors would tend to encourage better aeration and overcome any bad effects from high moisture. For the injurious effects caused by excess moisture become operative, it seems, only when it affects proper aeration. Gainey (35) stated that aeration will be sufficient to a depth of one foot with any degree of compactness, providing the moisture does not exceed two-thirds saturation. As the high moisture limits are determined largely by the point at which it interferes with proper aeration it naturally varies with the soil texture and structure.

From the above references it is evident that rather variable moisture percentages have been obtained for optimum nitrification, as well as for the highest and lowest percentages the moisture may reach without retarding or stopping nitrification. These variations are to be expected with the wide differences in soil types and methods of procedure.

From the foregoing citations, it appears that normally soil moisture does not become a very serious factor in limiting nitrification until the soil contains over two-thirds its moisture holding capacity or drops below one-third saturation while the optimum range lies between 18 and 25 per cent.

Influence of Organic Matter on Soil Nitrates

Temporary depressions in nitrification have often been noted when a large supply of organic matter is added to the soil. This depression seems to be more pronounced when the soil is already low in nitrates, or there exists a wide carbon-nitrogen ration in the organic material used. According to Sievers (108) (109) this ratio must approach 1:12 before the crops receive a benefit from the manurial applications.

Lyon (75) states that: "It is a well-known fact that straw when freshly plowed under produces to a greater or less extent a disappearance of nitrates."

Martin (15) found, when straw was incorporated with the soil, a marked decline in nitrate accumulation resulted. The duration and intensity of this decline was in proportion to the quantity of straw used. The nitrate depression was invariably accompanied with a decrease in crop yields. Colleson and

Conn (23) also report a decidedly depressive effect of straw applications on the subsequent crop.

Scott (105) and others (1) (22) received a marked decrease in nitrates by applications of straw, both under laboratory and field conditions. He noted as did Martin (80) that the nitrate loss was proportional to the amount of straw added, and crop yields were similarly affected. Brown (15), Gerlach (36), Albrecht (2), and others (117) (22) (105) (51) have noted similar results.

Idaho workers (53) tested the effects of sawdust and other forest residues on nitrification. They found that when sawdust, at the rate of 1 per cent, was incorporated with a soil, containing dried blood that there was a marked reduction in nitrate formation varying from 17 to 49 per cent. Of the other residues tested cedar needles proved the most toxic, reducing nitrate formation from 32 to 76 per cent. In summerizing the work, Iddings states, "In general, however, it may be definitely stated that all conifers used show inhibitory action upon the nitrogen-fixing powers of the soil bacteria."

Withers and Fraps (127) found when 16.1 grams of barnyard manure was added to 500 grams of soil, less nitrification took place, for a period of four weeks than in the uncultivated soils. Potter and Snyder (96) with Paterson and Scott (91) found a temporary nitrate depression occurred on the manured plots.

Normally, this shortage of nitrates is not prolonged; for as Greaves (46) states manure exerts a highly favorable effect on nitrogen-fixation, and reports that nothing in his results indicates that applications of manure up to 25 tons per acre were harmful to nitrate production.

Brown (11) found greater ammonification and nitrification, as well as higher crop yields, from the manured plots. He reports that applications of from 8 to 20 tons of manure per acre resulted in yields superior to those of the check plots, although the plots receiving 20 tons showed slightly less corn yields and nitrifying powers than did those receiving 16 tons, which were the highest plots in the entire series,

Brown (16) working on a Carrington loam reports that nitrification and the nitrifying power of this soil were increased with applications of manure up to a maximum treatment of 36 tons per acre.

Murphy (85) found over 1½ times more nitrates in manured soils under greenhouse conditions and 2¼ times more in soils kept in an open room for a period of two weeks, than in the unmanured soils.

Conn (24) states that the building of nitrates will not take place in the soil as long as there is any considerable amount of organic material or free ammonia present. The nitrate-forming bacteria will not grow either in the presence of organic material or ammonia. It is not until after decomposition has been

completed and practically all the organic compounds used up, that the nitrifying germs can begin to act."

Scott's (105) work does not agree with that of Conn (24) for he states, "That when cow manure was added to soil at rates varying from 1 ton to 160 tons per acre, good nitrification occurred in all cases, and organic matter was still present at the end of the period. The rate of nitrification was inversely proportional to the amount of manure added."

Snyder (110) observes that, "The principal organic food of the nitrifying organism is the organic matter of the soil and it is only when organic matter is incorporated with the soil that it can serve as food for the nitrifying organisms."

Breal (8) in 1892 reported an aerobic ferment associated with straw which possessed the power to reduce nitrates, and in the recent work of Collison and Conn (22) they reported, "That two separate harmful factors are associated with straw and other plant residues: first, a toxic chemical agent which acts upon the plant immediately after germination, although not having a very pronounced effect in the presence of much colloidal matter as in clay soils; second, a biological factor due to the stimulation of micro-organisms which compete with plants for their nitrogen." This second factor has been recognized by many workers (55) (122) (51) and it seems its ill effects are more pronounced in high carbonaceous material which, according to Lyon et al. (75), stimulates activities of nitrogen-fixing

organisms. This activity seems to be correlated with the nitrogen-carbohydrate ratio in the plant material consumed and the wider the ratio the more the nitrate accumulation is depressed.

Murray (88) explains the cause for such depressions in the following way: "The applications of straw stimulate the reproduction of bacteria. The bacteria use the straw as a source of carbon and use the nitrates as a source of nitrogen. The nitrates are transformed to organic nitrogenous materila and for the time being are lost as available plant food."

Lipman ét al. (68) found that under certain conditions small amounts of nitrogen may also encourage this minor nitrogen cycle. He states, "In considering the data at hand it should be remembered, of course, that small amounts of nitrates may favor the decomposition of inert humus compounds. Hence, where nitrates were used in the present experiment the decay bacteria were stimulated in their growth and were able thereby to attack the organic nitrogen compounds more vigorously. At the same time a large amount of nitrates was laid fast in the bodies of the bacteria by being converted into protein substances. Later on the bodies of the dead bacteria in their time passed through the process of ammonification and nitrification. We thus come to find that periodicity in the accumulation of

nitrates in the soil may be due to both the temporary prominence of species (of bacteria) especially capable of transforming large amounts of nitrates into protein nitrogen, as well as to the mere rapid increase of various decay organisms and their intense utilization of nitrates for the building of their bodies."

Ordinarily, the common forms and amounts of organic matter used on the farm, especially manure, tend to stimulate nitrate production. Nitrate depressions, however, have often occurred from heavy applications of organic matter. While the duration of this depression is usually rather short, it varies with the type and quantity of organic matter used. It appears that the slower the organic material decomposes, the greater the quantity and the wider the carbon-nitrogen ratio, the longer will be the period of nitrate depression.

Influence of Soil Reaction on Nitrification

Increased yields from the use of lime on acid soils are prevalent (128) (90) (66) (13) and are undoubtedly often encouraged by the increase in nitrate production facilitated by the use of lime. Brown (14) states, "The application of ground limestone increased considerably the nitrifying power of the soil."

Potter (97) found, "When organic matter in the form of

stable manure and the green manure, oats and clovers, is added to the soil, the total organic matter - that is, the organic matter of the soil plus the added organic matter - decomposes more rapidly under the influence of lime than without it. He also found that clover decomposed more rapidly than oats.

Christensen (20) found the soil content of basic lime and phosphoric acid combinations determined the speed at which mannite decomposition took place.

Brown (13) observed that applications of limestone up to three tons per acre increased the total number of soil bacteria; and from Runks (103) work, it appears that 60 mesh and 100 mesh limestone materials are as effective in encouraging decomposition, as is calcium oxide.

Lipman (69), in studying the availability of nitrogen fertilizers, found, "On the unlimed sections, total nitrogen recovered in the crop, where organic nitrogenous fertilizer was used, was somewhat more than where the mineral fertilizers were used. On the limed sections the reverse was true."

Stephenson (112) reports the sum of the nitrates and ammonia produced was greatest in the case of the unlimed plots where organic treatments were given. The reverse was true when the soil received applications of ammonium sulphate. Fred (32) obtained similar results which led him to state, "In the case of the acid soils, it seems that the nature of the compound to be nitrified plays an important part. For example, in acid

soils organic nitrogen nitrifies much more rapidly than nitrogen from ammonium sulphate. In non-acid soils, the reverse is true, ammonium sulphate nitrifies more rapidly." This conclusion is borne out by the following figures taken from an extensive table recording the work of Temple (118):

200 grams soil incubated for four weeks with 120 mg. of

1. Cottonseed meal produced - 16.5 mg. nitrogen (as nitrites and nitrates)

2. Ammonia sulphate produced 1.9 mg. nitrogen (as nitrites and nitrates)

3. Ammonia sulphate plus 1 gram of calcium carbonate produced 63.0 mg. nitrogen as nitrites and nitrates.

Gowda (42) reports, "Vigorous oxidation of ammonium sulphate by nitrite-formers took place when the reaction of liquid medium was around p H 8.0. For the nitrate-formers, the optimum reaction was between 8.5 and 8.8. Waksman (131) found that the nitrification of ammonium sulphate stopped when the p H reached 4.4 - 4.8.

Barthel (5) attributed the fact that nitrification proceeded better in the presence of organic nitrogen compounds than with ammonium sulphate to the effect of the acid (SO_4) produced by the latter.

It is evident from the above discussion that the decomposition and nitrification of organic compounds occur in soils with a rather high lime requirement. It seems, however, that ammonium sulphate is far less easily nitrified in an acid media than are organic fertilizers, particularly cottonseed meal.

Cultivation as Affecting Nitrification

It is not intended to give an extensive summary of the literature bearing on this topic, thus only a few citations are noted in this review.

The main objects of cultivation are: to improve the structural conditions of the soil, encourage better aeration, destroy weeds, conserve moisture and incorporate organic matter and fertilizers with the soil. All of these factors are directly associated with the problem of nitrate production and are conducive to nitrification.

Reed (100) stated, "Cultivated soils showed decidedly higher nitrifying powers than virgin soils." Lyon and Bizzell (71) found nitrates began to accumulate more rapidly after the soil had been stirred and that greater nitrate accumulation occurred in the fall plowed soils than in those plowed in the spring. Albrecht (1) and King (58) showed that early tillage, particularly plowing increased the nitrate content of the soil. Gourley (40) stated, "Stirring the soil readily increased the rate of nitrification." From this it would seem that the earlier the soil

is plowed the earlier the nitrification would occur.

Lyon et al (78) found that the tree growth on the sod plots was proportional to the quantity of sodium nitrates applied. This relation did not exist on the cultivated plots for the tree growth was not greatest where nitrate nitrogen was highest. This may have been because all of the cultivated plots, whether fertilized or not, contained an adequate supply, or even a surplus of nitrate nitrogen. The tree growth on the sod plots which received 900 pounds of sodium nitrate was only 2/3 as great as on the cultivated unfertilized plots. This higher nitrate content was also found to be associated with the cultivated plots in later work (77) on plum and cherry trees.

Chandler (16) calls attention to the danger of nitrate shortage resulting from delayed spring plowing and suggests early plowing where cover crops were used, particularly if there is a possibility of the cover crop becoming woody.

Martin (81) found that the more matured vegetable material is when incorporated in the soil the more slowly it decomposes while the more succulent it is the more rapidly it decomposes and that the value of the organic material depended upon the ease with which it breaks down and nitrifies, all of which seems to stress another need for early plowing when cover crops are used. This phase of the question will be emphasized in the body of this report.

Whiting et al (128) after reviewing tillage reports from England, Russia and the United States gives the following outstanding relations between tillage and nitrate production which also sums up the data presented here. He states, "Plowing increases nitrate production. Cultivation conserves nitrates by preventing weeds from using part of the available supply. Mulching reduces loss of rapid leaching and conserves moisture, thereby tending to maintain the nitrate supply in the soil. Fallowing enables the soil to accumulate large amounts of nitrates because none is used by the crop," and as emphasized above the early turning under of a cover crop stimulates early nitrate production.

Relation of Soil Type to Nitrate Production

There is little in the literature bearing directly on this subject. Yet the part soil type plays in the role of nitrate production is an imp rtant one. It is not only correlated with nitrate production but particularly pronounced in determining the nitrate retentive capacity the soil will possess when subject to heavy rains. It seems that little emphasis has been given to this latter consideration which will be stressed in part I-a of this thesis.

Withers et al (126) compared the nitrifying powers of several soil types by incubating 50 grams of soil with 4.31 grams of cottonseed meal (containing .03 grams nitrogen) for a period of four weeks and then determining the quantity of

nitrates present over and above that which the soil contained at the beginning of the experiment. Cecil sandy loam was chosen as the standard soil and the amount of nitrates found in it was place at 100 for the purpose of calculating the rank of the other soils which is given below.

Very Light Soils	Light Soils	Medium Soils
Tarbow sand 16	Norfolk fine sandy loam 50	Porters loam 84
Norfolk sand 18	Durham sandy loam 71	Porters black loam 106
	Herndon stony loam 36	
	Cecil sandy loam 87	
	Porters gravelly loam 71	
	Porters sandy loam 59	
	Cecil sandy loam 100	
	Durham sandy loam 11	

Heavy Soil

Porters red clay 74

From these results it is evident that the nitrifying power of the soil varies greatly wtih the soil type as well as with the soil class. Note that the loam soils possessed the highest nitrifying powers followed by the sandy loams and clay but that it dropped to a rather low point in the light open sands.

Reed (100) after determining the nitrifying efficiency of 44 virgin and cultivated soils gives the following relations:

Nitrifying efficiency of a number of virgin soils of various textures

Classification	Av. mgs. nitrate nitrogen per 100 gms. soil
Fine sand	3.46
Sandy loam	3.18
Loam	9.04
Clay loam	20.50
Clay	5.61

Nitrifying efficiency of a number of cultivated soils of various types.

Soil type	mgs. of nitrate nitrogen / 100 grams soil
Cecil sand	1.50
Sandy loam	7.28
Cecil loam	29.50
Clay loam	40.39
Cecil clay	25.11

"From this work it is evident that the open sandy soils are strikingly low, the loams and clay loams are as impressively high, and in the heavier clays again a falling off is evident."

From the above citations, it is evident that soil type is a very important factor influencing nitrate production.

Original Investigations

Methods Employed

A composite soil sample of the upper seven inches of surface soil was obtained at weekly intervals from each plot by making 20 to 24 borings with a one and one-half inch soil auger. The soil thus obtained was thoroughly mixed in a clean pan, placed in a quart fruit jar, tightly sealed and taken to the laboratory for analysis. Nitrate and moisture determinations were made immediately after sampling. The phenol-di-sulphonic acid method, as described in Bureau of Soils, Bulletin 31, was employed in all work. The soil temperatures were taken weekly and are recorded in the appendix of this report.

PART I

Nitrate Accumulation as Affected by Topography, Soil Class, and Barnyard Manure.

The moisture content of the soil is perhaps the most important factor influencing nitrification. While precipitation and irrigation determine the quantity of water the soil receives, the amount retained depends upon: first, topography; second, texture; and third, organic matter. The important part which these three factors play in the role of soil nitrification is emphasized by the nitrate determinations made on the soils described below.

Description of Soils

The soils from the five corn plots under consideration vary in texture, as shown by the mechanical analysis, (Table I, Page 30) from a sandy loam to a silt loam. They are of glacial origin and are members of the Hartford series. This series is characterized by typical lake-laid material occupying the lower shores and upper bottoms of the old glacial lakes. Most of the Hartford soils are fairly well assorted with rather distinct stratifications and bedding planes.

The soils of the first four plots are rather erratic phases of the Hartford series, in that they are alluvial terraces which have resulted from stream action upon the lake-laid Hartford material. The surface soil of plots 1 and 2, located on the brow of the upper terrace, is largely wind deposited sands which have been carried from the opposite bank and left on the windward face of this formation. This accounts for the high percentage of fine sand and very fine sand, also the low organic content of these first two plots. (Table II, Page 30).

Plots 3 and 4 are located on the second terrace 165 feet from plots 1 and 2 and 16 feet lower in elevation. This soil is slightly heavier with much higher organic content than the soil of the two preceding plots. The soil of plot 5 is of deeper lake deposition and a typical heavy Hartford silt loam.

Additional information concerning characteristics of soils studied is given in Table II.

Table I. Mechanical Analysis of Soil From Corn Plots

Plot	Soil Class	Fine Gravel	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Silt	Clay
1	Sandy Loam	0.12	0.43	1.36	34.27	56.58	4.66	2.56
2	Sandy Loam	.0	0.36	0.69	13.61	66.43	15.14	3.77
3	Loam	0.37	1.13	1.13	9.11	35.60	42.34	10.32
4	Loam	0.13	0.65	0.86	7.56	43.77	39.60	8.43
5	Silt Loam	1.08	1.67	1.95	8.90	27.76	48.59	10.05

Table II. Additional Information Concerning Soils Studied

Plot	Soil Class	Loss on Ignition	Moisture holding Capacity	Soil Acidity pH value
1	Sandy Loam	2.7 per cent	37.4 per cent	6.7
2	Sandy Loam	3.9 " "	48.3 " "	6.1
3	Loam	9.4 " "	69.1 " "	6.2
4	Loam	7.9 " "	63.1 " "	5.7
5	Silt Loam	7.2 " "	58.7 " "	6.2

All soil classes are designated under the new system of classification as given in Journal of the American Society of Agronomy, Volume 18, No. 3, March 1926.

Plot Treatment

In the fall of 1924, alfalfa stubble on plot 1, and sod on plot 3 were plowed under. Early the following spring 20 tons of cow manure, from the college barns where sawdust and wood shavings had been used for bedding, were thoroughly disked into the soil. On May 19, these fields were planted to Davis flint corn, two hundred and fifty pounds of acid phosphate being applied per acre in the corn rows at the time of planting.

Plots 2 and 4 which had been in hay for the preceding two years were also plowed in the fall of 1924 and planted to Davis flint corn on May 19 of the following spring. Four hundred pounds of a 3-10-6 fertilizer were applied per acre in the corn rows during planting. These plots have received no barnyard manure for at least 12 years.

Plot 5 was cleared and put under cultivation in the spring of 1918. The following year it was planted to corn and seeded down that fall to grass pasture which remained until the fall of 1924 when it was again plowed. Twenty tons of manure were applied per acre during the winter and it, with one ton application of lime, was worked into the soil as soon as the spring weather permitted. Rustlers White Dent was planted May 27 and two hundred and seventy-five pounds of acid phosphate per acre were applied to the soil.

The corn crop on all plots was good except on plot 3 which, for some unknown reason, had a poor stand.

Summary of Plot Treatment

Plots 1 and 3.	20 tons manure, 250 pounds acid phosphate per acre.
Plots 2 and 4.	No manure, 400 lbs. 3-10-6 fertilizer per acre.
Plot 5.	20 tons manure, 275 pounds acid phosphate per acre.

PART I-A.

Nitrate Accumulation as Affected by Topography.

Nitrate and moisture determinations were made weekly from May 15 to September 4. Two analyses followed this date one on September 18 and one on October 17.

Care was taken in obtaining the composite soil sample to make one boring in close proximity to the hill of corn, one equidistant between hills and one at a point where the diagonals from four hills, two in each row, would intersect each other. Eight such sets of borings were taken across the center of each plot.

The trend of soil nitrates and moisture for the first four plots, as well as the weekly precipitation, are graphically represented in figure I, page 40. The weekly precipitation is taken from the daily record of the local weather observatory and calculated for the week preceding the date of sampling. For illustration: the point on the graph showing 1.03 inches rainfall on the third date of sampling, May 29, indicates the amount of rainfall which occurred between noon of May 22 and noon of May 29.

The extreme irregularity in the nitrate curves is due to the topography of the plots and the heavy rains which occurred within the season. It should be remembered that plots 1 and 2 are located only 165 feet from plots 3 and 4

and are 16 feet higher in elevation, that approximately 90 per cent of the soil from plot 1 and 80 per cent from plot 2 is composed of fine sand with only 2.5 and 3.7 per cent organic matter, respectively. All of these factors are conducive to leaching of nitrates from the higher to the lower elevations. Thus note how high precipitation is accompanied with high nitrate accumulation in the lower plots 3 and 4, and conversely, how regularly the nitrates fall in the lower plots and rise in the higher ones during periods of low precipitation. This is an example of the important role which topography plays in nitrate accumulation.

The rapid gains of nitrates in plots 3 and 4, between May 29 and June 5, also between June 19 and July 3, occurred during heavy rains and are thought to be due largely to the accumulation of nitrates leached from the higher plots (43). This assumption is substantiated by the fact that on the same dates there resulted a corresponding loss of nitrates from the higher plots 1 and 2, except between May 29 and June 5 when accumulation slightly exceeded loss on plot 2.

Even though the first fall of nitrates in plots 3 and 4 occurred during a period of very low precipitation, the fall can in no way be attributed to lack of moisture; for at no time throughout the season did the moisture content of these two plots fall below 35* per cent, which according to Greaves (46), Lipman (65), Traaen (120), Harris and Butts (47) and other workers is above optimum moisture requirements

*Water percentage based on oven dry weight.
20 g. moist soil dried at 100° - 105° C.

for maximum azofication and nitrification. The greatest factor contributing to this early nitrate fall in the lower plots, as well as to the time of its occurrence - that is, during low rainfall - is believed to be the high precipitation of the preceding weeks, associated with differences in the rate of leaching between the two sets of plots. The location of the plots with structural and textural differences in the soil made possible a rapid movement of nitrates from the higher to the lower levels but a slower rate of nitrate removal from the lower plots. Thus the alternating rise and fall of nitrates in the two plots is largely due to a difference in rate of water movement through the two soils. This also accounts for the higher nitrate content of the lower plots without indicating a higher rate of nitrification; for, as Lyon and co-workers (75) have pointed out, the quantity of nitrates present is a measure of nitrate accumulation rather than of nitrate formation.

That a lack of moisture was at no time a limiting factor in the lower plots seems to be obvious in that the higher plots experienced their highest nitrate accumulation of the season on the dates of greatest fall for plots 3 and 4, except for the final drop occurring near July 1, at which time the corn was making its most rapid growth, and thus the heaviest drain on nitrates was taking place. This drain was also associated with heavy precipitation averaging over 1.5 inches rainfall per week for a period of six weeks. These two

factors caused an almost complete removal of nitrates from all plots. There was no marked rise of nitrates after this period.

The data here presented correspond quite closely to the normal nitrate trend, under a crop of maize, as obtained by Lyon and Bizzell (71), Batham (6), also Whiting and Schoonover (128). Gowda (4) of Ohio found the accumulation of nitrates to be greatest in June with a gradual decline in July and a rapid decrease to minimum in August and September, with a slight rise in October. The final loss of nitrates from these plots occurred somewhat earlier and with greater rapidity than is normally the case under a crop of corn. This indicates that the corn alone was not responsible for the entire nitrate removal but that it was unquestionably augmented by the heavy rainfall which caused loss of nitrates through leaching and perhaps denitrification. That high precipitation was perhaps the dominant factor is shown by the part it played in nitrate removal earlier in the season and also by the quantity of nitrates which disappeared within a period of from two to three weeks.

In light of the moisture relations obtained by the men previously cited, the moisture and nitrate relationships of these two sets of plots are rather abnormal, for at no time throughout the entire season did the moisture content (with the exception of plot 2) fall within the range given by any of the workers previously cited, whether it be for the an-

aerobic or aerobic conditions. Plot 1 never showed a known moisture content above 15.2 per cent and only four times during the season did it exceed 12 per cent; while the moisture content of plots 3 and 4 never dropped below 35 per cent and only once did plot 3 go below 41 per cent. As to the actual azofication or nitrification carried on in the lower plots, we do not know, because of the nitrates received from the higher plots. There was unquestionably some nitrification, however, even with a moisture percentage over 43 as is shown by the rise in nitrates between June 10 and 19, a two weeks' period, of low precipitation, when leaching could not have been operative.

Although the lower plots show the highest nitrate accumulation, perhaps the most rapid nitrification occurred on the upper plots, as is shown from the rapid rise following periods of leaching.

The highest nitrate accumulation of the season in plot 1 occurred on June 19 showing 100.8 parts of nitrate per million parts of soil, with a moisture content of but 7.9 per cent, this being the lowest percentage during the first three months of the determinations. On the same date plot 2 showed its highest nitrate content with a moisture percentage of but 14.1, this being next to the lowest moisture percentage during the first three months of the season. These moisture

percentages represent 21 and 29 per cent of the total water-holding capacity of these soils.

Lipman (68) observed quite marked nitrification with only 5 per cent moisture. This work was conducted under controlled "box soil" conditions and even then the low moisture relationship is rather unusual, as Lipman suggests; for in referring to this, he states: "Even more interesting is the fact that soils 47 and 48, which probably averaged less than 5 per cent of moisture during the entire period, still allowed a fairly active nitrification to go on." No nitrification occurred in his saturated soils. These results confirm the statement of Withers (122) that, "Soil with low water capacity, low absorptive power and low humus does not necessarily have a low nitrifying power."

Even with the wide range given by the workers previously cited, the soil moisture and nitrate relationships obtained in this work are rather unusual in that the highest nitrate accumulation of the season, reaching 240 parts per million in plot 3, was associated with 48 per cent moisture while only 55 yards away, plot 1 representing a different soil type, reached its highest nitrate content when the soil contained less than 10 per cent moisture. This low moisture percentage associated with high nitrates in no way indicates that nitrification was most rapid under these conditions but merely that nitrification was rather active and that most favorable moisture relationships existed for the retention of the

nitrates produced. Neither can the high nitrate content of plot 3 be attributed to high nitrification for this accumulation represents nitrates which have been leached from the higher to the lower elevations.

It is evident from this discussion that the nitrate accumulation of these soils was governed mainly by moisture relations and that these relations were established largely by the topography.

Summary of Part I - A.

1. Topography and rainfall caused great fluctuation in the nitrate and moisture content of these soils.
2. Nitrates were leached from the higher to the lower plots during periods of precipitation.
3. Greatest nitrate accumulation occurred on the lower plots during high precipitation and when the soil of the two plots had a moisture content of 42 and 48 per cent.
4. Greatest nitrate accumulation occurred on the two higher plots during periods of low precipitation with a soil moisture content of 8 and 14 per cent.
5. Indications are that nitrification was operative in the soils of plot 3 with a moisture content of 43 per cent.
6. Nitrification was operative in the soils of plot 1 with a moisture content below 10 per cent, greatest nitrate accumulation occurring when the soil contained but 8 per cent moisture.
7. Heavy July rains accompanied by rapid corn growth removed nitrates from all plots. No marked nitrate accumulation occurred after this date.

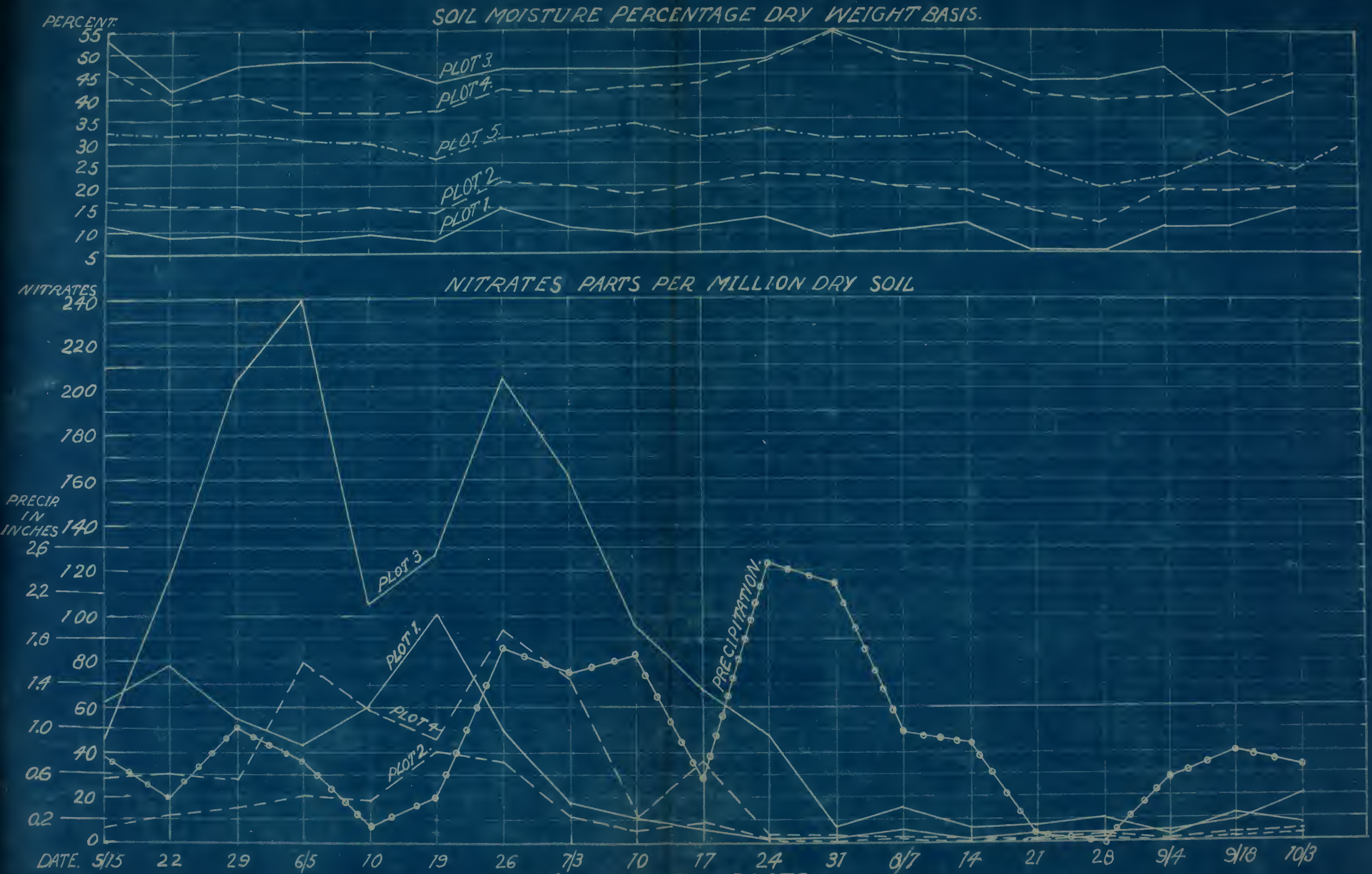


FIG. I CORN PLOTS

Part 1-b

Nitrate Accumulation as Affected by Soil Class

In view of the many external influences causing nitrate variations even in adjacent field plots, it may seem rather futile to try to show relationships between soil nitrates and soil classes. There are, however, certain characteristic tendencies inherent in the various soil classes which greatly affect their ability to furnish the plant with a sufficient nitrogen supply.

From the data given in Table I, Page 30 it can be seen that plots 1, 3 and 5 represent three distinctly different soil classes; sandy loam, loam and silt loam, respectively, and that these classes are rather characteristically different from one another, not alone in texture but also in percentage of organic matter and water-holding capacity. Attention has been called to differences in their formation in that they represent three very different phases of the Hartford series.

The results of weekly nitrate determinations are found in Table I of the appendix and are represented graphically in figure II, page 45.

Plot 3, with the loam soil, ranks notably higher in nitrates than did plots 1 and 5. There is very little

difference between the amount of nitrates in the light and heavy soil classes. The seasonal nitrate average in parts per million for these soils are: plot 1, sandy loam, 28.5; plot 3, loam, 75.0; and plot 5, silt loam, 31.5.

Virginia workers (100) in testing the nitrifying power of Virginia soils of various textures state, "This quality in light open sandy soils was strikingly low; in the loams and clay loams it reached its maximum height, and in the heavy clays there was again depression, yet not so low as in the extremely open soils." This statement corroborates to some extent the results under discussion, but, as previously stated, the data here presented in no way represent the total nitrates produced or the nitrifying power of these soil classes, but more their ability to maintain the nitrates that have been formed.

The irregularity and the alternating rise and fall of nitrates in plots 1 and 3 are thought to be due largely, as formerly explained, to the leaching of nitrates from the higher to the lower plot. Although this condition tends to enhance the nitrate standing of plot 3 and lower that of plot 1, this loss of nitrates through leaching is one of the inherent characteristics of light open sandy soils, although rather greatly accelerated, in this case, by the location of these plots. This again is rather typical, in that very often the light open soils of the field are found on the higher elevations.

Beginning on June 19, four and nine-tenths inches of rainfall occurred during the following three weeks. This resulted in the final removal of nitrates at weekly intervals, first from the sandy loam, second from the loam, and third from the silt loam.(Figure II, Page 50). It is interesting to note that the soil from plot 3 - receiving some of the excess water from plot 1 - became supersaturated and lost its nitrates before the soil of plot 5 even though under laboratory conditions it showed a higher moisture holding capacity and higher organic content, (Table II, Page 30). Thus in the field during heavy rains the period of nitrate retention was not governed by the moisture holding capacity of these soils but by their topography and texture. It appears that under laboratory conditions, the organic content was more powerful than soil texture in determining the water-holding capacity of the soils from plots 3 and 5.

Some interesting relations are shown in the moisture percentage of these soils at the period of nitrate removal, the percentage being 14.7 for the sandy loam, 46.0 for the loam and 33.9 for the silt loam. The moisture percentage of the sandy loam seems rather low to cause loss of nitrates through leaching; it represents, however, the highest moisture percentage of the entire season except for the last determination, October 3. Since sampling on June 1 did not occur until approximately 24 hours after raining had ceased,

and moreover, as the air temperature was 80 degrees and the soil 59 degrees, this moisture percentage is perhaps somewhat lower than it would have been had sampling occurred immediately following precipitation.

Summary of Part 1-b

1. Nitrate accumulation was found to be highest in a loam. Little difference was manifest between the sandy loam and silt loam. The average for the entire season, however, was slightly in favor of the heavier soil.
2. During heavy rains of late June and early July, nitrates were leached at weekly intervals: first, from the sandy loam; second, from the loam and third from the silt loam.
3. Due to topography, the soil in plot 3 was first to become saturated. Thus the order of nitrate removal does not agree with the moisture holding capacity of these soils, it being highest for the loam; second, for the silt loam, and third for the sandy laom.
4. The moisture holding capacity of the soils was in order of their organic content rather than fineness of texture.

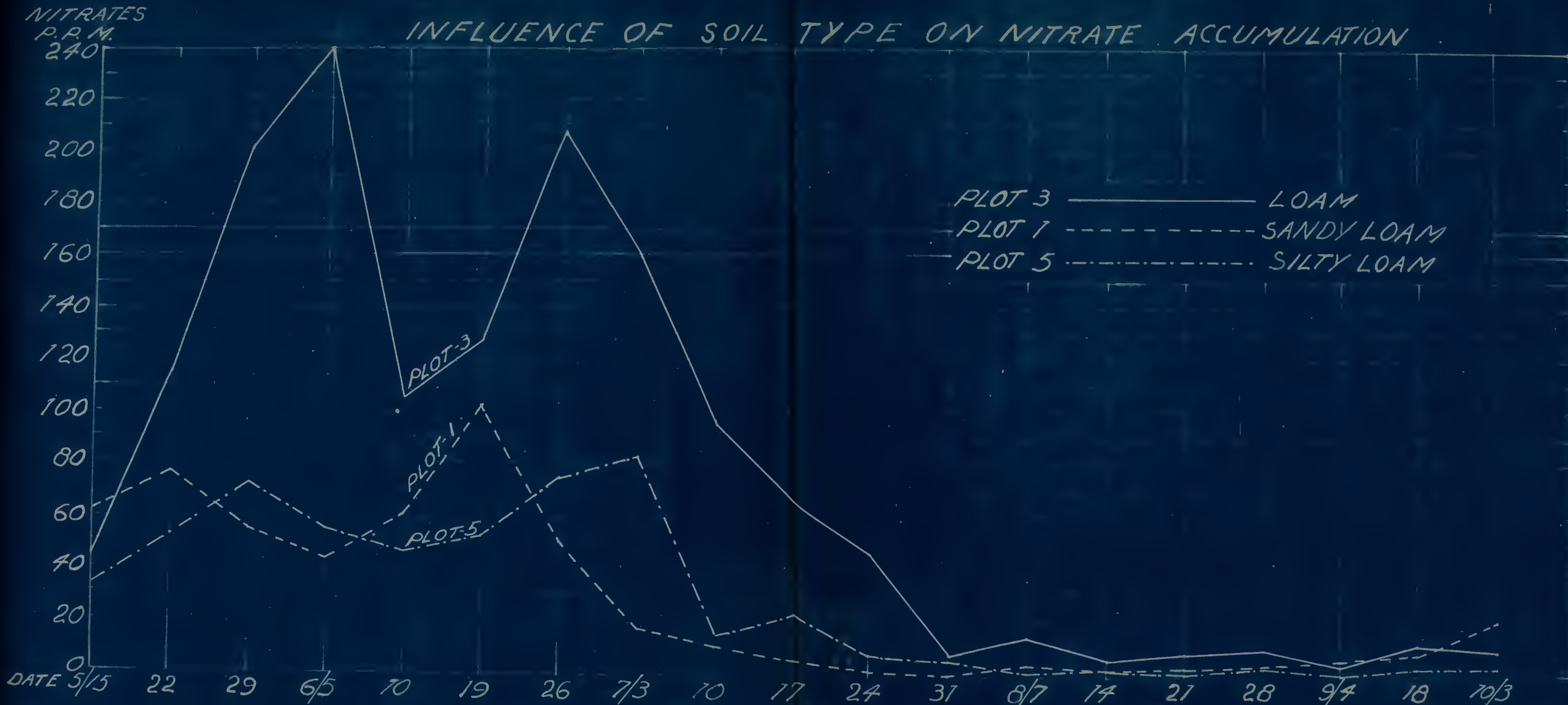


FIG 2. CORN PLOTS

Part 1-c

Nitrate Accumulation as Affected by Barnyard Manure.

Previous observations on heavily manured corn fields of the College Farm seemed to indicate, from the color and characteristics of the corn plants, that in the early stages of crop growth there occurred a shortage of available nitrates. Lyon (75) Withers (127) and others previously cited have noted this depression when the carbon-nitrogen ration was widened, as may result from heavy applications of barnyard manure.

With the hope of throwing some light upon the previous observations, a comparison is given between the nitrate accumulation of the manured and unmanured plots. These determinations showed that even when 20 tons of cow manure, rather high in wood shavings, were applied per acre, there was no nitrate depression indicated, but rather a marked increase in nitrate production on all manured plots. This is shown from the determinations given in Table I of the appendix, also by Figure III, page 50 where the average nitrates of the manured plots 1 and 3 and the average of the unmanured plots 2 and 4, as well as the nitrates for the manured plot 5, are graphically presented.

Nitrates in the manured plots - even in the heavy soils of plot 5 - were highest at the beginning of the determinations

(May 15) and remained distinctly higher until July 24 when the nitrates from all plots practically disappeared. Yet the nitrates in the manured plots retained their higher standing throughout the season.

These results would indicate that ordinarily normal field applications of barnyard manure under the condition described increase nitrate production in the soil. However, temporary nitrate decreases have often been noted when heavy applications of manure, high in undecomposed straw or wood shavings were applied to soils low in nitrates. The theories for such a loss are to the effect that by the presence of a large supply of energy forming material furnished by the manure, nitrogen assimulating organisms are greatly stimulated in growth. These rapidly increasing numbers of bacteria compete with the plant for the soil nitrates which are used in the anabolism of the nitrogenous compounds of their own bodies.

It is possible that nitrate depression, caused by heavy applications of manure, may at times be due to unfavorable physical effects produced in the soil. The high absorptive power which organic matter has for soil moisture brings the soil moisture to a point where nitrification would be checked. When we find from the work of Richards (102) and Tottingham (119) that with proper aeration, sufficient moisture and calcium carbonate, nitrification was carried on in horse

manure, it seems we are safe in assuming that any appreciable or extended depressive influence manure might have on nitrate production or plant growth would result from secondary causes such as ill physical effects, improper moisture relations or destructive biological disturbances rather than from an increase in bacteria causing a decrease in soil nitrates.

The cultural treatment of these plots prior to sampling may account for the persistently higher nitrates and the total absence of a minor nitrogen cycle in the manured plots. Stubble was plowed under the preceding fall. The manuring and preparation of the seed bed took place very early in the spring and some time before sampling began. These operations may have allowed a proper adjustment of the carbon-nitrogen ratio, a correction of any ill physical effects of the soil and encouraged hydrolysis and oxidization which must necessarily precede (32) nitrification, to become active and properly adjusted before the nitrate determinations were begun. That normal nitrification was in process at the first date of sampling is indicated by the higher nitrate standing of the manured soils at this period. This suggests a method whereby conditions may be made favorable for adjustments between the manure and the soil processes before planting occurs.

Summary Part 1-c.

Judging from the soil nitrates, which were determined weekly on manured and unmanured plots, there was no indications that 20 tons of manure, rather high in wood shavings, in anyway retarded nitrification, for the manured soils showed constantly higher nitrate content than did the unmanured soils throughout the entire season.

From the data presented, the results of other workers and previous observations on corn fields of the College Farm, it seems that if the manuring and the preparation of the seed bed occur a few weeks before planting, there is little danger of a depression of nitrates or a check in plant growth from normal applications of barnyard manure.

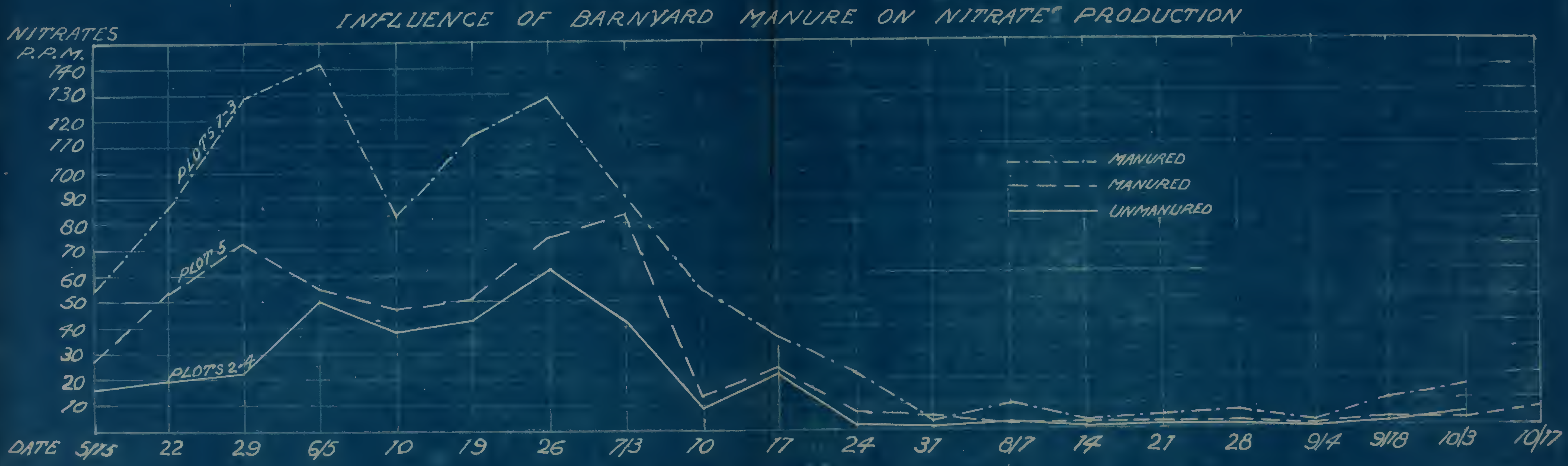


FIG. 3. CORN PLOTS

Conclusions for Part I

From the data here presented it appears that the three factors most operative in the moisture and nitrate retention of these soils, listed in order of their importance, were: first, topography; second, texture or soil class; and third, organic matter.

It seems that factors determining soil series, such as topography, organic matter, arrangement of soil in sections, natural drainage, etc., (137) exert a greater influence upon nitrate accumulation in the soil than does textural differences determining soil class.

The rapid movement of nitrates from the higher to the lower elevations indicates that nitrification may be far more active in the higher soils of the field than in those of lower elevations and yet contain less available nitrogen. This also suggests an inconsistency in an even distribution as well as a single application of nitrate fertilizer on a field varying in texture and topography.

The lighter color and earlier ripening of crops on the higher elevations of the field and the deeper green casts and slow maturity of crops on the lower levels might be not only a question of moisture but also of soil nitrates.

Normal applications of barnyard manure exert a highly favorable effect on nitrification in soils.

PART II

Nitrate Accumulation in Orchard Soils

The purpose of this project is to study soil nitrification as affected by different systems of orchard management. The practices considered as influencing soil nitrate accumulation are: first, sod and cultivation with and without a nitrogen fertilizer; second, straw mulching and third, single and complete fertilizer treatments.

Description of Soils

The orchard nitrate project is divided into seven blocks which are designated as D, E, F, G, H, A, and R. The first five blocks are located on the eastern slope of a small drumlin, the soil of which has been classified by the Bureau of Soils as Holyoke stony loam but would probably be reclassified a Gloucester stony sandy loam. It is derived primarily from igneous and metamorphic rocks with a small amount of sedimentary material present. This material varies in size from large stones to fine glacial flour. The surface soil is underlaid by a stratum of rather highly compacted material which tends to prevent excessive drainage. Only twice during the season did the moisture in this soil drop below 18 per cent; thus, at no time did the trees materially want for water.

Block A lies at the upper levels of the old glacial lake

and at the foot of the northwestern slope of the drumlin. The soil is a sandy loam of the Merrimac series and is a typical water worked material. As it is deeply underlaid by the same compacted stratum that is found beneath the surface soil of the drumlin, it is very efficient in moisture retention.

The field of block R slopes gently to the west. The soil is classified by the Bureau of Soils as Merrimac coarse sandy loam, analysis, however, showed it to be a sandy loam. Despite the rather high percentage of coarse separates there has been no indication that the trees have materially suffered from a lack of excess of moisture.

Plot Treatment

Each of the orchard blocks is divided into plots. Block A is a cultivated project containing six one-fifth acre plots which represent a nitrated and unnitrated series. The nitrated plots are 3 - 5 and 7; the unnitrated are 2 - 4 and 6. Block E is a project comparing cultivated plots 3 and 5 with sod-nitrated plots 2 - 4 and 6.

Block G and H are each divided into two one-half acre plots. One-half of each block is kept under cultivation and the other half under four to six inches of straw mulch.

Block D and F are series of sod fertilizer experiments with treatments of plots as given below in table III.

Table III. Summary of Plot Treatments

Block	Treatment	Fertilizer Applications in Pounds per Acre			
		None	Sodium Nitrate 300	Acid Phosphate 300 Potassium Sulphate 200	Acid Phosphate 300 Potassium sulphate 200 Sodium Nitrate 300
		Plots	Plots	Plots	Plots
A	Cultivated	2, 4, 6	3,5,7		
E	Cultivated	3, 5			
	Sod		2,4,6		
D	Sod	6, 7	1,4		3
F	Sod			1, 3, 5	2, 4
Grand H	Cultivated and Straw Mulch				

The fruit trees of the above blocks vary in age from ten to fifteen years.

Block R is divided into twelve plots, ten feet wide and one hundred and twenty feet long. It is under a cultixated cover crop system, but as cultivation has been only lengthwise through the plots a space of about three feet down the tree rows remains untilled. On this untilled area buckwheat and rye, which has been used as a cover crop, has made more or less growth, depending on the fertilizer treatments of the plots. It was from this uncultivated strip that soil samples were taken.

Table IV. Block R. Summary of Plot Treatment

Plot	Fertilizer Treatment Pounds per Acre		pH value of soils limed	pH value of soils unlimed
2	Sodium Nitrate....	160	6.4	5.9
3	Acid Phosphate.	320	6.1	5.7
4	Check....		6.1	5.7
5	Potassium chloride..........	160	6.1	5.8
9	Acid phosphate.............. Potassium chloride..........	320 160	6.1	5.6
10	Sodium nitrate............... Acid phosphate.............. Potassium chloride..........	160 320 160	6.2	5.7
11	Calcium sulphate............	800	6.1	5.6
12	Check....		6.0	5.8

Each year, near the first of August, all cultivated plots are planted to a cover crop which grows throughout the remainder of the season and is plowed under between the middle of April and the first of May the following spring. The grass on the sod plots is mowed from time to time during the year and allowed to remain on the field.

Part 2-a.

Sod and Sod-Nitrated Plots versus Cultivated and Cultivated-Nitrated Plots

It has been noted from the literature previously cited that fruit trees in sod usually do not make as much growth as do those in cultivation unless a nitrogen fertilizer is used. Cornell (78) workers noted that during the first four years of a McIntosh apple orchard that the tree growth was not as good on the sod-nitrated plots as on the cultivated plots receiving no nitrogen. For four years at least on the Cornell soil (Dunkirk silt loam) an adequate supply of nitrogen can be maintained by the cultivation-cover crop system. It is very probable that had cultivation continued over a longer period there would have resulted a shortage of nitrates under the cultivated system.

Shaw's results at the Massachusetts Experiment Station "Indicate that on this soil (Holyoke stony loam) apple trees cannot be maintained in a good growing and bearing condition by cultivation without fertilizers." His findings show heavier bloom and better set on the sod-nitrated plots. It also appears that more favorable nitrate relations for fruit-bud formation can be established under a sod-nitrate program.

With the hope of throwing more light upon the question of sod and cultivation in orchards, the seasonal nitrate trend in the soils of the cultivated and cultivated-nitrated plots is

compared with the trend in the sod and sod-nitrated plots. The effect these treatments had on the nitrate accumulation of each plot is given in Table 5 of the appendix. A better comparison is shown in the graph figure IV, page 62, where the nitrates in all plots of the same block similarly treated are averaged. Thus plots 3, 5 and 7 of block A represent the cultivated-nitrated plots* while 2, 4 and 6 of the same blocks, also 3 and 5 of block E, are the unfertilized cultivated plots. The sod-nitrated plots are 2, 4 and 6 of block E, while 6 and 7 of block D represent the unfertilized sod plots.

It appears that the sod-nitrate program furnishes a nitrate role strikingly similar to the one suggested by the men previously quoted as being optimum for fruit-bud formation. Notice the early rise and fall of nitrates in the sod-nitrated plots of block E. This ready supply of available nitrates early in the season should furnish the nitrogen Alderman (31) and Wiggans (129) found was needed in increasing the percentage of fruit-buds. It should also encourage an early growth in the spur-leaf area, thus facilitating rapid photosynthesis and the early carbohydrates production desired by Chandler (18). The fall which occurred the first week in June was not too soon to encourage dropping of the fruit, but perhaps soon enough to check growth, which, according to Kirby (60), Gourley (38) and others, seemed to be advantageous in encouraging fruit-bud formation. This rapid drop in nitrates

*As there were no cultivated-nitrated plots on the bromlin soil, Block A, a slightly different soil type, had to be included. To show the similarity in the nitrate trend of block A with the bromlin soils a cultivated plot from each is plotted separately.

after a period of abundance, and also of rapid growth would tend, it seems, to widen the carbohydrate-hitrogen ratio, as did the ringing done by Curtus (25) and at exactly the optimum time as shown from the work of Drinkard (28) and the ringing experiments conducted by Shaw (107).

The nitrates were low in the cultivated-nitrated plots during the month of May when nitrates were most needed, and at which time nitrates were being supplied to the trees on the sod-nitrated plots. This nitrate decline, under the cultivated-nitrated treatment, between the first and thrid weeks of May strongly indicates the operation of a minor-nitrogen cycle. The first determination on April 29 gave only a mere trace of nitrates. The following day, April 30, three hundred pounds of sodium-nitrate was applied per acre and it, with the cover crop of buckwheat, which had been planted the previous fall, was plowed under. The rise of nitrates on the second date of sampling (May 6) simply indicates a partial recovery of nitrates added. With conditions favorable for bacterial activities, including a ready supply of carbohydrates as food, there occurred a rapid multiplication of nitrogen assimulating bacteria which caused soil nitrates to decline for a period of about two weeks. Upon the death of these organisms and the decomposition of the nitrogenous compounds stored in their bodies, there resulted a rather rapid rise in available nitrates. The marked accumulation of nitrates in these same plots during June and early July would tend, it seems, to narrow the carbon-nitrogen ratio just

at the time it needed widening and also stimulates spur, shoot and leaf growth at the time they needed checking.

Only once during the season did the nitrates in the cultivated unfertilized plots of blocks A and E reach 15 parts per million. Although the highest nitrate accumulations in the cultivated plots are far below those in the cultivated-nitrated plots, it is interesting to note that the maxima for both treatments occurred at about the same time, that is, during June and early July.

There was seldom more than a trace of nitrates found in the unfertilized sod plots of block D.

The heavy precipitation occurring the latter part of June and first of July is thought to be largely responsible for the final drop in nitrates in all plots. Gourley's (40) work at New Hampshire, which covered a period of four years, showed a similar drop during the wet summer of 1916 while, in the other three years, the highest nitrate accumulation occurred in August. He too found that most rapid nitrate accumulation did not occur until after June first in his tilled and tilled cover-crop plots. His work with that of Lyon (77) also shows that nitrification proceeded very slowly in the unfertilized sod plots.

This nitrate discussion is based upon the findings of one season's work only and, although from the nitrate standpoint it appears that the sod-nitrate program is far better suited to meet the requirements of the nitrate role in orchard management,

the data here presented are perhaps insufficient to warrant any final conclusions. As to what would have been the nitrate trend in these blocks under different seasonal conditions, such as a shortage in the moisture supply, is hypothetical.

As the project for block A has only been in progess one year, information is not yet available as to the effect which the cultivated and cultivated-nitrated program will have on fruit production. There exists, however, a definite correlation between soil nitrates and fruit production in the sod-nitrated, and cultivated plots of block E. Yields reported by Shaw (106) for the years 1921 to 1924 inclusive, show that there has been approximately twice as high a yield in favor of the sod-nitrated plots. This has been due largely to better fruit-set, to an increase in tree growth, and perhaps to better fruit-bud formation, although the latter is hard to determine. Even a much lower yield and poorer growth has been obtained on the unfertilized sod plots than on the unfertilized cultivated plots.

From the results of this work, it seems that there is little hope of supplying sufficient nitrogen - in these soils - to maintain a good growing and bearing condition in the apple trees, unless a nitrogen fertilizer program is included in the system of orchard management. This nitrate program must now include not only the maintaining of an ample food supply to the growing crop, but the soil nitrates must be sufficiently under control that nitrification can be stimulated and retarded

at the proper time, and thereby establish a carbon-nitrogen relation suited for optimum production. It appears that the possibilities of effectively controlling the nitrate trend in orchard soils is far greater under a sod-nitrate program.

Summary of Part 2-a

1. Nitrates rose and fell at an earlier date in the sod-nitrated plots than under any other treatment.
2. During May nitrates were low in the cultivated and cultivated-nitrated plots, but at maximum accumulation under the sod-nitrated program.
3. The maximum nitrate accumulation for the cultivated and cultivated-nitrated plots occurred during June.
4. The nitrate production was low in the unfertilized cultivated plots.
5. There was seldom more than a trace of nitrates found in the unfertilized sod plots.
6. Fruit yields for 1921 to 1924, inclusively, are correlated directly with nitrate accumulation on the sod-nitrates, cultivated and sod plots being approximately intthe following ratio, 4 - 2 - 1 respectively.
7. Yields are not available for the cultivated-nitrated plots.

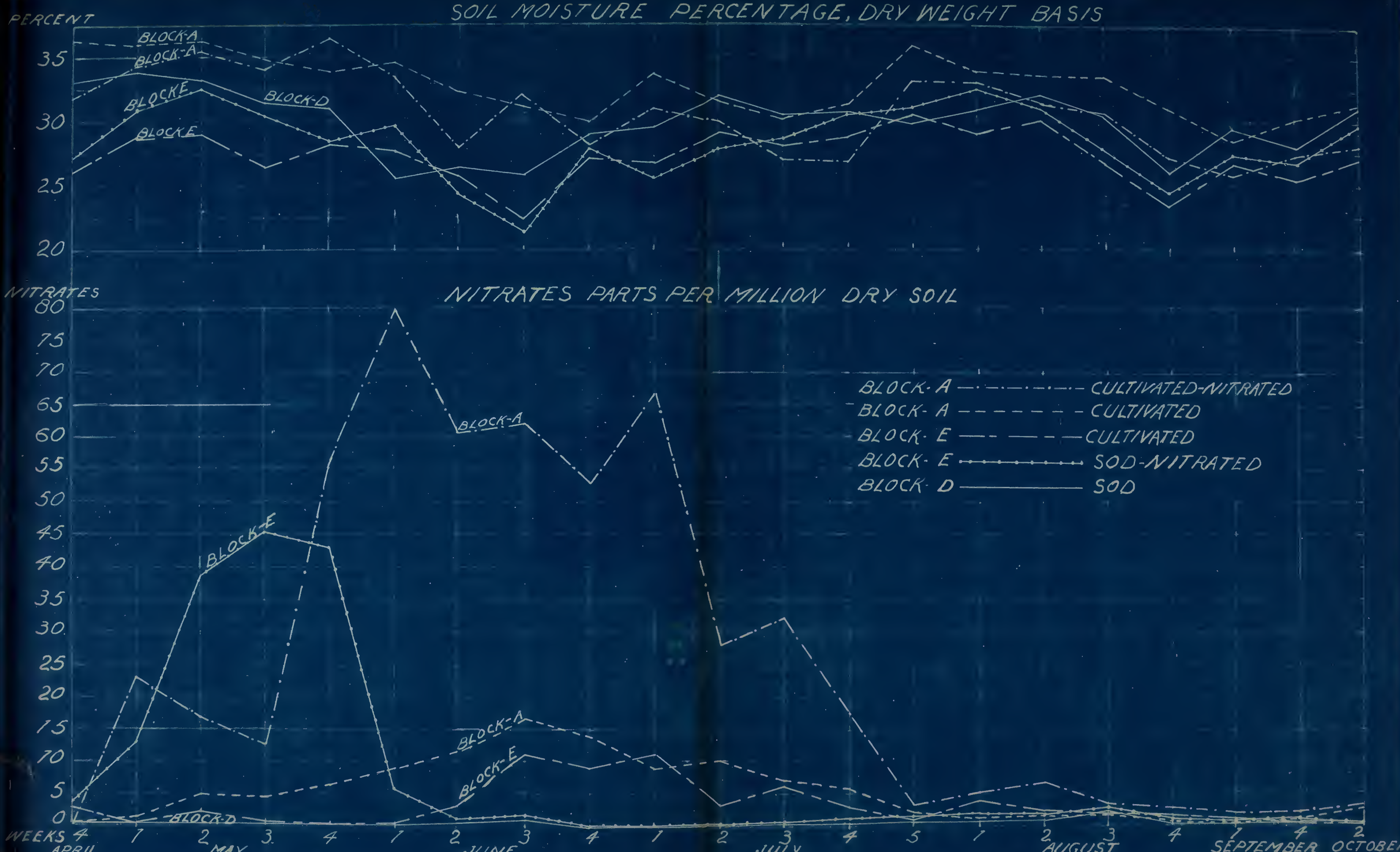


FIG. 4. SOD AND SOD-NITRATED VS. CULTIVATED AND CULTIVATED-NITRATED

Part 2-b

The Accumulation of Nitrates under Straw Mulch and Cultivation

Blocks G and H cover an area of about one acre and are located on the eastern slope of the glacial drumlin. The project was begun in 1922. Liberal appliaations of swale hay and similar material have been applied to the mulch plots twice a year so that four to six inches of straw mulch is constantly maintained. The cultivated plots received no fertilizer and the cultural methods were the same as for all cultivated plots; page 55.

The eastern slope of these blocks is rather marked. To partially overcome the inequality brought about by such a condition, the mulch plots of each block and the cultivated plots of each block were arranged in direct diagonals from each other, as shown in the chart below.

Chart I

Block H	Block G	
Mulched *8.2	Cultivated 6.6	-------North
Cultivated 7.4	Mulched 8.3	

*Percentage organic matter

The difference in elevation of these plots accounts for the slight nitrate variations occurring between similarly treated

plots, table 7, page 6, of the appendix.

The diagonal location of the similar treatments permits averaging the nitrates and moisture for the two mulched and two cultivated plots. These averages, showing the difference in nitrate and moisture accumulation under the straw mulched and cultivated plots, are show in figure 6, page 69.

Nitrate accumulation for the mulched plots is invariably higher than for the cultivated. These differences became greater as the season advanced. The mulched plots are rather outstanding in that they are the only plots in the entire project which show a gradual gain in nitrate accumulation throughout the season. They also show a higher seasonal nitrate average than any plot in the entire orchard project* The average nitrates, in parts per million, were 38.89 for the straw mulched plots and 10.07 for the cultivated. The highest nitrate average for any of the other treatments is found in the cultivated nitrated plots of block A, averaging 25.76 parts per million.

These seem to be rather unusual results, for other workers have noted a depressive influence of straw both under laboratory (88), (117), (51) and field conditions (57), (27), when the straw was incorporated in the soil, (91) when straw extract was added to water cultures (22) or when straw was used as mulch (1) (105).

*With the exception of plot 2 in block R; a young orchard, a different soil type, and a very erratic plot.

The recent work of Albrecht (2) and Scott (105) shows a marked depression in nitrification by the use of straw as a mulch. In Albrecht's work the mulch of the preceding year was removed in the spring, the plots plowed, harrowed and six tons of straw applied per acre. Nitrate determinations were made at six-week intervals throughout the year. In all cases, the mulched plots showed lower nitrates than the unmulched. He attributes this depression to the bad physical effect produced in the mulched soil. Referring to this he states, "With equal proportions of moisture in both soils, that from beneath the mulch was plastic, sticky and of poor tilth, but the unmulched soils worked well." When these soils were taken into the laboratory and placed in pots, those from mulched plots invariably showed greater nitrifying powers. The superiority of the soils from the mulched plots was especially marked when they were air dried, then brought back to their original moisture percentage. Albrecht's conclusions are: "Straw mulch, in applications as heavy as six tons per acre, cuts down evaporation, thereby increasing the moisture, lowering the temperature and preventing the normal exchange of air, all of which induces a poor physical condition and unfavorably environment for nitrate accumulation."

In the investigation with blocks G and H, no ill physical effects were noted in the soil under straw mulch. Although the moisture was slightly higher throughout the season under

the mulched plots (figure 6, page 92), it seemingly caused no bad effects. There was little difference in the weekly soil temperatures of the two treatments; table 7 of the appendix. The average temperature for the mulched soils was 15.6 degrees centigrade and 15.9 for the cultivated. Thus the forces operating in the depression on nitrates in the soils under straw mulch studied by Albrecht were not active in the soils studied here.

Other variations between this work and that of Scott and Albrecht lie in the time element and cultural treatments. For the past five years, these plots have not been plowed and new applications of straw have been made every sping and fall without the removal of that previously applied. There may have been some reduction in nitrification by the first applications of straw even though none was noted in the appearance of the trees. It seems very possible that after a short time an adjustment was made between the biological processes and the organic matter present so that now normal nitrification takes place. This method of application should not greatly alter the soil complex, when once properly established, for before the straw is actually incorporated with the soil it is rather well decomposed and the organic supply is uniform.

The problem of soil aeration might have been an acute one with some other soils similarly treated. That it did not occur here is perhaps due to the high percentage of very coarse loose material making up the texture of this soil.

That nitrates on the mulched plots were very abundant is not only evident from the determinations but the trees are somewhat larger, show a distinctly deeper color and a far more luxuriant growth than those on the cultivated plots. Total yields are perhaps a little better under the mulch but not so marked as would be expected from the difference in appearance of the trees. As yet the nitrifiable material is still relatively abundant in the cultivated plots, as is indicated by the nitrates produced and shown by the organic determinations, chart 5, page 63. Under continual cultivation, this organic supply will in time be exhausted, then nitrates as well as yields may be expected to diminish, as has been the case in the older cultivated plots. Thus greater differences in yields are expected to appear in the future than has previously occurred between these cultivated and straw mulched plots.

Summary of Part 2-b

1. Nitrate accumulation under the heavy straw mulch is invariably higher than under cultivated.

2. This difference becomes greater as the season advances.

3. The mulch plots are the only plots in the entire project to show a gradual gain in nitrates throughout the entire season.

4. More nitrates were found in the soil under the straw mulch than for any other treatment in the entire orchard project.*

*With the exception of plot two in block R, a young orchard, a different soil type and a very erratic plot.

5. The abundance of nitrates under the straw mulch is manifest by a large tree growth, having very luxuriant deep green foliage.

6. No ill physical effects of the soil or biological disturbances were noted from the use of straw as a mulch.

FIG. 5. ACCUMULATION OF SOIL NITRATES UNDER STRAW MULCH AND CULTIVATION

Part 2-c

Some Relations Between Fertilizer Treatments, Tree Growth and Nitrate Accumulation.

This orchard was planted in 1922 on an area then known as the "North Soil Test", but since designated as block R. For some thirty-six years prior to the planting of the orchard, various field and garden crops were grown on this soil under a fixed fertilizer program. This fertilizer program, table 4 , page 55, was unaltered when the orchard was planted, except that acid phosphate is now used in place of bone black, and that liming, which occurred on the lower half of the field, totaling four and one-half tons in all, was discontinued in 1916.

There was a marked variation in the nitrate accumulation of the plots in this block. This is due to the differences in fertilizer applications associated with the previous lime treatments which have greatly affected plant growth, and all of these factors have combined in influencing nitrate accumulation. This is seen in the following table which gives the average nitrate accumulation for both the limed and unlimed halves of each plot, as well as the total shoot growth made by the apple trees during the years 1922-1923 and 1924.

Table V. Block R

Plot	Fertilizer Treatment	Shoot growth for 1922-23-24: Given in feet and inches		Average nitrate accumulation in parts per million	
		Limed	Unlimed	Limed	Unlimed
2	N	11.4	13.5	188.5	159.2
3	P	9.8	8.9	6.1	5.3
4	Check	14.6	19.0	9.7	11.6
5	K	24.6	14.5	14.3	10.7
9	P - K	48.3	13.5	6.6	8.3
10	N - P - K	34.1	23.9	15.0	4.9
11	C_aSO_4	8.0	8.0	9.9	6.6
12	Check	12.3	16.7	7.9	9.4
Average		20.4	14.8	32.3	27.0

These results are graphically represented in figure 6, page 72.

Except for the phosphate-potash plot 9, and the two check plots 4 and 12, all plots showed a greater nitrate accumulation on the "limed" halves, and except for the nitrate plot 2 and the check plots, all trees showed greater shoot growth on the "limed" halves.

Even though this soil has received no lime since 1916, its effects are still manifest not only in the ~~lower~~ higher pH value of the "limed" halves, table IV, page 55, but also in higher nitrification and greater plant growth. Increased yields from the use of lime on an acid soil is frequent (128) (90) (66) (13) and are greatly facilitated by the increased nitrate production on the limed soils (92) (67) (112) (4) (20) (94).

The luxuriant growth on the "limed" portion of plot 9, in

RELATION OF FERTILIZER TREATMENT, TREE GROWTH AND NITRATE ACCUMULATION

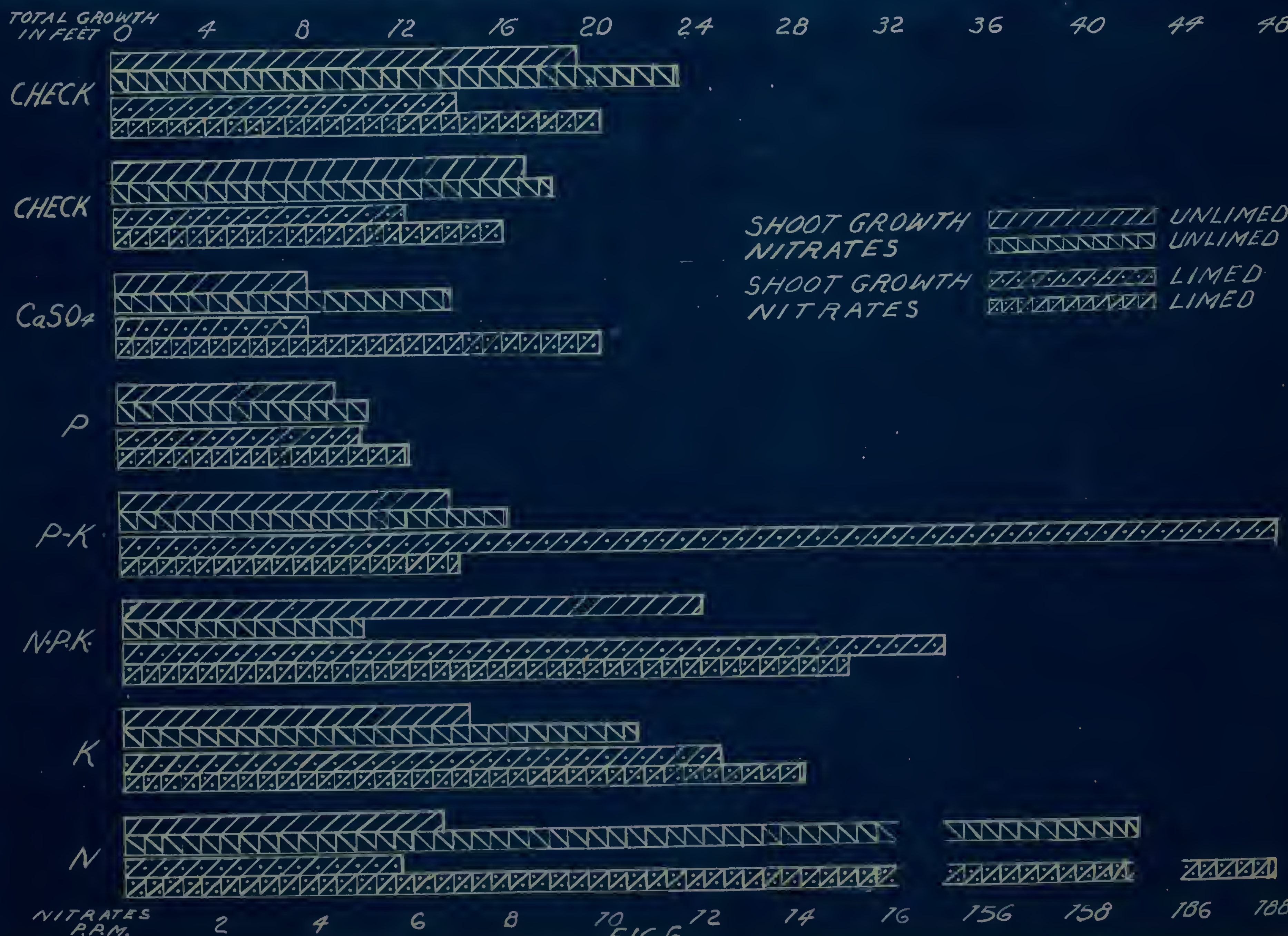


FIG. 6.

contrast to that of the unlimed, is thought to be responsible for the lower nitrate accumulation found in the limed half, figure 7, page (Also see plate I, page 76).

The lower nitrate accumulation and shoot growth on the "limed" half of the check plots, compared to that which is now being obtained on the unlimed, is attributed to the higher crop yields secured on the limed area prior to the planting of the orchard.

Between 1901 and 1922 approximately twice the amount of plant material was produced on the "limed" halves of these check plots as was produced on the unlimed (48). It appears that the liming, which occurred prior to 1916, promoted a more thorough exploitation of the limed soils which furnished a more liberal supply of available nutrients, and thus higher crop yields (84). Higher yields have meant greater removal of soil minerals and finally a lowering of the productive capacity of the once limed portions below that of the unlimed, yet not below that of several of the other plots, for remarkable growth and high nitrification are still obtained on these checks, even though they have received no fertilizer for over thirty-six years. This not only shows the high original fertility of the soil but, when comparisons are made between the growth obtained on the check plots and that obtained on plots 2, 3 and 11, it also appears that applications of calcium sulphate, acid phosphate and sodium nitrate are now tending to retard, at least

failing to stimulate tree growth. The first two of these materials is also depressing nitrification but the average nitrate accumulation on the sodium-nitrate plot 2 is approximately fourteen times that of any other plot in the series. For over five weeks, during the later part of June and early July, the nitrates on neither the limed nor the unlimed portions of this plot fell below three hundred parts per million. On July 1, it reached its maximum, the limed half showing 498.7 parts per million.(Table 8, page 7 of the appendix). The seasonal nitrate average for the entire plot was 174.4. This high nitrate accumulation in plot 2 stands unparalleled, as no other plot in the entire orchard project gave an average nitrate content of over 46 and no other plot in block R had an average above 14 or reached a nitrate content higher than 50 parts per million.

Plot 2 and the complete fertilizer plot 10 have received the same amount of sodium nitrate annually for the past thrity-six years, yet only once* during the season did the latter plot reach a nitrate content of over 19 parts per million.(Figure 7, page 79). This fact, coupled with the small amount of nittates present on the first and last date of sampling, shows that all the nitrates produced in plot 2, reaching 498 parts per million, were solely the product of this season's nitrifying processes

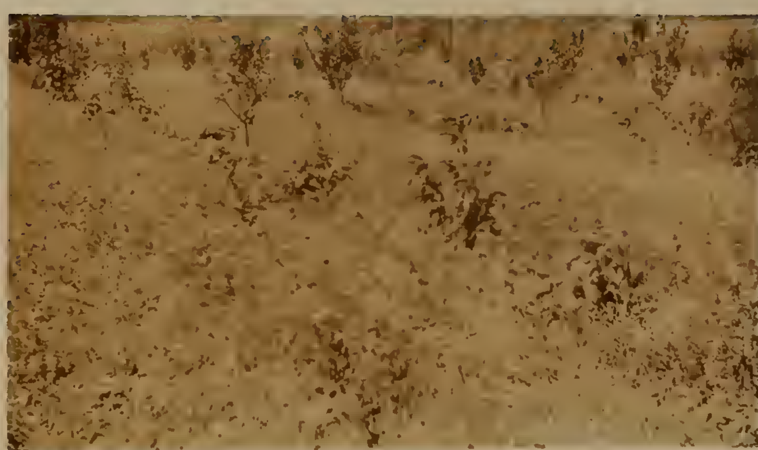
*On May 15, plot 10 showed a nitrate content of 42 p.p.m. but as sodium nitrate was applied to this plot only four days prior to the date of sampling it is evident that the fertilizer and not nitrification was responsible for this rise.

and not the results of several years' nitrogen accumulation in the nitrate form.

The cover crop and trees of plot 2 grow very sparingly. Both crops, however, show a much deeper green cast than that of any other plots indicating a higher percentage of nitrogen in the plant tissue. Thus, while the total cover crop plowed under in plot 2 is small, the quality of this material may be such that the actual quantity of nitrogen returned to the soil is perhaps equal to that of any other plot, (12), but, as this fact alone can only partially accountyfor the high nitrate accumulation in this plot, there is strong indications that free nitrogen-fixing bacteria are operative or that nitrates are not wholly removed from the soil during the winter, but merely converted into an unavailable form to be released again the following summer. It is possible that all of these factors were more or less operative in the high nitrate accumulation of plot 2.

There exists a rather constant relationship between nitrate production and plant growth on these plots. This is in harmony with the work of others previously cited. "It is conceivable however," as Allen (4) states, "that conditions which limit the growth of higher plants in one set of plots may be different from those in another. The factors or set of factors may limit nitrification, the others not." This is borne out in the case of plot 2 where factors operative in checking plant growth did not check nitrification.

Plot 9 Limed



Plot 9 Unlimed

Plate I. Block R. Comparison of Cover Crop
and Tree Growth. August 25, 1925.

Plot 10

Plot 2

Plot 4

Plate II. Block R. Comparative Growth of Cover Crop on Unlimed Untilled Area. June 3, 1925.

Summary of Part 2-c

1. No lime has been applied to this field since 1916, yet its effects are still manifest not only in a lower pH value of the limed halves but also in higher nitrification and plant growth.

2. Thirteen out of the sixteen treatments showed that lime encouraged nitrate accumulation and shoot growth.

3. Excessive growth was thought to be responsible for low nitrates in the limed half of plot 9.

4. The high growth and nitrate obtained on the check plots indicate the high original fertility of this soil.

5. The lower yields and nitrate production on the "limed" half of the check plots is attributed to the heavier yields obtained on this area prior to the planting of the orchard when liming was practiced.

6. When comparisons are made with the check plots it appears that sodium nitrate, acid phosphate and calcium sulpahte after continual use for thirty-six years are retarding growth. The last two of these salts are also retarding nittification.

FIG. 7 BLOCK R. NITRATE ACCUMULATION UNDER VARIOUS FERTILIZER TREATMENTS

Conclusions for Part II

It appears impossible to furnish the soils with sufficient nitrifiable material to maintain a good growing and bearing condition in the apple tree, unless the system of orchard management includes a nitrate supply from an outside source.

This nitrogen supply may be furnished through the addition of commercial fertilizers or by the use of a heavy straw mulch. The latter, however, because of its nature, is limited in its use to small areas and perhaps to suitable soils.

PART III

Nitrate Accumulation in Tobacco Soils as Affected by the Date of Plowing under Timothy and Rye Cover and as Influenced by Organic and Inorganic Sources of Nitrogen

Timothy is being used extensively as a cover crop in the Connecticut Valley tobacco fields. However, experiments conducted at the Massachusetts Agricultural College Experiment Station (56) indicate that timothy cover has depressed rather than improved tobacco yields. Nine out of the ten cover crop plots under consideration during 1923-1924 and 1925 gave smaller yields than did the plots with no cover crop. The average tobacco yield for these three years on the timothy cover crop plots was 1129 pounds per acre, while a similar number of no cover crop plots gave an average yield of 1302 pounds per acre. Brown of Maryland (10) reports a depression in tobacco yields of 140 pounds per acre when rye was used as a cover crop. The quality of the tobacco was also superior on the non-cover crop plots.

From the Cornell work of 1923 (75) and 1924 (74), it appears timothy roots when incorporated with the soil have a depressive effect on nitrification. The investigation of B. D. and J. K. Wilson, (130), shows that timothy is less easily oxidized than are the residues from clover when the two are mixed with the soil. They found that organisms were considerably fewer in the early counts made from the timothy cultures than

those made from the clover, but the later counts were in favor of the timothy cultures (130). "Since the assimilation of nitrate nitrogen is associated with the process of organic decomposition, the withdrawal of nitrates from the soil solution in a soil in which the residues of clover have been incorporated would not be as prolonged as in a soil in which timothy residues had been introduced, because of the more rapid destruction of the clover material. This order of performance is offered to explain the characteristic depression of nitrate nitrogen in soil, exerted by timothy and clover residues." Starkey (111) found that, of the six materials tested, cellulose decomposed most slowly and that rye straw came next, followed in turn by alfalfa meal, fungous material, dried blood and dextrose. He also stated that in the presence of rye straw, nitrate nitrogen entirely disappeared.

The fact that timothy and rye depress nitrification and have retarded tobacco growth naturally provokes the question: Are the lower tobacco yields resulting from the use of timothy and rye as cover crops due to a shortage in available nitrogen brought about by the depressive effects these plants have on nitrate production? With the hope of throwing some light upon this question, the following experiment was inaugurated.

Description of Soil and Field

The soil upon which the present experiment was conducted was fertile and in good tilth in the fall of 1924 when the investigation was started. The field consists of twelve plots thirty feet wide

and one hundred feet long which are in turn divided longitudinally into series A and B, figure 2 , page 87 The soil belongs to the Hartford series. The texture, however, is rather irregular ranging from a loam on the lower eastern plots 65 and 69 to a sandy loam on the higher elevations of plots 64 and 70. But for a marked depression leading westward through the extreme southern end of plots 59 and 64, the drainage from this particular field would have been toward the east rather than down the gully toward the west.

Plot Treatment

For three years preceding this investigation, tobacco was grown on this field under a normal system of management.

In the fall of 1924, plots 63, 64, 69 and 70 were planted to rye, plots 62 and 68 were left fallow and the remaining six plots were seeded to timothy. The following spring the plowing was done at intervals with the hope of determining whether or not the quantity of timothy and rye returned to the soil would in anyway alter nitrate production or crop yields.

The first plowing occurred on April 6 and included timothy plots 59 and 65 and rye plots 63 and 69. Timothy plots 60 and 66 and rye plots 64 and 70 were plowed one month later, May 7. Due to the rank growth of rye at this date, it was deemed inadvisable to further delay the plowing on the rye plots. Consequently, only the timothy plots 61 and 67 remained until the last date of plowing which occurred May 22. The check plots 62 and 68 were not plowed but disked on April 10, May 11 and May 29. All previously plowed plots were also disked on these dates.

Summary of Culture Previous to Planting

Date	Plowed		Disked		
	Timothy Plots	Rye Plots	Timothy Plots	Rye Plots	Check
April 6	59, 65	63,69			
April 10			59, 65	63, 69	62, 68
May 7	60, 66	64,70			
May 11			59,65,60 66	63,69,64,70	62, 68
May 22	61, 67				
May 29			All Plots		

To investigate whether nitrogen, when derived from organic or inorganic sources, would in anyway influence the decomposition of the timothy and rye, or alter the nitrate production or tobacco yields, the halves designated as series A and B were fertilized differently, in that twice as much cottonseed meal was applied to series A as to series B, the quantity of nitrogen being equalized by a corresponding increase of ammonium sulpahte in the latter series. Thus while the 5 -4 -5 fertilizer carried the same amount of plant food in all cases, series A represents a normal tobacco fertilizer receiving most of its nitrogen in the organic form, whereas the nitrogen applied to series B comes primarily from ammonium sulphate, an inorganic form.

Summary of Fertilizer Treatment Given in Pounds per Acre

Fertilizer	Series A	Series B
Ammophos	233	233
Fish	197	197
Sulphate ammonia	98.5	235
Cottonseed meal	814	407
Sulphate potash	262	262

Moisture Relations

Beginning May 4 and continuing until September 9, weekly nitrate and moisture determinations were made on the A and B sections of all plots. In obtaining each soil sample, twenty borings were made, six of which were taken in close proximity to the plant, the rest being procured midway between the tobacco rows, and the remaining procedure was as previously described.

From the moisture determinations, table 10, of the appendix, it is evident that there exists a marked variation in the moisture content of the east and west portions of the field. The northern half of the field also maintained a slightly higher moisture content than did the southern half. There differences were induced by the irregularity of the soil type which was augmented by surface drainage.

The greatest variation was between plot 70 with an average moisture content of twenty per cent and 59 with an average moisture percentage of forty-two. These plots represented the lightest and heaviest soils of the field. Even though the range in moisture is rather great, this variation is not so serious as the percentages would indicate, for the moisutre-holding capacity of these soils shows that the heavier soil never reached two-hhirds saturation and the lighter soil averaged about one-half of its moisture-holding capacity. While the moisture variation between plots is rather high, the fluctuation within the plots is very low, (table 10, page 9 of the appendix).

From work previously cited, it would seem that the moisture content of the lighter soil, averaging twenty per cent, would be ideal for nitrification. In view of the high moisture-holding capacity of the heavier soil and the fact that even with this high moisture percentage the soil temperature was not lowered, it is not likely that nitrification was greatly altered by an excess of moisture. It is, therefore, believed that the nitrification processes were not greatly affected by differences in moisture percentages. In case there should have been some impairment in nitrification from excess moisture on the eastern plots, it would only have tended to emphasize rather than detract from the findings brought out in this discussion.

PLOT 65 Timothy Plowed Apr.6 A B	PLOT 66 Timothy Plowed May 7 A B	PLOT 67 Timothy Plowed May 22 A B	PLOT 68 Check Disked A B	PLOT 69 Rye Plowed Apr.6 A B	PLOT 70 Rye Plowed May 7 A B
PLOT 59 Timothy Plowed Apr.6 A B	PLOT 60 Timothy Plowed May 7 A B	PLOT 61 Timothy Plowed May 22 A B	PLOT 62 Check Disked A B	PLOT 63 Rye Plowed Apr.6 A B	PLOT 64 Rye Plowed May 7 A B

Chart II. Plan of Tobacco Field

Plate III. Timothy Cover Crop on April 6, Date of First Plowing.

Plate IV. Rye Cover Crop on April 6, Date of First Plowing.

Plate V. Timothy Cover Crop on May 7, Date of Second Plowing.

Plate VI. Rye Cover Crop on May 7, Date of Second Plowing.

Part 3-a

Nitrate Accumulation in Tobacco Soils as Affected by the Date of Plowing under Timothy and Rye when used as a Cover Crop.

The timothy cover was beginning to show green shoots and the first leaves had developed on the rye by April 6, the date of first plowing. At the time of the second plowing, one month later, the timothy had made four to six inches growth while the rye stood about two feet high (see photographs, pages 88 to 91). The timothy cover on the two remaining plots was very dense and stood some twelve inches high before it was plowed under on May 22.

The influence the above treatment exerted on nitrate accumulation is shown by the graph on page 98. It is evident from this comparison that there exists a definite relationship between dates of plowing and the quantity of nitrates produced. The soil from the earlier plowed timothy plots 59 and 65 and rye plots 63 and 69 contained a much higher nitrate content throughout the entire season than did timothy plots 60 and 66 and rye plots 64 and 70 which were plowed one month later, May 7. The plots plowed May 7 also showed higher nitrate accumulation than did the two timothy plots 61 and 67 which remained unplowed until May 22. These differences are rather marked as is shown when the nitrate determinations from all early plowed timothy plots are averaged and all early plowed rye plots; and these averages compared with the similar averages for the later

plowings, as seen in the table below.

Table Nitrate Averages Under Different Dates of Plowing

Culture	Average Nitrate Accumulation Timothy	Rye	Check
Plowed April 6	162.1	116.9	-----
Plowed May 7	85.6	57.7	-----
Plowed May 22	62.9	----	-----
Disked Apr.10-May 11-May 29	-----	----	131.7

Had the check plots been plowed rather than disked, it is very probable that the nitrate accumulation would have been still greater. The high nitrate standing of the fallow check plot, accompanied with the fact that plots upon which the greatest cover crop growth occurred were lowest in nitrate production, and the plots upon which the smallest cover crop was produced were highest in nitrate production, indicates that timothy and rye cover crops exert an unfavorable effect upon nitrification and that a favorable condition was produced by early plowing. It is not known which of these forces, the time of plowing or the increased quantity of cover crop, was most influentail in causing these nitrate variations. It is very probable that both were operating, the former in stimulating nitrification, the latter in retarding it.

Regardless of the date at which these plots were plowed, there seemed to be required approximately one month before nitrification was greatly increased. The first determination, (May 4) approximately one month after the date of first plowing

showed that the nitrate content of these earlier plowed plots was 63 and 36 parts per million for timothy plots 59 and 65 and rye plots 63 and 69, respectively. The check plots 62 and 68 on this date (May 4) showed a nitrate content of 58.8 parts per million. On June 8, one month after timothy plots 60 and 66 and rye plots 64 and 70 were plowed, the soil contained approximately the same amount of nitrates ad did the earlier plowed plots one month previous. This same relation holds in the case of the soils plowed last (May 22); that is, it was approximately one month after plowing before marked nitrification began, and the accumulation is about two months behind that of the earliest plowed plots. (Table , below).

Table Date of plowing under Timothy and Rye

	Plots		Nitrate Parts Per Million Dry Soil		
			May 4-One mo. after 1st plowing	June 8 1 mo. after 2nd plowing	June 22 1 mo. after 3rd plowing
Plots included in first plowing	Timothy	59.65	63.8	118.6	220.4
	Rye	63.69	36.2	97.0	168.0
	Check	62.68	57.8	83.0	149.0
Plots included in second plowing	Timothy	60.66	Tr	58.5	101.3
	Rye	64.70	Tr	32.2	77.6
Plots included in third plowing	Timothy	61.67	Tr	13.3	66.6

These results confirm the findings of Percival (85) and others previously cited, that nitrification does not occur until the organic matter is in the advanced stages of decomposition.

The length of time elapsing between plowing and nitrification would have been nearer in proportion to the amount of organic matter plowed under had there not been such a great variation in soil temperature, but as the soil temperature ranged from ten to twenty degrees centigrade between the first and last dates of plowing (table , of the appendix) with scarcely any fluctuation in moisture, more rapid decomposition occurred in the later plowed plots, which tended to offset the depressive effect of the increased amounts of organic matter.

Had it not been for the heavy leaching of nitrates - caused by July rains - it is very likely that nitrate accumulation in these later plowed plots, which contained an abundance of nitrifiable material, would have continued later into the season than the accumulation in the earlier plowed plots. That the upward nitrate trend continued one week longer in the later plowed soils than in the earlier plowed and disked plots may be some proof in favor of this supposition.

During the heavy rains of July, washing occurred on the lower ends of the first six plots injuring some of the tobacco. Consequently, yields were only recorded for plots 65 to 70. As there remained only one plot representing each treatment, much stress should not be laid upon the yield records.

Although there existed a marked variation in nitrate content of these plots, this variation is not manifest in the tobacco yields as there seems to be no correlation between nitrate accumulation

and the crop produced. The greatest differences in yield appeared between the timothy and rye plots, but the significance of this variation is questionalbe in that only five plots are involved, all of which have been treated differently and whose soils are rather variable.

Yield Records

Timothy plot	65	Plowed April 6	1222 lbs. per acre.
" "	66	" May 7	1359 " " "
" "	67	" May 22	1269 " " "
Check plot	68	Disked	1197 " " "
Rye "	69	Plowed April 6	1184 lbs. per acre.
" "	70	Plowed May 7	1105 " " "

While this investigation shows that when plowing is delayed and a good growth of timothy cover is turned under there results a marked depression in nitrate accumulation, there is no evidence from the appearance of the tobacco or the yields obtained that the soil nitrates or the cover crops limited the growth of the tobacco. The reason why this nitrate depression was not manifest in the crop yield was because of the heavy applications of nitrogen fertilizer (150 lbs. of ammonia per acre applied June 5) associated with the high nitrate producing capacity of this soil, which was able to furnish an abundance of nitrates to the growing crop even under the unfavorable conditions produced by delayed plowing of the cover crops.

It is very possible, however, that in soil with lower nitrifying poweresthis depressive influence which timothy and rye exert upon nitrate production would be plainly manifest by a poorer

growth in the crop which followed. Thus the lower tobacco yields others have obtained by the use of timothy and rye as cover crops may be largely a question of insufficient nitrogen brought about through the ill effect these grasses have on nitrate accumulation.

Summary for Part 3

1. There existed a definite relationship between the dates at which timothy and rye cover crops were turned under and the quantity of nitrates produced.

2. Earlier plowing and smallest cover crop were associated with greatest nitrate production.

3. Later plowing and largest cover crop were associated with lowest nitrate production.

4. The growth of the cover crop prevented nitrate accumulation early in the season and, even after these crops were turned under, there was a period of decomposition lasting approximately one month before pronounced nitrification occurred.

5. Highest nitrate accumulation was accompanied with most rapid tobacco growth.

6. Because of the heavy applications of nitrogen fertilizer and the high nitrate-producing power this soil possessed, the tobacco did not lack for nitrogen regardless of the plot treatments. Therefore, lower yields were not accompanied with depression in nitrification.

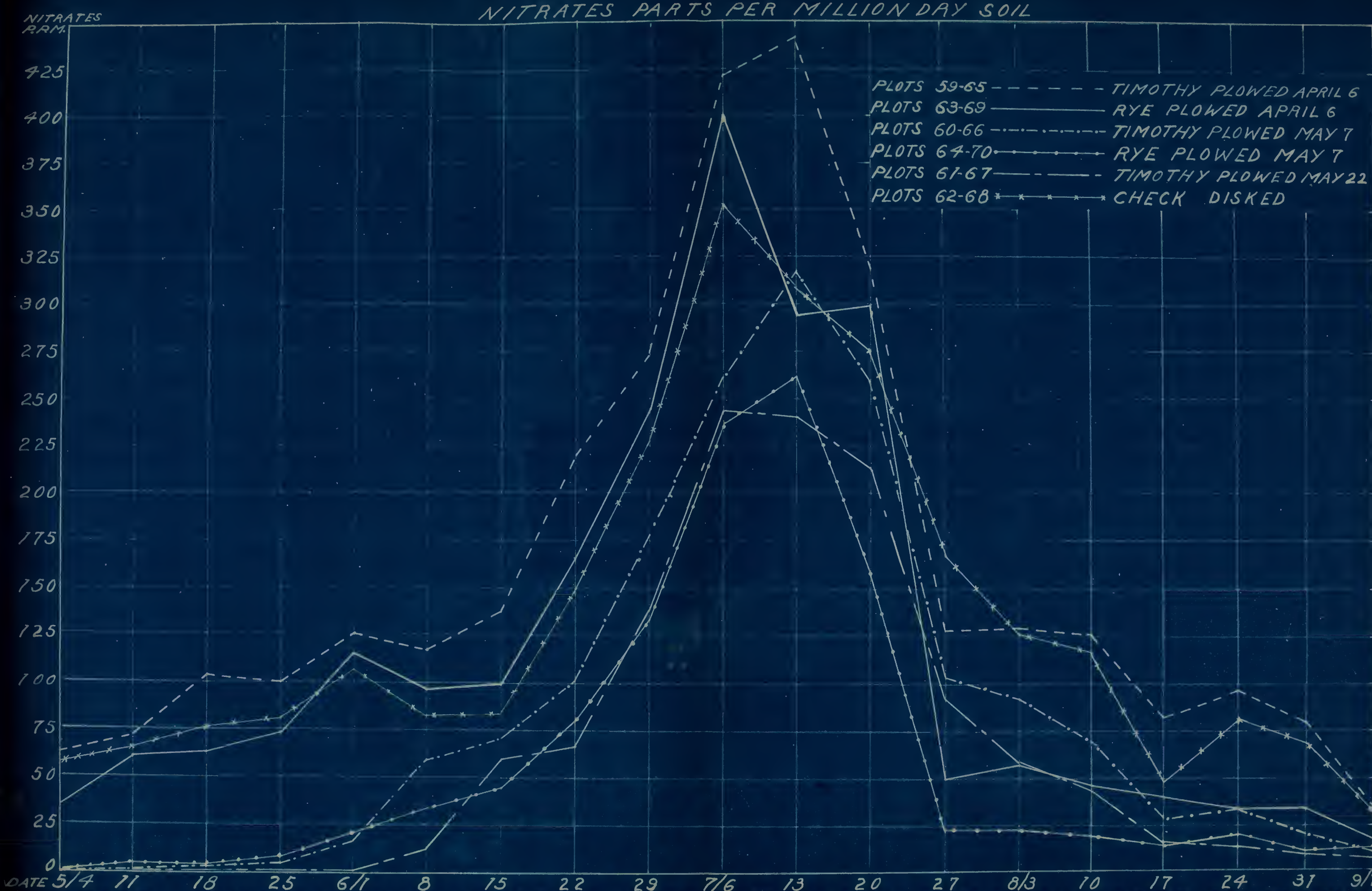


FIG. 8. NITRATE ACCUMULATION AS AFFECTED BY DATE OF PLOWING UNDER COVER CROPS

Part 3-b

Nitratd Accumulation in Tobacco Soils as Affected by Fertilizers high in Organic and Inorganic Sources of Nitrogen when Timothy and Rye are used as Cover Crops.

More perhaps from the result of experience than from the result of experiments, organic nitrogen, principally cottonseed meal, has become the major nitrogenous constituent of tobacco fertilizers. With the hope of throwing some light upon the question of the use of organic and inorganic soucces of nitrogen for tobacco fertilizers, but more particularly to determine what influence, if any, these sources would exert upon nitrification when associated with decomposition of timothy and rye as cover crops, each plot was divided longitudinally - as previously described - into A and B series, the former series receiving the greater part of its nitrogen from cottonseed meal and the latter from ammonium sulphate, see page
There were twelve duplications for each of these fertilizer treatments.

An average of the weekly nitrates produced in series A and B is shown by the graph on page It is evident from the similarity of the soil nitrates produced under these treatments that there was very little difference in the rate at which these fertilizers nitrified or the influence they exerted upon the nitrification of the cover crops plowed under. The seasonal average for nitrates in series A and 93 parts per million and for series B, 84.

It is very probable that in a less acid soil the ammonium sulphate would have nitrified more rapidly than the cottonseed meal but as this soil had a pH value of 4.9 the reverse was true, for the early nitrate determinations showed that nitrification was slightly greater under the organic treatments. These findings are in accord with those of other men previously cited.

There was little difference manifest in the tobacco yields between A and B series of this field. The average for the A series being 1217 and for the B series 1227 pounds per acre.

Summary for Part 3-b

1. There was little difference manifest in the rate at which cottonseed meal and ammonium sulphate nitrified or the effect they produced on the nitrification of timothy and rye when used as a cover crop.

2. There was no significant difference in the tobacco yields whether the nitrogen was derived from a fertilizer high in cottonseed meal or high in ammonium sulphate.

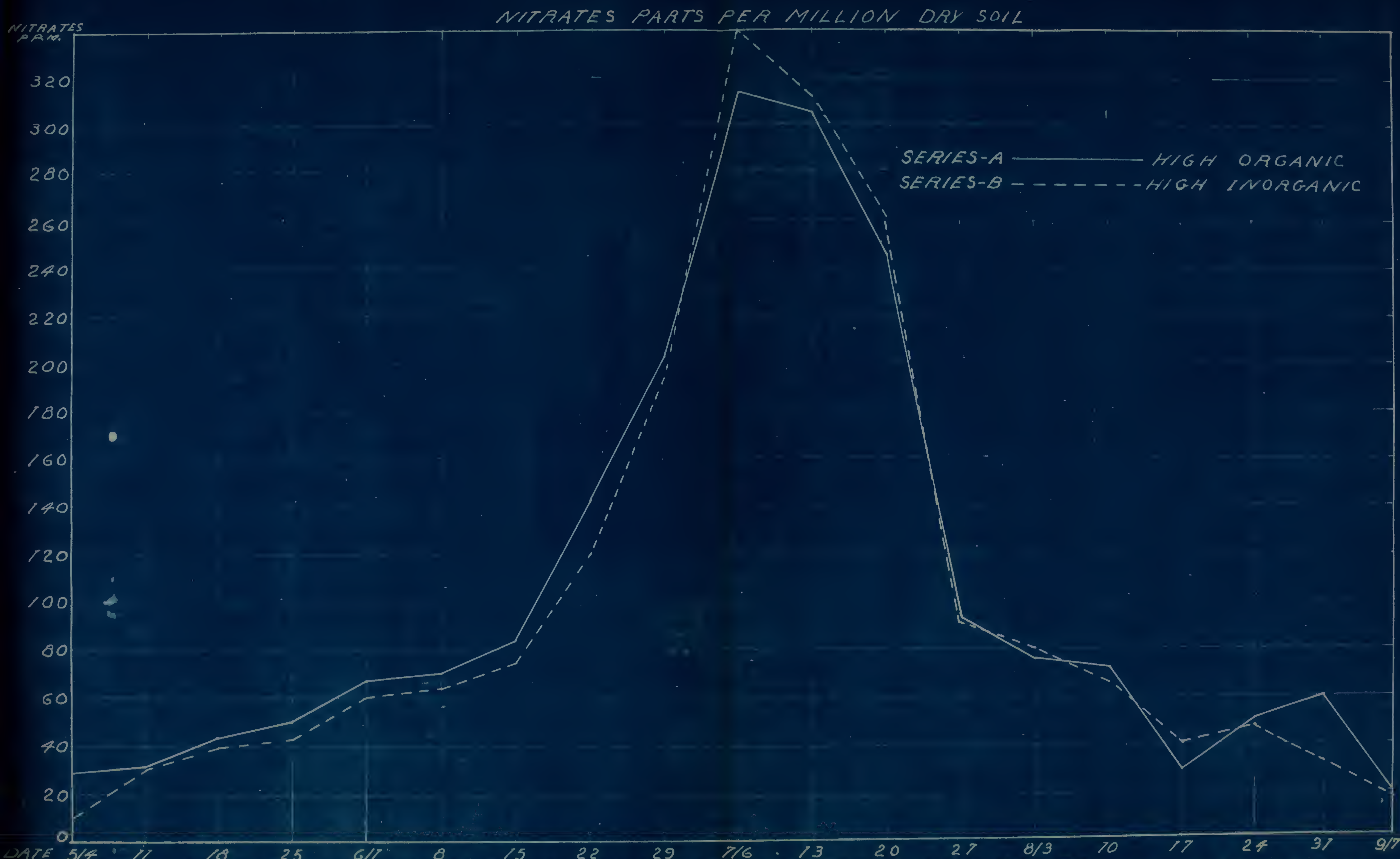


FIG.9. NITRATE ACCUMULATION AS AFFECTED BY ORGANIC AND INORGANIC NITROGEN

Conclusions for Part III

The fact that timothy and rye when used as cover crops on tobacco fields greatly delayed nitrate production indicates that the depressive effect these plants have exerted upon tobacco yields is due to their unfavorable action upon nitrification. As the depressive effect of these grasses is intensified by increased growth, it may be overcome by early plowing.

Whether the nitrogen in the fertilizer used comes from cottonseed meal or ammonium sulphate, there is little difference in the speed at which these fertilizers or the cover crops are nitrified if the pH value of the soil is not above 5.0.

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Table 1.

Nitrates Parts Per Million Dry Soil

Date of Sampling		May			June				July					Aug.				Sept.		Oct.	Aver.
		15	22	29	5	10	19	26	3	10	17	24	31	7	14	21	28	4	18	3	
Plot 1	Manured ---	63	78	55	44	61	101	50	18	12	7	2	2	5	2	3	4	4	9	21	28.5
Plot 2	Unmanured -	6	12	15	21	19	40	31	12	6	9	2	tr	1	tr	2	1	tr	1	4	9.6
Plot 3	Manured ---	46	116	203	240	105	128	205	162	96	68	48	7	15	6	8	10	3	12	9	78.2
Plot 4	Unmanured -	28	30	30	81	60	46	93	73	12	35	3	3	4	2	2	2	2	2	6	27.1
Plot 5	Manured ---	29	54	73	55	47	52	75	84	15	24	7	6	3	2	2	3	2	3	2	28.3

Moisture Percentage, Dry Weight Basis

Date of Sampling		May			June				July					Aug.				Sept.		Oct.	Aver.
		15	22	29	5	10	19	26	3	10	17	24	31	7	14	21	28	4	18	3	
Plot 1	Manured ---	11	9	9	8	9	8	15	10	9	11	13	9	10	13	6	5	11	11	15	10.1
Plot 2	Unmanured -	17	16	15	14	15	14	21	20	19	20	23	22	20	19	15	12	20	19	20	18.0
Plot 3	Manured ---	54	42	47	48	48	43	46	46	46	47	49	55	50	49	44	44	47	36	42	46.5
Plot 4	Unmanured -	46	39	40	37	36	36	42	41	42	43	48	56	49	47	42	40	40	42	45	42.7
Plot 5	Manured ---	32	32	32	30	30	26	30	33	34	31	33	30	30	32	24	20	22	28	25	29.2

Soil Temperature in Degrees Centigrade

Date of Sampling		May			June				July					Aug.				Sept.		Oct.	Aver.
		15	22	29	5	10	19	26	3	10	17	24	31	7	14	21	28	4	18	3	
Plot 1	Manured ---	15	13	13	23	21	21	15	18	20	21	26	18	20	18	20	16	16	19	15	18.3
Plot 2	Unmanured -	16	12	12	22	20	19	14	16	19	20	26	16	19	18	18	13	16	18	13	17.2
Plot 3	Manured ---	14	11	12	21	19	18	14	16	19	20	17	15	19	18	18	12	15	17	12	16.2
Plot 4	Unmanured -	14	10	12	21	19	18	14	16	19	20	18	15	19	17	18	11	15	17	12	16.1
Plot 5	Manured ---	17	12	13	22	20	19	15	16	19	21	17	16	20	18	19	13	16	19	13	17.1

Table 2. BLOCK F. Sod Fertilizer Program

Nitrates Parts Per Million Dry Soil

Date of Sampling		Apr.	May				June				July					Aug.				Sept.		Oct.	Aver.
		29	8	15	22	29	5	12	19	26	3	10	17	24	31	7	14	21	28	4	25	16	
Plot 1	P-K ----	5	tr	4	tr	tr	tr	tr	3	tr	tr	tr	tr	tr	2	2	tr	2	1	1	1	1	1.1
Plot 2	N-P-K --	4	10	98	53	21	tr	tr	6	tr	tr	tr	tr	tr	2	2	1	2	2	2	1	1	9.8
Plot 3	P-K ----	7	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	2	tr	tr	2	3	4	1	1	1	1.0
Plot 4	N-P-K --	4	4	89	3	22	2	6	tr	tr	tr	tr	tr	tr	tr	tr	2	3	2	2	1	tr	6.7
Plot 5	P-K ----	4	tr	tr	3	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	2	3	1	2	1	1	.8

Moisture Percentage, Dry Weight Basis

Date of Sampling		Apr.	May				June				July					Aug.				Sept.		Oct.	Aver.
		29	8	15	22	29	5	12	19	26	3	10	17	24	31	7	14	21	28	4	25	16	
Plot 1	P-K ----	29	28	30	28	27	26	22	20	26	24	25	27	29	26	28	29	24	23	27	22	27	26.1
Plot 2	N-P-K --	37	28	28	25	25	23	16	17	33	21	29	22	25	28	28	27	19	18	23	19	25	24.6
Plot 3	P-K ----	31	29	38	27	28	26	19	20	25	25	27	26	31	26	29	30	26	22	27	24	28	26.9
Plot 4	N-P-K --	30	28	29	28	28	27	21	19	24	24	25	23	30	29	28	29	25	21	25	22	26	25.8
Plot 5	P-K ----	32	28	30	30	31	29	24	23	28	27	28	28	31	31	31	34	28	24	29	26	28	28.6

Table 3. BLOCK D. Sod Fertilizer Program

Nitrates Parts Per Million Dry Soil

Date of Sampling	Apr.	May				June				July					Aug.				Sept.		Oct.	Aver.
	29	8	15	22	29	5	12	19	26	3	10	17	24	31	7	14	21	28	4	25	16	
Plot 1 N ------	tr	5	5	3	4	6	tr	3	4	4	2	3	2	2	2	2	2	2	2	2	1	2.7
Plot 3 N-P-K --	tr	tr	4	3	18	11	4	2	tr	5	tr	tr	tr	tr	2	2	2	2	2	1	2	2.9
Plot 4 N ------	tr	tr	15	3	3	15	16	14	6	5	20	3	3	1	2	2	2	2	2	1	2	5.6
Plot 6 Check --	tr	tr	tr	3	tr	tr	tr	tr	5	tr	tr	tr	tr	tr	tr	tr	2	1	1	tr	tr	.6
Plot 7 Check --	tr	tr	tr	tr	tr	tr	tr	5	tr	tr	tr	tr	tr	tr	2	tr	2	1	1	1	1	.6

Moisture Percentage, Dry Weight Basis

Date of Sampling	Apr.	May				June				July					Aug.				Sept.		Oct.	Aver.
	29	8	15	22	29	5	12	19	26	3	10	17	24	31	7	14	21	28	4	25	16	
Plot 1 N ------	30	32	34	30	31	27	24	22	28	26	26	28	31	27	23	32	28	24	28	26	29	27.9
Plot 3 N-P-K --	35	34	36	33	31	30	26	23	31	29	29	28	29	33	33	33	30	27	29	25	28	30.1
Plot 4 N ------	37	37	39	36	34	30	30	29	30	30	32	30	33	36	33	34	29	28	32	29	33	32.4
Plot 6 Check --	33	34	32	31	30	26	26	23	28	29	32	31	31	31	31	32	31	25	29	28	31	29.7
Plot 7 Check --	33	34	34	32	32	24	27	29	30	30	32	30	31	28	31	32	30	26	30	28	31	30.2

ORCHARD PLOTS

Table 4. BLOCK E. Cultivated versus Sod-Nitrated

Nitrates Parts Per Million Dry Soil

Date of Sampling	Apr.	May				June				July					Aug.				Sept.		Oct.	Aver.
	29	8	15	22	29	5	12	19	26	3	10	17	24	31	7	14	21	28	4	25	16	
Plot 2 Sod ----	5	39	34	87	43	8	tr	2	tr	tr	tr	tr	tr	2	2	2	3	1	2	1	1	11.2
Plot 3 Cult. --	6	tr	2	tr	tr	tr	tr	7	7	11	3	4	3	2	4	3	3	2	2	tr	1	2.9
Plot 4 Sod ----	tr	tr	38	24	14	4	4	3	tr	tr	tr	tr	2	2	3	2	3	2	1	2	1	5.0
Plot 5 Cult. --	tr	tr	2	tr	tr	tr	6	16	11	12	4	8	3	1	4	2	2	2	1	1	1	3.6
Plot 6 Sod ----	6	tr	44	23	71	6	tr	tr	tr	tr	tr	tr	3	2	2	2	3	2	1	1	1	7.9

Moisture Percentage, Dry Weight Basis

Date of Sampling	Apr.	May				June				July					Aug.				Sept.		Oct.	Aver.
	29	8	15	22	29	5	12	19	26	3	10	17	24	31	7	14	21	28	4	25	16	
Plot 2 Sod ----	28	30	31	26	28	27	19	19	26	25	26	25	29	30	30	30	25	23	26	24	28	26.4
Plot 3 Cult. --	28	28	28	27	29	26	26	23	27	25	27	28	29	30	29	30	26	23	25	25	26	26.9
Plot 4 Sod ----	30	29	31	30	28	27	24	20	26	24	27	26	28	31	31	30	26	22	25	24	29	27.1
Plot 5 Cult. --	24	29	30	26	28	29	25	22	27	28	31	28	28	31	29	30	26	24	28	26	28	27.5
Plot 6 Sod ----	23	33	35	35	29	35	30	26	31	29	30	34	35	31	36	33	32	28	31	32	32	31.4

Table 5. BLOCK A. Cultivated versus Cultivated-Nitrated

Nitrates Parts Per Million Dry Soil

Date of Sampling	Apr.	May				June				July					Aug.				Sept.		Oct.	Aver.
	29	6	13	20	27	3	10	17	24	1	8	15	22	29	5	12	19	26	2	23	14	
Plot 2 Check ---------	tr	5	7	6	8	3	6	11	6	6	4	3	3	2	2	2	2	tr	1	1	1	3.8
Plot 3 Sodium Nitrate	tr	31	13	17	56	102	36	56	81	71	35	31	15	4	5	8	4	2	3	1	2	27.3
Plot 4 Check ---------	tr	tr	4	4	tr	4	6	23	19	11	4	9	6	2	2	2	1	1	1	2	1	4.9
Plot 5 Sodium Nitrate	tr	19	14	13	40	34	104	38	32	24	25	30	13	4	5	3	4	3	2	3	1	19.6
Plot 6 Check ---------	tr	tr	4	4	11	19	21	17	18	11	22	8	8	3	2	2	1	2	1	2	4	7.6
Plot 7 Sodium Nitrate	tr	18	23	11	76	191	40	93	47	108	25	35	25	3	5	11	4	3	2	3	8	34.8

Moisture Percentage, Dry Weight Basis

Date of Sampling	Apr.	May				June				July					Aug.				Sept.		Oct.	Aver.
	29	6	13	20	27	3	10	17	24	1	8	15	22	29	5	12	19	26	2	23	14	
Plot 2 Check ---------	38	37	39	37	34	37	35	34	33	35	36	32	34	37	35	35	36	33	32	32	34	35.0
Plot 3 Sodium Nitrate	29	40	40	39	39	39	28	35	33	35	28	33	33	38	37	36	38	33	31	33	33	34.8
Plot 4 Check ---------	35	37	35	35	35	35	32	30	28	34	27	29	31	36	34	34	34	32	28	30	31	32.5
Plot 5 Sodium Nitrate	32	29	31	31	37	30	27	34	24	28	32	22	24	30	30	28	25	24	24	22	23	27.9
Plot 6 Check ---------	36	34	34	33	32	32	30	29	28	31	32	28	28	34	33	31	30	28	26	28	28	30.7
Plot 7 Sodium Nitrate	35	34	35	33	33	32	29	27	27	29	30	25	23	32	31	30	28	25	22	26	28	29.2

Table 6. Soil Temperature for Orchard Blocks, Given in Degrees Centigrade

Weekly Determinations	Apr.	May				June				July					Aug.				Sept.		Oct.	Aver.
	4	1	2	3	4	1	2	3	4	1	2	3	4	5	1	2	3	4	1	4	2	
BLOCK A. -------------	10	-	-	12	10	18	20	16	16	-	-	19	20	19	19	18	20	20	17	12	7	16.1
BLOCK E. -------------	-	9	11	14	12	18	17	18	15	17	19	20	18	18	18	18	19	16	18	15	11	16.1
BLOCK D. -------------	10	9	11	15	11	18	16	16	15	16	18	19	18	17	18	18	20	16	17	14	11	15.4
BLOCK F.--------------	9	9	11	12	11	18	17	18	15	16	18	19	18	18	18	18	19	16	18	15	11	15.4
BLOCK R. -------------	8	-	-	12	10	19	19	15	16	16	-	20	20	17	19	18	21	20	17	-	9	16.2

Table 7. BLOCKS G-H. Cultivated versus Straw Mulch

Nitrates Parts Per Million Dry Soil

Date of Sampling	May 8	15	22	29	June 5	12	19	26	July 3	10	17	24	31	Aug. 7	14	21	28	Sept. 4	25	Oct. 16	Aver.
Block G. Cult. --	tr	6	3	4	4	4	7	15	9	5	7	4	4	11	3	8	1	1	2	1	4.9
Block G. Mul. ---	29	18	10	16	28	25	37	33	21	20	49	25	24	50	67	41	35	97	63	38	46.3
Block H. Cult. --	12	12	7	18	19	12	35	36	27	21	28	9	6	11	21	17	6	5	1	1	15.2
Block H. Mul. ---	13	6	14	10	14	61	42	35	18	24	40	33	18	96	35	56	66	81	53	78	39.7

Moisture Percentage, Dry Weight Basis

Date of Sampling	May 8	15	22	29	June 5	12	19	26	July 3	10	17	24	31	Aug. 7	14	21	28	Sept. 4	25	Oct. 16	Aver.
Block G. Cult. --	26	27	25	24	23	18	18	24	22	24	23	27	27	26	27	20	18	23	19	21	23.1
Block G. Mul. ---	28	29	29	30	28	26	26	31	28	31	30	32	32	31	29	25	24	30	25	29	28.7
Block H. Cult. --	28	30	24	28	28	21	20	29	28	28	28	31	28	31	32	26	25	26	26	28	27.3
Block H. Mul . ---	28	31	27	28	28	27	24	26	27	27	29	29	28	29	30	23	23	29	23	29	27.3

Soil Temperature in Degrees Centigrade

Date of Sampling	May 8	15	22	29	June 5	12	19	26	July 3	10	17	24	31	Aug. 7	14	21	28	Sept. 4	25	Oct. 16	Aver.
Block G. Cult. --	8	11	13	12	18	15	18	15	16	19	20	18	17	18	18	18	16	17	13	16	15.8
Block G. Mul. ----	8	11	13	12	18	14	16	14	16	17	18	17	17	19	18	18	16	17	15	17	15.6
Block H. Cult. ---	8	12	13	12	18	17	18	15	16	19	20	18	17	18	18	17	16	17	13	18	16.0
Block H. Mul. ----	8	12	13	12	18	14	15	14	16	18	18	18	17	19	18	17	17	17	14	19	15.7

Table 8.

BLOCK R. Fertilizer Experiment

Nitrates Parts Per Million Dry Soil

Date of Sampling			Apr.	May				June				July					Aug.				Sept.		Oct.	Aver.
			30	6	13	20	27	3	10	17	24	1	8	15	22	29	5	12	19	26	2	23	14	
Plot 2	Limed	N ---	14	104	104	170	212	373	151	316	382	499	325	446	302	13	54	44	56	216	90	65	24	188.6
Plot 2	Unlimed	N ---	tr	13	159	82	175	270	140	320	405	330	303	304	238	49	61	54	34	206	127	48	42	160.0
Plot 3	Limed	P ---	tr	tr	4	5	6	3	9	15	3	4	9	8	4	3	15	17	12	3	2	4	2	6.1
Plot 3	Unlimed	P ---	tr	tr	2	2	3	7	5	tr	2	2	14	9	2	3	11	19	12	10	2	1	2	5.1
Plot 4	Limed	Check	7	9	2	5	4	11	5	18	7	4	5	18	4	2	22	22	21	26	8	2	2	9.7
Plot 4	Unlimed	Check	tr	tr	2	4	8	6	5	19	30	16	19	22	20	4	11	16	13	26	14	7	4	11.7
Plot 5	Limed	K ---	6	tr	7	9	10	9	14	35	50	22	33	11	21	4	16	16	14	10	17	3	3	14.8
Plot 5	Unlimed	K ---	tr	tr	3	3	5	5	10	23	28	18	21	9	17	3	10	16	12	21	12	5	4	10.8
Plot 9	Limed	P-K -	tr	tr	2	11	10	8	8	21	4	4	8	3	4	3	16	14	9	7	3	1	3	6.6
Plot 9	Unlimed	P-K -	tr	tr	3	6	12	3	11	26	7	11	9	10	11	3	16	11	13	11	7	3	3	8.4
Plot 10	Limed	N-P-K	5	94	11	12	12	15	15	20	11	6	3	8	3	3	27	17	16	25	8	2	4	15.1
Plot 10	Unlimed	N-P-K	tr	tr	4	tr	17	7	5	6	4	2	tr	4	3	3	12	13	9	9	4	2	2	5.1
Plot 11	Limed	$CaSO_4$	11	tr	tr	22	8	9	12	15	15	12	4	10	12	4	15	17	22	10	9	1	2	10.0
Plot 11	Unlimed	$CaSO_4$	tr	tr	tr	6	4	2	11	7	22	7	3	8	8	2	5	4	6	5	2	2	1	5.0
Plot 12	Limed	Check	10	6	tr	2	10	10	12	20	7	7	8	11	9	5	20	24	17	14	9	4	2	9.9
Plot 12	Unlimed	Check	tr	tr	tr	tr	7	7	25	24	34	26	tr	17	9	2	5	23	7	10	8	3	3	9.5

Moisture Percentage, Dry Weight Basis

Date of Sampling			Apr.	May				June				July					Aug.				Sept.		Oct.	Aver.
			30	6	13	20	27	3	10	17	24	1	8	15	22	29	5	12	19	26	2	23	14	
Plot 2	Limed	N ---	31	32	33	31	30	29	28	22	23	28	29	25	27	30	28	27	28	24	21	26	27	27.6
Plot 2	Unlimed	N ---	32	32	31	31	29	29	26	22	21	28	30	24	26	30	26	26	25	24	22	25	27	26.9
Plot 3	Limed	P ---	35	34	34	33	31	32	29	25	28	30	31	28	28	32	29	29	29	26	23	26	28	29.5
Plot 3	Unlimed	P ---	32	30	30	29	30	29	26	24	24	28	28	25	26	30	26	26	26	24	23	26	24	27.0
Plot 4	Limed	Check	33	33	35	32	31	31	28	26	27	30	31	25	28	31	30	28	28	28	26	28	28	29.4
Plot 4	Unlimed	Check	32	31	32	31	29	28	26	25	23	28	28	24	25	31	27	25	25	23	24	24	27	27.1
Plot 5	Limed	K ---	34	33	32	31	31	31	29	24	24	39	31	27	26	32	30	28	29	27	25	27	28	29.0
Plot 5	Unlimed	K ---	31	30	30	28	28	30	25	23	23	27	27	24	25	29	27	26	27	22	21	24	26	26.3
Plot 9	Limed	P-K -	34	33	32	30	31	30	28	24	27	29	30	25	26	31	28	27	27	24	22	27	28	28.2
Plot 9	Unlimed	P-K -	30	28	28	26	26	25	23	19	21	25	26	22	24	29	26	25	25	24	20	23	23	24.8
Plot 10	Limed	N-P-K	34	31	34	32	31	29	27	25	25	38	30	24	26	31	28	29	26	25	24	26	28	28.2
Plot 10	Unlimed	N-P-K	30	30	30	28	26	26	21	21	20	25	26	21	22	30	26	25	24	22	20	24	24	24.8
Plot 11	Limed	$CaSO_4$	34	31	33	29	31	29	28	24	22	29	29	25	27	32	29	28	28	25	25	27	28	28.2
Plot 11	Unlimed	$CaSO_4$	29	29	29	24	26	23	22	20	18	25	25	22	22	29	25	25	24	22	20	23	23	24.1
Plot 12	Limed	Check	36	34	33	33	31	31	28	27	25	29	30	26	28	33	30	29	30	28	25	28	30	29.7
Plot 12	Unlimed	Check	32	31	30	29	27	26	24	20	23	26	26	22	24	30	27	27	25	22	21	23	26	25.8

Table 9.

Nitrates Parts Per Million Dry Soil

Date of Sampling	May				June					July				Aug.					Sept.	Aver.
	4	11	18	25	1	8	15	22	29	6	13	20	27	3	10	17	24	31	7	
Plot 59A -------	97	87	106	109	141	134	179	233	279	456	422	340	159	162	132	86	90	85	33	175.3
Plot 59B -------	44	60	91	112	114	90	86	179	274	408	412	320	162	143	133	136	117	56	31	156.2
Plot 60A -------	tr	tr	3	5	13	45	60	94	179	244	289	232	119	93	52	23	20	6	8	78.2
Plot 60B -------	tr	tr	3	4	27	65	93	116	195	336	357	295	142	174	86	59	55	40	15	108.5
Plot 61A -------	tr	tr	tr	tr	tr	9	52	66	162	236	250	233	104	82	84	24	11	12	7	70.1
Plot 61B -------	tr	4	tr	tr	tr	15	35	62	176	248	238	206	86	81	60	23	8	13	6	66.4
Plot 62A -------	94	85	93	104	118	80	97	187	236	359	327	256	144	151	158	104	128	108	36	150.8
Plot 62B -------	66	89	117	104	145	117	108	192	304	436	326	338	247	234	231	68	135	114	49	180.0
Plot 63A -------	64	86	81	117	137	141	114	238	338	508	307	404	58	69	85	69	46	56	32	155.3
Plot 63B -------	35	60	71	74	139	85	108	173	258	479	361	358	99	69	80	81	66	64	31	142.2
Plot 64A -------	tr	3	4	8	21	40	46	87	140	235	239	207	42	52	34	31	26	12	14	65.3
Plot 64B -------	tr	3	6	5	26	32	44	59	151	188	215	185	30	25	28	14	34	19	12	56.6
Plot 65A -------	82	78	126	89	139	121	158	270	308	434	509	314	102	119	168	45	136	136	51	178.2
Plot 65B -------	31	65	87	93	108	129	126	200	238	394	432	305	85	90	73	68	49	40	25	138.8
Plot 66A -------	tr	4	3	4	14	58	52	104	166	207	281	228	61	60	67	12	25	11	8	71.8
Plot 66B -------	tr	3	4	5	16	66	72	92	171	253	342	286	91	49	58	22	37	21	8	84.0
Plot 67A -------	tr	tr	tr	tr	tr	14	22	78	123	278	224	214	114	35	20	9	19	9	7	61.4
Plot 67B -------	tr	tr	tr	3	tr	17	35	61	96	214	247	204	61	37	13	9	13	3	5	53.6
Plot 68A -------	44	49	55	54	100	67	67	106	179	311	275	224	196	74	48	11	29	38	21	102.5
Plot 68B -------	27	37	37	56	61	68	61	114	186	303	312	284	75	44	24	7	35	23	20	93.4
Plot 69A -------	28	51	51	57	109	104	105	164	212	260	303	224	22	17	14	6	9	9	12	92.5
Plot 69B -------	17	52	52	45	76	59	70	98	164	357	210	199	22	8	8	5	17	8	9	77.7
Plot 70A -------	tr	4	4	10	19	34	29	78	109	248	290	97	7	11	8	5	9	3	9	51.3
Plot 70B -------	tr	3	3	13	15	23	56	86	125	272	302	141	15	8	6	5	6	6	8	57.5

TOBACCO PLOTS

Table 10.

Moisture Percentage, Dry Weight Basis

Date of Sampling	May 4	11	18	25	June 1	8	15	22	29	July 6	13	20	27	Aug. 3	10	17	24	31	Sept. 7	Aver.
Plot 59A -------	47	45	43	46	42	41	41	40	40	41	40	39	47	44	43	42	42	39	46	42.5
Plot 59B -------	45	46	43	45	42	42	41	41	42	41	39	40	46	43	44	43	42	38	45	42.5
Plot 60A -------	47	46	43	46	41	40	39	40	41	40	39	41	47	42	44	43	42	41	47	42.6
Plot 60B -------	48	45	42	43	41	39	38	40	40	40	41	39	45	46	45	43	40	39	46	42.1
Plot 61A -------	46	45	44	44	40	38	37	39	39	39	39	38	44	43	43	44	39	31	45	40.9
Plot 61B -------	47	45	45	43	39	37	39	39	39	40	39	38	45	42	42	39	39	37	43	40.9
Plot 62A -------	44	43	43	41	39	38	39	38	39	39	38	38	39	40	40	37	39	39	43	39.8
Plot 62B -------	41	41	40	41	39	36	37	36	37	39	38	36	43	39	40	40	37	35	43	38.8
Plot 63A -------	40	37	37	39	36	34	35	35	34	35	33	33	40	37	36	36	36	33	38	36.0
Plot 63B -------	35	37	36	37	34	32	31	31	31	33	32	30	35	32	34	34	31	30	35	33.2
Plot 64A -------	37	32	32	33	29	31	30	29	28	30	30	27	34	32	30	30	29	25	33	30.6
Plot 64B -------	36	29	28	30	26	27	25	25	27	27	26	24	33	28	29	26	26	23	30	27.6
Plot 65A -------	43	42	41	42	40	38	37	38	38	39	37	38	44	41	40	39	39	37	42	39.7
Plot 65B -------	42	42	40	41	39	38	36	37	37	37	36	37	43	40	36	40	37	36	42	38.7
Plot 66A -------	43	39	38	40	37	35	34	34	36	36	34	33	41	38	37	33	34	33	40	36.6
Plot 66B -------	39	40	35	37	33	32	31	32	32	33	31	31	39	36	35	35	32	31	40	34.4
Plot 67A -------	39	35	35	36	31	30	29	29	29	30	28	28	37	32	32	31	29	27	36	31.7
Plot 67B -------	35	34	33	34	29	27	28	28	27	28	27	26	36	32	32	27	26	26	36	30.1
Plot 68A -------	36	33	30	31	30	29	28	28	28	28	29	27	33	33	31	28	27	26	34	29.9
Plot 68B -------	29	30	29	30	29	27	26	27	27	27	27	26	32	30	29	27	26	25	33	28.2
Plot 69A -------	26	26	25	27	24	23	22	24	25	26	23	22	30	26	25	24	22	18	30	24.6
Plot 69B -------	22	24	22	25	22	21	20	21	21	30	21	20	28	23	24	22	20	16	28	22.6
Plot 70A -------	23	17	20	24	21	18	17	19	19	20	19	17	27	22	22	19	16	15	27	20.1
Plot 70B -------	22	19	20	21	20	19	18	19	21	21	20	18	27	23	22	18	16	13	25	20.1

Table 11.

Soil Temperature, Given in Degrees Centigrade

Date of Sampling	May 4	May 11	May 18	May 25	June 1	June 8	June 15	June 22	June 29	July 6	July 13	July 20	July 27	Aug. 3	Aug. 10	Aug. 17	Aug. 24	Aug. 31	Sept. 7	Aver.
Plot 59A -------	Variation from 8° to 9° C.	11	Variation from 11° to 13° C.	9	15	20	21	18	21	19	20	19	20	20	21	19	16	18	21	17.3
Plot 59B -------		11		9	15	20	20	18	21	19	20	19	19	20	21	19	16	18	21	17.2
Plot 60A -------		13		9	15	20	21	18	21	19	20	19	19	19	21	18	16	18	21	17.3
Plot 60B -------		13		10	15	20	21	18	21	19	20	19	19	19	21	18	16	18	21	17.3
Plot 61A -------		12		7	15	20	20	18	22	19	20	18	20	19	21	18	16	18	21	17.1
Plot 61B -------		12		8	15	20	21	18	22	19	20	19	19	19	21	19	15	18	21	17.2
Plot 62A -------		11		9	15	20	21	19	21	20	20	19	19	19	21	19	16	18	20	17.3
Plot 62B -------		11		9	15	20	21	17	21	19	20	19	19	19	21	19	15	19	19	17.1
Plot 63A -------		12		9	15	20	21	18	21	19	20	19	19	18	21	18	16	19	20	17.2
Plot 63B -------		11		10	15	21	21	18	21	20	20	19	19	19	21	18	16	19	20	17.3
Plot 64A -------		12		10	15	21	21	18	22	19	20	19	20	19	21	18	15	19	20	17.4
Plot 64B -------		12		9	15	21	21	17	21	19	20	19	20	18	21	18	16	19	21	17.3
Plot 65A -------		11		9	16	20	21	18	21	19	21	20	20	19	21	19	16	19	21	17.5
Plot 65B -------		11		9	16	20	22	18	21	20	20	20	20	19	21	19	16	19	20	17.5
Plot 66A -------		13		9	16	20	22	18	21	19	20	20	20	19	21	20	16	18	21	17.6
Plot 66B -------		13		8	16	20	22	18	21	19	20	20	20	19	21	20	16	18	21	17.5
Plot 67A -------		13		8	16	21	22	18	21	20	20	19	20	19	21	20	17	19	20	17.6
Plot 67B -------		13		8	15	20	22	18	21	20	21	19	20	19	21	19	17	19	21	17.6
Plot 68A -------		12		9	16	20	21	18	21	20	21	20	20	19	21	19	16	19	21	17.5
Plot 68B -------		12		9	16	20	22	18	21	20	21	20	20	19	21	20	16	19	21	17.6
Plot 69A -------		12		8	16	20	22	18	21	20	21	20	20	19	21	20	16	19	19	17.5
Plot 69B -------		12		9	16	21	23	18	22	20	21	20	20	20	21	19	16	19	19	17.6
Plot 70A -------		12		9	15	21	22	18	22	20	21	20	20	19	21	20	17	20	20	17.7
Plot 70B -------		13		9	15	21	21	18	21	20	21	20	20	19	21	20	17	20	20	17.6