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The Ammonification and nitrification of cottonseed meal and the nitrification of ammonium sulphate

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906

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by

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INTRODUCTION

The problem of the nutrition of the tobacco plant (Tabacum nicotiana) is yet to be solved. In its broad aspects the problem is manifold and complicated, and its final and complete solution must of necessity come from the combined efforts of many workers. Owing to the economic importance of tobacco in Massachusetts agriculture the problem is being studied at the Massachusetts Agricultural Experiment Station, and this thesis is concerned with one phase of this station's investigations.

The part played by nitrogen in the nutrition of the higher plants is very important, and its role is of particular significance with respect to tobacco as grown in the Connecticut Valley. To this crop large quantities of nitrogen are supplied in commercial fertilizers and most of the nitrogen is furnished in the form of cottonseed meal. It is held by some, particularly practical tobacco farmers, that cottonseed meal is indispensable for the production of high-grade cigar wrappers.

Other studies made at this station have shown that nitrate is the form of nitrogen most readily assimilated by Havana tobacco. Further, it has been shown that certain ammonium compounds are toxic to tobacco. Therefore, the purpose of this thesis is to contribute experimental data regarding certain factors affecting the

ammonification and nitrification of cottonseed meal and the nitrification of ammonium sulfate. These processes are biological in nature and are affected by certain factors and conditions, including moisture, temperature and soil organic matter. It is these factors that have been studied.

Part I deals with ammonification and nitrification under field conditions. Part II covers similar studies conducted under better controlled conditions of temperature and moisture.

REVIEW OF LITERATURE

1. The Nitrification of Cottonseed Meal and Ammonium Sulfate.

Boname (11) collected the drainage water from soil to which different fertilizers had been added and tested it for different forms of nitrogen once a month. The nitrogenous fertilizers tested were sulfate of ammonia, dried blood, oil cake, fertilizer (5.4 per cent nitrogen), and fish guano. Sulfate of ammonia nitrified more slowly than the other fertilizer materials in unlimed soils, but, when limed the sulfate of ammonia readily nitrified.

It appears from work of others that cottonseed meal does not become available for the plants as completely as other fertilizers. Johnson, Jenkins, and Britton (36) performed three series of experiments (a) with oats followed by Hungarian grass; (b) with Hungarian grass; and (c) with rye and oats followed by Hungarian grass. The fertilizers used were nitrate of soda, dried blood, dried ground fish, ground bone, tankage, horn and hoof meal, linseed meal, castor pomace, and cottonseed meal. The availability of these materials was determined by use of the pepsin-hydrochloric acid method reported by the Connecticut Station (75). Varying amounts of these fertilizers were used and in practically every case the availability of cottonseed meal was the lowest of them

all, but higher than either of three grades of fine bone which were compared with cottonseed meal in another experiment. Jenkins and Britton (33), (34) found also that cottonseed meal was recovered more slowly than nitrate of soda but faster than hard raw bone when equal amounts of nitrogen were used in each case from the different sources.

With reference to the relative values of different fertilizer materials Withers and Fraps (67), (68), (69), (70) did considerable. They found that there was a great variation in the nitrification of the same fertilizer in different soils. Under certain conditions cottonseed meal nitrified even more completely than ammonium sulfate in some soils but in most of the soils ammonium sulfate was better. It was pointed out that the factors which produce this result are probably as follows: (a) the presence of ammonium sulfate diminished the activity of the nitrifying organisms, (b) the acids produced also hinder them and (c) different soils contain different classes of organisms, some of which nitrify organic in preference to ammoniacal nitrogen. Continuous application of ammonium sulfate to a soil previously limed increased its power of nitrifying ammonium sulfate. This happened only when there was more than enough lime added to make the soil reaction neutral. The nitrification of ammonium sulfate increased until the soil reaction was somewhat around neutral and after that the use of ammonium sulfate

decreased nitrification.

Withers and Frape (71) reported further in regard to the rate of nitrification of ammonia fixed by chabazite representing zeolitic silicates of the soil that the ammonia so fixed was nitrified more rapidly than ammonium sulfate or cottonseed meal, indicating that zeolitic silicates in soils may possibly aid in the nitrification of ammonium sulfate by fixing a portion of the salt.

That soil reaction seems to have some influence upon nitrification in the soil was confirmed by Temple (61) at the Georgia Station. His experiments showed that cottonseed meal, tankage, and dried blood nitrified in acid soils used more readily than ammonium sulfate, but not with soils which were limed. He suggested that ammonium sulfate is used by corn and cotton whether nitrified or not.

Other work by Temple (60) showed that tankage was nitrified more readily than ammonium sulfate and in some cases the nitrate recovered from the soil containing tankage was ten times that from soils containing sulfate of ammonia. Tankage, cottonseed meal, cowpea vines, gelatin, peptones, asparagin, urea, ammonium citrate, ammonium oxalate, ammonium tartrate, ammonium bicarbonate, and ammonium hydrate were nitrified faster than ammonium sulfate or chloride. The explanation offered for this condition was that the soils, (all of the Cecil group) were

aoid.

Grandeau (26) reported from experiments by Wagner that the nitrification of ammonium salts was more rapid the smaller the amount of the salts and the more thorough their diffusion in the soil.

From work reported by Waksman (63) and carried out by Lipman (47) it seems that the kind of material from which the nitrogen comes is an important factor. It was found that the nitrifying powers of soils of the arid region are no more intense than those of the humid region. In regard to this Lipman (47) says, "The data for soil nitrogen and dried blood nitrogen justify the further conclusion that the nitrifying powers of humid soils are greater than those of arid soils. Arid soils, however, nitrify the nitrogen of sulfate of ammonia and cottonseed meal with much greater vigor than do the humid soils. A reversal of efficiency is manifest between the two groups of soils as regards sulfate of ammonia and cottonseed meal on the one hand and dried blood and the soils own nitrogen on the other."

Waksman (63) also cited literature which states that nitrates are formed in the soil in the upper layers, 90 per cent of the process being carried out in the upper 40 to 50 cm. This is due to the need of oxygen for the activities of the organisms. Even nitrate formation in solution is greatly stimulated by aeration.

2. Ammonification of Cottonseed Meal.

Ammonification experiments conducted by Given and Willis (25) of Pennsylvania showed that ammonification was very similar in rate and amount in soils receiving very different treatments. In further ammonification experiments Given (24) found that ammonia production took place up to the seventh day. Nitrification of these soils using ammonium sulfate showed that the soils which had no influence upon ammonifying organisms had an entirely different effect upon nitrifying organisms. The acid plats seemed to hinder nitrification considerably.

Soil organisms seem to play a very important part in the rate of ammonification of different fertilizer materials in the soil. Mc Lean and Wilson (52) conducted experiments using dried blood and cottonseed meal with an acid gravelly loam and a neutral red shale for the purpose of determining the ammonifying efficiency of the fungi present in the soil. Results showed that fungi rather than bacteria were responsible for the large accumulations of ammonia in soils containing acid phosphate and organic nitrogen in the form of dried blood.

The results of these experiments make it appear that the ammonification of the soil organic matter, by fungi, depends not only upon the chemical and physical composition of the soil, but also upon the quality of the organic matter present as well as upon the presence of soluble phosphates.

ble phosphates.

Kelly (39) pointed out that chemical factors inherent in the nitrogen compounds themselves predetermine the availability to some degree. He found by the determination of the different groups of nitrogen compounds before and after bacterial action in casein, dried blood, soy bean, cake meal, cottonseed meal, linseed meal, cocoanut meal, globulin from cottonseed meal and zein from maize, that, with the exception of linseed meal and zein, the basic diamino acid nitrogen was converted into ammonia more rapidly than the nitrogen of the other groups.

3. Relation of Organic Matter to Nitrification and Denitrification.

The relation of organic matter to biochemical processes of the soil has been studied extensively, and there is a voluminous literature bearing on the subject. In this review of literature only those studies which have a rather direct relation to the problems at hand will be discussed.

The effect of timothy sod on nitrification in the soil has not received much attention by investigators.

Lyon and Bizzell (48) studied the rate of nitrification in fallow soils and those which had been continuously in alfalfa and timothy for several years by means of incubation experiments with dried blood, with and without the addition of lime. Results show a greater nitrification for

the alfalfa soil than for the timothy soil, both in the soil on which the crops had been grown continuously and in that from which they had been removed and the soil kept bare for two seasons. This was due to the direct effects of the plant on the nitrate production and not to the greater quantity of nitrogen which the plants stored in the soil. This is shown by the fact that the rate of nitrate formation was in the order named above when both soils contained the same amount of dried blood.

Lyon and Bizzell (49) also did some work on the nitrate content of soils under timothy, maize, potatoes, oats, millet and soy beans. The same soil under each of the crops was different in the amount of nitrates found. Timothy maintained a lower nitrate content in the soil than did any other crop.

Albrecht (2) found in his work at Missouri in regard to nitrate production in the soil by the crop that for the grasses, including oats and timothy sod, no significant accumulation ever occurred, although there was a slight increase after the crops were harvested. "A straw mulch had a decidedly depressing effect on nitrate accumulation. No significant accumulations occurred. Apparently the high moisture was responsible, since the curve of moisture percentage bears a negative correlation to that of nitrate accumulation."

Klyucharev (41) has shown definitely that the rate of

denitrification is dependent largely upon the amount of starch and similar compounds in the soil. Barthel (7) found that a small amount of dextrose not only hindered nitrification to a large extent but strongly promoted denitrification. Upon completely mineralizing the dextrose, however, nitrification began. Other carbohydrates such as sugar, starch and even straw, as demonstrated by Chirikov (15) have also caused reduction of nitrates as indicated by reduced yields where these materials were used.

The carbon-nitrogen ratio is an explanation of the above noted effects of carbohydrates. Jensen (35) experimented with wheat straw, sweet clover, blue lupine, barnyard manure, pea pods, alfalfa and fungus mycelium having carbon-nitrogen ratios from 85 : 1 to 10 : 1. These were tried out in both alkaline and acid soils and it was concluded that the C : N ratio influences nitrification as much as soil reaction. The higher the C : N ratio the fewer nitrates found.

Kezer (40) found that plowing under materials rich in nitrogen increased the nitrogen for a time, while plowing under materials low in nitrogen such as straw or cornstalks temporarily reduced nitrates.

Difficultly decomposable organic substances such as the woody residue from the manufacture of quinin (chinirind) was found by Nolte (53) to increase denitrification. These results seem to indicate that this woody

residue serves as a medium for the growth of denitrifying bacteria.

The report on soil work in Washington (93) showed that the application of straw appeared to have a depressing effect upon nitrification. This was overcome in about one year's time, when a beneficial residual effect was noted. Wood (73) (Aeby, Dorsch, Matz and Wagner (1)), Breal (12) Maercker (50), and Höflich (31) explained this condition by the fact that all forms of manure, straw, and soil contain denitrifying organisms which are responsible for the reduction of nitrates, especially if applied only a short time before planting. Wood (73) pointed out the fact that in comparing nitrates alone with nitrates and manure together that the former gave the greater yield of grain, thus showing the effect of manure in reducing nitrates. Voorhees also obtained similar results. Maercker (50) particularly warned against the use of dung as soils fertilized with such manure will produce less than unfertilized soil.

4. <u>The Effect of Chemicals and Enzymes on Nitrification and Denitrification.</u>

According to early theories it was at first thought that nitrification and denitrification were both purely chemical processes. According to Greaves (28) "Kuhlman, as early as 1846 expressed the belief that nitric nitrogen may be reduced in the soil to ammonia by the fermentation

of organic substances. This same idea was brought out twenty-one years later by both Froehde and Angus Smith, and it also appears prominently in the writings of Johnson in 1870, and Davy called attention to the fact that gaseous nitrogen was set free from decomposing organic matter in soil."

As late as the close of the nineteenth century Knovalov (42) showed that humus as well as ferrous salts is able to reduce nitrate of potash to ammonia. He stated that the reduction proceeds very slowly at ordinary temperatures, but becomes more rapid on heating, and that caustic alkali and a free access of air do not destroy the ability of humus to reduce nitrates. He concluded, therefore, that the possibility of denitrification of nitrate of potash in the soil under the influence of humus, without bacteria, is fully corroborated by laboratory experiments.

Waksman (64) concluded that the decomposition of green manure depends upon the composition of the plants used for this purpose. Some organic complexes are slowly decomposed and others are very rapidly broken down into humus.

Investigations reported by Hulme (32) and Maze (51) inform us to the effect that the reduction of nitrates might be caused (a) by bacterial reduction and (b) the enzymatic reduction. The chemical agent by which the

orgaism reduced the nitrate was nascent hydrogen. Stocklasa et al (58) showed that when glucose and salt of citric acid were present with culture tests in Giltay-Aberson solutions, there was considerable loss of nitrogen by denitrification.

Fowler et al, (21), however, asserted that losses of nitrogen in nature or in the operations of agriculture, due to purely chemical changes are negligible and that the losses are due to biochemical changes instead.

Potter (56) found that organic matter in the form of stable manure or green manure or both together decomposed more rapidly under the influence of lime than without it. Christensen (14) found that mannite also decomposed faster in the presence of basic lime and phosphoric acid combinations.

On unlimed sections Lipman (46) found that total nitrogen recovered in the crop, where organic nitrogenous fertilizer was used, was somewhat more than where the mineral fertilizers were used. On limed sections the reverse was true.

Barthel (8) attributed the fact that nitrification proceeded better in the presence of organic nitrogen compounds than with ammonium sulfate to the effect of the acid (SO_4) produced by the latter.

Ampola (3), (4), (5) pointed out that calcium nitrate was more resistant to the denitrifying process in the

presence of stable manure than potassium and sodium nitrates.

Fischer (20) found that when dried blood is applied to a light sandy soil, a greater loss of nitrogen by denitrification occurred than in heavier soils. With medium applications of sodium nitrate there was no denitrification.

Pichard (55) observed that humus soil gave considerably less nitric nitrogen than the cottonseed meal mixture under like conditions.

Other forms of organic matter such as is furnished by soil extracts, humates and acetates, and even peptones and sugar, was found by Karpinski and Niklewski (38) to favor nitrification in mixed cultures.

Joshi's results (37) showed that most of the immediate effect of green manures is due to the nitrogen contained in the leaves being quickly nitrified, and also that the effect of a leguminous crop on the succeeding cereal crop is due mostly to the fall of leaves from the leguminous crop. The failure to nitrify, so far as ascertained, did not depend on the nature of the materials such as cellulose and woody tissue.

Doyarenko (17) stated that with the addition of nitrogen in the form of sodium nitrate, ammonium sulfate, and ammonium nitrate, it was observed that an injurious effect resulted when strawy manure was used in connection with sodium nitrate and ammonium nitrate, but not in the

case of ammonium sulfate.

Barthel's results (7) showed that the influence of organic substances upon nitrification, if not present in too large proportions, is usually rather favorable than otherwise because of their ready solubility.

Deherain (16) found that manure increased nitrates in the soil regardless of the fact that it may contain denitrifying organisms. He condemned the idea of treating manure with ammonium sulfate to prevent denitfification as it is harmful, expensive and useless.

Wolff (72) claimed that denitrification is not due to the direct action of the organisms but that the products of fermentation reduce nitrates and eventually convert them into carbonates.

Warington (66) took exception to the conclusions of German investigators regarding denitrification as due to the action of manure in the soil. He maintained that the denitrifying organisms present in manure, straw, litter, etc., are derived originally from atmospheric dust.

5. <u>The Effect of Soil Reaction on Nitrification and Denitrification.</u>

Barthel and Bengtsson (9) found in comparing ammonium sulfate with stable manure in acid lowland moss that the nitrification of ammonium sulfate proceeded as powerfully in these soils as in neutral soils in spite of the high acidity. Liming did not increase the nitrification of

stable manure nitrogen in these soils, but did increase the nitrification of ammonium sulfate and of the nitrogenous compounds contained in the soils. Ammonium sulfate was nitrified more readily in these soils than in acid clay soils. As the nitrification of ammonium sulfate proceeded, the pH value of these soils was lowered from 5.4 to 4 and then remained constant, but notwithstanding the high acidity, nitrification proceeded unhindered.

Pfeiffer (54) found that in one culture of Bacillus denitrificans, admitting pure oxygen or air did not affect denitrification. This was corroborated by Knovalov (42). Pfeiffer (54) also found that when caustic lime and marl were mixed with a small amount of soil and a large amount of fresh horse manure, no denitrification was noted. It was concluded from Pfeiffer's studies that the danger of loss by denitrification is not so great as it was formerly supposed to be.

Arnd (6) found that denitrification reached a maximum in neutralized soil, but excessive liming caused no noteworthy increase in microbial activity.

Fischer (18) found that the addition of citric acid completely prevented denitrification. When, however, the acid was neutralized, denitrification went on normally. These results and others unmentioned seem to point to the fact that both the nitrifying and denitrifying organisms work to somewhat better advantage in soils near the neu-

tral point. Also that when such soils are moderately aerated, the denitrification process does not continue, all of which points to the fact that a moderately aerated neutral soil is a favorable medium for nitrification and less favorable for denitrification.

6. <u>The Effect of Moisture and Temperature or Climate on Nitrification and Denitrification.</u>

Greaves (27) and Waksman (63) reported that Deherain found the optimum moisture content for nitrification to be about 20 - 25 per cent. An insufficient supply of moisture checked both nitrification and nitrogen fixation. Greaves (27) reported that this would vary with the soil. The bacterial activity was less in fine-grained soils than in lighter, coarse-grained soils. In order that nitrification be equally active in both light and heavy soils, a difference in moisture content of a soil of 1 per cent is sufficient to produce a marked change in the oxidation going on in the soil.

Waksman (63) reported that air drying has a favorable effect upon the formation of nitrates in the soil. This may be noticed when the soil is spread out for 24 hours and then remoistened. Freezing also improved the nitrifying power of the soil.

Warrington (65) pointed out that denitrification is not a process of general occurrence in arable soils and that the reduction of nitrates is to be feared only when

the soil has been saturated with water for some time.

Giustiniani (23) compared the action of denitrifying organisms in liquid media with soil. In the former they acted most energetically at a temperature which retards the action of nitrifying organisms. With soils the results were more decided. "Denitrification took place to a marked extent only when the humidity (sic) was less than 6 per cent, an amount insufficient to promote the activity of the nitrifying organisms. The latter became decidedly active when the humidity (sic) rose to 10 per cent. In soils containing a small amount of moisture, denitrification is proportional to the amount of organic matter present." The results thus show that water is an important factor in controlling the action of the oxidizing and reducing organisms in the soil and in transforming and conserving the nitrogen compounds present.

Lemmerman and Wichers (45) found that most nitrates were destroyed at the saturation point of soil. The same held true with tropical soils as reported by Gerretsen (22).

Koch and Pettit (43) informed us that "in liquids and very wet soils from which oxygen is excluded, the bacteria take their oxygen from the nitrates present in the soil and thus liberate nitrogen, but in well aerated soils this does not occur as the bacteria can then use oxygen of the air. These denitrifying bacteria remain practically qui-

escent in soils with a water content below 25 per cent but at 25 to 30 per cent or more they become suddenly active and liberate considerable quantities of nitrogen." Fraaen (59) obtained similar results by finding that nitrogen fixation was most active when the soil contained medium amounts of moisture.

Reports from soil work in Washington (74) showed that moisture held in the surface foot of soil during the warm portion of the year had a favorable effect upon nitrification. This condition was no doubt due to the distribution of bacteria in the soil. Bazarewski (10) pointed out that denitrifying bacteria are in the upper layers of the soil and are irregularly distributed in the deeper layers, but frequently occur abundantly at a depth of one meter. The optimum temperature appears to be nearly the same for denitrifying and nitrifying bacteria in mixed cultures.

Buhlert and Feckendey (13) studied the influence of aeration on the decomposition of peptone. The peptone was shaken with a fixed amount of soil and water. The results showed that aeration reduced the formation of ammonia from peptone, decreased denitrification, and increased nitrification except in the case of humus soil.

Waksman (63) summarized the conditions which tend to promote nitrate formation in the soil as follows: "(a) temperature of 37.5° C., (b) an abundant supply of air (oxygen), (c) proper moisture supply, (d) a favorable

reaction (pH greater than 4.6), (e) presence of carbonates or other buffering agents, and (f) absence of large quantities of soluble organic matter in the soil, and (g) nature of the crop grown."

Anaerobic conditions. A series of experiments were reported by Kuhl (44) which showed (a) that the activity of denitrifying organisms was greatly increased under anaerobic conditions (covering the culture solutions with oil, paraffin, etc.), (b) the denitrifying power of pure cultures was greatly increased by adding mixed cultures, and (c) that sea slime set up rapid denitrification in culture solutions.

It is evident from the foregoing references that water is an important factor in controlling the action of the oxidizing and reducing organisms in the soil and in transforming and conserving the nitrogen compounds present. Medium amounts of water, a warm soil and proper aeration are invaluable aids to nitrification of organic matter in soils.

DISCUSSION OF AND DEDUCTIONS DRAWN FROM THE REVIEW OF LITERATURE

From the literature reviewed we find that many factors enter into and affect the rate and degree of nitrification, denitrification and ammonification of the different materials under consideration. These factors seem to have a more or less similar effect upon all of the different materials whether organic or inorganic. The factors, in a general way, with their reactions may be listed as follows:

1. Lime applied to an acid soil accelerates both the activities of nitrifying and denitrifying organisms and if moderately aerated only the nitrifying organisms function. If either too acid or too alkaline both nitrification and denitrification are hindered or stopped.

2. Nitrate formation is very slight in a soil with a very low moisture content, 5 per cent or below, increases with a 10 per cent, and reaches a maximum with 15 to 20 per cent (dry basis). When near the saturation point denitrification takes place because of the anaerobic condition which favors the action of the denitrifying bacteria.

3. Timothy sod ranks very low as compared with other materials in its ability to nitrify in the soil.

4. Early investigators suggested that nitrification

was solely a chemical process but more recent data show it to be a chemical change brought about by the action of microorganisms.

5. The rate of denitrification is dependent largely upon the amount of starch and similar compounds in the soil as well as a lack of oxygen resulting from the presence of too much water.

6. The nitrogen in manure and other similar organic materials is not as completely utilized as in artificial fertilizers because of the high carbon-nitrogen ratio.

7. Results show that ammonification is caused by fungi rather than bacteria in soils containing acid phosphate and organic nitrogen in the form of dried blood.

8. Ammonium sulfate has a tendency to make a soil acid and does not nitrify as readily in an acid soil as do other fertilizers. When lime is added to such soils, however, ammonium sulfate nitrifies as well as any of the other substances.

9. Danger of loss of nitrogen by denitrification is not so great as it was formerly supposed to be.

This review of literature shows that considerable study has been made of the various factors affecting nitrification and denitrification processes of the soil. Much of the work has been with reference to the natural supply of soil organic matter and soil nitrates. Some of it has involved the use of applied nitrogenous materials,

including green manures, crop residues, and organic and inorganic nitrogen compounds.

It appears that little study has been made of the interrelationship among timothy sod, cottonseed meal and ammonium sulfate on the one hand and temperature and moisture conditions on the other. Moreover, little study of these biological processes has been made at the high level of fertilization used in growing tobacco in the Connecticut Valley. With these ideas in mind the problem of this thesis was formulated. The following pages contain the results and conclusions of the investigations.

ORIGINAL INVESTIGATIONS

PART I

NITRIFICATION AND AMMONIFICATION STUDIES UNDER FIELD CONDITIONS

The purpose of this phase of the work was to study the effect of field conditions upon the nitrification and ammonification of various fertilizers. The very wet season of 1928 and the very dry season of 1929 made it possible to study the effect of extremes in regards to moisture.

DESCRIPTION OF SOILS

Field "B" is located directly north of the lawn between Stockbridge Hall and the Dining Hall.

Plots 23, 24, 25 and 26 (See Fig. I) have been growing tobacco ever since the Spring of 1926. Plots 19, 20, 21 and 22 grew corn in 1926, timothy hay in 1927, and tobacco in 1928 and 1929. Prior to 1926 the field was divided into smaller plots and various sorts of nitrogenous fertilizer experiments conducted.

Plots 15, 16, 17 and 18 grew timothy in 1927 and 1928, and tobacco in 1929. Plots 11, 12, 13 and 14 grew potatoes in 1928 and tobacco in 1929.

A mechanical analysis (See Table I) of the soil

North				
23.5'	Plot 11 1929 - $NaNO_3$	Plot 12 1929 - $(NH_4)_2SO_4$	Plot 13 1929 regular tobacco fertilizer	Plot 14 1929 cottonseed meal
23.5'	Plot 15 1929 - cotton-seed meal	Plot 16 1929 - regular tobacco ferti-lizer	Plot 17 1929 - $(NH_4)_2SO_4$	Plot 18 1929 - $NaNO_3$
23.5'	Plot 19 1928 - $(NH_4)_2SO_4$ 1929 - regular tobacco fertilizer	Plot 20 1928 - $NaNO_3$ 1929 - cottonseed meal	Plot 21 1928 - Cottonseed meal 1929 - $NaNO_3$	Plot 22 1928 - regular tobacco ferti-lizer 1929 - $(NH_4)_2SO_4$
23.5'	Plot 23 1928 - $(NH_4)_2SO_4$ 1929 - $(NH_4)_2SO_4$	Plot 24 1928 - $NaNO_3$ 1929 - $NaNO_3$	Plot 25 1928 - cottonseed meal 1929 - Cottonseed meal	Plot 26 1928 - regular tobacco fertilizer 1929 - regular tobacco fertilizer
	47.5'	47.5'	47.5'	47.5'

Fig. I. Field "B" showing Fertilizer treatments for 1928 and 1929.

showed it to be, according to the classification of the United States Bureau of Soils, a very fine sandy loam. At a depth of three or four feet the soil is gravelly thus permitting a natural, rather excessive drainage so that in extremely dry seasons, such as was experienced during the summer of 1929, the lack of moisture influences normal crop growth very materially.

Determinations made on the organic matter[1] in the soils experimented with showed 5.88 per cent for the old tobacco soil (plots 23, 24, 25 and 26) and 7.28 per cent for the timothy sod.[2]

PREPARATORY TREATMENT AND FERTILIZERS USED

In the fall of 1928 the land which comprises plots 11 to 18 inclusive of field "B" was plowed. This made it possible for the timothy sod to decay, at least partially, before the time for planting the following spring.

On June 26, 1928 plots 19 to 26 inclusive were fertilized at the rate of 3,500 pounds of a 5-4-5 fertilizer per acre and planted to Havana tobacco the same day. In 1929 additional plots were added and were fertilized and

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(1) Organic matter determinations are recorded in appendix.

(2) This sample of timothy sod was obtained in the fall of 1928 from what is now plot 16 (see Fig. I) before the timothy sod was plowed under.

MECHANICAL ANALYSIS OF SOIL FROM FIELD "B"

(RUN IN DUPLICATES)

Table I.

	% Fine Gravel	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Silt	Clay
	(2-1 mm)	(1-0.5 mm)	0.5 (0.05-0.25 mm)	(0.25-0.10)	(0.10-0.05 mm)	(0.05-0.005 mm	(0.005
Average	3.53%	3.29%	3.03%	6.72%	40.67%	30.34%	10.66%

planted to Havana tobacco in the same way on or about June 10. (See Fig. I).

The fertilizer applied to all plots was uniform in respect to all ingredients except the carrier of nitrogen which varied as shown in Fig. I. Mixtures applied were equivalent to 3500 pounds 5% NH_3 - 4% P_2O_5 - 5% K_2O. The basic mixture consisted of sulfate of potash magnesia and sulfate of potash for the potash, and precipitated bone for the phosphoric acid.

WEATHER CONDITIONS

The weather conditions for the years 1928 and 1929 made it possible to study the nitrification of these plots under extreme conditions of moisture, as the growing season of 1928 was exceptionally wet and the growing season of 1929 exceptionally dry. Table II shows the monthly precipitation for the months of June, July and August for the years 1928 and 1929. Daily temperature and precipitation tables are recorded in the appendix. All weather observations were made by Gunness (29).

In Table II it is shown that there was a little more than four times as much rain during the growing season of 1928 than during the growing season of 1929. Soil samples upon which moisture determinations were made varied from 20 to 30 per cent in 1928 and 10 to 20 per cent in 1929 on the dry soil basis.

MONTHLY PRECIPITATION FOR GROWING SEASONS

OF 1928 AND 1929

Table II

Month	Precipitation in inches for 1928	Precipitation in inches for 1929
June	7.97	2.83
July	6.23	0.70
August	7.74	1.54
Totals	21.94	5.07

Plots 14, 18, 22, 25 and 26 which lie on the east side of the field are a little lower and the drainage while good is not as good as the rest of the field. Moisture determinations showed that these plots contained from 1 to 2 per cent more water than the others.

PROCEDURE

During the months of June, July and August of each year, composite soil samples of the upper six to eight inches of surface soil were obtained at weekly intervals from each plot by making about twenty scattered borings with the soil auger. The soil thus obtained was placed in a clean pan, thoroughly mixed, placed in a clean jar, sealed and taken immediately to the laboratory where nitrate, ammoniacal and moisture determinations were made on the same day that samples were taken. The phenol-disulphonic acid method as described in Bureau of Soils, Bulletin 31, was used for the nitrate determinations, and Harper's method (30) slightly modified was used for determining the ammonia in the soil.

The method as carried out is as follows: Fifty grams of moist soil were weighed out and placed in a tall glass bottle to which was added 500 cubic centimeters of a ten per cent solution of potassium chloride. The bottle was then shaken on a mechanical shaker for half an hour. The solution was then filtered and 400 cubic centimeters of the filtrate saved and placed into a distilling flask.

This was distilled over into ten cubic centimeters of 0.02 normal sulfuric acid and by titrating with 0.02 normal sodium hydroxide the actual amount of sulfuric acid neutralized by the ammonia distilled over was determined. MgO was used in distillation of NH_3 and methyl red was used as an indicator.

Ammonia determinations were made during the summer of 1928 but not during the summer of 1929. Nitrate determinations, however, were made during the summer months of both years, the results are plotted on graphs, and the data is recorded in Tables III, IV and V.

Plots 19, 20, 21 and 22 were in timothy in 1927 and tobacco in 1928 and the nitrates are shown as parts per million of nitrogen on Graph I, and the data are in Table III. Plots 23, 24, 25 and 26 were planted to tobacco both in 1927 and 1928, the nitrates, as nitrogen, are shown on Graph II, and the data in Table III.

These same plots in the year 1929 were arranged differently, (see Fig. I). The nitrates, as nitrogen, on plots 19, 20, 21 and 22 are shown in Graph III, and for plots 23, 24, 25 and 26 in Graph IV. The data for both are tabulated in Table IV.

Plots 11 to 18 inclusive were planted to tobacco in 1929. In 1928 plots 15 to 18 grew timothy and plots 11 to 14 grew potatoes. The nitrates, as parts per million of nitrogen, for plots 11, 12, 13 and 14 are shown in

NITRATES ON FIELD "B" AS PARTS PER MILLION

OF NITROGEN FOR 1928

Table III.

Date	Tobacco After Timothy				Continuous Tobacco			
	Plot 19 Ammonium Sulfate	Plot 20: Sodium Nitrate	Plot 21 Cotton-seed meal	Plot 22 Regular Tobacco Ferti-lizer	Plot 23 Ammonium Sulfate	Plot 24: Sodium Nitrate	Plot 25 Cotton-seed Meal	Plot 26 Regular Tobacco Ferti-lizer
6/ 5/28	7.7	9.7	4.7	4.5	1.5	1.7	2.0	2.3
6/20/28	4.1	5.1	1.9	1.2	2.4	3.8	5.0	7.9
Average for samples before ferti-lization	5.9	7.4	3.3	2.8	1.9	2.7	3.5	5.1
6/28/28	5.0	9.1	1.6	2.3	3.8	10.2	4.6	10.3
7/ 5/28	8.6	3.5	none	1.5	2.9	4.4	3.4	6.5
7/11/28	4.1	1.2	3.7	3.2	9.9	9.7	6.3	9.8
7/18/28	33.4	18.0	5.5	7.5	16.2	16.0	14.5	15.8
7/25/28	47.5	39.8	24.0	24.1	48.4	41.3	20.3	31.2
8/ 1/28	34.0	39.9	6.0	15.0	57.0	55.7	17.3	20.9
8/ 8/28	19.2	32.6	5.4	9.8	40.5	29.6	16.3	15.3
8/15/28	41.8	21.5	6.2	4.2	30.3	27.5	11.1	13.6
8/22/28	21.8	17.0	2.2	2.5	34.8	14.7	9.2	12.5
8/29/28	2.1	1.5	none	none	1.2	none	none	3.1
9/ 5/28	0.6	trace	none	none	none	1.8	trace	none
Average for samples after ferti-lization	19.8	16.7	5.0	6.4	22.3	19.2	9.4	12.6

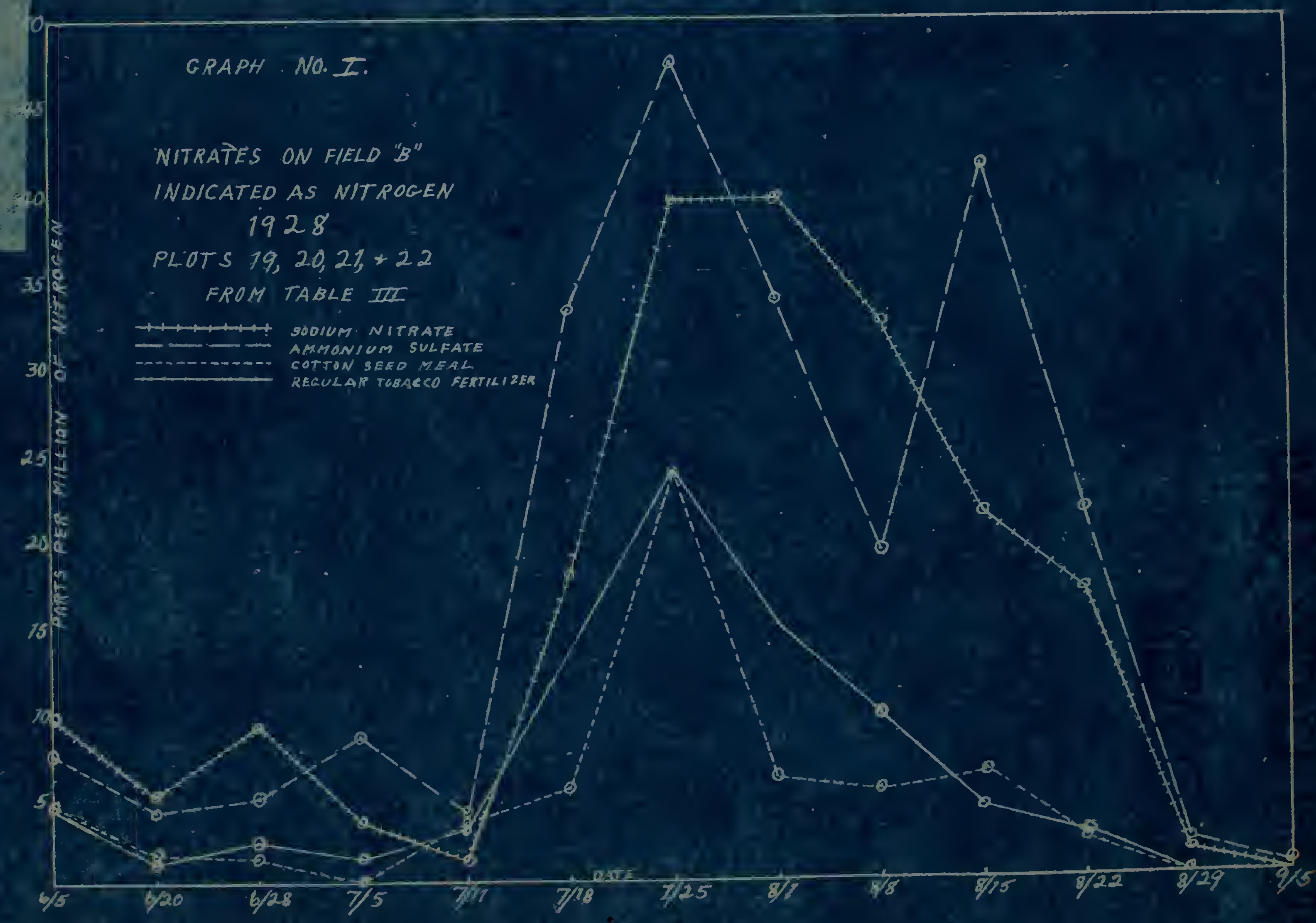
Table IV.

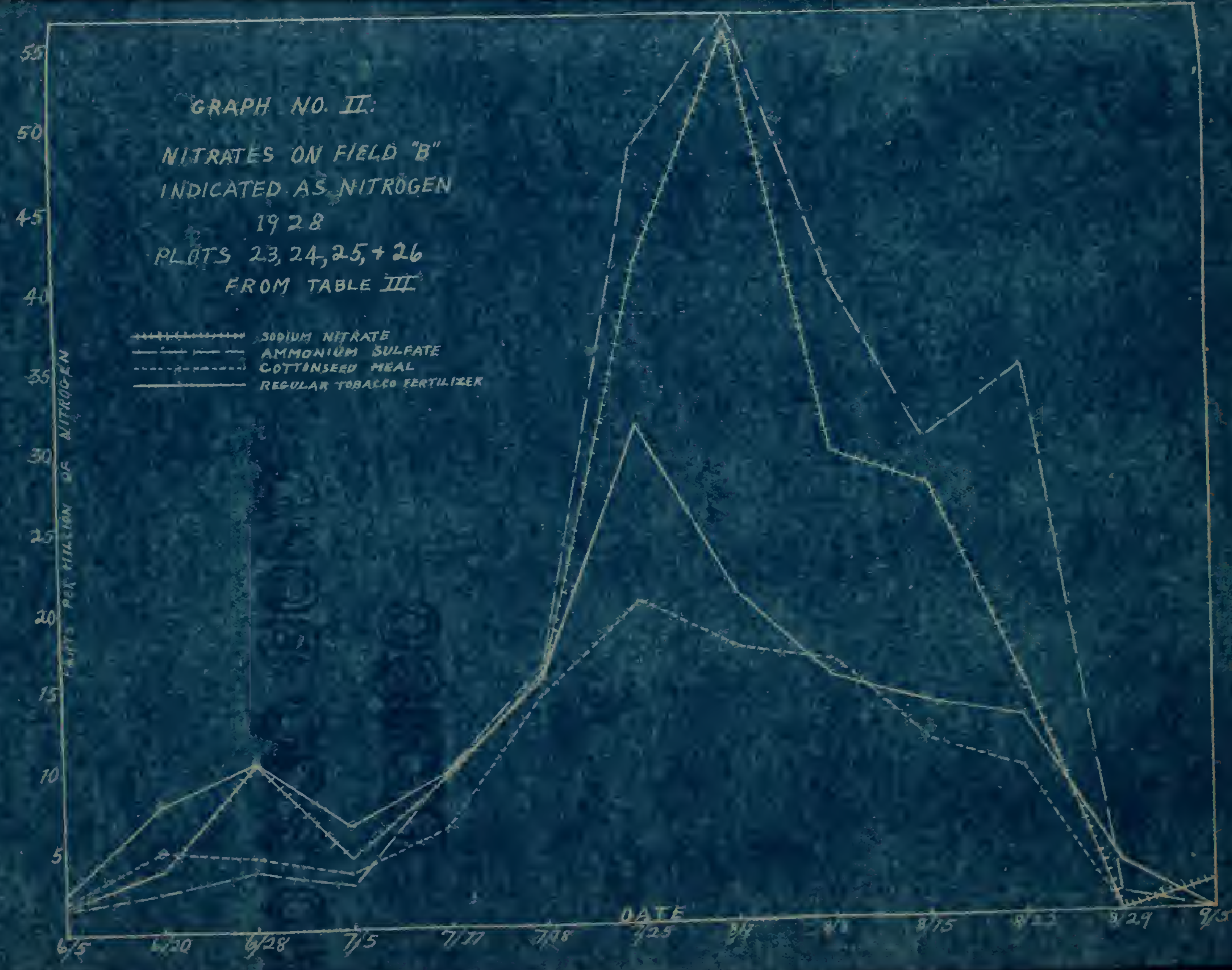
NITRATES ON FIELD "B" AS PARTS PER MILLION

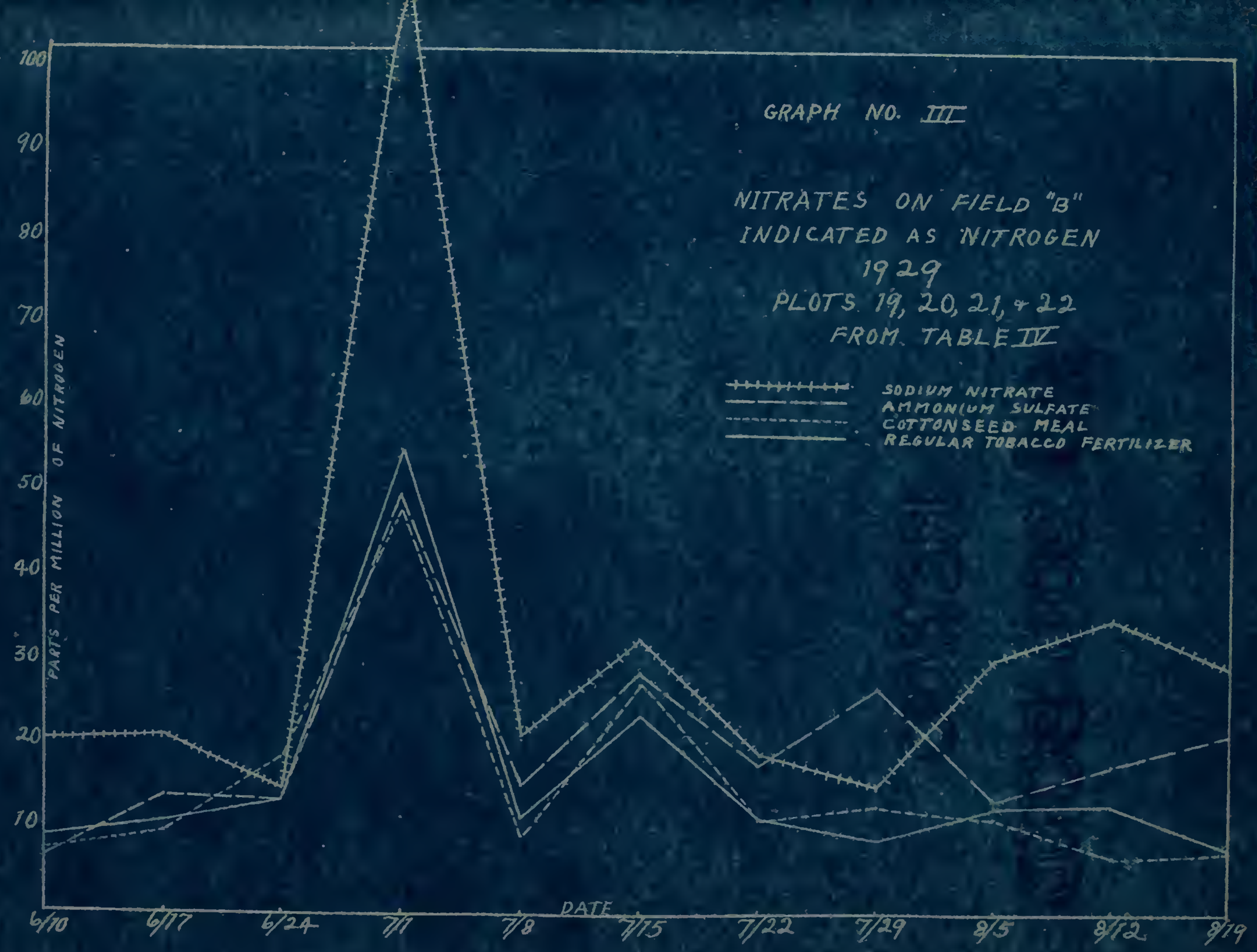
OF NITROGEN FOR 1929*

Date	Plot 19 Regular Tobacco Ferti-lizer	Plot 20 Cotton-seed Meal	Plot 21 Sodium Nitrate	Plot 22 Ammonium Sulfate	Plot 23 Ammonium Sulfate	Plot 24 Sodium Nitrate	Plot 25 Cotton-seed Meal	Plot 26 Regular Tobacco Ferti-lizer
6/10/29	8.8	7.2	20.1	6.3	5.0	19.5	8.8	8.8
6/17/29	10.6	9.5	20.3	13.9	5.1	12.1	10.5	7.3
6/24/29	13.3	18.1	14.2	13.1	12.4	32.2	21.6	11.5
7/ 1/29	55.2	47.8	111.0	49.5	26.2	109.0	63.7	41.8
7/ 8/29	11.3	9.1	21.2	15.0	7.9	14.2	20.6	11.8
7/15/29	23.6	27.4	32.5	28.6	12.8	32.5	21.3	32.8
7/22/29	11.4	11.4	19.0	17.8	3.6	26.2	18.2	29.2
7/29/29	8.7	12.5	15.4	26.9	8.4	8.5	21.0	13.0
8/ 5/29	12.2	11.3	30.3	13.5	11.2	30.9	24.2	21.9
8/12/29	12.7	6.3	35.4	17.8	9.9	25.2	7.3	15.9
8/19/29	7.9	7.5	29.6	21.2	5.0	22.1	5.4	9.5
Average	16.0	15.3	31.7	20.3	9.8	30.2	20.2	18.5

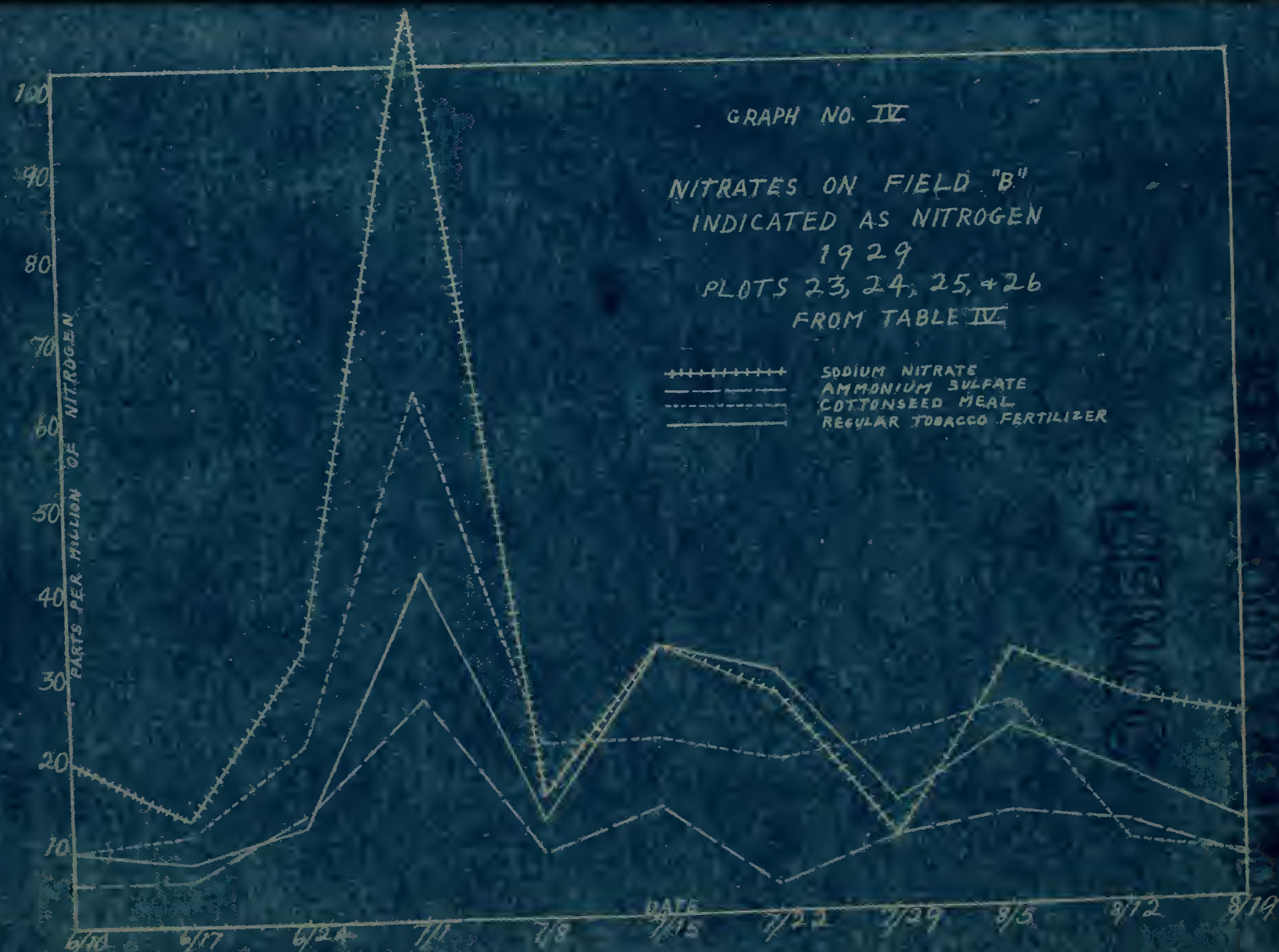
*1929 analytical work by G. J. Larsinos.

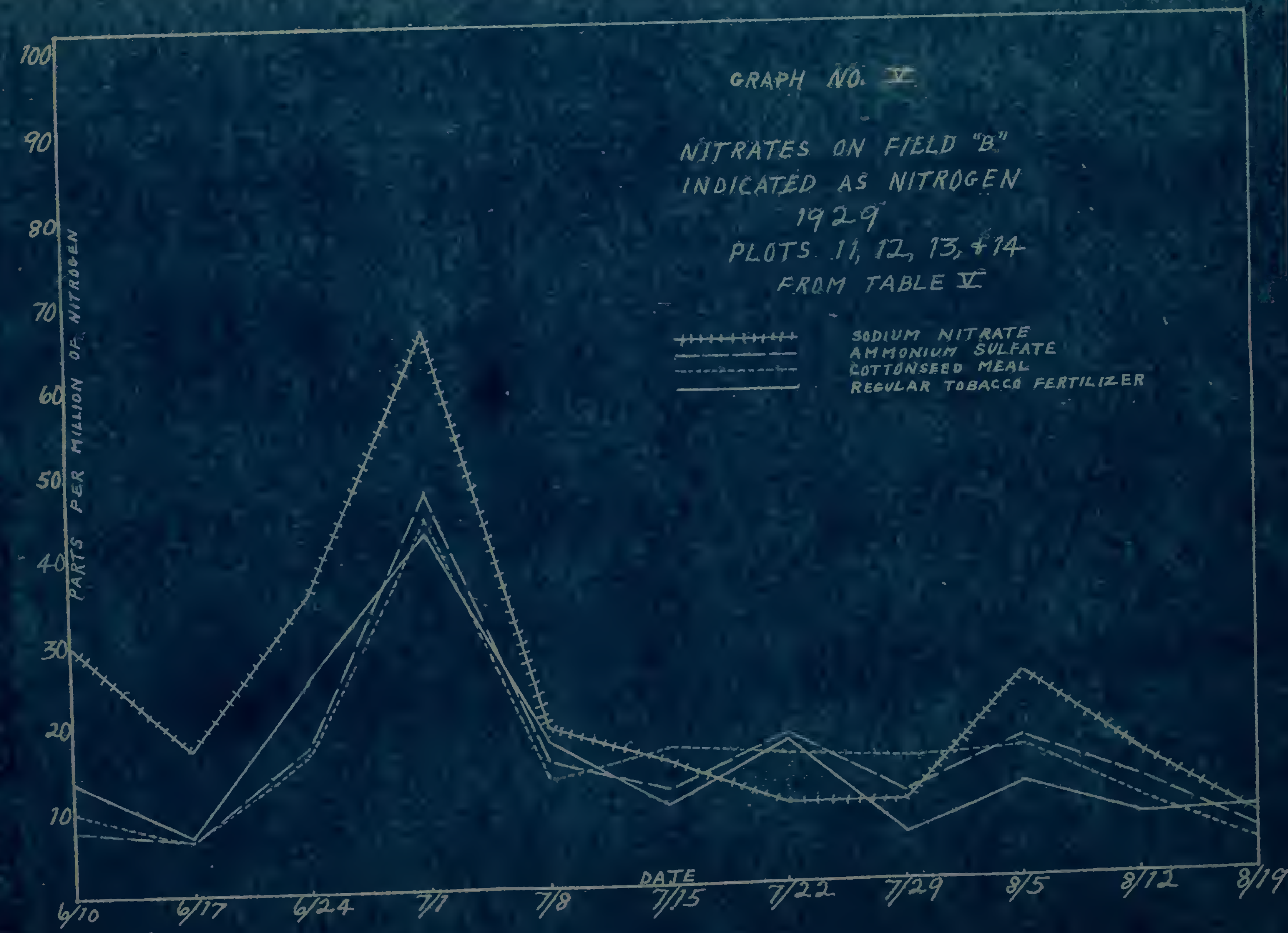

GRAPH NO. I.
NITRATES ON FIELD "B"
INDICATED AS NITROGEN
1928
PLOTS 19, 20, 21, + 22
FROM TABLE III
SODIUM NITRATE
AMMONIUM SULFATE
COTTON SEED MEAL
REGULAR TOBACCO FERTILIZER
PARTS PER MILLION OF NITROGEN
DATE
35
30
25
20
15
10
5
6/5
6/20
6/28
7/5
7/11
7/18
7/25
8/1
8/8
8/15
8/22
8/29
9/5


GRAPH NO. II.
NITRATES ON FIELD "B"
INDICATED AS NITROGEN
1928
PLOTS 23, 24, 25, + 26
FROM TABLE III
SODIUM NITRATE
AMMONIUM SULFATE
COTTONSEED MEAL
REGULAR TOBACCO FERTILIZER
PARTS PER MILLION OF NITROGEN
55
50
45
40
35
30
25
20
15
10
5
DATE
6/5
6/20
6/28
7/5
7/17
7/18
7/25
8/15
8/29
9/5

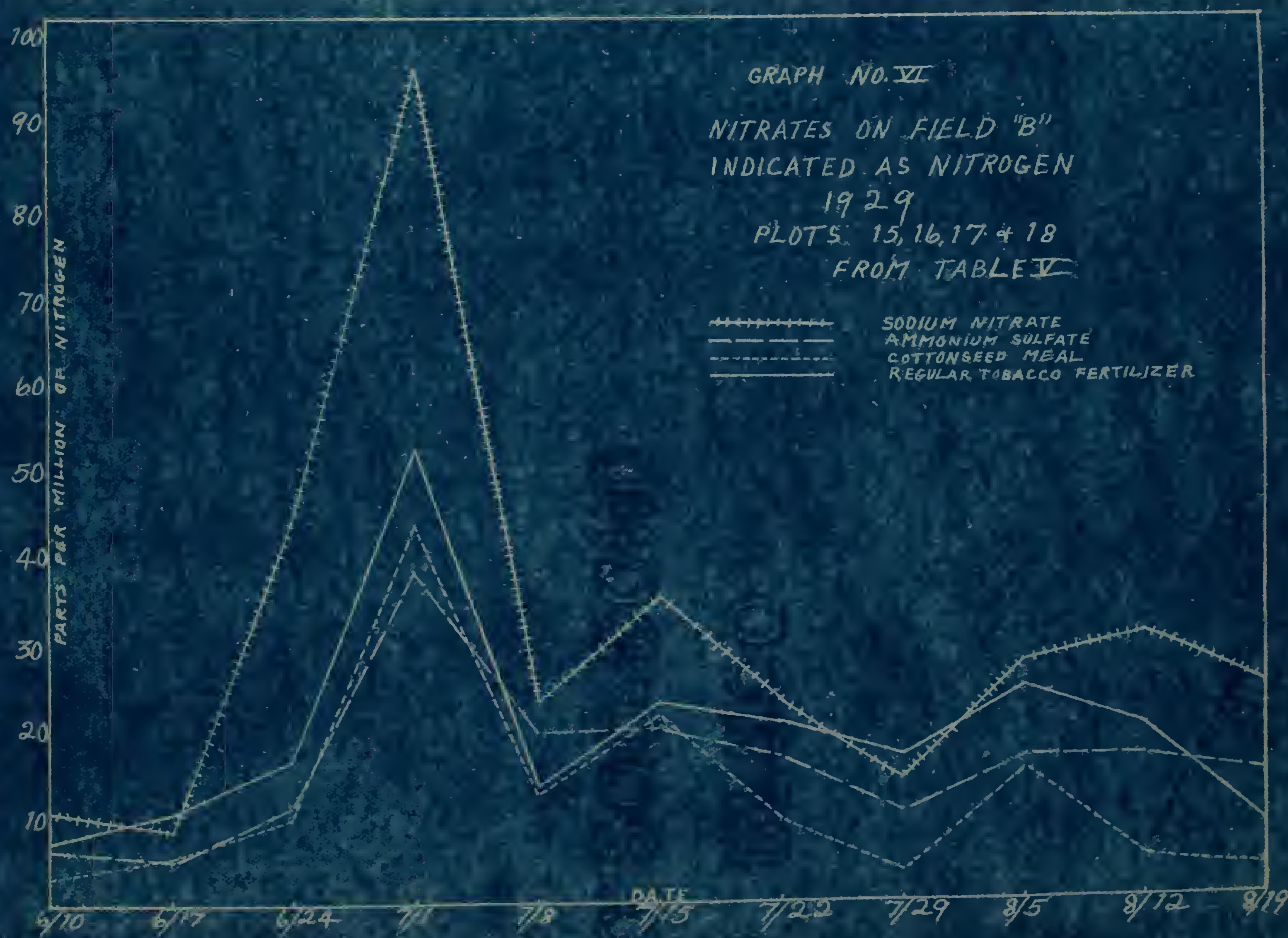


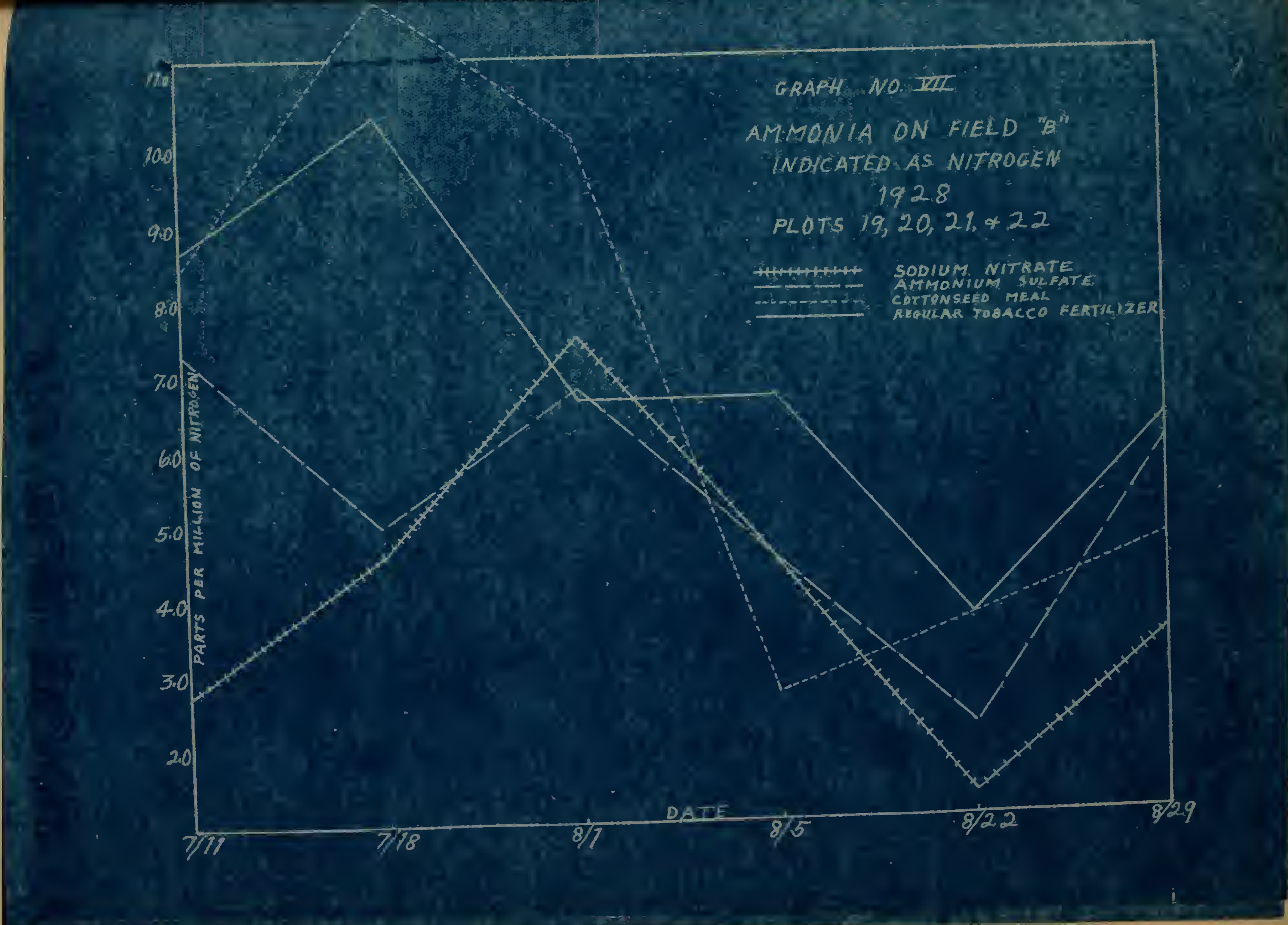
GRAPH NO. III
NITRATES ON FIELD "B"
INDICATED AS NITROGEN
1929
PLOTS 19, 20, 21, + 22
FROM TABLE IV
SODIUM NITRATE
AMMONIUM SULFATE
COTTONSEED MEAL
REGULAR TOBACCO FERTILIZER
PARTS PER MILLION OF NITROGEN
100
90
80
70
60
50
40
30
20
10
DATE
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19

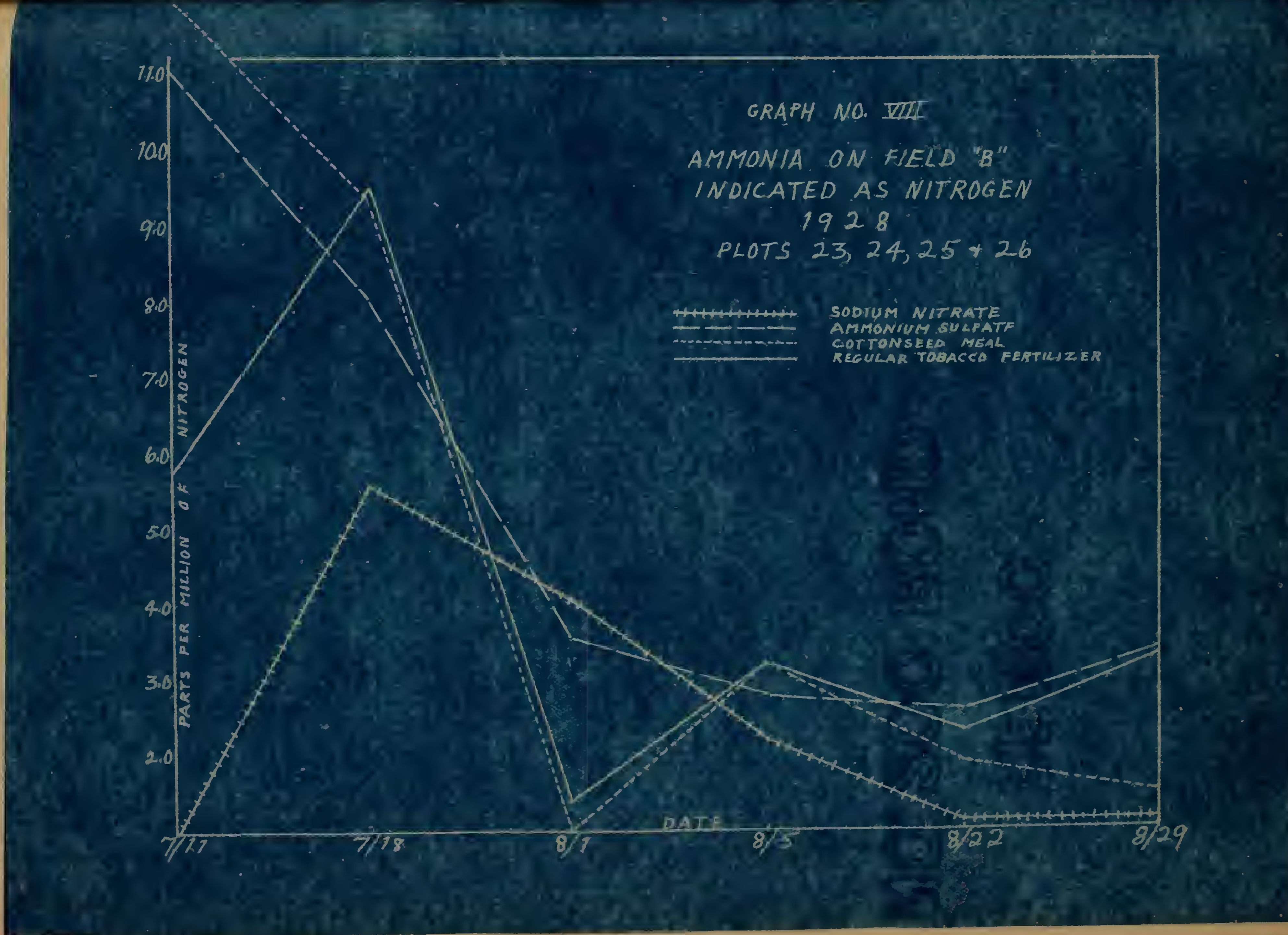

GRAPH NO. IV
NITRATES ON FIELD "B"
INDICATED AS NITROGEN
1929
PLOTS 23, 24, 25, + 26
FROM TABLE IV
SODIUM NITRATE
AMMONIUM SULFATE
COTTONSEED MEAL
REGULAR TOBACCO FERTILIZER
PARTS PER MILLION OF NITROGEN
100
90
80
70
60
50
40
30
20
10
DATE
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19



GRAPH NO. V
NITRATES ON FIELD "B"
INDICATED AS NITROGEN
1929
PLOTS 11, 12, 13, & 14
FROM TABLE V
SODIUM NITRATE
AMMONIUM SULFATE
COTTONSEED MEAL
REGULAR TOBACCO FERTILIZER
PARTS PER MILLION OF NITROGEN
100
90
80
70
60
50
40
30
20
10
DATE
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19


GRAPH NO. VI
NITRATES ON FIELD "B"
INDICATED AS NITROGEN
1929
PLOTS 15, 16, 17 & 18
FROM TABLE V
SODIUM NITRATE
AMMONIUM SULFATE
COTTONSEED MEAL
REGULAR TOBACCO FERTILIZER
PARTS PER MILLION OF NITROGEN
100
90
80
70
60
50
40
30
20
10
DATE
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19


GRAPH NO. VII
AMMONIA ON FIELD "B"
INDICATED AS NITROGEN
1928
PLOTS 19, 20, 21, + 22
SODIUM NITRATE
AMMONIUM SULFATE
COTTONSEED MEAL
REGULAR TOBACCO FERTILIZER
PARTS PER MILLION OF NITROGEN
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
DATE
7/11
7/18
8/1
8/5
8/22
8/29


GRAPH NO. VIII
AMMONIA ON FIELD "B"
INDICATED AS NITROGEN
1928
PLOTS 23, 24, 25 + 26
SODIUM NITRATE
AMMONIUM SULFATE
COTTONSEED MEAL
REGULAR TOBACCO FERTILIZER
PARTS PER MILLION OF NITROGEN
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
DATE
7/11
7/18
8/1
8/5
8/22
8/29

Graph V, and for plots 15, 16, 17 and 18 in Graph VI. The data for both are tabulated in Table V.

During the summer of 1928 ammonia was determined by Harper's method (see page 30). Not nearly as many determinations were made nor as often as with the nitrates. Ammonia was determined every two weeks from July 11 to August 29. It was also determined in the aqueous extract by Nesslerization but the results were unsatisfactory because of the extremely small amounts found. Table VI shows the results obtained by Harper's method for determining ammonia.

DISCUSSION OF RESULTS

In comparing Graphs I and II with Graphs III and IV it can be seen that there were about twice as many nitrates in all of the fertilizer plots in 1929 as compared to 1928 at the time when the peaks were reached, also that the sodium nitrate plots showed the greatest nitrification in 1929 and all of the others showed approximately 50 per cent as much except that ammonium sulfate in 1929 nitrified the least of all on the old tobacco soil. Within the wet season of 1928, however, ammonium sulfate was slightly better than sodium nitrate, which was followed by the regular tobacco fertilizer and cottonseed meal respectfully.

Toward the end of the dry season sodium nitrate was

NITRATES ON THE NEWLY PREPARED TOBACCO PLOTS

OF FIELD "B" FOR 1929 GIVEN AS NITROGEN

Table V.

Date	Plot 11 Sodium Nitrate	Plot 12 Ammonium Sulfate	Plot 13 Regular Tobacco Ferti- lizer	Plot 14 Cotton- seed Meal	Plot 15 Cotton- seed Meal	Plot 16 Regular Tobacco Ferti- lizer	Plot 17 Ammonium Sulfate	Plot 18 Sodium Nitrate
6/10/29	30.0	7.9	13.5	10.0	2.8	7.0	6.0	10.5
6/17/29	17.2	6.3	7.0	6.4	5.5	10.1	5.2	8.1
6/24/29	35.4	17.2	25.0	16.6	9.9	16.3	11.1	44.8
7/ 1/29	66.0	47.4	42.5	44.2	43.9	52.2	38.6	95.8
7/ 8/29	19.1	15.5	17.6	12.9	12.2	13.3	19.9	23.3
7/15/29	14.9	11.6	9.9	16.1	21.9	22.8	20.0	35.7
7/22/29	9.7	17.9	17.1	15.3	9.8	20.4	16.7	23.4
7/29/29	9.5	10.2	5.8	14.3	3.4	16.7	10.2	14.1
8/ 5/29	24.2	16.7	11.2	15.8	15.2	24.6	16.4	27.9
8/12/29	14.5	11.5	7.2	9.2	4.9	20.0	16.3	30.8
8/19/29	6.8	5.2	7.8	3.8	3.7	8.2	14.2	24.6
Average	22.5	15.2	15.0	15.0	12.1	19.2	15.9	30.8

AMMONIA ON FIELD "B" FOR 1928 GIVEN AS PARTS

PER MILLION OF NITROGEN

Table VI.

Date	Plot 19 Ammonium Sulfate	Plot 20: Sodium Nitrate	Plot 21 Cotton-seed Meal	Plot 22 Regular Tobacco Ferti-lizer	Plot 23 Ammonium Sulfate	Plot 24: Sodium Nitrate	Plot 25 Cotton-seed Meal	Plot 26 Regular Tobacco Ferti-lizer
7/11/28	7.3	2.8	8.5	8.7	11.0	1.0	12.0	5.8
7/18/28	5.0	4.6	12.0	10.4	8.1	5.6	9.4	9.5
8/ 1/28	6.8	7.5	10.1	6.7	3.6	4.1	1.0	1.4
8/15/28	4.5	4.5	2.7	6.7	2.8	2.2	3.2	3.2
8/22/28	2.2	1.3	3.7	3.7	2.6	1.1	1.9	2.3
8/29/28	5.9	3.4	4.7	6.3	3.4	1.1	1.5	3.3
Average	5.3	4.0	7.0	7.1	5.3	2.5	4.9	4.3

the highest of them all but toward the end of the wet season the sodium nitrate plot was as low as any of the rest of the plots. Just preceding the last drop sodium nitrate was second to ammonium sulphate. It doesn't seem justifiable to compare the same dates of both seasons because the 1928 season was about ten days to two weeks later than the 1929 season and the general curves of the two years are 3 weeks apart.

Possible explanations of the greater nitrification during the 1929 season as a whole are: (a) the chances of leaching the nitrates in 1929 were not as great as during the 1928 wet season, and (b) there was not as large a crop to draw the nitrates from the soil.

In 1928, before the fertilizer was applied, there was a general decrease in the nitrification of all of the nitrogenous materials on the old tobacco soil but a slight increase in the nitrates on the plot which had had timothy the year before. Field "B" was planted and fertilized, however, on June 26 and the next determination of nitrates showed an increase in both the old tobacco soil and that which had had timothy the year before. From this alone it appears as though the timothy sod which had been plowed under gave a slight advantage in respect to nitrification in the early part of the season. Neither the literature nor the experiments carried out by the writer under controlled conditions bear out this

contention but in all cases timothy sod and organic matter with a high carbon-nitrogen ratio decrease nitrate production. It may, however, be due to the fact that the timothy had decayed sufficiently to reduce the carbon-nitrogen ratio enough for the process of nitrate accumulation to take place.

In the wet season ammonium sulfate surpassed all the others followed fairly close by sodium nitrate, then by the regular tobacco fertilizer and cottonseed meal, the last two being nearly the same.

Within the dry season, on the other hand, sodium nitrate held itself at a higher level generally thruout the season. It stood well above the others near the beginning of the season and also at the end but during the middle of the season some of the other materials seemed to nitrify equally as well.

The curves on Graphs I, II, III, IV, V and VI show that in the middle of the summer a decided peak was reached, after which a decline was noticed and then another slight rise toward the end of the season. The peak for the dry year was reached three weeks earlier in the dry season then in the wet. It is probable that the wet season provided anaerobic conditions at certain intervals which retarded the nitrification process or it may be due to the lateness of the season in general, or to the earlier planting and earlier application of the fertili-

zers in the dry year of 1929. This would suggest that as soon as the fertilizers were added they began to undergo a cycle of change i.e. the organic matter was broken down to ammonia and the ammonia salts as well as other ammoniates were changed to nitrites and finally to nitrates.

This theory is obviously corroborated by Graphs VII and VIII which show a comparatively high ammonia content in the soil just before the abundant and rapid production of nitrates is noted, and a decrease in ammonia when the increase of nitrates is noted.

In a general way the ammonification and nitrification of cottonseed meal and the regular tobacco fertilizer is much less pronounced than with the ammonium sulfate and the sodium nitrate under field conditions.

Graph I shows a gradual decrease at first and Graph II shows fewer nitrates from the sodium nitrate plot than some of the other plots to begin with. This is accounted for by the fact that the field was planted and fertilized June 26, 1928, three weeks after the first nitrate determinations of the season were made.

PART II

NITRIFICATION AND AMMONIFICATION STUDIES UNDER CONTROLLED CONDITIONS

The purpose of this phase of the work was to determine the nitrification and ammonification of the materials in question under conditions somewhat similar to those of the field but under better controlled conditions of temperature and moisture.

PROCEDURE AND METHODS

In September 1928, surface soil from plots 23 and 25 of Field "B" and also of the timothy sod located on what was later divided into plots 15, 16, 17 and 18 was brought to the headhouse and prepared for potting. Earthen jars of one-gallon capacity were used and to each was added 2.3 kilograms of dry soil.

Fertilizers were applied to the pots at the rate of 5,250 pounds per acre as compared with 3,500 pounds for the field. The sources of nitrogen varied as follows:

Pots 1 - 36 ------ ammonium sulfate

Pots 37 - 72 ------ cottonseed meal

Pots 73 - 90 ------ timothy sod

There were thirty treatments each run in triplicate. In order to study the effect of moisture on ammoni-

fication and nitrification, the soil of certain pots was adjusted to moisture contents of 25 per cent, 50 per cent, and 75 per cent respectively of the total water holding capacity which was determined by the Hilgard method and found to be around 60 per cent[3] for both the timothy soil and the old tobacco soil.[4]

The effect of temperature was secured by placing one lot of pots in the warm headhouse and another lot in the cool root storage cellar. The temperature in either case was not constant, fluctuating from 67° to 97° F. in the headhouse and from 47° to 72° F. in the cool root room as shown by data in the appendix; but the temperature of the headhouse averaged 20.9° higher than that of the root cellar. All pots were covered to prevent evaporation.

Determinations were made of nitrates and ammonia in a sample of each soil as taken from the field before adding the fertilizers. The old tobacco soil had 47.3 parts per million of nitrates[5] and the timothy sod had none, calculated on the basis of dry soil.

The pots were weighed occasionally, and, when neces-

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(3) Table in appendix.

(4) Old tobacco soil refers to pots 23, 24, 25 and 26.

(5) 47.3 parts per million of nitrates or 10.7 parts per million of nitrogen.

sary, water was added to bring them up to the proper weight. They were covered, however, and it was therefore unnecessary to add much additional water.

At the end of every three weeks and covering a period of twelve weeks in all, the parts per million of nitrates and ammonia on the dry basis was determined in the soil of each pot.

Table VII gives in a condensed form the parts per million of nitrates obtained from the thirty different treatments. Each figure in the table is an average of the triplicates which were run four different times thruout the twelve weeks period from October 2 until December 22, 1928, or from twelve different determinations. Determinations were made at the end of each of the four three-week periods.

The term warm in Table VII refers to those soils which were kept at headhouse temperatures and the term cold refers to those soils which were kept in the root cellar as described above.

Results show that nitrate accumulation was on the whole somewhat greater under warm and medium moisture conditions. There was only a slight and not consistent excess of nitrates in soils held at 50 per cent of the water holding capacity, but there was a pronounced difference between the accumulation at 50 per cent and 75 per cent. This is true of the soils kept cool as well as

Table VII.

NITRATES IN POTS UNDER CONTROLLED CONDITIONS IN TERMS OF PARTS PER MILLION OF NITROGEN

Temperature	Moisture*	Ammonium Sulfate and Timothy Sod	Ammonium Sulfate and Old Tobacco Soil	Timothy Sod and Cottonseed Meal	Old Tobacco Soil and Cottonseed Meal	Timothy Sod
Warm	25%	107.3	118.0	37.6	46.0	24.9
Warm	50%	106.1	139.0	53.5	63.8	25.6
Warm	75%	23.3	64.0	4.3	12.5	1.8
Cold	25%	80.0	110.5	21.9	30.8	7.3
Cold	50%	83.0	118.0	13.3	38.0	2.3
Cold	75%	51.2	89.5	2.0	4.0	0.2

*Moisture is on the basis of the total water holding capacity of the soil.

those kept warm. This bears out the work of Lemmerman and Wichers (45) who found that the most nitrates were destroyed when the water content approached the total water holding capacity of the soil. This condition is brought about no doubt, by the anaerobic conditions which are caused by the presence of much water. Kuhl (44) has shown definitely that the activity of denitrifying organisms was greatly increased under anaerobic conditions, which was accomplished by covering the culture solutions with oil, paraffin, etc.

A decrease in temperature is apparently associated with a reduction in the production of nitrates. This is due to the fact that the soil microorganisms are more active at the "warm" temperatures of this experiment. This fact is fully corroborated by Giustiniani (23) and also by Bazarewski (10).

Table VII also shows that all of the fertilizers nitrify more on the old tobacco soil than on timothy sod. This is in general agreement with results reported concerning the effect of incorporated organic matter on soil nitrates. This is, without doubt, a probable explanation as to why the timothy sod has a tendency to reduce nitrates. One other fact which materially substantiates this viewpoint is that nitrate determinations on the old tobacco soil before being prepared for the pot tests showed 47.3 parts per million whereas there was none for

AMMONIA AS PARTS PER MILLION OF NITROGEN IN POTS

UNDER CONTROLLED CONDITIONS

Table VIII.

Temperature	Moisture Based on Total Holding Capacity of the Soil	Ammonium Sulfate and Timothy Sod	Ammonium Sulfate and Old Tobacco Soil	Cottonseed Meal and Timothy Sod	Old Tobacco Soil and Cottonseed Meal	Timothy Sod
Warm	25%	8.4	8.4	5.6	5.8	2.6
Warm	50%	8.0	7.2	5.5	4.1	4.0
Warm	75%	11.5	10.8	8.7	7.1	5.1
Cold	25%	9.5	17.3	7.2	4.8	2.6
Cold	50%	8.2	8.2	7.7	4.0	1.6
Cold	75%	20.4	7.4	8.6	4.7	5.1

the timothy sod.

Ammonium sulfate, under the most favorable conditions of the experiment, showed about the same amount of nitrification as did the cottonseed meal under the most favorable conditions of the experiment. The timothy sod alone ranked far below the other materials under the same conditions.

Table VIII gives the parts per million of ammonia determined at the same time and from the same pots as for the nitrates already described.

Results recorded in Tables VII and VIII show that where there is an abundance of moisture either under warm or cold temperatures, ammonification is more pronounced than when drier. The soils which contained 75 per cent of their total water holding capacity were very wet and contained some free water which made the conditions anaerobic rather than aerobic. The denitrification which goes on results in an increased amount of ammonia.

There was more ammonia found in the pots containing ammonium sulfate than in the pots containing timothy sod and cottonseed meal under the same conditions of temperature and moisture. It is also of interest to note that cottonseed meal ammonifies more in timothy sod than it does in the old tobacco soil, exactly opposite to that of nitrification. (Compare Tables VII and VIII). With ammonium sulfate, however, this condition does not prevail

except with the cold wet and medium warm conditions.

Timothy sod, when in the soil by itself, ammonifies but very little except when subjected to very moist conditions.

SUMMARY

1. This thesis gives the results of the ammonification and nitrification of organic and inorganic fertilizer materials (a) under moist and dry field conditions and (b) under controlled conditions of temperature and moisture.

2. The sodium nitrate plots showed a larger quantity of nitrates in the early and latter parts of the dry season than did ammonium sulfate, but within the wet season ammonium sulfate was generally higher; cottonseed meal was generally low.

3. During the middle part of the dry growing season there were no outstanding differences in the amount of nitrates found in the different plots.

4. On plots growing tobacco where timothy sod had been plowed under the fall before there was less accoumulation of nitrates than on the older cultivated soils. The timothy sod which had not been plowed showed no nitrates at all. This is due to the wide carbon-nitrogen ratio in timothy sod.

5. Soils fertilized with ammonium sulfate and sodium nitrate both under field and controlled conditions showed more nitrates than the plots receiving the other fertilizers.

6. The results of the pot work showed that nitrate

accumulation is more pronounced under warm and medium moisture conditions with all of the nitrogenous fertilizer materials used in the experiment.

7. The soils of pots low in moisture showed a slight decrease in nitrates under both warm and cold conditions as compared to the soils in pots containing a medium amount of moisture.

8. The soils in pots having a high moisture content showed a very marked decrease in the nitrate content accompanied by an increase in the amount of ammonia present. This was true in practically all cases.

9. In general, nitrification was more rapid under the warm conditions of the experiment than under the colder temperatures.

10. Ammonification apparently took place after the fertilizer was added to the soil and the amount of ammonia decreased in all of the plots after the first week, and the nitrates showed a corresponding increase thus showing that ammonia was probably being changed to nitrates.

11. At the beginning of the season ammonification was greatest in plots which had been fertilized with cottonseed meal, while ammonium sulfate and the regular tobacco fertilizer plots showed about the same amount of nitrates once they got started.

12. For the season as a whole the sodium nitrate plots showed less ammonia than any of the others, es-

pecially at the beginning.

13. The ammonium sulfate pots contained more ammonia than either cottonseed meal or timothy sod.

14. In the pot experiments the cottonseed meal ammonified more in timothy sod than in the old tobacco soil, while with ammonium sulfate it was just the reverse.

15. Timothy sod, when in the soil by itself, ammonified but very little except when subjected to very moist conditions.

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APPENDIX

Daily Temperature of Pots

Date		25 per cent of the maximum capacity of water		50 per cent of the maximum capacity of water		75 per cent of the maximum capacity of water	
		Cold	Warm	Cold	Warm	Cold	Warm
10/ 2/28	Tues.	57° F.	74° F.	57° F.	74° F.	57° F.	74° F.
10/ 3/28	Wed.	65	84	65	84	65	84
10/ 4/28	Thurs.	65	80	65	80	65	80
10/ 5/28	Fri.	65	70	65	70	65	70
10/ 6/28	Sat.	65	72	65	72	65	72
10/ 7/28	Sun.	62	70	62	70	62	70
10/ 8/28	Mon.	58	67	58	67	58	67
10/ 9/28	Tues.	61	68	61	68	61	68
10/10/28	Wed.	62	68	62	68	62	68
10/11/28	Thurs.	64	84	64	84	64	84
10/12/28	Fri.	65	80	65	80	65	80
10/13/28	Sat.	65	74	65	74	65	74
10/14/28	Sun.	58	75	58	75	58	75
10/15/28	Mon.	56	76	56	76	56	76
10/16/28	Tues.	63	79	63	79	63	79
10/17/28	Wed.	68	87	68	87	68	87
10/18/28	Thurs.	72	87	72	87	72	87
10/19/28	Fri.	71	97	71	97	71	97
10/20/28	Sat.	68	90	68	90	68	90
10/21/28	Sun.	65	88	65	88	65	88
10/22/28	Mon.	64	86	64	86	64	86
10/23/28	Tues.	65	87	65	87	65	87
10/24/28	Wed.	65	87	65	87	65	87
10/25/28	Thurs.	64	87	64	87	64	87

Daily Temperature of Pots

Date		25 per cent of the maximum capacity of water		50 per cent of the maximum capacity of water		75 per cent of the maximum capacity of water	
		Cold	Warm	Cold	Warm	Cold	Warm
10/26/28	Fri.	58° F.	80° F.	58° F.	80° F.	58° F.	80° F.
10/27/28	Sat.	56	85	56	85	56	85
10/28/28	Sun.	55	76	55	76	55	76
10/29/28	Mon.	54	71	54	71	54	71
10/30/28	Tues.	54	82	54	82	54	82
10/31/28	Wed.	54	79	54	79	54	79
11/ 1/28	Thurs.	54	80	54	80	54	80
11/ 2/28	Fri.	56	78	56	78	56	78
11/ 3/28	Sat.	57	75	57	75	57	75
11/ 4/28	Sun.	60	88	60	88	60	88
11/ 5/28	Mon.	56	86	56	86	56	86
11/ 6/28	Tues.	60	77	60	77	60	77
11/ 7/28	Wed.	60	80	60	80	60	80
11/ 8/28	Thurs.	58	75	58	75	58	75
11/ 9/28	Fri.	55	78	55	78	55	78
11/10/28	Sat.	54	80	54	80	54	80
11/11/28	Sun.	53	78	53	78	53	78
11/12/28	Mon.	51	79	51	79	51	79
11/13/28	Tues.	53	76	53	76	53	76
11/14/28	Wed.	51	77	51	77	51	77
11/15/28	Thurs.	51	70	51	70	51	70
11/16/28	Fri.	62	76	62	76	62	76
11/17/28	Sat.	63	77	63	77	63	77
11/18/28	Sun.	63	77	63	77	63	77
11/19/28	Mon.	61	75	61	75	61	75
11/20/28	Tues.	60	75	60	75	60	75
11/21/28	Wed.	52	76	52	76	52	76

Daily Temperature of Pots

Date		25 per cent of the maximum capacity of water		50 per cent of the maximum capacity of water		75 per cent of the maximum capacity of water	
		Cold	Warm	Cold	Warm	Cold	Warm
11/22/28	Thurs.	49° F.	77° F.	49° F.	77° F.	49° F.	77° F.
11/23/28	Fri.	48	78	48	78	48	78
11/24/28	Sat.	53	77	53	77	53	77
11/25/28	Sun.	54	78	54	78	54	78
11/26/28	Mon.	50	77	50	77	50	77
11/27/28	Tues.	51	71	51	71	51	71
11/28/28	Wed.	49	70	49	70	49	70
11/29/28	Thurs.	54	74	54	74	54	74
11/30/28	Fri.	57	76	57	76	57	76
12/ 1/28	Sat.	55	80	55	80	55	80
12/ 2/28	Sun.	51	85	51	85	51	85
12/ 3/28	Mon.	54	82	54	82	54	82
12/ 4/28	Tues.	56	80	56	80	56	80
12/ 5/28	Wed.	54	77	54	77	54	77
12/ 6/28	Thurs.	53	78	53	78	53	78
12/ 7/28	Fri.	48	76	48	76	48	76
12/ 8/28	Sat.	50	75	50	75	50	75
12/ 9/28	Sun.	47	73	47	73	47	73
12/10/28	Mon.	48	75	48	75	48	75
12/11/28	Tues.	48	77	48	77	48	77
12/12/28	Wed.	48	75	48	75	48	75
12/13/28	Thurs.	48	74	48	74	48	74
12/14/28	Fri.	50	75	50	75	50	75
12/15/28	Sat.	49	75	49	75	49	75
12/16/28	Sun.	54	80	54	80	54	80
12/17/28	Mon.	54	75	54	75	54	75
12/18/28	Tues.	60	74	60	74	60	74
12/19/28	Wed.	53	72	53	72	53	72

Daily Temperature of Pots

Date		25 per cent of the maximum capacity of water		50 per cent of the maximum capacity of water		75 per cent of the maximum capacity of water	
		Cold	Warm	Cold	Warm	Cold	Warm
12/20/28	Thurs.	53° F.	78° F.	53° F.	78° F.	53° F.	78° F.
12/21/28	Fri.	55	72	55	72	55	72
12/22/28	Sat.	48	70	48	70	48	70

ORGANIC MATTER OF SOILS

Soil	Percent Organic Matter Sample No. 1	Sample No. 2
Old Tobacco Soil	5.80%	5.90%
" " "	5.88%	5.96%
Timothy Sod	7.36%	7.33%
" "	7.32%	7.13%

FERTILIZER MATERIALS ADDED TO FIELD "B" JUNE 26, 1928

Plots 19, 23

Ammonium Sulfate	700	pounds per acre
Sulfate of Potash magnesia	282	" " "
Sulfate of Potash	160	" " "
Precipitated Bone	368	" " "

Plots 20, 24

Sodium Nitrate	972	" " "
The P_2O_5 and K_2O same as above		

Plots 21, 25

Cottonseed meal	2050	" " "
The P_2O_5 and K_2O same as above		

Plots 22, 26

Urea	94	" " "
Cottonseed meal	1108	" " "
Calcium Nitrate	200	" " "
P_2O_5 and K_2O same as above		

Each treatment is equivalent to 3,500 pounds of a 5-4-5.

PARTS PER MILLION OF AMMONIA FROM POTS IN GREENHOUSE

Temperature	% Moisture on basis of total water holding capacity	Date	$(NH_4)_2SO_4$ and Timothy sod	$(NH_4)_2SO_4$ and old Tobacco soil	Timothy sod and cottonseed meal	Cottonseed meal and old tobacco soil	Timothy sod
Warm	25%	10/20/28	20.0	23.0	9.7	12.7	4.7
Warm	50%	"	15.3	8.0	12.6	13.3	8.8
Warm	75%	"	19.2	8.7	17.9	14.6	7.4
Cold	25%	"	113.0	61.8	15.7	14.7	5.0
Cold	50%	"	18.7	12.5	16.0	10.7	4.6
Cold	75%	"	73.3	8.7	14.0	6.3	9.6
Warm	25%	11/10/28	16.0	14.0	10.0	9.7	4.3
Warm	50%	"	16.4	14.4	7.3	3.4	2.7
Warm	75%	"	23.4	25.5	12.1	5.8	5.0
Cold	25%	"	21.3	16.0	9.7	5.3	2.7
Cold	50%	"	9.1	11.7	11.4	6.1	0.76
Cold	75%	"	9.6	10.8	15.8	6.7	6.7
Warm	25%	12/ 1/28	2.7	0.33	0.33	0.7	0
Warm	50%	"	1.12	1.9	1.12	0.4	4.5
Warm	75%	"	3.8	6.7	1.7	5.8	7.5
Cold	25%	"	5.3	2.0	2.3	1.3	1.7
Cold	50%	"	2.24	5.7	2.2	0.76	0.38
Cold	75%	"	7.7	6.3	2.9	6.9	2.5
Warm	25%	12/22/28	8.3	4.0	7.0	5.0	3.7
Warm	50%	"	6.0	10.7	5.7	3.0	3.0
Warm	75%	"	9.2	11.3	10.8	8.3	5.0
Cold	25%	"	8.0	4.7	7.0	2.0	3.3
Cold	50%	"	8.2	10.3	7.6	2.3	1.9
Cold	75%	"	9.2	10.0	9.2	2.91	5.8

PARTS PER MILLION OF NITRATES FROM POTS IN GREENHOUSE

Temperature	% Moisture on basis of total water holding capacity	Date	$(NH_4)_2SO_4$ and Timothy sod	$(NH_4)_2SO_4$ and old Tobacco soil	Timothy sod and cottonseed meal	Cottonseed meal and old tobacco soil	Timothy sod
Warm	25%	10/20/28	407	433	139	163	59
Warm	50%	"	464	578	98	196	31.0
Warm	75%	"	226	387	26	118	trace
Cold	25%	"	88	307	163	100	33
Cold	50%	"	211	453	15	110	trace
Cold	75%	"	281	503	trace	67	none
Warm	25%	11/10/28	527	473	128	227	76
Warm	50%	"	444	637	179	288	109
Warm	75%	"	70	329	25	39	15
Cold	25%	"	407	540	55	148	20
Cold	50%	"	487	546	41	156	7
Cold	75%	"	251	374	13	21	trace
Warm	25%	12/ 1/28	428	549	175	230	179.4
Warm	50%	"	438	606	259	300	150
Warm	75%	"	83	248	8.8	50.5	11.4
Cold	25%	"	502	564	82.3	148	38.7
Cold	50%	"	456	502	80.8	198	7.6
Cold	75%	"	184	329	10.2	4.1	2.8
Warm	25%	12/22/28	539	640	225	208	125
Warm	50%	"	536	641	409	344	164
Warm	75%	"	31.7	169	17.3	15	3.2
Cold	25%	"	416	544	88	147	37.8
Cold	50%	"	316	587	100	191	29.1
Cold	75%	"	125.8	378	11.6	6.6	trace

MECHANICAL ANALYSIS OF SOIL FROM FIELD "B". TAKEN FROM THE SURFACE SEVEN INCHES.

	Sample No. 1	Sample No. 2
Fine gravel	3.24%	3.82%
Coarse sand	2.58%	4.00%
Medium sand	2.50%	3.56%
Fine sand	6.16%	7.28%
Very fine sand	41.66%	39.68%
Total of sand separates	56.14%	58.34%
Loss thru sieve	1.68%	1.84%
Total sand	57.82%	60.18%
Silt	30.00%	30.68%
Clay	12.18%	9.14%
	100.00%	100.00%