The Nitrogen Fertilization of *Connecticut Tobacco*

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THE NITROGEN FERTILIZATION OF CONNECTICUT TOBACCO

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In cigar leaf production, nitrogen exerts more influence on yield and quality than any other plant nutrient used. This is reflected in the qualities of the leaf which determine its commercial value. Nitrogen is also the most expensive of all fertilizers, either on a fertilizer unit or a fertilizer material basis.

Since nitrogen exerts such a pronounced effect on the growth, development and ultimate performance of the tobacco plant, an almost unending search for the most suitable nitrogen-carrying materials has been conducted, particularly during the last hundred years. In the preceding two centuries of Connecticut tobacco culture, nitrogen (as well as other nutrients) was supplied by various manures. Tobacco was grown in small units, seldom exceeding five acres, and most of the crop was sold in Connecticut. Before the first warehouse was established in 1825 at Warehouse Point, very little was marketed outside of New England.

When cigar smoking first became popular, Broadleaf was the principal wrapper used. It won favor because of its pleasant taste and aroma. With the introduction of the shade wrapper some 50 years ago, cigar consumption increased. The new wrapper, lighter in color and smoother, had an "eye-appeal." The preference of smokers for cigars with light colored wrappers prevails today. With few exceptions, lighter shades of colors are also desired in Broadleaf and Havana Seed tobaccos, now used mainly for binders.

The ultimate color and shading of the cured and fermented leaf are related to nitrogen nutrition, and growers find it of utmost importance to select and use those nitrogenous materials which by experience and experimentation have been found to give satisfactory performance.

In the following pages a resumé is given of results of nitrogen experiments conducted at the Tobacco Laboratory of The Connecticut Agricultural Experiment Station in Windsor during the last 25 years, together with some recent data on newer types of cottonseed meal and a new material, ureaform. Also included is a discussion of the soil-nitrogen relationship, together with references to research work done elsewhere which has a bearing on nitrogen nutrition.

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SOIL-NITROGEN RELATIONSHIP

Although it was probably a combination of climate and soil which made the Connecticut Valley a permanent tobacco area, land suitable for growing the crop must be carefully selected. Experience has shown that medium to light sandy loam (41) is most suitable; that is, a warm, well drained and well aerated soil. Such soils favor the quick conversion of organic nitrogen into the mineral forms, ammonia and nitrates.

The Plant's Nutrient Uptake

With the exception of carbon dioxide gathered from the air, the tobacco plant, like other green plants, derives its nutrients from the soil. The roots, besides functioning as firm anchors, collect water and nutrients dissolved in the soil solution.

Nitrates are most efficiently absorbed by plants in soils having an acid reaction (20), which fits in perfectly with tobacco culture. Under tobacco fertilization, as practiced in the Valley, nitrates are the most abundant anions in the soil solution, and together with bases (e.g. potassium, calcium and magnesium), supply readily available nutrients. In addition, nitrates furnish oxygen (21), which is a substantial contribution to the abundance of organic acids (47) so essential to taste and aroma of cigar tobacco.

Ammonium (ion) feeding of the tobacco plant should be discouraged (47), although it cannot be avoided in the early stages of growth. These ions, having a lower mobility (18) than nitrates, slow down the nitrogen assimilation within the plant (19), and retard the uptake of the equal-sized potassium ion (24). Nitrogen, absorbed as ammonium ion (NH_4^+), "definitely increases the relative nicotine content of tobacco" according to Dawson (12), who also found (13) that nicotine is manufactured in roots and from there distributed to various parts of the plant.

It was found in 1938 that a part of the nitrates is utilized in the roots of tobacco (11). Presumably, this is involved in the nicotine synthesis in the roots as Dawson reported in 1946 (13). Therefore, a healthy root system is paramount in tobacco production.

In this connection it should be mentioned that in plant beds surplus ammonia is injurious to roots of young tobacco seedlings. Calcium chloride is a remedy (40, p. 42) for this condition. Ammonia can be readily utilized by tobacco and related crops (27) but, as mentioned earlier, ammonia is not desirable because of adverse effect on quality of leaf. In the early stages of growth, however, this is immaterial.

Ammonia and Nitrate Production

Various oil meals and, to some extent, wastes from fisheries, are the main sources of nitrogen in tobacco fertilizers. Most of the nitrogen in these materials is in a protein form which must be broken down into simpler components before tobacco roots can take up the nitrogen. Although the initial decaying process may be caused by a number of fungi, bacteria and protozoa, the ammonia produced by these organisms is mainly attacked by a specialized organism, the bacterium *Nitrosomonas* (49). This bacterium partly oxidizes the ammonia to nitrites. Another specialized bacterium, *Nitrobacter,* utilizes the nitrites, adds oxygen from the soil air, and converts the nitrites into nitrates. This process proceeds most advantageously in light, well drained soils which experience has shown to be suitable for good tobacco production. These two bacteria are able to tolerate a wide range in soil reaction, from pH 4.0 to pH 8.0 (49).

When ammonia is being formed from organic fertilizers like cottonseed and fish meals (34), pH values rise initially from 1 to 1.5 units. This rise, however, is of short duration. The bulk of ammonia produced reaches a maximum within two weeks. Under favorable conditions, equivalent nitrogen added as urea is all transformed into ammonia in about five days.

Nitrification is so rapid that the major part of the ammonia is converted to nitrates in four to five weeks.[1] If the soil is deficient in bases, particularly lime, pH values will decrease, sometimes more than a unit (31). When fertilizers are balanced with sufficient lime to offset the acidity produced, soil reaction does not fluctuate appreciably (29). The acid-base balance of fertilizer is discussed elsewhere (40).

Soil Reaction

Although nitrogen-liberating bacteria tolerate a wide range in soil reaction (pH 4.0-pH 8.0), their optimum activity occurs at pH 6.5 (49). For most crops, growers should keep the soil reaction at about this pH value. For tobacco, however, the most favorable reaction falls at least one pH unit lower. Tobacco does not behave physiologically differently from other crops, but (a) with increasing alkalinity, there is the danger of black rootrot (*Thielaviopsis basicola*) infection and (b) with an increasing lime (calcium) content of the soil, potash absorption by the tobacco plant is retarded [cation antagonism (33)].

The function of potash in the proper burning of tobacco is too well known to discuss it further here. Excessive potash consumption is not beneficial. Therefore, as high a calcium content of the soil should be maintained as conditions will permit in order to promote maximum nitrification. Thus, sufficient liming materials should be added to the land to keep the reaction close to the upper limit of pH 5.5-5.6 for at least two reasons: (a) to effect proper nitrification and (b) to allow ample absorption of calcium by the tobacco plant (35). Newer strains of shade tobacco and Havana Seed are fairly resistant to black rootrot and they do well at a reaction approaching pH 6.0. Proper liming of tobacco soils has been discussed previously (40).

The Nitrogen Economy of the Soil

It is generally agreed that nitrate nitrogen is the most suitable form for tobacco. If there were practical methods of adding nitrate salts to the soil at the proper time and as needed by the plants, much work might be saved in handling bulky fertilizer materials and in carefully selecting soils suitable for tobacco growing. However, nitrates in the form of nitrate of soda or in combination with other bases have a limited use in tobacco fer-

[1] It should be pointed out that, although the nitrification studies were made on Merrimac sandy loam, typical of a great part of the tobacco growing area in Connecticut, the results reported here may not apply throughout the Tobacco Valley.

tilization. They are very soluble and leach readily from the sandy soils used for tobacco. Another limitation is the accompanying base; for instance, an accumulation of sodium from sodium nitrate would be harmful because excess sodium has a deleterious effect on crops. Organic fertilizer materials are an almost ideal source of nitrogen and, with few exceptions, are preferred for fertilization of Connecticut tobacco. Organic fertilizers break down slowly in the soil and furnish nitrates as plant growth progresses.

Leaching of nitrogen and other fertilizer constituents was studied for a period of years at the Tobacco Laboratory in Windsor (24). Much data from the lysimeter experiments have been published, but here reference is made only to a comparison between leaching in a wet year and in a year with "normal" rainfall.

The 1938 growing season was the wettest in the last 25 years. The total rainfall from May through August amounted to 21.9 inches, or about 6 inches above normal. Soil treated with 200 pounds per acre of nitrogen in the form of cottonseed meal lost more than 100 pounds of nitrogen by leaching. The season of 1934 was selected as one with "normal" rainfall, 15.6 inches, for the same period as above. About 60 pounds of nitrogen per acre from cottonseed meal were leached. Thus, "normally" some nitrogen is lost through leaching.

It has been established (22) that a tobacco crop (Havana Seed) utilizes less than 120 pounds of nitrogen per acre. However, the average application, based on extensive experiments (7), is 200 pounds to the acre. This quantity provides for reasonable leaching and, obviously, the soil carries a small amount of residual (available) nitrogen. The 200-pound amount gives good results on the majority of the soils (sandy loam) in the tobacco area. Occasionally, a grower with somewhat heavier soils will find that less than the standard application produces more satisfactory leaf quality.

There is another reason for liberal applications of organic nitrogen to the tobacco crop. The writer (45) confirmed previous findings (1) that only 54 to 58 per cent of the nitrogen in cottonseed meal is solubilized and thus made available to tobacco during the growing season; the nitrogen in castor pomace, however, is about 70 per cent solubilized. This means that some 30 to 40 per cent of the nitrogen from organic sources is unaccounted for by leaching and crop removal. Somewhere along the line of nitrogen conversion this element is lost either to the air, to soil organisms or to both. Therefore, assuming that some 60 per cent of the nitrogen applied to a tobacco crop becomes available for growth, an average application of 200 pounds should meet crop requirements. Whether the amount applied is actually sufficient depends on how much residual nitrogen was initially present in the soil, the retentive capacity of the soil for nitrogen, and how much is leached out by rainfall.

Nitrogen Availability in Relation to Soil Moisture

Soil moisture is dependent on annual precipitation and is related, not only to the rainfall during the growing season, but also to snow and rains falling during the remainder of the year. Equally important is the water-holding capacity of the soil which serves to keep the water from draining out of the soil. The water retentive capacity of Connecticut tobacco soils is not too great and in dry seasons irrigation is practiced to some extent.

In a 1947 experiment, irrigated and non-irrigated fields were compared for nitrate production. Four-tenths of one inch of water was added to the irrigated plots in one application. Shortly thereafter, 0.55 inch of rain fell, so that the irrigated soil actually received 0.95 inch of water. Nitrate and moisture determinations were made four days after the rains, and showed that the irrigated soil produced about 40 per cent more nitrate-nitrogen than the non-irrigated land, despite the fact that most of the water added by irrigation had leached from the soil by the time the determinations were made. The percentage of soil moisture in the irrigated and non-irrigated soils at that time was 13.4 and 13.1 per cent, respectively.

Under conditions of equal fertilizer treatments and in the same plots, in the fairly dry year of 1944 (45), 38 per cent less nitrate nitrogen was produced in the soil than in 1946, which had a rainfall slightly above normal. The mean precipitation for the period from May to August was 2.21 and 4.14 inches, respectively. The lower figure for 1944 probably would have satisfied a minimum water demand, but the *distribution* of the rains was far from ideal: precipitation for July was only 1.30 inches.

What may be done to improve the retentive power of the soil? Two cultural practices have been used for this purpose. In former years liberal applications of manure to tobacco soils were made. About two generations ago, this material became scarce and growers resorted to the use of cover crops. Both of these methods tend to maintain organic matter in the soil and hold residual nitrogen.

Old tobacco stalks or stubs, especially on "shade" land, help to preserve organic matter, and sometimes tobacco stalks are put back on the land. Tobacco stems from cigar factories are also used to some extent (mainly to furnish potash).

Contrary to what might be expected, the carbon furnished by the oil meals applied for fertilizing purposes [it amounts to as much as one ton per acre a year (38)] does not add materially to the organic matter in the soil. It is used by soil microorganisms as a source of energy in decomposing the oil meals, changing the nitrogen to a form available to plants.

The Effect of Certain Other Soil Constituents

It is generally considered that liming the soil promotes nitrogen availability, especially for leguminous plants. When a strongly acid-forming fertilizer is used (29), the lime neutralizes the acidity produced. But, under conditions of satisfactory soil reaction, liming is essential only if calcium is deficient as a plant nutrient. A neutral calcium salt, however, such as gypsum (land plaster) has a neutralizing effect on ammonia produced from cottonseed meal (50).

Manganese stimulates nitrification and is of importance in nitrate absorption through its effect on root respiration (10, 17).

Copper added to the soil as $CuSO_4$ (42) appears to stimulate nitrate production.

Boron is essential to nitrogen utilization in tobacco (30), and may have a favorable effect on nitrification (46).

Molybdenum is apparently indispensable to nitrogen bacteria (14).

Thus, the so-called trace elements play an important rôle in preparing nitrogen for plant growth.

UPTAKE AND DISTRIBUTION OF NITROGEN IN THE TOBACCO LEAF

If it is assumed that most of the nitrogen enters the roots as nitrates, they probably combine with essential base elements and are translocated to various parts of the plants. Calcium, for instance, is preferentially absorbed in the nitrate form (32).

Since the leaf is of primary importance in tobacco production, the following pages are devoted to a discussion of the ways in which fertilization and other factors influence the uptake and distribution of nitrogen in the leaf.

The Relation Between Rates of Growth, Nitrogen Uptake, and Leaf Color

The importance of growth development in the leaf in relation to nitrogen utilization is easily recognized from the fact that high leaf quality is quite dependent on the uptake of the proper amount of nitrogen as needed. Excesses and deficiencies always adversely affect the quality of the leaf.

In a five-year period, 1929-1934 (22), growth and nitrogen intake were studied on Havana Seed tobacco. The leaf material was gathered from crops grown on a typical Connecticut tobacco soil (Merrimac sandy loam), fertilized with standard applications of 200 pounds of nitrogen (⅘ in organic nitrogen, and the balance as nitrate of soda), 100 pounds of phosphoric acid and 200 pounds of potash to the acre. Weather conditions during these years were rather favorable, except that 1931 and 1933 were fairly dry in the midseasons.

Figure 1 shows that nitrogen deposition in the leaves keeps pace with growth as measured by leaf weight. The important point, however, is that the nitrogen uptake tapers off (as shown by the more S-shaped curve) at the end of the growing season. This tapering off of the uptake of nitrogen is a normal part of the maturing processes of the leaf.

Although the curves express an ideal of "supply and demand," seasons are frequently either too wet or too dry, providing, respectively, not enough or too much nitrogen.

The data show (Figure 1) that it is of utmost importance that nitrogen be applied in sufficient quantity to the growing crop. This amount may vary with individual soils, so that a finer textured one would need less and a very leachy soil would require more than the standard rate (200 pounds per acre of nitrogen). From knowledge of the kinds of soils a grower has on his farm, he must adjust his nitrogen applications to fit these soils, since it is difficult for the experimenter to deal with all of the soil types in the tobacco-growing area.

A lead, however, is obtained from lysimeter experiments (23, 25) carried on at this Laboratory (in cooperation with the Soils Department) during a five-year period, 1929-1934. In one experiment tanks 9 inches deep and 20

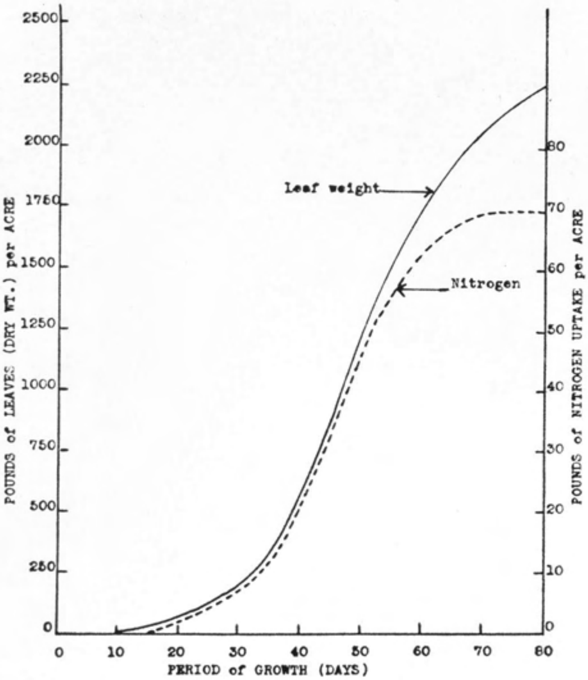

Figure 1. Rate of growth (in pounds of leaves per acre) in relation to nitrogen uptake.

inches in diameter were filled with four different soil series but kept fallow. Enfield very fine sandy loam, Merrimac loamy sand, Wethersfield loam and Merrimac sandy loam were the soils used.

In the following resumé, the average annual results are calculated from the published five-year totals. Out of several materials, only cottonseed meal is considered here, in comparison with nitrate of soda. (Nitrogen was applied at the rate of 200 pounds per acre.)

	Available cottonseed meal nitrogen	Nitrogen recovered in plants and leaching	Per cent of available cottonseed meal nitrogen
	Pounds per acre		
Merrimac loamy sand	102.4	110.5	51.2
Enfield very fine sandy loam	117.6	125.5	58.8
Wethersfield loam	121.0	134.0	60.5
Merrimac sandy loam	124.6	145.9	62.3

All the nitrate of soda nitrogen was fully recovered in the drainage water and is considered to be 100 per cent available. In sharp contrast is the cottonseed meal nitrogen applied to the Merrimac loamy sand where only 51.2 per cent of the nitrogen became available. More available nitrogen was produced in the other soils, somewhat in proportion to fineness of texture. The difference between "available" and "recovered" nitrogen in the above resumé is the amount originally present in the soil.

These findings should demonstrate, at least in part, the difficulties encountered in correctly balancing nitrogen applications to soil and crop needs, since on an individual farm several soils of different kinds and textures often occur.

About half of the nitrogen (26) is used in the "above ground" part of the crop and in this part about half goes into useful commercial leaves. In shade tobacco it is probably less than that, depending on how many leaves are primed off. Thus, three-fourths of the nitrogen is an "overhead charge," without considering the nitrogen lost in soil biological processes.

"Starved" tobacco, as judged on the sorting bench, has leaves with yellow streaks or blotches; sometimes the entire leaf has a lemon color. This is caused by an insufficient nitrogen supply in the soil (2). In most cases it is due to leaching, either from excessive rainfall or from over-irrigation (8). In the latter case it was shown that "starved" leaves occurred in a crop grown with insufficient amounts of cottonseed meal. Also, nitrogen in cottonseed meal is not quickly available and starvation may occur for this reason. The total nitrogen in the leaves grown with cottonseed meal varied from 2.74 to 3.61 per cent of the dry weight. In comparison, tobacco grown with an equal amount of nitrogen obtained from nitrate of soda applied at 10-day intervals contained no starved leaves; the nitrogen content varied from 3.53 to 4.53 per cent. It should be mentioned, too, that no *nitrate* nitrogen was found in the cottonseed meal tobacco, while 0.46 per cent was recovered in the "soda" treatment. In spite of the higher nitrogen content of the latter, less nicotine was present here than in the cottonseed meal tobacco. It is frequently found (15) that with increased nitrogen content of the leaf the percentage of nicotine is also larger. In one case (15) the nicotine content was doubled when the amount of nitrogen was larger by only 0.6 per cent.

"Dark" or "muddy-colored" tobacco (as distinguished from "black" tobacco, the cause of which is not entirely understood) comes from too high nitrogen content. It is manifested in the "darks" of stalk-cut tobacco, but occurs sometimes in the entire crop if too much fertilizer nitrogen has been added. In a dry season, it may also be apparent in the crop as a whole, for under these conditions nitrogen may be too efficient, since none is lost by leaching and nitrification usually is at a maximum.

Sometimes the lower pickings of shade tobacco show a "muddy" color and undertone of dark greenish brown, especially toward the tip of the leaf. In numerous instances, these leaf characteristics were found to be associated with considerable residues of nitrogen found in the soil after the crop had been removed. On the other hand, flawless leaves were produced where little or no residual nitrogen was found.[1]

Distribution of Nitrogen Compounds in the Leaf

It is commonly known that the lower part of a tobacco plant produces the more desirable leaves. One of the reasons is the lower content of nitrogen. A chemical analysis in 1939 (16) of Havana Seed tobacco showed a

[1] In cooperation with commercial growers.

variation in some nitrogenous compounds to exist in the leaves according to their position on the stalk. In a general way this is illustrated by Figure 2. The total nitrogen increases up to the 14th leaf and the nicotine to about the 12th leaf. Both curves are S-shaped but their patterns are somewhat different. It is of interest to note that the 5th to the 10th leaves contain more nitrogen in nicotine form than the leaves above and below. Those leaves include "long seconds," "lights," and "mediums," the "cream of the crop." It is evident that physical characteristics, such as elasticity, color, thickness, taste and aroma are favorably affected by this proportionment of the nitrogen.

Ammonia nitrogen showed the greatest variation, from very low in the bottom leaves to more than five times as much for the top leaves. The presence of ammonia nitrogen in the leaf indicates a stage of development; thus, the larger the content, the less mature would be the leaf.

In this connection it may be mentioned that the writer (35) found some correlation between an ammonia-nicotine ratio and taste of the cigar, that is, the flavor improved with decreasing ratio values. The ratio could be used as a criterion for judging the extent of maturing processes in cured or fermented tobacco.

In the same report it was indicated that by increasing the soil calcium, ammonia nitrogen decreased in the leaf. From this, it was inferred that calcium is active in the efficient utilization of nitrogen within the plant (36).

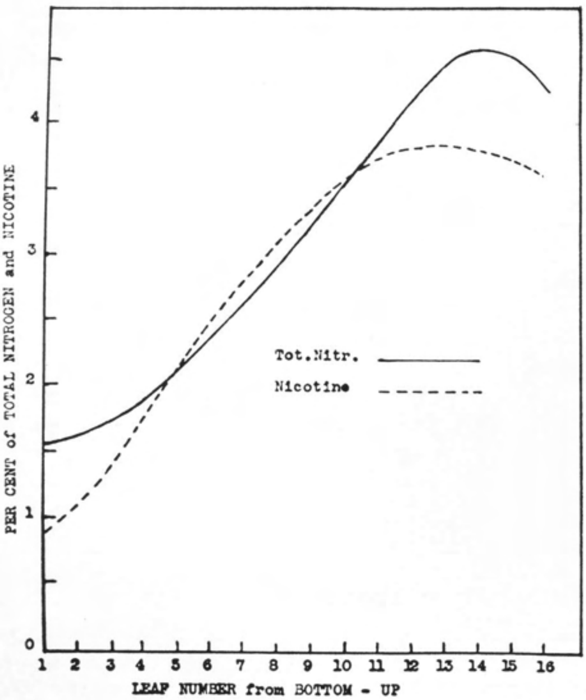

Figure 2. Percentage of total nitrogen and nicotine in relation to leaf position on the stalk.

Nitrate nitrogen in shade tobacco, according to Vickery *et al.* (48), decreases rapidly from the seedling stage (*ca.* 24 per cent) to traces at the end of 120 days. Other nitrogen fractions, such as asparagine, glutamine, and amino acids, were found to increase, but rather irregularly, as the leaves matured.

NITROGEN IN RELATION TO BURN

One of the most important qualities of the cigar leaf is its fire-holding capacity; i.e., its tendency to keep glowing (without flame) once it is lighted. From long experience the Connecticut grower has learned that slow acting nitrogenous compounds do not produce satisfactory leaf burn. In dry years the crop has a poorer burn than in a year with ample moisture.

A well known fact is the poor burn of "darks" in comparison with "seconds." This ties in with the surplus nitrogen content of the leaf. This fact, rather than the source of nitrogen or insufficiency of potash, often causes unsatisfactory burn. One source of nitrogen that is definitely harmful, however, is sulfate of ammonia, which is detrimental to burn even if small quantities are included in the fertilizer.

The fact that a dry year crop burns poorly and is associated with surplus nitrogen has been demonstrated (9) through burn tests and chemical analyses. Comparisons were made between the poor burning crop of 1924 and the excellent burning crop of 1927. It was found that samples from the former year contained about 44 per cent more *total* nitrogen than tobacco grown in 1927 (actual average 4.6 per cent N and 3.2 per cent N, respectively). Incidentally, the *ammonia* nitrogen content of the leaf in 1924 was almost three times larger than in 1927.

Thus, there is rather conclusive evidence that excessive deposits of nitrogen in the leaves retard burn; even all-organic fertilizers may cause poor burn if excessive amounts are used.

THE EFFECT OF FERTILIZER NITROGEN ON DEPOSITS OF NITROGEN AND BASES IN THE LEAF

In the mineral nutrition of plants, it is commonly known that the uptake of one element affects or is affected more or less by other elements. Chemical investigations in the early 1930's (7) revealed that increasing amounts of nitrogen fertilizer caused steady increases of nitrogen in the leaf, although not in proportion to the nitrogen applied to the crop. The curve in Figure 3, however, shows how nitrogen deposits are represented by a straight line when plotted against the rate of supply of nitrogen in the fertilizer. Almost parallel, but on a lower level, is the magnesia line. Thus, magnesia increased in the leaf with increased nitrogen fertilizer from a presumably non-varied supply of soil magnesia. Neither the potash nor the lime was varied, yet Figure 3 reveals a marked difference in the behavior of the two constituents. While potash deposits are little affected by nitrogen, calcium increases steadily up to a point and drops slightly at the highest application of nitrogen. This might be termed a coordination of bases since there is a reciprocal relation between them. Thus, there were no significant differences in the

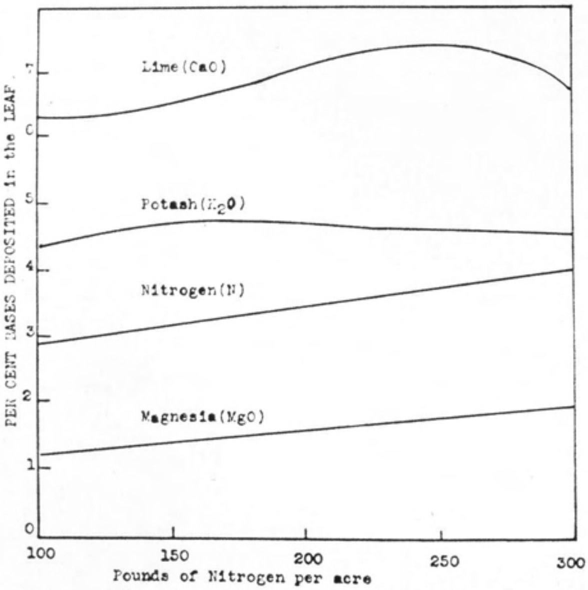

Figure 3. Leaf deposits of nitrogen and bases in relation to fertilizer nitrogen.

total amount of the three bases when the fertilizer nitrogen was varied. This constancy of bases has been previously observed (35).

Boron (39), manganese (12) and possibly other micro-elements play an important rôle in nitrogen metabolism. The writer (39) found some correlation between nitrate nitrogen and boron content of the cured leaf. With increased boron content, less nitrates were present and *vice versa*. This would indicate a more efficient utilization of the nitrogen when boron was present; that is, boron seemed to promote the completion of the nitrogen assimilation process. This confirms the findings (41) that boron applied to tobacco land improves the quality of the leaf.

In the foregoing review the writer has endeavored to give a general picture of the importance, functions and activities of nitrogen in tobacco production. The following resumé, on the other hand, cites experimental results with a number of nitrogenous compounds in the last 25 years, together with some recent data.

NITROGENOUS FERTILIZER MATERIALS

All of the organic nitrogen materials used in fertilization of Connecticut tobacco, e.g., the oil seed meals and fish meal, are waste products from other industries. Of animal wastes, manures are most important (when and if obtainable). While the bulk of the nitrogen used is of organic origin, a portion of it is synthetic and one material is mined (Chilean nitrate of soda). The materials are discussed in the order of economic importance and use.

Cottonseed Meal

The use of cottonseed meal in tobacco fertilization was introduced about 1870 by Mr. P. G. Pinney of Suffield. It gradually came into widespread use throughout the Valley and today is still the "backbone" of tobacco fertilizer.

Cottonseed meal is made by grinding the pressed cake from which the oil has been expelled. After first crushing the cotton seed, the hulls are separated from the meat. However, a portion of ground up hulls is added to the final meal product to equalize the protein content; hence, the common terms "41 per cent" or "43 per cent" meals.

The "41 per cent" meal, corresponding to about 6.5 per cent nitrogen, is most commonly employed. Cottonseed meal contains, besides nitrogen, about 3 per cent phosphoric acid and around 2 per cent potash, smaller amounts of magnesium and calcium, traces of boron and possibly other micro-elements.

Perhaps the most important reason for the satisfactory results and popularity of cottonseed meal is the fact that it decomposes and furnishes available nitrogen (nitrates) at the rate needed in the growth development of the tobacco plant. Extensive soil nitrification tests (34) have shown that the maximum amount of readily available nitrogen is produced about one month after application of the material, provided the soil contains ample moisture and otherwise favorable weather conditions prevail.

Employed as the only source of nitrogen, cottonseed meal produced fully as satisfactory yield and grading as combined nitrogenous materials. This was shown by a test conducted for five years (1932-1937) (6) at this Station, using Broadleaf tobacco.

In recent years various solvents have come into extensive use for better oil extraction. Less heat is used in this process and the residue seems to acquire a higher nitrogen content and is lighter in color.[1] To determine the usefulness of this "new type" meal, field experiments were made at this Laboratory in 1948-1950, comparing various cottonseed meals obtained by solvent extraction with regular expeller cottonseed meal. The "solvent" meals were designated regular solvent, special solvent and "new process" by their manufacturers, although the nature of the solvents was not revealed. All contained higher percentages of nitrogen (6.84-7.06 per cent) than regular cottonseed meal. This was taken into account in adjusting the applications for all treatments to 200 pounds of nitrogen to the acre. In addition, proper amounts of phosphoric acid and potash were applied.

Nitrification tests indicated that expeller type meal and regular solvent meal were equal in nitrate-producing ability. Special solvent meal increased the nitrate-producing capacity by 15 per cent, while the "improved process" meal produced 36 per cent more nitrates. Both yield and grading of the crop (Havana Seed, K1) grown with solvent materials were fully as good, if not better, than those from the old type meal. Thus, any of the "new" meals may be substituted for the old process (expeller) cottonseed meal.

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[1] Great heat is produced by hydraulic pressure in the expeller process, which sometimes is sufficient to "brown" the meal.

"Oldtimers" among the tobacco growers of this Valley have often expressed the opinion that cottonseed meal of today is not of the same good quality as years ago, hinting that a meal that stubbornly stuck to the clothing (no doubt because more oil was left in the product) really produced excellent quality tobacco. It is reasonable to believe that with improved extraction methods the meal gradually contained less oil residue and thereby decayed faster when applied to the soil. From this it follows (and it is supported in the account of solvent meal above) that the nitrification is speeded up and there will be a greater abundance of nitrates eventually exposed to excessive rainfalls. Thus, admittedly, cottonseed meal has lost some of its "foolproofness."

Therefore, it seems reasonable that cottonseed meal should be blended with some of the nitrogenous materials discussed below, as is generally done in commercial fertilizers.

Castor Pomace

Castor pomace is the material remaining after castor oil has been removed from the crushed castor bean, first by pressure and then by solvent extraction. The residue is then ground up, producing a light fluffy meal that may be used only for fertilizer purposes, because it contains a toxic alkaloid which makes it unsuitable for animal feed. This alkaloid, however, is readily decomposed in the soil, adding to the nitrogen supply.

Like cottonseed meal, castor pomace is a more or less complete fertilizer with nitrogen the main nutrient (4.5 to 6.0 per cent), 1 to 2 per cent phosphoric acid and about 1 per cent each of potash, lime and magnesia. In addition, there are traces of micro-elements.

Castor pomace came into use as a tobacco fertilizer long before the turn of the century, but a more widespread usage occurred some 30 years ago while there was a scarcity of cottonseed meal during the first World War.

An early objection to castor pomace was its tendency to produce unduly dark tobacco. This might readily have its origin in too high oil residue in the pomace, especially if extraction were made with pressure alone. With improved methods of extraction, the castor pomace of today is practically free of oil. Results of experiments carried out at this Laboratory (34) have shown that this material nitrifies at about the same rate as cottonseed meal. In this connection, however, an important fact was discovered concerning castor pomace. Briefly, it was found that 160 pounds of nitrogen in castor pomace has the same crop-producing effect as 200 pounds of nitrogen in cottonseed meal (cf. discussion on page 6). This is true at least for stalk-cut tobacco and should be taken into consideration when castor pomace is substituted for cottonseed meal.

Other Organic Sources of Nitrogen

Linseed meal, soybean oil meal and *dry ground fish* are rather expensive sources of nitrogen. Used as single sources of this nutrient (6), however, they invariably produce better grading than cottonseed meal. Thus, in the production of wrapper tobacco, it is safe to include them in the fertilizer formula as a source of part of the nitrogen. Linseed meal (6) rated nearly 10 per cent higher in grading than the average of several other sources of nitrogen over a five-year period.

Hoof and horn meal (12-15 per cent N), *corn gluten meal* (6-7 per cent N) and *sunflower seed meal* (6-7 per cent N) (40) are sometimes used to the extent they are commercially available. They are satisfactory sources of nitrogen.

Manures of various kinds were the earliest fertilizers used for Connecticut tobacco. The present day scarcity of stable manures prevents extensive use of these products.

The value of manure lies in its nitrogen content, but if the material is exposed to all sorts of weather, a great portion of the nitrogen is lost and it is then useful only as a soil amendment. This in itself, however, may be as important as its full fertilizer value, since it furnishes organic matter and a number of nutrients like calcium, magnesium, phosphorus and potash, besides many elements which have not been investigated but which may have an influence on tobacco quality.

Continuous and heavy use of stable manure may encourage the development of black rootrot (4), since manure has a tendency to "sweeten" the soil. It is possible also that the "increase in humus content of the soil would favor growth of the rootrot fungus" (3).

It is doubtful that nitrogen in stable (horse and cow) manures would be of any greater value than that from other sources; whatever other virtues are inherent fall outside the scope of this bulletin. Because of the variation in kind and quantity of litter in stable manure, possibly not more than 50 per cent of the N is available (4).

The use of poultry manure was rather thoroughly investigated (37, 43, 44) on Havana Seed tobacco at this Laboratory in 1942 and 1947-1949. The experiments were carried out with a fairly exact knowledge of the nitrogen content of the manure, together with the other main nutrients.

Briefly, it was found that, when half of a regular application of commercial fertilizer was replaced with poultry manure,[1] yield, quality and burn were fully comparable to those produced by commercial fertilizer alone. The material may be plowed under or harrowed in after plowing. Supplying all the nitrogen as poultry manure produced satisfactory yields, but grading and burning qualities did not quite measure up to results from standard commercial fertilizer.

Mineral and Some Synthetic Sources of Nitrogen

The most common materials in this group are *nitrate of soda* and *urea*. Connecticut growers in general are very familiar with the use of these and an adequate discussion on them may be found elsewhere (40).

Urea is a valuable source of nitrogen, but the objection to a more general use of the material lies in its solubility. The compound $CO(NH_2)^2$ is readily converted into ammonia within five days in the soil (34); hence, even if a minor portion of the nitrogen is furnished as urea, it adds to the ammonia supply which is abundantly formed from the oil seed meals in mixed fertilizer.

[1] To furnish at least 100 pounds of nitrogen per acre.

Recently, a new material, *ureaform*, was developed, which seems promising in overcoming the difficulties with urea. Ureaform is a chemical mixture of urea and formaldehyde, forming a polymer (1⅓ mol urea to 1 mol formaldehyde). The resulting compound is sparingly soluble in water and gradually breaks down into ammonia (and nitrates) in the soil. It is not hygroscopic, may be mixed in any desired way with other fertilizer materials, and contains from 38 to 40 per cent nitrogen. This compares with 46 per cent nitrogen for pure urea and 42 per cent for Uramon, one of the trade names under which urea is marketed.

Results from experiments carried on at this Laboratory on the use of ureaform in fertilizer mixtures are discussed in detail below, since they have not previously been published.

In 1948 a preliminary test[1] with ureaform indicated that 25 per cent of the nitrogen in that form was a suitable quantity to include in a 6-3-6 formula using only two forms of N (cottonseed meal and ureaform). This produced a 28 per cent higher crop value in Havana Seed tobacco than when cottonseed meal was used as the single carrier of nitrogen. Even half and all ureaform nitrogen gave higher grading than cottonseed meal alone.

In 1949 and 1950 experiments with this compound were continued and the Plant Industry Station, U.S.D.A., supplied two additional ureaform materials. For convenience the materials were designated A, B and C, the last being the same compound as the one used in the 1948 tests. The other two differed slightly in the molecular ratio of urea to formaldehyde. In 1950 Uramite, a commercial compound of ureaform, was included in the tests. The composition of this material corresponded closely to "C."

The ureaform materials were used as previously, supplying 25 per cent nitrogen in a 6-3-6 formula, compared with the effects of a formula where cottonseed meal furnished all the nitrogen (to supply 200 pounds N per

TABLE. 1. YIELD AND GRADING OF UREAFORM EXPERIMENTS IN 1949-1950

Source of nitrogen	Plot no.	Yield pounds per A			Grade index			Av. crop index	Relative crop value
		1949	1950	Av.	1949	1950	Av.		
Cottonseed meal	N1	2065	1927		.410	.528			
supplying 200	N1-1	1875	2036	1925	.382	.506	.462	889	100.0
lbs. N per acre	N1-2	1727	1921		.372	.573			
Ureaform A	N2	2084	2189		.535	.547			
supplying 25% N	N2-1	1823	2093	2010	.421	.525	.485	975	109.7
Balance in C. S. M.	N2-2	1921	1952		.415	.466			
Ureaform B	N3	1935	2063		.432	.517			
supplying 25% N	N3-1	1916	1976	2011	.415	.523	.467	939	105.6
Balance in C. S. M.	N3-2	2148	2036		.439	.478			
Ureaform C	N4	1942	1909		.487	.621			
supplying 25% N	N4-1	1950	1988	1969	.499	.494	.522	1,028	115.6*
Balance in C. S. M.	N4-2		2059			.508			
Uramite	N5		1959			.511			
supplying 25% N	N5-1		2096	1990		.547	.529	1,053	118.9*
Balance in C. S. M.	N5-2		1906			.530			

* Significant at odds 19:1.

[1] In cooperation with Plant Industry Station, U.S.D.A., Beltsville, Maryland.

acre for all treatments). The plots were laid out in triplicate in a randomized arrangement, with the exception that "C" material (for lack of space) was represented by duplicate plots in 1949. Again the test crop was Havana Seed.

The average results of the two years' tests are given in Table 1. The data show that ureaform included in the fertilizer mixture invariably produced higher crop value (yield and grading) than cottonseed meal nitrogen alone, with best results from compound "C" and Uramite.[1] Grading (quality) which is highly important in wrapper production, was more favorably affected than yields. That nitrification was not unduly delayed was shown in soil nitrate studies made in 1948-1950. With the nitrate-producing capacity of cottonseed meal taken as 100, the values for "C" compound and Uramite amounted to 127.6 and 128.6, respectively. The higher "efficiency" of the ureaform materials was doubtless responsible for their higher nitrate production. It may be inferred, however, that with suitable rates of nitrification, superior grading will result as is indicated from the data in Table 1.

It is true that excellent grading quality of the wrapper leaf may be obtained by adding, through trial and error methods, a little of this and that material to the cottonseed meal used as fertilizer. These experiments strongly suggest, however, that ureaform could replace other nitrogenous materials which may need to be added. By using ureaform, nitrate-producing processes are better controlled and less is left to conjecture in planning a fertilization program. A certain amount of uncertainty, however, will always remain because of soil differences and seasonal variations.

Ammonium nitrate was subjected to extensive experiments at this Laboratory in a search for suitable nitrogen compounds as substitutes for the expensive oil seed meals. During a five-year period, 1944-1949, various phases of its possible use in fertilization of Havana Seed tobacco were investigated. The findings have been published elsewhere (43).

Briefly, more than a third of the nitrogen could be derived from this material without impairing the quality of tobacco in comparison with that produced by cottonseed meal nitrogen. Ammonium nitrate may also be used for side dressing purposes in years with excessive rainfall.

Cal-Nitro (5) is another synthetic nitrogen product consisting of ammonium nitrate to which 35 per cent calcium carbonate has been added. Originally produced in Europe, it is now manufactured in this country and sold under the trade name *A-N-L*. The material contains 20.5 per cent nitrogen and the lime addition brings the CaO content to 9 and MgO to 5 per cent. Like other nitrate compounds, it may be used for side dressing.

Ammonium sulfate is a source of nitrogen long and widely used in agriculture. Experiments (5, p. 244) have shown, however, that it is *not* suitable for Connecticut tobacco. The material makes the soil too acid and, even if the acidity is neutralized through addition of sufficient lime (28), it does not produce leaf quality comparable to that produced by the oil seed meals. In

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[1] Uramite has a total content of 39.5 per cent nitrogen. Sixty per cent of this is insoluble reacted ureaform nitrogen; 25 per cent, soluble reacted nitrogen, and 15 per cent, unreacted nitrogen. The material is not yet generally available on the market.

addition, this compound nitrifies in the soil (34) at the slowest rate of all the many materials investigated. Moreover, ammonium sulfate produces inferior leaf burn.

In spite of all these bad features, however, the material has found one good usage in tobacco growing, i.e., as an acidifying agent. Sometimes, through the application of excessive amounts of ashes or lime, the soil reaction may reach a level too high for efficient control of black rootrot. Soils above pH value of 5.6 are favorable to this disease, especially during cold wet summers. Ammonium sulfate applications will correct this difficulty.

It was found (1) that 500 pounds of ammonium sulfate was just as efficient as larger quantities in reducing the pH values more than one unit on sandy soils. In order to avoid or reduce deleterious effects on the following tobacco crop, it would be best to treat fields immediately after the tobacco crop is harvested. Since bases would be leached by fall and winter precipitation, which is the desired effect and object of the treatment, no cover crop should be planted. However, if soil erosion would be more of a disadvantage than the gain through the corrective treatment, a late planting or light cover crop is preferred. In that way, because of the limited growth, basic material would be taken by the cover crop. It is a good plan to make a "quick" test of the soil the following spring as a check on the resulting pH value and possible nitrogen residue in the soil.

Miscellaneous Nitrogenous Materials

From time to time, other nitrogenous materials have received some attention at the Tobacco Laboratory but little has been published about them. Frequently after the tests were completed, the material was no longer on the market; in other cases, the compound was found to be a less desirable nitrogen carrier than those in common use.

In the period between the two World Wars *nitrate of lime* (1) was imported from Europe. This material was found to be fully comparable to nitrate of soda and had the advantage of carrying calcium instead of the unnecessary base, sodium.

Nitrate of potash (6) (and nitrate of soda-potash) did not show any particular virtue when included in mixed fertilizers in comparison with all organic nitrogen during a five-year experiment (1932-1937). The material, however, may be used as a source of potash when a neutral (or nearly neutral) compound is required. It is an excellent booster for plants in tobacco beds when it is found that both nitrogen and potash need to be replenished.

Calcium cyanamid and *Peruvian guano* (28) may be used in mixed fertilizers but have no advantage over the common oil seed meals. Peruvian guano is no longer available. Cyanamid has an alkaline effect on soil reaction which must be considered in balancing the fertilizer mixture. The nitrogen content of the compound is 21 per cent and the total active lime content is equivalent to 70 per cent hydrated lime.

Two other sources of nitrogen are *steamed bone* and *raw bone meal.* They contain a small percentage of nitrogen, and this may be included in computing the total nitrogen in mixtures.

Finally, there is some nitrogen (1.3 to 2.5 per cent) in *tobacco stems* (2), besides the potash for which they are mainly used. Experiments have shown that this nitrogen is fully as valuable as cottonseed meal nitrogen.

SUMMARY

A brief history is given of the early use of nitrogen for Connecticut tobacco, including observations on the change in wrapper demand for cigars and today's preference for light wrappers and binders, a factor affecting nitrogen fertilization of tobacco in Connecticut.

In the work on soil-nitrogen relationship, a major feature was the study of ammonification and nitrification of a number of nitrogenous materials and their effects on soil reaction. Thus, the maximum of ammonia nitrogen develops in about two weeks for oil seed meals and in less than a week for urea.

The acid soil reaction required for optimum growth of tobacco, restricted to an upper pH limit of 5.5-5.6 because of black rootrot, was found to be satisfactory for nitrification when small and frequent additions of lime materials were made to maintain the pH at this level.

Nitrate nitrogen, which is absorbed by plants preferably under acid soil reaction, was found to be more suitable than ammonia nitrogen.

Oil seed meals gave the highest production of nitrates, reflected in optimum growth of tobacco when these materials were used as a source of nitrogen.

Urea nitrogen is converted into nitrates at a more rapid rate than that in organic oil seed and fish meals.

Lysimeter studies showed that in seasons of excessive rainfall as much as 100 pounds of cottonseed meal nitrogen was leached from the soil. This contrasted to 60 pounds of nitrogen lost in a year with normal precipitation.

Results from irrigation experiments showed that as much as 40 per cent more nitrate nitrogen was produced on irrigated than on non-irrigated land.

Land plaster (gypsum) neutralized ammonia in the soil, and manganese stimulates nitrification; copper and boron were found to have similar properties, and molybdenum is indispensable to nitrogen bacteria.

Calcium in the leaf increased with increasing supply of soil nitrogen up to 250 pounds per acre but decreased at the highest rate, which was 300 pounds of N to the acre.

Nicotine content of the leaf increases with an increase in the amount of ammonium nitrogen absorbed by the plant.

Distribution of nitrogen compounds in the tobacco plant varies with position on the stalk and maturity of leaves. Excessive amounts of nitrogen in tobacco leaves retard burn.

Nitrogen is deposited in the leaf somewhat in proportion to nitrogen supplied in the soil.

Magnesia increased in the leaf with increased fertilizer nitrogen, while potash was almost unaffected by nitrogen.

Old process cottonseed meal, considered a "standard" source of nitrogen, was used as a measure to evaluate other nitrogenous materials investigated. "New process" cottonseed meal is more "efficient" and produces more nitrate N on an equal basis of fertilizer N.

On this same basis, castor pomace nitrogen is about 25 per cent more available than N in cottonseed meal.

Linseed meal, soybean oil meal and dry ground fish also have a higher rating than cottonseed meal. Among these, linseed meal produced about 10 per cent higher leaf grading quality than other sources.

Stable manure and poultry manure of known N content can furnish 20 to 50 per cent, respectively, of the total nitrogen needed. Continuous use of manure favors black rootrot since it tends to increase the pH of the soil.

Nitrate of soda nitrogen is comparable to organic nitrogen in its effect on yield and grading, if the total N requirement is divided and applied at intervals.

Urea nitrogen may be used to substitute for 25 to 50 per cent of the oil seed meal nitrogen without impairing quality of stalk-cut tobacco.

A new synthetic nitrogenous material, ureaform, a chemical mixture of urea and formaldehyde, gave promising results when it was used to supply 25 per cent of the required nitrogen, the balance coming from cottonseed meal.

Results from tests with ammonium nitrate indicate that this material may be used as a substitute for a part of the nitrogen obtained from oil seed meals, especially when there is a scarcity of the more suitable materials. The same may be said about Cal-Nitro and to a lesser degree, ammonium sulfate. The latter material finds use as an excellent soil acidifier; applied at the rate of 500 pounds per acre on sandy soils, it reduced pH values more than one unit.

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