FERTILIZING CONNECTICUT TOBACCO

New Methods for New Needs

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Contents

This discussion summarizes research with stalk-cut tobacco conducted at the Tobacco Laboratory of The Connecticut Agricultural Experiment Station in Windsor over the past 30 years. Much of this work is reported in detail in Annual Reports of the Tobacco Substation (1946 and earlier) or condensed in Bulletins 503, 546, 599, and 564 of The Connecticut Agricultural Experiment Station, New Haven, Connecticut. The results are now reappraised in the light of the need for more economy in fertilizer practices.

Summary

The advent of synthetic binder has revolutionized the production of stalk-cut tobacco in the Connecticut Valley. Increasing production costs and disappearing premium for certain qualities in high grade binder type tobacco compel a re-examination of fertilization practices as a means of lowering the cost of production.

In our search for more economy in the fertilization of Connecticut tobacco, we reviewed fertilizer experiments and practices in the Connecticut Valley as well as in other tobacco regions. Most attention is given to nitrogen, the most costly nutrient and the hardest to manage efficiently in our coarse to medium textured soils.

The choice of a nitrogen fertilizer, like the method and time of application, first of all turns on the problem of leaching in our sandy soils. The discussion of this problem introduces most of the information necessary to an understanding of the importance of rainfall in nitrogen fertilization.

Use of organic sources, such as meals and manures, insures against losses by leaching during the critical first 4 to 6 weeks of low nitrogen absorption by the crop, a time of leaching rains. Oil seed meals are low in total availability and are expensive.

Synthetic organic and inorganic nitrogen materials are suitable fertilizers for tobacco when used in accordance with their peculiar properties. They are best applied in part at planting time and then supplemented by side dressing with nitrates just prior to the time of maximum absorption by the crop. These materials are relatively cheap and their use should also result in savings in handling and application costs. High-analysis fertilizers applied during tillage, planting, and cultivation should give some significant savings.

Farm manures can provide an economical and suitable source of organic nitrogen. Cheap inorganic forms of nitrogen can be converted into organic form by fertilizing cover crops. Plowing under considerable amounts of organic matter maintains the organic fertility level of the soil and renders soils less susceptible to compaction and crusting.

Higher yields can be produced by higher applications of nitrogen, but the quality may be lowered.

Improved methods of fertilizer placement and supplemental applications are means of economizing in fertilization. Placement methods markedly affect the recovery of the nutrients applied; band placement is especially effective in reducing phosphate fixation.

The choice of phosphate and potash fertilizers offers no particular problems, except that extremely large applications of sulfur with these materials should be avoided. There are several good sources for these nutrients and relative price can be the guide.

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The introduction of synthetic binder for cigars is causing a technological revolution of major proportions among the growers of binder tobacco in the Connecticut Valley. The premium price for perfect leaf binders has disappeared at least temporarily. This hard fact has made it necessary to re-examine all phases of tobacco production with the view of producing tobacco at a price to compete in the open market. One of the large items of cost of production is fertilizer.

Two factors cause us all to examine anew our knowledge of how cigar tobacco in the Connecticut Valley responds to fertilizer. First, falling prices for binder and increased production costs for both wrapper and binder dictate more economy and efficiency in fertilizer practices. Second, many fertilizer practices have been in the past evaluated in terms of qualities some of which are no longer essential.

In our search for cheaper fertilizer materials that could replace a part, if not all of the expensive ingredients ordinarily used in tobacco fertilizer mixtures, we shall mainly consider farm manures and those mineral and synthetic chemicals which have been tested by the Tobacco Laboratory (Windsor) of The Connecticut Agricultural Experiment Station. The Merrimac sandy loam soils used in these experiments are typical of a considerable part of the tobacco-growing area of the Connecticut Valley, so that without any or only slight adjustments, the results should be applicable to a great part of the land of many tobacco farms.

As the advent of synthetic binder causes Connecticut Valley binder tobacco to be placed on the same market as tobacco from other regions (60), we shall also scrutinize practices in these other regions in the hope that they can be transferred to Connecticut with a saving to the producer. Therefore, we shall include in this bulletin the available evidence from other regions, bearing in mind the differences in tobacco types, soil, and climatic conditions.

Nitrogen is usually considered the most important element in nutrition of Connecticut tobacco. This, of course, is a half-truth, because balanced fertilization is essential to crop production. Tobacco, however, is more exacting in its requirements for nitrogen than for phosphorus and potash. Furthermore, nitrogen is the most expensive of all fertilizers, and it is easily lost from the soil.

NITROGEN (N)

The nitrogenous fertilizers are commonly classified into organic and inorganic, or mineral. The organic nitrogenous materials, with the exception of the synthetic compounds urea and calcium cyanamide, are derived from animal and plant sources. These natural organics are water-insoluble, the mined and chemical nitrogenous fertilizers are readily soluble in water.

The number of nitrogenous fertilizer materials which may be used to supply the nitrogen for tobacco is large. Long-established fertilizer practice in the Connecticut Valley, however, has sanctioned the use of a mixed fertilizer containing a high percentage of organic materials, such as cottonseed meal, castor pomace, linseed meal, soybean meal, and dry ground fish. The remainder of the needed nitrogen is furnished by such sources as nitrate of soda, ammonium nitrate, nitrate of potash and urea (1, 26).

However, a 5-year experiment at the Tobacco Laboratory failed to demonstrate any improvement in yield or grading by using multiple sources instead of a single organic nitrogen carrier (47). Furthermore, no accurate experimental evidence exists for a common belief among growers and fertilizer dealers that certain nitrogenous materials have specific effects on the tobacco crop (2).

Tobacco plants take up nitrogen in water-soluble form, mainly as nitrate or to a lesser extent, as ammonium. As long as the nitrogen of the natural nitrogenous materials is in an organic form it remains almost completely unavailable to the plants (3). Organic nitrogen is converted via the ammonium form into nitrate by soil micro-organisms. If conditions for nitrification are favorable, even when nitrogen is supplied to the soil as ammonium salts, much of the nitrogen will appear as nitrate (30).

The numerous extensive experiments on problems relating to the nitrogen nutrition of tobacco conducted at the Tobacco Laboratory (for reviews see references 1 and 38) have clearly shown that the important factors influencing the relative value of most sources of nitrogen for tobacco are: (a) Time, rate and amount of decomposition which determine ability to meet the plant requirements for nitrate nitrogen, (b) influence on soil reaction, and (c) resistance to loss by leaching.

If these factors are properly appreciated and the various nitrogen materials used in accordance with their peculiar properties, most of them will produce satisfactory crops of tobacco. The choice of a nitrogen fertilizer will then depend in large measure on its cost per unit of nitrogen and the ease with which it can be safely and efficiently used on the crop (4).

Table 1 shows most of the important nitrogen carriers, their nitrogen content, effect on soil reaction, a simple classification of their resistance to leaching, and of the convenience of storing, mixing, and handling them. Table 2 presents the relative costs of nitrogen from several sources.

The Problem Of Leaching

The predominantly sandy-textured tobacco soils in the Connecticut Valley have a minimum capacity to retain nitrates at times of excessive rains. This complicates the efficient management of nitrogen for meeting the demands of the tobacco crop.

The best tobacco is produced when it grows continuously without check, such as caused by an insufficient nitrogen supply (26). During June or the first 30 days after transplanting, the young tobacco plants need very little nitrogen, and an acre of stalk tobacco absorbs only 7 pounds of nitrogen. After the first 30 days, however, the nutritional demand increases quite rapidly (reaching the maximum in late July) (2). During this short period the plants must have an abundant supply of plant food in the soil in an easily available condition. It has been established that a tobacco crop (Havana Seed) utilizes about 120 pounds

of nitrogen per acre (5). Although a relatively low available soil nitrogen level at the time of harvesting is favored, the quality of Connecticut tobacco is less adversely affected by an overabundance of nitrogen than many of the other types of tobacco (22).

These demands of the tobacco for nitrate nitrogen can be met satisfactorily in several ways. First of all, as has been shown in extensive experiments, even

Table 1. Relative values of nitrogen carriers (33)

Material	Percentage N*	Acidity or alkalinity†	Resistance to leaching‡	Convenience quality§
Tobacco stems	2	+12	high	good
Fish scrap	5	— 8	high	good
Cottonseed meal	6	— 9	high	good
Animal tankage	6	+10	high	good
Ammonium phosphate	12	—65	medium	good
Sodium nitrate	16	+29	low	fair
Calcium nitrate	17	+20	low	poor
Calcium cyanamide	22	+62	medium	good
Ammonium sulfate	21	—110	medium	fair
Ammonium nitrate	35	—59	low	fair
Urea	46	—84	medium	fair
Ammonia (anhydrous)	82	—148	medium	fair

*Commercial products may contain somewhat less than these percentages.
†Acid (—) materials require the given pounds of $CaCO_3$ to neutralize 100 pounds; alkaline (+) materials will neutralize the same quantity of acid per 100 pounds as the given pounds of $CaCO_3$.
‡Capacity of soil to retain until used by plants.
§For storage, mixing, and spreading.

Table 2. Relative cost per pound of nitrogen in various nitrogen carriers (52)

Price per ton of material	Sodium nitrate 16% N	Ammonium sulfate 20.5% N	Ammonium nitrate 33.5% N	Nitrogen solution 37% N	Urea 45% N	Nitrogen solution 49% N	Anhydrous ammonia 82.2% N
Dollars	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
30	9.4	7.3	......	......	......	......	......
35	10.9	8.5	5.2	......	......	......	......
40	12.5	9.8	6.0	5.4	......	......	......
45	14.1	11.0	6.7	6.1	5.0	......	......
50	15.6	12.2	7.5	6.8	5.6	5.1	......
55	17.2	13.4	8.2	7.4	6.1	5.6	......
60	18.8	14.6	9.0	8.1	6.7	6.1	......
65	20.3	15.9	9.7	8.8	7.2	6.6	......
70	21.9	17.1	10.5	9.5	7.8	7.1	......
75	23.4	18.3	11.2	10.1	8.3	7.7	......
80	25.0	19.5	11.9	10.8	8.9	8.2	......
85	......	20.7	12.7	11.5	9.4	8.7	5.2
90	......	22.0	13.4	12.2	10.0	9.2	5.5
95	......	23.2	14.2	12.8	10.6	9.7	5.8
100	......	24.4	14.9	13.5	11.1	10.2	6.1
105	......	25.6	15.7	14.2	11.7	10.7	6.4
110	......	......	16.4	14.9	12.2	11.2	6.7
115	......	......	17.2	15.5	12.8	11.7	7.0
120	......	......	17.9	16.2	13.3	12.2	7.3
125	......	......	18.7	16.9	13.9	12.8	7.6
130	......	......	19.4	17.6	14.4	13.3	7.9
135	......	......	20.2	18.2	15.0	13.8	8.2
140	......	......	20.9	18.9	15.6	14.3	8.5

the most available and most easily leached nitrate salts can well maintain the nitrate supply if the applications are properly distributed throughout the growing season. By such fractional applications, excellent crops of tobacco have been grown on sandy land with nitrate of soda as the only source of nitrogen (2, 47). The second way, practiced by some growers, is to apply the greater part of the fertilizer before the crop is planted and the balance as a side dressing between the rows of tobacco, usually at the time of one of the last cultivations (22). The third and most generally practiced method is to broadcast before planting time all the fertilizer which should be needed by a normal crop in a normal year and only to apply additional, quickly available nitrogen in case of excessive rainfall and leaching of nitrogen. (26).

Since the results in crop production from fractional applications or later side dressings of readily soluble nitrogen are fully comparable with those from the natural organics, the experiments indicate that the main, if not the sole advantage of the use of oil seed and fish meals is that they furnish nitrates as plant growth progresses, provided the soil contains sufficient moisture and the weather is favorable (47, 40). These insoluble organic materials break down slowly in the soil, and unless they have been nitrified, they are effective in insuring against a serious loss of nitrogen, especially during early growth of the crop when the uptake of nitrogen is low.

As long as the costs of the "meals" were not excessively high and, furthermore, were sustained by a relatively high price for the cigar binder grades, the most economical or at least the most convenient practice was probably to apply all of the high grade organic fertilizer mixture before transplanting. Although we shall not try to analyze in this bulletin all the agronomic, economic, and managerial factors that influence the use of the different sources of nitrogen and methods of applying fertilizer, it is clear that later side dressings and fractional applications involve extra labor costs. Evaluations of the many factors involved can be made best by the individual grower, since most of these factors will vary from farm to farm.

What we would like to explore a little more, however, is the question of how much insurance against leaching do we generally need for a reliable tobacco production under our climatic conditions. Do we actually have to pay such a high premium in the form of these costly organic fertilizers to insure the crop against leaching? Furthermore, we must come to realize that even the use of the expensive "meals" cannot insure an ideal supply of nitrates that will perfectly match the rate of nitrogen absorption by the tobacco crop under any condition (40, 2, 53). Rainfall, temperature, and soil conditions mainly determine the decay and nitrification of these organics.

Tobacco growers agree that the rainfall during the months of June and July generally determines the yield and, to a somewhat lesser degree, the quality of the crop (53). The rains that cause serious leaching almost always occur sometime during late June (2). These general statements can be substantiated by the following observation during 5 years of experiments with fractional applications of nitrate of soda: the last application was always made within the first week of July, when the crops were less than half grown; leaching rains and irrigation occurring afterward caused no visible symptoms of nitrogen starvation of the leaf (47).

The data on leaching in Merrimac sandy loam in 20-inch deep lysimeter tanks (Table 3) shows that August is the month when leaching is least apt to occur. This is not surprising, since at this time of the year the effect of water use by the tobacco crop is the greatest. July ranks next to August as a month of low leaching risks. Most leaching during the growing season of the tobacco crop over these 11 years occurred in June (51). Soil leaching in July occurred in only two instances during these 11 years, and was of significant magnitude only as a result of the extremely heavy, 8.5 inches of rainfall in 1938. In only one instance did August show any leaching at all.

Table 3. Rainfall and amount of water leached from Merrimac sandy loam; based on average data for 20-inch deep lysimeter tanks, cropped to Shade tobacco, 1929-40 (51)

	June	July	August
	Inches	*Inches*	*Inches*
Rainfall	3.97	3.49	4.05
Leached	1.03	0.41	0.01

Since the effective rooting depth of Connecticut tobacco is much shallower than the depth of the aforementioned tanks and generally does not reach beyond the plow zone (34), it might be instructive to briefly extend on another lysimeter series. In this experiment, four soils under different fertilizer treatment were studied with respect to quantity and composition of the drainage water passing through a 7-inch depth or the normal plowed zone during the 5-year period 1929-1934 (55). Two relatively sandy soils, Merrimac loamy sand and Merrimac sandy loam, and two relatively loamy soils, Enfield very fine sandy loam and Wethersfield loam, were used. Each of the nitrogen treatments applied on May 26 of each year supplied 200 pounds of nitrogen per acre.

The picture of leaching seen from this work and from nitrification studies on field plots is as follows: a summer rain of less than an inch rarely produces leaching unless the soil is practically saturated by rains occurring during the preceding 2 days. After a week or more without rain, 2 inches of precipitation cause little or no leaching on loamy soils but may seriously deplete the available nitrogen from sandy soils. Severe storms with a rainfall of 4 inches or more within a 3-day period remove 50 to 75 per cent of the nitrate nitrogen from loamy soils, and 75 to 90 per cent from the sandier soils. However, if the leaching takes place during the first 2 or 3 weeks after the fertilizer is applied, a comparatively small proportion of the nitrogen from such non-nitrate materials as urea, cottonseed meal, or sulphate of ammonia will be lost, even though the rainfall is quite heavy. Severe leaching occurring 6 weeks or more after the fertilizer is applied practically exhausts the available nitrogen potentiality of the fertilizer, irrespective of the forms in which the nitrogen is supplied (55).

From all of this information emerges the concept that the use of natural organic nitrogen, i.e. "meals," normally insures a sufficient supply of nitrates for about 6 weeks after application at planting time. By then the meals are greatly nitrified and susceptible to leaching. After excessive rains following that period, side dressing with additional nirtate nitrogen is desirable.

Much cheaper organic nitrogen sources, such as urea, more quickly and completely available than the natural organics, give nearly the same protection against early leaching. They may need to be supplemented by a later side dressing of nitrate nitrogen at the time of one of the last cultivations, if weather conditions are favorable for leaching.

The difference in the applied-to-the-soil cost between meals and urea is then the price paid for insurance against leaching for 2 to 3 weeks, from the time of the last cultivation until about 6 weeks after planting. Usually this period will cover the first half of July, a month in which the amount of leaching is decreasing rapidly as compared with June (Table 3). An analysis of the rainfall data of the Hartford weather station over the last 30 years shows that only once out of every 5 years is the rainfall for the period July 1 to 15 more than 2.2 inches. As mentioned earlier, only if this amount came as one persistent rain would the root zone of tobacco grown in relatively sandy soils be depleted of nitrates after a week or more without any precipitation. Loss from loamy soils is even more rare. Irrigation, of course, will increase somewhat the probability of leaching.

Finally, we shall consider the most leachable inorganic nitrogen form, nitrate. Nitrates can be leached from the soil in June as well as in July if sufficient rain falls. Leaching occurred in 7 out of 11 years in the experiments summarized in Table 3. Consequently, nitrates as a single source of nitrogen fertilizer will need to be supplemented with side dressings most of the time in June and about 1 out of 5 years in the first half of July. As shown by experiments here mentioned, 200 pounds of nitrate of soda applied in five fractional applications provided a supply of nitrate at a rate about equal to that of any of the meals.

Therefore, the difference in cost between meals and nitrates is the premium paid for insurance against leaching in June and the first half of July. However, this saving in fertilizer cost must be balanced against the extra labor involved in the fractional applications.

Natural Organic Nitrogenous Materials Other Than Oil Seed Meals

Along with chemical fertilizers these fertility sources, especially if "home-grown," can be used to economize in the fertilization of Connecticut tobacco. These materials, such as animal manures, have value in maintaining fertility and improving the soil because of the plant nutrients and organic matter they contain. Besides nitrogen, these natural organics contain other plant food and also traces of minor elements, as do the oil seed meals. The greater portion of the nitrogen is in slowly available forms.

Farm manures. Manures of various kinds were the first fertilizers used in growing tobacco in Connecticut. Even after the commercial mixtures came into use, manures are still used on many farms as a supplement (1).

Horse and cow (stable) manure contains all of the plant nutrients needed and, for the tobacco crop in general, is an excellent fertilizer, especially on high phosphate land, or on land where proper phosphate applications are made (10, 11, 12, 13, 14, 16, 18, 24). There is, however, a wide variation in the nutrient value of manure. Solid manure is lower in nutrient value than the liquid. Much of the nitrogen may be tied up and not available for the plants if it contains considerable straw, shavings, leaves, or other bedding material. Its nutrient value varies also with time and method of storage, and with the ration consumed by the animal. Packed, rotted, and protected manure is much higher in nitrogen than fresh manure. To avoid leaching and loss of nitrogen and potash, stored manure should be protected from the rain. Unless manure is handled with fairly good care, much of the nitrogen, especially ammonia, is lost. Manure should be plowed under immediately after spreading to reduce loss of nitrogen as ammonia (19). If a great portion of the nitrogen is lost, then the manure is useful mainly for improving the physical properties of the soil.

Because of the variation in kind and quality of litter in stable manure, it is customary in the Connecticut Valley to calculate the crop-producing value of the nitrogen in manure at about 50 per cent of that shown by Table 4. For example, if 10 tons of manure (containing about 100 pounds of nitrogen) have been spread on an acre, the nitrogen in the commercial mixture can safely be reduced by 50 pounds. Some unpublished field tests and the experience of many growers support this estimate (1). A similar conclusion was reached in *West Virginia* on loam soil. On the basis of yield, manure furnished about 4½ pounds of nitrogen per ton. However, its beneficial effect on quality and value of burley tobacco indicated that it had accessory effects as well (11).

Table 4. Typical composition of manures (19)

Kind of manure	Nitrogen, pounds	Phosphoric acid (P_2O_5), pounds	Potash (K_2O), pounds
	Nutrients contained in 1 ton of moist manure, usually 75 to 80 per cent water content		
	Ave.	*Ave.*	*Ave.*
Fresh manures			
Horse, with straw	11	6	13
Steer, with straw	11	7	10
Dairy cow, with straw	9	6	8
Sheep, with straw	20	9	17
Hog	13	13	10
Poultry	18	18	10
Stall manure, fattening cattle	12	6	11
Yard manure, fattening cattle	8	5	3
Mixed horse and cow, fresh	12	6	15
Same rotted 6 months, protected	34	22	51
Same rotted 6 months, exposed	16	11	21

Potash and phosphorus in manure are about equal, pound for pound, to the same element in the commercial tobacco mixture and may, therefore, be reduced to the extent that they are supplied in manure. Manure is very effective in introducing potassium into the tobacco plant (16). The phosphorus content of manure is relatively low, but this deficiency is offset by excellent availability (12). The liquid portion of manure contains more than three-fourths of the potash (beside half the nitrogen), so sufficient bedding must be used to fully conserve this plant food. Superphosphate at the rate of 1 pound a day for each cow, used in the gutters or on the walks, will make cow manure a better balanced fertilizer and also help hold some nitrogen (20).

In *Wisconsin* the economy of the grower of binder tobacco is very closely tied up with the dairy farm and a plentiful supply of manure, which is supplemented with commercial fertilizer. A ton of manure is considered to supply about 10 pounds of nitrogen, 5 pounds of phosphoric acid and 8 pounds of potassium (18). To maintain a satisfactory level of fertility under continuous culture, an annual application of 12 to 15 tons of manure, plus 800 to 1000 pounds of commercial 3-9-18 tobacco fertilizer, is necessary.

Heavy applications of manures (20 to 30 tons annually) over a long period of years has sometimes been found to impair the burn of tobacco grown on the predominantly silt loam soils of Wisconsin. Poor burn is caused by the small amount (0.5%) of chlorides present in the manure. The detrimental effects of the chlorides can be controlled by the use of only low chloride commercial fertilizers on the farm and by raising the available amount of potash in the soils high enough to overcome the detrimental effects of the chlorides. The burning quality of the tobacco is due mainly to the balance between beneficial potassium and harmful chlorides in the leaf.

Tobacco grown for the synthetic or reconstituted binder market, however, could be raised with less care in this respect, since burning properties of the binder sheets can be controlled artificially. Furthermore, on the predominantly coarse to medium-textured tobacco soils in Connecticut, with good subsoil drainage, most chlorides are probably leached out of the root zone before they build up in the soil and cause luxury uptake.

Pennsylvania tobacco growing in the filler district is also a part of a well stabilized and diversified agriculture including steer feeding and dairy farming (12).

A variety of sources of barnyard manures have been found acceptable at the Tobacco Experiment Station at Lancaster. Best results have been produced by the application of steer, dairy cow, and horse manure, and sewage sludge. The more concentrated poultry and sheep manures should be used in reduced quantity or with allowance of adequate time for decomposition and leaching (12, 20).

If used with fertilizer (1000 lbs. of a 4-8-12 grade per acre), 15 tons of stable manure per acre is the most economical rate for the fertilization of Pennsylvania cigar filler tobacco.

The manure can be used on the crops of a traditional 4-year rotation rather than concentrated on the tobacco. Legume-grass mixtures are advocated to maintain a high level of organic matter. The use of manures also improves the physical character of the soil by increasing its capacity to take in and hold water, its aeration, and its temperature relations.

On the predominantly silt and clay loam soils of southeastern *Pennsylvania*, a liberal application of manure to the crop preceding tobacco is doubly beneficial because the release of nutrients from manure is gradual. For example, if the preceding crop grew in a dry season, the yield of tobacco may be greater from fields that received manure the preceding year than from fields manured in the year in which tobacco is grown. The most effective use of strawy manure is as a surface mulch.

The cigar tobacco of *Quebec*, Canada is grown largely on loamy soils in rotations of 4, 5, or 6 years with oats or barley, hay (preferably leguminous) and pasture. Growing tobacco for 2 or 3 years consecutively in the rotation is recommended. The cigar tobacco crop is very exacting as to organic matter; plowing under hay will complement the necessary application of farm manure (10).

Since maintaining organic matter is very important, the application of from 10 to 20 tons per acre of farm manure is advocated, according to the level of organic matter in the tobacco soils. Farm manure is considered as indispensable as a complement to chemical fertilizer, and a mixture of horse and cow manure seems to be the most effective.

Chemical fertilizers, 500 to 1200 pounds of a 5-8-7 or a 5-8-10 grade per acre according to the richness of the soil, are broadcast a few days before planting or before building ridges, if planting is done on ridges. They may also be applied in bands on each side of the row at planting time with a special attachment on the transplanter.

When tobacco is grown on the same land year after year, as is a common practice in the Connecticut Valley, continuous and heavy use of stable manure may encourage the development of black root rot since manure has a tendency to "sweeten" the soil. This objection may be overcome, however, by strains which are resistant to root rot, by crop rotation or possibly by vertical rotation through deep plowing every 3 to 5 years.

Poultry manure. The use of poultry manure on Havana seed tobacco was investigated at the Tobacco Laboratory in 1942 (21) and 1947-1949 (22).

Poultry litter manure, dropping board material mixed with bedding and waste from the floors of the chicken houses, is a valuable fertilizer material. Dropping board manure contained 1.1 to 1.3 per cent nitrogen, 0.7 per cent potash and 36 to 58 per cent moisture; litter manure about 2 per cent nitrogen, 0.6 to 0.7 per cent potash and about 26 per cent moisture. Phosphoric acid content was fully as high as that of nitrogen.

Five to six tons per acre of litter-mixed material was found to produce a crop about as valuable as that produced by nearly eight tons per acre of manure from dropping boards. Little or no difference was found between plowing under and harrowing in the manure, but somewhat better burn was obtained by plowing under. When half, or 100 pounds of nitrogen per acre of a regular application of commercial fertilizer was replaced with poultry manure, yield, quality, and burn were equal to those produced by commercial fertilizer alone. Supplying all the nitrogen as poultry manure produced satisfactory yields; grading and burning qualities did not quite measure up to results from standard commercial fertilizer, but these are now less important considerations for certain tobacco uses.

Since poultry manure is relatively low in potash, it is important to furnish additional amounts of this constituent. If the manure is composted, it may be layered with tobacco stalks or stems; otherwise, the manure may be enriched with 40 to 50 pounds of sulfate of potash per ton, or the equivalent of other forms of potash (obviously excluding muriates). If potash was not added, either in storing or in application, there is still time to give extra potash when side dressing the crop. Nitrate of potash may be one of the materials used.

Under the soil and climatic conditions of the filler district of southeastern *Pennsylvania*, it was found that poultry manures must be used with care as to amount and time of application. Poultry manure at the rate of 7½ tons per acre applied about a month before spring plowing resulted in top yields approaching a ton of tobacco per acre. However, due to an oversupply of nitrogen the tobacco was dark and oily and the quality was considered lower than tobacco grown with stable manure (20). Lower rates of application on these heavier and more retentive soils should correct this defect.

Green manuring with winter cover crops. Green manuring is a common way to supplement or replace organic or stable manure and is often used in vegetable rotations. Green manure or plowed-under cover crops add nitrogen to the soil for use by the following crop. Unfortunately, the amount and availability of the nitrogen thus supplied is even more difficult to control than with the use of animal manures.

With continuous tobacco the use of winter cover crops plays an important role. Oats, rye, or barley are commonly used on tobacco land in the Connecticut Valley (26). One of its major values is to conserve plant nutrients against winter leaching (23). After the tobacco is harvested, there is a considerable unused surplus of plant nutrients, part of which may be lost before the next tobacco season by leaching out, washing, or blowing off the soil or by becoming unavailable within the soil. In experiments at the Tobacco Laboratory, 56 pounds of nitrogen per acre were saved annually by an oat cover crop seeded at the rate of about 2 bushels per acre (9).

In other cigar-tobacco growing areas rotations of 3 to 5 years are generally practiced with legume-grass sod, corn or vegetables (10, 12, 24). In *Wisconsin* rotation is recommended if soil-borne diseases or soil erosion makes it necessary. Manure and tobacco fertilizer is used on corn for 2 years after sod before planting the field to tobacco (18).

Legumes, which not only conserve the plant food already in the soil but also add nitrogen from the air, have not been found satisfactory for cover crops on Connecticut tobacco soils. The main objections are the risk involved in obtaining satisfactory stand and growth of the crops, the cost of growing them, and adverse effects upon the quality of the tobacco (26). Vetch proved the best and most dependable legume cover crop (7).

In *Maryland* better returns from tobacco were obtained by using winter cover crops which contained both legumes and nonlegumes than by using either legumes or nonlegumes alone (27). Determinations of the amount of the total nitrogen incorporated into the soil by the cover crop showed a range from 40 to 190 pounds per acre. The decomposition of the cover crops as reflected by the soil nitrate nitrogen accumulation curves did not begin until about 3 to 4 weeks after the cover crops were plowed under (unless the cover crops were very high in nitrogen).

At Beltsville, rye grass alone reduced yield (nitrogen deficiency) and vetch alone lowered quality (excess nitrogen). Highest yields and quality of tobacco followed cover crops of rye and vetch or rye grass and vetch. Late turning (about May 15) of the mixed cover crops was better than early turning (about April 15). Without vetch, late turning decreased yields. Aside from applying more organic residues to the soil, late turning promoted a larger yield of tobacco of as good a quality as early turning (28).

Structural soil conditions are best improved and maintained by the heavy yields and more fibrous residues of the nonlegumes, such as rye grass. The legumes serve to add nitrogen to the residues of the nonlegumes, which are high in carbohydrates and low in nitrogen, so that their decomposition can proceed without tying up nitrogen needed by the following tobacco. The nitrogen-consuming effect of the plowed-under grasses controls the soil nitrogen accumulation derived from the readily decomposing legumes and this balances the nitrogen nutrition of the following tobacco. Whether the value of such a plowed-under, mixed cover crop to the following tobacco is more closely associated with nitrogen nutrition than with improvement in physical soil properties depends upon the soil, type of tobacco, and its management.

Nitrate depression following the plowing under of nonlegume cover crops is less serious with Connecticut tobacco than with most tobacco types since the nitrogen fertilization is so liberal. Much more nitrogen is applied in the fertilizer than can be utilized during the first few weeks after setting, and much of the nitrates temporarily tied up in the decomposing cover crop residues are restored to the soil solution by the time the tobacco begins to make heavy demands upon the soil (30).

However, such nitrogen-consuming effect can be averted by reinforcing the cover crop residues with enough nitrogen to raise their nitrogen content at least to about 1.5 per cent on a dry-matter basis. So, if rye or wheat straw containing 0.75 per cent nitrogen is plowed down, 15 pounds of actual nitrogen per ton of straw or the equivalent of about 50 pounds of nitrate of ammonia are sufficient to satisfy the needs of the soil's microbial population in rotting the organic matter (68).

Nitrogen fertilization of winter cover crops. Nitrogen fertilization of nonleguminous winter cover crops will increase their nitrogen content and produce residues somewhat comparable to those of legume-nonlegume mixed cover crops.

In view of our search for suitable substitutes for the expensive oil seed meals, the most important feature of applying nitrogen on cover crops is the feasibility of transforming mineral and synthetic nitrogen sources into nitrogenous green manure. In this way cheap nitrogen carriers can be applied to nonleguminous winter cover crops which under Connecticut conditions can be grown more satisfactorily than legumes. The nitrogen thus supplied plus the nitrogen and other nutrients left over by the preceding tobacco crop are absorbed and stored in the large amounts of organic matter produced; these stored nutrients are then released gradually as the plowed-under residue begins to decay.

The application of commercial fertilizer for growing cover and green manure crops as well as for the cash crop has been practiced intensively on the farms of the Seabrook Farming Corporation in *New Jersey*. Over 5 years, the yield of the cash crop has increased approximately 40 per cent without any increase in the application of fertilizer (31). Grass cover crops (rye grass, wheat, rye, and barley) which received 60 pounds of nitrogen or less, drew upon the soil nitrogen for decomposition for 7 to 9 weeks after they were plowed under. Those receiving 120 pounds of nitrogen and those mixed with legumes (crimson clover), stimulated the growth of the following corn crops from the very beginning.

The net amount of nitrogen released from an organic material depends on its nitrogen content, the degree to which it is decomposed, and the amount of nitrogen used by the decay organisms. If the plant material contains 1.5 per cent nitrogen on a dry-matter basis, the supply seems to be about adequate for microbial needs. If the nitrogen content is above 1.5 per cent, then most of the extra nitrogen will be released for plant use (25, 56).

In Connecticut, as well as in other states, no thorough tests have been made to establish for tobacco the value of this practice of transformation of mineral fertilizers into high protein cover crop residues. For Connecticut conditions it is important to investigate to what extent top dressing for winter cover crops with inorganic nitrogen could reduce nitrogen leaching and could replace the expensive oil seed meals for the following tobacco crop.

Recent work at the Tobacco Laboratory gives us some useful indications in this connection. The observations were made on a coarse-textured, leachy Windsor sandy loam, average organic matter content 1.1 per cent.

In the later part of September, 1954 the experimental field was plowed 11 inches deep after being fallow for some years. On September 24 several cover crops were seeded with a starter application of 16 pounds of nitrogen per acre in the form of nitrate of soda. On March 19 the overwintered cover crops on some plots were top dressed with 48 pounds of nitrogen which resulted in a much more vigorous top and root growth of these plants. The nitrogen content of top growth of some of the cover crops cut by hand on May 10 are shown in Table 5.

Table 5. Yield and nitrogen content of tops of 3 cover crops

Crop*	Relative dry weight	Nitrogen, per cent
Rye	100	1.23
Oats, rye + vetch	100	1.46
Oats, rye + spring-applied 48 lbs. N.	150	2.39

*Rosen rye seeded at the rate of 2½ bushels to the acre; Clinton oats and rye mixtures at 1 bushel to the acre each; hairy vetch at 40 lbs. to the acre.

On May 12 and 13 the whole field was shallow plowed 6 to 7 inches deep and fertilized at 2 nitrogen levels on June 6. The results (Table 6) indicate that a relatively small application of nitrogen at the rate of 48 pounds per acre fed to the cover crop in early spring can provide a sustaining source of nitrogen for the following Broadleaf tobacco crop, especially on coarse-textured soils under severe leaching such as occurred during the growing season of the experiment.

On the highly fertilized tobacco land in Connecticut it seems logical to expect better results from early spring than from fall applications of nitrogen on the winter cover crops. If seeded as soon as the tobacco is harvested, the nutrients left over from the tobacco fertilization will be absorbed by the cover crops and usually more than suffice for their fall growth (30). Then, early spring fertilization will get the small grains off to a quicker start, increase stooling, and produce lush plants with a deep green color and higher protein content. Such a cover crop should be turned under by the time the heads just start to show. Then the small grain has its highest concentration of nitrogen; further growth merely adds strawy material which rots slowly.

Table 6. Effect of cover crop fertilization on yield and quality of Broadleaf tobacco grown at two different nitrogen levels

Treatment	Yield/per acre	Grade index*
	Lbs.	
High N-fertilization of tobacco (3900 lbs. 6-3-6 tobacco mixture/A)		
Oats	1706	0.48
Oats, rye, and additional N, 48 lbs./A on rye	1920	0.57
Low N-fertilization of tobacco (1800 lbs. 6-3-6/A and additional phosphate and potash at the rate of 2100 lbs. 0-3-6/A)		
Oats	1495	0.29
Oats, rye, and additional N, 48 lbs./A on rye	1727	0.49

*Grade index as used here is a number expressing the grading quality of tobacco produced under the conditions of the experiment. It is based on a system used for many years at the Tobacco Laboratory (for further explanation of how these relative values are computed, see for example reference 22). The higher the index, the higher the quality.

Application of nitrogen fertilizers to winter cover crops for more vigorous top and root growth should be helpful to provide soil cover to improve soil structure and preserve tilth (34). More work, however, is needed to establish the value of this practice for the nitrogen nutrition, growth, and quality of the following tobacco.

If applying fertilizer to the cover crop for utilization by the following tobacco seems wasteful, let us remember the wastefulness of the fertilization ordinarily practiced today. Only 50 to 60 per cent of the nitrogen in cottonseed meal and 70 percent of the nitrogen in castor pomace is made available to tobacco during the growing season (22, 50, 51). This means that some 30 to 40 per cent of the nitrogen from the expensive oil seed meals is unavailable to the tobacco.

Some disadvantages have been attributed to luxurious growth of cover crops, especially when turned under late in the spring. The increased draft on soil moisture increases the hazard of water shortage for the young tobacco plants in dry years. Furthermore, when turned under, the cover crop may make such a mat of loose material in the soil that during a dry early season, the soil will not retain sufficient moisture for the best start and development of the tobacco transplants (7).

We believe that these hazards are not too serious. Supplemental sprinkler irrigation, recently coming into more general use, helps to solve this problem. Experiments and results in commercial operations have shown that irrigation immediately after transplanting often gives a much better stand (57). Thus, in dry years regardless of the drying effects of luxurious cover cropping, irrigation is highly desirable; otherwise imperfect stands of transplants will appear, stands which always result in loss of yield despite replanting.

In years with a wet early summer, however, the removal of water from the soil profile by the cover crop is certainly advantageous. It lessens materially the amount of water passing through the soil and thus decreases the early leaching losses of plant nutrients after fertilizer application (23). This leaching early in the growing season is one of the important problems in raising tobacco in Connecticut's sandy-textured soils as has been described in a previous chapter.

Sewage sludge. Activated sludge, which has a higher nutrient content than digested sludge, is dried by heat to a moisture content of 5 to 10 per cent if it is to be sold as fertilizer. This material contains about 30 to 40 per cent of ash, 5 to 6 per cent of nitrogen, and 1 to 3.5 per cent of phosphorus. Available nitrogen in activated sludge is almost equal to that in cottonseed meal. Furthermore, sludges contain many of the minor elements in appreciable quantities available for plant growth (35).

Eventually this very useful by-product of sewage treatment works may be produced in large quantities and possibly for lower costs. Unfortunately not much work has been done to determine the nitrogen supplying value of sludges for tobacco.

In *Pennsylvania* a 6-year comparison of 11 manurial treatments was started in 1941. Among manures applied at 15 tons per acre and plowed under in the spring the second largest yield was obtained with sewage sludge (obtained from the Lancaster sewage disposal plant) which contained about 4 per cent of nitrogen. The larger portion of this nitrogen was available because of the activation of the sludge. As mentioned before, the best yields were secured from an application of a partly rotted mixture of horse and stockyard manure (20).

Digested sludges are seldom sold for fertilizer because of their low content of plant nutrients. Studies at The Connecticut Agricultural Experiment Station at New Haven as well as those conducted elsewhere show that these sludges have considerable value for soil improvement, comparing favorably with manure if toxic industrial wastes are absent (36).

In the only test of digested sludge on Connecticut tobacco, yields were reduced, apparently due to the high application of sludge and fertilizer (37).

Sewage sludges and garbage wastes will undoubtedly become more important as organic nitrogen fertilizer materials. The cost of converting raw sewage and garbage into forms suitable for use as fertilizers, and their comparatively low content of nitrogen, make them uneconomical to produce if the sole aim is to produce fertilizer. The cities, however, must dispose of their wastes regardless of costs. In many instances the sale of fertilizer or compost could possibly reduce the costs of waste disposal (56).

Synthetic Organic And Inorganic Sources Of Nitrogen

At the Tobacco Laboratory several extensive studies were undertaken to determine the efficiency[1] of various materials of this group of nitrogen fertilizers for Connecticut tobacco. Inorganic nitrogen and that in synthetic organic forms such as calcium cyanamide and urea are generally much cheaper pound for pound than that in the commonly used natural organic forms such as oil seed meals.

Synthetic organic sources of nitrogen. *Urea* and *urea compounds,* which are soluble sources of nitrogen, produce greater amounts of nitrates than any of the natural organics, yet in the same order and at a rate in accord with the plant's requirements (2). In spite of some objections to its ready decomposition (2, 40), urea is an excellent source of fertilizer nitrogen for tobacco and can replace a part (43), or all (42), of the natural organics when used on the basis of its higher availability (see also Table 8).

After 10 years of experiments on nitrogen sources at Windsor the following optimistic statement was made in 1937. "While the trend to urea as a source of nitrogen in tobacco fertilizers must operate against a practice of several generations, it appears inevitable that this cheaper nitrogen source will gradually replace (meal) materials now supplying as much as a ton of (nitrogenous) organic matter per acre" (30).

[1] Efficiency of a nitrogenous material refers to its relative capacity to supply available nitrogen to the growing crop as compared with the performance of cottonseed meal, the "standard material."

Urea-form, a urea-formaldehyde reaction product, is sparingly soluble in water and was developed to supply nonleachable nitrogen. It is a relatively new material, has quickly become competitive with natural organic products on the basis of nutrient cost, and is designed to release its nitrogen in a manner similar to that of high-grade natural organics (41). Experiments at Windsor in 1948-50 showed that urea-form could replace other nitrogenous materials and provide a nitrate supply tailored to the demands of tobacco (38).

Calcium cyanamide is considered ideal for pre-plowing application on non-legume cover crops because of its high content of calcium which is transferred into hydrated lime in the soil. Its nitrogen is released in the form of urea when thoroughly mixed with moist soil before planting. Cyanamide has an alkaline effect on soil reaction which must be considered in balancing the fertilizer mixture. The total active lime content is equivalent to 70 per cent hydrated lime; the nitrogen content is 21 per cent.

At Windsor, cyanamide was used to replace one-fifth of the fertilizer nitrogen with good results (2). In Massachusetts one-half of the total of 175 pounds of nitrogen to the acre was supplied by cyanamide and the other half by cottonseed meal in a nitrogen-source experiment. Cyanamide produced yields and quality comparable to the standard mixture. All treatments produced tobacco of better than average yield and grade throughout the experiments as a whole.

These results indicate that calcium cyanamide can be used to supply at least 80 pounds of nitrogen per acre in mixed fertilizers. A pre-plowing application of cyanamide should not be considered less effective as long as it is plowed under not too long before the usual time of fertilizing.

Inorganic sources of nitrogen. *Nitrate of soda* is the most common material in this group. Connecticut growers are familiar with its use, especially as a side-dressing material, applied when it is necessray to add readily available nitrogen quickly after excessive rains (1).

Nitrate nitrogen, as mentioned before, is the most suitable form for tobacco. It is at the same time the only source of nitrogen subject to serious loss by leaching. We have already discussed leaching losses and how they can be prevented at a premium by organic sources of nitrogen. We shall now see how losses are compensated for by the method of fractional application (Table 7).

Table 7. Yield and grade index of tobacco produced with sodium nitrate and cottonseed meal (2)

Period	Description of conditions	Yield, lbs. per acre	Grade index
1926	Nitrate applied at planting, dry year	1440	.35
1927-1931	Nitrate applied at planting, normal years	701	.14
1932-1935	Nitrate applied in 5 applications*	1741	.42
1932-1935	Cottonseed meal applied at planting	1811	.34

*The five applications of nitrate of soda, each supplying 40 pounds of nitrogen per acre, were made at about 10-day intervals. First application was made a few days before planting together with all other nutrients called for in the formula; next was made a few days after planting; the rest at 10-day intervals or immediately after heavy rains. The last application was made within the first week of July.

When leaching is minimized as in 1926, a relatively dry year, or by fractional application, good yields of the highest grade tobacco were produced with nitrate of soda as the only source of nitrogen (2, 44, see also Table 8). The practicability of methods of adding nitrate salts to the soil at the proper time and as needed by the tobacco will be discussed later.

According to nitrogen-source studies in *Massachusetts*, nitrate of soda gave the best results as measured by the crop index of Havana Seed tobacco. On these experiments only one-half of the nitrogen in the fertilizer mixture was supplied by nitrate of soda, the remainder coming from cottonseed meal (43).

Ammonium nitrate is also a readily soluble material. The ammonium radical of this salt, however, is much less subject to leaching than the nitrate portion. The ammonium is fairly readily converted to nitrate. Ammonium nitrate was tested extensively at Windsor in a search for suitable nitrogen compounds as substitutes for the expensive oil seed meals (22). During a 5-year period, 1944-49, various phases of its possible use in fertilization of Havana seed tobacco were studied. From the results of the experiments as a whole, it is concluded: (a) A maximum of 175 pounds of nitrogen to the acre from ammonium nitrate has a crop-producing power almost equal to 200 pounds of nitrogen in cottonseed meal with both yield and quality evaluated, (b) Side dressing ammonium nitrate at the rate of 75 pounds of nitrogen per acre at the time of second hoeing (4 to 5 weeks after planting), to supplement a commercial mixture applied before the crop was planted, produces better quality than cottonseed meal alone and is also significantly more advantageous than using the ammonium nitrate as a single nitrogen source.

In *North Carolina* ammonium nitrate proved to be an excellent fertilizer material for burley tobacco when used as the only nitrogen source or in a mixture in which one-third of the nitrogen was derived from cottonseed meal and two-thirds from ammonium nitrate (45).

Ammonium sulfate, another relatively cheap source, has been considered in Connecticut to be the least desirable of all the nitrogenous substances tested under continuous applications (58). This material produced good yields of fair to good quality tobacco during the first 6 of 10 years of field experiments with single sources of nitrogen. During that time the soil had become so acid that yields for the last period were low and the crop was of poor quality (4 and Table 8).

During the first two periods, the yields secured with cottonseed meal were not as high as those with ammonium sulphate. Cottonseed meal, however, produced good yields during the entire experiment and the quality was generally good. Ammonium sulphate produced a higher quality during the first period and sodium nitrate produced a higher quality during the last period. Throughout the entire experiment, urea produced more and better quality tobacco than did cottonseed meal.

In another 4-year experiment ammonium sulphate, with sufficient lime to neutralize the soil acidity, kept the yield up to the level of other sources of nitrogen. The use of lime also improved the quality, although the tendency of ammonium sulphate to produce more dark, heavy, and veiny tobacco had not been completely overcome(2).

At present, with the shrinking market for natural binder, ammonium sulphate could be used to supply a part of the nitrogen in tobacco fertilizer mixtures. Its acidic effect on soil reaction, however, should be considered in balancing the fertilizer mixture (Table 1). Ammonium sulfate nitrifies in the soil at the lowest rate of all materials investigated (40) and is not easily leached from the soil.

Table 8. The yield and quality of Havana seed tobacco produced with different sources of nitrogen

Period	Sodium nitrate*	Ammonium sulphate	Cottonseed meal	Urea
		Yield, pounds per acre		
1926-1928	904	1267	1018	1131
1930-1932	1071	1615	1587	1668
1933-1935	1760	1060	1484	1912
Ave. 1926-1935	1245	1311	1363	1570
		Quality†		
1926-1928	.21	.35	.30	.39
1930-1932	.23	.35	.39	.41
1933-1935	.42	.15	.35	.37
Ave. 1926-1935	.29	.29	.35	.39

*Prior to 1932 all sodium nitrate was applied before planting, as were the other materials. Beginning in 1932 sodium nitrate has been applied in 5 fractional applications.

†The larger the figure (grade index), the better the quality.

Experiments with Havana seed tobacco in *Massachusetts* showed that neither yield nor quality suffered materially by replacing part (up to 70 pounds nitrogen per acre) of the standard mixture with ammonium sulfate (43), except for a slight impairment of the fire-holding capacity of the tobacco, which should not effect its value for converting into binder sheet.

Anhydrous and *aqua ammonia* are the cheapest sources of nitrogen. The use of these fertilizers is growing rapidly, particularly in the Midwest where contract or custom service is proving to be popular for the application of anhydrous ammonia. Such forms offer attractive advantages with reference to net cost of nitrogen, but problems of distribution and placement need further study (59). To our knowledge, no extensive tests have been made as yet to find out whether these nitrogen sources are suitable for tobacco.

However, the effect of these sources on the tobacco can be expected to be somewhat similar to that of ammonium sulphate. The acid effect of the anhydrous ammonia on the soil is even greater than that of the latter material (Table 1). The ammonia is not readily leached from the soil. It tends to be retained by the soil until it has been changed to nitrate. This change is usually delayed for some time since the ammonia has a partial sterilizing effect on the soil in the vicinity of its point of injection into the soil (33). This delay in nitrification is comparable with the low rate at which ammonium sulfate nitrifies in the soil. Therefore, the use of anhydrous ammonia as a single source of nitrogen can be expected to have the same deleterious effect on the quality — more dark, heavy, and veiny tobacco — as that described from ammonium sulphate as a single source.

Non-pressure nitrogen solutions which do not contain ammonia may be satisfactorily applied on the soil surface. These liquid nitrogen materials are water solutions of ammonium nitrate alone or with urea and contain 16 to 32 per cent of nitrogen. They require simpler and less expensive equipment for transportation, storage, and field distribution than anhydrous ammonia does. However, the difference in cost per unit nitrogen as derived from these solutions and the comparable solid forms of these materials is negligible. Furthermore, the solid formulations are better adapted to smaller operations than the application of liquid or volatile types of fertilizers.

Several other nitrogenous materials were tested at the Tobacco Laboratory. The findings of these experiments are reviewed and discussed in several bulletins and reports (1, 38, 7, 46, 47, 2, 58). Further discussion of the value of most of these nitrogen sources for Connecticut tobacco is not warranted because most of these other nitrogenous materials are comparable in their effect to one of the materials already discussed.

Rate Of Application

Under the conditions of almost continuous tobacco culture on the predominantly coarse to medium textured soils in the Connecticut Valley, it has been found that a comparatively high rate of application of fertilizer nitrogen is necessary for growing tobacco of high yield and quality.

The highest yield of Havana seed tobacco regardless of quality was obtained from about 300 pounds of nitrogen, all derived from standard organic materials, cottonseed meal being the main source. However, the best quality on average tobacco soil was secured from 200 pounds of organic nitrogen from these sources. On land that is heavier, less leachy, and naturally more retentive of fertility, the optimum may well be below 200 pounds to the acre (30).

In *Massachusetts,* on somewhat heavier land with a less leachy subsoil, optimum results were obtained at 165 pounds of nitrogen to the acre. Here the fertilizer nitrogen came from the following sources: one-half from cottonseed meal, one-fourth from calurea, about one-seventh from nitrate of potash, and the remainder from nitrate of soda (43).

As a result of extensive fertilizer experiments conducted by this Station at Poquonock (1892 to 1897) about 200 lbs. of nitrogen per acre has become the standard practice. From two-thirds to four fifths of this is from "organics" such as cottonseed meal, castor pomace, linseed meal, and fish. The remainder is from nitrate of soda, ammonium nitrate, nitrate of potash, or urea.

However, in determining the optimum amount of nitrogen to be applied to specific land it should be borne in mind that the response of the tobacco crop to applied nitrogen is governed by a complexity of factors. First of all, this response is influenced by the interaction of quantity and distribution of rainfall with the physical and chemical properties of the soil. This interaction determines the supply and distribution of nitrate nitrogen in the zone of root activity and thus affects its absorption by the plant. Further, the response to applied nitrogen is influenced by the level of residual nitrogen in the soil and by the nitrogen availability of the fertilizer material in which the nitrogen is supplied.

As this publication concerns itself mainly with fertilizer sources and practices, we shall briefly extend on only the last two factors, source and residue of nitrogen.

Although the chemical nature of soil nitrogen is not completely understood as yet, it is well known that soils like ours contain several hundred pounds of organic nitrogen per acre, part of which becomes available during the growing season by the process of nitrification (23). Most nitrogen is stored in the older, more

stable fraction that comprises the greater part (90 per cent or more) of the total organic matter. However, the residual effect of the newer and more dynamic fraction, the residues of the preceding crop and its applied organics, is usually greater than that from the total accumulation of all older residues combined (63).

A good reserve of organic matter in the soil may take an important part in the nitrogen nutrition of the tobacco crop. This was shown in our earlier discussions of the management and fertilizing practices in producing cigar tobacco in Wisconsin, Pennsylvania, and Canada. In these regions, rotations with other crops, preferably with a legume-grass mixture, and manuring are practiced to obtain and maintain the "luxury" level of nitrogen fertility needed to produce quality tobacco. Their soils, however, are generally heavier than ours, varying from loams to silty clay loams. As is indicated by their relatively high organic matter content, it is quite feasible to build up the inherent fertility of such soils.

Now let us examine the history of this residual effect of fertilization in tobacco growing on the sandy-textured tobacco soils of the Connecticut Valley.

The first evidence that a fairly good reserve of fertility is essential for Connecticut tobacco production is given by the fact, well known to growers, that new land as a rule does not grow a good crop of tobacco during the first 3 to 4 years.

In the early part of the century manure was rather generally used and fertilizers were almost exclusively of organic materials, supplying from 2000 to 3000 pounds of organic matter per acre. Under such conditions, it must have been possible to maintain soil fertility without cover crops under the traditional continuous tobacco. Extensive investigations have shown no evidence of decline in soil organic matter in these old tobacco soils (62).

A distinct residual effect of a preceding 10 years of heavy manure application was found to last for 2 years at Windsor (42). If available, manure is still used as a supplement to commercial tobacco fertilizer mixtures.

Today, expensive meals are used for continuous tobacco plus winter cover cropping. This apparently causes a small gain in soil organic matter. A soil containing approximately 40,000 pounds of organic matter per acre is improved to the extent of about 750 pounds per year due to the residues of the tobacco and cover crop (oats) plus the organic materials (about 2000 pounds per acre) in the tobacco fertilizer mixtures. Such an accumulation of organic matter could account for approximately 40 pounds of the annual application of fertilizer nitrogen that is neither leached nor removed by cropping (30).

Assuming that such readily soluble nitrogen sources as the nitrate salts are completely available, it is obvious that this residual nitrogen is derived mainly from the expensive organic meals. As mentioned before, the nitrogen availability of the oil meals varies from about 60 to 70 per cent so that 30 to 40 per cent is held back in the soil by the undecomposed organics and by the decay organisms.

Under the customary liberal fertilization, it is understandable that in a favorable season the tobacco does not utilize more than a small portion of this residual nitrogen. In wet years or years with poorly distributed rainfall, this additional nitrogen released from organic nitrogen residues of the soil can take a relatively important part in the nitrogen nutrition of the crop (55).

Thus, it is clear that the Connecticut grower is depending on a high-priced organic form of commercial fertilizer to build up soil fertility. The cigar tobacco growers in other areas with their more diversified agriculture accomplish this in a more economical way. They have available and utilize animal manures and residues of rotation crops to maintain soil fertility on such a high level that only a relatively small application of inorganic fertilizer is needed.

Thus, one way for the Connecticut grower to economize on this costly practice of maintaining soil fertility with high-priced organics would be to look into the feasibility of more diversification and eventual crop rotations on the tobacco farm. A second way, and for most specialized tobacco farms probably the only economical way, to get more organic matter of reasonably high nitrogen content in their soils is to grow more organic matter in the form of fertilized cover crops. This will supply a great residue or organic material with relatively decomposable nitrogen, the greater part of which will be released in synchrony with the needs of the growing tobacco and thus supplement the available nitrogen provided by the tobacco fertilizer. Furthermore, larger cover crops will mean more roots which are considered superior to manure in their capacity to improve the physical conditions of the soil.

PHOSPHORUS (P)

The liberal use of phosphatic fertilizers under continuous tobacco has resulted in heavy accumulations of residual phosphorus in the plow layer of the older tobacco soils. The usual practice is to apply 100 to 120 pounds of phosphoric acid (P_2O_5) per acre annually, although an acre of tobacco removes only about 20 pounds of P_2O_5 from the soil (26).

Phosphorus does not move appreciably in the soil and thus leaching is not a problem. However, here we deal with a different kind of problem, fixation by the soil. The purpose of these apparently superfluous phosphate applications is to furnish sufficient amounts to cover both nutrition for the tobacco and fixation by the soil (1).

Most of the total phosphorus supply in the soil is tied up in organic and inorganic compounds which are not soluble and readily available to the plant. Fertilizer phosphorus increases available soil phosphorus which is changed into fixed forms already present in the soil. Repeated restoration of the available phosphorus is necessary to meet the phosphorus requirements of the tobacco.

New tobacco land with lower amounts of fixed phosphorus and extremely acid soils with their higher hydrated iron and aluminum oxide contents will fix phosphates to a greater extent. Larger phosphate applications to bring the phosphorus level within a suitable range and liming to raise the pH help to solve this problem. At the same time, liming increases the rate at which soil microorganisms change the organic phosphorus to inorganic phosphorus which then acts as a source of supply for plant nutrition. Organic matter from manure and green or cover crop residues also increase the availability of fixed phosphorus.

Available phosphorus in abundance is needed in the early stages of plant growth; studies of phosphorus uptake usually show that 50 per cent of the total plant phosphorus is absorbed when only 20 per cent of the total growth has occurred. This explains the need for large supplies of available phosphorus early in the growing season (64).

Placing soluble phosphorus fertilizer in bands reduces contact with the soil and greatly increases the availability of the phosphorus in acid soils, getting the phosphorus into the plant without allowing the reactions between soil minerals and organisms and phosphorus to take place.

Sources of phosphorus well established in the growing of tobacco in the Connecticut Valley are *bone phosphates*, such as *precipitated bone, raw bone meal*, and *steamed bone meal* (1). Experiments at Windsor with several phosphatic fertilizers showed that best results with Havana seed tobacco were obtained from *calcium metaphosphate* and *triple superphosphate*; next in order of effectiveness were precipitated bone and bone meal (65).

The normal grade of *superphosphate* (20 per cent P_2O_5) is commonly used to correct deficient soil phosphorus levels. When this water soluble material is broadcast it readily combines with active aluminum, iron, or manganese (1). Ordinary superphosphate contains gypsum; high analysis or triple superphosphate does not. In some soils, gypsum may be of considerable value as a source of calcium (1).

Savings in phosphate fertilization, therefore, can be made by using a relatively cheap source such as triple superphosphate, and placing it in bands.

Generally speaking, producers of high value crops such as tobacco should concern themselves with raising the available levels of their soils to a point where the fixing power has been satisfied. After that, phosphate fertilization is a simple matter of maintenance by any convenient method. And band placement at planting time is an economical practice (44).

POTASSIUM (K)

Potassium is the second most important nutrient element for tobacco. It is loosely held in relatively small amounts by our acid sandy-textured tobacco soils in the Connecticut Valley. About 200 pounds of potash (K2O) to the acre is applied annually at planting time. It does not leach away as rapidly as nitrogen so additional applications during the growing season are exceptional. However, there is no great accumulation of available potash as it leaches slowly throughout the year. For this reason, it is necessary to apply the same amount annually (26).

When a high supply of readily available potassium is present and other growth conditions favorable, the uptake by tobacco may far exceed average requirements and reduce the uptake of calcium or magnesium. For example, increasing the application to 300 pounds of potash to the acre caused a reduction in yield in a 5-year test at Windsor (66).

Cottonhull ash, probably still the most commonly used carrier, contains potassium in the carbonate form. In addition to potassium it contains other beneficial elements: Calcium, magnesium, and some phosphorus. Pure, synthetic carbonate of potash is also a good source, but it is more expensive than carbonate in the form of cottonhull ash.

Sulfate of potash, one of the cheapest forms, has been shown a good source of potassium in many experiments. It has been used more than any other source since the beginning of the present century. When used in large amounts it falls short of being the ideal form in that it increases somewhat the percentage of sulfur in the leaf and thus reduces the fire-holding capacity. But this objection is usually not very serious because of the limited capacity of the tobacco plant to absorb sulfur (26). Furthermore, an eventual slight impairment of the burn should be less objectionable for tobacco used in synthetic binder.

Nitrate of potash is an excellent source of potash and also contains nitrogen.

Manure is the oldest source of potash for tobacco. Some 20 tons of manure (Table 4) will provide all the potash necessary for an acre of tobacco.

Muriate of potash is never used on tobacco because the chlorine is greedily absorbed by the plant and ruins the burn of the tobacco.

Granite stone meal was tested for 3 years at Windsor. An application of 2 tons of stone meal per acre combined with the normal amount of nitrogen and phosphate fertilizers produced as good a yield and quality of Havana seed tobacco as a standard 6-3-6 tobacco fertilizer mixture (29).

Thus, a variety of suitable potash sources exists. Since they are all soluble and since leaching is not of primary importance here, relative price can be the deciding factor.

METHODS OF APPLYING FERTILIZERS

The common method of fertilizing tobacco in the Connecticut Valley is to broadcast the fertilizer mixture on the field after the land has been plowed and harrowed. Then it is thoroughly disk-harrowed into the soil which gives a uniform distribution of the fertilizer in the upper 4 or, at the most, 6 inches of soil.

Band Application

Many workers have seen the wastefulness of broadcasting and have sought remedies. Unfortunately, no panacea has yet been found in the Valley. Let us examine their experiments and see if any opportunities have not yet been explored. These experiments showed:

1. No evidence favored the usual practice of applying the fertilizer early (1 to 2 weeks before planting time) and there may be some gain in applying it when the plants are set, probably through avoiding early leaching of some of the soluble nutrients.

2. Band application of all of the fertilizer on either side of the row during planting (only 4 inches from the plant stalk and about 4 inches deep) increased the quality but not the yield.

3. Band placement of the fertilizer mixture gave a better return than the broadcast method, indicating that by using the band method, the grower could reduce appreciably the amount of fertilizer needed.

4. Unfortunately, in dry seasons the band applications caused considerable root injury from an excessive concentration of fertilizer in the soil if the entire dose of fertilizer, 1900 to 2500 pounds 8-4-8 per acre, was within 4 inches of the plants. The plants were stunted and many failed to start, thus necessitating considerable restocking (39,65).

5. Placement experiments in *Massachusetts* indicated that on tobacco land well fertilized for a number of years with 3500 lbs. of 5-4-5 to the acre, a reduction of 1/4 to 3/8 in the fertilizer could be made by using band instead of broadcast application for a period of 2 to 4 years. After that time, both yield and quality decline with reduced quantities (43).

These experiments in Connecticut and Massachusetts led to the conclusion that for the Connecticut Valley, broadcasting is better than row application.

Now let us look for opportunities still unexplored, by examining experiments and practices elsewhere. First we see that a combination of broadcasting and row application may give better results than either method alone. For example, in regions where row application is practiced for tobacco as in the cigarette tobacco sections of the South, although the total rate has always been much lower, still it is recommended not to apply more than 500 to 800 pounds of mixed fertilizer in two bands at least 7 inches apart. The fertilizer in excess of this amount is broadcast to avoid injury to the tobacco under dry weather conditions (14, 24, 11).

In the growing of cigar tobacco in *Canada* moderate amounts of commercial fertilizer may be applied in two bands with the setter. Beneficial results may be obtained by applying a portion of the fertilizer in similar bands 2 or 3 weeks after the tobacco is planted, particularly in case of early, leaching rains. Broadcasting fertilizer on the surface and disking it in is considered wasteful of material and is avoided (13, 10).

For producing cigar tobacco in *Pennsylvania,* the following recommendations and results were given (12). A broadcast application of 500 pounds of 4-8-12 per acre before plowing to be followed by an equal application with the same method shortly before planting. Banding fertilizer with the transplanter along the sides of the row below the level of the plants has resulted in increased yield. Placing fertilizer directly under the plants may cause injury to the roots.

From this information concerning fertilizer practices and experiments in other regions, it is clear first of all, that concentrating the entire dose of fertilizer within a horizontal distance of 1½ to 4 inches of the plant, as was done in the Massachusetts and Connecticut experiments, is highly undesirable. With this lateral distribution, standard applications of 3500 to 3600 pounds of 6-3-6 tobacco fertilizer mixtures are very likely to cause root injury.

Vertical Distribution

Now let us examine the problem of vertical distribution of fertilizer, hoping that here too opportunities for savings can be found.

The usual practice of disking these liberal amounts of fertilizer into the soil after plowing, even when carefully done, result in an unfavorable vertical distribution of the fertilizer within the potential root zone of the tobacco. In dry years, distribution may not be deep enough for the plants to obtain full benefit from the fertilizer and may at the same time burn the roots.

At Windsor this question of the vertical distribution of the fertilizer within the plow layer has been tested in two sets of tests, a "plow under" series and the "plow sole" series (39). Conclusions were: (a) Distributing the fertilizer on the field before plowing generally did not give better results than the usual method of disking it in after plowing. In a dry year, however, it was found that a more uniform stand of plants with less restocking was obtained where the fertilizer was plowed under, (b) Placing all the fertilizer on the bottom of the plow furrow while plowing 8 inches deep gave the plants a poor start, stunted them, and resulted in reduced yield and poorer quality, and (c) When one-half of the fertilizer supply was placed on the plow sole and the other half was harrowed into the upper soil in the usual way, a higher yield was obtained but the difference in quality was not significant.

Here again, just as with the band placement studies at Windsor and in Massachusetts, perhaps none of the above treatments was the most efficient one.

In *Canada*, as already stated, this practice of broadcasting and incorporating by disking is considered wasteful (13). In *Pennsylvania* surface broadcasting of the entire application is not recommended as the material remains in the upper few inches of soil, the so-called "dust zone," and is thus unavailable to the plant under dry conditions. In the cigarette tobacco sections of the South, the recommendation if double band placement equipment is not available, is to place the first 800 pounds of the fertilizer 6 to 10 inches deep under the ridge that is to be the row. The ridge should be high enough that the roots of the newly set plants will be 1 to 2 inches above the fertilizer. Care should be taken to avoid placing the roots of transplants in contact with fertilizer (15).

The following considerations emerge from the experiments and practices described above.

A few hundred pounds of the complete fertilizer could be beneficially applied along the row at planting time. This quantity has to be kept relatively small to prevent root injury and to reduce the labor problem so that the period of planting is not too prolonged. Transplanters have to be equipped to apply this fertilizer in side bands.

As nutrients are ineffective in dry soil, part or half of the remainder of the fertilizer should be placed more deeply into the soil by plowing it under. The balance may be disked into the soil just before planting. Furthermore, the practice of plowing-down non-nitrate fertilizers has arisen from the desire to slow down the rate of nitrification, thus supplying the nitrogen to the crop at a somewhat less rapid rate comparable to that at which it is delivered by decaying organic matter (33).

Side dressing on our sandy-textured tobacco soils means a more efficient use of nitrogen. From our earlier discussions it is evident that additional or fractional applications of soluble nitrogen until early mid-season can be used to marked advantage for reliable and maximum tobacco production. In June supplementary applications can be made during cultivations. For this, conventional side dressing equipment or a side dressing attachment to the cultivators may be used. But here again, it is important that the fertilizer be placed in soil that will not become too dry. The use of non-pressure nitrogen solutions without ammonia could solve this problem in case of late side dressing without disturbing the roots by placement below the surface of the soil.

Side Dressing

Side dressing to replace nitrogen lost by leaching can be decided upon after a laboratory soil test, although previous experience on the same field may be a guide (26).

Starter Solutions

"Starter" solutions, small amounts of nitrate of soda (about 1 to 3 pounds to 50 gallons of water) dissolved in the setter barrel, conceivably might give plants a quick start. However, tests indicate that the value of this practice is questionable under the present fertilizer practices (26). Any starter solution should be high in phosphoric acid because it stimulates early growth, and according to recent findings a small amount of ammonia nitrogen will increase the intake of fertilizer phosphorus by the plant (44).

Foliar And Irrigational Applications

Finally, the use of foliar sprays and the application of fertilizer in irrigation water might be feasible.

The application of fertilizers in irrigation water is a fast growing practice in some areas (69).

Irrigation water is also being used successfully as a means of supplementing nitrogen, potash, and some micro-nutrients on several crops (44). At Windsor the effect of furrow irrigation of Havana Seed tobacco was greatly improved if supplementary applications of nitrate of soda in solution at a rate of 100 to 200 pounds to the acre, as determined by soil tests, were added to the water (65).

Nitrogen solutions are well adapted to such a method of application through sprinklers. Under our climatic conditions, however, the possibility exists that rains may delay irrigation to the extent that plants may suffer from deficiency of the nutrients that have not been applied. Other methods must be used then.

In periods following heavy rains and soil leaching, foliar sprays may often be valuable in getting the deficient nutrient into the plant quickly. Foliar applications of urea at 20 pounds per acre applied as a spray resulted in a rapid nitrogen response in nitrogen deficient tobacco (49). Tests with vegetable crops have shown that foliar sprays can be effectively utilized as a supplemental method of fertilization (67). The application of certain micro-nutrients by spraying has been a commercial practice in certain areas for a long time.

ADOPTION OF NEW FERTILIZERS

A great many materials are available to supply the nitrogen necessary for the tobacco crop. The grower who wants to reduce his fertilizer bill has a choice of suitable, cheaper nitrogen fertilizer materials extensively tested from time to time at the Tobacco Laboratory. However, there has always been a strong prejudice against the introduction of any new constituent in the tobacco fertilizer and particularly against any material which is not natural organic matter. Forgotten is the fact that cottonseed meal and fish scrap were violently opposed by the trade after their introduction. These objections have been based on alleged impairment of quality or taste of the product rather than reduction in yield or other measurable properties (1). Tobacco produced for synthetic binder, however, should hardly be affected by such claims as it is completely reconstituted and blended.

Oil seed meals are now preferred for fertilization of Connecticut tobacco because they must undergo decomposition in the soil before the nitrogen becomes available. This process continues through most of the growing season and normally insures enough nitrates in the soil as plant growth progresses. However, soil moisture conditions are important for the decomposition of these organics and the nitrogen balance in the soil. Seasons are frequently either too wet or too dry, providing not enough or too much nitrogen. Even the use of a standard material such as cottonseed meal will not guarantee a steady and uniform supply of nitrates (2).

Thus with the prevalent irregular distribution of rainfall in the Connecticut Valley, a blend of nitrogen sources is commonly believed to favor better quality, if not higher yields. The tobacco fertilizer mixtures which contain several sources of nitrogen are expected to decompose at different rates and thus supplement each other in bringing their supply successively into an available state.

In all the numerous studies of nitrogen sources for Connecticut Valley tobacco, new materials were tested as single sources or in combination with the natural organic materials. This was done to investigate the specific value of the material in question and to find out to what extent the proportion of organic nitrogen in the tobacco fertilizer could be reduced below that in the standard formula. Thus in *Massachusetts* an experiment was conducted in which the ratio of organic nitrogen supplied by cottonseed meal to inorganic nitrogen consisting of equal parts from nitrate of soda and ammonium sulphate varied from 1:7 to 1:1. Good yields and good quality of tobacco were obtained from these mixtures of meals and inorganic nitrogen over the 4-year period, 1932-35 (43).

Similarly, blends of inorganic and synthetic organic nitrogen sources of different availability, with no meals at all, may prove to be entirely satisfactory and most economical.

For example, in *Florida,* tests with flue-cured tobacco showed that: (a) results of single-source application of nitrogen were not as good as a combination of sources; (b) a nitrogen ratio of 1/3 from sodium nitrate, 1/3 from sulfate of ammonia, and 1/3 from urea produced highest yields with good quality; (c) fertilizers high in organic nitrogen are not necessary for the production of a high yield of good quality tobacco (17).

CONCLUSIONS

From the fertilizer experiments and practices discussed in this bulletin, it can be concluded that:

1. Fertilizers high in organic nitrogen of plant or animal origin are not necessary for the production of a high yield of good quality tobacco. Even when all fertilizer is applied before planting, certainly as much as one-half and perhaps as much as three-fourths of the nitrogen supply can come from inexpensive synthetic organic and inorganic sources with the remainder coming from natural organic sources; this substitution will not reduce either yield or quality. On relatively fine-textured soils and when cover crops are grown and fertilized to supply nutrients, use of all oil seed meals could probably be abolished as a means of saving on the cost of fertilization.

2. Mixtures of synthetic organic and inorganic nitrogenous materials are satisfactory sources of nitrogen for tobacco when used on the basis of their high availability and provided the acidity produced by the strongly acid-forming sources is neutralized. The synthetic organics, such as urea, and the ammoniacal forms, such as ammonium sulfate and ammonium nitrate, when used at moderate rates in complete fertilizer are excellent forms of nitrogen to apply before or at planting. Especially when supplemented by side dressing with readily available nitrates, they will supply nitrates at the proper time and as needed by the tobacco.

Nitrate, the most readily available form, is rapidly leached from our soils and is best applied to the soil in fractional applications. The excellence of nitrate of soda, for example, was shown in several experiments when the total application was split into fractions and applied at intervals during the first 4 to 5 weeks of the growing season. Quantity as well as form of the nitrogen carrier for side dressing should be given consideration for best results.

These high-analysis nitrogenous fertilizers, besides being relatively cheap, are more economical in transportation, storage, handling, and application than the bulky, low-analysis "meal" materials.

3. If quality is disregarded, yields can be increased over the present levels by higher nitrogen applications. About 200 pounds of nitrogen in natural organic form is satisfactory in most respects, the higher applications tending to oversupply the plants during the critical ripening period.

4. From the standpoint of fertilizer injury and the efficiency of fertilizer material, careful consideration should be given to proper placement of fertilizer. Only up to 800 pounds of fertilizer per acre can be placed safely in bands 3 to 4 inches on each side of the row and 1 to 2 inches below the root crown of the transplant. The remainder of the fertilizer may be plowed under in part, with the balance disked into the plowed land before the plants are set. In side dressing with nitrogen, care must be taken to keep the fertilizer off the plants to avoid burning and to incorporate it into the soil by cultivation or in solution where it is available to the roots.

5. Fertilizer applications must eventually be integrated with other operations, such as plowing, cultivation, and irrigation, in order to obtain the greatest savings in labor and materials. Furthermore, the fewer trips one makes through the field the less the danger of packing the soil and restricting the feeding zone of the crop.

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