TOBACCO

INFLUENCE OF FERTILIZERS ON COMPOSITION AND QUALITY

FIELD EXPERIMENTS WITH FERTILIZERS AND MANURE

OHIO
Agricultural Experiment Station

WOOSTER, OHIO, U. S. A., MAY, 1915

BULLETIN 285

OHIO AGRICULTURAL EXPERIMENT STATION

STATION STAFF

CHARLES E. THORNE, M. S. A., *Director*

DEPARTMENTAL ORGANIZATION

ADMINISTRATION

THE DIRECTOR, *Chief*
WILLIAM H. KRAMER, *Bursar*
W. K. GREENBANK, *Librarian*
HORATIO MARKLEY, *In charge of Exhibits*
W. J. HOLMES, *Printer*
DORA ELLIS, *Mailing Clerk*
GLENN HALL, *Engineer*

AGRONOMY

C. G. WILLIAMS, *Chief*[1]
F. A. WELTON, B. S., *Associate*
WILLIAM HOLMES, *Farm Manager*
C. A. PATTON, *Assistant*
C. A. GEARHART, B. S., *Assistant*
E. C. MORR, *Office Assistant*
C. H. LEBOLD, *Asst. Foreman*

ANIMAL HUSBANDRY

B. E. CARMICHAEL, M. S., *Chief*
J. W. HAMMOND, M. S., *Associate*
GEO. R. EASTWOOD, B. S., *Assistant*
DON C. MOTE, M. S., *Assistant*
W. J. BUSS, *Assistant*
ANTHONY RUSS, *Herdsman*
E. C. SCHWAN, *Shepherd* (Carpenter)

BOTANY

A. D. SELBY, B. S., *Chief*
TRUE HOUSER, B. S., *Asst.* (Germantown)
F. K. MATHIS, *Office Assistant*
D. C BABCOCK, A. B., *Assistant*
RICHARD WALTON, B. S, *Assistant*
J. G. HUMBERT, B. S., *Assistant*

CHEMISTRY

J. W. AMES, M. S., *Chief*
GEO. E. BOLTZ, B. S., *Assistant*
J. A. STENIUS, B. S., *Assistant*
C. J. SCHOLLENBERGER, *Assistant*
MABEL K. CORBOULD, *Assistant*
T. E. RICHMOND, M. S., *Assistant*

CLIMATOLOGY

J. WARREN SMITH, *Chief* (Columbus)[2]
C. A. PATTON, *Observer*

DAIRYING

C. C. HAYDEN, M. S., *Chief*
A. E. PERKINS, M. S., *Assistant*
T. R. MIDDAUGH, *Office Assistant*

ENTOMOLOGY

H. A. GOSSARD, M. S., *Chief*
J. S. HOUSER, M. S. A., *Associate*
W. H. GOODWIN, M. S., *Assistant*
R. D. WHITMARSH, M. S., *Assistant*
J. L. KING, B. S., *Assistant*

FORESTRY

EDMUND SECREST, B. S., *Chief*
J. J. CRUMLEY, Ph. D., *Assistant*
A. E. TAYLOR, B. S., *Assistant*
J. W. CALLAND, B. S., *Assistant*
D. E. SNYDER, *Office Assistant*

HORTICULTURE

W. J. GREEN, *Vice Director, Chief*
F. H. BALLOU, *Assistant* (Newark)
PAUL THAYER, M. S., *Assistant*
C. W. ELLENWOOD, *Office Assistant*
ORA FLACK, *Foreman of Orchards*
W. E. BONTRAGER, *Foreman of Grounds*
C. G. LAPER, *Foreman of Greenhouses*
J. B. KEIL, *Orchard Assistant*
S. N. GREEN, *Garden Assistant*

NUTRITION

E. B. FORBES, Ph. D., *Chief*
F. M. BEEGLE, B. S., *Assistant*
CHARLES M. FRITZ, M. S., *Assistant*
L. E. MORGAN, M. S., *Assistant*
S. N. RHUE, B. S., *Assistant*

SOILS

THE DIRECTOR, *Chief*
C. G. WILLIAMS, *Associate in soil fertility investigations*
J. W. AMES, M. S., *Associate in chemistry*
E. R. ALLEN, Ph. D., *Associate in soil biology*
H. FOLEY TUTTLE, M. S., *Assistant*
A. BONAZZI, B. Agr., *Assistant*
JOHN WOODARD, M. S., *Assistant*

FARM MANAGEMENT

C. W. MONTGOMERY, *Chief*
F. N. MEEKER, *Executive Assistant*

District Experiment Farms

Northeastern Test-Farm, Strongsville.
J. PAUL MARKLEY, *Resident Manager*

Southwestern Test-Farm, Germantown
HENRY M. WACHTER, *Resident Manager*

Southeastern Test-Farm, Carpenter.
H. D. LEWIS, *Resident Manager*

Northwestern Test-Farm, Findlay.
JOHN A. SUTTON, *Resident Manager*

County Experiment Farms

Miami County Experiment Farm, Troy
M. C. THOMAS, *Agent in Charge*

Paulding County Experiment Farm, Paulding
C. ELLIS BUNDY, *Agent in Charge*

Clermont Co. Experiment Farm, Owensville
VICTOR HERRON, *Agent in Charge*

Hamilton Co. Experiment Farm, Mt. Healthy
D. R. VAN ATTA, B. S., *Agent in Charge*

Washington County Experiment Farms, Fleming and Marietta
E. J. RIGGS, *Agent in Charge*

Mahoning Co. Experiment Farm
D. W. GALEHOUSE, *Agent in Charge*

Trumbull Co. Experiment Farm, Cortland
M. O. BUGBY, B. S., *Agent in Charge*

[1]With leave of absence. [2]In cooperation with Weather Service, U. S. Department of Agriculture.

BULLETIN

OF THE

Ohio Agricultural Experiment Station

NUMBER 285 MAY, 1915

TOBACCO

INFLUENCE OF FERTILIZERS ON COMPOSITION AND QUALITY

J. W. AMES AND G. E. BOLTZ

Tobacco is generally regarded as being an especially exhaustive crop, and soils devoted to the culture of tobacco require liberal applications of fertilizers for the maintenance of profitable production. It is desirable to follow methods of fertilization that will economically produce large yields, which at the same time have fine smoking qualities. The fertilizer used should carry the plant food required in such combinations as will not supply to the plant unnecessary constituents which will accumulate in the leaf and impair the quality.

During the year 1903 fertility investigations on tobacco were started at the Germantown Test Farm in the Miami valley district, where cigar filler tobacco is extensively grown. The experiments on the use of fertilizers on tobacco include the growing of tobacco in a 3-year rotation of tobacco, wheat and clover. For detailed description of tobacco experiments see Bulletins 161, 172 and 206.

While results obtained in this fertilizer experiment conducted during the period 1903-1913 have demonstrated that the yields may be profitably increased by use of fertilizers, no definite information has been furnished concerning the influence of different carriers of phosphorus, nitrogen, and potassium especially, on the quality of tobacco grown on this particular soil under the different conditions of treatment. This phase of the subject of tobacco production has been considered in this investigation in relation to the composition of the crop.

Mr. H. M. Wachter, Superintendent of the test farm at Germantown, has assisted in securing samples and in testing the cigars.

Samples of fermented tobacco from a number of the differently treated plots of the three-year rotation fertility test were available for this work, which is confined chiefly to the influence of fertilizing materials on the inorganic constituents. Separate lots of fermented and unfermented tobacco of the 1913 crop have been kept for additional studies concerning the effect of fertilizers on changes produced in the organic compounds of tobacco during the fermentation process.

CHARACTER OF SOIL

The soil of the Germantown test farm has been classed as Miami Clay Loam, and is typical of the soils extending over a considerable area in this region of the state. It is a light clay loam containing a large amount of silt. When newly plowed, it has a light yellowish brown color, but upon drying, the surface becomes white and resembles white clay. The subsoil, beginning at about ten inches, is a heavy clay loam which has a depth of from two to five feet, and is underlain by Niagara limestone. No lime carbonate is found in the surface six inches of the soil, and its reaction is only faintly acid. A very small amount of lime carbonate is present at a depth of twelve inches in samples taken during the year 1914. While only a slight trace of lime carbonate is present in the soil above a depth of twelve inches, no urgent need of lime has so far been indicated by crop growth. The composition of the soil is given in Table I.

TABLE I: Composition of Germantown soil, expressed in pounds per acre

Lab. No.	Depth	Total potassium	Total phosphorus	Total nitrogen	Total calcium	Total magnesium	$CaCO_3$	Reaction to litmus
5699-13a	0-6 in.	29,476	688	2,480	8,846	5,754	0	Faintly acid
5699-13b	6-12 in.	31,278	468	1,010	9,922	10,398	100	Neutral

Originally the soil upon which the Germantown fertility plots are located was practically uniform in character and composition, hence any variations observed in yield, composition, and quality of tobacco produced on this soil may be considered to be largely; if not entirely, the result of differences in fertilizer treatment.

FERTILIZER TREATMENT

Table II gives the amounts and combinations of fertilizers applied, also the yields obtained for 1912, and the 6-year average yields for 1909 to 1914 inclusive.

The fertilizers and manures are all applied to the tobacco, the wheat and clover following the tobacco receiving no treatment.

TABLE II: Plan of fertilizing and yield of tobacco at Germantown

Plot No.	Fertilizing materials per acre	Fertilizing elements per acre: Phosphorus Lbs.	Potassium Lbs.	Nitrogen Lbs.	Yield per acre, 1912: Wrapper Lbs.	Filler Lbs.	Trash Lbs.	Total Lbs.	6-year average Lbs.	Plot No.
2	Acid phosphate, 480 lbs	30	..	..	275	175	355	805	887	2
3	Acid phosphate, 480 lbs.; muriate potash, 180 lbs	30	75	..	760	260	160	1,180	1,271	3
5	Muriate potash, 180 lbs.; nitrate soda, 240 lbs	..	75	38	390	130	130	650	777	5
6	Acid phosphate, 480 lbs.; nitrate soda, 240 lbs.	30	..	38	450	210	320	980	1,102	6
8	Acid phos., 480 lbs.; mur. potash, 180 lbs.; nit. soda, 240 lbs.	30	75	38	1,030	225	155	1,410	1 408	8
9	Acid phos., 480 lbs.; mur. potash, 300 lbs.; nit. soda, 240 lbs.	30	125	38	1,170	225	115	1,510	1,398	9
10	None	..	..	..	270	105	155	530	607	10
12	Acid phos., 480 lbs.; mur. potash, 120 lbs.; nit. soda, 240 lbs	30	50	38	1,075	280	130	1,485	1,243	12
13	Acid phos., 720 lbs.; mur. potash, 180 lbs.; nit. soda, 240 lbs	45	75	38	1,020	270	200	1,490	1,387	13
15	Acid phos., 480 lbs.; mur. potash, 180 lbs.; nit. soda, 360 lbs	30	75	57	900	240	125	1,265	1,308	15
16	Acid phos., 480 lbs.; mur. potash, 180 lbs.; sulphate ammonia, 180 lbs.	30	75	38	680	235	185	1,100	1.209	16
18	Acid phos., 60 lbs.; tankage (7-20) 670 lbs.; mur. potash 180 lbs.	30	75	38	680	220	110	1,010	1,114	18
22	Acid phos., 480 lbs.; nit. potash, 200 lbs.; nit. soda, 80 lbs	30	75	38	820	255	100	1,175	1,263	22
23	Acid phos., 480 lbs.; sulphate potash, 190 lbs.; nit. soda, 240 lbs	30	75	38	755	290	140	1,185	1,257	23
25	Acid phos., 480 lbs.; sulph. potash, 190 lbs.; nit. soda, 240 lbs.; lime, 1,000 lbs.	30	75	38	745	210	175	1,130	1,172	25
26	Acid phos., 480 lbs.; mur. potash, 180 lbs.; nit. soda, 240 lbs.; lime, 1,000 lbs...	30	75	38	850	230	180	1,260	1,197	26
28	Acid phos., 480 lbs.; mur. potash, 180 lbs.; sulph. ammo. 180 lbs.; lime, 1,000 lbs.	30	75	38	875	220	155	1,250	1,246	28
29	Acid phos., 60 lbs.; tankage (7-20) 670 lbs.; mur. potash, 180 lbs.; lime, 1000 lbs.	30	75	38	690	200	145	1,035	1,072	29
33	Shed manure, untreated, 20 tons	..	..	..	905	230	120	1,255	1,242	33

Note: Table II shows the fertilization and yield obtained during 1912, also the 6-year average yield from 1909 to 1914 inclusive. The fertilizers and manures are all applied to the tobacco, the wheat and clover following without any treatment.

Taking the 6-year average as a basis, each application of fertilizer has produced a profitable increase of crop. The gain from the complete fertilizer carrying nitrogen, phosphorus and potassium, as applied to Plot 8, has been greater than that from any partial fertilizer or complete fertilizer carried in other combinations.

Considering the different amounts and forms of potassium used, the average yield for 6 years (1909-1914) shows that the yield from Plot 9 is practically the same as from Plot 8, although the potassium is considerably increased on the former plot. Potassium is applied to both plots as muriate of potash, Plot 9 receiving 300 pounds and Plot 8, 180 pounds per acre. Plot 12, which received a smaller amount of muriate of potash than Plot 8, yielded a smaller crop. Plots 2 and 6, where potassium was omitted from the fertilizer, yielded still less total crop, with an increased amount of trash, over any of the other plots during 1912.

Three different carriers of potassium, muriate, nitrate and sulphate, are used in Plots 8, 22 and 23. The 6-year average yields show a difference of 150 pounds in favor of the muriate on Plot 8 as compared with sulphate of potash on Plot 23. Potassium supplied in form of nitrate of potash on Plot 22 has given a result agreeing closely with that obtained from sulphate of potash.

The importance of providing a supply of available phosphorus adequate for the needs of the crop, is indicated by the yields for Plot 2, receiving phosphorus only, and Plot 8, to which complete fertilizer was added, compared with Plot 5, treated with potassium and nitrogen. Plot 2 gives an increase of 110 pounds over Plot 5, while the yield from Plot 8 shows an annual difference of 631 pounds in favor of the phosphorus treatment when used in combination with potassium and nitrogen. The addition of 240 pounds more of acid phosphate to Plot 13 has not increased the yield.

A comparison of Plot 3, treated with phosphorus and potassium, with Plots 8 and 15, which received the same quantity of phosphorus and potasssium in like carriers, together with 240 pounds of nitrate of soda on Plot 8, and 360 pounds on Plot 15, shows an increasd production of 137 pounds, due to addition of nitrogen on Plot 8, and only 37 pounds on Plot 15.

Nitrate of soda compared with ammonium sulphate (Plot 16) as a carrier of nitrogen has given an average annual gain of about 200 pounds per acre over the sulphate of ammonia. The limed plots produced a smaller yield than unlimed plots, excepting the ammonium sulphate plot treated with lime. which yielded more thân the corresponding unlimed plot. This has probably been due indirectly to the counteraction of so called acid conditions in the soil, following the use of ammonium sulphate.

These comparisons have reference to the tobacco crop only and do not include the wheat and clover crops following in rotation. It is a known fact that an essential element must be presented in the form of appropriate chemical combination. Furthermore, it is important that the amounts of essential elements stand in proper ratio to each other. This ratio differs for different crops. The fertilizer that produces a maximum yield of tobacco will not necessarily produce the largest yield of grain crops.

EFFECT OF FERTILIZERS ON COMPOSITION

Numerous investigations on the fertilization of tobacco have emphasized the effect of various chemicals upon the physiological changes within the plant and their influence on smoking qualities. Tobacco leaves retain a large portion of the mineral constituents assimilated from the soil during the growth of the plant. The variations in the amounts of ash constituents present in plants are the result of several factors including the quantity and form of plant food materials contained in the fertilizer. Where any appreciable deviations from the normal composition appear, following the order of increased or decreased supplies of materials added to the soil, they may be attributed to different conditions of fertilization.

Table III gives the composition of tobacco leaves from several of the 3-year fertilizer plots for 1912.

The total ash content is uniformly high in the several lots of tobacco analyzed. Where nitrogen is applied, in the form of nitrate, there is generally a decrease in the total ash, which is accompanied in some instances by decreased amounts of phosphorus, sulphur and chlorine.

While calcium, magnesium and potassium, the elements which constitute the greater part of the ash, do not stand in any direct relation to the total ash content of the leaf, in a number of cases the tobaccos with a high ash have a higher magnesium content than those with a smaller amount of ash.

Of the essential elements present in the tobacco leaf, calcium is found in the largest amount, followed by nitrogen, potassium, magnesium and phosphorus.

The addition of 1,000 lbs. of lime every three years has decreased the calcium and manganese content of the crop, and at the same time appreciably increased the amount of magnesium removed from the soil.

TABLE III: Percentage composition of tobacco leaves, 1912

Plot No.	Carbon-free ash	Calcium	Magnesium	Manganese	Sodium	Potassium	Phosphorus	Total nitrogen	Nitrate nitrogen	Nicotine	Total sulphur	Sulphur as sulphates	Chlorine	Plot No.
2	19.443	4.9574	1.1775	.0097	.1480	1.2846	.3065	3.72	.0910	2.862	1.0434	.7459	0.2925	2
3	20.131	4.6215	1.2599	.0105	.1946	1.5924	.2280	3.00	.0798	2.862	.7452	.4926	3.3598	3
5	18.987	3.8946	1.4510	.0077	.1761	2.4435	.1995	3.98	.2030	2.970	.6155	.3118	2.5000	5
6	16.744	4.6766	1.1409	.0097	.1618	1.2878	.2550	3.87	.1148	3.600	.8587	.6045	0.1064	6
8	19.257	4.8822	1.2665	.0216	.2567	1.6118	.1920	3.12	.1260	3.762	.7328	.5000	2.5974	8
9	21.729	5.0425	1.0688	.0232	.1693	1.8293	.1995	2.75	.0707	3.402	.7453	.4632	4.7428	9
10	19.613	3.8746	1.3036	.0092	.1104	1.1347	.2040	4.09	.0532	2.916	.6346	.3702	0.1640	10
12	18.264	5.0125	1.2954	.0184	.3493	1.7101	.2070	3.36	.1218	4.320	.7500	.5429	2.4290	12
13	19.297	4.9422	1.4434	.0111	.3668	1.6907	.2460	3.62	.1771	3.618	.7335	.5209	3.0141	13
15	19.888	5.0174	1.2211	.0206	.1975	2.0325	.2235	3.40	.1722	4.032	.6622	4280	2.2340	15
16	20.099	4.9924	1.1294	.0501	.1606	1.5586	.2175	2.88	.0910	3.186	.8105	.5659	3.2534	16
18	19.289	4.5212	1.2321	.0300	.1822	2.7787	.2205	3.82	.2528	4.032	.5406	.2781	2.9736	18
22	17.798	5.0576	0.8165	.0148	.3713	2.0341	.2520	2.55	.0644	3.096	.8792	.7140	0.1950	22
23	19.353	4.7142	0.8460	.0217	.2697	2.4870	.2235	3.33	.0980	4.716	.9196	.6970	0.1241	23
25	16.153	4.3709	1.3238	.0089	.3360	1.8989	.2228	3.24	.0868	3.600	.9169	.6782	0.1241	25
26	21.556	4.4460	1.8500	.0104	.2007	1.6601	.2250	3.45	.1652	3.672	.7226	.4984	2.8989	26
28	22.800	4.5162	1.8430	.0107	.2321	1.3250	.2010	2.86	.0952	3.996	.6992	.4858	3.2534	28
29	21.786	4.2656	1.9050	.0088	.1722	1.9825	.1950	3.45	.1680	4.194	.6285	.3755	3.1471	29
33	19.949	4 0050	1.6104	.0135	.1667	2.8465	.2160	3.92	.3080	4.158	.6279	.3934	1.3297	33

Plots 8, 16, 18 and 23 received the same fertilizer treatment as Plots 26, 28, 29 and 25, with the exception of 1,000 lbs. of lime added to the last set of plots. Comparing the plots in the order stated, the results show that each of the latter group of plots contains more magnesium.

As stated before, calcium is removed in greater amounts by tobacco than any of the other mineral elements considered essential for the proper nutrition of plant life. Its function in plants is considered to be quite different from that of magnesium. Calcium is not found to any appreciable extent in young plants or in seed, or in the storage organs where the ash constituents are present in small amounts, while magnesium has a distribution and importance similar to potassium. However, a certain relation appears to exist between the calcium and magnesium content of plants, for in samples where the percentage of calcium is high, the magnesium is low, and vice versa.

With few exceptions, the tobacco crops from limed plots contain less phosphorus, potassium and sulphur than correspondingly fertilized plots to which lime has not been added. The composition of the Germantown soil, together with the growth of clover on this soil, indicate that the soil is sufficiently well supplied with calcium, although practically all that in the surface soil is in other combinations than calcium carbonate. The elements calcium and magnesium, and potassium and soda, stand in opposite relation to each other. Where sodium nitrate has been used as the carrier of nitrogen, the sodium in the tobacco has been increased to some extent.

Although the tobacco yields have been decidedly increased by use of fertilizers carrying phosphorus, a small quantity of phosphorus is removed by the crop as compared with other materials, some of which are not necessary either for increasing yields or improving the quality of the crop. One favorable effect of phosphorus is that it promotes greater root development and consequently extends the plant's feeding surface. This stimulation of root growth is of special benefit during periods of drought, when the plant is enabled to secure its water supply from the moist soil at lower depths. Another important function of phosphorus is its influence on maturation. This effect on the wheat crop has been pointed out in Bulletin 221 of this Station.

The addition of phosphorus has tended to increase the calcium, potassium, sodium, manganese, total sulphur, sulphur in the form of sulphates, and chlorine, while it decreased the magnesium and nitrogen content of the several lots of tobacco analyzed. Increasing the supply of available phosphorus is generally accompanied by a decreased nitrogen content in crops, as has been shown by investigations made at this Station on other crops. (Bulletins 243 and 247.)

Tobacco is considered to be a heavy feeder on potassium, with the result that the importance of potassium in the fertilizer treatment is no doubt over emphasized, and not enough attention given to the need of phosphorus. The majority of tobacco fertilizers contain more potassium than phosphorus. Consequently in many instances soils devoted to the growing of tobacco become over supplied with potassium at the expense of the phosphorus.

Manganese is considered by some investigators to be a constituent of oxidases, and therefore, necessary for plant growth. Others consider the element to be non-essential. Certain manganese compounds increase oxidation, and small applications have favorably influenced the growth of plants.

There is a considerable variation in the manganese content of the tobacco from different plots, some of the samples analyzed containing six times as much as others. Tobacco from plots to which muriate of potash has been applied as a carrier of potassium, generally has a higher manganese content than the tobacco fertilized with other carriers of potassium.

The results also show that the addition of lime has decreased the manganese content and increased the magnesium in the tobacco leaf. A complementary relation exists between the manganese and magnesium, when the manganese is high, the magnesium is low.

NITROGEN CONTENT

The largest proportion of nitrogen is found in the tobacco from unfertilized plots. A comparison of the crops from the complete fertilizer plots, 8 and 26, where the same amount of nitrogen is supplied by nitrate of soda, with Plots 16 and 28 treated with ammonium sulphate, and Plots 18 and 29 where tankage is applied, shows that the percentage of nitrogen is lowest in tobacco from plots treated with ammonium sulphate. Where the nitrogen is furnished in organic forms, the percentage of nitrogen in tobacco leaves is higher than in the crops from plots treated with nitrate of soda or ammonium sulphate.

Nitrogen in the form of nitrates follows the same general order as the total nitrogen content of the tobacco. Shed manure increased nitrate nitrogen content to 0.31 percent, which is the highest amount found in any of the tobacco analyzed. The nitrate nitrogen results in Table III are expressed in terms of the element nitrogen.

The Connecticut Experiment Station* found that, where nitrogen was applied in large excess of the probable crop requirement, a much larger percentage of nitrates accumulated in the leaf than where smaller quantities of nitrogen were applied, amounting in some cases, where heavy applications of organic nitrogen were applied, to over 3% (N_2O_5). Available nitrogen, added to soils where the amount present is deficient for maximum crop production, manifests itself in the development of leaf and stem.

Organic carriers of nitrogen, shed manure and tankage, produce a crop high in nitrate nitrogen and nicotine. The nitrogen furnished by nitrate of soda is all available at the time of application. A large proportion of the nitrogen necessary for plant growth is taken up during the earlier period of the plant's growth and a considerable portion may be lost from the soil by leaching. Organic compounds are more slowly made available, and there is, therefore, a continual supply of nitrogen presented to the plant throughout its period of growth. This may be the explanation of the higher percentage of nitrate nitrogen present in the tobacco grown on plots where nitrogen was supplied by the organic carriers, tankage and manure.

POTASSIUM CONTENT

Published analyses of tobacco from various sources, produced under different conditions as to soil, variety of tobacco, climate and fertilizer treatment, exhibit a wide variation in the potassium content. While the results for potassium in the several lots of tobacco included in this investigation are fairly uniform, the maximum and minimum amounts present differ by over 50 percent, which is quite an appreciable variation when it is considered that this difference is due to fertilizer treatment alone.

Potassium is present in smallest amount in tobacco from the unfertilized plot, and the largest amount is found in tobacco grown on soil treated with manure, which is in accord with the quantity of potassium supplied. Assuming that shed manure used contained the average amount of potassium, one application of 20 tons of manure every three years will have furnished approximately 200 pounds of the element potassium, an amount considerably in excess of that furnished by the applications of potash salts made in any instance.

Plots treated with phosphorus alone, and with phosphorus and nitrogen without potassium, produced larger yields of tobacco hav-

*Annual Report, 1896, p 322.

ing slightly increased percentages of potassium present, than was found in the case of the tobacco from plots to which no fertilizer was applied.

While tobaccos from plots which have been treated with fertilizer containing potassium, have uniformly higher percentages of potassium than those from plots to which no potassium is applied, the amount present is influenced considerably by the salt of potassium used. Of the several lots of tobacco from plots treated with like amounts and carriers of phosphorus and nitrogen, that from plots treated with either sulphate or nitrate of potash has a much higher potassium content than the tobacco from plots to which potassium was furnished by muriate of potash. By referring to the tabulated results it will be observed that increasing the amount of muriate of potash applied has also influenced the amount of potassium in the tobacco leaves. Plot 9, which received 300 lbs. of muriate of potash, contains more potassium than the tobacco from either Plot 8 or Plot 12 treated with smaller quantities of muriate of potash, the phosphorus and nitrogen added being the same for the three plots compared.

Potassium in tobacco leaves is also increased where the quantity of sodium nitrate used in connection with potassium chloride is increased; comparing Plot 15 with Plot 8. Bearing on this subject, F. Pfeiffer* from experiments on the accumulation of potash and soda by plants, states that sodium salts act in two ways: (1) By setting free potassium in soil, and (2) By replacing potassium in plants. He concludes that an application of sodium salts in connection with potassium salts, results in a greater assimilation of potassium by the plant.

Where lime has been added, the fertilizer treatment remaining the same, there has been a tendency towards decreasing the potassium content of the tobacco, compared with that grown on soil not treated with lime.

The potassium content of tobacco leaves is of particular interest in relation to the quantity of chlorine or sulphate assimilated by the plant, where different forms of potassium have been used in the fertilizer applied. Although the carrier of potassium used has decidedly influenced the amounts of chlorine and sulphate contained in the tobacco, no correlation is found between the amounts of potassium and chlorine or sulphate present. Certain conditions of treatment appear to have exerted an influence on the potassium in one direction, while the constituent associated with the potassium in a given salt used in the fertilizer may be influenced by other factors.

*Mitt. Landw Inst Breslau 3, 1905.

For instance, the results show that the use of phosphorus without potassium chloride tends to increase both the chlorine and potassium taken up by the plant, while sodium nitrate decreases the chlorine content and does not materially change the potassium, except when used in combination with muriate of potash. This is illustrated by comparing Plots 8 and 15, treated the same with the exception that a larger application of sodium nitrate is made on Plot 15. The potassium content of tobacco from Plot 15 is greater than in that grown on Plot 8, while the chlorine is decreased, due evidently to increased amount of nitrate of soda used on Plot 15. The use of ammonium sulphate (Plot 16) compared with nitrate of soda on Plot 8, apparently produced a decided difference in the chlorine content without affecting the potassium appreciably, but when lime was added (compare Plots 26 and 28) the chlorine was increased and the potassium reduced.

These differences just noted illustrate the complexity of influences, either direct or indirect, produced by external factors dependent upon the fertilizing materials applied to the soil.

The composition of a plant which has such a high ash content as tobacco is easily modified by slight changes in fertilization, due either to increase of certain elements in the soil or to the interaction and changes in the solubility of different soil elements, brought about by the addition of fertilizing materials.

CHLORINE CONTENT

The chlorine content of the several lots of tobacco analyzed is of special importance for the reason that the use of fertilizing materials containing chlorides is condemned, the experience of tobacco growers indicating that chlorides are likely to injure the burning quality of tobacco leaves.

None of the other constituents determined have been influenced by the fertilizer treatment to as great an extent as the chlorine. The results exhibit a range from 0.10 percent to 4.70 percent, the largest amount being present in tobacco from soil receiving the heaviest application of muriate of potash.

That the prejudices which have been held against the use of materials containing chlorides are justified is evidenced by a comparison of the chlorine content and burning quality of tobacco grown on plots where muriate of potash is used in different fertilizer combinations. The smoking tests are considered in detail later on.

TABLE IV: Comparison of chlorine, sulphur and sulphate content

Plot No.	Treatment	Chlorine Percent	Sulphur Percent	Sulphates Percent
10	Untreated	0.1640	0.6346	.3702
33	Manure, 20 tons	1.3297	0.6279	.3934
2	Acid phosphate, 480 lbs	0.2925	1.0434	.7459
6	Acid phosphate, 480 lbs.; nitrate soda, 240 lbs	0.1064	0.8587	.6045
3	Acid phosphate, 480 lbs.; muriate potash, 180 lbs	3.3598	0.7452	.4926
5	Muriate potash, 180 lbs.; nitrate soda, 240 lbs	2.5000	0.6155	.3118
12	Acid phosphate, 480 lbs.; muriate potash, 120 lbs.; nitrate soda, 240 lbs	2.4290	0.7500	.5429
8	Acid phosphate 480 lbs.; muriate potash, 180 lbs.; nitrate soda, 240 lbs	2.5974	0.7328	.5000
9	Acid phosphate, 480 lbs.; muriate potash, 300 lbs.; nitrate soda, 240 lbs	4.7428	0.7453	.4632
13	Acid phosphate, 720 lbs.; muriate potash, 180 lbs.; nitrate soda, 240 lbs	3.0141	0.7335	.5209
15	Acid phosphate, 480 lbs.; muriate potash 180 lbs.; nitrate soda, 360 lbs	2.2340	0.6622	.4280
16	Acid phosphate, 480 lbs.; muriate potash, 180 lbs.; Sulphate ammonia, 180 lbs	3.2534	0.8105	.5659
18	Acid phosphate, 60 lbs.; muriate potash, 180 lbs.; tankage (7-20) 670 lbs	2.9736	0.5406	.2781
26	Acid phosphate, 480 lbs.; muriate potash, 180 lbs.; nitrate soda, 240 lbs.; lime, 1,000 lbs	2.8989	0.7226	.4984
28	Acid phosphate, 480 lbs.; muriate potash, 180 lbs.; sulphate ammonia, 180 lbs.; lime, 1,000 lbs	3.2534	0.6992	.4858
29	Acid phosphate, 60 lbs.; muriate potash, 180 lbs.; tankage (7-20) 670 lbs.; lime, 1,000 lbs	3.1471	0.6285	.3755
22	Acid phosphate, 480 lbs.; nitrate potash, 200 lbs.; nitrate soda, 80 lbs	0.1950	0.8792	.7140
23	Acid phosphate, 480 lbs.; Sulphate potash, 190 lbs.; nitrate soda, 240 lbs	0.1241	0.9196	.6970
25	Acid phosphate, 480 lbs.; sulphate potash, 190 lbs.; nitrate soda, 240 lbs.; lime 1,000 lbs	0.1241	0.9169	.6782

Comparing the chlorine content in relation to treatment, the results in Table IV show that the tobaccos from plots receiving potassium in the form of chloride all contain greatly increased amounts of chlorine over that in the tobacco leaves from plots to which no chlorides were added.

One thing, which is brought plainly to view by an inspection of the results, is that acid phosphate tends to increase the chlorine content, and nitrate of soda exerts an opposite influence. Plot 2, treated with acid phosphate, contains more chlorine than the tobacco from unfertilized soil, while on Plot 6, the addition of nitrate of soda to the phosphate treatment, has decreased the chlorine below that found in the tobacco from unfertilized soil. This antagonistic relation between acid phosphate and nitrate of soda, when these materials are used separately with the same quantity of muriate of potash, is shown by the figures obtained for Plot 3, treated with muriate of potash and acid phosphate, and Plot 5, where the fertilizer treatment has been muriate of potash and nitrate of soda; here the chlorine content is 2.5 percent, while on Plot 3, acid phosphate in combination with muriate of potash has increased it to 3.36 percent. Extending the comparison to include the plots treated with a like quantity of muriate of potash, but in the one instance a greater amount of acid phosphate, and in the other a greater amount of nitrate of soda, the chlorine results follow the same order just referred to. The chlorine result for Plot 13, treated with 720 pounds of acid phosphate, is higher than for Plot 8, treated with a less amount of acid phosphate; Plot 15 treated with more sodium nitrate has less chlorine than Plot 8 which received a smaller application of nitrate of soda than Plot 15.

The action produced by acid phosphate towards increasing the chlorine content appears to be greater than the opposite effect noticed where nitrate of soda has been used.

Where ammonium sulphate supplies the nitrogen in the fertilizer, on Plots 16 and 28, there is a decided increase in the amount of chlorine over that in tobacco from Plot 8.

Tobaccos from Plots 18 and 29, where tankage supplied all the nitrogen and the greater part of the phosphorus, contain more chlorine than tobacco from plots where nitrate of soda supplied the same amount of nitrogen. These results, together with those secured for the tobacco grown on the plots which have nitrogen supplied in the form of ammonium sulphate, suggest that the sodium carried by the sodium nitrate is the factor responsible for the decreased chlorine content observed.

Shed manure increased the chlorine considerably over the plots to which no chlorine was added by fertilizers. The explanation of this is given by the average composition of manure, which shows the chlorine content to be approximately 0.20 percent. Twenty tons of manure would have supplied 80 lbs. of chlorine, a quantity sufficient to appreciably affect the chlorine content, providing the chlorides in manure are combinations as readily utilized by the plant as is the chlorine in muriate of potash. This may explain the prejudice held by certain growers against the use of manure.

Smoking tests of the tobacco give no indication that the use of 20 tons of manure has impaired the quality of tobacco produced. Although some lowering of quality had attended its use, this would be more than compensated for by the many beneficial effects brought about by manure aside from its fertilizing action.

Analyses of tobacco grown at the Connecticut Experiment Station in 1896* shows that the ash of tobacco from plots dressed with manure contained five times as much chlorine as any of the other plots in the series. None of the other plots, however, received fertilizer salts containing chlorides.

Increasing the chlorine supply where muriate of potash is used is followed by the greatest increase in the amount of chlorine in the tobacco. Comparing results for Plots 12, 8 and 9, Plot 12 treated with 120 lbs. of muriate of potash, contains 2.42 percent chlorine, while Plot 9, treated with 300 lbs. of muriate of potash has a content of 4.74 percent, the largest application of muriate of potash and the highest content of chlorine standing in direct relation to each other. In striking contrast to the figures given for the chlorine content following this large application of muriate of potash, are the results for the plots treated with nitrate and sulphate of potash, the chlorine content of tobacco from these plots being approximately the same as for the tobacco grown on soil where no chlorine was carried in the fertilizer.

Normally, the chlorine content of tobacco is less than the other constituents, either essential or accidental, which have been stored in the tobacco leaves. The extreme variations manifested by the several different lots of tobacco and remarkable coincidence between the fertilizer treatment and the chlorine stored in the leaves, make the results for this constituent more significant than the results for the other constituents determined. Aside from the direct application in relation to the quality produced under different conditions of fertilization, they are of interest from a physiological standpoint.

*Conn. Expt. Station Report 1896, p. 333.

SULPHUR AND SULPHATES

When the tobacco plant is grown on soil which has not had its chlorine content increased by treatment with fertilizing materials carrying chlorine, the leaves normally contain more sulphur than chlorine. However, any increase in the sulphur supply of the soil following the use of potassium or ammonium sulphate, and the addition of calcium sulphate in acid phosphate, has not modified the composition of the tobacco leaves to the same degree as has the addition of chlorides in the fertilizer. The amount of sulphur retained in the leaves is equal to over three times the amount of phosphorus present. A large proportion of the sulphur exists in the leaves combined with bases as sulphates; this is due partly to the sulphates carried by acid phosphate and ammonium or potassium sulphates, since the sulphates are increased in all the tobacco from soil receiving such treatment. A part of the sulphates may be present in the plant in excess of the amount it can utilize for building up its organic structure, but as higher forms of plant life seem to be able to assimilate sulphur only in the form of sulphates, and as the amount in the tobacco plant is quite large, it is assumed that a sufficient supply of sulphates is just as necessary for optimum conditions of plant growth as an adequate supply of other materials considered to be essential.

However, the yields obtained on the plots where potassium sulphate furnished the potassium, do not indicate that any benefit has been derived from addition of sulphur, for the yields on the soil treated with muriate of potash are considerably in excess of those from the sulphate treated plots, where the phosphorus and nitrogen applied were the same.

Fertilizers containing sulphate of potash have produced a larger accumulation of total sulphur and sulphates in the tobacco leaves than any other fertilizer treatment except acid phosphate used alone on Plot 2.

The same tendency of acid phosphate and nitrate of soda observed in relation to the chlorine content applies also to the sulphur. Tobacco from plots treated with acid phosphate and sodium nitrate contains a decreased amount of sulphate as compared with tobacco from soil treated wih acid phosphate only. This applies also to the tobacco from soil treated with acid phosphate and muriate of potash compared with that from plots fertilized with muriate of potash and sodium nitrate.

The addition of ammonium sulphate to the fertilizer has contributed to some extent toward increasing the sulphur content of the tobacco leaves. Sulphates when present in excessive amounts are considered to be injurious to the burning quality. The amount supplied by acid phosphate and potassium sulphate, as used in the fertility experiment on soil which produced the tobacco tested, are about the maximum limit of economic application, but the tests made in this study give no indication of the addition of sulphate having produced harmful results.

INFLUENCE OF FERTILIZER ON QUALITY

Cigars were made from the tobacco grown on the differently fertilized plots previously described. These cigars were made as uniformly as possible by an experienced cigar manufacturer. A Wisconsin binder and a Connecticut seed leaf wrapper were used with the filler which was all of the same variety, Zimmer Spanish, which is grown quite extensively in the district where the experimental plots which furnished the tobacco tested in this work are located.

The experience of tobacco experts is that in order to secure a good burn, a heavy filler should be wrapped with a comparatively heavy wrapper, and a light bodied filler with a light bodied wrapper. While the wrapper and binder influence the character of the ash and the ash of the wrapper in turn is materially affected by the binder, the filler exerts the strongest influence on the burning quality.

Since the cigars were made up with the same binder and wrapper, and the filler was of the same variety of tobacco, grown on differently fertilized plots, it is safe to assume that any variations observed in the smoking quality of the tobacco from the several plots may be considered to be due largely to factors introduced by the use of different fertilizer materials.

The data for the smoking test given in Table V, p. 189, include the average results for the several lots of tobacco.

The length of time the cigars remained lighted under uniform conditions of aspiration is stated in minutes and seconds under the heading, fire-holding capacity. These figures are the average of not less than three trials for each lot of tobacco tested. The statements made for flavor and aroma are based upon the judgment of different observers who participated in the smoking tests.

The burning test, or the fire-holding capacity, is of interest in relation to the inorganic constituents of the tobacco found to be modified by different conditions of fertilization, since good burning quality is considered to be one of the essential factors in determining the excellence of a tobacco used for the manufacture of cigars.

TABLE V: Results of smoking tests, 1912 crop

Plot No.	Treatment	Fire-holding capacity	Character of ash	Flavor	Aroma
10	Untreated	6 min. 41 sec.	Light; fairly firm	Fair	Fair
33	Manure, 20 tons	7 " 7 "	Light gray; fairly firm	Good	Good
2	Acid phosphate, 480 lbs	7 " 11 "	Light; firm	Excellent	Excellent
6	Acid phosphate, 480 lbs.; nitrate soda, 240 lbs	5 " 55 "	Gray; flaky	Fairly good	Good
3	Acid phosphate, 480 lbs.; muriate potash, 180 lbs	3 " 0 "	Dark; firm	Fairly good	Good
5	Muriate potash, 180 lbs.; nitrate soda, 240 lbs	6 " 0 "	Dark gray; flaky	Fairly good	Fair
12	Acid phosphate, 480 lbs.; muriate potash, 120 lbs.; nitrate soda, 240 lbs	4 " 22 "	Dark gray; flaky	Fair	Fair
8	Acid phosphate, 480 lbs.; muriate potash, 180 lbs.; nitrate soda, 240 lbs	4 " 52 "	Dark, charred; firm	Good, but strong	Fair
9	Acid phosphate, 480 lbs.; muriate potash, 300 lbs.; nitrate soda, 240 lbs	3 " 52 "	Dark; flaky	Fair, strong	Fair
13	Acid phosphate, 720 lbs.; muriate potash, 180 lbs.; nitrate soda, 240 lbs	3 " 0 "	Dark; firm	Fair	Fair
15	Acid phosphate, 480 lbs.; muriate potash, 180 lbs.; nitrate soda, 360 lbs	3 " 37 "	Light gray; flaky	Good	Good
16	Acid phosphate, 480 lbs.; muriate potash, 180 lbs.; sulphate ammonia, 180 lbs	4 " 26 "	Light gray; flaky	Flat, lacking	Fair
18	Acid phosphate, 60 lbs.; muriate potash, 180 lbs.; tankage (7-20) 670	5 " 18 "	Dark gray; fairly firm	Fair	Good
26	Acid phosphate, 480 lbs.; muriate potash, 180 lbs.; nitrate soda, 240 lbs.; lime, 1,000 lbs	3 " 11 "	Dark; firm	Fair	Fair
28	Acid phosphate, 480 lbs.; muriate potash, 180 lbs.; sulphate ammonia, 180 lbs.; lime, 1,000 lbs	4 " 7 "	Dark; firm	Fair	Fair
29	Acid phosphate, 60 lbs.; muriate potash, 180 lbs.; tankage (7-20) 670 lbs.; lime, 1,000 lbs	4 " 18 "	Dark gray; firm	Fair	Fair
22	Acid phosphate, 480 lbs.; nitrate potash, 200 lbs.; nitrate soda, 80 lbs	7 " 11 "	Light gray; firm	Excellent	Excellent
23	Acid phosphate, 480 lbs.; sulphate potash, 190 lbs.; nitrate soda, 240 lbs	8 " 11 "	Light; very firm	Excellent	Excellent
25	Acid phosphate, 480 lbs.; sulphate potash, 190 lbs.; nitrate soda, 240 lbs.; lime, 1,000 lbs	7 " 26 "	Gray; flaky	Fair	Good

The flavor and aroma are influenced by many factors, including the completeness of combustion as influenced by salts present in the tobacco; the nature of the decomposition products resulting from combustion; and the form in which the nicotine exists.

Tobacco which permits of complete combustion usually has a better fire-holding capacity than tobacco which does not burn freely and leaves a dark ash. Desirable flavor and aroma are usually, although not always, accompanied by a light ash and good fire-holding capacity. Although the flavor and aroma are affected to some extent by the completeness of combustion, many other factors contribute to this quality.

Changes in the organic compounds, during the curing and fermentation processes, are largely responsible for the flavor and aroma. Variations in the amounts of the different organic compounds change the nature of the decomposition products formed during the curing and fermentation of tobacco, which in turn affect the smoking qualities. It is believed that the aroma of tobacco is partially due to the decomposition products formed by breaking down of gums and resins.

Tobacco smoke examined by Thom[1] was found to contain nicotine, pyridine, ammonia, carbonic and butyric acids, carbon monooxide and two volatile oils, one of which could be steam distilled from the tobacco. The other oil was extremely toxic, of dark color and narcotic odor. About 75% of the nicotine passed over with the smoke, being afterwards partly decomposed.

The smoke from tobacco which was heavily fertilized with muriate of potash contained some chlorides, while the tobacco smoke from samples of all the plots contained more or less sulphur in the form of sulphides. Recent investigations by Toth[2] on the smoke of Hungarian tobacco show that hydrogen sulphide constitutes from .02% to .03% of the smoke. These various products would influence the flavor and aroma to some extent. The flavor and aroma are not dependent so much upon the amount of nicotine present as upon its combination and decomposition products. The undesirable sharpness and pungency associated with the smoke from certain types of cigar filler tobacco is due almost entirely to the volatile and soluble form of nicotine, which acts as if it were in the free state, while the direct physiological effects of the smoke, as embodied in the term fulness, are proportional to the total quantity of nicotine.[3]

[1]Jour Soc Chem. Ind 20, 1901, No. 6, p. 626.
[2]Chem Ztg. 1913, 37; 897.
[3]Garner, U. S. D. A. Bur. Plant Ind Bul 141, Part 1, p. 16.

Tobacco from Plots 2, 22 and 23 is rated as being of better quality than that from any of the other plots, while the percentage of nicotine is practically the same as that in tobaccos which were graded much lower.

The flavor, aroma and fire-holding capacity are not entirely due to the presence or absence of any one compound, but are more or less dependent upon the total constituents of the tobacco.

Many investigations have been conducted with the view of ascertaining the causes responsible for good or poor smoking quality of tobacco. Among the more recent is that of Garner[1] whose conclusions are as follows:

"1. The fire-holding capacity is dependent primarily on the content of potash combined with organic acids.

2. Lime, in general, does not greatly affect the fire-holding capacity, but is an essential factor in the production of a good ash.

3. A large amount of magnesia tends to injure the capacity for holding fire.

4. Chlorine injures the burning qualities, but it is seldom that tobacco contains enough of this element to do any serious harm.

5. Sulphates in general injure the burning qualities, but the effects are not so marked when all the sulphuric acid is combined with potash.

6. So far as is known, none of the organic constituents of tobacco, with the possible exception of the so-called tarry acids and the albuminoids, exert an important influence on the burning qualities.

The principal objects to be attained in efforts to improve the burning qualities of tobacco by breeding and improved methods of production are (1) a relatively high content of potash combined with citric and malic acids, with a minimum amount of inorganic salts, especially chlorides and sulphates; (2) a moderate content of lime; (3) a comparatively small percentage of magnesium; and (4) a low content of organic nitrogenous compounds, more especially the albuminoids or proteids."

From a series of experiments conducted at the Connecticut Experiment Station[2], general conclusions are that there is no best tobacco fertilizer or best formula for all seasons, even on the same soil. Nevertheless, by comparing the effects of fertilizers for a term of years, it appears that certain ones are, on the whole, and generally speaking, more likely to impart a satisfactory quality to the leaf than certain others. Furthermore, occasional changes in the form

[1]U. S D A Bur. of Plant Industry Bul 105
[2]Connecticut Experiment Station, Report for 1897.

of nitrogen and potash supplied, may be a distinct advantage, providing chlorides, which experience has shown may damage the leaf, are avoided.

Medeelingern[1] recommends a fertilizer carrying about the same amount of nitrogen demanded by sugar beets, a larger quantity of potash and a smaller amount of phosphoric acid, for the fertilization of tobacco. The dry matter of a good tobacco is supposed to contain about 6-8 percent potassium, 2-3 percent nitrogen, and .15 to .20 percent phosphoric acid, but must be free from chlorine.

The terms used in describing the character of the ash refer to completeness of combustion. Where the ash is described by the terms light, gray, firm, flaky, etc., the completeness of combustion is indicated. In some instances the texture of the ash was found to be firm and charred, indicating that the fusibility of the salts was such that particles of carbon were occluded. Where a firm ash was obtained, it was due more or less to the charred and incompletely oxidized organic matter, except on a few of the plots where the treatment was such that a firm, light ash resulted from the combustion.

All of the tobaccos tested have rather a high calcium content, which may account for the flaking of the ash in many instances. A loose, flaky ash is objectionable on account of the scattering of the ash over the clothes of the smoker. The evenness of burn seems to be due to the manufacture of the cigars rather than to the tobacco of which it is composed.

The addition of lime had little, if any, effect on the flavor and aroma, nor was there any material difference in the character of the ash of tobacco grown on plots receiving lime compared with that from unlimed plots.

EFFECT OF FORM AND QUANTITY OF POTASSIUM APPLIED

Tobaccos from plots treated with the same carriers of phosphorus and nitrogen, in combination with potassium supplied by three different salts, muriate, sulphate and nitrate, differ in the duration of burn. Twelve of the plots included in this test were treated with muriate of potash, only two with sulphate and one with nitrate. One of the sulphate treated plots was limed, which introduces an additional factor contributing to variations noted in the results of the smoking tests.

[1]Mededeelingern Van Het Deli Proefstation Te Medan 6 de Jaargang, July 1911-July 1912

Muriate of potash was included with varied combinations of phosphorus and nitrogen, both as to the carriers and amounts used, so that differences found in burning quality are due in part to other influences than the muriate of potash treatment.

However, the average time of burning for the tobacco from plots which received muriate of potash is approximately half that obtained for plots treated with sulphate and nitrate. An inspection of the chlorine results for the tobacco from the muriate treated plots, in contrast with that from plots receiving no chlorides, is sufficient explanation for the differences found. The addition of chloride to the soil is reflected by the chlorine content of the leaf, which in turn affects the burning qualities.

The tobacco having a low chlorine content had a good fire-holding capacity, while a contrary result was obtained for practically all of the tobacco having a high percentage of chlorine. The most pronounced exception to this is the tobacco from soil treated with shed manure where the chlorine amounts to 1.3 percent, approximately half that found in the case of the muriate treated plots, and the burning quality of the tobacco is rated high.

While the smoking tests are closely related to the chlorine results, the impairment of quality can not always be attributed to the chlorine unless the amount of this constituent taken up by the plant from any increased supply in the soil exceeds certain limits. Plot 5, to which muriate of potash and nitrate of soda were applied, has a fire-holding capacity of 6 minutes, while the figure obtained for Plot 8, treated with the same amount of muriate and nitrate of soda with addition of acid phosphate, was 4 minutes and 52 seconds. The effect produced by muriate of potash is strikingly illustrated by comparing Plots 2 and 3. Plot 2, treated with acid phosphate alone, has a burn of 7 minutes and 11 seconds, while Plot 3, where muriate of potash is added to the phosphorus treatment, has a fire-holding capacity of only 3 minutes. If the untreated plot is taken as a standard, the results show that the burn of the tobacco from Plot 10 differs only slightly from that of the sulphate and nitrate of potash treated plots, but the flavor and aroma are rated much lower.

The combination in which the potassium exists influences the quality. When combined with organic acids it is assumed that it exerts a favorable influence on the flavor and aroma as well as on the burning quality. It is probable that, where excessive amounts of chlorine have accumulated in the leaf following the fertilizer treatment, a larger portion of the potassium exists in combination as chlorides than where lesser amounts of chlorides are found.

All of the tobaccos containing larger amounts of chlorine have a poor flavor and a black charred ash resulting from the combustion. In most instances tobacco fertilized with muriate of potash produced a dark colored, firm ash, which in some cases did not cohere with the ash of the binder and wrapper, with the result that the ash of the binder and wrapper shattered easily.

Variations in the chlorine content of the tobacco resulting from different fertilizer treatment have exercised a more pronounced effect on the burn than that due to the other elements present. This may be due partly to fusing of chlorides over particles of organic matter, and to the chlorine compounds, set free from salts present by the action of heat, being absorbed by the organic matter and consequently retarding the oxidation. The dark colored ash resulting from the burning of the cigars can not be attributed to the bases present but rather to the acids with which they are combined. In this test, where the salts of chlorine are not too abundant, the resulting ash is light in color, but where the bases present are largely in combination with chlorine, the ash residue from the combustion is dark colored.

The results for the smoking tests of tobacco grown on soil to which potassium sulphate and potassium nitrate were applied, as potassium carriers, are better both in length of time the cigar held fire and the character of the ash than those of the tobacco from plots treated with muriate of potash, where no lime was used. The flavor and aroma are rated as excellent. The results indicate that the addition of lime to the potassium sulphate treated plots has slightly impaired the smoking quality of the tobacco. Lime modified the effect of the potash treatment since the results for fire-holding capacity show that the addition of 1,000 lbs. of lime has shortened the time of burning when used with either muriate or sulphate of potash.

The presence of sulphates exerts no appreciable influence on the smoking quality. However, the quantity present in all the tobaccos tested is small, the addition of potassium sulphate having contributed only slightly towards increasing sulphates in the tobacco leaf.

EFFECT OF PHOSPHORUS

Smoking tests of tobacco from Plot 2, where 480 lbs. of acid phosphate were applied without potassium or nitrogen, indicate that phosphorus has favorably influenced the quality of the tobacco. Both the burn and character of the ash are better than that of the tobacco grown on unfertilized soil, while the flavor and aroma are rated as excellent. Any favorable effect of phosphorus on the quality, however, has been counteracted where muriate of potash and other fertilizing materials have been used in combination with acid phosphate.

Phosphorus hastens maturity, and mature tobacco cures better than immature tobacco. Heavy applications of acid phosphate on light soils, especially when deficient in nitrogen, have a tendency to cause premature ripening and firing of bottom leaves.

EFFECT OF NITROGEN

The fertilizer treatment includes comparison between two inorganic nitrogen carriers, sodium nitrate and ammonium sulphate, with tankage. Where tankage is used, the phosphorus treatment is modified so that no direct comparison between inorganic carriers and tankage under like conditions can be made. Results of the tests are too indefinite to give more than a general indication of the influence produced by different forms of nitrogen used in the fertilizers.

Where sodium nitrate is used in connection with acid phosphate, Plot 6, the quality of the tobacco is below that from the acid phosphate treated plot. Addition of sodium nitrate to acid phosphate and muriate of potash, Plot 8, increased the fire-holding capacity but does not appear to have changed the smoking quality in other respects. Increasing the amount of sodium nitrate applied, Plot 15, the phosphorus and potassium in the fertilizer being the same as applied to Plot 8, has appreciably decreased the fire-holding capacity, while the character of the ash, flavor and aroma are improved. Where an equal amount of nitrogen was applied in the form of ammonium sulphate, Plot 16, the tests indicate small difference in quality. If too large an amount of nitrogen is used in the fertilizer, it may prevent the tobacco from maturing and properly curing.

BURNING TESTS

The illustrations, which were made from cigars smoked under uniform conditions, show the character of the ash and rate of burning of cigars made from these several lots of tobacco tested.

The cigars were smoked by means of an artificial smoker, similar in construction to that used by the Bureau of Plant Industry, United States Department of Agriculture. The volume of the container used for aspiration of air through the apparatus was such that the combustion of each cigar continued for a uniform length of time, 15 minutes. The rate of burn during this period is inversely as the length of the unburned portions of the cigars represented in the illustrations.

Reference to the figures indicates a relation between the rate of combustion and fire-holding capacity. This is strikingly pointed out by the burn of cigars from Plots 2, 3 and 10, represented in Figure 1.

SUMMARY

Composition and quality of tobacco grown on the same soil treated with various forms and combinations of fertilizers have been considered.

The results show that the composition has been modified to a greater or less extent by different fertilizer treatments.

The several lots of tobacco have a high ash content. When sodium nitrate is applied there has been, in most instances, a decrease in total ash, phosphorus, sulphur and chlorine.

Of the essential elements present, calcium is found in largest amount, followed by nitrogen, potassium, magnesium sulphur and phosphorus.

The addition of lime to the soil has decreased the calcium and increased the magnesium in the tobacco. A complementary relation is found to exist between the calcium and magnesium, when the one is high the other is low.

Tobacco from limed plots, as a rule, contains less phosphorus, potassium and sulphur than that from unlimed plots.

Relatively small amounts of phosphorus are removed by the crop, as compared with other constituents which are regarded as less essential for plant growth.

The highest percentage of nitrogen is found in tobacco from unfertilized soil. Where organic carriers of nitrogen were applied, the percent of nitrogen in tobacco leaves is higher than where inorganic materials supplied the nitrogen. Tobacco from plots to which organic carriers of nitrogen, shed manure and tankage, were applied, have a higher nitrate nitrogen and nicotine content.

While tobaccos from plots treated with potassium salts contain more potassium than where none was applied, the amount present is influenced by the carrier of this element. Tobacco from sulphate or nitrate of potash plots contains larger amounts of potassium than that from muriate of potash treated plots, fertilized with like carriers and quantities of phosphorus and nitrogen. Sodium nitrate has tended to increase the potassium content.

The smallest amount of potassium is found in case of untreated land, and the largest amount in tobacco from the manure treated plot, which is in accord with the large amount of potassium furnished by 20 tons of manure.

The carrier of potassium used has decidedly influenced the amounts of chlorine and sulphur in the tobacco leaf, but certain conditions of fertilization have so modified the amounts of potassium and chlorine or sulphate present, that no direct relation exists between them.

The chlorine content is in close agreement with the excess of chlorine supplied to the soil by muriate of potash, the largest amount being present in tobacco from soil receiving the heaviest application of muriate.

Tobacco from the manure treated plot contains more chlorine than any of the other tobaccos not fertilized with muriate of potash. This is in agreement with the amount of chlorine furnished by 20 tons of manure. The amount of chlorine present in this case, 1.32 percent, has not impaired the quality of the tobacco.

Acid phosphate, when used in combination with muriate of potash, tends to increase the chlorine content, while nitrate of soda decreases it.

While the sulphur content of tobacco is normally greater than the chlorine, when no excessive amount of chlorine has been furnished, the addition of sulphates in the fertilizing material has modified the sulphur content in a much less degree than has been found with regard to the chlorine following treatment with muriate of potash.

Smoking tests of cigars from the several lots of tobacco show that the quality of tobacco is impaired where muriate of potash is used in the fertilizer.

Tobaccos with a low chlorine content have a good fire-holding capacity in contrast with the tobacco containing excessive amounts of chlorine due to the fertilizer treatment.

All the tobaccos with a high chlorine content had a black, charred ash, which in some instances did not cohere with the ash of the binder and wrapper, with the result that the ash of the binder and wrapper shattered easily.

The average length of time the cigars made from tobacco from the muriate treated plots held fire was approximately half that for tobacco from plots treated with sulphate or nitrate of potash.

Muriate of potash was included with varied combinations of phosphorus and nitrogen so that differences observed in burning quality are due in part to other influences.

Although muriate of potash when used with acid phosphate and nitrate of soda increased the yield above that obtained by the use of other forms of potash, any improvement in this respect has been more than offset by poor quality of the tobacco.

Potassium when used in other combinations than the chloride, improved the quality of the tobacco.

The quantity of sulphur as sulphates present in the tobacco exerted very little, if any, influence on the burning quality.

Acid phosphate alone improves the quality of the tobacco; when applied in combination with muriate of potash, any favorable effect produced, appears to be counteracted.

Variations in flavor, aroma and fire-holding capacity are not due entirely to the presence or absence of any one compound, but are more or less dependent upon the total constituents of the tobacco.

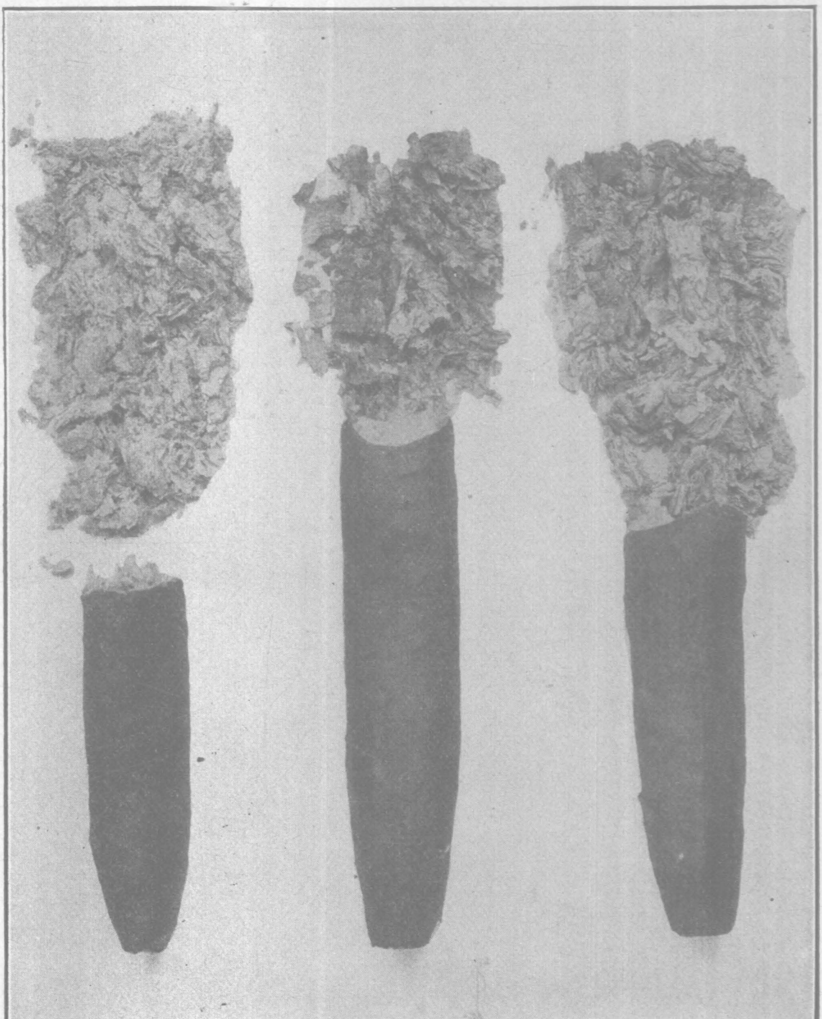

Fig. 1
Plot Nos.

2	3	10
	FIRE HOLDING CAPACITY	
7 min. 11 sec.	3 min. 0 sec.	6 min. 41 sec.
	COMBUSTION DURING 15 MINUTES	
5.7 cm.	3.5 cm.	5.3 cm.

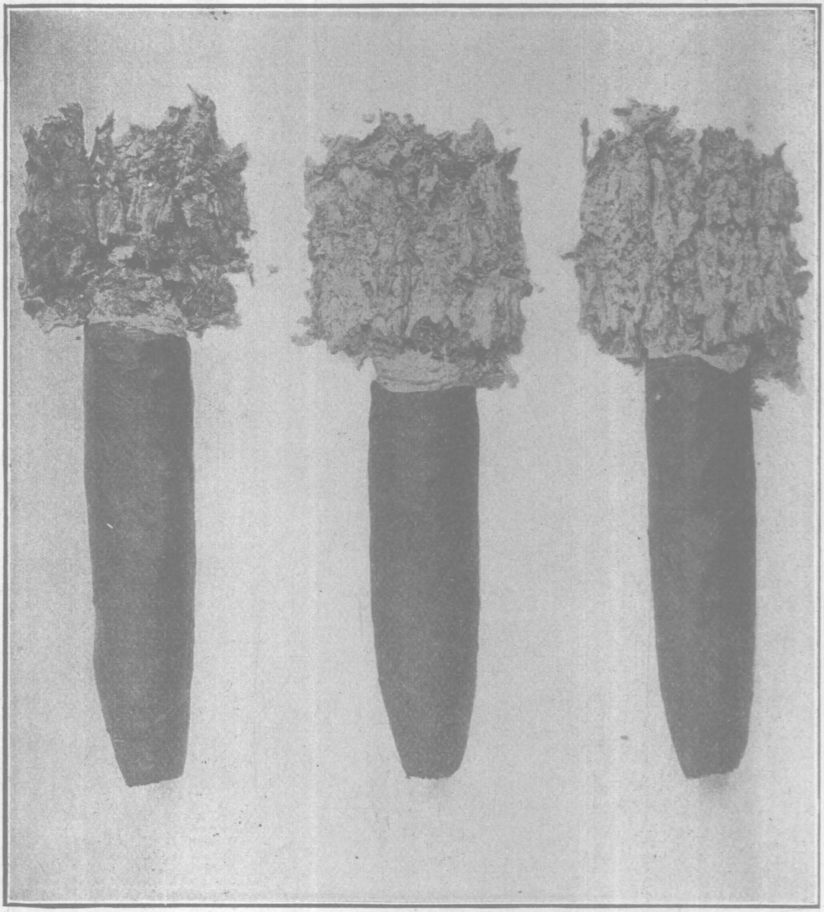

Fig. 2
Plot Nos.

8	22	23
	FIRE HOLDING CAPACITY	
4 min. 52 sec.	7 min. 11 sec.	8 min. 11 sec.
	COMBUSTION DURING 15 MINUTES	
4.3 cm.	5.5 cm.	5.0 cm.

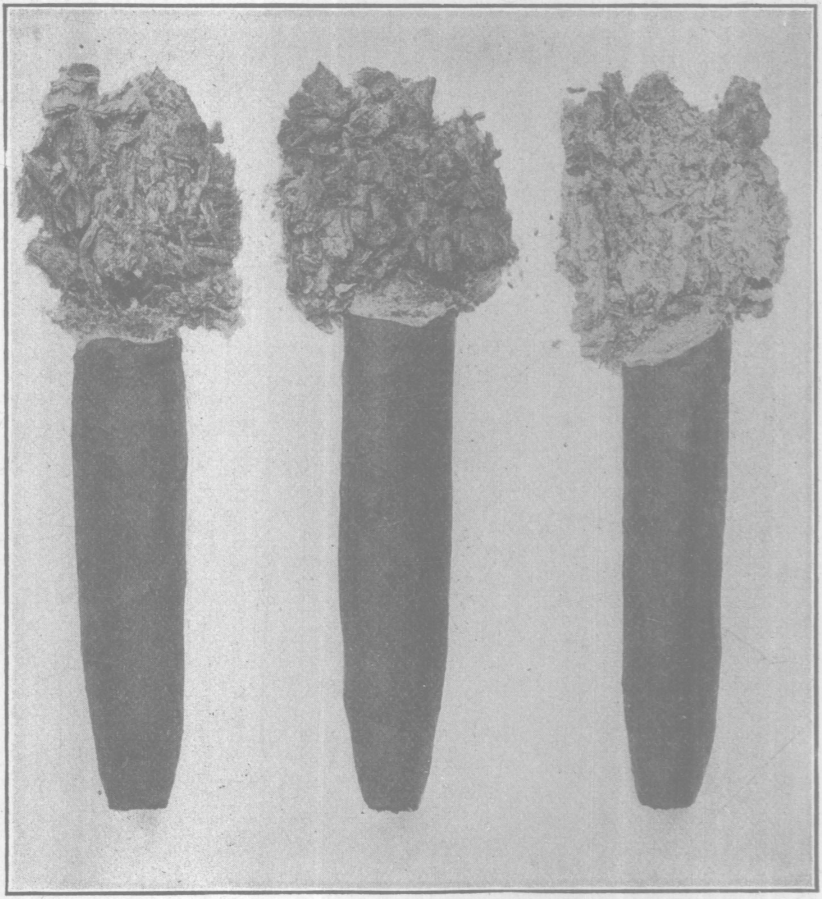

Fig. 3

Plot Nos.

26	29	33
	FIRE HOLDING CAPACITY	
3 min. 11 sec.	4 min. 18 sec.	7 min. 7 sec.
	COMBUSTION DURING 15 MINUTES	
4.2 cm.	4.0 cm.	4.3 cm.

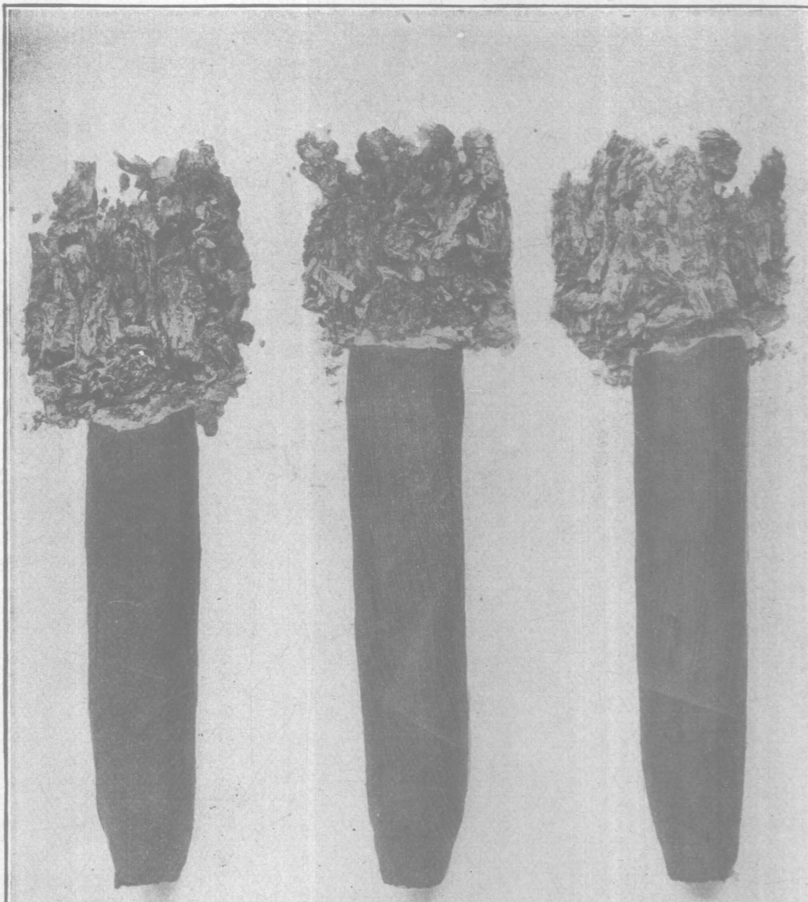

Fig. 4

Plot Nos.

9	13	15
	FIRE HOLDING CAPACITY	
3 min. 52 sec.	3 min. 0 sec.	3 min. 37 sec.
	COMBUSTION DURING 15 MINUTES	
4.4 cm.	3.3 cm.	3.5 cm.

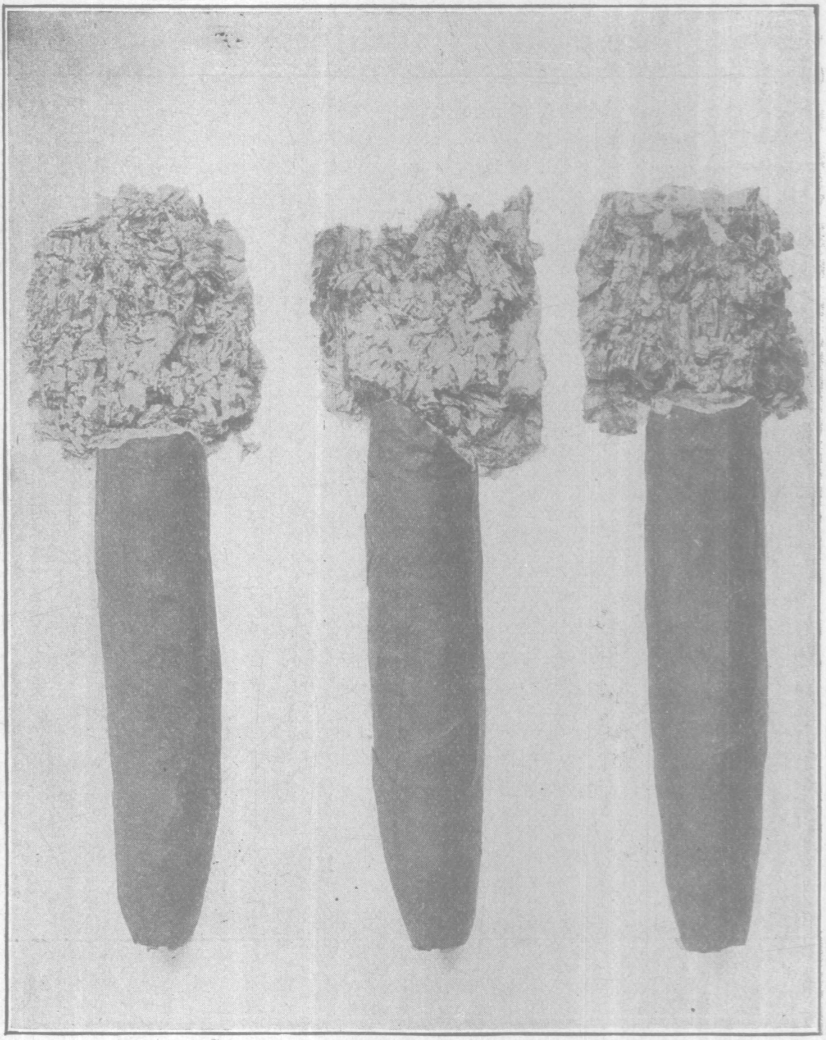

Fig. 5

Plot Nos.

12	16	26
FIRE HOLDING CAPACITY		
4 min. 22 sec.	3 min. 26 sec.	4 min. 7 sec.
COMBUSTION DURING 15 MINUTES		
4.1 cm.	3.9 cm.	3.8 cm.

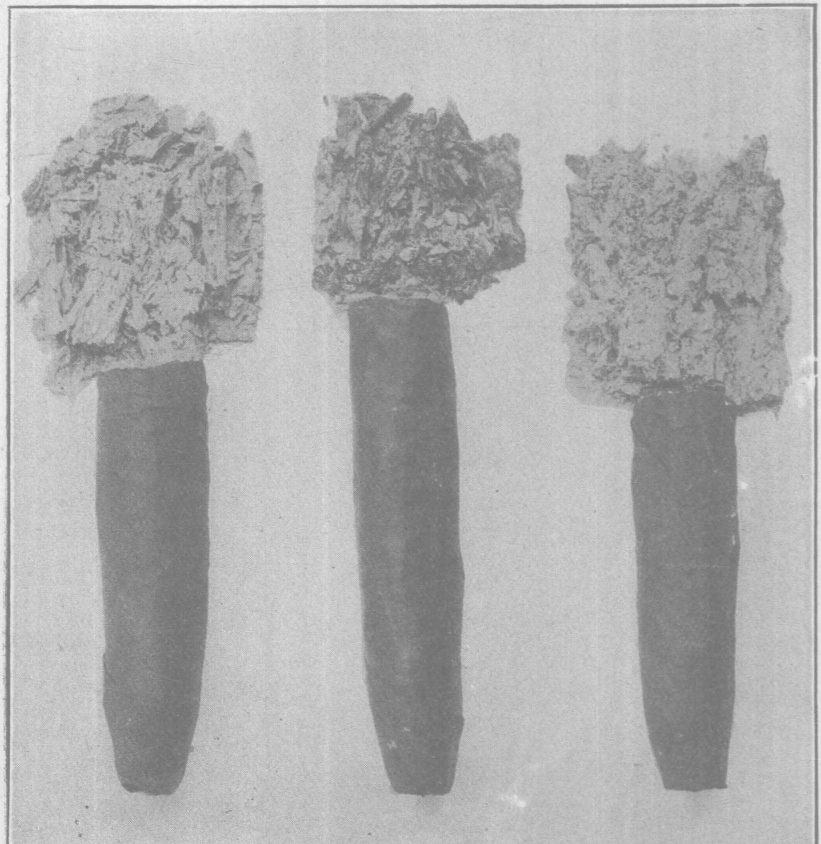

Fig. 6

Plot Nos.

5	18	25
	FIRE HOLDING CAPACITY	
6 min. 0 sec.	5 min. [illegible] sec.	7 min. 26 sec.
	COMBUSTION DURING 15 MINUTES	
4.7 cm.	3.9 cm.	5.3 cm.

ADDENDA

METHODS EMPLOYED

Samples: collection and preparation: Enough leaves to make about five hands of tobacco for each sample were taken from different parts of a number of plants at the time of stripping the tobacco. The midrib was removed and the remainder of the leaf dried at a temperature below 50° C. After being thoroughly dried, the samples were finely ground, thoroughly mixed and preserved in glass containers.

Moisture: From 2 to 3 grams of the prepared samples are weighed into aluminum drying dishes and dried to constant weight in vacuum desiccators.

Ash: Two grams of the sample are ignited in platinum dishes over low flame until most of the carbon is burned off. Allow to cool and add 20 cc. hot water through lip of covered dish. Filter and wash residue three or four times with hot water, receiving filtrate and washings in weighed 200 cc. Erlenmeyer flask, transfer the filter paper with residue into the platinum dish, dry and ignite until practically all the carbon is consumed. Transfer the remaining ash to the Erlenmeyer flask with hot water, using a policeman to loosen any particles that may adhere to dish. Evaporate moisture, and dry flask and contents at 110° C. for 2 hours. Total dry weight less weight of flask represents crude ash.

The flask containing crude ash is then connected to an apparatus* for determination of carbon dioxide, treated with 80 cc. of distilled water free from carbon dioxide and 20 cc. of dilute hydrochloric acid (1:1), boiled for 30 minutes with aspiration of purified air and the gas absorbed by 50 cc. of a 4 percent solution of sodium hydroxide. The sodium hydroxide solution is then drawn out of the absorption tower and the tower washed out with 400 cc. of carbon dioxide free water, exactly neutralized with normal hydrochloric acid, using phenolphthalein as indicator. Two drops of methyl orange solution (1 gm. to 1000 cc.) are added and the solution titrated with N-20 Hydrochloric acid until the color of the methyl orange indicator is just darkened to a slight orange color. From the number of cc.'s Hydrochloric acid used, substract blank. 1 cc. N-20 Hydrochloric acid = 0.0022 grams CO_2. The first neutralization, where phenolphthalein is used as indicator, is ignored.

The carbon, sand and silica are determined as outlined on page 22 in Bulletin 107, U. S. Bureau of Chemistry. Crude ash less carbon dioxide, carbon and sand represents the carbon-free ash.

*Jour Ind & Eng Chem Vol 4, p 611

Sulphuric and nitric acid digestion of plant substances for determination of phosphorus and potassium: Transfer 5 grams of material into a 500 cc. Kjeldahl digestion flask; add 7 cc. concentrated sulphuric acid and 5 cc. concentrated nitric acid, mix thoroughly and heat over low flame until frothing ceases, then add 1 cc of nitric acid; repeat treatment with 1 cc. portions of nitric acid until organic matter is destroyed. Cool, add about 50 cc. of water, filter into 250 cc. flask, wash filter paper and residue thoroughly with water, and make filtrate up to 250 cc. mark.

Phosphorus: Transfer 50 cc. portion (1 gram sample) of the above solution into 250 cc. beaker, add ammonium hydroxide until slightly alkaline, clear with nitric acid adding about .3 cc. of nitric acid beyond neutral point. Add 5 grams of dry ammonium nitrate, heat in water bath to 55° C. and precipitate the phosphorus with 30 cc. of molydate solution. Stir thoroughly.

Heat at 55° C. for one hour, allow to stand out of bath for one hour. Filter on asbestos pad in filtering tube and wash with a solution of potassium nitrate (5 grams per liter) until free from acid. Transfer filtering pad and precipitate to precipitating beaker. Dissolve in small excess of standard alkali, add a few drops of phenolphthalein indicator and titrate with standard acid. 1 cc. N/10 potassium hydroxide solution = .00013488 grams Phosphorus (P).

Potassium: Transfer 50 cc. of the solution obtained from the sulphuric and nitric acid digestion to porcelain evaporating dish. Excess of water and acid is removed by evaporation on steam bath and finally over burner adapted especially for removal of sulphuric acid without direct heating of bottom of dish and consequent spattering. This burner consists of a small laboratory burner 3 inches high and 5 inches in diameter, in the center of which is placed a circular piece of asbestos board 2½ inches in diameter, which spreads the flame so that it heats the dish above the surface of the liquid contained. By the use of a battery of twelve of theses burners, excess of sulphuric acid can be removed from a number of dishes in a short time without danger of loss from spattering.

After acid is removed, heat at low red heat over Bunsen burner to volatilize remaining ammonium salts and organic matter. Allow dish to cool, add 1 cc. of concentrated hydrochloric acid and about 25 cc. of hot water, rub with glass rod, and heat if necessary to bring salts into solution. Transfer to a 150 cc. beaker, add necessary excess of platinic chloride solution and evaporate just to dryness on steam bath. Cool, add 15 cc. of acidulated alcohol. (To make acidulated alcohol use 15000 cc. 95% alcohol, add 1139.9 cc. hydrochloric acid sp. gr. 1.2 and pass enough hydrochloric acid gas into the solution to make it 2.25 normal hydrochloric acid). Allow to stand 2 or 3 minutes, filter in special potassium filter tube* using suction. Transfer all precipitate from beaker to filter, with 80% alcohol. Wash precipitate and filter free from platinic chloride solution with 80% alcohol, then wash several times with Gladding Wash, and finally wash free from ammonium chloride with 80% alcohol. Dry to insure complete removal of alcohol and fit filter tube into opening of bell jar filtering apparatus. Make repeated additions of hot water for complete solution of potassium platinic chloride, receiving washings in weighed platinum dish.

Evaporate on steam bath to dryness, cover dish with watch glass, place in drying oven and heat for 1 hour at 110° C. Cool in desiccator and weigh.

Sodium: Ash a 2 gram sample and follow procedure as outlined in U. S. Bureau of Chemistry, Bulletin 107, p. 17.

The sodium and potassium may be determined by ashing enough sample to make about .5 gram ash and proceeding as outlined in Crookes' Select Methods, 2nd Edition, pp. 28-40.

Calcium and Magnesium: Char 5 grams of material in platinum dish at low heat. Cool, cover dish with watch glass, moisten with water, add 3 cc. hydrochloric acid and sufficient water to make about 25 cc. of solution. Filter into 150 cc. beaker, wash residue on filter paper three or four times with hot water, return filter paper with residue to platinum dish, dry and ignite to a white ash; transfer residue in dish to beaker containing filtrate with hydrochloric acid and hot water. Evaporate to dryness, take up with a small amount of hydrochloric acid and hot water and filter into a 500 cc. graduated flask. Wash with hot water and make volume in flask up to about 250 cc. To solution in flask add one-third more standard ferric chloride solution than is necessary to precipitate the phosphorus present. Neutralize with ammonium hydroxide, acidify with hydrochloric acid, adding only very slight excess. Add 10 cc. of 20 percent solution of ammonium acetate, boil for two minutes, cool and make volume of solution upto 500 cc. Mix, filter into dry beaker and measure off 200 cc. of filtrate. Make alkaline with ammonium hydroxide using about 1 cc. excess and precipitate the calcium with 10 cc. of a saturated solution of ammonium oxalate. Allow the precipitate to settle, filter on asbestos mat in filter tube, using suction, and wash with hot 2 percent ammonium hydroxide solution. The precipitate and asbestos mat are transferred to pre-

*Jour. Ind. & Eng. Chem., Vol. 4, p. 436.

cipitating beaker. Add 100 cc. of distilled water and 25 cc. of concentrated sulphuric acid, heat to 80° C., and titrate with standard potassium permanganate solution.

Magnesium: To the filtrate from the precipitation of calcium oxalate add 30 cc. of nitric acid, evaporate to dryness, take up with hydrochloric acid and water, filter and wash with distilled water. To the filtrate add 10 cc. of a 10 percent solution of ammonium phosphate, make slightly alkaline with ammonium hydroxide, after standing for 30 minutes add 15 cc. concentrated ammonium hydroxide and allow to stand over night. Filter and wash precipitate thoroughly with 2 percent ammonium hydroxide solution, dry, ignite and weigh the precipitate as magnesium pyrophosphate. Where the amounts of calcium and magnesium are large, it is best to dissolve and reprecipitate both the calcium and magnesium. A correction is made for the manganese present in the magnesium pyrophosphate if there be an appreciable amount present in the material analyzed.

Manganese: Weigh out 5 to 10 grams of sample into a platinum dish, char over low flame, add about 20 cc. of water and extract with hot water by filtering into a 250 cc. beaker. Wash the residue three or four times with hot water, return the filter paper with residue to dish and heat until all of the carbon is destroyed. Cover the dish with a watch glass and add 10 cc. of a dilute solution of nitric acid (1 to 4), transfer residue to beaker containing filtrate and evaporate to dryness, take up with a small amount of nitric acid and evaporate to dryness again to expel all chlorides. Dissolve salts with 2 cc. nitric acid and 50 cc. hot water, filter into a 200 cc. Erlenmeyer flask, washing residue and filter thoroughly. Add 15 cc. concentrated nitric acid to the filtrate and evaporate solution to 50 cc. Cool, add .5 gram sodium bismuthate, heat to boiling, add a few drops of 10 percent sodium thiosulphate solution until color is destroyed, heat until all nitrous oxide has been driven off. Allow to cool and transfer to a 200 cc. graduated flask with a solution containing 30 cc. of nitric acid to the liter. Cool to about 15° to 20° C., add an excess of bismuthate and shake at intervals of one to two minutes for 10 minutes. Make up to mark with solution containing 30 cc. of nitric acid to the liter, mix thoroughly and filter by suction through asbestos filter. Discard the first 20 cc. of filtrate and use a second portion of the filtrate for comparison with standard. Where sample contains a large amount of manganese, the oxidized solution may be filtered into an Erlenmeyer flask of convenient size and titrated with standard solutions of ferrous ammonium sulphate and potassium permanganate. For further details of method see Blair's Chemical Analysis of Iron, 7th Edition, pp. 121-122.

Total Sulphur: The method for total sulphur in organic materials as outlined by Herman Schreiber in Circular 56, Bureau of Chemistry, U. S. D. A., is used.

Sulphur existing as Sulphates: Weigh 5 grams of the dried prepared sample into a liter bottle, add 500 cc. of 1 percent solution of hydrochloric acid, place in a shaking machine and shake for three hours. Filter into dry beaker, take an aliquot representing 2 to 4 grams of sample and precipitate with barium chloride in the cold solution. Allow to stand at least 12 hours, filter and wash thoroughly, first with cold then with hot water. Ignite and weigh as barium sulphate.

Chlorine: The provisional method for chlorine in plants as outlined in Bulletin 107, page 23, Bureau of Chemistry, is followed.

Total Nitrogen: The Official Kjeldahl method modified to include the nitrogen of nitrates is used for determination of total nitrogen.

Nitrogen and Nitrates: Weigh 5 to 10 grams into a clean 500 cc. Kjeldahl flask, add 200 cc. nitrate and nitrite free water and sufficient 50 percent sodium hydroxide solution (about 2 cc.) to make approximately a N/10 normal solution, add a few pieces of pumice stone and boil for about 10 minutes without connecting Kjeldahl flask with the distilling apparatus. Cool to about 20° C. and add a little paraffin to prevent frothing, then add about 1 gram of Devarda's alloy, 60 mesh. Connect the flask with distilling apparatus and distill as fast as the foaming in the Kjeldahl flask will permit. Boil for 40 minutes, receiving distillate in standard acid. To eliminate error due to carrying over alkaline spray into the receiver, the contents of the receiving flask are transferred to boiling flask and redistilled over magnesium oxide. Correction obtained for blanks on reagents, etc., is applied.

See article by E. R. Allen, "Determination of Nitric Nitrogen in Soils," Journal of Industrial and Engineering Chemistry. Vol. VII, 1915, for further details of method.

Nicotine: Method of Garner used as given in Bulletins 102 pt. 7, Bureau of Plant Industry.

EXPERIMENTS WITH FERTILIZERS AND MANURE ON TOBACCO GROWN CONTINUOUSLY AND IN ROTATION WITH WHEAT AND CLOVER

By C. E. THORNE

These experiments were begun in 1903, and previous reports have been made in Bulletins 161 and 206. The soil under experiment is the Miami clay, derived from a thick sheet of glacial drift lying over limestone. Limestone pebbles are found 25 to 30 inches below the surface, and limestone slabs are sometimes turned up in plowing. In well drilling no stratified limestone was encountered within 115 feet.

The soil had been subjected to exhaustive husbandry for many years before the experiments were begun.

FERTILIZERS AND MANURE ON TOBACCO GROWN CONTINUOUSLY

Eighteen plots, of one-twentieth acre each, are devoted to this part of the work, and receive the following treatment annually:

Plot 1, None
" 2, Acid phosphate, 160 lbs.; muriate potash, 60 lbs.; nitrate soda, 80 lbs.
" 3, Acid phosphate, 160 lbs.; muriate potash, 60 lbs.; nitrate soda, 160 lbs.
" 4, None
" 5, Acid phosphate, 160 lbs.; muriate potash, 60 lbs.; nitrate soda, 320 lbs.
" 6, Acid phosphate, 160 lbs.; muriate potash, 60 lbs.; nitrate soda, 480 lbs.
" 7, None
" 8, Acid phosphate, 320 lbs.; muriate potash, 60 lbs.; nitrate soda, 320 lbs.
" 9, Acid phosphate, 320 lbs.; muriate potash, 120 lbs.; nitrate soda, 320 lbs.
" 10, None

Plots 11 to 18, inclusive, are cross dressed with untreated shed manure, 8 tons per acre. The following additional treatment is given:

Plot 11, None
" 12, Acid phosphate, 160 lbs.
" 13, Acid phosphate, 160 lbs.; muriate potash, 60 lbs.; nitrate soda, 160 lbs.
" 14, None
" 15, Acid phosphate, 160 lbs.; muriate potash, 60 lbs.; nitrate soda, 320 lbs.
" 16, Phosphated shed manure, 5 tons.
" 17, None
" 18, Phosphated yard manure, 5 tons.

Table VI gives the average yields and increase obtained in this experiment for the two 6-year periods, 1903-8 and 1909-14.

TABLE VI: Yield and increase of tobacco grown continuously, 1903 to 1914

Plot No.	6-yr. average, 1903-8			6-yr. average, 1909-14			12-yr. average, 1903-14			Plot No.
	Wrapper and filler	Trash	Total	Wrapper and filler	Trash	Total	Wrapper and filler	Trash	Total	
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
				Yield per acre						
1	310	143	453	208	98	306	259	121	380	1
2	675	157	832	582	102	684	629	129	758	2
3	732	155	887	649	113	762	690	134	824	3
4	302	152	454	243	98	341	273	124	397	4
5	820	172	992	781	118	899	800	145	945	5
6	807	165	972	782	115	897	795	140	935	6
7	250	127	377	208	98	306	229	112	341	7
8	882	182	1,064	898	114	1,012	890	148	1,038	8
9	996	153	1,149	919	104	1,023	957	129	1,086	9
10	196	113	309	239	86	325	218	99	317	10
*	265	134	399	224	95	319	245	114	359	
				Increase per acre						
2	367	11	378	362	4	366	365	7	372	2
3	427	6	433	417	16	433	422	11	433	3
5	535	28	563	550	20	570	542	24	566	5
6	539	30	569	563	17	580	552	23	575	6
8	652	59	711	680	20	700	666	39	705	8
9	782	35	817	690	14	704	736	25	761	9
				Cross dressed with manure. Yield per acre						
11	738	159	897	659	105	764	737	159	896	11
12	803	183	986	778	118	896	791	150	941	12
13	1,006	172	1,178	928	102	1,030	968	136	1,104	13
14	809	137	946	637	102	739	723	119	842	14
15	1,100	152	1,252	947	108	1,055	1,023	130	1,153	15
16	1,121	145	1,266	986	117	1,103	1,053	131	1,184	16
17	909	189	1,098	783	123	906	846	156	1,002	17
18	1,103	161	1,264	947	123	1,070	1,025	142	1,167	18
*	819	161	980	693	110	803	755	136	891	
				Increase per acre over manure						
12	42	32	74	126	14	140	84	23	107	12
13	221	28	249	285	—1	284	253	13	266	13
15	257	—2	255	261	—1	260	259	—1	258	15
16	245	—27	218	251	1	252	248	—13	235	16
18	194	—28	166	163	0	163	179	—14	165	18
				Increase over average unmanured and unfertilized yield						
12	538	49	587	554	23	577	546	36	582	12
13	741	38	779	704	7	711	723	22	745	13
15	835	18	853	723	13	736	778	16	794	15
16	756	11	867	762	22	784	808	17	825	16
18	838	27	865	723	28	751	780	28	808	18

*Average unfertilized yield.

The plots employed in this test are 16 feet wide by 136 feet long, containing one-twentieth acre each. They are separated by paths two feet wide and tile drains are laid under alternate paths, making the drains 36 feet apart. In the continuously grown tobacco the plots are arranged in a single range of 18 plots; in the rotative cropping the plots are arranged in blocks of ten plots each and in three sections, A, B and C, of 40 plots each, as indicated by the diagrams, and every third plot is left continuously untreated. The increase due to treatment is calculated on the assumption that if Plots 1 and 4, untreated, were to yield 300 and 330 pounds respectively, the unaided yields of Plots 2 and 3 would probably be 310 and 320 pounds.

Section A is located on a small farm of 13 acres, which had been owned separately from the tract on which B and C are located before the land was leased by the Experiment Station.

Table VII gives the financial outcome of this experiment, reckoning 14 percent acid phosphate at $16.00 per ton, muriate of potash at $50 per ton and nitrate of soda at $60 per ton, prices at which these materials were sold in small quantities during the progress of the experiment, and estimating tobacco wrapper and filler at 8 cents per pound and trash at one and one-half cent.

TABLE VII: Fertilizers and manure on tobacco grown continuously
Annual value of increase by 6-year periods

Plot No.	Fertilizing materials per acre				Cost of treatment	Annual value of increase			
	Acid phosphate	Muriate potash	Nitrate soda	Manure		First 6 years		Second 6 years	
						Total	Net	Total	Net
	Block I. Fertilizers only								
2	160	60	80	....	$ 5.20	$29.52	$24.32	$29.02	$23.82
3	160	60	160	...	7.60	34.45	26.85	33.60	26.00
5	160	60	320	....	12.40	43.22	30.82	44.30	31.90
6	160	60	480	...	17.20	43 57	26.37	45.29	28.09
8	320	60	320	...	13.70	53.05	39.35	54.70	41.00
9	320	120	320	....	15.20	63.08	47.88	55.41	40.21
	Block II. Fertilizers, and manure at $2.00 per ton								
11-14-17	...	.	..	8 tons	16.00	44.74	28.74	37.72	21.72
12	160	.	..	8 "	17.30	43.77	26.47	44.66	27.36
13	160	60	80	8 "	21.20	59.85	38.65	56.42	35.22
15	160	60	160	8 "	23.60	67.07	43.47	58.03	34.43
16	...	..	..	13 "	27.60	60.64	33.04	61.29	33.69
18	...	..	...	13 "	27.60	67.44	29.84	58.26	30.66
	Fertilizers, and manure at 50 cents per ton								
11-14-17	...	..	...	8 tons	4.00	44.74	40.74	37.72	33.72
12	160	..	...	8 "	5.30	43.77	38.47	44.66	39.36
13	160	60	80	8 "	9.20	59.85	50.65	56.42	47.22
15	160	60	160	8 "	11.60	67.07	55.47	58.03	46.43
16	...	..	...	13 "	8.10	60.64	52.54	61.29	53.19
18	...	..	..	13 "	8.10	67.44	59.34	58.26	50.16

Table VII shows that in this continuously grown tobacco the total yield has steadily increased with the quantity of fertilizer, and the average net gain has increased with every increase of fertilizer excepting on the land receiving 480 pounds of nitrate of soda, this application having produced but a small increase over that of 320 pounds. It will be observed that the net return from the large applications on Plots 8 and 9, costing $13.70 and $15.20 per acre, has been nearly twice as great as from the smallest dressing, costing one-third as much.

In these computations manure has first been rated at $2.00 per ton, and at this price the net gain from the manure has been greater than from any except the largest dressings of fertilizers. Were manure estimated at merely its cost of application—say 50 cents per ton—the net gain would be greater than from any of the fertilizers without manure.

Whether manure be valued at 50 cents per ton or $2.00 per ton, it has been profitable to reenforce it with chemical fertilizers.

FERTILIZERS AND MANURE ON TOBACCO GROWN IN ROTATION WITH WHEAT AND CLOVER

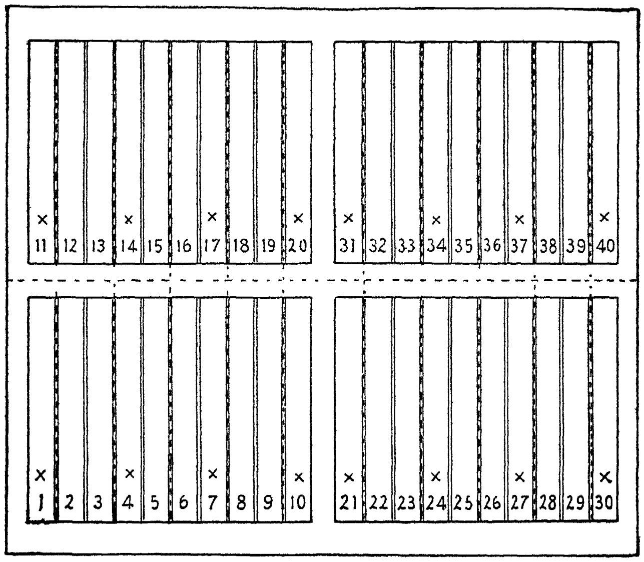

DIAGRAM I: Arrangement of plots in tobacco-wheat-clover rotation
Section A

In Table VIII are given the average yield and increase per acre for each crop over the entire period of the experiment, and in Table IX are given the plan of treatment and the value of the increase, reckoning tobacco at eight cents per pound for the wrapper and filler and one and one-half cent for the trash, wheat at 80 cents per bushel, straw at $2.00 per ton, and hay at $8.00. This table also shows the cost of the fertilizing, rating 14 percent acid phosphate at $16.00 per ton, muriate of potash at two and one-half cents per

TABLE VIII: Tobacco, wheat and clover grown in rotation. Average annual yield and increase per acre

Plot No.	Average annual yield per acre						Average annual increase per acre						Plot No.
	Tobacco—12 years			Wheat*—11 years		Clover 10 years	Tobacco—12 years			Wheat*—11 years		Clover 10 years	
	Wrapper and filler	Trash	Total	Grain	Straw	Hay	Wrapper and filler	Trash	Total	Grain	Straw	Hay	
	Lbs.	Lbs.	Lbs.	Bus.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Bus.	Lbs.	Lbs.	
1	471	144	615	12.66	1,533	2,466	...	..	...	.....	.....	.....	1
2	705	201	906	20.16	2,502	3,383	240	56	296	7.33	953	960	2
3	1,063	163	1,226	22.43	2,647	3,805	602	17	619	9.41	1,083	1,423	3
4	458	146	604	13.20	1,581	2,340	...	..	...	.....	.....	.....	4
5	708	144	852	18.08	2,029	2,982	230	—4	226	4.73	423	552	5
6	949	198	1,147	24.88	2,941	3,835	448	50	498	11.39	1,311	1,316	6
7	523	148	671	13.65	1,655	2,609	...	..	...	.....	.....	.....	7
8	1,209	143	1,352	25.22	2,912	3,874	706	—6	700	12.17	1,323	1,384	8
9	1,174	159	1,333	26.18	2,898	3,941	692	10	702	13.75	1,375	1,570	9
10	462	150	612	11.81	1,456	2,252	...	..	...	.....	.....	.....	10
11	434	138	592	12.05	1,537	2,643	...	..	...	.....	.....	.....	11
12	1,071	146	1,217	23.18	2,905	3,721	636	10	646	10.97	1,361	1,128	12
13	1,204	158	1,362	26.90	3,132	4,279	766	24	790	14.54	1,579	1,736	13
14	440	130	570	12.52	1,560	2,494	...	..	...	.....	.....	.....	14
15	1,159	134	1,293	26.03	2,980	3,799	737	5	742	13.74	1,448	1,298	15
16	1,075	145	1,220	24.09	2,807	3,592	673	15	688	12.02	1,303	1,084	16
17	384	128	512	11.84	1,477	2,515	...	..	...	.....	.....	.....	17
18	909	131	1,040	23.53	2,649	3,760	525	3	528	12.27	1,234	1,254	18
19	994	136	1,130	23.85	2,608	3,568	611	6	617	10.38	1,256	1,071	19
20	382	131	513	10.09	1,289	2,487	...	..	...	.....	.....	.....	20
21	446	137	583	10.92	1,336	2,237	...	..	...	.....	.....	.....	21
22	1,044	160	1,204	22.84	2,726	3,411	598	25	623	12.19	1,429	1,233	22
23	1,056	157	1,213	22.71	2,715	3,511	608	26	634	12.33	1,456	1,392	23
24	449	128	577	10.11	1,221	2,060	...	..	...	.....	.....	.....	24
25	1,018	157	1,175	23.42	2,747	3,472	589	26	615	12.93	1,512	1,447	25
26	1,046	154	1,200	24.59	2,851	3,592	639	17	656	13.70	1,602	1,602	26
27	387	140	527	11.27	1,264	1,955	...	..	...	.....	.....	.....	27
28	1,061	148	1,209	25.10	2,882	3,603	676	10	686	14.01	1,603	1,627	28
29	916	141	1,057	20.66	2,346	3,487	532	6	538	9.74	1,051	1,490	29
30	382	131	513	10.74	1,310	2,018	...	..	...	.....	.....	.....	30
31	442	124	566	10.06	1,227	1,790	...	..	...	.....	.....	.....	31
32	925	124	1,049	21.27	2,564	3,034	499	—1	498	11.29	1,304	1,204	32
33	1,055	134	1,189	25.61	3,140	3,634	644	9	653	15.71	1,847	1,764	33
34	394	126	520	9.82	1,325	1,909	...	..	...	.....	.....	.....	34
35	945	149	1,094	23.80	2,772	3,700	562	25	587	13.81	1,475	1,764	35
36	825	139	964	22.86	2,615	3,358	453	14	467	12.71	1,347	1,396	36
37	361	124	485	10.32	1,241	1,989	...	..	...	.....	.....	.....	37
38	850	127	977	22.71	2,672	3,127	498	2	500	12.76	1,450	1,255	38
39	678	143	821	18.96	2,241	2,925	335	18	353	9.38	1,038	1,038	39
40	333	125	458	9.20	1,184	1,638	...	..	...	.....	.....	.....	40
Average...	422	134	556	11.27	1,387	2,077		.	.	....	.....	.....	

*The wheat failed in 1912, hence this average is for 10 crops.

pound, and nitrate of soda at three cents, and estimating the cost of potassium in the sulphate as 20 percent greater than in the muriate. The cost of nitrogen is assumed to be the same in nitrate of soda, nitrate of potash and sulphate of ammonia. The tankage used in the test is computed at $28.00 per ton. Lime is figured at $6.00 per ton. No values are placed upon the manure, as the cost of manure varies for each farm and for different parts of the same farm, owing to the distance from the barn. The phosphated manure has been dusted with floats applied at the rate of 40 to 50 pounds per ton of manure, equivalent to one pound per 1000-pound animal per day.

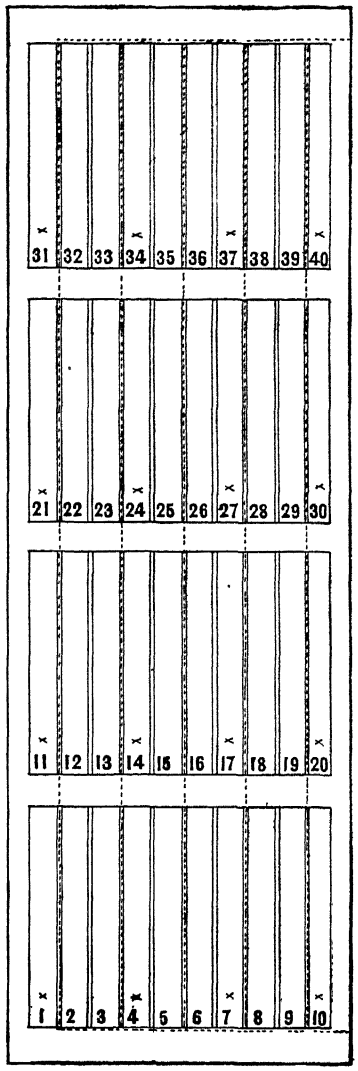

DIAGRAM 11: Arrangement of plots in tobacco-wheat-clover rotation Sections B and C

The fertilizers and manures are all applied to the tobacco, the wheat and clover following without any treatment.

Comparing the increase on the first five fertilized plots, as given in Table VIII, we find that each application of fertilizers has produced a profitable increase of crop, but the gain from the complete fertilizer, as applied on Plot 8, carrying nitrogen, phosphorus and potassium, all three, has been so much greater than that from any partial fertilizer, as to more than offset the greatly increased cost, so that the largest net gain has resulted from this application.

When the potassium in this fertilizer is increased, on Plot 9, the total tobacco yield remains the same, while those of wheat and hay are slightly increased; but while the total tobacco yield is stationary, there appears to have been a small transfer from the valuable parts of the plant to those less valuable and the consequence is a slight reduction in the value of the output.

TABLE IX: Plan of fertilizing and average value of increase in tobacco-wheat-clover rotation for the 12-year period, 1903-14

Plot No.	Fertilizing materials per acre (All applied to the tobacco crop)	Fertilizing elements per acre			Cost of fertilizers	Value of increase	Net gain	Plot No.
		Phosphorus	Potassium	Nitrogen				
		Lbs.	Lbs.	Lbs.	$	$	$	
1	None	..	..	..	.....	.....	.....	1
2	Acid phosphate, 480 lbs	30	..	..	3.90	30.78	26.88	2
3	Acid phosphate, 480 lbs.; muriate potash, 180 lbs	30	75	..	8.40	62.82	54.42	3
4	None	..	..	..	.....	.....	.....	4
5	Muriate potash, 180 lbs.; nitrate soda, 240 lbs	..	75	38	11.70	24.78	13.08	5
6	Acid phosphate, 480 lbs.; nitrate soda, 240 lbs	30	..	38	11.10	52.38	41.28	6
7	None	..	..	..	.....	.....	.....	7
8	Acid phos., 480 lbs.; mur. potash, 180 lbs.; nit. soda, 240 lbs	30	75	38	15.60	73.10	57.50	8
9	Acid phos., 480 lbs.; mur. potash, 300 lbs.; nit. soda, 240 lbs	30	125	38	18.60	74.45	55.85	9
10	None	..	..	..	.....	.....	.....	10
11	None	..	..	..	.....	.....	.....	11
12	Acid phos., 480 lbs.; mur. potash, 120 lbs.; nit. soda, 240 lbs	30	50	38	14.10	65.79	51.69	12
13	Acid phos., 720 lbs.; mur. potash, 180 lbs.; nit. soda, 240 lbs	45	75	38	17.50	81.92	64.42	13
14	None	..	..	..	.....	.....	.....	14
15	Acid phos., 480 lbs.; mur. potash, 180 lbs.; nit. soda, 360 lbs	30	75	57	19.20	76.79	57.59	15
16	Acid phos., 480 lbs.; mur. potash, 180 lbs.; sulphate ammonia, 180 lbs	30	75	38	15.60	69.41	53.81	16
17	None	..	..	..	.....	.....	.....	17
18	Acid phos., 60 lbs.; tankage (7-20) 670 lbs.; muriate potash, 180 lbs	30	75	38	14.40	58.23	43.83	18
19	Acid phos., 320 lbs.; mur. potash, 180 lbs.; nit. soda, 240 lbs	20	75	38	14.30	65.18	50.88	19
20	None	..	..	..	.....	.....	.....	20
21	None	..	..	..	.....	.....	.....	21
22	Acid phos., 480 lbs.; nitrate potash, 200 lbs.; nit. soda, 80 lbs	30	75	38	15.60	64.45	48.85	22
23	Acid phos., 480 lbs.; sulphate potash, 190 lbs.; nit. soda, 240 lbs	30	75	38	16.50	66.03	49.53	23
24	None	..	..	..	.....	.....	.....	24
25	Acid phos., 480 lbs.; sulph. potash, 190 lbs.; nit. soda, 240 lbs.; lime 1,000 lbs	30	75	38	19.50	65.26	45.76	25
26	Acid phos., 480 lbs.; mur. potash, 180 lbs.; nit. soda, 240 lbs.; lime, 1,000 lbs	30	75	38	18.60	70.46	51.86	26
27	None	..	..	..	.....	.....	.....	27
28	Acid phos., 480 lbs.; mur. potash, 180 lbs.; sulph. am., 180 lbs.; lime, 1,000 lbs.	30	75	38	18.60	73.65	55.05	28
29	Acid phos., 60 lbs.; tankage (7-20) 670 lbs.; mur. potash, 180 lbs.; lime, 1,000 lbs.	30	75	38	17.40	57.55	40.15	29
30	None	..	..	..	.....	.....	.....	30
31	None	..	..	..	.....	.....	.....	31
32	Shed manure, untreated, 10 tons	..	..	..	.....	55.15	.....	32
33	Shed manure, untreated, 20 tons	..	..	..	.....	73.24	.....	33
34	None	..	..	..	.....	.....	.....	34
35	Shed manure, phosphated, 10 tons	..	..	..	.....	65.06	.....	35
36	Yard manure, phosphated, 10 tons	..	..	..	.....	53.66	.....	36
37	None	..	..	..	.....	.....	.....	37
38	Shed manure, untreated, 10 tons; lime, 1,000 lbs	..	..	..	.....	56.70	.....	38
39	Yard manure, untreated, 10 tons; lime, 1,000 lbs	..	..	..	.....	40.34	.....	39
40	None	..	..	..	.....	.....	.....	40

On the other hand, the reduction of the potassium, on Plot 12. results in a falling off in yield sufficient to more than neutralize the saving in the cost of the fertilizer, and a still greater loss occurs when it is entirely omitted, on Plot 6.

When sulphate of potash is substituted for the muriate, on Plot 23, there is a reduction in yield, as compared with Plot 8; and as the sulphate is more expensive than the muriate there is a still greater reduction in the net gain.

This comparison of sulphate with muriate of potash is repeated on two limed plots, numbers 25 and 26, and here again the sulphate falls behind the muriate in total yield and net gain.

The substitution of the nitrate of potash, on Plot 22, has been followed by a still greater reduction in yield.

When the phosphorus is increased, on Plot 13, there is a marked gain in yield, this plot producing a greater total yield and a greater net gain than any other one in the series; while the reduction of the phosphorus, on Plot 19, is followed by a reduction in net gain as well as in total yield, and its entire omission, on Plot 5, reduces the increase to the lowest point in the series.

The increase of the nitrogen, on Plot 15, brings up the total yield to the second highest point in the series, and notwithstanding the high cost of nitrogen in nitrate of soda, this plot also gives next to the highest net gain. Comparing Plot 3, which receives phosphorus and potassium, but no nitrogen, with Plots 8 and 15, which receive the same quantities of phosphorus and potassium, in the same carriers, reinforced with 240 pounds of nitrate of soda on Plot 8 and 360 pounds on Plot 15, it will be seen that the total gain is increased from $54.42 on Plot 3 to $57.50 on Plot 8 and $57.59 on Plot 15.

Comparing nitrate of soda with sulphate of ammonia as carriers of nitrogen, on Plots 8 and 16, and again with lime, on Plots 26 and 28, there is an apparent loss for the sulphate of ammonia in the absence of lime and a gain when lime is added.

When nitrogen and phosphorus are given in tankage, on Plots 18 and 29, there is so great a reduction in the yield of tobacco as to much more than offset the small saving in the cost of the fertilizer. As tankage is the carrier of nitrogen usually employed in ready-mixed fertilizers this becomes an important point, the more so as the farmer generally pays more for the pound of nitrogen in such fertilizers than he would need to pay in nitrate of soda.

The manure used in this experiment for the first rotation was horse manure; since then it has come from cattle, but in both cases it has accumulated on earth floors. Theoretically, ten tons of such manure should contain, when unleached, 100 to 120 pounds each of nitrogen and potassium and 25 to 30 of phosphorus. On this basis the constituents of the manure have not been quite as effective, pound for pound, as the same constituents in the chemical fertilizer. It will be observed, however, that when the manure has been used at the rate of 10 tons per acre it has produced increase to the average value of more than $5.00 per ton of manure.

Comparing Plots 32 and 35 it appears that the reinforcement of the manure with phosphorus (in the form of floats, and at the rate of approximately 40 pounds to the ton of manure) has materially increased its effectiveness.

In both comparisons between shed manure and yard manure the unleached shed manure has produced much the larger yields.

EFFECT OF LIME

The effect of lime is shown in Table X, in which are contrasted the yields of 5 pairs of plots, which are treated alike in all respects except the use of lime. Apparently lime is not yet needed on this soil for the crops grown in this experiment, the soil being chiefly derived from decomposition of limestone and limestone gravels, the only plot which shows any decided benefit from lime being the one receiving its nitrogen in sulphate of ammonia.

TABLE X: **Effect of lime on tobacco, wheat and clover, grown in rotation**

Plot	Treatment	Average increase per acre			Value of increase	
		Tobacco	Wheat	Hay	Total	Net
No.		Lbs.	Bus.	Lbs.	$	$
8	Acid phosphate, muriate potash, nitrate soda	700	12.17	1,384	73.10	57.50
26	Acid phosphate, muriate potash, nitrate soda, lime	656	13.70	1,602	70.46	51.86
23	Acid phosphate, sulphate potash, nitrate soda	634	12.33	1,392	66.03	49.53
25	Acid phosphate, sulphate potash, nitrate soda, lime	615	12.93	1,447	65.26	45.76
16	Acid phosphate, muriate potash, sulphate ammonia	688	12.02	1,084	69.41	53.81
28	Acid phos., muriate potash, sulphate ammonia, lime	686	14.01	1,627	73.63	55.05
18	Tankage, muriate potash	528	12.27	1,254	58.23	44.83
29	Tankage, muriate potash, lime	538	9.74	1,490	57.55	40.15
32	Untreated shed manure	498	11.29	1,204	55.15	.....
38	Untreated shed manure, lime	500	12.76	1,255	56.70	....

COMPARISON OF CONTINUOUS WITH ROTATIVE CROPPING OF TOBACCO

The cost of fertilizers, value of increase and net gain are computed annually in Table VII, whereas they are computed for each rotation of 3 years in Table IX. It is evident that the annual value of all the crops has been smaller in the rotative than in the continuous cropping, because of the much higher acre-value of tobacco than of wheat or clover.

On the unfertilized land the average annual total yields for the two 6-year periods of the test have been 399 and 319 pounds for the continuously grown tobacco and 576 and 536 pounds for that grown in rotation, thus showing that a clover sod has produced 177 and 217 pounds of tobacco per acre during the two periods in excess of that grown on tobacco stubble. At an average of 6 cents per pound for the entire product these increases would have a value of $10.62 and $13.02 per acre, respectively.

The fertilizers and manure have not been so used as to permit an exact comparison between the two systems, but the approximate comparison shown in Table XI is suggestive.

TABLE XI: Comparison of continuous with rotative cropping of tobacco

Cropping	Treatment per acre	Cost of fertilizer	Value of increase	
			First 6 yrs.	Second 6 yrs.
Annual value of increase per acre				
Continuous, Plot 9	Acid phosphate, 320 lbs. Muriate potash, 120 lbs. Nitrate soda, 320 lbs.	$15.20	$63.08	$55.41
Rotative, Plot 12	Acid phosphate, 480 lbs. Muriate potash, 180 lbs. Nitrate soda, 240 lbs.	13.40	61.42	73.95
Value of increase per ton of manure				
Continuous, Plots 11, 14, 17	Untreated shed manure, 8 tons		$4.10	$3.63
Continuous, Plot 16	Untreated shed manure, 8 tons Phosphated shed manure, 5 tons		3.84	3.62
Continuous, Plot 18	Untreated shed manure, 8 tons Phosphated yard manure, 5 tons		3.83	3.47
Rotative, Plot 32	Untreated shed manure, 10 tons		4.93	6.09
Rotative, Plot 35	Phosphated shed manure, 10 tons		5.46	7.43
Rotative, Plot 36	Phosphated yard manure, 10 tons		4.88	5.27

The data for the rotative cropping are given by periods in Tables XII and XIII.

TABLE XII: Tobacco, wheat and clover grown in rotation...Average annual yields per acre by periods

Plot No.	Tobacco						Wheat				Clover		Plot No.
	6-yr. average, 1903-8			6-yr. average, 1909-14			6 yr. av., 1904-1909		5-yr, av, 1910 1914		6-yr. av., 1905-10	4-yr. av., 1911-1914	
	Wrapper and filler	Trash	Total	Wrapper and filler	Trash	Total	Grain	Straw	Grain	Straw			
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Bus.	Lbs.	Bus.	Lbs.	Lbs.	Lbs.	
1	498	150	648	444	138	582	11.27	1,583	14.33	1,472	2,635	2 212	1
2	729	197	926	683	204	887	17.07	2,399	23 88	2,625	3,352	3,430	2
3	1,013	168	1,181	1 114	157	1,271	18.66	2,531	26.95	2,787	3,837	3,758	3
4	471	155	626	442	137	579	10.90	1,550	15.95	1,617	2,463	2,154	4
5	778	149	927	639	138	777	17 05	2,061	19.32	1,990	3,133	2,754	5
6	999	193	1,192	899	203	1,102	21.36	2,749	29.12	3,173	3,873	3,777	6
7	539	160	699	507	137	644	12.39	1,657	15.17	1,654	2,701	2,470	7
8	1,141	155	1,296	1,277	131	1,408	22 74	2,809	28.70	3,036	3,959	3,746	8
9	1,079	190	1,269	1,269	129	1,398	22.90	2,689	30.12	3,148	4,078	3,736	9
10	462	154	616	361	146	507	11.98	1,528	11.62	1,369	2,317	2,155	10
11	422	143	565	345	133	478	11.68	1,559	12.48	1,511	2,899	2,260	11
12	1,027	165	1,192	1,116	127	1,243	21.34	2,766	25.38	3,073	3,988	3,321	12
13	1,155	182	1,337	1,254	133	1,387	24.76	3,001	29.46	3,288	4,578	3,830	13
14	427	132	559	453	129	582	11.29	1,516	14.00	1,612	2,599	2,336	14
15	1,131	148	1,279	1,187	121	1,308	24.49	2,860	27.88	3,123	3,952	3,568	15
16	1,074	157	1,231	1,077	132	1,209	22.36	2,632	26.17	3,018	3,792	3,292	16
17	394	140	534	375	115	490	10 32	1,388	13.67	1,584	2,577	2,423	17
18	821	146	967	998	116	1,114	22.51	2,593	24.75	2,716	3,891	3,562	18
19	936	152	1,088	1,052	120	1,172	22.76	2,616	25.17	2,598	3,709	3,355	19
20	358	139	497	407	122	529	9.78	1,240	10.47	1,348	2,612	2,299	20
21	459	142	601	434	132	566	10.94	1,390	10.88	1,271	2,508	1,832	21
22	958	187	1,145	1,131	132	1,263	21 95	2,726	23.90	2,726	3,539	3,219	22
23	991	178	1,169	1,121	136	1,257	21.79	2,602	23 82	2,851	3,641	3,315	23
24	474	135	609	424	121	545	10 19	1,272	10 02	1,159	2,187	1,869	21
25	1,010	165	1,175	1,026	150	1,176	22 63	2,596	24.38	2,929	3,459	3,491	25
26	1,042	161	1,203	1,051	146	1,197	23 44	2,704	25.97	3,028	3,564	3,633	26
27	430	142	572	345	138	483	10.95	1,343	11.67	1,168	2,157	1,652	27
28	1,017	155	1,172	1,105	141	1,246	23.73	2,730	26.75	3,075	3,737	3,402	28
29	894	148	1,042	939	133	1,072	19.63	2,254	21 90	2,458	3,660	3,227	29
30	389	128	517	276	135	411	11.14	1,358	10.27	1,252	2,059	1,957	30
31	470	125	595	415	122	537	9 93	1,251	10.22	1,199	1 864	1,679	31
32	893	125	1,018	958	122	1,080	20.29	2,546	22.45	2,585	3,104	2,927	32
33	986	150	1,136	1,124	118	1,242	24.19	2,932	27 32	3,389	3,738	3,478	33
34	428	137	565	360	115	475	9.79	1,189	9.85	1,489	2,004	1,767	34
35	893	150	1,043	998	149	1,147	21.46	2,536	26.60	3,056	3,789	3,566	35
36	895	125	1,020	756	152	908	20.83	2,568	25 18	2,673	3,469	3,191	36
37	405	123	528	317	125	442	9.70	1,278	11.07	1,196	2,017	1,946	37
38	837	130	967	863	124	987	19 73	2,433	26.30	2,959	3,001	3,316	38
39	788	142	930	568	144	712	17.47	2,135	20.75	2,367	2,999	2,813	39
40	368	129	497	300	121	421	8.27	1,153	10.32	1,221	1,725	1,508	40
*	437	139	576	407	129	536	10.66	1,391	12.00	1 383	2,112	2,025	

*Average unfertilized yield.

TABLE XIII: Tobacco, wheat and clover grown in rotation. Average annual increase per acre by periods

Plot No.	Tobacco						Wheat				Clover		Plot No.
	6 yr. average, 1903-8			6-yr. average, 1909-14			6 yr. av., 1904-9		5 yr. av., 1910 14*		6-yr. av., 1905-10	4-yr. av., 1911-14	
	Wrapper and filler	Trash	Total	Wrapper and filler	Trash	Total	Grain	Straw	Grain	Straw			
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Bus.	Lbs.	Bus.	Lbs.	Lbs.	Lbs.	
2	121	33	154	240	66	306	5.92	827	9.01	1,105	774	1,237	2
3	169	28	197	671	19	690	7 66	970	11.61	1,218	1,316	1,584	3
5	284	—8	276	175	1	176	5 66	475	3 63	361	591	495	5
6	482	35	517	413	66	479	9.47	1,127	13.69	1,532	1,251	1,413	6
8	627	—3	624	786	—9	777	10 49	1,195	14 22	1,476	1,386	1,381	8
9	591	34	625	793	—14	779	10.79	1,119	17 32	1,684	1,633	1,477	9
12	604	26	630	668	—5	663	9.79	1,221	12.39	1,528	1,189	1,036	12
13	729	46	775	804	2	806	13 34	1,470	15.97	1,710	1,879	1,520	13
15	715	14	729	760	—4	756	13.53	1,387	14 00	1,520	1,360	1,203	15
16	669	19	688	677	12	689	11 72	1,201	12.39	1,425	1,208	896	16
18	439	7	446	612	—1	611	12.54	1,254	12.15	1,211	1,302	1,181	18
19	567	12	579	655	1	656	12.80	1,326	13.63	1,171	1,109	1,014	19
22	494	47	541	701	3	704	11.26	1,376	13.31	1,492	1,139	1,374	22
23	522	41	563	694	12	706	11 35	1,291	13.51	1,655	1,347	1,458	23
25	550	28	578	628	23	651	12.19	1,300	13.82	1,767	1,282	1,695	25
26	598	21	619	681	13	694	12.75	1,384	14 85	1,863	1,396	1,909	26
28	601	17	618	749	4	753	12.72	1,382	15.55	1,867	1,313	1,649	28
29	490	15	505	573	—3	570	8.56	899	11.17	1 234	1,568	1,371	29
32	437	—3	434	562	1	563	10 40	1,316	12 35	1,289	1,194	1,219	32
33	544	17	561	745	1	746	14.35	1,722	17.35	1,997	1,780	1,741	33
35	473	18	491	652	31	683	11.70	1,318	16.34	1,665	1,780	1,739	35
36	482	—3	479	425	31	456	11 20	1,320	14.52	1,379	1,456	1,305	36
38	443	5	448	552		552	10.50	1,197	15.48	1,755	1,080	1,516	38
39	410	14	424	262	22	284	8.73	942	10.18	1,154	1,172	1,159	39
**	437	139	576	407	129	536	10.66	1 391	12 00	1,383	2,112	2,025	

*5-year average, crop of 1912 being a failure.
**Average unfertilized yield.