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THE PHOSPHORUS REQUIREMENTS OF OLD TOBACCO SOILS

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PHOSPHORUS is necessary for the growth of tobacco but an acre of tobacco removes less than seven pounds annually.

Very little leaches away and, since it can get out in no other way, large quantities have accumulated in our old tobacco soils through continuous heavy fertilizer applications.

The unused supply does not revert to an unavailable form, forever beyond the reach of succeeding crops. The old tobacco fields show a larger supply of easily soluble phosphorus as well as of total phosphorus than is found in newer fields.

Plots which received no phosphorus (other than that in cottonseed meal and castor pomace) for five years produced just as much and just as good tobacco as plots which had various quantities of phosphorus applied.

On old tobacco fields it is reasonable to believe that the grower may greatly reduce or even eliminate phosphorus carriers from his fertilizer mixture for many years without harm.

There is no danger that this practice will deplete the soil of its phosphorus supply since the organic constituents of the usual fertilizer mixture contain four times as much of this element as is lost annually.

A very large part of New England's thirty-five thousand acres of tobacco is grown on old tobacco land. The annual bill for phosphorus on these acres is approximately a quarter of a million dollars. At least half of it is unnecessary.

The Phosphorus Requirements of old Tobacco Soils

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Phosphorus is an essential element for the growth of all plants and tobacco is no exception to the rule. The soil is the only source from which the plant can derive phosphorus. It is therefore essential that roots in this soil always be in contact with a sufficient supply of phosphorus in a form which they can take up. Tobacco, however, is not a very heavy feeder on phosphorus as compared with corn or most other crops. About 15 lbs. of phosphoric acid* is enough for an 1800 lb. crop of tobacco. The crop uses over 5 times as much nitrogen and 9 times as much potash as phosphoric acid. Yet the grower for many years has applied almost as much phosphorus to his soils as he has of nitrogen or potash. Is this necessary or has he been wasting his money to supply what is not needed? What is the minimum amount which he needs to produce a crop of good yield and quality?

In order to answer these questions, a series of plot experiments was begun at the Windsor Tobacco Substation in 1922. These experiments have been continued on the same plots for five years. The results of the first four years have been published previously in Bulletins 5 and 6 of the Tobacco Series of this station. In the present bulletin it is our purpose first to describe the results of the fifth year's trials, then to summarize the experiments of the 5 years. This will be followed by a more general discussion of the whole phosphorus problem as related to the growing of tobacco.

Plot Tests at the Windsor Station

Plan of the field tests. Twelve plots, each containing one-fortieth of an acre, were located on Field I of the experiment station farm at Windsor. Tobacco has been grown most of the time on this field for a generation or more† before it was acquired by the station and it had a reputation of producing good tobacco. The

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* *Phosphorus* (P), the chemical element, does not occur in nature in a free state but always in combination. In the chemical analyses of fertilizers the percentage is expressed in terms of *phosphoric acid* (p. 205). Both this and the term *phosphorus* are in common use. To convert figures for *phosphoric acid* to *phosphorus*, multiply by .44; the reverse may be accomplished by multiplying by 2.3.

† We do not have an exact cropping record of this field previous to 1922. It was in grass in 1921.

soil is a sandy loam of the Merrimac series and appears quite uniform but a survey by the Soils Department showed some variation. With the object of overcoming variation which might be produced in yield or quality by soil differences, the three replicate groups of plots were located on different parts of the field. All plots received the same quantity of nitrogen, potash, and magnesia but there were four different rates of application of phosphoric acid as indicated in Table 1.

TABLE 1. COMPOSITION OF THE FERTILIZER MIXTURES AND QUANTITY OF PHOSPHORIC ACID.

	Pounds of Carrier per Acre			
Name of Carrier	Plots P2, P2*, P2**	Plots P3, P3*, P3**	Plots P1, P1*, P1**	Plots P4, P4*, P4**
Cottonseed meal	1,463.4	1,463.4	1,463.4	1,463.4
Castor pomace	588.2	588.2	588.2	588.2
Nitrate of soda	212.7	212.7	212.7	212.7
Precipitated bone ...	None	122.1	277.9	485.7
Sulf. of potash	172.2	172.2	172.2	172.2
Carb. of potash	132.5	132.5	132.5	132.5
Lbs. of P_2O_5	53†	100‡	160‡	240‡

In the P2 formula, all *special* carriers of phosphorus were omitted but it is not practical to reduce the phosphorus content to zero because nearly all growers use considerable organics such as cottonseed meal and castor pomace, all of which contain small quantities of phosphorus.

PLOT TESTS AT THE WINDSOR STATION IN 1926

The fertilizer was applied May 22. All plots were set on June 4 with Havana seed plants of uniform size. All cultural operations were the same throughout the growing season. All were harvested on August 16.

No differences in growth or development were observed during the summer. There was no hastening or retarding of maturity on any of the plots as compared with the others. The growing season was unusually dry until about time for harvesting. The curing season on the other hand was marked by long continued periods of rainy weather which caused some pole-sweat in these plots. It was especially bad in plots P1 and P2**. The cured tobacco was sorted in the sorting shop of the Tobacco Station by experienced sorters. Since the percentage of pole-sweat was not uniform in the different plots, it was necessary to sort the brokes into the respective grades to which they would have belonged if

* Asterisks are used throughout to denote first (*) and second (**) replications.

† Only that which is in the cottonseed meal and castor pomace.

‡ In precipitated bone, in addition to cottonseed meal and castor pomace.

they had not been spoiled by sweat. In the tables given below, the weight of these sorted brokes is added to that of their supposed respective grades because it is not at all probable that the degree of pole-sweat has any relation to percentage of phosphorus in the fertilizer.

Careful observations were made during the sorting to see whether there were any differences in color, body or veins. Although some slight differences between plots were recorded, they were not consistent when compared with replicates. In general the tobacco from plots which received no phosphorus seemed a little superior in having less prominent veins and the quality was just as good as, if not a little superior to, any of the others. Samples from the light wrappers, medium wrappers, dark wrappers and long seconds were kept from each plot and later were submitted to experts, Messrs. J. W. Alsop and Walter Edwards of the Connecticut Valley Tobacco Association, for judging and pooling. The forty-eight samples were assigned by them to three different pools but the differences were not consistently in favor of any one treatment when all the replicates were compared.

The sorting record, acre yield and grade index* are presented below in Table 2. The acre yields were calculated from the weights after sorting and sizing. If they had been calculated on the bundle weights they would have been somewhat larger. Since there was apparently a fertility difference in the different parts of the field, each group of four is averaged and the deviation from that particular average recorded for each plot. This brings out more clearly any difference due to the fertilizer treatment—as opposed to differences due to character of the soil.

From a study of the data presented in this table it is apparent that the differences both in yield and in quality (as indicated by the grade index) between the plots treated with different quanti-

* *The Grade Index.* In comparing the quality of tobacco grown on different plots it is very difficult to keep in mind the percentage of six to eight commercial grades of tobacco from one plot and compare with a like number from another. To simplify these comparisons a grade index was devised. The grade index is a single number expressing the quality of *all* the tobacco grown on a particular plot. It is based on the percentage of carefully assorted commercial grades and the relative price value of the different grades. Although market prices vary from year to year, it was found, after consultation with experienced dealers, that the ratios of prices between the different grades are fairly constant. These adopted price relationships for the different grades are as follows:

(L)	Light wrappers	1.00	(LD)	Long darks (19" up) ..	.30
(M)	Medium wrappers ...	.60	(DS)	Dark stemming (17")	.20
(LS)	Long sec. (19" up) ..	.60	(F)	Fillers	.10
(SS)	Short seconds (15" and 17")	.30	(Br)	Brokes	.01

The grade index of any plot is obtained by multiplying the percentage of each grade by the price in the above schedule and adding the products.

TABLE 2. FIELD TESTS AT WINDSOR, 1926. ACRE YIELD AND SORTING RECORDS.

Plot No.	Acre Yield: Pounds	Acre Yield: Group Average	Acre Yield: Deviation from Average %	L	M	LS	SS	LD	DS	F	Br	Grade Index	Group Average	% Deviation from Average
				Percentage of Grades										
P1	1802	1811	−0.5	17	12	22	1	35	0	9	4	.495	.482	+2.8
P2	1796		−0.8	15	11	28	1	35	0	9	1	.502		+3.9
P3	1823		+0.7	11	7	31	2	39	0	10	1	.472		−2.1
P4	1822		+0.6	10	4	34	2	37	1	11	1	.459		−4.7
P1*	1900	1896	+0.2	14	7	26	5	41	0	5	2	.483	.506	−4.5
P2*	1943		+2.5	25	10	18	4	33	0	8	2	.539		+6.5
P3*	1881		−0.8	18	7	23	3	37	1	10	1	.493		−2.5
P4*	1860		−1.9	19	9	23	3	35	1	9	1	.508		+0.4
P1**	1656	1724	−3.9	14	6	25	4	42	0	8	1	.473	.479	−1.3
P2**	1724		+0.0	15	8	25	2	39	1	9	1	.483		+0.9
P3**	1744		+1.2	19	11	20	4	34	0	10	1	.501		+4.6
P4**	1772		+2.8	14	11	18	3	41	1	11	1	.460		−3.9

SUMMARY OF TABLE 2

Plot No.	Pounds Phos. Acid per A.	Average Yield in lbs.	Average Grade Index
P1, P1* P1**	160	1,786	.484
P2, P2* P2**	53	1,821	.508
P3, P3* P3**	100	1,816	.489
P4, P4* P4**	240	1,818	.476

ties of phosphoric acid are too small to be significant and that they are not consistently in favor of any one treatment. Although we are not inclined to call any of these differences significant, nevertheless the fact that even these small differences are in favor of the plots which received no phosphoric acid (in special carriers) indicates, at least, that nothing was gained during 1926 by the addition of any quantity of phosphoric acid to the fertilizer.

SUMMARY OF THE FIVE YEAR EXPERIMENT ON RATE OF APPLICATION OF PHOSPHORIC ACID

Since this experiment has now been in progress for five years it is now possible to bring together the data and analyze the results. During this period each treatment has been replicated fifteen times. Since the quantity of fertilizer applied during the first three years was considered excessive, it was reduced during the fourth and fifth years. The reduction in the quantity of phosphoric acid thus effected was:

P2 plots reduced from	75	to	53	lbs.	per	acre.
P3 " " "	190	"	100	"	"	"
P1 " " "	225	"	160	"	"	"
P4 " " "	306	"	240	"	"	"

No *special* phosphorus carriers were used at any time on the P2 plots, while the quantity applied to the P4 plots was much in excess of common practice. Intermediate quantities were applied to the P1 and P3 plots.

The experiment was designed to answer two questions: (1) effect of varying rates of application of phosphoric acid on the *yield* and (2) effect on the *quality* of the tobacco. The answer to the first question may be found in Table 3 where the plot yields for the five years are recorded individually and the averages for each plot computed.

TABLE 3. FIELD TESTS AT WINDSOR. YIELD IN POUNDS PER ACRE FOR FIVE YEARS

Plot No.	Yield in Pounds per Acre: 1922†	1923†	1924	1925	1926	Average for 5 Yrs.	Average of the 15 Replications	Five Yr. Total P_2O_5 Lbs.
P1	1,419	1,919	1,493	1,894	1,802	1,705	1,662	995
P2	1,425	1,863	1,413	1,879	1,796	1,675	1,663	331
P3	1,456	1,826	1,493	1,742	1,823	1,668	1,649	770
P4	1,386	1,853	1,387	1,826	1,822	1,655	1,648	1,398
P1*	1,419	1,919	1,387	1,753	1,900	1,678	....	....
P2*	1,425	1,863	1,387	1,885	1,943	1,701	....	....
P3*	1,456	1,826	1,360	1,899	1,881	1,684	....	....
P4*	1,386	1,853	1,333	1,886	1,860	1,664	....	....
P1**	1,419	1,919	1,307	1,717	1,656	1,603	....	....
P2**	1,425	1,863	1,387	1,673	1,724	1,614	....	....
P3**	1,456	1,826	1,333	1,614	1,744	1,595	....	....
P4**	1,386	1,853	1,333	1,731	1,772	1,615	....	....

† During 1922 and 1923 we have only the records of the *average* yield of the three replications; in order to complete the table it is assumed that the yield was the same on the triplicates.

By comparing the final averages of each treatment (each representing fifteen trials) it is apparent that the differences are remarkably small. The greatest difference—comparing the highest with the lowest quantity of phosphorus—is only fifteen pounds and that in favor of entire omission of phosphorus carriers. This difference (about 1%) is too small to be significant. Thus we can safely conclude that the entire omission of phosphorus carriers for five years has not been attended by any decline in yield.

In order to answer the second question—relation of *quality* to phosphoric acid—the grade index was computed for each plot on the same basis for the years 1924, 1925 and 1926,† compared, and averaged in Table 4.

TABLE 4. FIELD TESTS AT WINDSOR. GRADE INDEX FOR 1924, 1925, 1926

Plot No.	Total Lbs. of P_2O_5 Applied in 5 Yrs.	1924	1925	1926	Average of 3 Yrs.	Average of 9 Replications
P1	995	.247	.472	.495	.405	.383
P2	331	.216	.478	.502	.399	.394
P3	770	.263	.422	.472	.386	.387
P4	1,398	.194	.427	.459	.360	.375
P1*	995	.241	.367	.483	.364	....
P2*	331	.247	.398	.539	.395	....
P3*	770	.258	.414	.493	.388	....
P4*	1,398	.269	.402	.508	.393	....
P1**	995	.252	.412	.473	.379	....
P2**	331	.266	.413	.483	.387	...
P3**	770	.249	.378	.501	.376	....
P4**	1,398	.243	.413	.460	.372	....

Comparison of the averages of the nine replications of each treatment show only small differences. The greatest difference is less than two cents a pound and this again is in favor of the no-phosphorus plots. The high-phosphorus plots had the lowest grade index. This corresponds with our observations during the sorting.

During the first year of this experiment, Chapman (26)‡ recorded the observation that the tobacco on the high-phosphorus plots had a distinct tendency to early ripening and the buds appeared fully a week before those on the other plots. This tendency was not evident during the succeeding four years. The writers watched for this carefully during the last two years but no such difference was observed. Certain objectionable colors were also observed in the tobacco from the high-phosphorus in the early years but careful observation during the last two years failed to show this.

† Sorting data for the years 1922 and 1923 were not preserved in a form which admits of direct comparison with the data for the later years. However, it is probably preferable to confine the comparison to the later years of the experiment which reflects better the results of *continued* use of each treatment.

‡ Numbers in parentheses refer to bibliography on page 23 of this bulletin.

Conclusions. The effect of omitting all phosphorus carriers from the fertilizer ration has not been detrimental either to the yield or to the quality of the tobacco produced on this field. In fact there is some indication that both have been improved slightly. On the other hand the evidence that there has been a detrimental effect from the annual application of considerable quantities of phosphoric acid is not conclusive.

EFFECT OF RATE OF APPLICATION OF PHOSPHORUS ON THE BURN

Although no significant differences were noticed in the yield, grade index, or other points of quality which could be observed during the sorting, it was still conceivable that there might be some effect on the burn. Burn tests were therefore conducted in two ways on the samples from the twelve plots at Windsor after they had been fermented for two months in the force sweat room.

The first was a fire-holding capacity test on single leaves ignited with an electric match (cigar-lighter). From each plot, twenty individual tests were made on the seconds, light wrappers, medium wrappers and dark wrappers, making a total of 80 tests per plot or 240 tests for each treatment. The results are presented in Table 5. It will be observed from this table that the results are variable but certainly do not indicate a favorable influence from the high phosphorus. In fact the highest phosphorus plots have the lowest fire-holding capacity.

TABLE 5. RELATIVE FIRE-HOLDING CAPACITY. (ELECTRIC MATCH METHOD)

Plot No.	Lbs. P_2O_5 Per Acre	Average of 20 Tests in Seconds: Dark Wrappers	Medium Wrappers	Light Wrappers	Seconds	Average
P2	53	....	28.6	38.9	28.6	32.0
P2*	53	9.6	12.4	32.2	18.7	18.2
P2**	53	42.4	39.0	46.7	53.9	45.5
Ave.		26.0	26.6	39.2	33.7	32.0
P3	100	25.5	31.7	37.8	47.3	35.5
P3*	100	16.8	24.7	....	40.2	27.2
P3**	100	53.4	37.1	....	47.0	45.8
Ave.		31.9	31.2	37.8	44.8	36.1
P1	160	22.8	21.6	32.1	30.8	26.8
P1*	160	19.2	18.4	24.6	26.7	22.2
P1**	160	17.2	18.7	19.9	28.7	21.1
Ave.		19.7	19.6	25.5	28.7	23.3
P4	240	19.9	16.8	19.3	28.3	21.1
P4*	240	21.5	25.4	23.3	38.5	27.2
P4**	240	23.5	38.1	38.2	36.8	34.1
Ave.		21.6	26.7	26.9	34.5	27.5

In the second test, leaves from the fermented samples were used in making cigars. Some of the cigars from each plot were "clears," i. e., wrapper, binder and filler from the tobacco grown on that plot. Others had only the wrapper and binder from that plot put on a standard filler which was the same for all plots. All were smoked and records taken on the number of minutes during which they held fire when laid on the desk, the color and coherence of the ash and the evenness and closeness of burn.

The burn was satisfactory on all of them. In over one hundred tests and direct comparison, all held fire more than five minutes and none of them over nine, the ash was light to medium gray, the burn was even and fairly close and there were no consistent differences between the plots treated with different quantities of phosphorus.

In summary, we may say that the entire omission of special phosphorus carriers from the fertilizer mixture for five years has had no injurious influence on the burn of the tobacco.

Phosphorus Tests in Other Tobacco Sections

Since our tests show no response to phosphorus it will be instructive to compare with them the results of tests conducted along the same line in other tobacco sections.

Virginia. Concerning the flue cured tobacco districts of Virginia, Mathewson (24) says "Phosphoric acid may be considered the most generally needed plant food material throughout this tobacco growing region. It not only increases growth but hastens maturity and also strongly tends to brighten the color because of its decided effect in ripening the leaf." In experiments where tobacco was grown every fifth year in rotation and was the only crop to receive any fertilizer, Hutchison and Berger (15) found that "Of the single element carriers, acid phosphate gave the highest acre value." It was used at the rate of 700 lbs. per acre (112 lbs. P_2O_5). A 3-8-3 fertilizer is recommended for tobacco (5, 15) in Virginia.

Tennessee. In a ten year experiment on dark tobacco, starting with a field which was very low in productiveness, grown continuously the first three years and then in a three year rotation, Moores and Milton (25), speaking of acid phosphate, conclude that "The results of the first three years show a profitable increase from the 300 lb. rate, as compared with the 200 lb. rate. Four hundred pounds per acre was indicated to be of doubtful value over 300 pounds."

"Of the three rates of application under trial for seven years in the three year rotation of tobacco, wheat and clover and grass, 300 pounds per acre of acid phosphate produced both the largest and most profitable yields."

Ohio. Here also it was found (27) in the three year rotation with wheat and clover (when all the fertilizers were applied to tobacco) that "when the phosphorus is increased to 720 lbs. acid phosphate per acre, there is a marked gain in yield, this plot producing a greater total yield and a greater net gain than any one in the series." The value of manure was increased when phosphate was added to it. There was also an increase from phosphorus when tobacco was grown continuously. Selby and Houser state (33) that "In nearly all Ohio soils, phosphorus is the most deficient element, and until this element is supplied, the application of nitrogen or potassium produces but little or no effect." "Phosphorus when used alone on the typical upland soil of this region will produce a decided increase in the yield for several years, after which the production decreases, attended with decided marginal dying or drying up of the leaves. The bad effect on the quality of tobacco is entirely corrected by the addition of potash salts or nitrate of soda." They recommend 720 lbs. of acid phosphate per acre. In all of these Ohio experiments, fertilizer was applied only once in three years.

Canada. Experiments by the Dominion Department of Agriculture (4, 7, 8, 11, 34) on Burley, on Bright Flue Cured Tobacco, and on cigar leaf tobacco have shown improvement both in yield and quality by application of acid phosphate at the rate of 350-600 lbs. (56-96 P_2O_5) per acre. Freeman (11) writes "In all our experiments phosphorus in the form of acid phosphate has been shown to be needed on all tobacco soils and, until this is supplied, an application of nitrogen or potash produced little effect." Tobacco is grown in their system of agriculture only once in three or four years and is in rotation with general farm crops. Usually fertilizer is applied only to the tobacco.

Wisconsin. Johnson (16) says "It is believed that the average soil when set to tobacco in Wisconsin will respond quicker to phosphoric acid fertilizer than to any other." Later, Johnson and Slagg (17) write that "most of our tobacco soils respond to fertilization with phosphate fertilizers, and this element can profitably be applied alone or in combination with barnyard manure at the rate of 400-800 lbs. per acre in the form of acid phosphate." They recommend a 2-12-2 fertilizer.

Georgia. Experiments at the Georgia Coastal Plain Experiment Station show that (2) "Of the three plant foods, the absence of phosphoric acid resulted in the smallest growth, indicating that this constituent is the first limiting factor of the soil of the Coastal Plain."

Kentucky. Early experimenters (32) in Kentucky found that phosphorus was beneficial. Later work (29), however, in the Burley section does not show any significant response to phosphorus, since the yield differences between phosphorus and no phosphorus plots are no greater than those between two adjacent untreated plots. Neither do other crops in the blue-grass section of Kentucky show a significant response to phosphorus.

Pennsylvania. Concerning the tobacco fertilizer experiments in Pennsylvania, Frear (10) says "The soil showed a marked need for phosphoric acid . . . this constituent cannot be safely omitted."

Maryland. Concerning early experiments on tobacco fertilizers in Maryland, Patterson (28) writes: "Phosphoric acid seemed to have but little direct bearing upon the combustibility, but generally produced a marked increase in the yield." In more recent and more extensive field tests, however, Garner and Brown (12) got no response whatever to phosphates. "In no instance," they write, "has any of the phosphates given a marked increase in yield and when the results are averaged for the six year period, there are no substantial differences in yield, either between the plots receiving the various phosphates or between these and the plots receiving no phosphate."

Summary. With two exceptions every fertilizer field test dealing with the phosphorus need of tobacco in the above mentioned tobacco growing states has shown a definite response to phosphate fertilizers. Why do we not get the same response in Connecticut?

1. In the other sections tobacco is not grown continuously but is rotated with crops which carry away considerable phosphorus.
2. Phosphorus is applied only once in the rotation, since the other crops are not fertilized.
3. The amount applied is very small compared with our heavy applications.
4. In some of these sections the soil contained a smaller supply of phosphorus before tobacco was grown.
5. The fertilizer mixture commonly used in other sections does not include organic substances containing phosphorus.

The two exceptions are readily explained. The soil in the Burley section of Kentucky is naturally very rich in phosphorus (see table 7). Garner and Brown explain the Maryland results on the grounds of (a) the cottonseed meal used in their mixture, (b) low phosphorus requirement of tobacco and (c) a phosphorus reserve in this particular soil.

The Role of Phosphorus in Plants

The early experiments on the functions of phosphorus and other essential elements were conducted either on poor, non-productive soils or in water and sand cultures. The physiological effects as stated in standard texts apply more directly to results obtained on low planes of nutrition. Field experiments, with acid phosphate or precipitated bone, have indicated that growth, earliness of maturity and seed production have been promoted by addition to phosphorus-deficient soils. The greater number of these experiments have been on small grains and corn. With these crops, seed production is more important to the farmer than leaf growth. In the growing of tobacco, on the other hand, we are more directly concerned with vegetative growth than with seed production. Also, since the tobacco soils of Connecticut are managed on a high plane of fertility, it is doubtful if the conclusions derived from such experiments apply in the same way to tobacco in this section as grown under present day methods.

An adequate available supply of phosphoric acid is absolutely necessary for cell division and growth. It has been observed that algae (21) supplied with all the soil nutrients except phosphoric acid made no growth over a period of two months but algae supplied with it during the same interval doubled in size. The starved plants at the end of eight weeks when given a dose of available phosphoric acid showed energetic cell division.

Phosphorus is also necessary for protein formation. Not only do certain proteins contain phosphorus but Kraybill has found in tomato plants that "nitrate nitrogen is not available for protein synthesis even in the presence of an abundance of carbohydrates if phosphates are deficient." Phosphorus enters into the composition of the nucleus and plastids of the plant cells, and is identified in substances such as neucleoproteins, lecithin, chromatin and plastin.

The early growth of a seedling depends on phosphorus stored in the seed. At the time of blossoming and seed formation there is a rapid movement of phosphorus to the seed-producing portion of the plant. This may explain why seed crops such as the grains respond so well to phosphorus treatment. The quality of the grain is also improved because an added amount of phosphoric acid tends to increase the protein content. It may be stated that anything which promotes an absorption of phosphorus is accompanied by an increase in the protein content of the plant (35).

When there is a phosphorus deficiency, maturity is delayed and growth stops. Excessive amounts of available phosphoric acid produce symptoms of prematurity. On a tobacco plant this is made evident by so-called "firing." The leaves prematurely dry up from the bottom of the plant. This condition would naturally be more pronounced in a hot-dry than in a cool-wet season.

Since tobacco is primarily a leaf producing rather than a seed producing plant, the inference would be that it is not a high phosphorus requiring plant. This idea is further substantiated by chemical analyses showing the actual amount taken into the plant. In comparison with nitrogen, potash and calcium, the amount of phosphorus assimilated is very low.

Phosphoric Acid Content of Tobacco Leaves

Experiments by Jenkins (18) showed that tobacco absorbs from the soil relatively small amounts of phosphoric acid. The average analyses of tobacco taken from thirteen of his fertilizer plots showed that an 1800 pound crop (30% moisture) contained only 7.4 pounds. This gives an average of only .58% phosphoric acid on the basis of dry matter. The highest was .84% and the lowest .47%. In his work there is no correlation between the amount of phosphoric acid applied to the soil and the amount recovered in the leaf. Analyses on the phosphoric acid content of tobacco grown in other sections show about the same variation found in Connecticut. Kissling (19) has made an extensive review of analyses of the ash constitutents in tobacco leaves and shows variations between .49% and .70% with an average about the same as that determined by Jenkins.

As a further check on the effects of increasing amount of phosphoric acid applied to the soil in the fertilizer, analyses of samples taken from the crop of 1925 as reported by Dr. E. M. Bailey, chemist in charge of the analytical laboratory, New Haven, are given in Table 6.

Table 6. Phosphoric Acid Content of Tobacco Leaves on Basis of Air Dry Material, 1925 Crop

Lbs. P_2O_5 Applied Per Acre	% of P_2O_5 in 23" Darks on Triplicate Plots				% of P_2O_5 in 21" Lights on Triplicate Plots			
		*	**	Ave.		*	**	Ave.
53	.64	.82	.89	.78	.56	.64	.65	.62
100	.64	.74	.77	.72	.66	.70	.54	.63
160	.82	.78	.88	.83	.57	.68	.70	.65
250	.64	.73	.73	.70	.61	.69	.54	.61

The results of the above analyses show that there is no consistent relation between the amount of phosphoric acid applied to the soil and the phosphoric acid content of the leaf. The darks, however, consistently had a higher phosphoric acid content than the lights.

The Functions of the Phosphorus Constituent of a Fertilizer

The primary value of the phosphoric acid contained in a fertilizer can be properly ascribed to its direct effect of supplying an adequate amount of available phosphorus when the soil is unable to furnish it. On soils containing a very small amount of available phosphorus before fertilization, the growing plant must depend almost entirely upon the fertilizer for a supply of phosphorus which can be absorbed in suitable amount during the

period when it is demanded. Vast areas of crop land in eastern United States have been inadequately fertilized with respect to phosphorus, and contain relatively small total amounts of this element. On such land, phosphatic fertilizers have produced great increases in crop, and the high response to phosphorus relative to that of nitrogen and potassium on field crops has been to a great measure responsible for the popularity of 2-12-2, 4-8-4 and similar ratios of nitrogen, phosphoric acid and potash.

But when the soil is well supplied with phosphorus in an available form, the value of fertilizers supplying phosphorus can be expected to produce relatively less direct benefit. Phosphorus fertilization shows remarkable returns on soils which are seriously deficient in an available supply of this element, but when there is a high natural supply or a considerable accumulation of the residues of previous phosphate applications, the soil may be in such condition that the additional amount of phosphorus supplied in the fertilizer may produce little or no effect.

Phosphorus fertilization may produce indirect effects of great importance. Chief of these is probably the benefits to the essential soil micro-organisms. But here, too, we are dealing with conditions where the phosphorus supply and availability must be taken into account. It is on the soil which liberates an inadequate amount of phosphorus for crop growth that the activities of micro-organisms might be impaired, since phosphorus is essential to their proper development.

Another outstanding indirect effect of phosphorus fertilization is its function on strongly acid soils, which contain considerable amounts of soluble aluminum, toxic to the growth of many plants. Hartwel and his co-workers (14, 3), as well as several other investigators, have shown quite conclusively that large quantities of phosphate, much in excess of the probable demands of the crop for plant food material, can produce great increases in crop through its action in precipitating the injurious soluble aluminum out of the soil solution. Under such conditions the same result can be brought about by lime, and it is questionable whether phosphorus fertilization primarily for the correction of the injurious effects of acid soil conditions will ever prove desirable.

The Supply and Availability of Phosphorus in Connecticut Tobacco Soils

In their natural unfertilized condition, the total supply of phosphorus in the soils of the Connecticut tobacco district probably ranges from 1,000 to 2,000 pounds of phosphorus (equivalent to 2,300 to 4,600 pounds of phosphoric acid) per acre within average plow depth. To investigate the cumulative effect of tobacco fertilization, a series of 68 soils from the tobacco section were analyzed for total and "available" phosphorus. Twenty-one of these soils, from fields either never in tobacco or less than 5 years in that crop ("new land") showed an average of 1,528 pounds of total phosphorus, with an average deviation of 281 pounds above or below this amount. Twenty-seven soils, in tobacco for from 5 to

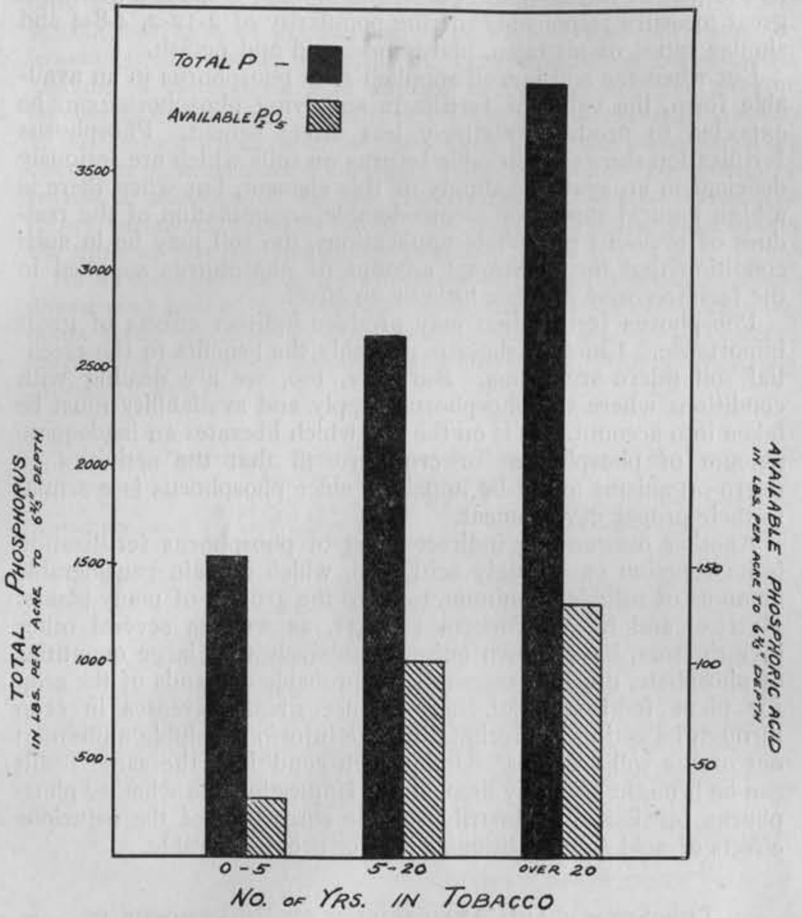

FIG. 1. The accumulation of phosphorus in heavily fertilized tobacco soils in Connecticut.

20 years, averaged 2,655 pounds (± 538 lbs.), 20 soils, in tobacco 20 or more years, averaged 3,855 pounds (± 566 lbs.). This is shown graphically in Figure 1.

The above very strikingly shows the rapid accumulation of phosphorus with the tobacco fertilization practice usually followed in Connecticut. Thus in less than 20 years the phosphorus con-

tent of the soil is built up to almost twice the original amount, and rapidly exceeds this with increasing years of fertilization. This result, while perhaps not anticipated, is not difficult to explain. If we assume the complete removal of both stalks and leaves of an 1,800 pound crop of tobacco, not more than 15 pounds of phosphoric acid is removed per year. The average fertilization is at least 150 pounds of phosphoric acid. There remains 135 pounds phosphoric acid, equivalent to about 60 pounds of phosphorus. Thus a soil originally containing 1,500 pounds of phosphorus could be built up to 3,000 pounds in twenty-five years of continuous fertilization.

Besides the fertilizer, other materials which contain phosphorus are added to the soil. A ton of tobacco stalks or stems contains at least 13 pounds of phosphoric acid (5.7 lbs. phosphorus). Ten tons of manure contains probably 50 pounds of phosphoric acid (about 22 lbs. phosphorus).

How much of the phosphorus which is not taken up by the crop is lost from the soil through leaching? Experiments at Rothamsted (20) and Cornell (22, 23) and at the Florida Station (6) have shown that the loss of phosphorus in this manner is practically nil. There is a lack of evidence on this point where heavy fertilization is applied to sandy soils, though Fraps (9) has shown that there is a possibility of a small loss under such conditions. Several samples of drainage water collected during the first year of an experimental type of lysimeter at Windsor has shown a concentration of 2 to 3 parts per million of P_2O_5, and if such a concentration is maintained throughout the year, this represents a possible loss of around 5 pounds of phosphorus (11.5 lbs. phosphoric acid) per acre per year. It is hoped that further evidence on this point will be obtained during the next two or three years.

The total phosphorus to be found in an old tobacco soil represents a rather high amount as compared with other soils of the country. A comparison is shown in Table 7.

TABLE 7. TOTAL PHOSPHORUS CONTENT OF SOME SOILS IN EASTERN UNITED STATES

State	Remarks	Total Phosphorus in Lbs. Per Acre to 6 2/3 in. Depth
Connecticut	Tobacco fields over 5 years in tobacco, 48 soils	3,260
	Tilled areas in general farm crops, never in tobacco, 58 soils	1,858
	Pasture fields, 52 soils	1,540
New Jersey	Types similar to Connecticut, 14 soils	1,452
New York	Average loam	1,480
Ohio	Average of 126 soils	1,125
West Virginia	Average of 485 soils	1,040
Illinois	Light colored silt loams	1,200
	Heavy black prairie soils	2,000
Kentucky	"Blue grass" soils	9,000

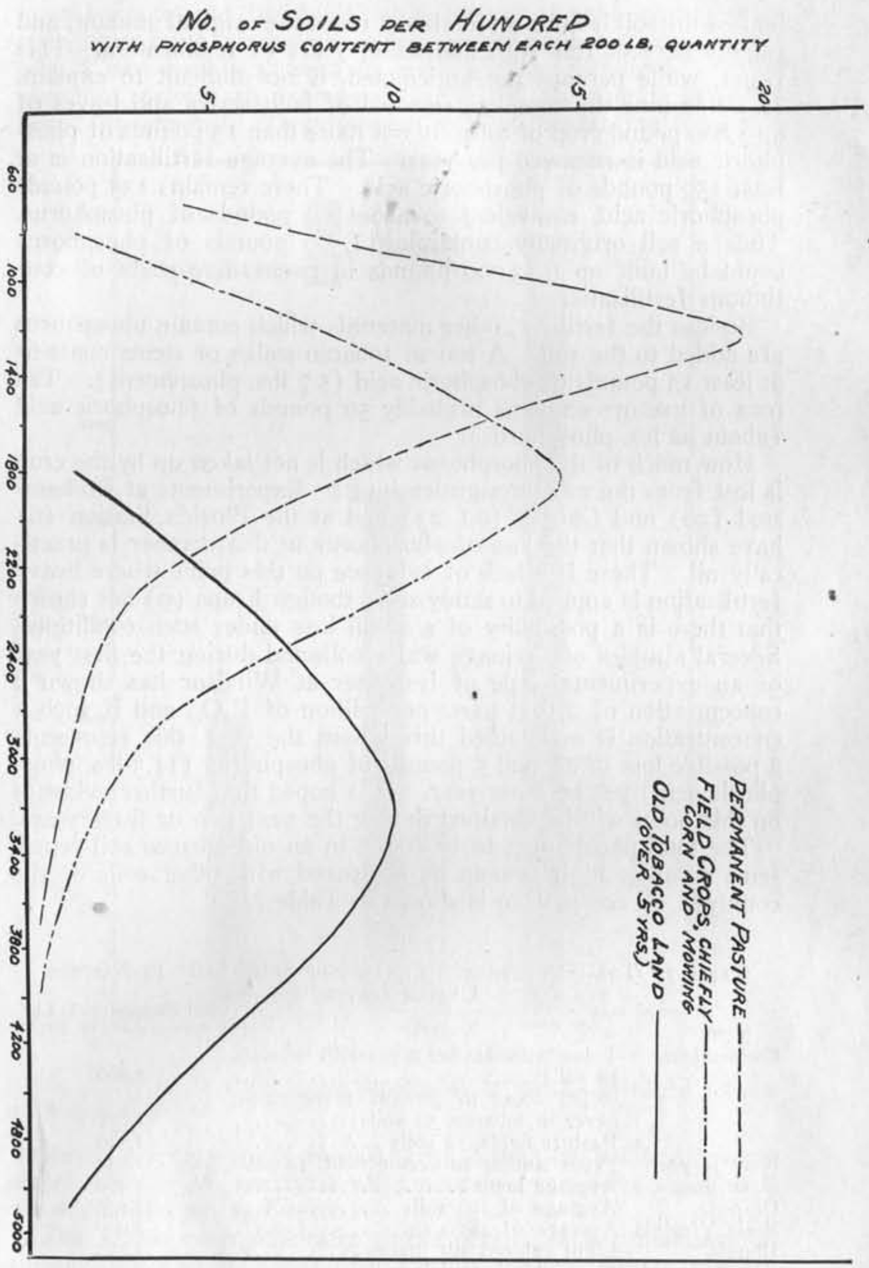

FIG. 2. The distribution of total phosphorus content in old tobacco soils as compared with other soils of Connecticut.

The distribution of total phosphorus in old tobacco soils in comparison with soils under other systems of management is shown graphically in Figure 2.

Since the residual effect of several years of tobacco fertilization at the rate of 150 to 200 pounds of phosphoric acid is sufficient to build up the soil to a relatively high total phosphorus content, one naturally asks if this accumulation is sufficiently available to provide subsequent crops with all the phosphorus they require for adequate yield and quality. The only absolute answer is found through trials such as have been made at Windsor during the last five years to ascertain whether or not there is a response to continued use of phosphatic fertilizers. The result on this particular field has shown conclusively that applications of phosphate in excess of that furnished by the organic ammoniates are no longer required.

Chemical tests of the availability of the soil phosphorus while furnishing us with valuable indications along this line must always be arbitrary in character. Phosphorus available for one species of plant may not be so for another, and the same amount of chemically "available" phosphorus may be easily obtained by the crop on a certain soil, and with difficulty on a different one. Such tests of Connecticut soils have shown that on the old tobacco fields there is a relatively high amount of phosphorus which is soluble in carbonated water and very dilute acids, of similar concentration to the soil solution. The following figures are significant:

> 21 soils, never in tobacco or less than 2 years in tobacco (new land) average *30 lbs.* phosphoric acid per acre soluble in dilute (N/100) sulfuric acid, ranging from 10 to 60 lbs.
>
> 20 soils, 5 to 20 years in tobacco average *100 lbs.* "available" phosphoric acid per acre, ranging from 70 to 140 lbs.
>
> 21 soils, over 20 years in tobacco, average *130 lbs.* "available" phosphoric acid per acre, ranging from 90 to 160 lbs.
>
> This is also shown graphically in Figure 1.

The plots at Windsor upon which no response for phosphorus is obtained range from 100 to 160 pounds "available" phosphoric acid by this test.

In a series of plot experiments on different soils at New Haven, growing alfalfa, soils which show less than 60 pounds of "available" phosphorus have shown decided crop increases from phosphatic fertilizers, while an old tobacco soil in these trials, with 90 pounds of "available" phosphoric acid, showed no increased growth when phosphorus was applied, although it responded to both lime and potash. Alfalfa is a crop which is very sensitive to deficiencies of phosphorus.

The residual phosphorus from fertilizers in which precipitated bone is the principal phosphorus carrier, while reverting very quickly to less soluble forms, remains absorbed in the soil in a condition from which it is much more easily liberated than the native phosphorus in the original soil, which is probably chiefly composed of particles of mineral phosphate (apatite) (13, 36). A considerable amount of this residual phosphorus may be in organic compounds (30) from the residues of tobacco roots and stalks and of the organic ammoniates applied. Much of such phosphorus is easily broken down into forms which are readily available to the plant (31).

Summary

Field plot tests over a period of five years on old tobacco land at Windsor show that tobacco is indifferent to the quantity of phosphorus used in the fertilizer. No significant differences could be found in the yield or quality of tobacco irrespective of quantity of phosphorus in the fertilizer.

Extensive burn tests failed to show that the burn was affected by the rate of application of phosphorus in the fertilizer.

These results are different from those secured from fertilizer tests in other tobacco-growing sections of the country. Of the numerous field tests reported in other states, only two fail to show definite favorable response from phosphorus application.

This difference in response between Connecticut soils and that in other sections is due to long continued heavy applications of phosphates which have built up an immense surplus more than adequate to supply the needs of the crop.

When additional phosphorus is added to old tobacco soils it is not taken up by the plant. Analyses of tobacco from the different plots showed that there was no correlation between the quantity of phosphorus in the leaves and that applied to the soil.

Very little of the phosphorus is removed by the plant (6½ lbs. per acre) and only a very small quantity is lost by leaching. Neither is it forever lost by forming unavailable combinations with the soil constituents. Analyses show that these old soils are well supplied with available as well as total phosphorus.

Special carriers of phosphorus could probably be omitted from the fertilizer mixture for an indefinite period of years without harm to the tobacco crop on fields where this crop has been grown continuously. The organic constituents alone in the ordinary tobacco mixture supply four times as much phosphorus as the plant needs. This alone should guard against depletion.

No secondary benefits from phosphorus (as a soil correctant) have been observed in these experiments. The corrective action on very acid soils (if needed) may be accomplished as well, if not better, by lime.

New Tobacco Fields

Although the great bulk of tobacco is raised where tobacco has been grown more or less continuously for many years, there are always some new fields which have not been previously cropped to tobacco or have grown tobacco for a short time. Unless previous crops on this land are known to have received considerable phosphates, it would seem advisable to apply considerable phosphorus in the fertilizer. We suggest about 160 pounds of phosphoric acid per acre. Up to the present we have not had any new land available for experimental work along this line, but it is hoped that this may be started in 1927.

By reference to Table 8 the grower who wishes to mix a fertilizer for new land may compute the quantity of carrier needed. This table of analyses was kindly prepared by Dr. E. M. Bailey of the Chemistry Department of this station and includes most of the materials containing phophorus which have been used on tobacco fields. Some of them are used for their phosphorus alone, while others contain other plant foods. Some which are used primarily as nitrogen carriers also contain some phosphorus. For this reason we have included all which contain more than a trace of phosphorus and have given also the percentage of nitrogen and potash as well as some other elements which are of interest to the tobacco grower.

TABLE 8. AVERAGE OR TYPICAL ANALYSES OF TOBACCO FERTILIZER MATERIALS CONTAINING PHOSPHORUS

Name	Phos. Acid				Potash					
	Total P_2O_5	"Avail." P_2O_5	Nitrogen (N)	Ammonia (NH_3)	Total K_2O	Water-Sol. K_2O	Chlorine (Cl)	Lime (CaO)	Magnesia (MgO)	Sulf. Acid (SO_2)
	%	%	%	%	%	%	%	%	%	%
Precipitate bone	38.3	37.7	....	....	....	....	....	45.3[1]	....	....
Bone meal	24.0	([2])	3.1	3.8	....	....	0.3	28.4[1]	....	....
Steamed bone	28.0	([2])	1.5	1.8	....	....	0.3	33.6[1]	....	....
Acid phosphate	17.2	16.0	....	....	....	....	....	20.4[1]	....	....
Rock phosphate	32.0	([3])	....	....	....	....	....	37.9[1]	....	....
Ammo-phosphate	22.3	21.7	16.4	19.9	....	....	trace	....	....	....
Dry ground fish	7.6	([5])	8.7	10.6	1.1	....	0.3	8.7	0.4	5.2
Tankage, high grade	9.2	([2])	7.6	9.2	....	....	0.4	11.0[1]	....	....
low grade	20.2	([2])	4.2	5.1	....	....	0.4	24.2[1]	....	....
Wood ashes	2.1	....	....	....	....	6.6	0.5	36.6	5.7	1.2
Cottonhull ashes	9.8	8.0	....	....	....	25.0	0.2	5.2	11.2	2.4
Tobacco stems	0.5[6]	....	2.1[6]	2.6	6.4[6]	....	0.5	3.8	0.5	0.5
Cottonseed meal	2.9	....	6.8	8.3	1.9	....	trace	0.3	0.7	....
Linseed meal	1.7	....	6.0	7.3	1.3	....	none	....	....	....
Castor pomace	2.2	....	5.0	6.1	....	....	0.1	0.9	0.8	....
Cow manure[7]	0.3	....	0.4	0.5	0.5	....	0.1	0.2	0.1	0.1
Horse manure[8]	0.4	....	0.7	0.9	0.6	....	0.1	0.5	0.2	0.1
Sheep manure	1.5	1.3	2.1	2.6	....	2.4	....	....	....	....

[1] Based on the calcium equivalent to phosphoric acid.
[2] Approximately ½ "available."
[3] From 1 to 2 per cent "available."
[5] About 5 per cent "available."
[6] Average of 50 analyses.
[7] Wet, 72 per cent water.
[8] Wet, 66 per cent water.

LITERATURE CITED.

(1) Anderson, P. J., et al. Report of the substation at Windsor, 1925. Conn. Agr. Exp. Sta., Tobacco substation Bul. 6. 1926.
(2) Anonymous. Georgia tests again show tobacco's need of added plant food. Fertilizer Review 1:(No. 8)3. 1926.
See also Ga. Coastal Plain Sta. Bul. 5:49-52. 1925.
(3) Burgess, Paul S. and F. R. Pember. "Active" aluminum as a factor detrimental to crop production in many acid soils. R. I. Agr. Exp. Sta. Bul. 194. 1923.
(4) Charlan, F. Dom. Dept. of Agr. Rpt. of tobacco division for 1921. 1922.
(5) Cocke, R. P. Crop rotation and fertilizer experiments with bright tobacco. Va. Agr. Exp. Sta. Bul. 198. 1912.
(6) Collison, S. E. and S. S. Walker. Loss of fertilizers by leaching. Florida Agr. Exp. Sta. Bul. 132. 1916.
(7) Digges, D. D. Summary of three years' experiments on the tobacco station at Harrow, Ontario. Dom. Dept. Agr. Bul. 41 (2d ser.). 1919.
(8) Digges, D. D. and H. A. Freeman. Flue cured tobacco in Canada. Dom. Dept. Agr. (Tob. Div.) Bul. 38. 1920.
(9) Fraps, G. S. The fixation of phosphoric acid by the soil. Texas Agr. Exp. Sta. Bul. 304. 1922.
(10) Frear, Wm. Field fertilizer experiments with tobacco. Penna. Exp. Bul. 49. 1900.
(11) Freeman, H. A. White Burley tobacco in Canada. Dom. Dept. of Agr. Bul. 45 (2d ser.). 1921.
(12) Garner, W. W. and D. E. Brown. Fertilizer experiments with tobacco. Md. Agr. Exp. Sta. Bul. 225. 1919.
(13) Hall, Thomas D. and J. C. Vogel. Reversion of acid phosphate in acid soils. Soil Science 15:367-370. 1923.
(14) Hartwell, B. L. and F. R. Pember. Presence of aluminum as a reason for the difference in the effect of so-called acid soil on barley and rye. Soil Science 6:259-278. 1918.
(15) Hutchison, T. B. and D. J. Berger. Experiments with bright tobacco and other crops grown on bright tobacco farms. Va. Agr. Exp. Sta. Bul. 233. 1923.
(16) Johnson, James. The management of tobacco soils. Wis. Agr. Exp. Sta. Bul. 277. 1917.
(17) Johnson, James and C. M. Slagg. Tobacco in Wisconsin. Wis. Exp. Sta. Bul. 337. 1921.
(18) Jenkins, E. H. Studies on the tobacco crop of Connecticut. Conn. Agr. Exp. Sta. Bul. 180. 1914.
(19) Kissling, R. Tabakkunde, tabakbau und tabakfabrikation. Berlin, Germany. 1925.
(20) Lawes, J. B., J. H. Gilbert and R. Warington. On the amount and composition of rain and drainage water collected at Rothamsted. Jour. Roy. Agr. Soc. Ser. II, 17:269-271. 1881.
(21) Loew, O. The physiological rôle of mineral nutrients in plants. U. S. D. A. B. P. J. Bul. 45. 1903.
(22) Lyon, T. L. and J. A. Bizzell. Lysimeter experiments. Cornell Univ. Agr. Exp. Sta. Memoir 12. 1918.
(23) Lyon, T. L. and J. A. Bizzell. Lysimeter experiments—II. Records for tanks 13 to 16 during the years 1913 to 1917 inclusive. Cornell Univ. Agr. Exp. Sta. Memoir 41. 1921.
(24) Mathewson, E. H. The culture of flue cured tobacco. U. S. D. A. Bul. 16. 1913.
(25) Moores, C. A. and R. M. Milton. Dark tobacco fertility experiments. Tenn. Agr. Exp. Sta. Bul. 129. 1924.

(26) Nelson, N. T. and P. J. Anderson. Fertilizer experiments with tobacco. Conn. Agr. Exp. Sta., Tobacco substation Bul. 5. 1925.

(27) Ohio Agr. Exp. Sta. Field experiments with fertilizers and manures on tobacco, corn, wheat and clover in the Miami Valley. Ohio Agr. Exp. Sta. Bul. 206. 1909.

(28) Patterson, H. J. The culture and handling of tobacco. Md. Agr. Exp. Sta. Bul. 67. 1900.

(29) Roberts, George and A. E. Ewan. Report on soil experiment fields. Ky. Agr. Exp. Sta. Bul. 228. 1920.

(30) Schollenberger, C. J. Organic Phosphorus of Ohio Soils. Soil Science 13: 127-141. 1920.

(31) Schreiner, Oswald. Organic Phosphorus in Soils. Jour. Am. Soc. Agron. 15: 117-126. 1923.

(32) Scovell, M. A. Experiments with fertilizers on tobacco. Ky. Agr. Exp. Sta. Bul. 28. 1890.

(33) Selby, A. D. and True Houser. Tobacco culture in Ohio. Ohio Agr. Exp. Sta. Bul. 238. 1912.

(34) Slagg, C. M. Rpt. of Tob. Division. Dom. Dept. Agr. for 1924.

(35) Truog, E. The utilization of phosphates by agricultural crops, including a new theory regarding the feeding power of plants. Wis. Agr. Exp. Sta. Res. Bul. 41. 1916.

(36) Wiley, R. C. and N. E. Gordon. Availability of absorbed phosphorus. Soil Science 15: 371-372. 1923.