1-1-1916

The Residual Effects of Fertilizers

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Bulletin 160 August, 1916

West Virginia University Agricultural Experiment Station

MORGANTOWN

DEPARTMENT OF SOILS

THE RESIDUAL EFFECTS OF FERTILIZERS

BY

Firman E. Bear and Robert M. Salter

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†In co-operation with the University of Chicago.
*In co-operation with the United States Department of Agriculture.

CONCLUSIONS.

These conclusions are summarized from analyses of fertilizer plots at the West Virginia Agricultural Experiment Station which have been under experiment for the last fifteen years.

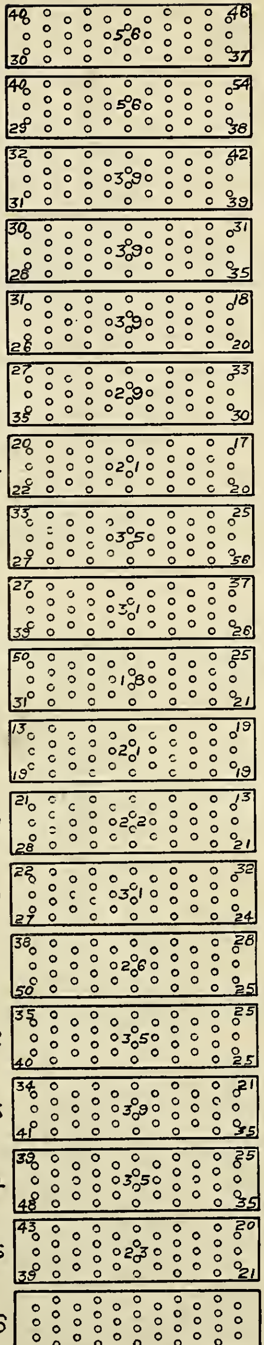
1. Nitrogen fixation from the air averaging 20 pounds per acre per year has taken place on the plot receiving acid phosphate. On the plot on which acid phosphate and sulphate of potash have been applied, the fixation of nitrogen amounted to 78 pounds per acre per year.

2. The phosphorus applied to the soil in excess of the needs of the crops was not lost in the drainage water but was fixed in the surface 6⅔ inches of soil.

3. Organic matter has been maintained and increased by the use of fertilizers without plowing under green manuring crops or crop residues other than the stubble left behind after the crops were harvested.

4. The use of quicklime in excess of the needs of the soil has caused a loss of nitrogen, phosphorus, and organic matter from the surface soil considerably larger than the increased yields produced would justify.

5. The use of manure or fertilizers (with the exception of sulphate of potash) has had a tendency to decrease the acidity of the soil.



18	No Fertilizer.
19	Nitrate of Soda, Acid Phosphate, Sulphate of Potash, Lime.
20	Manure and Lime.
21	No Fertilizer.
22	Lime.
23	Ash of Manure and Nitrate of Soda.
24	No Fertilizer.
25	Manure.
26	Nitrate of Soda, Acid Phosphate, and Sulphate of Potash.
27	No Fertilizer.
28	Acid Phosphate and Sulphate of Potash.
29	Nitrate of Soda and Sulphate of Potash.
30	No Fertilizer.
31	Nitrate of Soda and Acid Phosphate.
32	Sulphate of Potash.
33	No Fertilizer.
34	Acid Phosphate.
35	Nitrate of Soda.
36	No Fertilizer.

DIAGRAM I.—Fertility Plots, (one-tenth acre each). This diagram shows the points at which samples were chosen for a composite sample of the soil of each plot and also the depth of the underlying rock at five points.

The Residual Effects of Fertilizers†

By FIRMAN E. BEAR and ROBERT M. SALTER.

INTRODUCTION.

In a previous publication* of the West Virginia Agricultural Experiment Station may be found a summary of the results obtained by the experimental use of fertilizers on the Experiment Station farm. It is the purpose of this bulletin to present for consideration the effects on the soil of these fertilizer treatments and of the crops produced as a result of the use of the fertilizers, in so far as we have been able to measure these effects by laboratory methods.

HISTORY OF THE EXPERIMENTS.

During the summer of 1900 a series of 19 tenth-acre plots was set aside at the Experiment Station farm for work with fertilizers. Each plot was made two rods wide and eight rods long. A three-foot space was left between plots. These plots were numbered serially from 18 to 36. Every third plot was left unfertilized. Accordingly, plots 18, 21, 24, 27, 30, 33, and 36 are check plots. Three of these check plots, 18, 24, and 36, are no longer satisfactory checks. The tile drain passing near plot 18 became stopped up and the yields on one end of the plot were somewhat abnormal. Plot 24 accidentally received an application of manure intended for plot 25. The manure was raked off with a hand rake a few days later but the leachings from the manure materially increased the productive power of the soil. Plot 36 was discarded because of its tendency to wash. Plots 18 and 36 have been cropped each year and have never received any fertilizer. Their present productivity corresponds rather closely to that of plots 21 and 33 so that the present condition of these plots is practically the same as though they had been checks, although complete records of their yields are not available.

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†Credit is due M. F. Morgan and E. B. Wells for assistance in securing samples and in doing part of the analytical work.

*Bear, Firman E., Experiments with Fertilizers, West Virginia Agricultural Experiment Station, Bulletin 155, 1915.

THE SOIL.

The United States Bureau of Soils has mapped the soil on the Experiment Station farm as Dekalb silt loam. It is a residual soil formed by the disintegration of grayish shales and sandstones overlying the Pittsburgh vein of coal. The depth of the underlying rock varies from 18 to 56 inches. The diagram on page 4 shows the depths of the rock at five points in each plot. The variation in the depths of the rock may have had some influence on the productivity of the plots under various treatments although we have no evidence to this effect.

The soil is of a grayish yellow color with a yellowish subsoil. The original timber was largely oak and chestnut. At the time the experiments were begun the productivity of the soil was very low. The vegetation consisted principally of red top, yarrow, poverty grass, and sorrel together with some broomsedge.

THE CROPS GROWN.

No definite rotation of crops has been followed. Rye was grown in 1900 and 1907; wheat in 1901 and 1914; clover in 1902, 1909, and 1915; corn in 1903, 1905, and 1912; cowpeas in 1904; potatoes in 1906; timothy in 1909, 1910, and 1911; oats in 1913. A complete record of the crop yields calculated to the acre basis will be found on pages 7 and 8.

TABLE I.—Pounds of Produce per Acre.

Plot	Fertilizer	1900 Rye Grain	1900 Rye Straw	1901 Wheat Grain	1901 Wheat Straw	1902 Clover Hay	1903 Corn Grain	1903 Corn Stover	1904 Cowpeas Hay	1905 Corn Ensilage	1906 Potatoes Tubers	1907* Rye Grain	1907* Rye Straw
19	N, K, P, CaO	2076	3524	†1665	†3760	6700	6200	6800	6950	27700	6120	1170	3030
20	M, CaO	1578	2762	1840	4560	8850	7700	9400	6750	34700	13060	2140	4860
21	Check	1186	2064	1140	1160	2050	2000	3800	1250	11200	2600	140	360
22	CaO	1077	1813	1010	1490	1500	1620	3200	1200	9800	1520	†130	†330
23	M(ash), N	2095	4845	1880	3320	7900	4410	5800	2750	15300	2500	170	280
24	Check	1100	2070	1070	1830	2100	1770	3650	1350	12100	2610	140	380
25	M	1913	3587	1920	4580	9550	5230	6500	6100	34800	11300	1880	4420
26	N, K, P	2463	4317	1750	3950	7250	5620	7000	6300	29000	7030	1170	2530
27	Check	1297	2583	1120	1780	2850	1980	3450	2200	12500	2850	160	290
28	P, K	1411	2739	1550	3350	5500	5160	6200	4400	16100	6360	850	1850
29	N, K	1980	3560	1080	1820	2000	1500	3300	2300	15000	3520	140	260
30	Check	1340	2540	1050	1650	2650	1820	3600	2100	10900	2140	160	250
31	N, P	2267	4153	1550	3350	7900	5400	7000	5150	18900	3830	1030	2270
32	K	1402	2678	1030	1670	2500	2000	3750	1950	11800	2630	140	360
33	Check	1330	2600	1110	1990	2200	1930	3600	2450	8700	2400	120	280
34	P	1360	2810	1390	2610	5400	4570	5750	3650	14100	3800	770	1930
35	N	1914	3716	930	1770	2600	1330	3300	2500	10200	2250	210	290

*Plots were sown to timothy and clover but on account of unfavorable weather conditions gave very poor crop in 1908. Plots were mowed and hay was left on the ground.

†Calculated yields.

N, K, and P are symbols for nitrogen, potassium, and phosphorus respectively. CaO is the symbol for burned lime. M indicates manure.

TABLE I (continued).—Pounds of Produce per Acre.

Plot	Fertilizer	1909 Timothy-Clover Hay	1910 Timothy Hay	1911 Timothy Hay	1912 Corn Grain	1912 Corn Stover	1913 Oats Grain	1913 Oats Straw	1914 Wheat Grain	1914 Wheat Straw	1915 Clover Hay	Total Produce
19	N, K, P, CaO	5600	9000	6090	4630	4190	875	2625	1720	4380	5800	120605
20	M, CaO	6800	10400	6240	5010	4600	1250	6000	1080	5420	7400	152400
21	Check	755	1305	1130	1500	2900	220	680	350	710	100	38600
22	CaO	535	1240	1100	2470	3080	250	650	580	1270	750	36615
23	M(ash), N	490	1120	890	3550	4620	530	1170	1490	3060	2100	69270
24	Check	535	1180	900	1330	1400	280	420	*1190	*3010	*2660	43075
25	M	7800	9000	6640	4800	4400	1040	3760	1380	3420	5650	139670
26	N, K, P	4700	8700	6090	4890	4450	800	1800	1590	3460	3250	117910
27	Check	505	1275	850	1550	2900	250	400	370	780	230	42170
28	P, K	1640	3475	2280	3170	4020	620	1130	1230	2520	1440	76995
29	N, K	2125	3880	2390	2050	2300	380	820	560	890	360	52215
30	Check	705	1375	930	1900	1990	290	710	370	780	230	39480
31	N, P	4500	7300	4320	4080	4200	790	1410	1500	2450	2590	95940
32	K	430	1285	850	2330	2400	330	570	380	820	260	41565
33	Check	305	1260	570	1900	1920	300	550	330	770	230	36845
34	P	845	3410	2290	2100	2050	750	1250	560	990	1030	63415
35	N	720	2885	1740	1400	1380	330	470	340	760	160	41195

*Abnormal yields due to an accidental application of manure which was subsequently removed with a hand rake.

FERTILIZER TREATMENTS.

Much heavier applications of fertilizers have been made during the fifteen years that have elapsed since the beginning of the experiment than would be used in actual practice. This was done in order to magnify the effect and to shorten the period of time necessary to produce a measurable effect on the soil. The following amounts of fertilizers have been applied annually to the plots with the exceptions noted:

Plots 18, 21, 24, 27, 30, 33, and 36. No fertilizer.

Plot 19. 40 pounds sodium nitrate; 40 pounds acid phosphate; 15 pounds potassium sulphate (20 pounds in 1906); 100 pounds lime in 1900; 150 pounds lime in 1906; and 200 pounds lime in 1912.

Plot 20. Two tons stable manure; 100 pounds lime in 1900; 150 pounds lime in 1906; and 200 pounds lime in 1912.

Plot 22. 100 pounds lime in 1900 and in 1903; 150 pounds in 1906; and 200 pounds in 1912.

Plot 23. Ash from two tons of stable manure, together with an amount of nitrogen in the form of sodium nitrate equivalent to the nitrogen originally present in the stable manure. Applications made in 1900 and in 1901. Since then no further applications have been made until 1912 when it received 40 pounds of a 4-16-4 fertilizer.

Plot 25. Two tons stable manure applied annually except in 1903.

Plot 26. 40 pounds sodium nitrate; 40 pounds acid phosphate; 15 pounds potassium sulphate (20 pounds in 1906).

Plot 28. 40 pounds acid phosphate; 15 pounds potassium sulphate (20 pounds in 1906).

Plot 29. 40 pounds sodium nitrate; 15 pounds potassium sulphate (20 pounds in 1906).

Plot 31. 40 pounds acid phosphate; 40 pounds sodium nitrate.

Plot 32. 15 pounds potassium sulphate (20 pounds in 1906).

Plot 34. 40 pounds acid phosphate.

Plot 35. 40 pounds sodium nitrate.

In 1902, 1907, 1908, 1914, and 1915 no fertilizer was applied on any of the plots. In 1913 only one-half of the original application of fertilizer was given.

TABLE II.—Total Amounts of Fertilizers Applied per Acre from 1900 to 1915 Inclusive.

Plot	Nitrate of Soda, Pounds per Acre	Acid Phosphate, Pounds per Acre	Sulphate of Potash, Pounds per Acre	Lime, Pounds per Acre	Manure, Tons per Acre
19	4200	4200	1625	4500	......
20	....	....	....	4500	210
21	....	....	....	....	......
22	....	....	....	5500	......
23	300	Ash of 40 tons of manure until 1912		....	......
24	....	....	....	....	......
25	....	....	....	....	190
26	4200	4200	1625	....	......
27	....	....	....	....	......
28	....	4200	1625	....	......
29	4200	....	1625	....	......
30	....	....	....	....	......
31	4200	4200	....	....	......
32	....	....	1625	....	......
33	....	....	....	....	......
34	....	4200	....	....	......
35	4200	....	....	....	......

THE EFFECTS OF THE FERTILIZERS ON THE CROPS.

The record of the crop yields shows some very interesting effects. The total produce per acre has varied from 36,615 pounds on the plot receiving burned lime to 152,400 pounds on the plot receiving manure and lime. We are particularly interested in the yields in calculating the elements of plant food which have been removed from the soil by the crops grown. Unfortunately no analyses have been made of the crops from the various plots. We are compelled, therefore, to base our calculations on average analyses of these crops. We have chosen the analyses as given by Hopkins* with a few exceptions in which analyses given by Henry and Morrison† were more nearly comparable.

*Soil Fertility and Permanent Agriculture.

†Feeds and Feeding.

TABLE III.—Pounds of nitrogen, phosphorus, and potassium removed by crops from fertility plots since 1900, calculated on the acre basis.

Plot	Treatment	N	P	K
19	N, P, K, CaO	1146	177	964
20	M, CaO	1382	213	1213
21	Check	313	55	279
22	CaO	312	57	235
23	M(ash), N	687	109	538
24	Check	378	60	306
25	M	1278	195	1098
26	N, P, K	1082	171	916
27	Check	351	59	304
28	P, K	705	115	587
29	N, K	417	73	385
30	Check	341	57	290
31	N, P	945	148	799
32	K	349	60	296
33	Check	321	55	271
34	P	591	95	490
35	N	356	61	312

TABLE IV.—Pounds of nitrogen, phosphorus, and potassium, calculated from check plots, which would have been removed per acre in crops if no fertilizer had been applied.

Plot	N	P	K
19	313	55	279
20	313	55	279
21	313	55	279
22	319	56	283
23	326	56	287
24	332	57	292
25	338	58	296
26	345	58	300
27	351	59	304
28	347	58	299
29	343	57	295
30	341	57	290
31	334	56	284
32	328	55	277
33	321	55	271
34	321	55	271
35	321	55	271

Table V gives the amounts of nitrogen, phosphorus, and potassium removed from the soil of each plot by the increased crops according to these analyses, and also the number of pounds of these elements supplied in the fertilizers used. The columns headed "Gain or Loss" represent the relative conditions of the various plots as they would be if there had been no losses in the drainage water or no gains from the air.

TABLE V.—Calculated Gain or Loss in Nitrogen, Phosphorus, and Potassium.

		Nitrogen			Phosphorus			Potassium		
Plot	Treatment	*Removed in Increased Crops	Added in Fertilizer	Gain or Loss	*Removed in Increased Crops	Added in Fertilizer	Gain or Loss	*Removed in Increased Crops	Added in Fertilizer	Gain or Loss
19	N, P, K, CaO....	833	672	—161	122	293	+171	685	675	— 10
20	M, CaO	1069	?	?	158	?	?	934	?	?
22	CaO	— 7	......	+ 7	1	......	— 1	—48	......	+ 48
23	M(ash), N	361	?	?	53	?	?	251	?	?
25	M	940	?	?	137	?	?	802	?	?
26	N, P, K................	737	672	— 65	113	293	+180	616	675	+ 59
28	P, K	358	......	—358	57	293	+236	288	675	+387
29	N, K	74	672	+598	16	......	— 16	90	675	+585
31	N, P	611	672	+ 61	92	293	+201	515	......	—515
32	K	21	......	— 21	5	......	— 5	19	675	+656
34	P	270	......	—270	40	293	+253	219	......	—219
35	N	35	672	+637	6	......	— 6	41	......	— 41

*Calculated from Tables III and IV.

ANALYTICAL DATA.

During the spring of 1915 the plots were sampled by the use of a soil auger. Thirty-eight borings each to a depth of 6⅔ inches were taken for a composite sample of soil on each plot. These borings were distributed over the plots as shown in the diagram on page 4. The samples were air dried and put through a 2-mm. sieve to remove stones and undecomposed pieces of organic matter. After thorough mixing a sufficient amount of this composite sample was chosen for analytical purposes and pulverized to pass a sieve with 100 meshes to the inch. Samples of the subsoil from 6⅔ to 20 inches were also taken and prepared for analysis.

It was thought desirable to determine the probable error in sampling a plot. Accordingly six composite samples of 38 borings each were chosen from plot 26 and prepared for analysis. A record of the total carbon, nitrogen, and phosphorus as found in these six samples is given below:

TABLE VI.—Percentages of carbon, nitrogen, and phosphorus in a soil as determined by duplicate analyses of six composite samples from the same plot.

Sample	Total Carbon		Total Nitrogen		Total Phosphorus	
	Analysis A	Analysis B	Analysis A	Analysis B	Analysis A	Analysis B
1	1.53	1.51	.130	.129	.045	.045
2	1.55	1.56	.138	.138	.047	.046
3	1.51	1.49	.134	.133	.046	.046
4	1.52	1.54	.133	.133	.045	.045
5	1.64	1.64	.148	.147	.048	.049
6	1.52	1.52	.135	.135	.045	.046

It will be seen from the table that there is a very close agreement among five of the six samples. No explanation is available for the differences to be noticed in sample 5. However, these differences necessitate a more careful study of the results to follow in order to be sure that the conclusions drawn are correct.

TABLE VII.—Analyses of Composite Samples of Surface Soil from Fertility Plots.

Plot No.	Treatment	Fe	Ti	Al	Mn	Ca	Mg	K	S	P	N A*	N B†	C	Lbs. CaCO₃ Requirement A*	Lbs. CaCO₃ Requirement B†
		Percent of Air Dry Soil													
18	Check	......	......	......	......	......	......	1.25	......	0.030	0.097	0.054	1.19		
		......	......	......	......	......	......	1.26	......	0.030	0.098	0.055	1.20	2800	6800
19	N, P, K, CaO	1.91	0.79	4.22	0.22	0.21	0.19	1.23	.062	0.037	0.106	0.066	1.23		
		1.92	0.74	4.15	0.22	0.21	0.19	1.21	.063	0.037	0.107	0.066	1.22	0	3600
20	M, CaO	1.94	0.72	4.01	0.21	0.23	0.20	1.24	.063	0.053	0.135	0.066	1.63		
		1.90	0.72	4.00	0.22	0.22	0.20	1.24	.062	0.052	0.135	0.066	1.62	0	2800
21	Check	1.94	0.76	4.30	0.24	0.11	0.22	1.21	.062	0.030	0.092	0.054	1.06		
		1.94	0.68	4.39	0.23	0.12	0.21	1.21	.060	0.029	0.091	0.054	1.06	2800	5600
22	CaO	2.06	0.77	4.29	0.18	0.24	0.21	1.26	.048	0.026	0.088	0.051	0.97		
		2.04	0.73	4.37	0.19	0.26	0.22	1.28	.044	0.026	0.088	0.051	0.97	0	3600
23	M(ash), N	2.18	0.74	4.48	0.18	0.14	0.22	1.29	.053	0.033	0.097	0.059	1.03		
		2.17	0.72	4.45	0.18	0.13	0.23	1.28	.055	0.033	0.097	0.058	1.04	2800	6000
24	Check	2.60	0.71	4.77	0.19	0.14	0.26	1.41	.058	0.035	0.102	0.058	1.04		
		2.59	0.70	4.77	0.18	0.13	0.28	1.40	.062	0.035	0.102	0.058	1.04	3000	3600
25	M	2.35	0.70	4.72	0.28	0.14	0.24	1.29	.071	0.061	0.162	0.067	1.84		
		2.33	0.70	4.71	0.27	0.15	0.25	1.29	.075	0.061	0.162	0.066	1.84	2800	3200
26	N, P, K	1.82	0.69	4.43	0.27	0.11	0.19	1.27	.070	0.045	0.133	0.064	1.53		
		1.85	0.69	4.47	0.25	0.11	0.20	1.28	.065	0.045	0.133	0.065	1.51	3200	4400
27	Check	1.77	0.70	4.44	0.19	0.13	0.20	1.21	.064	0.030	0.098	0.057	1.10		
		1.76	0.70	4.49	0.20	0.12	0.20	1.23	.062	0.031	0.098	0.057	1.09	3800	5200
28	P, K	1.80	0.70	4.45	0.26	0.13	0.20	1.28	.070	0.043	0.114	0.073	1.31		
		1.79	0.70	4.51	0.25	0.13	0.20	1.28	.071	0.043	0.114	0.073	1.29	3600	5200
29	N, ·K	1.89	0.70	4.57	0.27	0.11	0.20	1.28	.066	0.032	0.115	0.067	1.35		
		1.89	0.71	4.50	0.28	0.11	0.19	1.28	.063	0.032	0.115	0.067	1.35	3400	5200
30	Check	2.00	0.67	4.78	0.22	0.13	0.19	1.30	.066	0.035	0.113	0.059	1.31		
		2.00	0.67	4.76	0.25	0.13	0.17	1.30	.071	0.035	0.114	0.060	1.32	3800	5600
31	N, P	2.00	0.68	4.77	0.19	0.15	0.19	1.35	.058	0.044	0.120	0.064	1.41		
		2.04	0.68	4.78	0.21	0.14	0.20	1.35	.062	0.044	0.120	0.065	1.39	3200	5200
32	K	2.18	0.73	4.82	0.28	0.13	0.20	1.33	.071	0.036	0.115	0.059	1.46		
		2.14	0.72	4.84	0.28	0.11	0.21	1.34	.066	0.036	0.116	0.059	1.46	3600	5600
33	Check	2.23	0.72	5.24	0.25	0.12	0.20	1.37	.069	0.037	0.115	0.063	1.37		
		2.16	0.72	5.27	0.25	0.12	0.20	1.34	.070	0.037	0.115	0.063	1.37	3600	5200
34	P	2.27	0.73	5.24	0.22	0.13	0.22	1.34	.063	0.044	0.115	0.059	1.41		
		2.28	0.73	5.16	0.22	0.13	0.23	1.36	.066	0.044	0.115	0.060	1.41	3400	5600
35	N	2.21	0.73	5.11	0.18	0.13	0.19	1.33	.070	0.031	0.113	0.049	1.44		
		2.16	0.72	5.19	0.22	0.13	0.20	1.35	.067	0.031	0.113	0.049	1.44	3400	5600
36	Check	......	......	......	......	......	......	......	......	0.032	0.104	0.055	1.22		
		......	......	......	......	......	......	......	......	0.032	0.104	0.055	1.22		

*Surface soil to 6⅔ inches.
†Subsoil, 6⅔ to 20 inches.

INTERPRETATION OF ANALYSES.

Analyses of Check Plots.

The analyses of the check plots indicate that the fertility increases as we proceed from plot 21 to plot 33, and then decreases from 33 to 36. Plot 18 shows a slightly higher content of nitrogen and carbon than plot 21. It must be remembered that plot 24 is no longer a check, having accidentally received an application of manure. Any calculations as to the effect of fertilizers applied on the present composition of the soil must take into consideration this gradual increase in the plant food content of these soils from one end of the series to the other. By dividing the differences in the analyses of the check plots by the number of plots between the checks we are able to calculate what the plant food content of each of the plots would have been at the present time if it had received no fertilizer. Table VIII shows the results of this calculation on the basis of pounds of elements per 2,000,000 pounds of surface soil and 4,000,000 pounds of subsoil.

TABLE VIII.—Present Analyses of Plots as Calculated from Check Plots Had no Fertilizer or Manure Been Applied. (Pounds per Acre of 2,000,000 Pounds of Surface Soil or 4,000,000 Pounds of Subsoil.)

Plot No.	Nitrogen A*	Nitrogen B†	Phosphorus	Carbon	$CaCO_3$ Requirement A* Lbs.	$CaCO_3$ Requirement B† Lbs.
18	1960	2180	600	23,900	2800	6800
19	1917	2174	597	23,000	2800	3600
20	1873	2166	593	22,100	2800	2800
21	1830	2160	590	21,200	2800	5600
22	1852	2180	593	21,317	2967	3600
23	1873	2200	597	21,433	3133	6000
24	1895	2220	600	21,550	3300	3600
25	1917	2240	603	21,667	3467	3200
26	1938	2260	607	21,783	3633	4400
27	1960	2280	610	21,900	3800	5200
28	2063	2314	640	23,367	3800	5200
29	2166	2346	670	24,833	3800	5200
30	2270	2380	700	26,300	3800	5600
31	2280	2426	713	26,667	3733	5200
32	2290	2474	727	27,033	3667	5600
33	2300	2520	740	27,400	3600	5200
34	2227	2420	707	26,400	3600	5600
35	2153	2320	673	25,400	3600	5600
36	2080	2220	640	24,400	-------	-------

*Surface soil to 6⅔ inches.
†Subsoil, 6⅔ to 20 inches.

The Nitrogen Balance.

Every plot which has received an application of acid phosphate shows a higher content of nitrogen than it should, according to the calculations as given in Table IX. In every case the amount of nitrogen present is in excess of what it should be if there had been no application of nitrogen other than that in nitrate of soda. The data seem to indicate that nitrogen has been secured from the air through the growth of legumes or otherwise. Even on the check plots the nitrogen content is apparently as high as it was fifteen years ago when the experiment was begun. Analyses made at that time of a composite sample chosen from eight different points over the plots showed a nitrogen content of 1900 pounds per 2,000,000 pounds of surface soil. The average nitrogen content of the check plots in 1915 was 2042 pounds per 2,000,000.

It will be noticed that the plot receiving only nitrate of soda has suffered a loss of 890 pounds of nitrogen although the amount of nitrogen added was only 672 pounds. By comparing this plot with the one receiving sulphate of potash and nitrate of soda it will be observed that the loss is considerably reduced, being only 138 pounds. Plots 31, receiving nitrate of soda and acid phosphate, shows a gain of 213 pounds. One is led to infer from this that acid phosphate and sulphate of potash have in some way either prevented this loss or have been responsible in some way for an accumulation of nitrogen sufficient to offset this loss. Plot 26, receiving an application of acid phosphate and sulphate of potash, shows an increase amounting to 1173 pounds per acre.

The evidence seems to be sufficient to justify the statement that there has been a nitrogen fixation in the soil on the plots receiving acid phosphate and sulphate of potash varying from 20 pounds per acre per year, on the plot receiving acid phosphate alone, to 78 pounds per acre per year on the plot receiving acid phosphate and sulphate of potash. Table IX shows the amount of nitrogen fixed on the various plots since 1900, figured on the basis of an acre of soil to a depth of 20 inches and weighing 6,000,000 pounds. Of course it may be possible that the crops contained more nitrogen than the analyses given in Table III would indicate, but even so, we have not taken into consideration the loss of nitrogen in the drainage water which in the case of plots receiving nitrate of soda must have been considerable. The analyses of the drainage water from Broadbalk field at Rothamsted* indicate

*Hall, The Soil, p. 201.

that this must have been true. The soil on the Experiment Station farm overlies sandstone and is very well drained. Plots receiving nitrogen but no phosphorus show a serious loss of nitrogen. Only three legumes have been grown on the plots during the experiment and these crops were removed from the plots, so that most of the nitrogen fixation must have been brough about by some other agency. Azotobacter chroococcum and Clostridium pasteurianum are both present in the soil of the fertility plots.

Either acid phosphate or sulphate of potash has been of value in aiding nitrogen fixation but a combination of both has been considerably more effective than either applied alone.

DIAGRAM II.

Correlation Between Total P, N, and C in Soil of Fertility Plots.

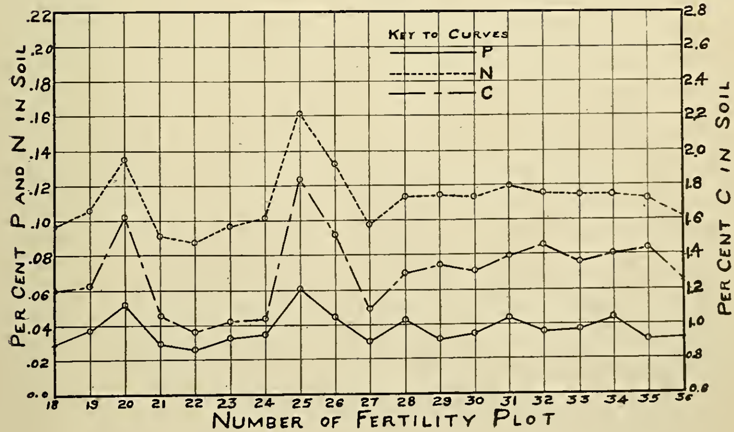

TABLE IX.—The Nitrogen Balance. (Pounds of Nitrogen per Acre.)

Plot No.	Treatment	From 0 to 6⅔ Inches: Nitrogen Present†	From 0 to 6⅔ Inches: Nitrogen Calculated from Checks*	From 0 to 6⅔ Inches: Gain or Loss	From 6⅔ to 20 Inches: Nitrogen Present†	From 6⅔ to 20 Inches: Nitrogen Calculated from Checks*	From 6⅔ to 20 Inches: Gain or Loss	Total Gain or Loss 0 to 20 in.	Calculated Gain or Loss‡	Nitrogen Balance
19	N, P, K, CaO	2130	1917	+213	2640	2174	+466	+679	—161	+840
22	CaO	1760	1852	— 92	2040	2180	—140	—232	+ 7	—225
26	N, P, K	2660	1938	+722	2572	2260	+312	+1034	— 65	+1099
28	P, K	2280	2063	+217	2912	2314	+598	+815	—358	+1173
29	N, K	2300	2166	+134	2672	2346	+326	+460	+598	—138
31	N, P	2400	2280	+120	2580	2426	+154	+274	+ 61	+213
32	K	2310	2290	+ 20	2364	2474	—110	— 90	— 21	— 69
34	P	2300	2227	+ 73	2372	2420	— 48	+ 25	—270	+295
35	N	2260	2153	+107	1960	2320	—360	+253	+637	—890

†Table VII.
*Table VIII.
‡Table V.

The Phosphorus Balance.

Every plot which has received applications of manure or acid phosphate shows a high content of phosphorus. Apparently all or most of the phosphorus applied in the form of fertilizer which was not used by the crops is still present in the surface soil, having never diffused to any considerable extent into the subsoil. This is shown in Table X in which the actual gain in phosphorus as measured by the check plots is compared with the calculated gains as given in Table V. It will be seen that there is a rather close agreement between the two, sufficiently so to justify the statement that the phosphorus applied to the soil in excess of the needs of the crop has been fixed within the first 6⅔ inches of soil.

TABLE X.—The Phosphorus Balance. (Pounds per 2,000,000 Pounds of Surface Soil.)

Plot No.	Treatment	Phosphorus Present	Phosphorus Calculated from Checks†	Gain or Loss	Calculated Gain or Loss*	Phosphorus Balance
19	N, P, K, CaO	740	590	+150	+171	— 21
22	CaO	520	593	— 73	— 1	— 72
26	N, P, K	900	607	+293	+180	+113
28	P, K	860	640	+220	+236	— 16
29	N, K	640	670	— 30	— 16	— 14
31	N, P	880	713	+167	+201	— 34
32	K	720	727	— 7	— 5	— 2
34	P	880	707	+173	+253	— 80
35	N	620	673	— 53	— 6	— 47

†See Table VIII.
*See Table V.

The Carbon Balance.

The amounts of organic matter present in the soil on the plots vary considerably with different fertilizer treatments. There is a very close correlation in most cases between the amounts of carbon, phosphorus, and nitrogen in the various plots as shown in Diagram II. The relation between total carbon and the organic matter in the soil is not definitely known. The factor 1.724* is used frequently to estimate the organic matter from the total carbon. In all plots receiving fertilizing materials the content of organic matter is greater than in the check plots. It must be remembered that no green manuring crop or manure was applied to any of the fertilizer plots. Any increase in organic matter must have come from the roots and stubble of the crops produced. We have already shown that the content of nitrogen in the check plots is as much as or more than it was at the beginning of the experiment. We assume from the correlation between nitrogen and carbon

*Wiley, Principles and Practice of Agricultural Analysis, Vol. I.

as shown in Diagram II referred to before that the content of organic matter has remained practically constant in the check plots, and largely because the soil was so low in fertility originally that the organic matter remaining behind represented only that which was very resistant to decay. The evidence indicates that organic matter can be maintained and increased by the use of fertilizers without plowing down green crops or anything other than the stubble left behind after the crop is harvested. It will be observed that there is a considerable increase in the amount of organic matter in the soil of the plot receiving the complete fertilizer.

TABLE XI.—Carbon and Organic Matter Balance. (Pounds per 2,000,000 Pounds of Surface Soil.)

Plot No.	Treatment	Carbon Present	Carbon Calculated from Checks†	Carbon Gain or Loss	Organic Matter* Gain or Loss
19	N, P, K, CaO....	24500	23000	+ 1500	+ 2586
20	M, CaO	32500	22100	+10400	+17930
22	CaO	19400	21317	— 917	— 1581
25	M	36800	21667	+15133	+26089
26	N, P, K..............	30400	21783	+ 8617	+14856
28	P, K	26000	23367	+ 2633	+ 4539
29	N, K	27000	24833	+ 2167	+ 3736
31	N, P	28000	26667	+ 1333	+ 2298
32	K	29200	27033	+ 2167	+ 3736
34	P	28200	26400	+ 1800	+ 3103
35	N	28800	25400	+ 3400	+ 5875

†Table VIII.
*Carbon x 1.724.

THE BAD EFFECTS OF BURNED LIME.

On the plots to which lime has been applied there are certain outstanding effects which can be observed by a study of the analyses. Referring to Table I, it will be noticed that the use of lime alone has been responsible for a loss in yield as an average of the last fifteen years. When used in connection with manure or fertilizer it has produced an increase in yield. As to what this increase amounted to when applied with manure cannot be ascertained since the plot receiving manure and lime had a total of 210 tons of manure as compared to 190 tons on the plot receiving no lime. On the fertilizer plot the use of lime has produced an increase amounting to a total of 2695 pounds of produce in fifteen years, little more than sufficient to pay for the lime. However, the application of lime has caused a decrease in nitrogen, phosphorus, and carbon in the soil out of all proportion to the increased crops produced. Table XII shows this loss. In every case the application of lime has proved detrimental to the surface soil.

TABLE XII.—Loss of Nitrogen, Phosphorus, and Carbon from Limed Plots.
(Pounds per 2,000,000 Pounds of Surface Soil.)

Plot No.	Treatment	Nitrogen Present	Nitrogen Check*	Nitrogen Difference	Phosphorus Present	Phosphorus Check*	Phosphorus Difference	Carbon Present	Carbon Check*	Carbon Difference	Organic Matter
26	N, P, K	2660	1938	728	900	607	293	30400	21783	8617	
19	N, P, K, CaO	2130	1917	213	740	590	150	24500	23000	1500	
	Loss			515			143			7117	12270
25	M	3240	1917	1323	1220	603	617	36800	21667	15133	
20	M, CaO	2700	1830	870	1050	590	460	32500	21200	11300	
	Loss			453			157			3833	6608
21	Check	1830	1830	0	590	590	0	21200	21200	0	
22	CaO	1760	1852	–92	520	593	–73	19400	21317	–1917	
	Loss			92			73			1917	3235

*See Table VIII.

One reason for this may be the fact that an excess of lime was applied as compared to the needs of the soil although in no case did the application exceed 5500 pounds per acre in 15 years, which would not be considered excessively heavy. The lime requirement of the check plots at present amounts to practically 3000 pounds of $CaCO_3$ per 2,000,000 pounds of surface soil, which is equivalent to 1680 pounds of CaO. It will be seen, therefore, that lime was applied in considerably larger amounts than the surface soil required. However, the subsoils on the plots receiving lime still show a lime requirement averaging over 3200 pounds of $CaCO_3$ to a depth of twenty inches.

THE EFFECT OF MANURE AND FERTILIZERS ON THE LIME REQUIREMENT OF THE SOIL.

The use of manure and fertilizers has had a tendency to decrease the acidity of the soil as shown in Table XIII. Sulphate of potash is the only one of the three commercial fertilizers used which did not have this tendency.

The statement is frequently made that the use of acid phosphate will make a soil acid. This work verifies the statements published by certain other experiment stations*† and indicates that the belief that the soil will become acid from the use of acid phosphate is without foundation. The analyses of the plots together with the data showing their present crop producing power indicate that it is possible to grow very large crops on acid soils without the use of lime and at the same time to be able to bring about a gradual decrease in the lime requirement of these soils.

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*Connor, S. D., Jour. Ind. & Eng. Chem., Vol. VIII, No. 1, p. 35.

†Brooks, Wm. P., Bulletin 162, Massachusetts Agricultural Experiment Station

TABLE XIII.—The Lime Requirement of the Soil of the Fertilizer Plots. (Pounds of $CaCO_3$ Required per Acre.)

Plot No.	Treatment	From 0 to 6⅔ Inches: $CaCO_3$ Requirement	From 0 to 6⅔ Inches: $CaCO_3$ Requirement Calculated from Checks	From 0 to 6⅔ Inches: Gain or Loss	From 6⅔ to 20 Inches: $CaCO_3$ Requirement	From 6⅔ to 20 Inches: $CaCO_3$ Requirement Calculated from Checks	From 6⅔ to 20 Inches: Gain or Loss	$CaCO_3$ Requirement Balance to 20 Inches
19	N, P, K, CaO	— 920	2800	—3720	1800	3200	—1400	—5160
20	M, CaO	—1160	2800	—3960	1400	3000	—1600	—5560
22	CaO	—1600	2967	—4567	1800	2767	— 967	—5534
23	M(ash), N	2800	3133	— 333	3000	2733	+ 267	— 66
25	M	2800	3467	— 667	1600	2667	—1067	—1634
26	N, P, K	3200	3633	— 433	2200	2633	— 433	— 866
28	P, K	3600	3800	— 200	2600	2667	— 67	— 267
29	N, K	3400	3800	— 400	2600	2732	— 132	— 532
31	N, P	3200	3733	— 533	2600	2732	— 132	— 665
32	K	3600	3667	— 67	2800	2667	+ 133	+ 66
34	P	3400	3600	— 200	2600	2600	— 0	— 200
35	N	3400	3600	— 200	2600	2600	— 0	— 200

THE APPLICATION OF THESE INTERPRETATIONS.

The analyses of these plots and the interpretations put on them, if they are correct, indicate several things of far-reaching importance to the agriculture of West Virginia:

1. The nitrogen of the soil can be maintained and increased without purchasing it in the form of commercial fertilizers, even if all the crops are removed from the farm. In fact it does not seem at all necessary, in view of the results obtained on the Experiment Station farm as to crop yields and also as to the present nitrogen content of the soil on the plots receiving phosphorus and potassium, to buy nitrogen in the form of fertilizers for permanent soil building.

2. The value of phosphorus and potassium over phosphorus alone as a fertilizer may, at least partly if not largely, be explained by an indirect function of potassium: viz., its value as an aid to nitrogen fixation. It seems possible from these analyses that it may be advisable to include potassium in the fertilizer used on soils in a low state of fertility instead of using acid phosphate alone as is now being largely practiced in West Virginia. This does not mean that the use of acid phosphate alone is objectionable but that a combination of potash salts and acid phosphate may be more effective not alone in its present crop-producing power but also in its residual effect on the soil. However, this potash supply may be manure instead of fertilizer.

3. Soil acidity is not necessarily a condition of the soil which must be overcome by the use of lime in order to produce satisfactory crops. The soil on the Experiment Station farm has a higher lime requirement than the average West Virginia soil. Yet, excellent crops have been produced at a profit on the Experiment Station farm without the use of either lime or limestone. The plots receiving acid phosphate, acid phosphate and sulphate of potash, complete fertilizer, and manure are in much better condition today than they were when the experiment was begun in 1900. These plots not only show a lower acidity than the check plots but they have a much higher content of both organic matter and nitrogen than they had originally.

This would indicate that farmers living some distance from a railroad station or from a source of lime or limestone are not compelled to buy and apply lime in order to produce large crops economically. This does not mean, however, that limestone, where it can be secured at a reasonable cost, can not be applied to advantage on acid soils.

4. These analyses indicate that organic matter can be maintained and increased in the soil without plowing down anything but the stubble left behind after the crops have been harvested, if a rotation of crops is followed and use is made of either fertilizer or manure. Organic matter can be increased in the soil by growing large crops in rotation, even though the crops are removed from the farm. It has always seemed doubtful in the minds of writers whether the spasmodic attempts to increase the organic matter in the soil by plowing down some crop such as soybeans, which could have been used for some other purpose, is advisable. Such a procedure not only means the loss of the use of the land for that season but also a considerable cost for labor and seed. The soybeans could have been fed as hay and the manure returned to the field, or they could have been sold and a part of their value invested in fertilizer. Either the fertilizer or the manure, by reason of the fact that it produced a large crop, would have increased the organic matter in the soil by the roots and stubble of this crop.

This is not meant to discourage the plowing down of cover crops but is meant to imply that it does not seem advisable to lose the use of the soil during the main growing season for this purpose.

5. The evidence indicates that the acidity of the soil can be reduced by increasing the organic matter in the soil. The plots receiving manure show a reduced acidity. The plots which have received any combination of fertilizers which increased the yields materially show a higher content of organic matter and a lower acidity than neighboring check plots. In general it may be said that the acidity of the plots has been reduced wherever the content of organic matter has been increased. Limestone boulders which by accident were buried in an acid soil, when excavated a few years later, were covered with a heavy coating of very black organic matter such as to make them have the appearance of coal. It seems possible that the reverse of this may be true: viz., that if the soil is well stocked with organic matter, the lime in solution in the soil may be precipitated by this organic matter. On the subsequent decay of this organic matter the lime may be released as the carbonate. We consider this statement merely as a working hypothesis.

6. The best means of maintaining the fertility of the soil is to make it produce large crops. If for any reason the yield begins to gradually decrease, the result will be that the nitrogen and organic matter will begin to decrease and the acidity of the soil will increase. When once the soil has reached the state of unproductivity in which many West Virginia soils are found today heroic efforts may be required to bring them back to a normal state of productivity. We feel quite sure, however, that these worn out soils can be made to produce large crops by making use of nothing but acid phosphate in connection with good farming. We believe it can be done more rapidly and perhaps more economically by the use of potash and lime. Again it can be hastened by the use of nitrogenous fertilizers, but we are inclined to believe that this is doubtful economy.