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NITROGEN—THE MAJOR CAUSE IN THE PRODUCTION OF SPOTTED WHEAT FIELDS

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CONCLUSIONS

The data accumulated during the investigations herewith reported are adequate to permit of the following definite conclusions:

1. Spots of the type herein described are found in wheat fields throughout Kansas.

2. The growth of plants, as measured in terms of height and dry weight, on such areas is significantly greater than upon equal areas immediately adjacent.

3. The percentage and total quantity of nitrogen contained in the plant material from such areas are much greater than that in the material from equal areas immediately adjacent.

4. The plants in such spots are equally resistant to lodging.

5. The quantity of grain maturing upon such spots is very much greater than that maturing upon equal adjacent areas.

6. The protein content of the grain from such spots is significantly higher than that of the field at large.

7. The nitrogen content of the soil from such spots is significantly higher than that from adjacent soil.

8. The nitrate content of soil from the spots is on the average several times as great as that of adjoining soils.

9. Soil from such spots is capable, under laboratory conditions, of accumulating nitrate nitrogen from its store of nitrogen very much more rapidly than is the surrounding soil.

10. There is no deficiency in the nitrifying flora of soil adjacent to the spots, and the ability of soil from spots to accumulate nitrate nitrogen more rapidly is apparently associated with the quantity and quality of the excess nitrogen contained therein.

11. Spots, apparently identical in every respect with those occurring naturally, can be induced experimentally in fields exhibiting natural spotting, by the judicious surface application of nitrogen.

12. The application of nitrogen will not induce the development of spots in fields in which spots will not occur normally.

13. Typical spotting under Kansas conditions is due to deposits of urine by grazing animals, and the nitrogen in the urine is the factor responsible for the development of the spot.

14. The experimental surface application of nitrogen to wheat on soils subject to spotting may result in any one of the following conditions, depending upon the time and quantity of nitrogen applied:

a. No appreciable effect with light summer or fall applications.

b. Increased yield and decreased protein content with medium fall and light to medium early spring applications.

c. Increased yield and increased protein content with medium to heavy fall and early spring applications.

d. Decreased yield and increased protein content with very heavy fall and early spring applications.

e. Marked increase in protein content and slight effect upon yield with light to medium late spring applications.

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NITROGEN—THE MAJOR CAUSE IN THE PRODUCTION OF SPOTTED WHEAT FIELDS[1]

P. L. GAINEY, M. C. SEWELL, AND H. E. MYERS

INTRODUCTION

During the past 25 years the Kansas Agricultural Experiment Station has endeavored in its research activities to follow as far as practicable any clue which might throw light on the relation of soil nitrogen to wheat production, particularly in those parts of the state where the precipitation is relatively small.

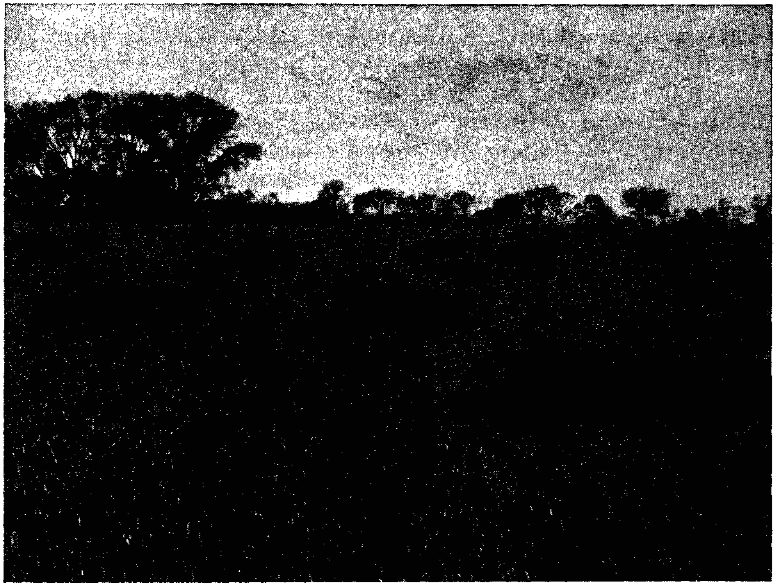

FIG. 1.—A typically spotted wheat field.

In the small-grain fields of Kansas there are frequently observed well-defined spots on which the growing grain is darker green in color and apparently growing much more vigorously than that of the surrounding areas. So abundant are these spots in the eastern half of Kansas that some fields present a polka-dot appearance as is shown in figure 1. Such spots are not peculiar to Kansas, having been reported by Lipman[2] in California, and observed by the senior writer in several states of the Union, in Canada, and in both eastern

1. Contribution No. 163 from the Department of Bacteriology and No. 250 from the Department of Agronomy.

2. Lipman, C. B. The nitrifying powers of soils as indices to their fertility. Soc. Prom. Agr. Sci. Proc. 35:73-79. 1915.

and western European countries. These spots are ordinarily two to three feet in diameter, circular or oblong in shape, and frequently the immediate central portion of the area is either void of plants or contains only badly-stunted specimens. In a typically spotted field, when the plants are in the booting stage, such spots are easily visible a half mile away. They are more frequently observed in fields that have been grazed and are commonly attributed to deposits of feces or urine. They seem to occur upon heavy potentially fertile soil as frequently as upon light unfertile soil. They are found most frequently in low-lying areas more or less poorly drained. The general appearance of the spots, together with their supposed origin, indicates that they might in some way be connected with the nitrogen metabolism of the plants, hence, the undertaking of the studies herein reported.

Some preliminary studies were conducted as early as 1916, and during the spring and summer months of the years 1929 to 1934 the studies were extended as far as the problem and facilities would seem to justify. The primary objects of these studies were to determine: (1) The rôle, if any, that available nitrogen plays in the production of the spots; (2) in case available nitrogen was found to be a factor, to ascertain why more nitrogen became available in the soil of the spot than in the soil immediately adjacent to it; and (3) to measure the relative yield and quality (as indicated by the protein content) of the grain produced on the spot as compared with that on the area immediately surrounding it. Two previous short reports,[3] involving a limited amount of the data have been presented.[4] The present paper includes either the complete data or such summaries of the experimental data as seem essential in a final report.

The experimental work has been directed along three main lines of inquiry: (1) The collection and analysis of actively-growing plant material and soil, and the bacteriological examination of soil from naturally-occurring spots and from immediately adjacent areas. (2) The collection and analysis of mature wheat plants from spots and areas adjacent thereto. (3) The experimental production of spots; and the collection and examination of both growing and mature plants and soil therefrom. It seems best to present the data secured under these three headings.

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3. Gainey, P. L., and Sewell, M. C. Indications that available nitrogen may be a limiting factor in hard winter wheat production. Jour. Amer. Soc. Agron. 22:639-641. 1930.

4. Gainey, P. L., and Sewell, M. C. The rôle of nitrogen in the production of spots in wheat fields. Jour. Agr. Research 45:129-149. 1932.

STUDIES CONDUCTED UPON GROWING PLANT MATERIAL AND SOIL COLLECTED FROM NATURALLY OCCURRING SPOTS

METHODS

The Collection of Material.—For these studies plant material and soil were collected from typical spots and from the area immediately adjacent to them (always within a radius of five feet). Not many samples could be handled at any one time, particularly when bacteriological studies were being made. This necessitated spreading the collection of material over the active growing period. As a result, the stage of development of plants when collected varied from the beginning of jointing to full bloom. As is shown in figure 2, samples were taken from many fields over a wide territory. In all, 172 samples from 38 counties have been studied, and with the excep-

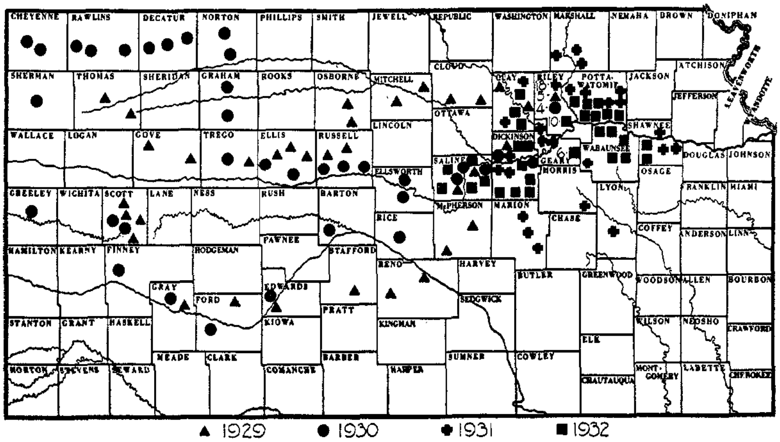

FIG. 2.—Locations from which samples of soil and growing grain were collected for study.

tion of the small number of 1934 samples, taken purposely from the same field, each sample represents an entirely different field or set of conditions.

The samples taken from the spots are designated as G (good) and those taken immediately adjacent thereto as P (poor). Since spots frequently occur in productive soils the designation good and poor should be used literally only in comparing a G soil with its corresponding P sample. Measured in terms of growing grain the P samples collected in some fields were far more productive than G samples collected in other fields.

The exact technic followed varied somewhat for different seasons. Most of the samples studied in 1929 and 1930 were collected at considerable distances from Manhattan, hence, laboratory studies could not be made for several days. This necessitated, in the case of soil to be analyzed for nitrate nitrogen, some treatment to prevent, as far as possible, changes in the nitrate content during the time elapsing between sampling and analysis. At the same time it was desired to make certain bacteriological tests. Obviously, bacteriological tests could not be conducted upon soil to which a preservative had been added. To overcome these difficulties two samples of soil were taken from the spot and the adjacent area in 1929 and a heavy application of toluol was mixed into one of the duplicates. Waxed ice cream cartons were used as containers and were found to prevent rapid loss of moisture effectively. If the soil was dry enough to handle with a soil tube, one was used; otherwise, a garden trowel was employed in securing the sample of the soil. In either case the sample was a composite of a number of smaller samples, usually not less than five, taken to a depth of 6 to 7 inches. The samples collected in 1930 were not submitted to any bacteriological tests, hence the nontoluol treated samples were omitted. The samples collected in 1931, 1932, and 1934 were all taken within a radius of 100 miles of Manhattan, making it possible to initiate laboratory studies within a few hours after the samples were collected and to utilize the same sample for both chemical and bacteriological studies. Experience has shown that the change in the nitrate content of soils with relatively low organic content during a period of 24 hours is negligible.

The growing plant material was collected in 1929 by pulling plants from the spot and immediately adjacent, thus including the crown and such roots as adhered. The plants were not pulled from a definite area, but after reaching the laboratory the soil was carefully washed from the roots and the number of plants counted, thus making it possible to calculate the dry material and nitrogen per single plant. Since, in general, there was no marked variation in the stand of plants in the spot as compared with the adjacent areas, a comparison on the individual plant basis is more or less comparable to a comparison based upon a unit area. In all subsequent collections the plants were cut just above the surface of the ground over a measured area, usually from the same drill rows within and without the spot, care being taken to select spots where a uniform stand existed both in and immediately adjacent to the spot. Height-of-plant measurements were made before the plants were collected.

Chemical Analysis.—As soon as possible after the soil reached the laboratory the moisture and nitrate (NO_3) contents were determined, the former by drying at 110° C. and the latter by the phenoldisulphonic acid colorimetric method in which a Dubosque colorimeter was employed. The soil remaining after the moisture and nitrate determination and bacteriological examinations were made was spread in a thin layer and dried at room temperature. Later an aliquot was ground in a ball mill and total nitrogen determinations made by the Kjeldahl method.

The plant material was dried at room temperature, weighed, ground to a fine powder, and the moisture and total nitrogen contents determined as in the case of the soil.

Bacteriological Examinations of Soil.—In the studies conducted by Lipman on soil collected from spots, presumably similar to and probably of the same origin as those under discussion, the conclusion was reached that the higher productivity of the spot soil was due to its more efficient nitrifying flora. It, therefore, seemed desirable to conduct tests upon these soils to ascertain if the efficiency of the nitrifying flora played any rôle in the higher productivity of soil from the spots. To this end the fresh soil was passed through a coarse sieve (three meshes per centimeter) and the moisture content and water-holding capacity then determined. Duplicate samples, the equivalent of 100 grams of dry soil, were weighed into wide-mouthed, cotton-stoppered bottles and sufficient water added to bring the moisture content up to two thirds saturation. These samples were held at room temperature for four to six weeks, the moisture lost through evaporation being replaced weekly. After incubation the nitrate content was determined. The nitrate content after incubation, minus the initial nitrate, is designated as the nitrate formed from the soil's store of nitrogen. Experiments of this kind were conducted on the 1929, 1931, and 1932 samples.

In addition, duplicate bottles of the 1931 and 1932 samples were treated as just described except that one gram of cottonseed meal containing 7 percent nitrogen was thoroughly mixed into the soil. After four to six weeks of incubation (incubation of P and G samples always being of the same duration) these samples were analyzed for nitrates. The difference in the nitrate content between the incubated samples containing cottonseed meal and those containing no cottonseed meal has been designated as the nitrates formed from added nitrogen.

The 1931 and 1932 samples of soil were examined for Azotobacter and their ability to fix nitrogen measured by spreading 0.5 or 1 gram soil uniformly over the surface of a Petri dish containing 20 c.c. mannite agar, prepared from carefully washed agar, and incubating at 28° C. The relative density of the Azotobacter flora as indicated by the colonies developing in the plate was recorded, and after incubation the nitrogen content measured and the nitrogen fixed computed by deducting the nitrogen content of similarly treated unincubated controls. The 1931 samples were incubated 14 days, but subsequent studies (Gainey and Briscoe[5]) indicated that a much shorter incubation period would probably give a better differentiation between low and high nitrogen fixing abilities, therefore, the 1932 samples were incubated four to seven days. This procedure is designed to facilitate fixation of nitrogen by the Azotobacter group of organisms and probably is inaccurate for all other types, hence, only those samples from which Azotobacter developed in the P or G samples are included in the records.

5. Gainey, P. L., and Briscoe, Faith. Concerning the length of incubation period in physiological studies of bacteria. Soil Sci. 36:165-171. 1933.

TABLE I.—DATA OBTAINED FROM A STUDY OF PLANTS AND SOIL TAKEN FROM SPOTS AND FROM SURROUNDING AREAS, 1929

SAMPLE No.	Height of plants.		Dry weight of plant material.		Nitrogen in plant material.		Total nitrogen in soil.		NO_3 in soil when collected.		NO_3 formed from soil nitrogen.	
	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.
	Ins.	*Ins.*	*Gm.*	*Gm.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*
1	6	28	1.48	3.76	1.21	2.38	0.1350	0.2020	9.7	17.5	78.3	248.5
2	9	28	2.01	5.38	1.00	1.85	.2160	.2180	9.2	8.5	165.8	304.5
3	5	21	1.68	3.05	.88	2.17	.0560	.0605	9.0	18.0	71.0	168.0
4	5	21	.56	2.67	1.06	1.74	.0760	.0810	8.7	8.5	54.3	96.5
5	6	15	.80	2.91	.98	2.31	.1025	.1035	7.5	9.0	74.5	101.0
6	10	27	1.08	5.67	1.73	2.24	.1030	.0990	20.2	26.7	69.8	77.3
7	5	18	.20	1.47	1.39	2.61	.1655	.1950	22.7	31.0	164.3	537.0
8	18	33	1.74	4.59	1.05	2.43	.1080	.1100	19.8	28.5	66.2	117.5
9	12	26	1.58	5.93	1.07	1.89	.1290	.1395	19.2	27.8	88.8	212.2
10	14	26	1.62	7.39	1.20	2.29	.1410	.1765	19.2	16.9	80.8	409.1
11	7	12	.27	.53	1.49	2.81	.1135	.1380	18.5	73.6	98.5	986.4
12	10	20	2.33	4.44	.82	2.15	.0330	.0360	17.0	120.7	44.0	—6.7
13	8	16	.25	.88	1.64	2.21	.1100	.1140	17.7	26.2	132.3	153.8
14	6	12	.60	.73	1.38	2.82	.1145	.1360	16.3	42.3	130.7	777.7
15	10	16	2.12	2.10	1.17	1.96	.1415	.1530	16.8	58.3	152.2	323.7
16	8	16	1.42	4.90	1.38	1.86	.1590	.1660	14.7	60.8	185.3	371.2
17	7	12	.44	.72	1.47	2.57	.1380	.1410	24.4	60.1	132.6	212.9
18	6	10	.33	.51	1.75	3.03	.1080	.1250	18.1	34.4	94.9	631.6
19	4	5	.28	.51	2.06	3.97	.1160	.1485	19.1	163.5	76.9	461.5
20	5	11	.09	.49	1.91	2.84	.1330	.1380	18.5	157.0	101.5	96.0

TABLE I—CONCLUDED

SAMPLE No.	Height of plants.		Dry weight of plant material.		Nitrogen in plant material.		Total nitrogen in soil.		NO_3 in soil when collected.		NO_3 formed from soil nitrogen.	
	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.
	Ins.	*Ins.*	*Gm.*	*Gm.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*
21	5	8	.31	.54	1.99	3.35	0.1425	0.1415	17.4	21.0	194.6	238.0
22	5	8	.32	.63	2.10	3.86	.1175	.1150	18.3	35.8	148.7	524.2
23	5	7	.22	.31	2.01	3.62	.1325	.1260	19.1	72.4	144.9	315.6
24	10	15	.72	1.18	1.43	2.87	.1730	.1865	18.0	58.4	147.0	781.6
25	11	17	1.92	5.58	1.65	2.50	.1405	.1480	18.3	73.2	137.7	78.8
26	10	16	1.52	2.53	1.30	2.69	.1405	.1580	15.9	23.2	98.1	778.8
27	10	14	.44	.49	1.53	2.65	.1685	.1885	16.2	67.9	269.8	430.1
28	8	16	.74	1.26	1.49	2.21	.1285	.1375	17.8	22.4	248.2	199.6
29	12	18	1.06	3.05	1.34	2.69	.1490	.1870	20.9	21.9	219.1	1,418.1
30	12	18	1.14	2.65	1.31	2.46	.1105	.1195	33.9	35.8	132.1	445.2
31	8	11	.40	.89	1.85	3.45	.1855	.2210	15.8	35.4	232.2	1,080.6
32	11	20	.59	1.36	1.26	2.94	.1605	.1780	118.5	146.5	141.5	1,199.5
33	9	20	.61	1.42	1.34	2.17	.1120	.1385	17.3	65.0	148.7	380.0
34	6	12	.24	.35	1.52	2.99	.1335	.1630	22.5	29.4	138.5	1,570.6
35	9	18	.28	1.04	1.33	3.01	.1235	.1510	20.6	73.7	151.4	1,126.3
36	8	14	.61	1.14	1.63	3.47	.1395	.1445	18.4	137.6	341.6	62.4
37	9	19	.47	2.57	1.45	2.53	.1455	.1565	16.0	31.7	120.0	368.3
38	10	24	.45	2.62	.99	2.40	.0960	.1075	16.1	49.1	141.9	403.9
Mean	8.4	17.1	0.87	2.32	1.43	2.63	0.1289	0.1434	20.2	52.4	137.4	465.3

Note.—The total nitrogen determinations on both soil and plant materials for 1929 and 1930 were made in the analytical laboratory of the Department of Chemistry under the supervision of Prof. W. L. Latshaw.

RESULTS

The data obtained from this phase of the work are presented in Tables I and V and summarized in Tables VII and VIII.

Data from the 1929 Studies.—Samples of growing grain and soil were collected from 38 fields in the spring of 1929. (Table I.) The fields from which they came were distributed over 19 counties. The average height of the G plants was 17.1 inches and of the P plants 8.4 inches, the former being taller than the latter in every comparison. The average weight of the G plants was 2.32 grams and of the P plants 0.87 gram, there being only one instance in which the weight of the P plant exceeded that of the G.

The percentage of nitrogen in the P plants ranged from 0.82 to 2.10, with an average of 1.43, while the corresponding values for the G plants were 1.74 to 3.97 and 2.63. Without exception, the percentage nitrogen of the G sample exceeded that of the P sample. There were only five instances in which the nitrogen of the P sample exceeded 1.9 percent, while there were only four G samples with a nitrogen content lower than this value. The average weight of the G plants was 2.67 times that of the P plants, and the average percentage nitrogen of the former was 1.84 times that of the latter. Therefore, the average quantity of nitrogen removed from the soil occupied by a G plant was 4.91 times that removed from a corresponding area occupied by a P plant. In spite of this large excess in the quantity of nitrogen removed from the G soil it still contained approximately 2.6 times as much nitrate nitrogen as the P soil, the average NO_3 content being 52.4 and 20.2 p. p. m., respectively.

When the two soils were made up to optimum moisture content and placed under identical incubation conditions the average increase in the NO_3 content of the P soils was 137.4 and in the G soils 465.3 p. p. m. In other words, the G soil was able to accumulate NO_3 3.45 times as rapidly as the P soil when the two were placed under identical laboratory conditions for a limited period of time. The difference was in favor of the G soil in 33 out of the 38 comparisons.

The G soils contained on the average 11 percent more nitrogen than did the P soils, the average for the P soil being 0.1289 and for the G soil 0.1434 percent. The nitrogen content of the G soil was higher than that of the P soil in 34 of the 38 comparisons.

Data from the 1930 Studies.—Samples were collected from 40 fields in 21 counties during the early summer of 1930. (Table II.) In every instance except one, the plants collected from the spots were taller than the surrounding plants, averaging for the G plants 23.5 and for the P plants 16 inches. In the single exception the two were recorded as of equal height. In every comparison the weight of the G plants exceeded that of the P plants, the former averaging 23.4 and the latter 66.3 grams. Furthermore, the percentage of nitrogen in the G plants was invariably greater than that in the P plants, the former varying from 1.295 to 3.705 and averaging 2.457 percent, while the latter ranged from 1.01 to 2.47 and averaged

TABLE II.—DATA OBTAINED FROM A STUDY OF PLANTS AND SOIL TAKEN FROM SPOTS AND FROM SURROUNDING AREAS IN 1930

Sample No.	Height of plants.		Dry weight of plant material.		Nitrogen in plant material.		Total nitrogen in soil.		NO_3 in soil when collected.	
	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.
	Ins.	*Ins.*	*Gm.*	*Gm.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*P. p. m.*	*P. p. m.*
1......	20	34	36.5	116.0	1.010	1.295	0.1120	0.1100	10.90	9.26
2......	26	34	28.2	104.0	1.220	1.650	.1400	.1450	11.99	29.72
3......	15	30	23.7	98.7	1.370	2.090	.2040	.2105	15.08	29.34
4......	15	27	29.5	65.7	1.375	1.620	.1565	.1585	52.97	28.76
5......	18	24	16.0	......	1.520	....	.1470	.1550	10.60	42.10
6......	24	36	41.0	124.0	1.440	1.745	.1975	.2095	7.88	19.88
7......	18	30	19.0	80.0	1.440	1.950	.1545	.1800	10.98	21.01
8......	16	22	11.0	55.0	1.610	1.830	.1200	.1295	12.63	28.13
9......	18	28	25.0	95.0	1.595	2.160	.1220	.1215	10.24	52.95
10......	12	18	14.0	38.0	1.485	2.435	.1065	.1080	8.67	16.27
11......	14	24	18.0	70.0	1.410	2.475	.0895	.1000	14.26	38.96
12......	18	18	22.0	25.0	1.545	2.580	.0905	.1020	11.05	52.47
13......	15	18	32.0	56.0	1.830	2.425	.1685	.1610	10.63	12.91
14......	15	23	40.0	81.0	1.550	2.990	.1490	.2200	9.51	329.22
15......	10	16	10.0	38.0	1.885	2.750	.1130	.1070	14.01	16.93
16......	16	21	20.0	45.0	1.690	2.715	.1310	.1340	12.54	33.72
17......	15	18	23.0	62.0	1.570	2.685	.1400	.1520	10.21	31.20
18......	12	16	16.0	46.0	1.840	2.970	.2100	.2150	8.52	17.04
19......	6	11	9.0	25.6	2.470	3.440	.0990	.1250	8.49	35.38
20......	11	20	22.0	34.0	2.215	3.270	.1520	.1510	12.22	29.48
21......	12	17	21.0	49.0	1.600	2.920	.1680	.1750	8.48	14.15
22......	18	24	34.0	50.0	1.490	2.530	.1265	.1940	9.29	39.00
23......	12	18	12.0	29.0	1.770	3.040	.1180	.1280	9.41	45.92
24......	12	18	17.0	49.0	1.895	3.265	.1410	.1565	10.69	52.00
25......	8	11	8.5	22.0	2.000	3.705	.1190	.1210	9.61	18.13
26......	13	21	23.0	58.0	1.330	2.970	.1120	.1200	10.04	17.94
27......	10	18	13.0	56.0	1.870	3.055	.1165	.1300	9.86	36.48
28......	18	28	16.0	71.0	1.325	2.165	.1310	.1260	9.75	16.02
29......	13	18	25.0	62.0	1.475	2.755	.1220	.1160	10.00	14.10
30......	15	21	18.0	49.0	1.560	3.180	.1130	.1145	8.67	83.31
31......	17	23	23.0	66.0	1.520	1.940	.1420	.1455	10.21	14.15
32......	16	24	20.0	80.0	1.800	2.770	.1270	.1450	9.55	51.57
33......	20	36	32.0	93.0	1.610	2.130	.1885	.1985	9.51	19.78
34......	20	32	28.0	108.0	1.390	1.770	.1620	.1600	9.41	14.07
35......	20	28	27.0	69.0	1.330	1.720	.1460	.1455	8.72	33.51
36......	25	29	59.0	99.0	1.120	1.990	.1200	.1365	7.73	46.55
37......	18	30	30.0	119.0	1.150	2.080	.1150	.1390	9.14	42.91
38......	18	20	18.0	43.0	1.700	2.780	.1360	.1610	9.53	33.18
39......	24	28	29.0	63.0	1.330	2.080	.1555	.1840	8.91	87.73
40......	18	28	27.0	91.0	1.550	1.900	.1550	.1515	10.00	12.85
Mean...	16.02	23.5	23.41	66.30	1.572	2.457	.1379	.1486	11.297	39.20

1.572 percent. There were only three of the P samples in which the nitrogen content exceeded 1.9 percent, whereas, only seven of the G samples contained less than that amount.

Since the average weight of dry matter from the G area was 2.83 times that from the P area and the nitrogen content of the G plants was 1.56 times that of the P plank, the G plants had actually absorbed 4.41 times as much nitrogen as the P plants growing upon an equal area.

The average NO_3 content of the P soil was 11.3 p. p. m. and the corresponding value for the G soil was 39.2. The G values exceeded

TABLE III.—DATA OBTAINED FROM A STUDY OF PLANTS AND SOIL TAKEN FROM SPOTS AND FROM SURROUNDING AREAS, 1931

Sample No.	Height of plants.		Dry weight of plant material.		Nitrogen in plant material.		Total nitrogen in soil.		NO_3 in soil when collected.		NO_3 formed in incubated soil.				Nitrogen fixed per plate.	
											From soil's store of nitrogen.		From added cottonseed meal nitrogen (*a*).			
	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.
	Ins.	*Ins.*	*Gm.*	*Gm.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*Mg.*	*Mg.*
1	....	....	....	....	....	....	0.1200	0.1185	10.0	10.0	41.0	71.4	963.0	870.6	3.37	3.86
2	....	....	....	....	....	....	.1631	.1815	10.3	10.7	78.0	155.9	1,055.7	986.4	....	....
3	....	....	....	....	....	....	.1571	.1590	3.2	3.1	47.2	110.6	1,105.6	1,096.3	....	....
4	....	....	....	....	....	....	.1433	.1536	4.5	3.2	52.3	192.7	958.2	1,668.1	1.05	5.13
5	9	20	29.5	90.5	1.94	3.34	.1883	.2141	9.7	50.7	60.3	724.3	1,015.0	451.0	3.87	3.56
6	8	13	17.6	51.2	1.56	2.68	.1324	.1354	42.1	15.9	16.7	79.8	997.2	1,116.3	....	....
7	8	11	35.4	62.3	1.68	2.99	.1270	.1444	7.7	99.3	45.1	372.7	723.2	564.0	3.80	3.44
8	....	....	....	....	....	....	.1358	.1500	7.8	342.7	38.7	55.3	989.5	826.0	3.83	3.61
9	....	....	....	....	....	....	.1268	.1380	6.1	27.5	61.0	243.5	914.9	1,215.0	....	....
10	6	15	34.1	82.1	1.75	2.96	.1669	.1811	6.7	86.6	42.8	413.4	1,299.5	1,445.0	4.13	3.71
11	11	18	44.1	119.8	2.83	2.65	.1838	.1909	16.7	21.3	110.8	97.7	604.5	1,077.0	....	....
12	8	14	25.0	68.0	2.24	4.10	.1234	.1301	9.3	158.2	63.4	188.1	1,230.3	1,401.7	2.88	3.29
13	....	....	....	....	....	....	.1508	.1616	9.6	140.2	59.2	250.4	1,259.2	1,299.4	3.86	4.12
14	8	16	37.0	118.5	1.62	2.62	.1699	.1740	4.5	10.5	59.4	89.0	1,201.1	1,271.5	4.35	3.64
15	8	10	19.5	45.1	1.72	2.95	.1665	.1680	5.7	12.2	92.3	124.6	844.0	1,032.8	....	....
16	7	11	21.7	74.2	1.51	3.01	.1695	.1883	6.2	64.8	74.5	611.2	1,101.3	260.8	2.78	3.90
17	13	26	43.4	179.5	1.55	2.30	.1796	.1875	16.5	22.3	82.9	223.1	1,124.6	1,420.6	4.28	3.90
18	12	22	35.5	122.0	1.65	2.75	.1451	.1661	1.7	16.9	79.3	340.4	1,075.0	681.3	.22	1.31
19	10	16	41.4	82.0	1.85	3.18	.1585	.1770	3.4	147.0	114.4	294.8	1,362.2	1,052.2	1.57	.69
20	10	18	20.5	73.4	1.79	2.71	.1376	.1703	5.3	156.3	101.4	1,027.7	958.8	778.0	4.75	3.94
21	10	17	32.4	90.7	1.50	2.32	.1564	.1613	4.2	4.4	95.5	101.2	929.1	1,047.4	....	....
22	15	22	52.2	105.2	1.54	2.38	.1125	.1309	3.9	27.6	43.5	267.3	771.6	735.1	.98	.30
23	14	24	75.2	195.7	1.35	2.28	.1808	.1868	5.6	96.0	85.4	254.1	955.0	617.9	....	....
24	12	18	27.7	72.7	1.48	2.62	.1568	.1579	6.7	15.4	55.1	111.6	918.2	767.0	....	....
25	13	20	46.0	107.1	1.44	2.71	.1436	.1568	4.8	25.1	43.7	201.1	737.7	952.8	4.38	3.97

TABLE No. III—CONCLUDED

Sample No.	Height of plants.		Dry weight of plant material.		Nitrogen in plant material.		Total nitrogen in soil.		NO_3 in soil when collected.		NO_3 formed in incubated soil. From soil's store of nitrogen.		NO_3 formed in incubated soil. From added cottonseed meal nitrogen (a).		Nitrogen fixed per plate.	
	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.
	Ins.	*Ins.*	*Gm.*	*Gm.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*Mg.*	*Mg.*
26	8	12	14.6	34.1	1.84	3.76	0.1215	0.1245	4.0	31.4	67.1	64.3	1,053.9	1,311.6	....	....
27	11	16	32.1	80.1	1.75	2.89	.1496	.1628	3.8	32.7	70.6	170.8	709.6	1,172.5	5.09	2.41
28	12	18	42.4	90.4	1.63	2.91	.1459	.1538	4.8	47.1	72.5	273.8	1,245.7	1,336.1	3.89	3.90
29	10	24	36.0	193.0	1.43	2.26	.0955	.1028	2.5	6.4	52.0	116.4	1,492.5	1,321.2	4.55	5.17
30	12	26	67.0	214.1	1.34	1.54	.1294	.1275	3.2	3.1	59.9	52.0	1,012.7	1,261.9	2.39	.75
31	15	30	89.9	170.7	1.33	2.71	.1376	.1613	4.7	109.0	57.1	596.9	1,275.2	434.7	5.36	4.76
32	9	26	28.7	212.2	1.54	2.44	.0611	.0915	3.1	24.4	35.6	559.4	1,423.9	940.2	4.64	4.88
33	17	31	31.7	219.7	1.25	2.12	.1305	.1451	3.9	21.8	99.0	520.0	972.3	1,178.2	3.79	3.90
34	15	34	24.2	139.5	.95	1.75	.0379	.0443	1.4	5.8	32.7	127.9	488.9	202.3	3.56	3.66
35	14	29	24.5	129.7	1.72	2.07	.1245	.1298	3.4	43.4	74.5	347.8	1,228.1	888.8	....	....
36	20	30	60.4	188.0	1.35	1.55	.1534	.1553	3.2	4.0	110.4	161.4	1,486.4	1,360.6	4.04	4.27
37	18	22	83.2	103.9	1.29	2.23	.2063	.2306	5.2	48.0	158.3	768.8	975.5	1,208.2	....	....
38	11	25	27.9	143.8	1.28	1.94	.1875	.1946	4.0	9.2	....	546.0	....	840.8	....	....
39	11	24	34.2	82.7	1.72	2.42	.1365	.1556	4.4	26.5	88.4	413.5	799.2	941.0	2.00	.18
40	9	18	15.6	88.0	1.61	2.88	.1508	.1549	3.0	5.9	74.9	189.3	1,458.1	1,206.8	3.89	5.24
41	16	20	30.2	79.7	.80	2.51	.1473	.1477	6.5	53.4	71.7	143.4	1,066.8	872.2	....	....
42	24	30	97.8	150.5	.92	1.22	.1324	.1376	3.2	3.7	58.6	69.1	896.3	1,095.2	....	....
43	15	20	43.7	76.6	1.17	2.36	.1819	.1844	4.1	4.0	100.7	135.6	1,040.2	989.4	....	....
Mean	11.9	20.7	39.5	114.9	1.55	2.56	0.1447	0.1555	6.5	47.6	69.7	275.8	1,040.9	1,004.5	3.45	3.39

(a) Cottonseed meal 1 gm. per 100 gm. of soil.

the P values in 38 of the 40 comparisons, the average NO_3 content of the G soil being 3.47 times that of the P soil.

The average nitrogen content of the P soils was 0.1379 percent and of the G soils 0.1486 percent. There were 11 instances among the 40 comparisons in which the nitrogen content of the P soil exceeded that of the G soil. No samples of soil were incubated during the 1930 season.

Data from the 1931 Studies.—During the early summer of 1931, samples were collected from 43 fields (Table III) in 11 counties, all within a radius of 100 miles of Manhattan. In every one of the 36 possible comparisons (growth being so small in seven fields where samples were collected during the early part of the season that no plant material was obtained) the height and weight of plants from the spot exceeded that from the surrounding area, the average height P being 11.9 and G 20.7 inches and average weight P being 39.5 and G 114.9 grams.

The nitrogen content of the P plants ranged from 0.8 to 2.83 percent and averaged 1.55 percent, while that of the G material varied from 1.22 to 4.1 percent and averaged 2.56 percent. There were only three samples in which the nitrogen content of the P material exceeded 1.9 percent and only four G samples in which the nitrogen content was lower than that amount. Since the nitrogen content of the G plants was 1.65 times that of the P plants and the weight 2.91 times as great, it is evident that plants growing upon the G soil had removed 4.8 times as much nitrogen per unit area as those growing upon the P soil. In spite of the fact that 4.8 times as much nitrogen had been removed from the G as from the P soil, the soil from the spots still contained an average of 47.6 p.p.m. NO_3 as compared with an average of 6.5 p. p. m. in the surrounding soil. There were only five of the 43 comparisons in which the NO, content of the P soil exceeded that of the G. In one case they were the same.

When the P and G soils were compared as to their ability to accumulate NO_3 from their own stores of nitrogen by incubating them under identical conditions for four weeks, the average accumulation in the P soil was found to be 69.7 p. p. m. as compared with 275.8 p. p. m. in the G soil. In only three of the 42 comparisons did the NO_3 accumulation in the P soil exceed that in the G soil. When the abilities of the P and G soils to accumulate NO_3 from added nitrogen (cottonseed meal) are compared by substracting the NO_3 present in incubated samples receiving no added nitrogen, from that present in incubated samples receiving an addition of nitrogen, the average value for the P samples was 1,040.9 p.p.m. and that for the G samples was 1,004.5 p. p. m. Furthermore, in 22 of the 42 comparisons the accumulation of NO_3 from added nitrogen was greater in the P soil than in the G soil.

Again as in the two preceding seasons, the average nitrogen content of the G soil, 0.1555 percent, exceeded the average nitrogen content of the P soil, 0.1447 percent, the difference being approximately 7.5 percent. In only two of the 43 comparisons did the nitrogen content of the P soil exceed that of the G soil.

An effort was made during the 1931 studies to measure the nitrogen fixing abilities of the P and G soils by spreading weighed quantities of soil, one gram, over the surface of mannite agar plates and counting the colonies developing after varying periods of incubation. After incubation total nitrogen determinations were made upon the contents of the plates and by deducting the nitrogen found in unincubated controls a measure of the nitrogen fixing abilities of the various soils was obtained. Only 27 of the samples compared in 1931 showed the presence of Azotobacter. Of these the G soil fixed the larger quantity of nitrogen in 13 instances. The average nitrogen fixed per plate by the P soil was 3.45 mg. while the corresponding value for the G soil was 3.39 mg. Where differences were evident in the number of colonies developing on the plates they were more frequently in favor of the P sample.

Data from the 1932 Studies.—During the 1932 season samples were collected from 44 fields in eight counties within a radius of 100 miles of Manhattan. (Table IV.) The average height and dry weight of the plants cut from the spots exceeded that of the plants collected immediately adjacent thereto in every comparison. The average height of the P plants was 16 inches and of the G plants 23.4 inches; the corresponding weights of dry material were 50.8 grams for the P and 138 grams for the G material.

The P plants averaged 1.41 percent nitrogen compared with 2.18 percent for the G plants. The nitrogen content of the P plants ranged from 0.79 percent to 2.26 percent and that of the G plants from 1.14 percent to 3.24 percent. In no instance did the nitrogen content of the P plants exceed that of the G plants, and in only one sample did the nitrogen content of the P plants exceed 1.9 percent, while in only 12 of the G samples did the nitrogen content fall below 1.9 percent; most of these 12 samples were collected late in the season or near maturity. Inasmuch as the dry weight of the G plant material was 2.71 times as great as that of the P material and the former contained 1.55 times the percentage nitrogen that the latter contained, it is evident that the G plants had removed 4.2 times as much nitrogen from a given area of soil as had the P plants. Notwithstanding this much larger removal of nitrogen from the soil by the G plants, the G soil still contained, on the average, 51.8 p.p.m. NO_3 as compared with 2.6 p. p. m. in the P soil. Thirty-five of the 44 P soils contained only traces of NO_3 as compared with 11 of the G soils, indicating that a much larger percentage of the P plants than of the G plants were receiving an inadequate supply of available nitrogen. In the 33 possible comparisons of the NO_3 content of the soils when collected that of the G exceeded that of the P in all instances, except one, and in it the two were equal.

Measuring the ability of the P and G soils to accumulate NO_3 from their native supply of nitrogen it was found that on the average

TABLE IV.—DATA OBTAINED FROM A STUDY OF PLANTS AND SOIL TAKEN FROM SPOTS AND FROM SURROUNDING AREAS, 1932

Sample No.	Height of plants.		Dry weight of plant material.		Nitrogen in plant material.		Total nitrogen in soil.		NO_3 in soil when collected.		NO_3 formed in incubated soil. From soil's store of nitrogen.		NO_3 formed in incubated soil. From added cottonseed meal nitrogen.		Nitrogen fixed per plate.	
	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.
	Ins.	*Ins.*	*Gm.*	*Gm.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*Mg.*	*Mg.*
1	5	15	8	43	1.87	2.68	0.0598	0.0611	Tr.	Tr.	71.0	108.0	633.0	576.0	....	....
2	12	22	38	130	1.57	2.37	.0741	.0767	Tr.	25.5	82.5	104.5	755.5	872.0	2.87	1.96
3	10	20	20	83	1.50	2.89	.1220	.1400	9.1	100.0	85.2	647.0	1,067.7	1,137.0	.49	1.02
4	10	14	25	72	1.81	2.61	.1860	.1970	Tr.	47.0	128.0	741.0	1,300.0	1,074.0	1.19	1.16
5	18	27	54	121	1.18	2.52	.0770	.0870	Tr.	13.0	71.0	141.5	925.0	809.5	....	....
6	13	24	21	25	1.64	2.11	.1030	.1020	14.0	14.0	91.0	140.5	1,378.0	1,013.5	1.82	.91
7	9	15	18	63	1.89	3.03	.1118	.1300	16.0	61.0	96.5	507.0	1,091.6	596.0	3.11	2.73
8	11	17	31	86	1.81	2.86	.1600	.1720	17.0	71.0	88.0	461.0	1,143.0	1,072.0	2.48	2.17
9	9	16	16	74	1.63	2.76	.1130	.1350	13.0	200.0	61.0	609.5	1,074.0	602.5	....	....
10	12	22	35	113	1.53	2.72	.1470	.1670	12.0	93.0	90.5	553.5	1,041.5	867.5	....	....
11	10	16	35	132	1.79	2.70	.1500	.1630	12.0	88.0	176.0	537.5	1,252.0	934.5	2.62	1.82
12	8	10	14	35	2.26	3.12	.1890	.1760	Tr.	61.0	279.5	330.0	1,442.5	1,449.0	....	....
13	18	26	68	179	1.27	1.70	.1350	.1400	Tr.	9.0	193.0	200.5	1,159.0	982.5	....	....
14	15	25	60	181	1.53	2.72	.1830	.1920	11.0	36.0	100.5	302.0	1,442.5	1,330.0	2.41	4.09
15	10	18	37	113	1.38	1.63	.1370	.1460	Tr.	Tr.	34.0	121.0	668.0	1,239.0	....	....
16	22	28	116	264	1.12	2.03	.1720	.1781	10.0	21.0	180.5	372.5	931.5	770.5	.59	.04
17	18	27	93	314	1.17	2.11	.1890	.2080	.0	119.0	207.5	545.5	1,000.5	747.5	....	....
18	15	20	52	133	1.35	2.65	.1810	.1980	Tr.	169.0	194.5	471.0	1,315.5	1,438.0	.31	.59
19	14	18	61	130	1.61	2.59	.2300	.2310	Tr.	60.0	214.5	331.5	1,055.5	1,122.5	.98	1.01
20	18	27	78	163	1.21	2.16	.1660	.1820	.0	52.0	180.5	514.5	975.5	931.5	....	....
21	23	28	108	164	0.98	1.74	.2110	.2020	.0	43.0	181.5	348.5	1,296.5	1,162.5	2.13	1.33
22	18	25	61	162	1.26	2.01	.2150	.2210	Tr.	9.0	163.5	446.5	1,534.5	1,504.5	1.43	1.50
23	16	24	83	148	1.25	2.18	.1440	.1500	Tr.	42.0	176.5	466.0	1,599.5	1,184.0	2.76	2.97
24	18	24	35	108	1.30	1.98	.1470	.1580	.0	Tr.	91.5	381.5	1,012.5	1,212.5	.98	.25
25 (*a*)	10	18	61	84	1.55	3.24	.1560	.1650	.0	66.0	110.5	186.0	1,249.5	1,212.0	2.38	1.36

TABLE IV—CONCLUDED

Sample No.	Height of plants.		Dry weight of plant material.		Nitrogen in plant material.		Total nitrogen in soil.		NO_3 in soil when collected.		NO_3 formed in incubated soil. From soil's store of nitrogen.		NO_3 formed in incubated soil. From added cottonseed meal nitrogen.		Nitrogen fixed per plate.	
	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.
	Ins.	*Ins.*	*Gm.*	*Gm.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*Mg.*	*Mg.*
26	11	13	26	56	1.85	2.94	0.1550	0.1710	.0	84.0	180.5	633.0	1,119.5	751.0	....	....
27	12	22	17	123	1.57	1.68	.1010	.1130	.0	.0	87.0	190.0	1,117.0	1,234.0	1.99	.94
28	22	24	88	138	1.16	2.34	.1390	.1520	.0	56.0	154.0	1,086.0	1,142.0	1,090.0	....	....
29	14	21	54	137	1.63	1.96	.1470	.1450	Tr.	Tr.	193.0	213.5	1,751.0	1,508.5	1.89	2.03
30	15	17	31	58	1.72	2.37	.1270	.1460	.0	116.0	183.5	846.5	1,184.5	773.5	....	....
31	17	30	52	226	1.03	1.66	.1600	.1730	Tr.	Tr.	193.5	247.0	1,316.5	1,445.0	.63	.91
32	20	27	87	175	1.34	2.22	.1710	.1950	Tr.	104.0	221.0	875.0	1,203.0	535.0	....	....
33	20	24	75	152	1.04	1.90	.1050	.1290	Tr.	85.0	136.0	283.0	1,070.0	153.5	2.69	.21
34	17	35	48	193	1.27	1.48	.1540	.1680	Tr.	Tr.	156.0	251.0	1,114.0	1,041.0	....	....
35	17	27	43	203	1.33	1.43	.1370	.1270	Tr.	Tr.	197.5	146.5	1,366.5	1,175.5	2.73	1.78
36	37	42	79	229	.83	1.43	.1440	.1500	.0	22.0	188.5	177.0	991.5	1,071.0	....	....
37	30	36	79	275	.79	1.14	.1570	.1660	Tr.	29.0	80.0	320.0	1,122.0	1,527.0	3.57	3.70
38	28	32	66	201	1.21	1.33	.1400	.1590	.0	.0	128.0	234.0	914.0	1,194.0	....	....
39 (*a*)	10	18	42	69	1.51	2.60	.1400	.1460	.0	54.0	141.0	309.0	1,455.0	997.0	2.04	.76
40	24	30	69	204	1.20	1.79	.1320	.1580	.0	231.0	151.0	889.0	1,185.0	896.0	1.33	2.61
41	18	22	22	80	1.39	1.91	.1360	.1510	.0	18.0	138.0	738.0	742.0	906.0	....	....
42 (*a*)	8	20	27	122	1.51	2.20	.1030	.1010	.0	Tr.	139.5	218.5	1,240.5	1,047.5	....	....
43 (*a*)	8	22	25	102	1.42	1.98	.0550	.0610	.0	Tr.	134.0	85.0	1,446.0	907.0	2.74	3.08
44	36	42	76	209	.79	1.30	.1240	.1360	.0	79.0	101.5	254.5	1,068.5	572.5	....	....
Mean,	16.0+	23.4+	50.8—	138	1.41	2.18	0.1428	0.1528	2.6	51.8—	142.2	399.2	1,156.9	1,015.1	1.93	1.62

(*a*) Oats.

the accumulation in the former was 142.1 p.p.m. and in the latter 399.2 p. p. m., or the G soil accumulated NO_3 2.81 times as rapidly as the P soil during a limited incubation period, and the accumulation in the G soil exceeded that in the P soil in 41 of the 44 comparisons. On the other hand, when organic nitrogen (cottonseed meal) was added it was found that the transformation of this added nitrogen into NO_3 took place just as rapidly in the P as in the G soil, the average accumulation from added nitrogen being in the P soil 1,156.9 p.p.m. and in the G soil 1,015.1. In only 13 of the 44 comparisons did the accumulation of nitrate nitrogen from added nitrogen in the G soil exceed that in the P soil.

The average nitrogen content of the P soil was found to be 0.1428 percent and that of the G soil 0.1528 percent, the latter exceeding the former in 38 of the 44 comparisons.

Only 25 of the 44 samples examined during 1932 gave any Azotobacter development. The average nitrogen fixed per plate by G soils was 1.62 mg. and by the P soils 1.93 mg. These samples were incubated only three or four days, compared with two weeks for the 1931 series, hence, the lower quantity of nitrogen fixed. As was expected, however, the differences in the quantities of nitrogen fixed, where differences appeared in the density of the Azotobacter flora, were more marked with the shorter incubation period. Again, where differences appeared in the density of the Azotobacter population the higher values were more frequently found in the P soil than in the G soil.

TABLE V.—WEIGHT AND NITROGEN CONTENT OF PLANT MATERIAL COLLECTED FROM P AND G AREAS, 1934

SAMPLE No.	Weight of plant material (gm.).		Nitrogen in plant material (percentage).		Weight of nitrogen in plant material (gm.).		Relative weight of nitrogen in plant material P = 100.
	P area.	G area.	P area.	G area.	P area.	G area.	
1	71.4	132.7	1.08	1.31	0.193	0.435	225
2	64.0	124.6	1.24	1.85	.199	.576	289
3	57.6	138.5	1.29	1.15	.186	.388	209
4	56.8	90.3	1.13	1.12	.161	.253	157
5	40.8	82.2	1.18	1.71	.121	.351	290
6	71.4	156.0	1.13	1.50	.202	.585	290
7	78.3	138.8	1.20	1.59	.235	.552	235
Mean	62.9	123.3	1.18	1.46	....	....	....

Data from the 1934 Studies.—No material was collected from P and G areas in 1933. In the early summer of 1934 a limited number of collections were made of plant material from P and G areas in the same field (Table V), primarily for the purpose of determining the uniformity in the composition of material collected under more or less similar conditions and also for comparison with material collected from experimentally-produced spots.

The average weight of plant material from the P area was 62.9 grams and from the G area 123.3 grams. The nitrogen content of the P material varied from 1.08 percent to 1.29 percent, averaging 1.18 percent, while the corresponding values for the G material were 1.12 percent to 1.85 percent, with an average of 1.46 percent. The quantity of nitrogen removed per unit area from the G soil by the growing plants was 2.42 times as much as from the P soils.

DISCUSSION OF DATA SECURED FROM A STUDY OF MATERIAL COLLECTED FROM NATURALLY OCCURRING SPOTS

A number of very interesting and significant facts are evident from a study of the data collected in connection with this phase of the investigation. The relative average height of the plants collected from 158 spots was 204, 147, 174, and 141, compared with 100 for the surrounding plants, for the four years, 1929 to 1932. The G plants were taller in 157 of the 158 comparisons. A similar comparison of the dry weight of material collected gave 267, 283, 291, and 271 for the corresponding years. The weight of the G material exceeded that of the P material in 156 of the 157 comparisons. These differences, while striking, might not be regarded as so surprising in view of the fact that the location of the spots was dependent upon visible differences, primarily in height, and hence the more marked such differences, the greater were the chances of a spot's being studied.

Of very much more significance is the consistently marked difference in the nitrogen content of the plant material collected from the spots as compared with that of the surrounding areas. Assigning the P material an arbitrary value of 100, the relative percentages of nitrogen in the G material averaged 184, 156, 165, and 155 for the four years. The percentage of nitrogen in the G material was higher than that in the P material in 156 of the 157 comparisons. In only 12 of the 157 samples of P material did the percentage of nitrogen exceed the arbitrarily chosen value of 1.9 percent, while in only 27 instances did it fall below this value in the G material. Especially unexpected are these values if it is recalled that the dry weight of the plant material collected from the spots averaged 2.67, 2.83, 2.91, and 2.71 times that collected from an equal area immediately adjacent. Calculating the relative quantities of nitrogen contained in the plant material collected from the two areas it was found that the G plants had actually removed an average of 4.9, 4.41, 4.8, and 4.2 times as much nitrogen per unit area of soil for the four years under study as had the P plants.

An extremely interesting point in question is that of a satisfactory explanation for this remarkable difference in the quantities of nitrogen absorbed by groups of plants growing in such close proximity and under apparently identical conditions. Remarkable differences have been recorded in the nitrogen content of the grain of individual plants grown adjacent and with their roots unquestionably intermingling, but such differences have been ascribed to inherent physiological differences in the individual seeds. It is inconceivable, however, that the observed peculiar distribution of plants, arising from seed of the same inherent characteristics, could be obtained in random seeding. It was hoped that the soil and bacteriological studies conducted in connection with the plant studies would throw some light upon this interesting question and such hopes have not been altogether ill-founded.

Contrary to what might have been expected in view of the removal from the soil of much greater quantities of nitrogen by G plants, it was found that the nitrate content of the G soil was consistently higher than that of the P soil. In 144 of the 165 comparisons the nitrate content of the G soil exceeded that of the P soil, while the reverse was true in only nine instances. In 11 of the remaining 12 comparisons both the P and G plants had reduced the nitrate content to such a low level that quantitative measurements were impossible by the methods employed. In an additional 24 instances the plants had reduced the nitrate content of the P soil to a trace, indicating an inadequate supply of available nitrogen in such soils.

Assigning an arbitrary value of 100 for the average nitrate content of the P soils, the relative values for the G soils were 259, 347, 732, and 1,992 for the four years. The very high value for 1932 resulted from the large number of P soils containing an immeasurable quantity of nitrates. It is evident, therefore, that even though four to five times as much nitrogen had been removed by the plants growing on the spots as those growing on the adjoining areas, the soil of the spots still contained on the average much more available nitrogen than did the surrounding soil.

When the relative abilities of the P and G soils to transform their stores of nitrogen into nitrate nitrogen were measured in the laboratory, an apparent explanation for the differences in the available nitrogen supplied the plants was forthcoming. In 113 of 124 comparisons the G soil was found capable of accumulating nitrate nitrogen more rapidly than was the P soil; the average relative values for 1929, 1931, and 1932 being 339, 396, and 281. This increased ability to accumulate nitrates on the part of the G soils might be due, as suggested by Lipman,[6] to a more active nitrifying flora. If this were true it was believed it should be evident in the more rapid transformation into nitrate nitrogen of added organic nitrogen. Experiments of this kind were conducted on the soils collected during 1931 and 1932. One gram of cottonseed meal (70 mg. N) was added to 100 grams soil and the moisture content made up to optimum, after which the soil was incubated at room temperature. The nitrate accumulating from the soil's store of nitrogen was deducted from that accumulating where the organic nitrogen was added and the net nitrate thus found regarded as having been formed from the

6. Lipman, C. B. *Loc. cit.*

added nitrogen. The average values thus obtained in 1931 were 1,040.9 and 1,004.5 p. p. m. NO_3 respectively, for the P and G samples, and the corresponding values for 1932 were 1,156.9 and 1,015.1 p. p. m. NO_3. Furthermore, in 1931 only 20 of the 42 comparisons, and in 1932 only 13 of the 44 comparisons showed the accumulation of NO, in the G soil to exceed that in the corresponding P soil. These values certainly give no indications of the presence of a more active nitrifying flora in the soil from the spots than from the surrounding soil.

As an additional possible explanation of the origin of the different quantities of nitrates, quantitative measurements of the total nitrogen content of the soils were made. It was found that the G soils contained, on the average, 11.2, 7.7, 7.5, and 7 percent more nitrogen than did the P soils for the corresponding years. Not only were the average percentages of nitrogen higher for the G samples, but the differences were fairly consistent in that the nitrogen content of the G sample exceeded that of the P sample in 142 of the 165 comparisons, or in 86 percent of the cases. This difference in the total nitrogen content is, no doubt, adequate to explain the observed differences in the accumulation of nitrates in the P and G soils if at the same time it be postulated that this small quantity of nitrogen is in such a condition that it can be transformed more readily into nitrate nitrogen than is the major portion of the soil's store of nitrogen.

In an effort to determine whether the higher nitrate accumulation in the G soils was associated with this small difference in total nitrogen content, the data for 1929, 1931, and 1932 have been so arranged in Table VI as to show in parallel columns the actual observed differences both in the total nitrogen content and in the NO_3 accumulation in the P and G samples. It is evident from a casual observation of these data that the two are more or less associated but that there are many marked exceptions. The correlation coefficients calculated from these values were found to be: For 1929, 0.527 ± 0.079; for 1931, 0.843 ± 0.030; and for 1932, 0.605 ± 0.065. Undoubtedly, the greater accumulation of nitrates in the G soils is correlated with the higher total nitrogen content. However, a more detailed study of certain of these data leads to the conclusion that the quantitative differences in the nitrogen content cannot alone account for the observed differences in nitrate accumulation, as the following facts will prove.

The P soils contained on the average 0.1393 percent or 1,393 p. p. m. nitrogen and transformed, on the average, 26 p. p. m. or 1.87 percent of this nitrogen into nitrate nitrogen (115.1 p. p.m. NO_3). The G soil contained, on the average, only 0.0116 percent or 116 p. p. m. more nitrogen than did the P soil. However, the presence of this 116 p. p. m. nitrogen resulted in the accumulation of 59.2 p. p. m. more nitrate nitrogen (262.3 p. p. m. NO_3). In other words, 59.2 p. p. m., or slightly more than 51 percent of this extra 116 p. p. m. total nitrogen, was transformed into nitrate nitrogen. It must be

TABLE VI.—RELATIONSHIP BETWEEN EXCESS NITROGEN AND EXCESS NO_3 ACCUMULATION IN SOIL FROM SPOTS (DATA FROM TABLES I, III, AND IV), COMPARISONS BEING ARRANGED IN ORDER OF MAGNITUDE OF EXCESS NITROGEN.

1929 (a).			1931 (a).			1932 (a).		
Sample No.	Excess N in G soil (b).	Excess NO_3 accumulation in G soil.	Sample No.	Excess N in G soil (b).	Excess NO_3 accumulation in G soil.	Sample No.	Excess N in G soil (b).	Excess NO_3 accumulation in G soil.
	Lbs. per acre.	*P. p. m.*		*Lbs. per acre.*	*P. p. m.*		*Lbs. per acre.*	*P. p. m.*
1	1,340	170	20	654	926	40	520	738
29	760	1,199	32	608	524	32	480	654
10	710	328	5	516	664	33	480	147
31	710	848	37	486	611	9	440	549
19	650	385	31	474	540	10	400	460
7	590	373	18	420	261	30	380	663
34	590	1,432	39	382	325	17	380	338
35	550	975	16	376	537	38	380	106
33	530	231	19	370	180	7	364	411
11	490	888	2	368	78	3	360	562
14	430	647	22	368	224	18	340	277
27	400	160	7	348	328	26	320	453
26	350	681	33	292	421	20	320	129
32	350	1,058	8	284	17	41	300	600
18	340	537	10	284	371	34	280	95
24	270	635	25	264	157	28	260	931
15	230	172	27	264	100	11	260	362
38	230	262	9	224	183	31	260	55
37	220	248	13	216	191	8	240	373
9	210	123	4	206	140	44	240	153
28	180	—49	17	158	140	27	240	103
30	180	313	28	158	201	4	220	613
25	150	—59	29	146	64	24	220	290
16	140	186	11	142	—13	5	200	71
4	100	42	12	134	125	37	180	240
36	100	—279	34	128	95	14	180	202
20	100	—6	23	120	169	15	180	87
3	90	97	35	106	273	25	180	66
13	80	22	42	104	11	16	122	192
12	60	—51	21	98	6	39	120	168
17	60	80	14	82	30	23	120	290
2	40	139	40	82	114	36	120	—12
8	40	51	6	60	63	43	120	—49
5	20	27	26	60	—3	13	100	8
21	—20	43	43	50	35	22	80	283
22	—50	376	36	38	51	2	52	22
6	—80	8	3	38	63	1	26	37
23	—130	171	15	30	32	19	20	155
			24	22	57	6	—20	50
			41	8	72	42	—40	79
			1	—30	30	29	—60	21
			30	—38	—8	21	—180	167
						35	—200	—51
						12	—260	51

(a) Correlation coefficients: 1929, 0.52±0.079; 1931, 0.843±0.03; 1932, 0.605±0.065.
(b) 2,000,000 pounds of soil.

assumed then that the average additional 232 pounds nitrogen per acre (2,000,000 pounds of soil) in the G soil was being transformed into nitrate nitrogen more than 27 times as rapidly as was the 2,786 pounds present in the P soil, if the observed differences in nitrate accumulation are to be accounted for on this basis.

Again, the fact that the large number of instances in which G soils with very low nitrogen contents accumulated large quantities of nitrates while P soils with high total nitrogen contents accumulated relatively small quantities of nitrates is rather convincing evidence that the quantity of nitrogen was not the sole factor influencing the accumulation of nitrates. One or two concrete illustrations will suffice to emphasize this point.

In the 1931 series, sample 34 contained the lowest percentage of nitrogen of any G samples, followed by sample 32, both containing less than any P sample except their corresponding numbers. Yet the accumulation of NO_3 in sample 34 G was exceeded by only one P sample and that in 32 G was more than three and one half times as great as in any P sample, even though many P samples contained twice as much total nitrogen as did 32 G and four times as much as did 34 G. Another striking illustration of the same point is provided in the summary of averages of NO_3 accumulation given in Table VII. The accumulation of NO_3 in the 10 G soils containing an average of only 0.0698 percent nitrogen was 146.3 p. p.m., whereas the accumulation in the 33 P samples containing more than twice as much nitrogen, that is, 0.1485 percent, was only 116.6 p. p. m. NO_3. Such facts as these are numerous and can lead to only one conclusion, that is, that the small quantities of extra nitrogen in the G soils must have been in such a form that it was capable of being more easily transformed into the nitrate condition than was the remainder of the soil's store of nitrogen.

TABLE VII.—EFFECT OF THE NITROGEN CONTENT OF SOILS UPON THEIR ABILITY TO ACCUMULATE NO_3 (*a*)

P soils.				G soils.			
Range in nitrogen content.	Av. N content.	Soils in group.	Av. NO_3 content.	Range in nitrogen content.	Av. N content.	Soils in group.	Av. NO_3 content.
Percent.	*Percent.*	*Number.*	*P. p. m.*	*Percent.*	*Percent.*	*Number.*	*P. p. m.*
Less than 0.10.....	0.0656	11	71.8	Less than 0.10...	0.0698	10	146.3
.10 to .12........	.1092	18	101.3	.10 to .12.....	.1097	11	225.7
.12 to .14........	.1305	32	110.5	.12 to .14......	.1328	21	322.6
.14 to .16........	.1485	33	116.6	.14 to .16......	.1505	34	373.8
.16 to .18........	.1675	15	134.4	.16 to .18......	.1689	23	453.6
.18 to .20........	.1851	10	149.9	.18 to .20......	.1896	17	500.4
More than 20...	.2157	5	176.7	More than .20.	.2164	9	533.2
Mean.........	0.1393	....	115.1	Mean.......	0.1509	....	377.4

(*a*) For a detailed analysis of this factor see: Gainey, P. L. Total nitrogen as a factor influencing nitrate accumulation in soils. Soil Science, 42:157-168, 1936.

A further analysis of the data presented in Table VII produces evidence of the influence of both the quantity and form of the excess nitrogen found in the G sample of soil upon the ability of the soil to furnish growing plants with available nitrogen, that is, nitrate nitrogen. If the G samples collected each year are arbitrarily divided into two groups, depending upon whether the excess nitrogen is more or less than 200 pounds, and the average excess nitrogen in the two groups is compared with the average excess accumulation of nitrate the values thus obtained indicate, very strikingly, the influence of the total excess nitrogen upon nitrate accumulation. Such a division will result in separating the samples into two approximately equal groups for each year. If the group in which the excess nitrogen equals 200 pounds or more is designated as the "high group" and the other as the "low group" and the average excess nitrogen content and nitrate formation are compared some interesting values are obtained.

	1929	1931	1932
Average excess nitrogen in G soils, "low group" (pounds),	58.8	76.6	42.0
Average excess nitrate accumulation in G soils, "low group" (p. p. m.)	62.0	74.0	99.0
Average excess nitrogen in G soils, "high group" (pounds),	497.5	370.2	328.5
Average excess nitrate accumulation in G soils, "high group" (p. p. m.)	568.0	339.0	394.0

On the other hand, there are recorded in these data 12 instances in which the total nitrogen content of the P soil exceeds that of the G soil, yet in only two of these did the accumulation of nitrate in the P soil exceed that in the G soil. Evidently, in some instances the G soil was capable of accumulating nitrate more rapidly than the P soil, even though it actually contained less total nitrogen, indicating very strongly that some of the nitrogen in the G soils must have been in a more easily nitrifiable form.

A general summary of the data obtained from a study of the soil and growing plant material collected from P and G areas is given in Table VIII. The data recorded in the bottom line of this table show very strikingly the uniformly higher values obtained from the G samples in height of plants, dry weight of plant material, percentage nitrogen in plant material, percentage nitrogen in soil, nitrate content of soil when collected, and nitrate formed from the soil's store of nitrogen. The G sample exceeded the P sample in from 86 to 99 percent of all such comparisons. On the other hand, less than half of the G samples exceeded the P samples in ability to form nitrate from added organic nitrogen or in nitrogen-fixing ability.

TABLE VIII.—SUMMARY OF DATA OBTAINED FROM A STUDY OF PLANT MATERIAL AND SOIL FROM P AND G AREAS

	Average height of plant (ins.).		Average weight of plant material (gm.).		Av. N in plant material (pct.).		Average total N in soil (pct.).		Av. NO_3 in soil when collected (p. p. m.).		Av. NO_3 formed from soil N (p. p. m.).		Av. NO_3 formed from added cottonseed meal nitrogen (p. p. m.).		Av. N fixed per plate (mg.).	
	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.	P area.	G area.
1929 (*a*)................	8.4	17.1	0.87	2.32	1.43	2.63	0.1289	0.1434	20.2	52.4	137.4	465.3	....	....	......	......
1930 (*b*)................	16.0	23.5	46.82	132.60	1.57	2.46	.1379	.1485	11.3	39.2	....	....	....	....	......	......
1931 (*b*)................	11.9	20.7	39.50	114.90	1.55	2.56	.1447	.1555	6.5	47.6	69.7	275.8	1,040.9	1,004.5	2.28	2.18
1932 (*b*)................	16.0	23.4	50.80	138.00	1.41	2.17	.1428	.1528	2.6	51.8	142.1	399.2	1,156.9	1,015.1	1.93	1.60
Number of comparisons..	158		157		157		165		(*c*) 165		124		86		52	
Pairs, G > P...........	157		156		156		142		144		113		33		24	
Pairs, G > P, percentage.	99+		99+		99+		86		94		91		38		46	

(*a*) Weight of plant material based upon the individual plant.
(*b*) Weight of plant material from 2 square feet.
(*c*) Among the 1932 samples there were 11 in which there was an immeasurable quantity of NO_3 in both the P and G samples. These are not included in calculating the percentage of samples in which G > P.

SUMMARY

The, data accumulated from this phase of the investigation and presented in Tables I to VIII, definitely substantiate the following summary: (1) The total growth of wheat supported by the G (spot) soil, far exceeds that supported by the P (immediately surrounding) soil. (2) The percentage nitrogen contained in plant material collected from G soils exceeds that in material collected from P soil. (3) The total quantity of nitrogen removed from the soil by the plants growing upon the G soils far exceeded that removed by plants growing upon an equal area of P soils. (4) The G soils contained a slightly higher quantity of nitrogen than did the P soils. (5) The G soils contained much larger quantities of nitrate nitrogen than did the P soils, unless the plants growing thereon had reduced the quantities practically to zero in both instances. (6) The G soils were capable of transforming a much larger proportion of their store of nitrogen into nitrate nitrogen within a limited period of time than were the P soils. (7) This ability to accumulate nitrate nitrogen from their store of nitrogen was independent of the microbial flora, for when organic nitrogen was added to both soils the P soils were capable of transforming the added nitrogen into nitrate nitrogen just as rapidly as were the G soils.

The facts to which attention is called in the preceding paragraph indicate very pointedly that available nitrogen is associated with and probably is responsible for the development of the type of spots under study. Apparently limited quantities of nitrogen, capable of being readily transformed into nitrate nitrogen, find the way into the isolated areas and subsequently undergo such transformation.

STUDIES CONDUCTED UPON MATURE WHEAT COLLECTED FROM NATURALLY OCCURRING SPOTS

METHODS AND RESULTS

The indications that nitrogen may play a possible role in the production of spots of the type under study, coupled with the widespread opinion among wheat growers of Kansas that a surplus of available nitrogen results in overactive vegetative growth followed by lodging and poor yields, suggested the desirability of observing wheat in such spots until maturity.

Collection and Analysis of Material.—Because of the wide distribution of fields from which the collection of soil and immature plant material were made and the very short time in which samples of mature grain could be collected, it was impossible to obtain yield data from the same fields studied in the previous section. Therefore, comparisons of yield have been confined to Riley and adjoining counties. Because of the somewhat taller and more stocky plants produced on them the spots can usually be detected at maturity. Such spots are especially easy to detect in fields of Blackhull wheat, widely grown in this section, since there is a much more marked development of the characteristic dark pigment evident in the heads of this variety.

TABLE IX.—YIELD OF GRAIN FROM P AND G AREAS, 1929

SAMPLE NO.	Yield of grain (gm.) (4 sq. ft.).		Relative yield of grain from G, P = 100.	SAMPLE NO.	Yield of grain (gm.) (4 sq. ft.).		Relative yield of grain from G, P = 100.
	P area.	G area.			P area.	G area.	
1............	48	97	202	14..............	18	78	433
2............	36	118	328	15(*a*)...........	17	146	859
3............	42	109	260	16..............	47	122	260
4............	56	138	246	17..............	50	108	216
5............	28	165	589	18..............	50	144	288
6............	31	147	474	19..............	51	108	212
7............	50	139	278	20..............	67	168	251
8............	43	96	223	21..............	50	111	222
9............	51	115	225	22(*a*)...........	52	222	427
10............	37	145	392	Mean (*b*).........	44.10	127.5	289
11............	56	110	196	Protein content (*b*)	10.89	1,237.0	....
12............	46	124	270				
13............	44	96	218				

(*a*) Oats.
(*b*) Oat samples not included.

Data for 1929.—For the season of 1929, samples of ripe grain were collected from spots and immediately adjacent in 20 wheat fields and two oat fields. Data secured from a study of these samples are recorded in Table IX.

The average yield of grain from the P areas was 44.13 grams and from the G areas 127.54 grams, the latter value being 2.89 times the former. The analysis of a composite of the P and of the G grain samples gave 1.91 and 2.17 percent nitrogen, respectively. The relative yields of grain and protein from the spots were therefore 289 and 329, respectively, compared with 100 for the fields at large. Translated into bushels per acre the average yield of the P areas was 17.6 and that of the G areas 53.

Data for 1931.—In 1931, samples of mature grain were harvested from P and G areas in 27 fields. The weight of grain, percentage protein, excess protein in G over P, and relative yields of grain and protein are recorded in Table X. The essential points to be noted in connection with these data are that the weight of grain per unit area was 2.12 times as much from the spot as from the adjacent area; that the G grain contained an average of 3.01 percent more protein than the P grain, representing a percentage excess of 29.19;

TABLE X.—YEILD AND PROTEIN CONTENT OF GRAIN FROM P AND G AREAS, 1931, 1932, 1933, AND 1934

SAMPLE No.	Weight of grain (gm.) (4 sq. ft.).		Protein in grain (percentage).				Relative yield of G.	
	P area.	G area.	P area.	G area.	Difference in favor of G area.	Increase in G area.	Grain, P = 100.	Protein, P = 100.
1931								
1.......	33	123	....	....	....	....	371	....
2.......	108	228	10.55	11.46	0.91	8.6	211	229
3.......	67	212	9.52	12.48	2.96	31.1	316	414
4.......	93	143	10.55	12.48	1.93	18.3	154	182
5.......	53	150	9.29	12.65	3.36	36.2	283	385
6.......	43	102	10.60	13.79	3.19	30.1	237	308
7.......	25	84	12.08	13.45	1.37	11.3	336	374
8.......	57	127	9.86	12.08	2.22	22.5	223	273
9.......	89	169	10.15	13.62	3.47	34.2	190	255
10.......	96	148	10.03	14.42	4.39	43.8	153	220
11.......	61	182	9.86	13.00	3.14	31.9	298	393
12.......	40	132	7.40	13.11	5.71	77.2	330	585
13.......	82	117	9.58	12.83	3.25	33.9	130	174
14.......	87	119	8.15	9.80	1.65	20.3	137	165
15.......	64	112	7.13	13.96	6.83	95.8	175	343
16.......	50	114	10.66	11.46	.80	7.5	228	245
17.......	26	63	10.66	14.25	3.59	33.7	242	324
18.......	65	119	9.69	14.02	4.33	44.7	183	265
19.......	82	166	9.12	15.05	5.93	65.0	202	333
20.......	80	162	10.54	10.20	—.34	—3.2	203	197
21.......	43	113	10.83	13.11	2.28	21.1	263	318
22.......	53	132	10.94	11.40	.46	4.2	249	259
23.......	59	101	10.03	14.02	3.99	39.8	171	239
24.......	52	110	11.06	13.51	2.45	22.2	211	258
25.......	65	95	12.77	20.98	8.21	64.3	146	240
26.......	52	104	12.08	14.54	2.46	20.4	200	240
27.......	47	109	14.93	14.76	—.17	—1.1	232	229
Mean....	61.9	131.1	10.31	13.32	3.01	31.3	225	286.4
1932								
1.......	47	155	11.90	14.15	2.25	18.9	330	393
2.......	34	155	10.27	14.90	4.66	45.4	456	663
3.......	35	145	12.89	12.60	—.29	—2.3	403	394
4.......	49	159	10.82	10.04	—.78	—7.2	324	301
5.......	44	99	11.93	10.89	—1.04	—8.7	225	205
6.......	83	197	10.19	11.75	1.56	15.3	237	273
7.......	28	85	13.53	14.12	.59	4.4	304	317
8.......	61	172	10.74	13.56	2.82	26.3	282	356
9.......	65	167	9.67	10.82	1.15	11.9	257	288
10.......	50	113	11.38	12.86	1.48	13.0	226	255
11.......	53	149	10.12	14.79	4.67	46.1	281	411
12.......	60	132	12.49	15.56	3.07	24.6	220	274
13.......	70	107	11.01	14.34	3.33	30.2	153	199
14.......	40	124	10.93	16.15	5.22	47.7	310	458
15.......	68	123	12.19	11.93	—.26	—2.1	181	177
16.......	47	100	12.49	16.60	4.11	32.9	213	283
17.......	52	112	10.60	14.93	4.30	40.6	215	303
18.......	121	200	9.86	12.12	2.26	22.9	165	203
19.......	64	202	10.89	14.82	3.93	36.1	316	430
20.......	84	195	10.71	16.60	5.89	55.0	232	360
21.......	67	185	12.27	13.45	1.18	9.6	276	303
22.......	66	187	10.60	13.90	3.30	31.1	283	371
23.......	55	172	10.78	12.63	1.85	17.2	313	367
24.......	64	122	10.67	11.04	.37	3.5	191	198
25.......	35	113	12.30	13.45	1.15	9.3	323	353

TABLE X—CONCLUDED

SAMPLE No.	Weight of grain (gm.) (4 sq. ft.)		Protein in grain (percentage).				Relative yield of G.	
	P area.	G area.	P area.	G area.	Difference in favor of G area.	Increase in G area.	Grain, P = 100.	Protein, P = 100.
1932								
26.......	17	102	12.34	17.04	4.70	38.1	600	829
27.......	35	115	11.34	12.13	.79	7.0	329	352
28.......	51	87	11.60	12.52	.92	7.9	171	185
29.......	79	198	10.45	11.78	1.33	12.7	251	283
30.......	60	124	10.86	13.26	2.40	22.1	207	253
Mean....	56.1	143.1	11.29	13.49	2.20	20.3	275.8	334
1933								
1.......	90	147	10.30	13.17	2.87	27.9	163	208
2.......	65	127	10.58	13.95	3.37	31.9	195	257
3.......	43	125	10.43	14.22	3.79	36.3	291	387
4.......	62	154	11.00	13.22	2.22	20.2	248	298
5.......	77	187	10.02	14.10	4.08	47.2	243	342
6.......	61	105	9.98	14.97	4.99	50.0	172	258
7.......	80	131	11.01	13.58	2.57	25.3	164	202
8.......	45	72	12.19	17.67	5.48	45.0	160	232
9.......	42	72	11.58	16.88	5.30	45.8	171	250
10.......	51	71	13.05	18.61	5.56	42.6	139	198
11.......	47	105	12.76	13.38	.62	4.9	223	234
12.......	43	69	13.26	15.88	2.62	19.8	160	192
13.......	60	124	11.28	16.32	5.04	44.7	207	299
14.......	52	60	12.43	15.76	3.33	26.8	115	190
15.......	54	135	12.77	13.31	.54	4.2	250	261
16.......	68	149	13.14	16.47	3.33	25.3	219	274
17.......	61	116	13.22	12.11	—1.11	—8.4	190	174
18.......	71	217	10.93	13.86	2.93	26.8	306	388
19.......	36	87	12.15	17.12	4.97	40.9	229	323
20.......	37	117	12.03	14.49	2.46	20.4	316	381
21.......	74	136	11.84	14.93	3.09	26.1	184	232
22.......	91	179	10.41	11.09	.68	6.5	197	210
23.......	60	98	11.13	16.53	5.40	48.5	163	242
24.......	52	84	13.34	14.85	1.51	11.3	162	180
25.......	52	117	10.93	13.38	2.45	22.4	225	276
26.......	41	165	12.19	14.41	2.22	18.2	402	471
27.......	53	124	11.52	16.68	5.16	44.8	234	399
28.......	46	102	11.72	13.30	1.58	13.5	222	252
29.......	65	189	11.64	14.02	2.38	20.4	291	351
30.......	45	126	12.59	14.37	1.78	14.1	280	320
31.......	22	107	13.62	14.73	1.11	8.1	486	526
Mean....	56.3	122.5	11.77	14.75	2.98	26.1	226	284
1934								
1.......	36	96	12.48	14.76	2.28	18.2	266	314
2.......	53	110	12.65	13.68	1.03	8.1	208	225
3.......	31	143	13.00	13.05	.05	.4	461	463
4.......	38	108	12.71	12.88	.17	1.3	284	288
5.......	37	131	13.22	13.68	.46	3.5	354	366
6.......	48	147	13.51	14.25	.74	5.5	313	325
7.......	35	111	13.11	14.54	1.43	10.9	317	351
8.......	68	93	11.91	16.53	4.62	38.8	137	190
9.......	62	129	11.00	14.65	3.65	33.2	208	277
10.......	65	101	11.69	14.08	2.39	20.4	155	187
11.......	76	111	10.83	15.11	4.28	39.5	146	204
12.......	77	139	11.40	15.56	4.16	36.5	181	247
Mean....	52.17	118.25	12.29	14.40	2.11	18.0	253	286

and that the average relative yields of grain and protein were 225 and 286, respectively, P being assigned a value of 100. In terms of bushels per acre the average yield of the P areas was 24.6 and that of the G areas 52.5.

Data for 1932.—Samples of mature wheat were collected from 30 P and G areas in 1932 and the data obtained from a study of these samples are presented in Table X. Again the grain produced on the spot averaged 2.55 times as much by weight as that produced on an equal area immediately adjacent to it. The G grain averaged 2.2 percent more protein, and the average relative yields of grain and protein were 276 and 334 compared with 100 for the P areas. The yields in bushels per acre were for the P areas 22.4 and for the G areas 57.3.

Data for 1933.—Grain was harvested from 31 P and G areas in 1933 and the data obtained from an examination of the samples are also presented in Table X. The grain harvested from the G areas averaged 2.26 times that from the corresponding P areas and contained 2.98 percent more protein, equivalent to a percentage increase of 25.5 in the protein; or the yield of protein was 2.84 times as great from an equal area of G soil as from the P soil. Calculated in terms of bushels per acre the average yield of the P areas was 22.6 and that of the G areas 49.

Data for 1934.—Only a few samples of grain from P and G areas were collected during the season of 1934. These were taken from fields where experimentally produced spots were under study and were collected primarily to compare with the yield and protein content of the artificially produced spots. The data are presented in Table X. The first four samples were collected in field G; the next three in field F; and the last five in field H, all being taken near the experimentally produced spots in the corresponding fields for 1934.

The average weight of grain from the G area was 2.53 times that from the P area and contained 2.11 percent more protein, representing an average yield of protein from the G areas of 2.86 times that of the P areas. A rather striking point in connection with these data is the much higher relative grain yield from the G areas in fields F and G as compared with field H and the much higher percentage of protein in the grain from G spots in the latter field. In fields F and G the increased available nitrogen went primarily to increase the quantity of grain, whereas in field H it was utilized in the production of an increased protein content. Similar conditions were noted for the grain from the experimentally produced spots in these fields. Compare the percentage protein in the grain of the sodium nitrate treated spots, Table XIX, with the corresponding values in Table XXI. This may possibly be accounted for in this particular case by the type of soil. Fields F and G were much more sandy in nature and did not suffer so much from the drought as did the grain in field H.

SUMMARY

The studies conducted upon mature wheat collected from spots and immediately adjacent thereto may be summarized as follows: (1) The yield of grain from the G areas far exceeded that from equal P areas in the fields and for the particular years during which comparisons were made. If available nitrogen is the factor responsible for the production of spots, certain of these years were not conducive to the maximum response, in that hot dry weather preceded and accompanied maturity. (2) The percentage protein in grain harvested from G soils is materially higher than that in grain harvested from the corresponding P soils. (3) The total yield of protein from G soils far exceeded that from an equal area of the P soils.

THE EXPERIMENTAL PRODUCTION OF SPOTS AND THE COLLECTION AND EXAMINATION OF GROWING AND MATURE PLANTS THEREFROM

It is quite evident that if the development of spots of the type under study is dependent upon an increased supply of any nutritive element, one should be able to produce them at will in soils in which this element is deficient, by supplying the element in question in an available form. On the other hand, if as suggested by Lipman,[7] their development is due to variations in the microbial flora, the more desirable flora acting either directly or indirectly upon the plants, one could not expect to regularly reproduce such conditions by the addition of a nonavailable plant food element. A third possibility exists in that the microbial flora of the spot soil and adjacent soil may be equally efficient, but more of a particular nonavailable plant-food element may find its way into localized areas of the soil and upon subsequently being changed into an available form results in the production of spots. If this condition exists, then it should be possible to reproduce the spots at will in a soil in which this element is deficient, by the addition of the element in question in either an available or nonavailable form.

Since the available evidence pointed to nitrogen as being the most probable nutritive element concerned in the production of spots, most of the experimental efforts to produce spots have been conducted with nitrogen.

METHODS

The general methods followed in carrying out this phase of the experimental work have been to apply as top dressing different forms of nitrogen, varying the quantity of nitrogen applied and also the time of application. The areas treated have been usually much larger than the naturally occurring spots, in most instances 200 square feet. Subsequent to the application of the nitrogen, records were kept of the general appearance of the treated areas, particularly

7. Lipmn, C. B. *Loc. cit.*

as to their variation from untreated areas and their resemblances to naturally occurring spots. In addition, soil, growing plants, and mature plants have been collected from the treated and immediately adjacent areas and analyzed as described for the corresponding material collected from naturally occurring spots. Considerable variation occurred in the treatments applied from year to year, and inasmuch as these variations may have materially influenced the results obtained it seems best to discuss the treatment somewhat more in detail as the results obtained for each year are presented.

The 1929-'30 Studies.—The field selected for study for the 1929-'30 season was known to be low in productivity, having been cultivated by disking only at seeding time for a period of about 20 years, Sixteen plots 10 by 20 feet in area were laid out in the order and treated as indicated in Table XI. The uniformity of the area of soil is indicated by the variation in the yield of the five uniformly

TABLE XI.—YIELD AND PROTEIN CONTENT OF GRAIN FROM EXPERIMENTALLY PRODUCED SPOTS, 1930

TREATMENT, (acre basis).	Yield of grain.		Protein (percentage).			Relative yield of—	
	Harvested area (gm.).	Bus. per acre.	In grain.	Difference in favor of treated areas.	Increase in treated areas.	Grain.	Protein.
Untreated	730	(a) 14.5	10.5	....	....	(b) 100	(b) 100
Urine, ⅛ in., August	1,030	20.5	12.1	1.2	11.0	203	225
Urea, 110 lbs., August	960	19.1	10.7	—.2	—1.8	189	186
Untreated	450	8.9	11.1	....	....	(b) 100	(b) 100
Cyanamid, 220 lbs., August	780	15.6	10.2	—.7	—6.4	154	144
Urine, ⅛ in., March	920	18.3	16.6	5.7	55.0	181	281
Untreated	480	9.5	11.2	....	....	(b) 100	(b) 100
Urea, 110 lbs., March	1,000	19.9	10.4	—.5	—4.6	197	188
Cyanamid, 220 lbs., March	970	19.3	9.8	—1.1	—10.1	191	172
Untreated	380	7.5	10.9	....	....	(b) 100	(b) 100
Urea, 55 lbs., August; 55 lbs., March	1,040	20.6	9.6	—1.3	—11.9	204	180
Cyanamid, 110 lbs., August; 110 lbs., March	930	18.5	9.8	—1.1	—10.1	183	165
Untreated	530	10.5	10.6	....	....	(b) 100	(b) 100
Superphosphate (20%), 300 lbs	530	10.5	10.6	—.3	—2.8	104	101
KC1, equivalent K in urine	560	11.1	10.4	—.5	—4.6	110	105
Urea at seeding, equivalent N in urine	1,290	25.6	13.9	3.0	27.5	253	323

(a) Plot adjacent to road and subject to drainage and blowing from road.
(b) Average of five untreated areas.

TABLE XII.—DATA OBTAINED FROM A STUDY OF GREEN PLANT MATERIAL COLLECTED FROM EXPERIMENTALLY PRODUCED SPOTS, 1930

TREATMENT (acre basis).	Height of plants. (ins.)	Weight of plants (gm.).	Nitrogen in plant material (percentage).	NO_3 in soil (p. p. m.).
Untreated	14	19.6	1.44	12.4
$Ca(CN)_2$, 220 lbs., March	20	34.1	1.52	9.5
$CO(NH_2)_2$, 110 lbs., March	20	40.5	1.56	28.7
Urine, ⅛ inch	19	33.9	2.27	57.8
Untreated	14	16.2	1.54	20.2

distributed, untreated plots. The application of urine was based upon the estimated deposit of urine that would be made by an average cow. The quantities of Cyanamid and urea applied represent approximately 50 pounds of nitrogen per acre. There was some lodging in the plot receiving the very heavy application of urea, the only instance in which lodging has been observed to follow the application of nitrogen in these experiments.

The data in Table XI indicate that the various applications of nitrogen increased the yield of grain from 54 to 153 percent and the yield of protein from 44 to 223 percent. In this particular series the applications of nitrogen, unless excessively heavy as in the case of urine and an equivalent quantity of nitrogen as urea, resulted in increasing the yield, but decreased the percentage of protein in the grain. The heavy applications increased both the yield and percentage protein.

The data presented in Table XII indicate that the quantity of plant material per unit area, the percentage of nitrogen in the plant material, and the quantity of nitrate nitrogen in the soil were increased in all cases, except the quantity of nitrate nitrogen where the nitrogen was applied as Cyanamid ($CaCN_2$), by the applications of nitrogen. Where urine was applied the increased growth, percentage nitrogen in plant material, and nitrogen in the soil were comparable to the corresponding values for the naturally-occurring spots.

The 1930-'31 Studies.—The 1930-'31 studies were conducted upon a soil identical in every respect with that employed the previous year except that its productivity had not been permitted to depreciate to the same extent.

It is evident from the data presented in Table XIII that available nitrogen was not the factor limiting wheat production upon this particular area, at least for this particular year. The growth and yield upon the single phosphorus-treated plot would indicate that available phosphorous might be a major limiting factor. However, the applications of all the forms of nitrogen tried resulted in marked increase in the protein content of the grain, varying from 7 to 37.6 percent, so that the yield of protein was appreciably increased in

TABLE XIII.—YIELD AND PROTEIN CONTENT OF GRAIN FROM EXPERIMENTALLY PRODUCED SPOTS, 1931

TREATMENT, (acre basis).	Yield of grain.		Protein (percentage).			Relative yield of—	
	Harvested area (gm.).	Bus. per acre.	In grain.	Difference in favor of treated areas.	Increase in treated areas.	Grain.	Protein.
Untreated	1,578	22.9	11.65	....	....	(b) 100	(b) 100
Urine, 1/8 inch, August	1,303	(a) 18.9	15.05	3.60	31.4	77	90
Urea, 110 lbs., August	1,710	24.9	14.55	3.10	27.1	101	128
Untreated	1,606	23.4	11.85	....	....	(b) 100	(b) 100
Cyanamid, 220 lbs., August	1,836	26.7	13.50	2.05	17.9	109	129
Urine, 1/8 inch, March	1,970	28.6	15.75	4.30	37.6	116	160
Untreated	1,819	26.4	11.35	....	....	(b) 100	(b) 100
Urea, 110 lbs., March	1,952	28.4	13.85	2.40	21.0	116	140
Cyanamid, 220 lbs., March	1,960	28.5	13.25	1.80	15.7	116	134
Untreated	1,691	24.6	11.85	....	....	(b) 100	(b) 100
Urea, 55 lbs., August; 55 lbs., March	1,510	22.0	14.25	2.80	24.5	90	112
Cyanamid, 110 lbs., August; 110 lbs., March	1,594	23.2	14.00	2.55	22.3	94	115
Untreated	1,756	25.5	10.55	....	....	(b) 100	(b) 100
"Ammo-Phos" (11-46-0), 110 lbs. at seeding	2,445	35.6	13.05	1.60	14.0	145	165
Cyanamid, 200 lbs. at seeding	1,830	26.6	12.05	.80	7.0	108	116
Cyanamid, 400 lbs. at seeding	1,852	26.9	14.50	3.05	26.6	110	139

(a) Several plots, this one in particular, were injured by foot-rot.
(b) Average of five untreated areas.

all except the August application of urine and this area was badly injured by foot-rot.

The data tend to show that if the soil naturally supplies a quantity of available nitrogen adequate to produce the maximum yield permitted by other factors, any further application of nitrogen, provided it is applied early enough, will be reflected in an increased protein content of the harvested crop.

The 1931-'32 Studies.—In the spring of 1932 an effort was made to experimentally induce the development of spots in wheat fields on five different farms in the vicinity of Manhattan. Naturally occurring spots had previously been observed in four of the fields, A, B, D, and E, while field C had been cropped recently to alfalfa and had given little or no evidence of nitrogen deficiency.

Field A was a level creek-bottom loam, apparently in good state of productivity, but the field in question had been cropped to wheat a number of years. Plots 10 by 20 feet in area were treated March

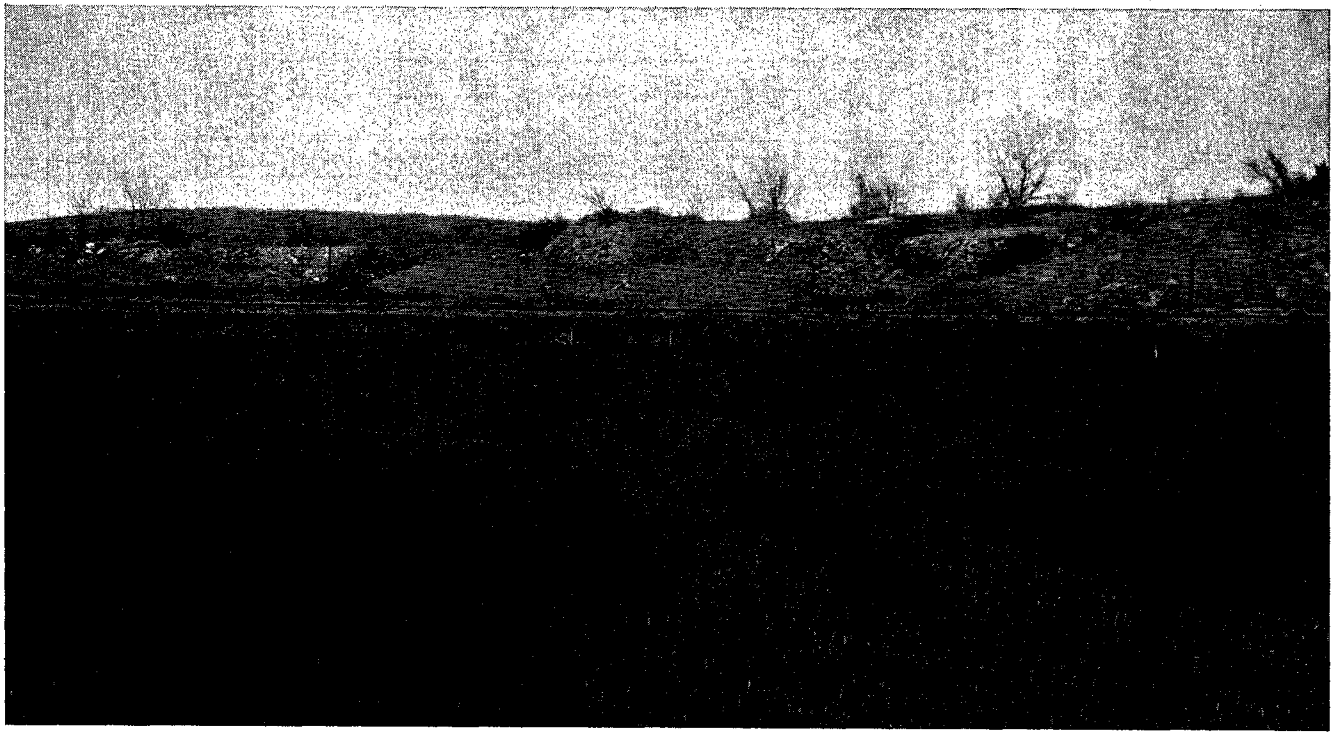

FIG. 3.—Experimentally produced spots in foreground; natural spots in background. (Five weeks after treatment.)

2 with surface applications as indicated in Table XIV, Field A. Figure 3 is a photograph taken of this field April 12. In the foreground is visible an area which received nitrogen in the form of urea at the rate of 50 pounds of nitrogen per acre distributed in rows so that there would be no danger of confusing the treated areas with naturally occurring spots, such as are visible in the background of this photograph and in figure 1. On the extreme right is visible one of the 10- by 20-foot areas treated broadcast with 25 pounds nitrogen in form of urea.

TABLE XIV.—YIELD AND PROTEIN CONTENT OF GRAIN FROM EXPERIMENTALLY PRODUCED SPOTS

TREATMENT, (acre basis).	Yield of grain. Harvested area (gm.).	Yield of grain. Bus. per acre.	Protein (percentage). In grain.	Protein (percentage). Difference in favor of treated areas.	Protein (percentage). Increase in treated areas.	Relative yield of— Grain.	Relative yield of— Protein.
FIELD A—1932							
Urea, 25 lbs. N	3,866	30.9	10.19	—0.26	—2.5	121	118
Urea, 50 lbs. N	4,825	38.7	10.23	—.22	—2.1	153	150
$NaNO_3$, 50 lbs. N	5,200	41.6	10.67	.22	2.1	163	166
$(NH_4)_2SO_4$, 50 lbs. N	4,936	39.5	10.30	—.15	—1.4	155	153
No treatment	3,195	25.6	10.45	....	....	100	100
"Ammo-Phos B," 50 lbs. N	5,003	40.0	10.15	—.30	—2.9	157	152
Superphosphate (a)	3,155	25.2	10.00	—.45	—4.3	99	95
$CaCN_2$, 50 lbs. N	4,335	34.7	9.92	—.53	—5.1	136	129
FIELD D—1932							
Urea, 25 lbs. N	1,500	24.0	11.23	—1.00	—8.2	186	171
Urea, 50 lbs. N	1,900	30.5	11.08	—1.15	—9.4	236	214
$NaNO_3$, 50 lbs. N	1,930	30.9	11.19	—1.04	—8.5	240	220
$(NH_4)_2SO_4$, 50 lbs. N	1,420	22.8	11.34	—.89	—7.3	176	163
No treatment	806	12.9	12.23	....	....	100	100
"Ammo-Phos B," 50 lbs. N	1,730	27.7	11.38	—.85	—7.0	215	200
Superphosphate (a)	937	15.0	12.15	—.08	—.7	116	115
$CaCN_2$, 50 lbs. N	1,600	25.7	11.41	—.82	—6.7	199	186
FIELD B—1932							
Urea, 25 lbs N	1,400	22.4	10.78	—.85	—7.3	127	118
Urea, 50 lbs. N	1,880	29.0	11.26	—.37	—3.2	165	160
$NaNO_3$, 50 lbs. N	1,868	29.8	12.37	.74	6.4	170	181
$(NH_4)_2SO_4$, 50 lbs. N	2,108	33.7	11.01	—.62	—5.3	192	182
No treatment	1,100	17.6	11.63	....	....	100	100
"Ammo-Phos B," 50 lbs. N	2,460	39.3	10.52	—1.11	—9.5	224	203
Superphosphate (a)	1,393	22.2	10.64	—.99	—8.5	127	116
$CaCN_2$, 50 lbs. N	2,054	32.8	11.82	.19	1.6	187	190
FIELD E—1932							
No treatment	622	10.0	11.34	....	....	(b) 100	(b) 100
Urea, 25 lbs. N	1,500	24.0	9.63	—1.73	—15.2	188	159
Urea, 50 lbs. N	2,005	32.0	9.63	—1.73	—15.2	251	213
$NaNO_3$, 50 lbs. N	2,200	35.2	10.60	—.76	—6.8	276	257
$(NH_4)_2SO_4$, 50 lbs. N	2,300	36.8	10.08	—1.28	—11.3	288	255
No treatment	1,073	17.2	11.12	....	....	(b) 100	(b) 100
"Ammo-Phos B," 50 lbs. N	2,045	32.7	10.86	—.50	—4.4	256	245
Superphosphate (a)	958	15.4	9.75	—1.61	—14.2	120	103
$CaCN_2$, 50 lbs. N	1,600	25.6	9.78	—1.58	—13.9	201	173
No treatment	700	11.2	11.63	....	....	(b) 100	(b) 100

(a) Phosphorus equivalent to one half that in the "Ammo-Phos B" treatment.
(b) Average of three untreated areas.

From the data presented in Table XIV it is evident that the soil of Field A was in a fair state of productivity, since the untreated area yielded at the rate of 25 bushels per acre. However, the application of 50 pounds of nitrogen per acre increased the yield of wheat slightly more than 50 percent. In this particular instance the nitrogen applied was used entirely in the production of increased quantities of grain, there being a slight decrease in percentage of protein in all nitrogen-treated areas.

The soil of Field D was a heavy river valley silt loam, apparently abundantly supplied with total nitrogen, but poorly drained. It was selected because naturally occurring spots have been observed very frequently on similar soils. The treatments were applied March 3 as recorded in Table XIV. This soil was unquestionably very deficient in available nitrogen, since the application of 50 pounds nitrogen per acre more than doubled the yield. An appreciable decrease, approximately 1 percent, in the protein content of the grain is recorded for all forms of nitrogen applied so that the response to nitrogen was wholly in increased yield.

The soil of Field C was a high river bottom loam in good state of tilth and productivity, having been cropped recently to alfalfa. At no time was any effect of the applications of nitrogen visible, and while still in the bloom stage the entire field lodged so badly that yield data possessed no significance, hence, are not recorded.

Field B was located on level river bottom land and the soil was a well-drained, fairly fertile light loam that had previously exhibited typical spotting. The treatments applied March 2, together with yield and protein data, are recorded in Table XIV. The average increase in yield from the application of 50 pounds nitrogen was slightly less than 90 percent and once more a decrease in the percentage protein in the grain was evident following all applications of nitrogen.

The treatments described in Table XIV, Field E, were located upon a very sandy river bottom soil, subject to erosion both by water and wind, and hence not very uniform, as indicated by the variation in yield from untreated plots. However, the enormous difference in yield between the untreated plots and those receiving nitrogen, that is, averaging 154 percent where 50 pounds nitrogen were added, could not possibly be attributed to variations in the soil. Again a marked decrease in percentage protein, varying from 4.4 to 15.2 percent is recorded for the grain from plots receiving applications of nitrogen. The percentage increase in yield of grain resulting from the application of 50 pounds nitrogen varied from 101 in the case of Cyanamid to 188 in the case of ammonium sulfate, and averaged 154; while the corresponding values for increase in yield of protein were from 73 for Cyanamid to 157 for sodium nitrate, and averaged 129. The application of only 25 pounds of nitrogen increased the yield of grain 88 percent and the yield of protein 59 percent. The average increase in yield of grain, expressed in bushels per acre, was 19.7.

TABLE XV.—YIELD AND PROTEIN CONTENT OF GRAIN FROM EXPERIMENTALLY PRODUCED PLOTS, 1933

Sodium nitrate (acre basis).	50 pounds.		150 pounds.		500 pounds (*a*).		500 pounds.		1,000 pounds.	
Date of treatment.	Yield, bus. per acre.	Protein, percentage.	Yield, bus. per acre.	Protein, percentage.	Yield, bus. per acre.	Protein, percentage.	Yield, bus. per acre.	Protein, percentage.	Yield, bus. per acre.	Protein, percentage.
No treatment......	11.05	12.19	....	....	10.61	12.19	8.87	12.43	9.16	13.03
October 28.........	9.03	12.71	11.37	11.97	14.00	12.67	12.35	15.17	8.39	18.78
November 28.......	10.19	12.31	7.51	12.83	13.47	15.92	14.51	15.96	13.02	18.93
March 3...........	14.53	12.63	16.98	13.14	12.65	16.03	11.32	17.19	7.77	19.88
No treatment......	7.61	13.70	8.93	12.24	9.34	12.51	8.31	13.54	7.64	(*b*) 18.85
March 17..........	11.06	12.75	12.63	13.38	11.17	16.55	12.44	16.35	6.53	19.01
March 31..........	9.72	14.06	9.14	15.48	6.13	19.01	8.06	18.02	3.37	20.36
April 13...........	9.39	13.14	9.07	15.64	5.24	18.77	5.54	18.69	4.44	19.92
No treatment......	8.47	13.07	9.02	12.91	8.01	13.14	....	....	7.17	13.74
April 28...........	6.96	14.41	7.14	15.52	7.85	17.35	8.07	16.47	8.68	17.31
May 12............	7.67	14.89	5.90	14.73	6.59	16.39	10.85	15.44	7.74	15.52
No treatment......	8.23	13.94	7.28	14.06	....	....	8.34	13.14	9.77	13.14

(*a*) Sodium nitrate applied as dry salt.

(*b*) There was evidence that nitrate applied to adjoining plots washed on to this plot but so late as to affect only protein content. The average yield of 17 untreated areas was 8.69 bushels per acre. The standard deviation for 17 untreated areas is 1.056 ± 0.712 bushels. The average percentage protein content of 17 untreated areas is 13.11. The standard deviation for protetn content of 17 untreated areas is 1.50 ± 1.01. If untreated plot (*b*) is left out of consideration in calculating the average protein content and standard deviation, the value becomes for the remaining 16 plots: Average protein content, 13.06 percent; standard deviation, 0.60 ± 0.40. These values probably represent more accurately the correct values than do those obtained from the 17 plots.

The 1932-'33 Studies.—The treatments carried out in an effort to induce the development of spots in 1932-'33 differed from those of previous years in that sodium nitrate was the only form of nitrogen employed and both the time and rate of application were varied. Two fields were selected for experimental purposes and treated as indicated in Table XV. One of the fields was grazed rather late, and the wheat growing upon the treated areas was so much more palatable than the surrounding wheat that many treated areas were completely ruined and the damage to others could not be estimated, hence, no records of yield were kept. This same preference on the part of both grazing cattle and herbivorous wild animals, mice and rabbits, was observed in many fields during these investigations, and because of the small size of treated and naturally occurring areas, caused appreciable damage. In no other instance, however, was damage severe enough to render the results worthless. In several instances the yields would have been relatively much more markedly in favor of both the experimentally produced and the naturally occurring spots if such damage had not occurred.

The data recorded in Table XV were secured upon a sand silt loam soil which had exhibited typical spotting for several years. The seasonal conditions were very unfavorable for the production of spots by the surface application of nitrogen in that the nitrogen applied remained in the dry surface soil in some instances for weeks before adequate moisture fell to convey it to the roots. Then, too, there was inadequate moisture to sustain late growth, resulting in the harvesting of more immature grain from the treated areas where the applied nitrogen delayed maturity than from the untreated area.

In spite of the unfavorable season the data presented in Table XV show marked response in certain areas to the application of nitrogen, both in the quantity of grain and in the protein content of the grain. As a basis for comparison it will be assumed that increases equal to or exceeding 3.2 times probable error of the untreated areas are significant. It will also be assumed that the grain from the "no treatment" plot marked *(b)* was abnormally high in protein, owing to the washing onto it of nitrogen from adjoining heavily treated plots, a condition that was observed to take place. With these assumptions any increase in yield of grain in excess of 25 percent, or in protein content in excess of 10 percent, can be attributed to the treatment.

A glance at the location of plots showing an increase in yield in excess of 25 percent, Table XVI, reveals a distribution that tends to substantiate the significance of such an increase, since a line can be drawn around all plots showing such increases that will include but one plot below this value (150 pounds treatment, November 28, relative grain yield 86). As might be expected, there are a number of instances in which a decided detrimental effect was recorded. These include the 1,000 pounds applications of March 17 and 31, and April 13, and the 500 pounds applications of April 13. This would indicate that there is possibly a certain period in the development

TABLE XVI.—RELATIVE YIELD AND RELATIVE PERCENTAGE PROTEIN CONTENT OF GRAIN FROM EXPERIMENTALLY PRODUCED SPOTS, 1933

Sodium nitrate (acre basis).	50 pounds.		150 pounds.		500 pounds (*a*).		500 pounds.		1,000 pounds.	
Date of treatment.	Yield.	Protein, percentage.	Yield.	Protein, percentage.	Yield.	Protein, percentage.	Yield.	Protein, percentage.	Yield.	Protein, percentage.
No treatment	100	100	....	....	100	100	100	100	100	100
October 18	104	97	**131**	91	**161**	97	**142**	116	95	143
November 28	117	94	86	98	**155**	121	**167**	122	**150**	144
March 3	**167**	96	**195**	100	**146**	122	**130**	131	**189**	152
No treatment	100	100	100	100	100	100	100	100	(*b*) 100	100
March 17	**127**	97	**144**	102	**129**	126	**143**	125	75	144
March 31	112	107	105	118	71	144	93	137	38	155
April 13	108	100	104	119	60	143	64	143	59	152
No treatment	100	100	100	100	100	100	....	....	100	100
April 28	80	110	82	118	90	132	93	126	100	132
May 12	88	114	68	112	76	125	125	118	89	118
No treatment	100	100	100	100	....	....	100	100	100	100

(*a*) Sodium nitrate applied as dry salt.

(*b*) There was evidence that the nitrate applied to adjoining plots washed on to this area, but so late as to affect only the protein content. If it is assumed that any plot yield which exceeded the average yield of untreated plots by 3.2 times the probable error of the untreated plots is significant, then relative yields in excess of 125 are significant. If a similar assumption is made relative to percentage protein, then any protein content in excess of 125 is significant. However, if the protein content of grain from the plot marked (*b*) is left out of consideration, for reasons already given, then any protein content in excess of 110 is significant. The relative yield of protein is obtained by multiplying the relative yields by the relative protein content and dividing by 100. If this is done it will be found that in many instances the increased percentage of protein is associated with and probably due to a decreased yield.

of the wheat plant when the application of even moderate quantities of sodium nitrate is injurious. After the plant has passed through this stage even very heavy applications of nitrogen are without effect upon yield. Under more normal rainfall, however, the response in yield might be entirely different.

The area within which significant responses in yield lie is as follows: October 18, 150 to 500 pounds; November 28, 150 to 1,000 pounds; March 3, 50 to 1,000 pounds; and March 17, 50 to 500. It is significant that the maximum increase in yield, that is, 95 percent, resulted from an application of only 150 pounds of sodium nitrate, or 24 pounds of nitrogen, applied on March 3 or at approximately the time growth began in spring. No application later than March **17** gave a significant increase in yield. On the other hand, light fall applications were without effect upon yield.

The area within which increases in percentage protein lie is much more extensive and is the result, in many instances, not of an increased elaboration of protein, but of decreased yield resulting from the immature condition of grain when harvested. This condition possibly obtained for all, April 13, April 28, and May 12 applications since in all but three of these (150 pounds, April 13, 500 pounds, May 12, and 1,000 pounds, April 18) a decrease in yield is recorded. Definite increases in the yield of protein are confined largely to the same area as increases in yield. In case of the lighter applications giving increases in yield, that is, 50 and 150 pounds, and the October 18 application of 500 pounds, no appreciable alteration in the protein content of the grain is evident, whereas, the heavier applications afforded adequate nitrogen for both an increase in yield of grain and an increase in the protein content of the grains.

The 1933-'34 Studies.—Efforts were made to induce the development of spots in five fields in the spring of 1934. Typically appearing spots developed in all five fields, but in one the wheat was grazed so late that no grain matured.

Field F was on river bottom, silt loam soil, very near to and of same type as the field employed in 1932-'33. The treatments, yield of grain, and protein content of grain are recorded in Table XVII. The maximum increase in yield from the application of nitrogen in the form of sodium nitrate was 55 percent from an application of 40 pounds nitrogen. The yield with heavier applications was reduced, but owing to the very marked increase in protein content, 46.8 percent when 160 pounds nitrogen were applied, the yield of protein from both the heavier applications was higher.

With urea the maximum yield was obtained with an application 80 pounds of nitrogen and the maximum yield of protein from the 160 pounds application of nitrogen. The addition of 40 pounds nitrogen gave practically as high a yield as did 80 pounds. The late application of nitrogen in either form was less effective in stimulating yield, but gave a much more marked increase in protein content than did the corresponding quantities of nitrogen applied earlier.

TABLE XVII.—YIELD AND PROTEIN CONTENT OF GRAIN FROM EXPERIMENTALLY PRODUCED SPOTS

Field F—1934

TREATMENT, MARCH 10 (acre basis).	Yield of grain.		Protein (percentage).			Relative yield of—	
	Harvested area (gm.).	Bus. per acre.	In grain.	Difference in favor of treated areas.	Increase in treated areas.	Grain.	Protein.
$NaNO_3$, 40 lbs. N (a).....	644	10.3	17.93	5.01	38.8	85	118
No treatment..............	720	11.5	13.24	....	....	(b) 100	(b) 100
$NaNO_3$, 160 lbs. N........	838	13.4	18.97	6.05	46.8	111	163
$NaNO_3$ 80 lbs. N.........	1,032	16.5	16.55	3.63	28.1	136	174
$NaNO_3$, 40 lbs. N.........	1,172	18.8	12.93	.01	.1	155	155
$NaNO_3$, 20 lbs. N.........	909	14.5	13.54	.62	4.8	120	126
No treatment..............	772	12.4	12.93	....	....	(b) 100	(b) 100
Urea, 160 lbs. N...........	996	15.9	17.78	4.86	37.6	131	180
Urea, 80 lbs. N............	1,120	17.9	15.39	2.47	19.1	147	175
Urea, 40 lbs. N............	1,088	17.4	13.58	.66	5.1	144	151
Urea, 20 lbs. N............	881	14.1	12.55	—.37	—2.9	116	113
No treatment..............	782	12.7	12.58	....	....	(b) 100	(b) 100
Urea, 40 lbs. N (a).........	911	14.6	14.27	1.35	10.4	120	133

(a) Treatment applied late, April 9, that is, after the effect of other treatments became visible.
(b) Average of three untreated areas.

Samples of the growing grain were collected from these plots, dried, weighed, and analyzed for total nitrogen. The data thus obtained are presented in Table XVIII. The weight of dry plant material, percentage nitrogen in dry material, and total nitrogen in plant material from the treated areas receiving the large quantities of nitrogen are comparable to the corresponding values from naturally occurring spots in the immediate vicinity (samples 5, 6, and 7, Table V). These values varied directly as the quantity of nitrogen added in most instances, the exceptions being where apparently overstimulated growth resulted in a lower percentage nitrogen than might be expected.

Field G was located on a light sandy loam, usually a fairly productive soil. The field had been in wheat a number of years and almost invariably exhibited typical spotting when the wheat was grazed. The treatments, yield of grain, and protein content of grain are recorded in Table XIX. In this series all the urea treatments were applied after the effect of the nitrate treatments became visible. Incidentally at this time, one month after the nitrate nitrogen was applied, the treated areas were plainly visible one half mile away.

TABLE XVIII.—DATA OBTAINED FROM A STUDY OF GREEN PLANT MATERIAL OBTAINED FROM EXPERIMENTALLY PRODUCED SPOTS

Field F—1934

TREATMENT, MARCH 10 (acre basis).	Dry weight of plant material, (gm.).	N in dry plant material, percentage.	Total quantity of N in plant material, (gm.).	Relative weight of plant material.	Relative quantity of N in plant material.
$NaNO_3$, 40 lbs. N (*a*)...	24.1	1.94	0.467	144	225
No treatment...........	17.3	1.16	.201	(*b*) 100	(*b*) 100
$NaNO_3$, 160 lbs. N.....	59.4	1.82	1.081	356	520
$NaNO_3$, 80 lbs. N......	40.7	1.39	.566	244	272
$NaNO_3$, 40 lbs. N......	42.2	1.18	.498	253	238
$NaNO_3$, 20 lbs. N......	20.2	1.55	.313	121	150
No treatment...........	15.6	1.32	.206	(*b*) 100	(*b*) 100
Urea, 160 lbs. N.........	34.4	1.78	.613	206	295
Urea, 80 lbs. N..........	34.2	1.69	.577	205	277
Urea, 40 lbs. N..........	29.7	1.19	.353	178	170
Urea, 20 lbs. N..........	26.9	1.19	.320	161	154
No treatment...........	17.3	1.26	.218	(*b*) 100	(*b*) 100
Urea, 40 lbs. N (*a*)......	22.1	1.66	.367	132	176

(*a*) Nitrogen applied late, that is, after its effect was evident on other treatments.
(*b*) Average of three untreated areas.

TABLE XIX.—YIELD AND PROTEIN CONTENT OF GRAIN FROM EXPERIMENTALLY PRODUCED SPOTS

Field G—1934

TREATMENT, MARCH 10 (acre basis).	Yield of grain.		Protein (percentage).			Relative yield of—	
	Harvested area (gm.).	Bus. per acre.	In grain.	Difference in favor of treated areas.	Increase in treated areas.	Grain.	Protein.
No treatment..............	471	7.5	13.08	....	....	(*b*) 100	(*b*) 100
$NaNO_3$, 160 lbs. N........	1,421	22.7	17.12	4.73	38.2	265	366
$NaNO_3$, 80 lbs. N.........	1,232	19.7	13.16	.77	6.2	230	244
$NaNO_3$, 40 lbs. N.........	1,241	19.9	11.58	—.81	—6.5	232	216
$NaNO_3$, 20 lbs. N.........	1,007	16.1	11.27	—1.12	—9.0	188	171
No treatment..............	529	8.5	11.31	....	....	(*b*) 100	(*b*) 100
Urea, 160 lbs. N(*a*).........	1,087	17.4	16.85	4.46	36.0	203	276
Urea, 80 lbs. N (a)..........	942	15.1	16.16	3.77	30.4	176	229
Urea, 40 lbs. N (a).........	942	15.1	13.81	1.42	11.5	176	196
Urea, 20 lbs. N (a)..........	814	13.0	13.35	.96	7.7	152	164
No treatment..............	609	9.7	12.77	....	....	(*b*) 100	(*b*) 100

(*a*) Urea applied late, April 9, that is, after the effect of nitrate treatments became visible.
(*b*) Average of three untreated areas.

The treated areas exhibited all the characteristics of naturally occurring spots, though to a more marked extent in case of the heavier applications. Owing to the character of the soil, this field did not suffer from the drought so much as the other fields under study, but there was insufficient moisture to enable the grain on heavily treated areas to fill out well. Also, the grain receiving the late applications of urea was materially delayed in maturing, and it was necessary to harvest it while still in an immature stage. This, no doubt, influenced to some extent the protein content of this grain, for it has been shown repeatedly that grain harvested in an immature condition is relatively high in protein.

In the case of the lighter applications of sodium nitrate there was a very marked increase in yield of grain accompanied by a decrease in protein content, the quantity of available nitrogen apparently being inadequate to maintain the normal protein content with the large increase in quantity of grain. With 160 pounds of nitrogen, however, there was sufficient nitrogen available to produce an increase of 165 percent in quantity of grain and a 38 percent increase in protein content, so that the total yield of protein was 3.66 times that from the untreated areas. (Fig. 4.)

The late applications of urea, on the other hand, produced significant, but much smaller increases in yield, accompanied by marked increases in protein content even with the lighter applications. If the application of urea had been delayed only a few days longer it probably would not have resulted in any appreciable increases in yield. The differences in the yield of protein between the early sodium nitrate and late urea applications are insignificant except with the heaviest quantities. These observations tend to bear out the indications of numerous previous observations that there is a certain stage in the development of the wheat plant prior to which a limited amount of available nitrogen will be utilized almost entirely in increasing the yield of grain, and after which it will result almost wholly in an increased protein content of the grain. In this particular experiment the sodium nitrate was applied prior to, while the application of urea must have been almost coincident with this critical period.

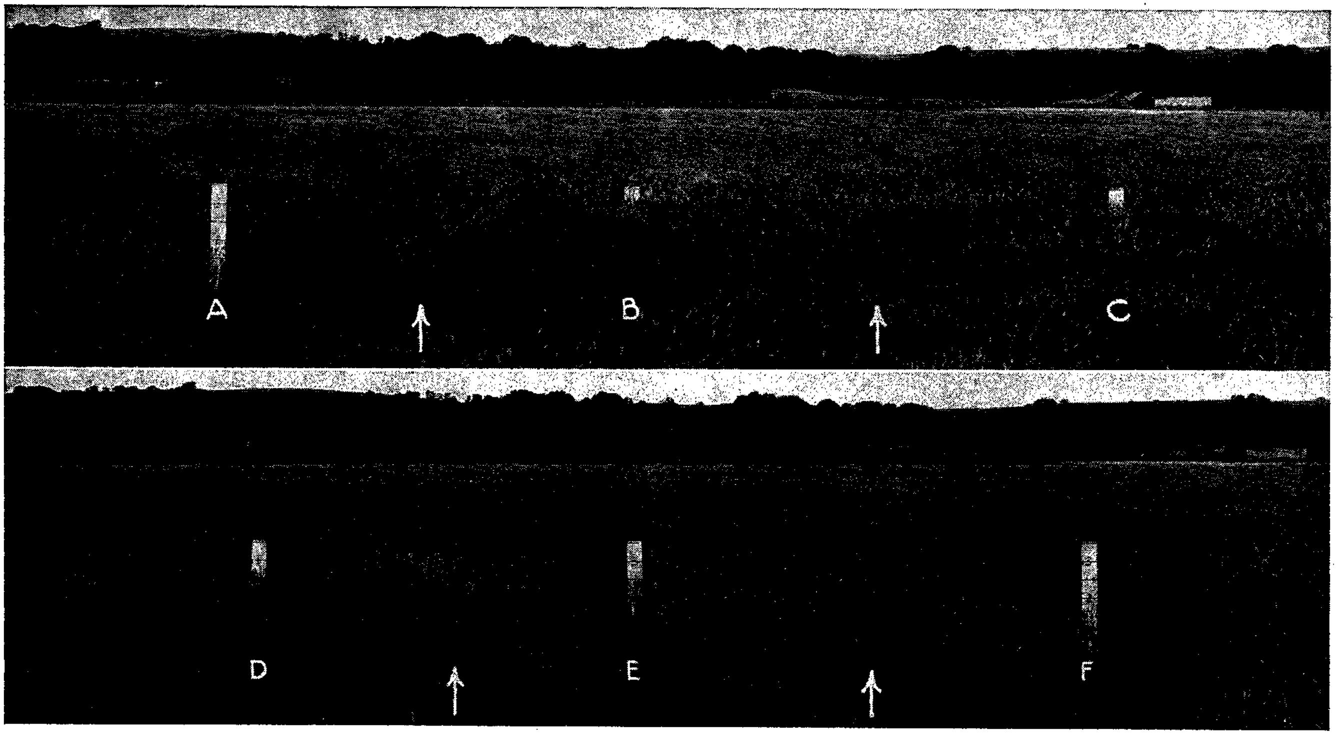

FIG. 4.—Experimentally produced spots, photographed near maturity. A, control; B, 160 pounds N per acre; C, 80 pounds N per acre; D. 40 pounds N per acre; E, 20 pounds N per acre; F, control. Height of markers, 3 feet, 6 inches. Arrows indicate dividing lines between plots which are only 20 feet deep.

TABLE XX.—DATA OBTAINED FROM A STUDY OF GREEN PLANT MATERIAL COLLECTED FROM EXPERIMENTALLY PRODUCED SPOTS

Field G—1934

TREATMENT, MARCH 10 (acre basis).	Dry weight of plant material, (gm.).	N in dry plant material, percentage.	Total quantity of N in plant material, (gm.).	Relative weight of plant material.	Relative quantity of N in plant material.
No treatment	14.7	1.17	0.172	(b) 100	(b) 100
$NaNO_3$, 160 lbs. N	66.1	1.88	1.243	444	661
$NaNO_3$, 80 lbs. N	78.5	1.59	1.248	527	664
$NaNO_3$, 40 lbs. N	46.4	1.14	.529	311	281
$NaNO_3$, 20 lbs. N	24.7	1.09	.269	166	143
No treatment	14.4	1.26	.181	(b) 100	(b) 100
Urea, 160 lbs. N (a)	17.2	2.42	.416	115	221
Urea, 80 lbs. N (a)	15.7	2.34	.367	105	196
Urea, 40 lbs. N (a)	16.8	1.96	.329	113	175
Urea, 20 lbs. N (a)	19.0	1.56	.296	128	157
No treatment	15.6	1.35	.211	(b) 100	(b) 100

(a) All applications of urea were made late, that is, after effect of nitrate treatments was evident.

(b) Average of three untreated areas.

In Table XX are recorded data obtained from the analysis of growing wheat plants collected from the areas described in Table XIX. The significant points to be noted from these data are: (1) The marked increase in plant growth where nitrogen was applied early and the slight increase following the late applications. (2) The large increase in percentage nitrogen in the plant material following the late applications with only moderate or no increase following the earlier application of corresponding quantities. If the data relative to these samples of growing grain are compared with those of the first five samples in Table V, a comparison between growing grain from experimentally produced and naturally occurring spots is possible. In relative quantity of plant material, percentage nitrogen in plant material, and relative quantity of nitrogen in plant material the plants from the area receiving an application of 40 pounds nitrogen are more or less comparable to the material from the naturally occurring spots.

TABLE XXI.—YIELD AND PROTEIN CONTENT OF GRAIN FROM EXPERIMENTALLY PRODUCED SPOTS

TREATMENT, (acre basis).	Yield of grain.		Protein (percentage).			Relative yield of—	
	Harvested area (gm.).	Bus. per acre.	In grain.	Difference in favor of treated areas.	Increase in treated areas.	Grain.	Protein.
FIELD H—1934							
No treatment	1,297	20.7	11.43	....	....	(a) 100	(a) 100
$NaNO_3$, 40 lbs. N (b)	1,600	25.6	15.04	2.83	23.2	110	135
Urea, 40 lbs. N (b)	1,573	25.2	14.53	2.32	19.0	108	129
$NaNO_3$, 160 lbs. N	1,199	19.2	17.32	5.11	41.9	81	115
$NaNO_3$, 80 lbs. N	1,487	23.8	16.35	4.14	33.9	102	137
$NaNO_3$, 40 lbs. N	1,693	17.1	14.31	2.10	17.2	116	136
$NaNO_3$, 20 lbs. N	1,514	24.2	13.58	1.37	11.2	104	116
No treatment	1,540	24.6	12.16	....	....	(a) 100	(a) 100
Urea, 160 lbs. N	1,909	30.5	16.77	4.56	37.3	131	180
Urea, 80 lbs. N	1,834	29.3	16.19	3.98	32.6	126	167
Urea, 40 lbs. N	1,871	29.9	14.85	2.64	21.6	129	156
Urea, 20 lbs. N	1,879	30.0	13.62	1.41	11.5	129	144
No treatment	1,528	24.4	13.03	....	....	(a) 100	(a) 100
FIELD I—1934							
No treatment	1,700	27.2	10.46	....	....	(a) 100	(a) 100
$NaNO_3$, 40 lbs. N (c)	1,949	31.2	13.85	3.36	32.0	123	162
Urea, 40 lbs. N (c)	1,932	30.9	12.62	2.13	20.3	122	147
$NaNO_3$, 160 lbs. N	2,280	36.5	15.93	5.44	51.1	144	219
$NaNO_3$, 80 lbs. N	2,603	41.6	14.22	3.73	35.6	165	224
$NaNO_3$, 40 lbs. N	2,364	37.8	11.74	1.25	11.9	149	167
$NaNO_3$, 20 lbs. N	1,986	31.8	10.77	.28	2.7	126	129
No treatment	1,554	24.9	10.24	....	....	(a) 100	(a) 100
Urea, 160 lbs. N	1,761	28.2	16.78	6.29	60.0	111	177
Urea, 80 lbs. N	1,950	31.2	14.08	3.59	34.2	123	165
Urea, 40 lbs. N	1,876	30.0	12.50	2.01	19.2	112	142
Urea, 20 lbs. N	1,829	29.3	11.39	.90	8.5	116	126
No treatment	1,493	23.9	10.77	....	....	(a) 100	(a) 100

(a) Average of three untreated areas.
(b) Treatment applied late, April 7, that is, after the effect of other treatments became visible.
(c) Treatment applied late, April 6, that is, after the effect of other treatments became visible.

Field H (treated March 19) was located on fairly heavy clay loam creek bottom soil that for several years had exhibited typical spotting. The treatments, yield, and protein content of grain are recorded in Table XXI. This being a heavy soil, the crop suffered severely from the drought. At harvest time there were cracks 2 inches wide and several feet deep on the immediate area. As a result, yields were increased only slightly, the surplus available nitrogen producing increase in the percentage protein in the grain varying from 11 percent with the lightest to approximately 40 percent with the heaviest application of nitrogen. The percentage protein in grain and the relative yield of protein increased as the quantity of nitrogen applied increased, except in the case of yield of protein where 160 pounds nitrogen as sodium nitrate was applied which caused a marked decrease in yield of grain.

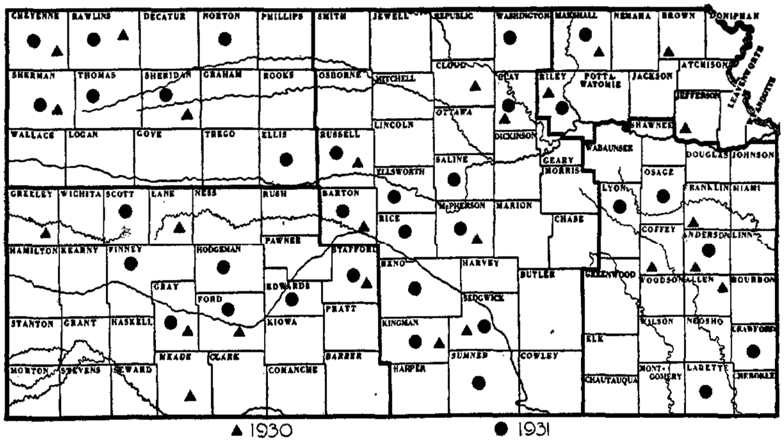

FIG. 5.—Location of Cyanamid experiments.

Field I (treated March 21) was located on a normally fertile silt loam creek-bottom soil. The treatments and data relative to yields and protein content of grain are also recorded in Table XXI. The early effects of the application of nitrogen were typical of naturally occurring spots, but the drought curtailed the yield and probably materially decreased the response to nitrogen that otherwise would have been evident in yield. The available nitrogen, however, was utilized in increasing the protein content of the grain, a maximum increase of 124 percent in yield of protein being recorded for the area receiving 80 pounds of nitrogen in the form of sodium nitrate.

STUDIES WITH CYANAMID

Through the coöperation of the American Cyanamid Company it was possible to conduct rather extensive and widely distributed field tests with Cyanamid ($CaCN_2$)[8] in an effort to produce condi-

8. Cyanamid contained 21 percent N.

tions comparable to the naturally occurring spots and to study the subsequent effects upon yield and protein content of the grain. Owing to the wide distribution of the treated areas it was necessary to enlist the aid of county agricultural agents in locating fields and harvesting 10 representative rod-row samples for yield tests. The work was conducted for two seasons, and in figure 5 is indicated the points at which fairly satisfactory completion of the tests was accomplished. The large territory involved made it impossible to make many records as to the growth of the wheat, but sufficient observations were taken to show that in many instances the treated areas exhibited all the growth characteristics of naturally occurring spots.

The treated areas were one tenth acre in size. The Cyanamid was applied with the aid of a portable distributor at the rate of 200 pounds per acre in the eastern part of the state and 100 pounds per acre elsewhere. The August application was made after the land had been plowed, but before the last cultivation and a month to six weeks before planting, hence, was more or less cultivated into the surface soil. The March application was made between February 26 and March 20 or prior to the beginning of spring growth. This was distributed on the surface and received no cultivation. Owing to dry weather following the application of the Cyanamid it remained on the surface in many instances from four to six weeks before sufficient moisture fell to dissolve it. This was particularly true of the spring application in 1930.

In 1929-'30 three different treatments were included, that is, a full application in August, a full application in March, and a one half application in August followed by a one half application in March. In 1930-'31 full applications of Cyanamid were made in August and March and in addition a March application of 100 pounds of "Ammo-Phos B."[9] The rod-row samples were harvested by county agricultural agents, shipped to Manhattan, threshed, weighed, and analyzed for protein.

A summary of the data relative to yields secured from 54 fields in 1930 and 53 fields in 1931 is recorded in Table XXII. These fields have been grouped depending upon the section of the state in which they were located, the division of the state being indicated in figure 5.

Because of the widely scattered and varied conditions there is no satisfactory method of arriving at the mathematical significance of these data. The following facts, however, will aid in their interpretation.

In 1929-'30 there were 54 fields involving 155 comparisons between treated and untreated areas. Of these comparisons 132 gave an increase, 18 a decrease, and 5 no change in yield of grain as a result of the application of Cyanamid. There were 11 increases in yield and one decrease in excess of 10 bushels per acre. In these 11 instances the increase averaged 77 percent. There were 26 instances in which

9. "Ammo-Phos B" contains 16.5 percent N and 20 percent available P_2O_5.

TABLE XXII.—EFFECT OF CYANAMID UPON THE YIELD OF WHEAT IN DIFFERENT PARTS OF THE STATE

SECTION OF STATE.	Season of 1929–1930.				Season of 1930–1931.			
	Untreated.	$CaCN_2$, August treatment.	$CaCN_2$, Aug.-Mar. treatment.	$CaCN_2$, March treatment.	Untreated.	$CaCN_2$, August treatment.	$CaCN_2$, March treatment.	"Ammo-Phos B," March treatment.
	Bus.	*Bus.*	*Bus.*	*Bus.*	*Bus.*	*Bus.*	*Bus.*	*Bus.*
Southeastern Kansas:								
Average yield per acre	23.2	27.5	27.6	29.8	23.2	27.8	29.7	25.3
Average increase per acre	....	4.3	6.8	6.5	....	4.5	6.5	2.1
Northeastern Kansas:								
Average yield per acre	18.9	24.7	24.9	25.0	21.4	21.7	24.7	26.7
Average increase per acre	....	5.8	6.0	6.6	....	.2	3.3	5.3
Central Kansas:								
Average yield per acre	17.6	20.0	20.5	20.1	22.6	25.5	26.5	25.4
Average increase per acre	....	2.4	3.0	2.6	....	2.9	3.9	2.7
Southwestern Kansas:								
Average yield per acre	12.6	13.8	14.7	14.2	22.7	26.1	26.6	25.8
Average increase per acre	....	1.2	2.1	1.6	....	3.5	3.9	3.3
Northwestern Kansas:								
Average yield per acre	20.1	24.6	22.8	23.8	25.5	29.3	29.2	28.4
Average increase per acre	....	4.5	2.7	3.8	....	3.8	3.7	2.8
Total number of comparisons	54	54	53	48	53	53	53	53
Number of comparisons, increase exceeding 10 bushels	....	3	2	6	....	5	7	4
Number of comparisons, increase exceeding 7.5 bushels	....	7	10	9	....	10	14	8
Number of comparisons, increase exceeding 5 bushels	....	16	19	13	....	16	22	15

the increase in yield exceeded 7.5 bushels and only one instance in which the decrease exceeded this value, the average increase for this group was 60 percent. There were 48 instances in which the increase in yield exceeded 5 bushels per acre and only two in which a decrease of this magnitude was recorded. Of the 54 individual fields represented there were 8 fields in which one or more treatments gave an increase of 10 bushels, 14 which gave increases greater than 7.5 bushels per acre, and 26 which gave increases in excess of 5 bushels per acre. There were only two fields in which a decrease of as much as 5 bushels per acre was recorded.

In 1930-'31 there were 53 fields and 159 comparisons of untreated areas with areas receiving nitrogen. In 123 of these comparisons an increased yield of grain was recorded, while a decrease was recorded in 36 instances. There were 16 areas showing increases in yield of 10 or more bushels, averaging 56 percent increase; 32 areas in which the increase exceeded 7.5 bushels, averaging 46 percent; and 53 instances in which an increase of 5 bushels or more per acre was recorded. There were only 4 treated areas that gave a decrease in yield of 5 bushels, three of these located in the same field, and none in which the decrease was so great as 10 bushels per acre. In 11 of the 53 fields, one or more areas gave an increase of 10 or more bushels, 19 fields an increase of 7.5 or more bushels, and 28 fields an increase of 5 or more bushels per acre. In only two fields was a decrease as great as 5 bushels per acre recorded. These data are presented in parallel columns in Table XXIII.

TABLE XXIII.—NUMBER AND PERCENTAGE OF FIELDS AND PLOTS GIVING VARIOUS RESPONSES TO TREATMENTS WITH CYANAMID (*a*)

SEASON.	1929-'30.	1930-'31.	Total.	Percentage.
Experimental fields	54	53	107	100.0
Nitrogen treated plots	155	159	314	100.0
Plots giving increased yield	132	123	255	81.2
Plots giving decreased yield	18	36	54	17.2
Increase: 10 or more bushels per acre	11	16	27	8.6
Increase: 7.5 or more bushels per acre	26	32	58	18.5
Increase: 5 or more bushels per acre	48	53	101	32.5
Decrease: 5 or more bushels per acre	2	4	6	1.9
Fields in which an increase of 10 bus. was recorded.	8	11	19	17.8
Fields in which an increase of 7.5 bus. was recorded	14	19	33	30.8
Fields in which an increase of 5 bus. was recorded.	26	28	54	50.5
Fields in which a decrease of 5 bus. was recorded	2	2	4	3.7

(*a*) One of the six series of treatments was "Ammo-Phos B."

In analyzing the data presented in Tables XXII and XXIII the following points should be kept in mind. No effort was made to select fields to be treated on a basis of their probable deficiency in available nitrogen. In fact, the method followed, that is, selection by county agricultural agents, would probably result in exactly the opposite, since these agents for obvious reasons would undertake co-operative enterprises with their better class of farmers, thus more or less insuring tillage methods and farm practices that would tend to supply the maximum of available nitrogen. The large number of instances, 32.5 percent, in which the increase in yield following the application of nitrogen equaled 5 bushels, and the extremely small number of instances, only 1.9 percent of 314 comparisons, in which the decrease in yield following such treatment amounted to that value, though inconclusive, would indicate that a 5-bushel increase is probably significant. Also, the weather conditions in many if not all instances were unfavorable for the maximum response from a nutritive element applied as was the nitrogen contained in the Cyanamid.

The average increases in yield following the various applications of nitrogen, as recorded in Table XXII, do not appear very large. For the eastern part of the state, however, the average of 79 individual tests is 5.2 bushels per acre. Individual treatments in every section of the state gave early responses similar to and equally as marked as the naturally occurring spots in the immediate vicinity. There were also treatments in every section of the state that gave increases in yield greater than 50 percent, in a few instances exceeding 100 percent.

In 8.6 percent of all individual tests and in at least one plot in 17.8 percent of all fields, increases in yield of 10 or more bushels per acre were recorded. In 18.5 percent of all tests and in at least one plot in 30.8 percent of all fields, increases in yields exceeding 7.5 bushels per acre were recorded. In 32.5 percent of the individual tests and in 50.5 percent of all test fields increases of 5 or more bushels per acre were secured.

The protein content of grain from 254 Cyanamid treated plots was measured and compared with that in grain from untreated areas immediately adjacent. The data thus obtained are, however, so variable that no definite conclusions can be drawn from them. Of the 254 treated plots, the grain from 129 contained a somewhat higher and from 111 a lower percentage of protein than did the grain from the corresponding untreated areas. In a few instances the apparent alteration in the protein content as a result of the application of Cyanamid was rather marked, but in most instances only slight increases or decreases were recorded. Increases in yield were sometimes accompanied by increases in the percentage protein, but in approximately as many instances the protein content was lowered. Decreases in yield were somewhat more consistently accompanied by increases in protein content.

Apparently the quantity of available nitrogen supplied by the various soils, as well as the demands of the particular crop for nitrogen, was so variable that consistent responses could not be obtained. The variable effects, insofar as the application of the nitrogen in the Cyanamid affected the percentage protein in these experiments, may be explained upon the following bases: (1) Some of the soils probably supplied available nitrogen in such quantities that nitrogen was not a limiting factor in yield of grain, percentage protein in grain, or yield of protein. (2) In other instances the available nitrogen was probably adequate for the maximum yield of grain permissible by other factors, but not to give the maximum protein content of the grain; in which case the addition of nitrogen would have no effect upon yield of grain but would increase the percentage protein in the grain. (3) In other soils available nitrogen was limited and its application stimulated the formation of grain, thus increasing the yield, but the supply was inadequate to give the maximum protein content of the grain. (4) In still other fields the application of nitrogen stimulated the formation of grain and the quantity applied plus that furnished by the soil was sufficient to give an increase in the protein content as well as an increase in the quantity of grain.

The influence of the Cyanamid treatments upon the total yield of protein per unit area was somewhat more consistent than upon the percentage of protein in the grain. Of the 254 treated areas, 196 yielded protein in excess of untreated areas, while only 56 yielded less protein than the controls. The average increases in protein in pounds per acre following the 1929-'30 Cyanamid treatments were as follows: August treatment (33 plots), 25.1 pounds; August-March treatments (34 plots), 25.1 pounds; and March treatment (31 plots), 23.8 pounds. The corresponding values for 1930-'31 were: August treatment (52 plots), 24.4 pounds; March treatment (52 plots), 27 pounds; and March "Ammo-Phos" treatment (52 plots), 18.1 pounds. The treatments apparently did result in slight increases in the yield of protein per unit area.

SUMMARY

From the investigations relative to the experimental production of spots comparable to those occurring naturally in wheat fields the following points appear to be definitely established: (1) In fields where spots occur naturally, experimental spots, apparently identical in every aspect, can be produced at will by the surface application of all forms of nitrogen thus far tested, provided the time of application and quantity applied are judiciously selected. (2) Some fields will not respond to such treatment. (3) The quantitative growth of the wheat plants, the color, the percentage nitrogen in plant material, the total nitrogen absorbed from the soil per unit area, the yield of grain, the protein content of the grain, and the yield of protein per unit area following the judicious surface application of nitrogen are all comparable to the corresponding values for naturally occurring spots.

GENERAL DISCUSSION

The occurrence of limited areas of growing wheat comparable to those herein discussed and pictured in figures 1 and 3, is very widely distributed, particularly in the older small-grain-growing regions. The general appearance of the growing plants on these small spots would indicate that such areas are potentially more productive of grain. A satisfactory explanation of the immediate cause of such spots seemed of special theoretical interest, with possibly far-reaching, practical applications. In the foregoing pages the major results of five years' investigation relative to the cause of this phenomenon are recorded. Attention has already been called to the major facts brought forth in these investigations. Suffice it to say here that all the evidence accumulated from a study of both the naturally occurring and experimentally produced spots points to available nitrogen as playing the fundamental role in their production. This does not mean that somewhat similar appearing spots may not be produced by other factors, but that the phenomenon of spotted wheat fields, such as are so abundant in the eastern two thirds of Kansas, is the direct result of the limited area of soil supplying the wheat plants with more available nitrogen.

With this basic fact established the next problem to be solved was that of the origin of the larger quantities of available nitrogen in the soil of the spots. In a rather limited study of somewhat similar spots Lipman[10] reached the conclusion that a more active nitrifying flora existed in the soil of the spots and through its activity more of the soil's store of nitrogen was made available. No explanation was offered as to why the bacteria in such limited areas should suddenly become so much more active. It is possible that the type of spots studied by Lipman had an entirely different origin from those studied here. A superficial investigation of a typically spotted Kansas wheat field during the early development of spots leaves no doubt but that the common conception of their origin, that is, from deposits of urine or feces, is generally correct. A more careful examination reveals the fact, however, that they do not arise from feces deposited during the current season. On the other hand, many spots have been investigated that certainly did not arise from deposits of urine. The origin or form of nitrogen finding its way into the soil probably does not matter; if it is capable of being readily transformed into an available condition it will result in the formation of spots, provided the soil is limited in available nitrogen. In the investigations herein recorded no evidence has been secured that would indicate that microorganisms play more than a secondary rôle in the production of the type of spots under study. Practically every soil examined appeared to be provided adequately with the organisms concerned in the transformation of the more common forms of nitrogen into an available condition.

Once the nitrogen is made available to the wheat plant it may manifest itself in several different ways: (1) Almost invariably in

10. Lipman, C. B. *Loc. cit.*

increased vegetative growth, containing a higher percentage of nitrogen. (2) An increased production of grain, provided the nitrogen becomes available early enough in the development of the plant, and further, provided there is adequate moisture to mature the grain. (3) An increased protein content in the grain, in case the quantity of nitrogen is adequate to more than provide for the increased quantity of grain. (4) An increased protein content may result from the presence of rather limited quantities of available nitrogen, unaccompanied by an increase in the quantity of grain, if the nitrogen becomes available so late in the development of the plant that its capacity to form grain has already been established. (5) If a marked stimulation of growth takes place, resulting in the formation of relatively large quantities of grain, and the supply of available nitrogen becomes somewhat limited, a marked increase in the production of grain may be accompanied with an actual decrease in the percentage of protein in the grain.

In a preceding paragraph it was stated that the yield of grain from an equal area of a spot exceeded that from the immediately adjacent soil provided there was adequate moisture to mature the grain formed. During the five years of this investigation in no instance have the spots failed to mature more grain than the surrounding soil in this vicinity. At least one of these years, 1934, was very unfavorable in this respect.

As previously suggested, there is a widespread conception among farmers that an excess of available nitrogen will cause lodging. In less than half a dozen instances among the thousands of naturally occurring spots examined has any evidence of lodging been noted, and in these few instances the size of the spots indicated that they were not caused by deposits of urine. Furthermore, hundreds of areas have been treated with various forms and quantities of nitrogen up to 320 pounds nitrate nitrogen per acre, and in only one or two instances has lodging been recorded.

In order to get a quantitative measure of the relative strength of the straw from spots and immediately adjacent thereto the breaking strength of the straw of 22 samples of P and G grain harvested in 1930 was determined. Ten separate tests, comprising 10 straws per test, were carried out on each sample. With one exception, the average breaking strength of the G sample was greater than that of the P sample, the average resistance to breaking being 37.5 percent greater in the case of the G straw. These observations do not support the view that nitrogen is the primary factor concerned in lodging.

The quantities of grain harvested from naturally occurring spots have been so small that tests of quality other than general appearance and protein content could not be made. As a rule, the grains are equally well filled and freer from yellow berry than that of the field at large. Grain from the experimentally produced spots has not always been so well filled as that of the control. This failure to fill out was due, at least in many instances, to the fact that maturity was somewhat delayed, particularly where nitrogen was applied late, and it was necessary to harvest the treated areas ahead of the regular harvest; hence, the grain was harvested before maturity.

This station has directed attention on previous occasions[11] to the rapid losses of nitrogen taking place in cultivated Kansas soils, particularly when grown to grain. The inevitable end result of such losses as have been recorded must be soils deficient in total nitrogen. The data collected in this study relative to the nitrogen content of soils of Kansas wheat fields tend to substantiate former findings as to the existence already of many soils with relatively low nitrogen contents. In Tables I to IV, inclusive, are recorded the nitrogen contents of soils from 165 wheat fields, located in 39 wheat-growing counties of Kansas, 8.5 percent of which contained less than 0.10; 25 percent of which contained less than 0.12; and 67 percent of which contained less than 0.15 percent nitrogen.

There were many soils studied in this investigation, however, that were adequately supplied with total nitrogen, and yet apparently were not furnishing the growing wheat plant with all the nitrogen it could utilize in its growth. Most of these were fairly heavy low-lying soils, frequently exhibiting evidence of poor seedbed preparation, and almost invariably containing very limited supplies of available (nitrate) nitrogen. When placed under favorable conditions in the laboratory these soils exhibited rapid nitrification, thus indicating that a physical alteration is all that is needed to enable them to transform their stores of nitrogen into nitrates rapidly.

The highly significant rôle played by nitrogen in the production of naturally occurring spots, with the accompanying marked increase in protein content and yield of grain occurring thereon, suggests the desirability of further research as to the possible rôle of commercial nitrogenous fertilizers in the future economic growth of wheat in the hard-winter-wheat belt. More information is especially desirable relative to the influence of time of application, method of application, and quantity of nitrogen applied upon both the quality and quantity of grain produced.

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