BULLETIN No. 465. JUNE, 1919.

New York Agricultural Experiment Station.

GENEVA, N. Y.

AN EXPERIENCE IN CROP PRODUCTION.

W. H. JORDAN AND G. W. CHURCHILL.

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AN EXPERIENCE IN CROP PRODUCTION.

W. H. JORDAN AND G. W. CHURCHILL.

SUMMARY.

1. The experience with crop production herewith recorded covers seventeen years of observation, and the data herein given may be regarded as a report of progress.

2. The experiment was extended thru four years of rotations of four years each, the crops being corn, oats, wheat and grass, in the order named. On four of the plats, covering the four methods of treatment, clover was included in the rotation, and on the other four plats, receiving entirely similar treatments, timothy was included in the rotation.

3. The points concerning which conclusions more or less definite may be drawn are the following:

The relative production of crops with farm manure, complete commercial fertilizer and acid phosphate which was supplemented by a small application of sodium nitrate.

A comparison of farm manure and complete commercial fertilizer.

The influence of clover as a factor in fertility.

Soil analysis as a means of measuring fertility.

The relative profitableness of the several methods of treatment.

4. The largest yield of crops, measured in terms of dry matter, was with farm manure altho this did not greatly exceed the production with complete commercial fertilizer. Both the farm manure and the complete commercial fertilizer produced approximately 56 per ct. more dry matter than the plats receiving no fertilizer. The plats receiving phosphoric acid with partial nitrogen and no potash produced about 33 per ct. more than the untreated plats.

5. The production of dry matter with the farm manure and complete commercial fertilizer was in the proportion of 118.3 for the former to 113.9 for the latter. If, however, allowance is made for

the difference in yield of hay due to the fact that timothy sod was maintained for only one year, and comparison is made of the cereal crops produced, the relation of farm manure to commercial fertilizer is as 91 to 90 with clover in the rotation, and with timothy in the rotation as 84 to 89.

6. A comparison of the clover plats with the timothy plats shows that in the seventeen years there were produced of all crops 29,800 lbs. more of dry matter on the clover plats than on the timothy plats. If, however, we make the comparison on the basis of the cereal crops, the difference in favor of clover is 13,500 lbs. of dry matter. These results indicate considerable advantage from the use of clover.

7. A study of the yield of dry matter on the plats receiving no fertilizer, one with clover in the rotation and the other with timothy, shows that production was maintained on these plats as effectively with timothy as with clover in the rotation. The yields following the first rotation were maintained without any essential drop.

8. A comparison of the analysis of the soils on the several plats before and after seventeen years of cropping showed no differences or changes which gave either any indication of the effect of the unlike systems of treatment or of the unlike productivity of the plats at the end of the seventeen years.

9. A comparison of the results of the experiment on the basis of the cost of the fertilizers and the value of the crops shows that the cheapest increase of production was with acid phosphate combined with a minimum amount of nitrate of soda.

INTRODUCTION.

The general problem of crop production is exceedingly complex. Many factors, physical, chemical and biological in their nature, are immediately related to fertility and the aggregate influence of these factors determines whether any particular soil is fertile. Because of the complicated activities and influences originating in the soil, progress in the solution of soil problems has been very slow and in no phase of agricultural science has the development of well established knowledge been so unsatisfactory.

The study of soil problems has been prosecuted along two general lines, laboratory investigations and experience in the growth of

plants, either in forcing houses or in the fields. Laboratory research has been essential and useful in establishing certain fundamental facts, but has been inadequate for the determination of what would occur under field conditions. Forcing-house experiments have been enlightening in certain directions, but it is a matter of common observation that results in growing plants under glass have not been entirely comparable with those secured in field culture. In field experiments it has not been possible in most instances to determine either the absolute or relative influence of the various individual factors which influence plant growth. Moreover, the results of such experiments are determined by local conditions which may or may not be similar to the conditions of any other farm or region. The records reveal a great activity during many years in carrying on field experiments with fertilizers, of which there has been a very large number, but it is safe to assert that these experiments have established few principles or facts of general application, which would serve as a safe guide to an individual farmer in regulating his practice. It would appear that the maintenance of fertility is a local problem.

GENERAL CONDITIONS INVOLVED IN THE EXPERIMENTS.

The field experiment, the results of which are herewith discussed, was begun in the year 1896 and the data now presented cover the years from this beginning until and including 1913. The season of 1896 was devoted to determining the relative productiveness of each of the two halves of the field utilized. Beginning with 1897 a rotation of crops was followed: corn, oats, wheat and grass, with the exception that two crops of corn were grown in succession in 1897 and 1898. This means that the period thru which the experiment was conducted included four rotations covering 17 years of time. The area of the field selected for this work was twelve acres. This was divided into eight plats with a space of four feet dividing the plats, thus allowing approximately one acre and a half to each plat. The actual dimensions of the plats were 4 rods x 60 rods.

NOTE.—The chemical analyses involved in the data herewith reported were performed by E. B. Hart, E. L. Baker, M. P. Sweeney, and R. F. Keeler.

The following diagram shows the arrangement of the plats and the treatment which each plat received:

No. of plat.	Arrangement and General Treatment of the Plats.	
1.	Farm manure,	Clover in rotation.
2.	No fertilizer,	Clover in rotation.
3.	Partial fertilizer, P_2O_5 and minimum N.	Clover in rotation.
4.	Farm manure,	Timothy in rotation.
5.	Complete fertilizer, P_2O_5, K_2O and maximum N.	Clover in rotation.
6.	No fertilizer,	Timothy in rotation.
7.	Partial fertilizer, P_2O_5 and minimum N.	Timothy in rotation.
8.	Complete fertilizer, P_2O_5, K_2O and maximum N.	Timothy in rotation.

The following points should be noted:

1. With four of the plats clover was used in the rotation and on the other four plats, timothy.

2. Two plats received no fertilizer whatever during the seventeen years.

3. Two plats received phosphoric acid with a minimum amount of nitrogen.

4. Two plats received what is known as a complete fertilizer, namely, nitrogen, phosphoric acid and potash.

5. Two plats received farm manure.

In 1897 winter vetch was sown in the corn on Plats 1, 2, 3 and 5 at the last cultivation. The seed catch was good, the plants did not winter kill and much growth was made in the spring before the second crop of corn.

In 1898 crimson clover was sown on Plats 1, 2, 3 and 5 at time of last cultivation. The seed catch was good, the autumn growth was satisfactory, but the plants winter-killed largely.

The fertilizers of all kinds were applied to the corn and the wheat, no application being made to the oats and grass.

The yearly and total quantities of fertilizers applied to the several plats during the seventeen years are given for each plat in Table I.

TABLE I.— QUANTITIES OF FERTILIZERS APPLIED EACH YEAR DURING THE EXPERIMENTS.

YEAR.	PLATS 1 and 4.	PLATS 3 AND 7.				PLATS 5 AND 8.			
	Farm manure.	Acid Phos-phate.	Dried blood.	Nitrate soda.	Muriate potash.	Acid Phos-phate.	Dried blood.	Nitrate soda.	Muriate potash.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
1897.....	33,325	450	450	75	75	450	525	225	300
1898.....	30,000	600	.....	150	.....	600	525	225	300
1899.....	30.000	300	150	50	.....	300	750	225	90
1900.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1901.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1902.....	30,000	300	.....	150	.....	300	360	300	150
1903.....	30,000	200	100	25	.....	200	500	100	70
1904.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1905.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1906.....	30,000	300	.....	200	.....	300	700	200	225
1907.....	30,000	300	.....	300	.....	300	500	300	150
1908.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1909.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1910.....	30,000	300	250	50	.....	300	700	200	225
1911.....	30,000	300	250	50	.....	300	700	200	225
1912.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1913.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Totals....	273,325	3,050	1,200	1,050	75	3,050	5,260	1,975	1,735

RELATIVE YIELD OF THE SEVERAL PLATS UNDER DIFFERENT METHODS OF TREATMENT DURING THE ENTIRE PERIOD OF THE EXPERIMENT, INVOLVING FOUR ROTATIONS.

PRODUCTION OF CROPS AS HARVESTED.

The yield of the several plats involved in this experiment is measured in two ways: first, by the weights of the crops as harvested and, second, by the amount of dry matter contained in the crops. The latter measurement is the one which should be chiefly considered because the dry matter is a fundamental measurement of the production of crops either for human food or for food for animals. Table II gives the weights of the crops of each kind for each year as well as the totals for the four rotations. It should be explained that in 1897, 1898 and 1906 two rows out of the twenty-two rows in each plat were allowed to stand and ripen for husking while the other twenty rows were cut before complete ripeness and stored in a silo. In order to compute the total yield of fresh corn for silage in those years, the weights of corn in the silage condition were increased for each plat by one-tenth. In 1902, all the corn was cut and stacked in the field. The probable weight in the fresh

TABLE II.— CROPS AS HARVESTED.

CORN CUT FOR SILAGE.

YEAR.	PLATS.							
	1.	2.	3.	4.	5.	6.	7.	8.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
1897[1]	35,120	28,793	33,368	34,497	38,612	31,970	33,970	37,760
1898[1]	37,638	26,469	31,126	32,486	34,624	25,421	29,260	32,644
1902[2]	17,620	12,528	14,525	14,466	16,504	11,273	13,283	15,634
1906[1]	25,355	19,700	21,106	23,081	25,219	17,464	20,978	25,725
1910	45,416	27,574	38,059	42,286	38,702	29,790	33,916	45,697
Total	161,149	115,064	138,184	146,816	153,661	115,918	131,407	157,460
Corrected figures[3]	187,607	130,335	158,718	166,481	176,325	131,820	149,216	183,594
Increase over check	57,272	.....	28,383	34,661	45,989	.....	17,395	51,774

OAT STRAW.

1899	3,337	2,742	3,735	3,549	3,966	2,906	3,224	3,463
1903	1,751	1,790	1,969	2,417	2,006	1,724	2,073	2,506
1907	3,216	2,192	3,086	3,197	3,082	2,225	2,510	2,851
1911	2,445	1,120	2,014	2,518	2,138	1,342	1,768	2,470
Total	10,749	7,844	10,804	11,681	11,192	8,197	9,575	11,290
Increase over check	2,905	.....	2,960	3,484	3,348	.....	1,378	3,093

OATS — GRAIN.

1899	3,195	2,386	3,301	2,959	3,148	2,548	2,612	3,053
1903	814	749	780	728	778	626	751	924
1907	2,416	1,568	2,224	2,233	2,342	1,535	1,850	1,900
1911	1,940	1,262	1,942	2,216	2,080	1,450	1,832	2,160
Total	8,365	5,965	8,247	8,136	8,348	6,159	7,045	8,037
Increase over check	2,400	.....	2,282	1,977	2,383	.....	886	1,878

WHEAT — STRAW

1899	3,395	1,258	2,340	3,426	3,506	1,590	2,020	3,185
1908	4,797	2,346	3,964	3,954	4,563	2,302	3,665	3,962
1912	5,127	2,297	4,150	5,367	5,084	2,032	3,976	3,225
Total	13,319	5,901	10,454	12,747	13,153	5,924	9,661	10,372
Increase over check	7,418	.....	4,553	6,823	7,252	.....	3,737	4,448

WHEAT — GRAIN

1899	2,670	1,022	1,890	2,950	2,940	1,380	1,780	2,470
1908	3,200	1,788	3,120	2,838	3,540	1,840	2,750	2,958
1912	3,174	1,246	2,211	3,030	3,155	1,086	2,202	3,270
Total	9,044	4,056	7,221	8,818	9,635	4,306	6,732	8,698
Increase over check	4,988	.....	3,165	4,512	5,519	.....	2,426	4,392

[1] Ten-elevenths of the crop.
[2] Weight of air dry crop.
[3] Figures for 1897, 1898 and 1906 increased one-tenth. Fresh crop for 1902 estimated by multiplying the dry matter by four.

TABLE II — (*Continued*).

HAY

YEAR.	PLATS.							
	1.	2.	3.	4.	5.	6.	7.	8.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
1901	6,281	2,917	4,828	7,388	5,028	3,406	4,586	5,502
1905	12,955	8,364	10,823	5,841	11,250	3,104	3,163	2,796
1909	8,005	2,685	4,756	8,132	6,006	2,633	4,004	4,357
1913	7,609	4,132	6,001	9,397	7,220	4,204	6,581	6,520
Total	34,850	18,098	26,408	30,758	29,504	13,347	18,334	19,175
Increase over check	16,752	.....	8,310	17,411	11,406	.....	4,987	5,828
BARLEY — STRAW								
1904	3,533	2,650	3,387	2,998	3,524	2,416	2,551	3,579
Increase over check	883	.....	737	582	874	.....	135	1,163
BARLEY — GRAIN								
1904	1,902	1,242	1,484	1,615	1,867	1,209	1,413	1,939
Increase over check	660	.....	242	406	625	.....	204	730

condition is computed by multiplying the pounds of dry matter by four, as 25 per ct. was the general average for dry matter in corn harvested for silage. The detailed figures in Table II are followed by a summary (Table III) showing the total yields of

TABLE III.— SUMMARY OF YIELDS OF CROP AS HARVESTED DURING FOUR ROTATIONS COVERING A PERIOD OF 17 YEARS.

KIND OF CROP.	Plat 1.	Plat 2.	Plat 3.	Plat 4.	Plat 5.	Plat 6.	Plat 7.	Plat 8.
Corn for silage	187,607	130,335	158,718	166,481	176,325	131,820	149,216	183,599
Oat, straw	10,749	7,844	10,804	11,681	11,192	8,197	9,575	11,290
Oat, grain	8,365	5,965	8,247	8,136	8,348	6,159	7,045	8,037
Wheat, straw	13,319	5,901	10,454	12,747	13,153	5,924	9,661	10,372
Wheat, grain	9,044	4,056	7,221	8,818	9,635	4,306	6,732	8,698
Barley, straw	3,533	2,650	3,387	2,998	3,524	2,416	2,551	3,579
Barley, grain	1,902	1,242	1,484	1,615	1,867	1,209	1,413	1,939
Hay	34,850	18,098	26,408	30,758	29,504	13,347	18,334	19,175

each crop for the entire period and also (Table IV) giving the increase in yield over the check plats for the entire period.

As before stated the latter figures are the more significant, because the crops as harvested carry unknown quantities of water.

TABLE IV.— SUMMARY OF INCREASES OF YIELDS OVER THE CHECK PLATS FOR THE FOUR ROTATIONS COVERING A PERIOD OF 17 YEARS.

KIND OF CROP.	Plat 1.	Plat 2.	Plat 3.	Plat 4.	Plat 5.	Plat 6.	Plat 7.	Plat 8.
Corn, silage	57,272	.....	28,383	34,661	45,698	.....	17,395	51,774
Oat, straw	2,905	.....	2,960	3,484	3,348	.....	1,378	3,093
Oats, grain	2,400	.....	2,282	1,977	2,383	.....	886	1,878
Wheat, straw	7,418	.....	4,553	6,823	7,252	.....	3,737	4,448
Wheat, grain	4,988	.....	3,165	4,512	5,519	.....	2,426	4,392
Barley, straw	883	.....	737	582	874	.....	135	1,163
Barley, grain	660	.....	242	406	625	.....	204	730
Hay	16,752	.....	8,310	17,411	11,406	.....	4,987	5,828

PRODUCTION OF DRY SUBSTANCE.

In Table V are given the weights of dry substance produced on each plat during the entire period of four rotations. In order to determine the yield of dry substance, very large samples were taken from each plat at each harvest, either by cutting many hills of corn distributed over the entire area of each plat or by taking samples of straw and grain at the time the grain was threshed or by selecting samples of hay at the time of storage in the barn. These samples were re-sampled for preparation for laboratory uses, the large samples being again weighed at the time of the selection of the smaller samples. The difficulty of absolute accuracy in such sampling is well recognized, but it is believed that the methods employed precluded serious errors.

A study of the following table reveals certain facts worthy of some attention.

TABLE V.— YIELD OF DRY SUBSTANCE UNDER THE SEVERAL METHODS OF TREATMENT.

Number of plat and treatment.	Corn.	Oats.	Wheat.	Barley.	Hay.	Total.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
1. Farm manure	48,659.9	17,036.3	20,636.5	4,973.3	27,061.8	118,367.8
2. No fertilizer	32,998.1	12,422.4	9,059.8	3,555.1	14,818.4	72,853.8
3. Partial fertilizer	41,273.0	17,184.7	15,563.5	4,381.1	21,689.6	100,091.9
4. Farm manure	42,932.0	17,898.2	19,311.8	4,206.1	25,211.4	109,559.8
5. Complete fertilizer	45,442.5	19,451.0	20,418.9	4,882.0	23,722.8	113,917.2
6. No fertilizer	34,615.2	12,812.8	9,198.9	3,343.4	10,649.6	70,619.9
7. Partial fertilizer	40,731.6	14,941.2	14,727.4	3,670.7	14,921.5	88,932.4
8. Complete fertilizer	50,489.0	17,191.3	17,251.5	5,013.0	16,353.1	106,297.9
Total	337,141.6	128,937.9	126,168.3	33,964.7	154,428.2	.....

Plats 1, 2, 3 and 5 with clover in the rotation.
Plats 4, 6, 7 and 8 with timothy in the rotation.

The most fundamental consideration is the great variation in production, due to the different methods of treatment. The plats receiving farm manure and complete commercial fertilizer produced approximately 56 per ct. more dry matter than the plats receiving no fertilizer. The plats receiving phosphoric acid with partial nitrogen and no potash produced about 33 per ct. more than the untreated plats. In considering these figures, it should be kept in mind that the crops were produced under a system of rapid rotation and, in case of four of the plats fine crops of clover were grown in each rotation so that there was turned under on these plats an excellent clover sod together with more or less second growth in certain years. Moreover, in the year 1910 all the plats received one ton of burned lime per acre, previously slaked. If any evidence is necessary, such figures should completely dispose of the doctrine somewhat prevalent at one time that the chief function of commercial fertilizers was palliative in character and that with proper rotation and soil treatment desirable production could be maintained. Another interesting and important fact displayed is the relative productivity of the several crops entering into the experiment. The figures show that the growth of dry substance in corn is over twice that in either oats or wheat (counting the yield of barley as part of the wheat), or even of hay — notwithstanding the fact that the crops of the cereal grains and hay were considered very satisfactory. This is a fact to which the dairy farmer should give careful consideration in planning to secure the largest amount possible of available food for milk production.

THE RELATIVE EFFICIENCY OF FARM YARD MANURE AND CHEMICAL FERTILIZERS.

A question much discussed, especially thruout the Eastern States, is the maintenance of fertility by the use of commercial fertilizers. The figures obtained in this experiment should serve as a partial answer to this question. A comparison of the results of these two methods is found in Table VI.

If we accept the figures on their face value, the superiority of farm manure must be conceded, altho comparison does not show a large difference in results from the two methods of treatment. In considering these figures, it should be borne in mind that altho

the amount of farm manure applied did not exceed what is regarded as a liberal quantity, doubtless the quantities of the valuable plant food elements present in the farm manure were much above those applied in the complete commercial fertilizer.

TABLE VI.— COMPARATIVE YIELD OF DRY MATTER, ALL CROPS, WITH FARM MANURE AND " COMPLETE " COMMERCIAL FERTILIZER.

	Total yield dry substance with clover in rotation	Total yield dry substance with timothy in rotation
	Lbs.	*Lbs.*
Farm manure	118,367.8	109,559.8
" Complete " fertilizer	113,917.2	106,297.9
	4,450.6	3,262.9

In Table I it is seen that on Plats 1 and 4 thirty thousand pounds of farm manure were applied to each plat twice in each rotation.

Analyses were made of this manure for five consecutive years, with the following results:

TABLE VII.— COMPOSITION OF FARM MANURE USED IN EXPERIMENT.

	Water.	Nitrogen.	Phosphoric acid P_2O_5.	Potash K_2O.	Lime Ca.O.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
	75.9	.386	.357	.339	.441
	77.8	.340	.222	.564	.317
	76.3	.486	.531	.784	.964
	76.7	.584	.500	.917	....
	71.4	.390	.398	.744	.744
Average	.....	.437	.401	.673	.611

It appears from these figures that on the average the following quantities of nitrogen, phosphoric acid and potash were applied every second year to Plats 1 and 4.

Nitrogen.	Phosphoric acid.	Potash.	Lime.
131 lbs.	120 lbs.	202 lbs.	183 lbs.

These are quantities much larger than were supplied in the most liberal application of commercial fertilizer.

Another factor to be considered is that the plats were allowed in grass but one year, so that the timothy plats were placed at a great disadvantage because of the well known fact that a timothy sod should be maintained more than one year in order to get maximum results. If, therefore, we subtract from the total quantities of dry matter produced under the two systems the dry matter contained in clover hay and timothy hay we are then able to compare the relative influence of farm manure and a complete commercial fertilizer in the production of the cereal grains. The figures are somewhat discordant. The farm manure appears to have produced somewhat better results on the clover plats but induced a yield on the timothy plats inferior to that of the commercial fertilizers. This is shown in Table VIII.

TABLE VIII.— FARM MANURE VS. CHEMICAL FERTILIZER FOR GRAIN CROPS.

	Total yield dry substance from grain crops with clover in the rotation.	Total yield dry substance from grain crops with timothy in the rotation.
	Lbs.	*Lbs.*
Farm manure	91,306.0	84,348.4
" Complete " fertilizer	90,194.4	89,944.8
	+1,111.6	—5,596.4

As this experiment so far conducted covers a period of seventeen years, these results have some weight in considering the efficiency of the two methods of maintaining fertility.

CLOVER AS A FACTOR IN FERTILITY.

Scientific investigation has shown conclusively that under certain conditions the leguminous plants are able to acquire atmospheric nitrogen. Basing arguments upon this fact, agricultural teachers have advised the farmers that clover is a very important factor in maintaining the fertility of the soil. Conclusive measurements of this value might not easily be discovered in the records of investigation. The claims for clover rest upon its acquisition of nitrogen, its extensive root development thereby enlarging the area from which plant food may be derived and also furnishing a relatively

large amount of organic matter to the soil when a clover sod is turned under. One of the objects of this experiment now under discussion was to make observation on the influence of clover on fertility. It is to be noted that during a period of seventeen years four of the plats in question have been seeded to clover and four plats to timothy. Fairness requires the statement that the timothy plats have not been wholly free from leguminous plants of one kind or another — red clover to a slight extent and one or more species of Trifolium in addition. Moreover, as only one year of cutting of timothy was permitted, the cereal crops have had a certain advantage because the crops from the timothy plats were not nearly as large as the crops from the clover plats. Nevertheless, there has been turned under a fine clover sod on four of the plats during each of the rotations. It was expected that the advantage of the clover would be seen particularly on the check plats and on the plats receiving a very limited amount of nitrogen in the commercial fertilizer. Table IX summarizes the relative yields on

TABLE IX.— EFFECT OF CLOVER ON CROPS IN ROTATION.

	Yield dry substance from the various methods of treatment with clover in the rotation.	Yield dry substance from the various methods of treatment with timothy in the rotation.	Differences: excess with clover. All crops.	Differences: excess with clover. Cereal crops.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*
Farm manure	118,367.8	109,559.8	8,808.0	6,957.6
Complete fertilizer	113,917.2	106,297.9	7,619.3	249.6
Partial fertilizer	100,091.9	88,932.4	11,159.5	4,391.4
No fertilizer	72,853.8	70,619.9	2,233.9	−1,934.9
Total difference	.....	.....	29,820.7	13,533.5

the plats with clover in the rotation and on the plats with timothy in the rotation.

If we were to accept these figures as they stand for all the crops, the claims for the value of clover in a rotation would be justified. In view of the fact that the yield of hay on the timothy plots was not as large as would have been true had the rotation continued for five years, giving a second year's growth of the timothy, it is probably fairer to judge the influence of the clover by its effect upon the yield of the cereal grains. If, therefore, we subtract from the total figures the yields of hay, the excess of the yield of the

clover plats (see last column of Table IX) is considerably reduced in all cases and with the check plats the larger yield is seen to be on the timothy plats. Perhaps a severer test of the value of the clover is to be seen in its influence upon the maintenance of crop production on the check plats. These plats produced crops during four rotations, covering seventeen years, and the figures given in Table X show the total value during these periods.

TABLE X.— RATE OF YIELD OF DRY SUBSTANCE IN A SERIES OF YEARS WITH NO FERTILIZER.

PLAT 2 — CLOVER IN ROTATION.

Rotations 4 years each.	Corn.	Oats.	Wheat.	Hay.	Total.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
First	7,887.7	4,436.4	2,060.6	2,256.0	16,946.7
Second	5,075.8	2,153.1	3,555.1	3,336.4	14,120.4
Third	6,024.4	3,553.5	3,046.0	1,834.7	14,458.6
Fourth	6,135.2	2,219.1	3,194.6	3,211.8	14,760.7

PLAT 6 — TIMOTHY IN ROTATION.

Rotations 4 years each.	Corn.	Oats.	Wheat.	Hay.	Total.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
First	7,677.0	4,690.6	2,578.4	2,757.8	17,705.8
Second	4,922.3	2,084.9	3,343.3	2,314.8	12,665.3
Third	5,660.4	3,415.9	3,793.1	3,398.2	16,267.8
Fourth	7,215.1	2,561.4	2,827.4	3,488.4	16,092.3

The figures in Table X are somewhat surprising. It appears that after the first rotation the yield of dry matter was practically maintained on a level with the exception of a crop in the timothy plats in the second rotation. The yield in the fourth rotation is found to have been practically as large as in any previous period excepting the first. It is well known that the soil on the Experiment Station farm has large potential fertility, but it is rather surprising that without the use of any fertilizer no decrease in productivity was observed during the last twelve years of cropping. The outstanding fact in this connection is that on the timothy plats the crop production was maintained as efficiently as on the clover plats.

SOIL ANALYSIS AS A MEANS OF MEASURING FERTILITY.

This long continued experiment in cropping land under different treatments has given an opportunity to make observations on the value of soil analysis as a means of measuring soil fertility. When the experiment was begun, in 1897, samples of soil were taken from the several plats, one set of samples representing the first six inches of soil and another set the second six inches. The samples were at that time analyzed, the total nitrogen and the percentage of other ingredients soluble in 1.2 sp. gr. strength hydrochloric acid being determined. At the end of the four rotations, covering seventeen years' cropping, samples were again taken from the several plats, one set representing the first seven inches in depth of soil and another set the second seven inches. In the latter case the plats were divided into two halves and separate samples were taken from the east and west halves. These latter samples were analyzed by methods which determined the total percentages present of the various ingredients and the first set of samples taken in 1897 were re-analyzed by a similar method. Table XI, XII and XIII give the results of these analyses.

TABLE XI.— SOIL NITROGEN IN SOIL OF 12 ACRE FIELD.

Old sample, first six inches; new sample, first seven inches.

No. plat.	Total nitrogen.						
	Old sample.		New samples, after 17 years' cropping.			Variation.	Treatment.
	1st analysis.	2nd analysis.*	East.	West.	Av. both halves.		
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	
1.	.191	.169	.190	.167	.178	.009	Clover, farm manure.
2.	.158	.158	.162	.121	.142	—.016	Clover, check.
3.	.197	.203	.243	.127	.185	—.018	Clover, P and min. N.
4.	.195	.197	.209	.146	.178	—.019	Timothy, farm manure.
5.	.194	.196	.175	.138	.157	—.039	Clover, P, K and max. N.
6.	.224	.217	.195	.122	.159	—.058	Timothy, check.
7.	.201	.208	.212	.142	.177	—.031	Timothy, P and min. N.
8.	.257	.257	.237	.156	.197	—.060	Timothy, P, K and max. N.

* After 16 years' storage.

Old sample, 7 to 12 inches; new sample, 8 to 14 inches.

1.	.106	.108	.109	.092	.100	—.008	Clover, farm manure.
2.	.089	.092	.094	.073	.084	—.008	Clover, check.
3.	.111	.132	.177	.107	.142	.010	Clover, P and min. N.
4.	.135	.142	.163	.088	.126	—.016	Timothy, farm manure.
5.	.159	.160	.113	.083	.098	—.062	Clover, P, K and max. N.
6.	.150	.145	.141	.092	.127	—.018	Timothy, check.
7.	.103	.104	.149	.081	.115	.009	Timothy, P and min. N.
8.	.164	.151	.176	.096	.136	—.015	Timothy, P, K and max. N.

TABLE XII.— PHOSPHORUS IN SOIL OF 12 ACRE FIELD.

Old sample, first six inches; new sample, first seven inches.

No. plat.	P_2O_5					
	Old sample.	New samples, after 17 years' cropping.			Variation.	Treatment.
		East half.	West half.	Av. both halves.		
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	
1	.112	.159	.121	.140	.028	Clover, farm manure.
2	.113	.133	.126	.130	.017	Clover, check.
3	.146	.202	.123	.163	.017	Clover, P and min. N.
4	.135	.179	.131	.155	.020	Timothy, farm manure.
5	.132	.136	.128	.132	.....	Clover, P, K and max. N.
6	.157	.171	.127	.149	—.008	Timothy, check.
7	.151	.177	.127	.152	.001	Timothy, P and min. N.
8	.158	.206	.124	.165	.007	Timothy, P, K and max. N.
Old sample, 7 to 12 inches; new sample, 8 to 14 inches.						
1	.093	.136	.114	.125	.032	Clover, farm manure.
2	.104	.120	.131	.125	.021	Clover, check.
3	.129	.184	.124	.154	.025	Clover, P and min. N.
4	.112	.163	.127	.145	.033	Timothy, farm manure.
5	.132	.123	.129	.126	—.006	Clover, P, K and max. N.
6	.140	.166	.124	.145	.005	Timothy, check.
7	.127	.161	.124	.142	.015	Timothy, P and min. N.
8	.139	.177	.122	.150	.011	Timothy, P, K and max. N.

TABLE XIII.— CALCIUM OXIDE IN SOIL OF 12 ACRE FIELD.

Old sample, first six inches; new sample, first seven inches.

No. Plat.	CaO.				
	Old sample.	New samples, after 17 years' cropping.		Average both halves.	Variation.
		East half.	West half.		
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
1	1.16	.95	1.25	1.10	—.06
2	1.16	.98	1.43	1.20	.04
3	1.16	1.07	1.49	1.28	.12
4	1.05	1.02	1.43	1.22	.17
5	1.13	.96	1.28	1.12	—.01
6	1.26	1.07	1.43	1.25	—.01
7	1.15	1.08	.86	.97	—.18
8	1.37	1.17	.73	.95	—.42

The figures are worthy of careful consideration. Much difference of opinion has existed as to the value of soil analysis in a study of the fertility of any given area of soil. It has been strongly held,

probably by a majority of those who have carefully considered this question, that a soil analysis is not competent to measure available plant food or to differentiate between the fertility of two apparently unlike soils or soils having greatly unlike treatment. Others have held that soil analysis is important in indicating potential fertility. A close study of these figures which give the percentages of nitrogen, phosphorus and calcium oxides in the soil from these several plats reveals no relation of these percentages to the productivity of the plats at the end of the experiment; nor do the figures indicate appreciable changes in the composition of the soils after seventeen years of greatly unlike treatment in the application of fertilizing materials. It might be expected that plats 1, 4, 5 and 8 would show not only in increased percentages of nitrogen, or at least would not show so large a decrease in the percentages as plats 2, 3, 6 and 7. A close examination of the figures does not show that the composition of the several soils or the changes in composition have any relation to treatment or productivity. Those who have carefully analyzed the possibilities of soil analysis will not be surprised at this result. The weight of soil in an acre to the depth of a foot is from three to four million pounds, according to the character of the soil, and in order to affect the composition of this weight of material sufficiently to be revealed through present methods of analysis would require the removal of very large quantities of soil compounds. We have yet much to learn concerning the laboratory examination of soil as a means of measuring soil fertility.

THE BUSINESS SIDE OF THE EXPERIMENT.

It has been quite customary in discussing field experiments with fertilizers to measure the results of the different methods of treatment by the market value of the increase of crops which the fertilizers produce. Such experiments, if expressed only in terms of market values, are merely tests of business methods. The final figures are merely an expression of profit or loss, and with a given system of fertilization profit might be realized one year and loss the next, or profit might be secured in one locality and loss in another. The conclusions regarding an experiment formulated in this way do not express anything fundamental. It is possible, however, to study results as expressed in market values so as to get a comparison of

relative profits under a given set of circumstances, but the figures displayed may have a very limited application.

Since the experiment under consideration was begun, there has been a very great change in market prices both of fertilizers and crops. In Table XIV there is stated as nearly as can be estimated the prices of fertilizing materials and crops during the main portion

TABLE XIV.— RANGE OF PRICES DURING EXPERIMENT.

FERTILIZER PRICES.	Ton prices during experiment.	Present prices per ton.
Acid phosphate	$14.00	$26.00
Dried blood, 10% N	40.00	80.00
Nitrate soda, 15% N	54.00	90.00
Muriate potash, 50%	45.00	225.00
Stable manure	2.00	4.00

PRICES OF PRODUCE.	Prices during experiment per ton.	Present prices per ton.
Silage	$3.00	$6.00
Hay	10.00	20.00
Oat straw	8.00	12.00
Oat grain	*.40	*.70
Wheat straw	6.00	12.00
Wheat grain	*1.00	*2.50
Barley straw	5.00	10.00
Barley grain	*1.00	*1.00

* Price per bushel.

of the time covered by the experiment and also prices at the present time. There is given in Tables XV to XVIII the increase in crops from various methods of treatment, both of the crop as harvested and of the dry substance, the cost of the fertilizers and the values of the crops. On the basis of these figures there is calculated the excess of crop values over fertilizer costs and the cost of one pound of increase of both total and dry substance on all of the plats.

TABLE XV.— INCREASES OF PRODUCTION DUE TO FERTILIZERS ON PLATS WITH CLOVER IN ROTATION.

	PLAT 1.		PLAT 3.		PLAT 5.	
	Crops as harvested.	Dry Substance.	Crops as harvested.	Dry substance.	Crops as harvested.	Dry substance.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Corn silage	57,289	15,617	28,380	8,275	46,006	12,444
Oat straw	2,905	2,535	2,960	2,747	3,348	2,900
Oat grain	2,400	2,079	2,282	2,015	2,383	2,128
Wheat straw	7,418	7,125	4,533	3,629	7,252	6,455
Wheat grain	4,988	4,451	3,165	2,875	5,579	4,904
Barley straw	883	821	737	605	874	767
Barley grain	660	597	242	221	625	560
Hay	16,752	12,243	8,310	6,871	11,406	8,904
Totals	.....	45,514	.....	27,238	.....	39,063

TABLE XVI.— COMPARISON OF FERTILIZER COSTS, CROP INCREASES AND VALUES ON PLATS WITH CLOVER IN ROTATION.

	PLAT 1.		PLAT 3.		PLAT 5.	
	Former value crops.	Present value crops.	Former value crops.	Present value crops.	Former value crops.	Present value crops.
Corn silage	$85.92	$171.87	$42.51	$85.14	$69.00	$178.00
Oat straw	11.62	17.43	11.85	17.76	13.39	20.08
Oat grain	30.20	52.56	28.52	49.97	29.80	52.19
Wheat straw	22.25	44.50	13.60	27.20	21.75	43.50
Wheat grain	83.13	207.82	52.75	131.87	93.00	242.50
Barley straw	2.20	4.40	1.84	3.68	2.18	4.36
Barley grain	9.44	9.44	3.52	3.52	8.96	8.96
Hay	83.76	167.52	41.15	82.50	57.03	114.06
Value crops	328.52	675.54	195.79	40.144	295.11	663.65
Fertilizer cost	267.32	544.00	70.29	145.73	220.69	618.26
Excess	61.20	131.54	125.50	255.71	74.42	45.39
Fertilizer cost of 1 lb. dry substance	.587¢	1.195¢	.258¢	.535¢	.565¢	1.583¢

TABLE XVII.— INCREASE IN PRODUCTION DUE TO FERTILIZERS ON PLATS WITH TIMOTHY IN ROTATION.

	Plat 4.		Plat 7.		Plat 8.	
	Crops as harvested.	Dry substance.	Crops as harvested.	Dry substance.	Crops as harvested.	Dry substance.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Corn	34,661	8,317.1	17,395	6,116.4	51,774	15,513.0
Oat straw	3,484	3,343.4	1,378	1,302.4	3,092	2,732.7
Oat grain	1,977	1,751.9	886	835.9	1,878	1,655.9
Wheat straw	6,823	6,163.9	3,737	3,354.2	4,448	4,125.5
Wheat grain	4,512	3,949.5	2,426	2,074.6	4,392	3,927.6
Barley straw	348	496.	204	187.5	1,163	1,014.7
Barley grain	406	365.8	135	79.8	730	654.9
Hay	17,411	14,561.8	4,987	4,271.8	5,829	5,703.5
Totals	.....	38,950.1	.....	18,322.6	.....	35,387.8

TABLE XVIII.— COMPARISON OF FERTILIZER COSTS AND CROP VALUES ON PLATS WITH TIMOTHY IN ROTATION.

	Plat 4.		Plat 7.		Plat 8.	
	Former value crops.	Present value crops.	Former value crops.	Present value crops.	Former value crops.	Present value crops.
Corn	$51.99	$103.98	$26.09	$52.18	$77.67	$155.34
Oat straw	13.92	20.88	5.51	8.35	12.37	18.55
Oat grain	24.72	43.29	11.04	19.32	23.48	41.09
Wheat straw	20.46	40.92	11.21	22.42	13.34	26.68
Wheat grain	75.00	187.50	40.40	101.00	73.20	183.00
Barley straw	.87	1.74	.34	.68	2.90	5.80
Barley grain	5.60	5.60	2.91	2.91	10.40	10.40
Hay	87.00	174.00	24.93	49.86	29.15	58.30
Value crops	279.56	577.91	142.53	256.72	242.51	599.16
Fertilizer cost	267.32	534.	70.39	145.73	220.69	618.26
Excess value crops	12.24	43.91	72.14	80.99	21.82	—19.10
Fertilizer cost, 1 lb. dry substance	.686¢	1.372¢	.384¢	.795¢	.623¢	1.747¢

It is entirely clear from the foregoing figures that the cheapest increase of production was secured by the use of acid phosphate, supplemented by a small proportion of sodium nitrate. Unquestionably, with this method of treatment the additional

yield of crops cost much less than the sum for which they could have been purchased either at former prices or at the prices now prevailing. Whether or not the increased yield from the use of the complete fertilizer with a maximum amount of nitrogen would be profitable would depend upon circumstances. It is very difficult to draw conclusions as to business results which would be generally applicable. It is certain that the returns from the use of farm manures indicate that this fertilizer was worth approximately the prices named.

CHANGE IN THE EXPERIMENTAL PLAN.

Beginning with the year 1914, each of the eight plats involved in the first seventeen years of the experiment was divided into two, making sixteen plats in all. This was done in order to study the results from the use of raw ground phosphate and to get additional information concerning the use of nitrogenous fertilizers. There follows the general scheme under which the experiment is now being conducted.

PLAN OF FERTILIZATION FOLLOWING THE YEAR 1913

12 ACRE FIELD

1 a. 15,000 pounds manure *twice* in rotation — corn, wheat.
1 b. 15,000 pounds manure once in rotation — wheat.
2 a. Raw ground phosphate, 300 pounds — corn, wheat.
2 b. Nothing.
3 a. Acid phosphate, 300 pounds. / Dried blood, 175 pounds, nitrate soda, 50 pounds — corn, wheat.
3 b. Acid phosphate, 300 pounds. / Dried blood, 350 pounds, nitrate soda, 100 pounds — corn, wheat.
4 a. 15,000 pounds manure, *twice* in rotation — corn, wheat.
4 b. 15,000 pounds manure, *once* in rotation — wheat.
5 a. Raw ground phosphate, 300 pounds. / Dried blood, 350 pounds, nitrate soda 100 pounds, muriate potash, 100 pounds. — corn, wheat.
5 b. Acid phosphate, 300 pounds. / Dried blood, 350 pounds, nitrate soda, 100 pounds, muriate potash, 100 pounds. — corn, wheat
6 a. Raw ground phosphate, 300 pounds.
6 b. Nothing.
7 a. Acid phosphate, 300 pounds. / Dried blood, 175 pounds, nitrate soda, 50 pounds — corn, wheat.
7 b. Acid phosphate, 300 pounds. / Dried blood, 350 pounds, nitrate soda, 100 pounds — corn, wheat.
8 a. Raw ground phosphate, 300 pounds. / Dried blood, 350 pounds, nitrate soda, 100 pounds, muriate potash, 100 pounds. — corn, wheat.
8 b. Acid phosphate, 300 pounds. / Dried blood, 350 pounds, nitrate soda, 100 pounds, muriate potash, 100 pounds. — corn, wheat