Soil and Crop Yield Analyses of a Long Term Crop Rotation Experiment

A THESIS

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ABSTRACT

The long term soil fertility experiment under study involved a 4-year rotation of fallow, wheat, corn, wheat. A range of manure treatments using rates from 5 to 30 tons per acre, was applied once each cycle of the rotation for 36 years. Soil and crop yield analyses were used to measure the effects on the fertility of the soil of these repeated applications of manure.

Soil analyses indicated that the content of organic matter, nitrogen, total, inorganic and available phosphorus was proportional to the rates of manure applied. The carbon-nitrogen ratio was similar for all rates. The organic phosphorus content was greater on the lower rates. Movement into the profile of nitrogen and phosphorus had occurred.

Long term yield increases on corn and wheat after corn were proportional to the rates of manure applied, although increases on the wheat on fallow crop from 10-ton and 30-ton rates were not significantly different. Short term yield increases on corn and wheat after corn were larger in later cycles of the experiment, due to the cumulative effect of manure treatments and to declining check yields. There was little difference between returns of wheat on fallow in later years compared with those of earlier cycles. Crop yields, particularly those of corn and wheat after corn on the high rate treatments, indicated a high level of fertility, in agreement with the high nutrient contents obtained by soil analyses. Under favorable seasonal conditions large yield increases resulted from this high yield potential. Under less favorable conditions very low returns were often recorded. The largest returns per ton of manure applied, were obtained from the 5-ton rate.

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I. INTRODUCTION

For more than one hundred years agricultural scientists have used field experiments to evaluate the effects of management practices on crop yields and on soil fertility. Since organic materials were frequently the principal source of plant nutrients available, numerous experiments were established to determine their effects on crop production. As mineral fertilizers were developed they have gradually received more emphasis in experimental work.

Mineral fertilizers, as a rule, are useful only as sources of plant nutrients. Beneficial effects of organic fertilizers are usually attributable to their value both as sources of plant nutrients and their effect on physical properties of the soil.

The long term farm-manure experiment reported herein is of interest since Manitoba soils are known to respond to the nitrogen and phosphorus supplied by manure. In addition these soils respond to improvement in soil structure due to manure. As physical condition and fertility of soil decline with continued cultivation and through erosion the value of organic materials becomes more important.

This paper presents an interpretation of the effects of repeated applications of manure on the level of soil fertility as measured by such chemical analyses as organic matter, nitrogen and total, organic, inorganic and available phosphorus. In addition, these effects on the resulting crop yields are interpreted.

II. REVIEW OF LITERATURE

Farm manure is a valuable by-product of livestock production because of its content of plant nutrients and organic constituents. When used to increase crop production its effects may be due to the nutrients supplied or to improvement in the physical properties of the soil. These two-fold effects have been shown to be most pronounced on soils of low fertility or poor structure. Farm manure may be applied to the soil as fresh undecomposed material or as rotted material. The term rotted manure indicates that the original structure of the materials has largely disappeared. Since the experiment outlined here is mainly concerned with the rotted material, further use of the term manure refers to this form.

In addition to supplying approximately 0.5%N, 0.25% P_2O_5, and 0.5% K_2O, rotted farm manure contains appreciable quantities of calcium, magnesium, and sulphur, and may also supply significant amounts of manganese, zinc and copper. Small amounts of boron may be present (12). Farm manure also provides such plant growth promoting substances as creatinine (12). The reducing action of manure decomposing in the soil aids in making iron and manganese available; these elements are sometimes insoluble under excessively oxidizing conditions. The soluble organic matter supplied by manure is believed to aid in keeping phosphates in solution, thus increasing their availability (19).

A. EFFECT OF FARM MANURES ON SOIL STRUCTURE

The value of farm manure in relation to soil structure has been emphasized frequently in the literature. The benefits from its use have been most marked in heavy and on light textured soils. Manure improves such physical properties as aggregation, aeration, water holding capacity, permeability and temperature relations. It also increases the biological activities of soil organisms, thus making plant nutrients available for immediate use.

The importance of favorable soil physical conditions has been emphasized by Baver and Farnsworth (14) in an experiment with sugar beets. As aeration was improved yields increased 3 to 5 fold; while, at the same time, the need for fertilizers increased on a soil which previously had given no response to applications of fertilizers. Russell and Appleyard (3) have shown that the addition of manure to a fallow soil tripled the CO_2 content of the soil air, an indication of greatly increased biological activity. Root crops have produced the greatest returns from improvement in soil structure.

When used as a surface mulch, manure will retard soil erosion by wind or water and reduce evaporation of soil moisture.

B. EFFECT OF FARM MANURES ON SOIL FERTILITY

1. Soil Organic Matter and Nitrogen

Under most cropping systems there is a gradual and continuous decrease in soil organic matter and hence nitrogen, since the two are closely related. On a Red River clay soil Poyser et al. (15) showed that there has been an over-all decrease of 27.9% in the organic carbon content, and 15.9% of the nitrogen during a twenty-five year period of cropping to a fallow, wheat, corn, wheat rotation. This decrease in soil fertility had been significantly retarded by the application of 10 tons of rotted farm manure in the fallow year. Data from the Ohio experimental station indicated that after 32 years of a corn, oats, wheat, clover, timothy rotation with no manure, the organic matter content was 76% of the original. With 8 and 16 tons of manure, applied in the rotation, the organic matter was 93 and 102% of the original (22).

Soil organic matter is not maintained only by the incorporation of straw or other material, the composition of which differs greatly from that of stabilized soil humus. Much of the organic matter of farm manure has a

C:N ratio of 10:1 which is approximately the same as that of soil humus, whereas straw has a C:N ratio of about 50:1 (22). While straw requires nitrogen from the soil to decompose, good farm manure contains sufficient available nitrogen to decompose a normal amount of straw and also to supply some nitrogen for the immediate needs of the crop.

Through increased biological activity manure increases the rate at which nitrogen is made available. In two-year rotations of non-legumes on a very fine sandy loam soil in Nebraska (22) where manure had been applied at the rate of 6 tons per acre annually for 30 years, the nitrification rate in the surface soil was doubled, as compared to the non-manured plots. The nitrification rate in the 6 to 12 inch layer was also greatly increased.

During the fallow year of a fallow, wheat, wheat, wheat rotation in an experiment located on a Red River clay soil, Michalyna (11) found that 76.7 pounds of nitrate nitrogen per acre were accumulated to a depth of 3 feet on manured plots as compared to 49.5 pounds on the non-manured plots. Four tons of manure per acre had been applied for each crop grown on the manured plots.

Since about 50% of the nitrogen of farm manure is in organic fractions which are relatively resistant to decomposition, the nitrogen in manure is considered to be about one half as effective as the nitrogen in commercial fertilizer. With continued applications of manure the nitrogen is released at a constant rate and over a period of years the over-all efficiency is considerably greater than 50% of that of commercial fertilizer (19).
The residual effects of annual applications of manure at 14 tons per acre from 1852 to 1872 were determined on a long time experiment in England (8). Forty years after these applications had ceased the yield of barley on these plots was still double that of the untreated plots. Since farm manure contains nitrogen and phosphorus in organic form the effects

of manure on crop yields tend to be distributed over a longer period of time than those of commercial fertilizers.

2. Soil Phosphorus

Applications of farm manure will increase soil phosphorus content. On a Nebraska soil, 6 tons of manure applied annually for 30 years doubled the content of soluble phosphorus as compared to the non-manured soil (22). On a Red River clay soil application of 10 tons of manure in a fallow, wheat, corn, barley rotation significantly increased the total, inorganic and available phosphorus in the surface 6 inches of soil (17). Manure had been applied once every four years over a period of 37 years.

The phosphorus in farm manure occurs in both organic and inorganic combination. During decomposition the phosphorus is released from the organic compounds into available phosphorus in such forms as ammonium phosphates and mono-calcium phosphates. A review of a large number of experiments indicates that the phosphorus in farm manure is as effective as phosphorus in commercial fertilizer (22). Under some conditions the phosphorus in farm manure may be more effective than that in commercial fertilizers. This is due to increase in acidity from release of CO_2 and to other products of decomposition which aid in making phosphorus available. In addition, the gradual release of phosphorus from the organic complex may result in less fixation by the soil (22). Olsen and Fried (14) show that availability of phosphorus may be increased by the presence of organic matter. An increase in total and available phosphorus due to applications of manure has been obtained by Lipps and Fox (10).

The effect of the phosphorus in farm manure is apparent for a number of years. In a North Carolina experiment (22) the phosphorus was found to be effective for 10 years after applications had ceased.

In a greenhouse experiment on Grey Wooded soil, Wyatt (27) showed that the yield of four consecutive crops grown in pots receiving manure was equal to that obtained from pots fertilized with commercial fertilizers supplying N, P, K and lime. The complete commercial fertilizer resulted in a higher yield of the first crop but gave very little residual effect. Manure, on the other hand, resulted in a 28% increase in yield of the fourth crop as compared to the yield of checks.

Wright et al. (25) indicated that applications of manure have increased the organic matter level, the readily soluble phosphorus and the exchangeable base content of an acid fine-sandy-loam soil. They state that manure has been extremely beneficial on this soil.

C. EFFECT OF APPLICATIONS OF MANURE ON CROP YIELDS

On a Red River clay soil applications of 10 tons of manure in the fallow year of fallow, wheat, corn, wheat and fallow, wheat, corn, barley rotations considerably increased yields on all crops (9, 17). On the other hand, Ridley (17) found that mineral phosphorus fertilizer increased yields on the first crop, but gave no residual effect on second and third crops.

In general the less fertile the soil the more valuable the manure. In one experiment in Ohio (22) the surface soil was removed from a plot and spread over a similar untouched area of the same size. These two plots and one with a normal depth of top soil, were cropped for a number of years with and without applications of manure. The manure was most valuable on the area with the top soil removed and least valuable on the plots with a double thickness of top soil.

On eroded Souris light sandy loam, an experiment was established to compare manure with commercial fertilizers on a fallow, wheat, wheat rotation (16). The 20-year average yields of wheat on fallow resulting from 10 tons of manure applied in the rotation have been equal to those obtained from 11-48-0 at 40 pounds per acre. Increases in yield of second crop wheat due to the residual effect of the manure have been similar to those from 16-20-0 at 96 pounds per acre.

In an experiment which compared fertilizers with manure on a podzol gravelly loam in Quebec, cropped to a rotation of turnips, oats, clover, hay and timothy, applications of manure gave the highest yields of all crops (20). The best combination appeared to be manure and superphosphate.

A similar experiment which compared the effects of manure and chemical fertilizers for the production of potatoes on a fine sandy loam soil (pH 5.0) was conducted in Prince Edward Island (25). The largest yields were obtained on the manured plots. The yields were larger where manure alone was used than where half manure and half fertilizer was employed.

In general, manure has been most effective in increasing crop yields when applied on soils of low fertility, on eroded soils, or on those of poor structure. Root crops appear to benefit most from the use of manure.

III. EXPERIMENTAL PLOT DESIGN AND METHOD OF SAMPLING

The experiment outlined here consists of a four-year crop rotation of: Year 1 - Fallow; Year 2 - Wheat; Year 3 - Corn; Year 4 - Wheat. Although established in 1919 annual yields from these crops are incomplete since barley was substituted for wheat in 1919, 1920, 1927, 1929 and 1930. The rotation is located on four fields, or blocks, each block representing a year in the rotation.

Each block is divided into eleven plots 1/40 acre (16 x 68 feet) in size. There is a four-foot guard strip between plots and along each end to eliminate the border effect. The manured and non-manured treatments are located on these eleven plots in a systematic order. The experiment provides for all crops and all treatments, once each year, with no replication. Table 1 shows the arrangement of the treatments and the rates of manure applied. The manure is applied on wheat stubble of year 2, and plowed down. Corn is thus the first crop after manuring.

Individual plots were harvested each year. Yields of wheat were recorded in bushels per acre and yields of corn were recorded in tons per acre, green weight.

In the fall of 1956 duplicate samples at two depths, 0 to 6 and 6 to 12 inches, were obtained from plots 1, 2, 4, 5, 6, 8, 10 and 11 on each block. Each sample was a composite of three sites. The samples were air dried in the laboratory and ground to pass through a 2mm sieve.

Table 1. Experimental plot arrangement and manure treatment.

Plot No.	Treatment and rate of application		Represented by:
1.	Check		Check
2.	Fresh manure, long straw,	10 tons per acre	F.M.L.S. 10T.
3.	Fresh manure, short straw,	10 tons per acre	F.M.S.S. 10T.
4.	Rotted manure	5 tons per acre	R.M. 5.T.
5.	Rotted manure	10 tons per acre	R.M.10.T.
6.	Check		Check
7.	Rotted manure	15 tons per acre	R.M.15.T.
8.	Rotted manure	20 tons per acre	R.M.20.T.
9.	Rotted manure	25 tons per acre	R.M.25.T.
10.	Rotted manure	30 tons per acre	R.M.30.T.
11.	Check		Check

IV. SOIL TYPE

The soils on which the experiment is located have been described by Ehrlich *et al.* (5) as members of the Red River and Fort Garry associations. These are clay textured soils developed from lacustrine deposits. The clay is variable in depth and is underlain by a highly calcareous silty clay loam substrate.

The soils in the map of the experiment (Appendix i) representing the plot area have been interpreted on the basis of the depth of the clay over the calcareous material.

They are represented by the following:

1. Fort Garry clay, imperfectly drained, 0 to 12 inches
2. Fort Garry clay, imperfectly drained, deep phase, 12 to 24 inches.
3. Red River clay, imperfectly drained, 24 to 36 inches.
4. Red River clay, imperfectly drained, 36 inches or more.
5. Red River clay, poorly drained, 36 inches or more.

V. INVESTIGATIONAL PROCEDURE

A. Soil Analyses

1. Organic Carbon, Organic Matter and Inorganic Carbon.

The total carbon and inorganic carbon were determined by the wet combustion method developed by Adams (1) and Waynick (24) and modified by O. G. Caldwell of the Soils Department, University of Manitoba. The organic carbon, i.e., the difference between the total carbon and the inorganic carbon content was multiplied by the Van Bemmelen factor of 1.724 to obtain the organic matter content (Waksman 23).

The total carbon was determined by oxidizing a 1 gram sample of less than 2mm. oven-dry soil with a 55 ml. of a chromic-sulphuric acid mixture. The carbon dioxide evolved was dried by passing it through a sulphuric acid bath and over calcium chloride and magnesium perchlorate crystals. Any chlorides present were removed from the gas by passing it over amalgamated zinc. The carbon dioxide was collected in a tared Nesbitt tube containing Ascarite. The weight of carbon dioxide evolved was converted to total carbon.

The inorganic carbon was determined by digesting 2 grams of less than 2 mm. oven-dry soil with 60 ml. of 1:10 HCl. Carbon dioxide was removed from the air entering the digestion flask by bubbling it through concentrated NaOH. The carbon dioxide evolved from the digestion was drawn through an absorption train consisting of a tube of Dehydrite and calcium chloride. The gas was then collected in a Nesbitt tube containing Ascarite. The weight of the carbon dioxide collected in the Nesbitt tube was converted to inorganic carbon.

The difference between the total and the inorganic carbon represented the organic carbon content. The organic carbon, expressed in percent of the total weight of the samples was then converted to percent organic matter by multiplying by the factor 1.724.

In addition, the inorganic carbon was expressed as calcium carbonate in percent of the weight of the sample.

2. Total Nitrogen

Total nitrogen content was determined by the modified Kjeldahl method (2). A 2-gram sample of 2 mm. oven-dried soil was placed in a digestion flask and the following materials were added: 10 grams of K_2SO_4, 0.3 grams of $CuSO_4$, 0.7 grams of HgO and 25 ml. of concentrated H_2SO_4. The sample was digested for 30 minutes. After cooling, 200 ml. of H_2O, 25 ml. of $Na_2S_2O_3$ solution, 60 ml. of concentrated NaOH and a few pieces of zinc were added.

The flask was placed on the distillation rack and the contents were distilled for 20 minutes into 25 ml. of 0.1N H_2SO_4. The distillate was then titrated with 0.1N NaOH. A Blank titration of the 25 ml. of acid was made with the NaOH. The ml. of NaOH, equivalent to the nitrogen in the soil sample converted to $(NH_4)_2SO_4$, was equal to the difference between the ml. of base required for the blank and the ml. of base used for the sample titration.

The nitrogen content was then calculated in percent by weight as follows:

$$\text{Percent nitrogen} = \frac{\text{Normality of NaOH} \times \text{ml. of NaOH} \times 14 \times 100.}{1000 \times \text{weight of sample}}$$

3. Carbon-Nitrogen Ratio

The carbon-nitrogen ratio was calculated by dividing the organic carbon by the total nitrogen content.

4. Total Phosphorus

The total phosphorus content of the soil was determined by the ignition method outlined by Saunders and Williams (18). A 2-gram sample of less than 2 mm. air dry soil was ignited in a muffle furnace at 550°C for one hour. The ignited sample was shaken in 100 ml. of 0.2N H_2SO_4 for 3 hours and filtered.

A 10 ml. aliquot of filtrate was placed in a 100 ml. volumetric flask and diluted to approximately 90 ml. with distilled water. Four ml. of 2.5 percent ammonium molybdate in 10N H_2SO_4 were added and the solution was shaken several times. One ml. of a freshly prepared 0.8 percent solution of $SnCl_2 \cdot 2H_2O$ in 10 percent by volume HCl was then added. The solution was diluted to 100 ml. with distilled water, shaken and allowed to stand for 30 minutes to permit maximum color development.

The total phosphorus extracted by this method was measured colorimetrically as ammonium phosphomolybdate by means of a Coleman Universal Spectrophotometer set at a wavelength of 450 millimicrons. Results were expressed in parts per million of soil.

5. Inorganic Phosphorus

The method used for inorganic phosphorus was the same as that used for total phosphorus except that the soil sample was not ignited.

6. Organic Phosphorus

The difference between the total phosphorus and the inorganic phosphorus represented the organic phosphorus content.

7. Available Phosphorus

Available phosphorus was determined using the method described by Olsen _et al._ (13). Five grams of less than 2 mm. air dry soil were shaken for 30 minutes with a teaspoonful of pre-treated charcoal in 100 ml. of 0.5M $NaHCO_3$. The extraction mixture was then filtered and a 50 ml. aliquot of the filtrate was placed in a 100 ml. volumetric flask.

The colorimetric method of Dickman and Bray (6) was used to quantitatively determine the available phosphorus extracted. The following steps were performed in a minimum of time. To the 50 ml. aliquot of filtrate were added 1.5 ml. of concentrated HCl and 20 ml. of ammonium molybdate in HCl solution. These were added slowly and with constant shaking. The neck of the flask was rinsed with distilled water and 10 ml. of dilute reducing agent were added.

The solution was diluted to 100 ml. with distilled water, shaken well and allowed to stand for 5 to 20 minutes to permit maximum color development.

The available phosphorus was determined colorimetrically as outlined for the total phosphorus determination. Results were expressed in parts per million of soil.

B. Crop Yield Analyses

The soil fertility experiment under study provided for each crop and all fertility treatments each year, but did not include the other two factors necessary for a standard statistical analysis of the yield data, i.e., randomization and replication. Terman and Freeman (21) suggested that lack of replication for any one year in the experiment is partially offset by providing for repetition of all crops and treatments each year. They presented a method of analysis which uses a cycle of one crop in the rotation, to represent a replicate. A similar procedure has been outlined by Cochran (5). In the interpretation of this experiment the following procedures were applied to each of the three crops.

1. Years as Replication

Average annual yields of all treatments were arranged in 4-year cycles, according to the ranges on which these yields occurred. The 28 annual yields were considered as replicates and analyzed to determine the effect on production of seasonal factors and of differences among ranges. The results of this procedure for wheat on fallow are outlined in Appendix (iii).

2. Cycles as Replication

Since each crop completed a cycle of the 4 ranges every 4 years, 28 years of the experiment were represented by 7 complete cycles or replicates. Each treatment therefore, occurred 7 times on each range. This analysis was used to determine significant differences within treatments, 4-year cycles and ranges and to indicate differences in response to treatments on different ranges. The ranges or fields were analyzed as main plots and the 11 treatments as sub-plots. This method for wheat on fallow is presented in Appendix (iv).

3. Long Term Yield Trends and Yield Variability

The long term trends in yields for each crop, representing seasonal and treatment effects, were determined by calculating a regression coefficient for each treatment. This term indicates the slope of the linear equation representing the yields obtained during the experiment. The degree of yield variability was measured by means of the standard deviation applied to check, 10-ton and 25-ton treatments. The variability of each treatment was expressed in percent of its mean yield, i.e., the coefficient of variability. Annual yields and yield trends of treatments 1, 4, 5, 6, 8, 10 and 11 are presented in Figures 1 to 9 in Appendix (ii).

4. Short Term Yield Increases due to Treatments

Four-year average increases in yield over the adjacent checks were determined to demonstrate the short term effects of manure treatments on yields of each crop.

5. Long Term Yield Increases due to Treatments.

Average yield increases for each of the three crops, for the 28-year period were compared with the recent 12-year period.

VI. EXPERIMENTAL RESULTS AND DISCUSSION

A. Soil Analyses

The results from soil analyses of plots which have been under treatment once every 4-year rotation cycle for 36 years are presented in Tables 2 and 3.

Table 2. Organic carbon, organic matter, inorganic carbon, nitrogen and organic carbon-nitrogen ratio, of samples taken from the 0 to 6 and 6 to 12 inch depths on check plots and those receiving manure treatments every 4 years for 36 years. (Average of 4 ranges - in percent by weight).

Plot No.	Treatment tons/acre	Organic carbon 0 to 6"	Organic carbon Increase over checks 1,6	Organic matter 0 to 6"	Organic matter Increase over checks 1,6	Inorganic carbon 0 to 6"	Nitrogen 0 to 6"	Nitrogen Increase over checks 1,6	Nitrogen 6 to 12"	Nitrogen Increase over checks 1,6	Organic carbon-nitrogen ratio 0 to 6"
1	check	3.00		5.17		1.14	0.259		0.142		11.4
2	F.M.L.S.10T.	3.14	0.14	5.41	0.24	1.01	0.261	0.002	0.159	0.017	12.1
4	R.M. 5T.	3.00		5.17		0.73	0.293	0.005	0.179	0.021	10.2
5	R.M.10T.	3.35	0.14	5.77	0.24	0.48	0.292	0.004	0.154		11.4
6	check	3.21		5.53		0.39	0.288		0.158		11.0
8	R.M.20T.	3.74	0.53	6.45	0.92	0.64	0.342	0.054	0.216	0.058	10.9
10	R.M.30T.	4.42	1.21	7.62	2.09	0.67	0.371	0.083	0.223	0.065	11.8
11	check	3.57		6.15		0.66	0.305		0.192		11.6
Average 1,6,11		3.26		5.62		0.73	0.284		0.164		11.3

Plot 2 compared to check 1.

The results in Table 2. for checks 1, 6 and 11 indicate an increase in organic matter and nitrogen content from plots 1 to 11. It is possible that there has been sufficient movement of soil from the adjacent plots to affect the organic matter contents. This would be expected to affect plot 6 more than plot 1 because it is between two manured plots. It would also be expected to have an appreciable effect on plot 11 since its adjacent plot has received the highest rate of manure application, i.e., 30 tons per acre. Due to this lack of agreement among checks comparisons were made between treatments and checks 1 and 6.

Following applications of manure every four years for thirty-six years there has been no increase in organic matter due to the 5-ton rate. The increase due to the fresh manure at 10 tons per acre was 0.24%. This is equal to that obtained with the same rate of rotted manure. While 10 tons of rotted manure increased the organic matter content by 0.24% the difference due to the 20-ton rate was 0.92%. The 30-ton rate has produced an eight-fold greater increase in organic matter than the 10-ton rate. In general, rates greater than 10 tons per acre resulted in organic matter contents which were substantially higher than those on the check plots.

Applications of manure have had a similar effect on nitrogen content as on organic matter at the 0 to 6 inch depth. There was little difference between the 5-ton and 10-ton rates or between fresh or rotted manure. However, as rates were increased from 10 to 20 tons per acre the increase in nitrogen content as compared to check plots, rose from 0.004% to 0.054%. The increase due to an application of 30 tons per acre was 0.083%.

The average increase in nitrogen resulting from manure treatments at 6 to 12 inches was almost equal to those at the 0 to 6 inch depth. This could be due to greater root growth in the lower depth of manured plots. This fact could also be the result of downward movement of nitrate nitrogen and its reduction to organic form at that level.

The carbon-nitrogen ratios calculated from organic carbon and nitrogen determinations on the 0 to 6 inch depth represent the effect of repeated applications of manure. A relatively high carbon level in relation to nitrogen on the fresh manure treatment was probably due to the fact that this application supplied more organic matter per ton than rotted manure. The lower ratio of carbon-nitrogen on the 5-ton rate indicates a greater rate of decomposition of organic matter, i.e. increased biological activity on these plots over those of the checks or other rates.

The inorganic carbon content expressed as calcium carbonate does not appear to have been influenced by applications of manure.

Table 3. Soil phosphorus content at 0 to 6 and 6 to 12 inches in depth on check plots and those receiving the manure treatments indicated. (Average of the 4 ranges in p.p.m.).

		Organic phosphorus				Inorganic phosphorus			
Plot No.	Treatment tons/acre	0 to 6"	Increase over checks 1,6	6 to 12"	Increase over checks 1,6	0 to 6"	Increase over checks 1,6	6 to 12"	Increase over checks 1,6
1	check	282		226		214		241	
2	F.M.L.S.10T.	292	10	218		230	16	239	
4	R.M. 5T.	286	17	206	13	234		225	
5	R.M.10T.	286	17	234	41	280	32	236	1
6	check	269		193		248		235	
8	R.M.20T.	250		228	35	386	138	296	61
10	R.M.30T.	209		192		457	209	299	64
11	check	275		220		279		246	
Average 1,6,11		274		213		247		241	

		Total phosphorus				Available phosphorus			
Plot No.	Treatment tons/acre	0 to 6"	Increase over checks 1,6	6 to 12"	Increase over checks 1,6	0 to 6"	Increase over checks 1,6	6 to 12"	Increase over checks 1,6
1	check	496		467		14.6		6.5	
2	F.M.L.S.10T.	522	26	457		20.6	6.0	7.2	.7
4	R.M. 5T.	520	3	431	3	25.2	2.0	6.9	
5	R.M.10T.	566	49	470	42	35.0	11.8	8.3	1.1
6	check	517		428		23.2		7.2	
8	R.M.20T.	636	119	524	96	62.3	39.1	29.9	22.7
10	R.M.30T.	666	149	491	63	83.3	60.1	35.6	28.4
11	check	554		466		28.0		10.2	
Average 1,6,11		499		454		21.9		8.0	

The results in Table 3 for check plots 1, 6 and 11 indicate increasing inorganic and available phosphorus contents from plots 1 to 11. The amounts of inorganic phosphorus at the 0 to 6 inch depth of these plots were 214, 248 and 279 p.p.m., respectively. Good agreement has been obtained between plots 1, 6 and 11, (241, 235 and 246 p.p.m. respectively) at the 6 to 12 inch depth. Available phosphorus increased from check 1 to check 11 at each depth. At 0 to 6 inches 14.6, 23.2 and 28.0 p.p.m. for 1, 6 and 11, respectively, were obtained. The amount determined at 6 to 12 inches was 6.5, 7.2 and 10.2 p.p.m. These results, which are similar to those obtained with organic matter and nitrogen, appear to be due to either inherent soil differences in the ranges or to a surface transfer of manure to the checks from adjacent treatments. Because of this lack of agreement between checks comparisons were made between treatments and checks 1 and 6 for all phosphorus determinations.

Following repeated applications of manure there appears to be an inverse relationship between organic phosphorus and the amount of manure applied when measured at the 0 to 6 or 6 to 12 inch depths. In fact, more organic phosphorus occurs on the lower rates at each depth. On 20-ton and 30-ton rates the phosphorus level was generally less than the checks. This would suggest that the rate of mineralization to inorganic forms is greater on the higher rates.

Applications of rotted manure at five tons per acre did not increase the inorganic phosphorus content over that of the adjacent check 6, at the 0 to 6 inch depth. The 10-ton rate of rotted manure produced a 32 p.p.m. increase compared to 16 p.p.m. from the same rate of fresh manure. This is due to a greater content of phosphorus per ton in rotted manure than in fresh manure. Although the 10-ton rate raised the inorganic phosphorus content by 32 p.p.m., the 20-ton rate produced an increase of 138 p.p.m.

The difference between the 30-ton rate and check 6 was 209 p.p.m.

Although little or no increase of inorganic phosphorus was obtained on the low rates at the 6 to 12 inch depth, increases of 61 and 64 p.p.m. were determined on the 20-ton and 30-ton rates.

The total phosphorus content above that of check 6 at the 0 to 6 inch depth became greater as rates of manure were increased, e.g. 3 p.p.m. at 5 tons and 149 p.p.m. at 30 tons per acre. More phosphorus has been accumulated from the rotted manure, 49 p.p.m., than from the fresh manure treatment, 26 p.p.m., at 10 tons per acre. Very little difference was obtained between the 5-ton rate and the adjacent check 6. The increase in total phosphorus was 3 p.p.m. on the 5-ton and 63 p.p.m. on the 30-ton rate at the 6 to 12 inch depth.

The amount of available phosphorus increased rapidly from low to high rates of manure at each depth. At 0 to 6 inches the 5-ton rate of rotted manure resulted in 2.0 p.p.m. more than the adjacent check 6, while from the 30-ton rate an increase of 60.1 p.p.m. was obtained. More available phosphorus over that of the check was determined on the rotted manure rate of 10 tons per acre i.e., 11.8 p.p.m., compared to the increase on the fresh manure treatment of 6 p.p.m. Ridley (17) found that on non-manured plots the content was usually below 20 p.p.m. Although this is true for check 1, a transfer of manure from adjacent treatments could explain why checks 6 and 11 are somewhat higher than the 20 p.p.m. level. Although little increase in available phosphorus occurred on the low rates at the 6 to 12 inch depth, 22.7 and 28.4 p.p.m. respectively, were obtained on the 20-ton and 30-ton treatments.

The fact that relatively high levels of total, inorganic and available phosphorus have been obtained on the 20-ton and 30-ton rates at

6 to 12 inches indicates a downward movement of these constituents. This has been observed by Ridley (17), who suggested that repeated phosphate applications result in a saturation of the phosphorus fixing capacity of the soil. This leads to a high level of soluble phosphorus and its downward movement.

B. Crop Yield Analyses

The results of yield analyses of each of the three crops from plots which have been under treatment of various rates of manure every 4 years for 36 years are presented in Tables 4 to 20.

Table 4. The variability of annual yields of wheat on fallow, determined by using 28 years as replication in the analysis. (Average of all treatments in bushels per acre).

Cycles		Ranges			Mean 4 years
	22	23	24	25	
1. Year	1923	1922	1925	1924	
Yield	19.2*	35.5	31.7	28.0	28.6
2. Year	1931	1926	1933	1932	
Yield	39.7	55.9*	34.1	28.4	39.5
3. Year	1935	1934	1937	1936	
Yield	14.4*	40.3	34.8	18.4*	27.0
4. Year	1939	1938	1941	1940	
Yield	39.8	23.0*	47.0*	41.9*	37.9
5. Year	1943	1942	1945	1944	
Yield	38.1	51.5*	34.4	44.2*	42.1
6. Year	1947	1946	1949	1948	
Yield	27.0*	38.3	28.4	38.2	33.0
7. Year	1951	1954	1953	1952	
Yield	37.3	23.4*	32.8	36.5	32.5
Mean of ranges					
	30.8	38.1	34.8	33.7	
	1955				
	40.6		Mean 28 years		34.4

C.V. = 22.0% Year L.S.D. (P = 0.05) = 6.5 bushels

Yields significantly above or below the 28-year average, *.

The results shown in Table 4. represent average annual yields, of all treatments, of wheat on fallow arranged in 4-year cycles according to the ranges on which they occurred. The yield of 40.6 bushels per acre for the year 1955 is presented as an extra year in addition to the seven complete cycles. The highest average yield (38.1 bushels per acre) was obtained on Range 23 while the lowest (30.8 bushels per acre) occurred on Range 22. The average yield for the 28-year period was 34.4 bushels per acre, although yields varied from 14.4 to 55.9 bushels per acre. These extremes were probably due to severe rust damage in 1935 and to unusually favourable growing conditions in 1926. The wide variation between years is also indicated by the high coefficient of variability of 22% and a relatively high L.S.D. of 6.5 bushels required to show significant differences between years. In 11 of the 28 years, yields were significantly above or below the average yield.

Four-year average yields also indicate a considerable range from 27.0 to 42.1 bushels per acre. Above average yields were recorded in the periods 1926 - 33 (cycle 2) and 1938 - 45 (cycles 4 and 5). The lowest averages occurred in cycle 3. Figures 1, 2 and 3 (Appendix ii) showing annual yields of wheat on fallow for the manured and non-manured treatments illustrate a similar seasonal effect i.e., cycles 2, 4 and 5 have been periods of high yields and cycle 3 of low production.

Table 5. An analysis of yields of wheat on fallow by treatments, using seven 4-year cycles as replication. (Bushels per acre).

Treatments	Ranges (Mean - 7 years)				Mean - 28 years
	22	23	24	25	
1. Check	28.1	34.0	32.8	26.8	30.4
2. F.M.L.S.10T.	30.7	35.2	35.6	30.1	32.9*
3. F.M.S.S.10T.	30.7	35.2	36.8	31.0	33.4*
4. R.M. 5T.	32.0	37.0	36.8	30.6	34.1*
5. R.M.10T.	32.4	42.0	36.0	33.9	36.1**
6. Check	29.7	35.4	28.7	30.8	31.2
7. R.M.15T.	30.0	41.2	33.4	37.0	35.4**
8. R.M.20T.	29.2	42.1	37.7	36.7	36.4**
9. R.M.25T.	31.3	39.9	37.8	40.1	37.3**
10. R.M.30T.	31.3	42.8	35.6	38.6	37.1**
11. Check	33.2	36.2	31.0	34.5	33.7
Mean of ranges	30.8	38.1	34.8	33.7	
Mean of the checks					31.8

Cycles (4 year) N.S.

Ranges N.S. C.V. = 10.7%

Treatment L.S.D. Mean - 28 years, (P = 0.05) = 2.3 bus.*

L.S.D. (P = 0.01) = 3.1**

Treatment x Range L.S.D. (Mean - 7 years, P = 0.05) = 3.8 bus.

L.S.D. P = 0.01 = 5.1

Significant at 5% level *

Significant at 1% level **

Treatment effects on the crop yields for the 28 years of the experiment were interpreted by the results shown in Table 5. These data have been arranged in 4-year cycles representing the 4 fields or ranges of the experiment. Each treatment has therefore occurred 7 times on a particular range. Table 4. indicated that crop yields have been influenced appreciably by seasonal effects and to some extent by differences between ranges. The method used in Table 5. measures the variations due to these factors under "cycles" and "ranges". This procedure has resulted in a coefficient of variability for the analysis of 10.7% compared with the 22% obtained in Table 4. This method has also produced a relatively low L.S.D. for significant differences between treatments i.e., 2.3 bushels per acre. The variations between cycles and between ranges were not significantly different from one another. However certain treatments reacted differently on different ranges as shown by the significant treatment x range interaction.

A comparison of the non-manured checks shows that the 28-year average yield of check 11 was significantly greater than that of 6 or 1. The fact that yields increased from plots 1, 6 to 11 (30.4, 31.2 and 33.7 bushels per acre, respectively) is in agreement with the increasing organic matter and nitrogen contents as shown in Table 2. The results in Table 3. also indicate increasing inorganic and available phosphorus from plots 1 to 11. Inherent soil differences, in addition to possible movement of manure from adjacent treated plots has probably affected yields, particularly on Range 25, where 26.8, 30.8 and 34.5 bushels per acre were the 7-year average yields obtained for checks 1, 6 and 11, respectively. A height of land at plot 8 on this range (Soil map Appendix i) and the fact that the ground slopes toward plots 6 and 11 emphasize the possibility of transfer of nutrients from treated plots.

Because of average yield differences between checks, comparisons were made between treatment rates and checks 1 and 6. On the basis of these comparisons all rates produced a significant increase in yield. Rates of 10 tons per acre or more of rotted manure produced an increase in yield that was significant at the 1% level. However yields from these rates were not appreciably different from one another e.g., the 10-ton rate produced 36.1 while the 30-ton rate yielded 37.1 bushels per acre. Therefore little yield advantage resulted from use of the higher rate on this crop. The yield from the 10-ton rate of rotted manure was significantly larger by 2.7 and 3.2 bushels, than those obtained with fresh manure at the same rates.

Although the differences between ranges were not significant Range 23 produced above average while Range 22 produced below average yields. Ranges 24 and 25 agreed with the 28-year average of 34.4 bushels per acre for the experiment (Table 4). The response to treatments on the various ranges differed somewhat e.g., there was a low yield response on Range 22, particularly at the higher rates. This low response may have been the result of occasional lodging of the crop. The relatively low average returns on the higher rates from all ranges suggest that due to such factors as crop lodging the yield potential of these treatments has not been fully utilized.

Table 6. Long term trends and variability in yields of wheat on fallow by treatments as measured by the standard deviation and the coefficients of regression and variability. (Bushels per acre).

Treatment	Mean yield (29 years, bus/acre)	Coefficient of regression	Standard deviation x	Coefficient of variability x / mean yield x 100
1. Check	30.5	0.004	9.18	30.1
2. F.M.L.S.10T.	33.3	0.11		
3. F.M.S.S.10T.	33.8	0.15		
4. R.M. 5T.	34.4	0.10		
5. R.M.10T.	36.2	0.10	10.51	29.0
6. Check	31.2	0.11		
7. R.M.15T.	35.4	0.06		
8. R.M.20T.	36.5	-0.003		
9. R.M.25T.	37.5	0.23	11.36	30.3
10. R.M.30T.	37.4	0.21		
11. Check	34.2	0.23		
Mean of 1,6,11	32.0	0.08		

Table 7. A comparison of the mean wheat yields for each check on cycle 1, (1922-25) with those of cycle 7 (1951-54). (Bushels per acre).

Check	Cycle 7	Cycle 1	Difference
1	24.2	26.1	-1.9
6	30.4	26.6	3.8
11	34.8	27.5	7.3

Table 6. presents results indicating the long term effects of treatment and seasonal factors on yields of wheat on fallow. The magnitude of yield fluctuations under treatments 1, 5 and 9 were measured by means of their standard deviations. These values were then expressed in percent of the mean yield for their respective treatments. The long term trends in yields of each treatment were determined by means of the coefficient of regression. These trends have been compared with the annual yields of check 6 and treatments 4, 5, 8 and 10 in Figures 2 and 3 (Appendix ii).

When expressed as a percentage of the mean yield for each treatment the yield variability was similar on treated and non-treated plots. The differences in coefficients in Table 6., for the unfertilized checks 1, 6 and 11 (0.004, 0.11 and 0.23) suggest that yields on plots 6 and 11 have been affected by adjacent manure treatments. In the initial years of the experiment (cycle 1, Table 7.) these checks agreed quite well. However yields of check 1, cycle 7 show a decline of 1.9 bushels per acre compared with increases of 3.8 and 7.3 bushels per acre on checks 6 and 11 respectively.

A comparison of long term trends in Table 6. shows yield trends varied from -0.003 bushels per acre per year for the 20-ton rate to 0.23 on the 25-ton rate and the check 11. The cause of the relatively low yield trends on the high rates appear to be seasonal factors, such as crop lodging on the high rates, particularly in later years. Although yields have been increased by the different treatments high rates have not necessarily produced high yield trends.

Table 8. Short term yield increases due to manure treatments of wheat on fallow over the adjacent checks 1 and 6, determined as 4-year average increases for the 7 cycles in the period 1922-54. (Bushels per acre).

	Treatments							
	2	3	4	5	7	8	9	10
	F.M.L.S.10T.	F.M.S.S.10T.	R.M.5T.	R.M.10T.	R.M.15T.	R.M.20T.	R.M.25T.	R.M.30T.
	Average increases over check 1		Average increases over check 6					
Cycles								
1	0.8	1.3	1.5	3.8	3.6	4.2	3.7	4.1
2	2.8	3.3	6.5	7.8	7.7	9.0	13.0	13.3
3	2.8	2.6	3.0	2.7	3.2	5.2	0.9	4.2
4	2.6	3.2	3.0	5.4	4.2	5.7	5.4	2.4
5	4.4	4.3	4.6	5.9	1.3	0.5	0.7	0.9
6	0.5	0.6	3.0	7.1	6.2	5.2	10.8	9.6
7	3.7	5.8	-0.8	2.1	3.6	4.8	8.5	9.1

A review of the short term average increases in yield in Table 8. shows that the largest returns did not always occur in the later years of the experiment as might be expected. For example, the highest increases occurred on treatments 4, 5, 7, 8, 9 and 10 in cycle 2. In this period the four-year average increases over the checks ranged from 2.8 at 10 tons to 13.3 bushels per acre at 30 tons per acre. A rapid increase in average response occurred between cycles 1 and 2, followed by lower returns on nearly all treatments in cycles 3, 4, 5, 6 and 7. Rather large increases occurred on some of the higher rates in cycles 5, 6 and 7. Table 8. indicates the high yield potential of the manure treatments, particularly the higher rates, under favorable conditions of climate, such as moisture, freedom from disease and lodging of crop.

Although the level of fertility of these treatments i.e., their yield potential has definitely been improved as shown by actual yield increases and chemical analyses, seasonal factors have resulted in frequent low average returns regardless of the period in the experiment. That is, favorable seasonal conditions were required in order to obtain satisfactory yield increases. Therefore high positive long term yield trends i.e., increasing yield returns from repeated applications during the period of the experiment did not occur on all treatments of this crop.

Table 9. The variability of annual yields of corn after wheat determined by using 28 years as replication in the analysis. (Average of all treatments in tons per acre, green weight).

Cycles	Ranges				Mean 4 years
	22	23	24	25	
1. Year	1924	1927	1926	1925	
Yield	10.60*	2.42*	14.49*	12.44*	9.99
2. Year	1932	1931	1930	1929	
Yield	10.55*	6.16*	4.64*	4.68*	6.51
3. Year	1936	1935	1934	1933	
Yield	8.35	6.36*	12.25*	5.77*	8.18
4. Year	1940	1939	1938	1937	
Yield	8.25	6.96	9.17	7.38	7.94
5. Year	1944	1943	1942	1941	
Yield	8.21	6.04*	13.14*	12.33*	9.93
6. Year	1948	1947	1946	1945	
Yield	9.74	10.40*	9.31	8.15	9.40
7. Year	1952	1951	1950	1949	
Yield	7.58	10.36*	6.74*	8.27	8.24
Mean	9.04	6.97	9.96	8.43	8.60 Mean 28 years

1939 = Mean of range 23

Year L.S.D. (P = 0.05) = 1.70 tons

Yields significantly above or below the 28-year average, *.

The results in Table 9. present average annual yields of corn for all treatments and are arranged in 4-year cycles according to the ranges on which these yields occurred. The highest average yield of corn, 9.96 tons was obtained on Range 24 followed by 9.04 tons per acre on Range 22. The lowest yield of 6.97 tons per acre occurred on Range 23, where the highest yield of wheat on fallow was recorded. It would appear that yield differences among ranges were due mainly to seasonal factors. The relatively high L.S.D. of 1.70 tons per acre required to show significant differences between years indicates the wide variation in corn yields. The average yield for the 28-year period was 8.60 tons per acre, while annual yields varied from 2.42 in 1927 to 14.49 in 1926. The latter has already been observed as a highly favorable year for wheat on fallow. Four-year average yields also show a considerable range from 6.51 to 9.99 tons per acre. Above average yields of corn occurred in the periods 1924-27 (cycle 1) and 1941-48 (cycles 5 and 6), compared with above average wheat yields in cycles 2, 4 and 5. The lowest yields occurred in cycle 2 (1929-32) compared with cycle 3 for wheat. In 17 out of the 28 years corn yields were significantly above or below the 28-year average. For wheat on fallow in 11 of the 28 years average yields were significantly above or below the 28-year average. These results indicate the greater dependence of corn on such seasonal factors as moisture. Figures 4, 5 and 6 (Appendix ii) showing annual yields of corn on the manured and non-manured treatments illustrate this seasonal effect on yields.

Table 10. An analysis of yields of corn by treatments, using seven 4-year cycles as replication. (Tons per acre, green weight).

Treatments	Ranges (Mean - 7 years)				Mean - 28 years
	22	23	24	25	
1. Check	7.60	5.93	9.10	6.85	7.37
2. F.M.L.S.10T.	9.34	6.20	10.82	8.13	8.62**
3. F.M.S.S.10T.	9.03	6.50	10.22	8.26	8.50**
4. R.M. 5T.	8.83	6.52	9.93	7.90	8.30**
5. R.M.10T.	8.91	7.19	9.57	8.64	8.58**
6. Check	7.10	5.87	8.26	7.53	7.19
7. R.M.15T.	9.26	7.74	9.87	8.84	8.93**
8. R.M.20T.	9.25	7.43	11.17	9.00	9.21**
9. R.M.25T.	10.20	7.57	11.14	9.19	9.60**
10. R.M.30T.	11.12	8.62	10.89	9.49	10.03**
11. Check	8.82	6.96	8.30	8.90	8.25
Mean of ranges	9.04	6.97	9.96	8.43	
Mean of checks					7.60

C.V. = 10.8%

Cycles (4 years) N.S.

Ranges N.S.

Treatment L.S.D. Mx - 28 years (P = 0.05) = 0.58 tons*
L.S.D. = (P = 0.01) = 0.77 tons**

Treatments x Range L.S.D. (Mx - 7 years, P = 0.05) = 0.99 tons
L.S.D. (P = 0.01) = 1.30 tons

Significant at 5% level *

Significant at 1% level **

The effect of applications of manure every four years, applied the previous fall, on yields of corn were interpreted by the results found in Table 10. The variations between cycles and between ranges were not significantly different from one another although the highest average yield occurred on Range 24. A comparison of the non-manured checks shows that the mean yield of check 11 was significantly higher than checks 1 or 6. This difference has occurred on Ranges 22, 23 and 25. These results are similar to those obtained with wheat on fallow.

A comparison of check yields on cycle 1 with those of cycle 7 in the Table 11. indicate increasing yields in cycle 1 from 1 to 6 and 11. However in cycle 7, yields on check 11 were about 1 ton larger than 1 or 6.

Table 11. A comparison of the mean corn yields for each check on cycle 1, (1924-27) with those on cycle 7, (1949-52). (Tons per acre, green weight).

Check	Cycle 7	Cycle 1	Difference
1	6.79	8.72	-1.93
6	6.77	9.03	-2.26
11	7.70	9.33	-1.63

Due to the lack of agreement between check 11 and checks 1 and 6 comparisons were made between treatments and checks 1 and 6.

On the basis of these comparisons all rates of manure produced a highly significant increase in yield. The response to treatments increased from 1.11 tons per acre for the 5-ton rate to 2.84 for the 30-ton rate. The higher rates have produced a definite yield advantage over those of the lower rates. This effect was less apparent with wheat on fallow. This would indicate that corn has utilized the manure treatments to a greater extent than the previous wheat crop. No significant yield differences between fresh or rotted manure treatments on corn were obtained.

Table 12. Long term trends and variability in yields by treatments of corn, as measured by the standard deviation and the coefficients of regression and variability. (Tons per acre, green weight).

Treatment	Mean yield (31 years, tons/acre) green weight	Coefficient of regression	Standard deviation x	Coefficient of variability $\frac{x}{\text{mean yield}} \times 100$
1. Check	7.56	-0.04		
2. F.M.L.S.10T.	8.87	-0.04		
3. F.M.S.S.10T.	8.73	-0.04		
4. R.M. 5T.	8.54	-0.03		
5. R.M.10T.	8.72	-0.03	3.05	35.0
6. Check	7.39	-0.06		
7. R.M.15T.	9.00	0.05		
8. R.M.20T.	9.27	0.01		
9. R.M.25T.	9.73	0.03	3.26	33.5
10. R.M.30T.	10.07	0.05		
11. Check	8.36	-0.03		
Mean of 1,6,11	7.77	-0.04	2.70	34.7

When expressed as a percentage of the mean yield (Table 12.) there was little difference in yield variability between treatments. A comparison of long term trends in Table 12. shows that yield trends of corn ranged from -0.06 to 0.05 for check 6 and treatments 7 and 10 respectively. The untreated checks, 5-ton and 10-ton rates indicate low negative trends while the higher rates were positive. Although yields have been increased by the various treatments high rates have not necessarily produced high yield trends.

Table 13. Short term yield increases due to manure treatments of corn over the adjacent checks 1 and 6, determined as 4-year average increases for the 7 cycles in the period 1922-54. (Tons per acre, green weight).

	Treatments							
	2	3	4	5	7	8	9	10
	F.M.L.S.10T.	F.M.S.S.10T.	R.M.5T.	R.M.10T.	R.M.15T.	R.M.20T.	R.M.25T.	R.M.30T.
	Average increases over check 1		Average increases over check 6					
Cycles								
1	1.22	1.48	0.93	1.24	1.44	1.42	1.48	1.93
2	0.77	0.69	0.77	1.00	1.38	1.48	1.92	2.02
3	0.83	0.74	1.33	1.21	1.28	1.78	1.85	2.63
4	0.48	0.47	0.83	0.99	1.30	1.39	1.18	1.05
5	2.59	1.80	1.46	1.50	2.07	1.90	2.94	2.93
6	1.94	1.77	1.32	2.06	3.13	3.73	4.65	5.86
7	0.95	0.99	1.09	1.73	1.57	2.48	2.88	3.47

A review of the short term average increases in yield in Table 13. shows that the largest returns occurred most frequently in cycles 5 and 6 and occasionally in cycle 7. The lowest response occurred on cycle 4 while relatively high returns were obtained in earlier cycles. There is a greater tendency toward higher positive trends with corn compared with declining check yields than with wheat on fallow compared with relatively unchanged check yields. However the effect of seasonal factors is still evident. For example, the favorable growth seasons of cycles 5 and 6 have produced generally higher yield increases.

Table 14. The variability of annual yields of wheat after corn, determined by using 28 years as replication in the analysis. (Average of all treatments in bushels per acre).

Cycles	Ranges 22	23	24	25	Mean - 4 years
1. Year	1925	1924	1923	1922	
Yield	28.7	29.4	22.0*	39.3*	29.8
2. Year	1933	1932	1931	1926	
Yield	29.0	20.0*	33.3	51.0*	33.3
3. Year	1937	1936	1935	1934	
Yield	38.1*	16.2*	20.9*	40.6*	28.9
4. Year	1941	1940	1939	1938	
Yield	43.7*	40.9*	31.7	23.4*	34.9
5. Year	1945	1944	1943	1942	
Yield	23.4*	28.9	35.4	54.5*	35.5
6. Year	1949	1948	1947	1946	
Yield	24.2*	28.9	25.9*	29.4	27.1
7. Year	1953	1952	1951	1954	
Yield	26.4	32.1	38.1*	21.9*	29.6
Mean, Ranges	30.5	28.1	29.6	37.2	Mean 28 years 31.3
Year	1921			1930	
Yield	30.8			25.5	

Year L.S.D. (P = 0.05) = 5.2 bushels.

Yields significantly above or below the 28-year average, *.

Average annual yields of wheat after corn of all treatments, shown in Table 14. were arranged in 4-year cycles according to the ranges on which these yields occurred. Two additional years beyond the seven complete cycles were included at the end of the table. The highest average yield of wheat after corn, 37.2 bushels per acre, was obtained on Range 25 while the lowest yield, 28.1 bushels per acre, occurred on Range 23. When the three crops are considered the highest yields were obtained on Range 24, followed by Ranges 25, 22 and 23. High yields were recorded on the ranges containing considerable Fort Garry soil, particularly Ranges 24 and 22 (see soil map, Appendix i). The relatively high L.S.D. of 5.2 bushels per acre required to show significant differences between years indicates the high variability in wheat yields. In 17 of the 28 years, yields were significantly above or below the average of 31.3 bushels per acre. The average yield of wheat on fallow was 34.4 bushels per acre. Yields by individual years of wheat after corn varied from 16.2 in 1936 to 54.5 in 1942 (cycle 5). Four-year average yields also show a considerable range from 27.1 bushels in cycle 6 to 35.5 in the previous cycle 5. The highest average yield of wheat on fallow also occurred in cycle 5 while those of corn were obtained on cycles 1 and 5. Therefore favorable seasonal factors in cycle 5 have contributed to high average yields on the three crops. High yields also occurred on cycles 2 and 4 on each wheat crop. Figures 7, 8, 9 (Appendix ii) showing annual yields of wheat on the manured and non-manured treatments illustrate the effect of seasonal factors on yields. It may be concluded that high yields were not necessarily limited to later years of the experiment.

Table 15. An analysis of yields of wheat after corn by treatments, using seven 4-year cycles as replication. (Bushels per acre).

Treatments	Ranges				Mean - 4 years
	22	23	24	25	
1. Check	26.1	21.9	26.8	28.1	25.7
2. F.M.L.S.10T.	32.1	26.3	28.1	33.5	30.0**
3. F.M.S.S.10T.	31.5	26.3	28.6	34.6	30.3**
4. R.M. 5T.	28.6	25.3	28.7	34.2	29.2
5. R.M.10T.	29.6	28.6	29.4	36.4	31.0**
6. Check	23.8	25.4	27.0	34.5	27.7
7. R.M.15T.	30.8	32.4	31.2	38.8	33.3**
8. R.M.20T.	30.6	31.5	32.9	42.2	34.3**
9. R.M.25T.	33.5	31.6	33.6	42.4	35.3**
10. R.M.30T.	36.8	32.6	31.6	43.4	36.1**
11. Check	31.9	26.4	27.7	40.8	31.7
Mean of ranges	30.5	28.1	29.6	37.2	
Mean of checks					28.7

Cycles N.S. C.V. = 10.0%

Ranges N.S.

Treatments L.S.D. Mean - 28 years, (P = 0.05) = 2.1 bus.*
L.S.D. (P = 0.01) = 2.8 bus.**

Treatment x Range L.S.D. (Mean - 7 years, P = 0.05) = 3.3 bus.
(P = 0.01) = 4.3 bus.

Significant at 5% level, *.

Significant at 1% level, **.

The effects of repeated applications of manure on yields of wheat after corn were interpreted by the data shown in Table 15. The variations between cycles and between ranges were not significantly different from one another.

However there was a treatment x range interaction response e.g., higher yields were obtained on all treatments on Range 25. Although, due to correspondingly high check yields, particularly on plots 6 and 11, the increases over the checks were similar to the other ranges.

The residual effect of the treatments on this, the second crop following application has produced a highly significant increase from all rates except the 5-ton rate. Between the 10-ton rates of fresh manure and rotted manure no significant differences were obtained. The range in response increased from 1.5 bushels per acre on the 5-ton rate to 8.4 on the 30-ton rate. Similar returns on the wheat on fallow crop were 2.9 and 5.9 bushels per acre. A decline in response on the second wheat crop occurred on the 5-ton rate, indicating a reduced carry-over of nutrients. The increase which occurred on the 30-ton rate suggests a greater utilization of nutrients at the high rate.

Table 16. Long term trends and variability in yields of wheat after corn by treatments as measured by the standard deviation and the coefficients of regression and variability. (Bushels per acre).

Treatment	Mean yields (31 years, bus/acre)	Coefficient of regression	Standard deviation x	Coefficient of variability x / mean yield x 100
1. Check	25.2	-0.34		
2. F.M.L.S.10T.	29.2	-0.24		
3. R.M.S.S.10T.	29.7	-0.27		
4. R.M. 5T.	28.8	-0.29		
5. R.M.10T.	30.3	-0.24	9.65	31.8
6. Check	27.2	-0.21		
7. R.M.15T.	32.6	0.03		
8. R.M.20T.	34.0	-0.04		
9. R.M.25T.	34.9	0.05	9.48	27.2
10. R.M.30T.	35.2	0.18		
11. Check	31.1	-0.13		
Mean of 1,6,11	27.8	-0.23	8.85	31.8

Table 17. A comparison of the mean wheat yields for each check, on cycle 1, (1922-25) with those of cycle 7, (1951-54). (Bushels per acre).

Check	Cycle 7	Cycle 1	Difference
1	20.4	27.1	-6.7
6	25.7	27.1	-1.4
11	31.8	29.2	2.6

Table 16. presents data indicating the long term effects of manure applications on wheat yields. The degree of yield fluctuations has been obtained by determining the standard deviation on treatments 5, 9 and the mean of checks 1, 6 and 11. In percentages of the mean yield for each treatment there was a reduction of 4.6% on treatment 9 compared to the average check. The long term trends of treatments 4, 5, 8 and 10, compared with check 6, are shown in figures 8 and 9 (Appendix ii).

The long term trends in yields of checks 1, 6 and 11 were -0.34, -0.21 and -0.13 respectively. The differences in negative trends on checks 1 to 11 also indicate that these plots have been influenced by adjacent manure treatments. However in the initial years of the experiment as shown under cycle 1, Table 17., yields of the checks agreed quite well e.g., 27.1, 27.1 and 29.2. When compared with those of cycle 7, checks 1 and 6 had declined by 6.7 and 1.4 bushels while on check 11 an increase of 2.6 bushels per acre was recorded. On Range 25, Table 15., yields were considerably higher on checks 6 and 11 than on check 1. This was also true on the previous corn and wheat crops.

A comparison of long term trends in Table 16. shows a range from -0.34 bushels per acre, per year, for check 1 to 0.18 for treatment 10 at 30 tons per acre. In fact negative trends occurred on the checks and rates up to 20 tons per acre. Beyond this, low positive trends occurred.

Table 18. Short term yield increases due to manure treatments of wheat after corn over the adjacent checks 1 and 6, determined as 4-year average increases for the 7 cycles in the period 1922-1954. (Bushels per acre).

	Treatments							
	2	3	4	5	7	8	9	10
	F.M.L.S.10T.	F.M.S.S.10T.	R.M.5T.	R.M.10T.	R.M.15T.	R.M.20T.	R.M.25T.	R.M.30T.
	Average increases over check 1		Average increases over check 6					
Cycles								
1	2.7	4.3	2.5	3.4	3.6	4.0	3.4	4.1
2	3.5	4.5	3.5	5.4	3.8	5.9	8.2	9.6
3	3.6	3.6	2.6	3.4	3.4	5.1	4.9	5.4
4	2.7	1.0	-0.4	2.3	5.1	5.8	6.0	4.2
5	8.3	7.7	0.7	3.7	7.3	7.9	9.3	9.0
6	4.6	4.2	0.4	2.9	10.9	8.8	11.4	13.7
7	4.4	6.4	1.4	2.8	5.3	9.0	10.3	13.2

The reason that higher long term trends were not obtained is found in Table 18., in which 4-year trends were interpreted. The largest increases in yields over the checks did not always occur in the later cycles, although yields on the checks have declined during the experiment. On 5-ton and 10-ton rates the largest returns were obtained in cycles 2 and 5 while on 15-ton to 30-ton rates they occurred in cycles 6 and 7. In cycle 6, the average increase due to 15 tons was 10.9 bushels per acre while that resulting from 30 tons was 13.7 bushels. Therefore relatively low long term trends of -0.29 bushels per acre for 5-ton and 0.18 for the 30-ton treatments were the result. Similar trends which occurred on the wheat on fallow crop were attributed to more favorable seasonal factors in earlier years. There is a tendency on the higher rates of manure on wheat after corn for increasing returns with the progress of the experiment, i.e., larger increases have occurred on the later cycles. These results are in agreement with those from the corn crop, indicating greater utilization of available nutrients. It may be expected that lodging of this crop under high rates of manure was of less importance than on the wheat on fallow crop. In general the results indicate the high yield potential of these treatments, particularly the high rates, under favorable seasonal conditions.

Table 19. Long term increases in yield due to manure treatments on wheat and corn over the adjacent checks 1 and 6, (28 year average increase for the period 1922-1954).

	Wheat increases, (bus./acre).				Corn increases, (tons/acre).	
Treatment	on fallow	after corn	total	per ton of manure	total	per ton of manure
2. F.M.L.S.10T.	2.5	4.3	6.8	0.68	1.25	0.13
3. F.M.S.S.10T.	3.0	4.6	7.6	0.76	1.13	0.11
4. R.M. 5T.	2.9	1.5	4.4	0.88	1.11	0.22
5. R.M.10T.	4.9	3.3	8.2	0.82	1.39	0.14
7. R.M.15T.	4.2	5.6	9.8	0.65	1.74	0.12
8. R.M.20T.	5.2	6.6	11.8	0.59	2.02	0.11
9. R.M.25T.	6.1	7.6	13.7	0.55	2.41	0.10
10. R.M.30T.	5.9	8.4	14.3	0.48	2.84	0.09
Average increase (8 treatments)	4.3	5.2				

Table 20. Long term increases in yield due to manure treatments on wheat and corn over the adjacent checks 1 and 6, 12-year average increase for the period 1942 - 1954.

	Wheat increases, (bus./acre).				Corn increases, (tons/acre)	
Treatment	on fallow	after corn	total	per ton of manure	total	per ton of manure
2. F.M.L.S.10T.	2.9	5.8	8.7	0.87	1.83	0.18
3. F.M.S.S.10T.	3.6	6.1	9.7	0.97	1.52	0.15
4. R.M. 5T.	2.3	0.8	3.1	0.62	1.29	0.26
5. R.M.10T.	5.0	3.1	8.1	0.81	1.76	0.18
7. R.M.15T.	3.4	7.8	11.2	0.75	2.26	0.15
8. R.M.20T.	3.5	8.6	12.1	0.61	2.70	0.14
9. R.M.25T.	6.7	10.3	17.0	0.68	3.49	0.14
10. R.M.30T.	6.5	11.9	18.4	0.61	4.09	0.14
Average increase (8 treatments)	4.2	6.8				

The long term increases in yield from each treatment of the two crops shown in Tables 19. and 20. were determined on the basis of the 28-year average and the recent 12-year average. Yield increases in each period were larger on the second crop than on the first, except for treatments 4 and 5. The average increase obtained with wheat on fallow on the 12-year period, 4.2 bushels, was similar to that obtained in the 28-year period of 4.3 bushels per acre. However, the average increase was 6.8 and 5.2 bushels on the wheat after corn crop in the 12 and 28-year periods, respectively. Hence the combined wheat returns were larger in the last three cycles of the experiment, and increased from 3.1 bushels on the 5-ton rate to 18.4 on the 30-ton rate. Corn yield increases were larger on all rates in the recent 12-year period than in the 28-year period. As outlined previously these increases on corn and wheat after corn have occurred mainly in cycles 5 and 6, periods of generally high production.

The total yield increases expressed on the basis of increases per ton of manure applied, show that the 5-ton rate, in the 28-year period has produced the largest returns. This is also true for the 12-year period. Although larger returns of wheat were obtained from 10 and 15-ton rates in the 12-year period, this effect is offset by larger corn returns on the 5-ton rate.

VII. SUMMARY AND DISCUSSION

The objectives of the soil and crop yield analyses of this long term experiment were to determine the effects of repeated applications of manure on the fertility of the soil. The experiment involved a 4-year rotation of fallow, wheat, corn and wheat where a series of rates of manure had been applied once each cycle of the rotation for 36 years.

Soil samples from the 0 to 6 inch depth were analyzed in the laboratory for organic matter and inorganic carbon. Samples from the 0 to 6 and 6 to 12 inch depths were analyzed for total nitrogen, total, inorganic, organic and available phosphorus.

Since standard statistical procedures could not be applied to the yield data because of the lack of replication of treatments each year a number of methods were used in order to measure long and short term effects of treatments on yields. An analysis using years as replication was used to measure the degree of variability in yields among years due to seasonal factors. A method using 4-year cycles of the rotation as replicates was used to determine significant treatment effects on crop yields as well as differences between ranges and 4-year cycles. Long term yield trends and yield variability due to treatments were determined. Short term trends in yields resulting from manure applications were measured by determining 4-year average increases for each treatment. Treatment effects on crop yields were compared using average results for 28-year and 12-year periods.

The soil analysis showed higher levels of organic matter, nitrogen, total, inorganic and available phosphorus as higher rates of application of manure were used. For example, 10, 20 and 30-ton rates resulted in increases in organic matter of 0.24%, 0.92% and 2.09%, respectively. Similarly, these rates increased available phosphorus contents by 11.8, 39.1 and 60.1 p.p.m. The 5-ton rate produced slight increases in soil nutrient levels. However the organic phosphorus content was larger on the lower rates. The carbon-nitrogen ratios were generally unaffected by the manure treatments. From the amount of total, inorganic and available phosphorus obtained on the 6 to 12 inch depth it was concluded that leaching of phosphorus had occurred. More phosphorus per ton was obtained from rotted manure treatments than from fresh manure, although there was little difference in organic matter and nitrogen content between these treatments. The non-manured checks, particularly checks 6 and 11 have been affected by adjacent treatments since the level of nutrients and average yields increased from 1 to 6 and 11.

The 28-year average yield of all treatments of wheat on fallow was 34.4 bushels per acre compared with that of wheat after corn of 31.3 bushels. However the yields of the first wheat crop varied from 14.4 bushels in 1935 to 55.9 bushels per acre in 1926, while those of the second wheat crop ranged from 16.2 in 1936 to 54.5 in 1942. Corn yields were even more variable e.g., 2.42 tons were recorded in 1927 and 14.49 tons in 1926, while the 28-year average yield was 8.60 tons per acre. On a 4-year average basis, above average yields occurred in cycle 5 (1942 - 1945) on each of the three crops.

Significant 28-year average increases in yield over the adjacent checks 1 and 6 were obtained from all treatments on all crops, except for the 5-ton rate of wheat after corn. Yields of wheat on fallow from high rates (15 - 30 tons) were only slightly larger than those from the 10-ton rate, e.g., the 10-ton rate produced a 4.9 bushel increase while the 30-ton produced a 5.9 bushel increase. The yield from the rotted manure treatment was 2.7 bushels per acre more than that from the fresh manure rate of 10 tons. However no significant differences occurred between these treatments on the corn or wheat after corn crops. On these crops higher rates produced correspondingly larger increases in yield, e.g., the response on corn from the 5-ton rate was 1.11 tons per acre, while that from the 30-ton rate was 2.84 tons per acre. On the wheat after corn the 5-ton rate produced a 1.5 bushel increase while the 30-ton rate produced an increase of 8.4 bushels. These higher yields resulting from higher rates agree with a similar trend in levels of organic matter, nitrogen and phosphorus.

There was little difference in yield variability among treatments.

Long term trends in yields of the non-manured plots indicated the effect of adjacent treatments on checks 6 and 11. Declining yields occurred on the low rates and checks of corn and wheat after corn. Although the higher rates of 15 or more tons per acre generally produced higher yield trends the results were not always consistent with the rates applied. Short term trends (4-year average increases over the checks) show that these effects were due to seasonal factors which resulted in high returns in earlier years. These trend results could also be due to crop lodging in later years, particularly on the higher rates of wheat on fallow.

The largest 4-year average increase of wheat on fallow occurred in cycles 2, 6 and 7. Corn increases in yield were largest on cycles 5, 6 and 7, and those of wheat after corn in 2, 5, 6 and 7. Generally the largest returns occurred in cycles 2, 5, 6 and 7, periods of above average production on the three crops.

On the basis of a recent 12-year and the 28-year average little difference in returns due to treatments occurred between periods of the wheat on fallow crop. However larger increases were obtained on the corn and wheat after corn in the 12-year period than in the 28-year period. Yield increases were generally larger on the second wheat crop than on the first.

The total yield increases of the three crops determined on the basis of response per ton of manure applied showed that the 5-ton rate in each period has produced the largest returns.

A review of the experiment should consider that certain limitations inherent in its design have influenced the results to some extent. For example the widths of the plots and border strips have not been sufficient to prevent a transfer of nutrients from manured to adjacent plots e.g., from high rate treatments to non-manured checks. This transfer has had the effect of reducing the nutrient status of the treated plot as well as increasing that of the check. The systematic arrangement of treatments within each range has permitted certain rates of manure to occur in more favorable positions within each range than others. The lack of replication of crops and treatments each year has made it difficult to separate effects due to differences among ranges from those due to years. For example, favorable seasons of crop growth and yield response to treatment could occur more frequently on certain ranges than on others, preventing an accurate measurement of possible soil differences among ranges. Continuous annual wheat yields were not available since barley was substituted for wheat in five of the years between 1919 and 1930. In general these limitations have reduced the favorable effects of manure treatments on crop yields.

VIII. CONCLUSIONS

1. Manure applications, especially at higher rates, resulted in substantial increases in the soil content of organic matter, nitrogen, total, inorganic and available phosphorus.

2. Large yield increases were obtained from these treatments particularly on the corn and wheat after corn crops.

3. The largest returns per ton of manure applied were obtained from the lowest rate of application.

4. The fact that the largest returns per ton were obtained from the lowest rate and that relatively high yield increases were obtained in early 4-year cycles suggest that the fertility level increased rapidly following a few applications, particularly with wheat on fallow.

5. The combination of manure treatments and favorable seasonal conditions have resulted in large increases in yield in a number of cycles throughout the experiment. Although there does not appear to be a long term cumulative effect of manure treatments on yields of wheat on fallow there is evidence of this effect with corn and wheat after corn.

6. Results of this study were influenced by limitations encountered in the design of the experiment. Further experimental work of this nature should attempt to avoid these deficiencies.

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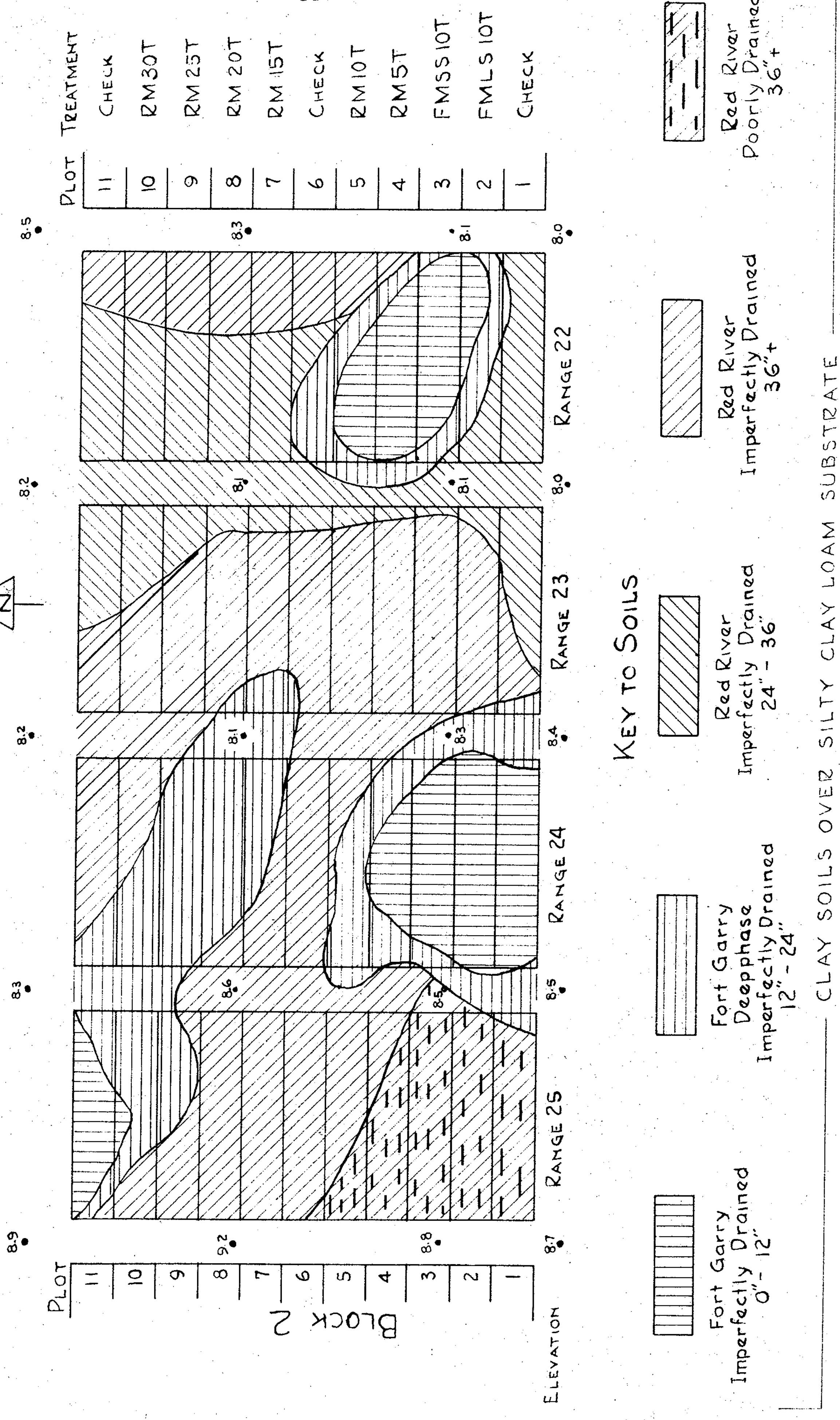
Appendix i.



Soil Map of Experiment

Appendix ii.

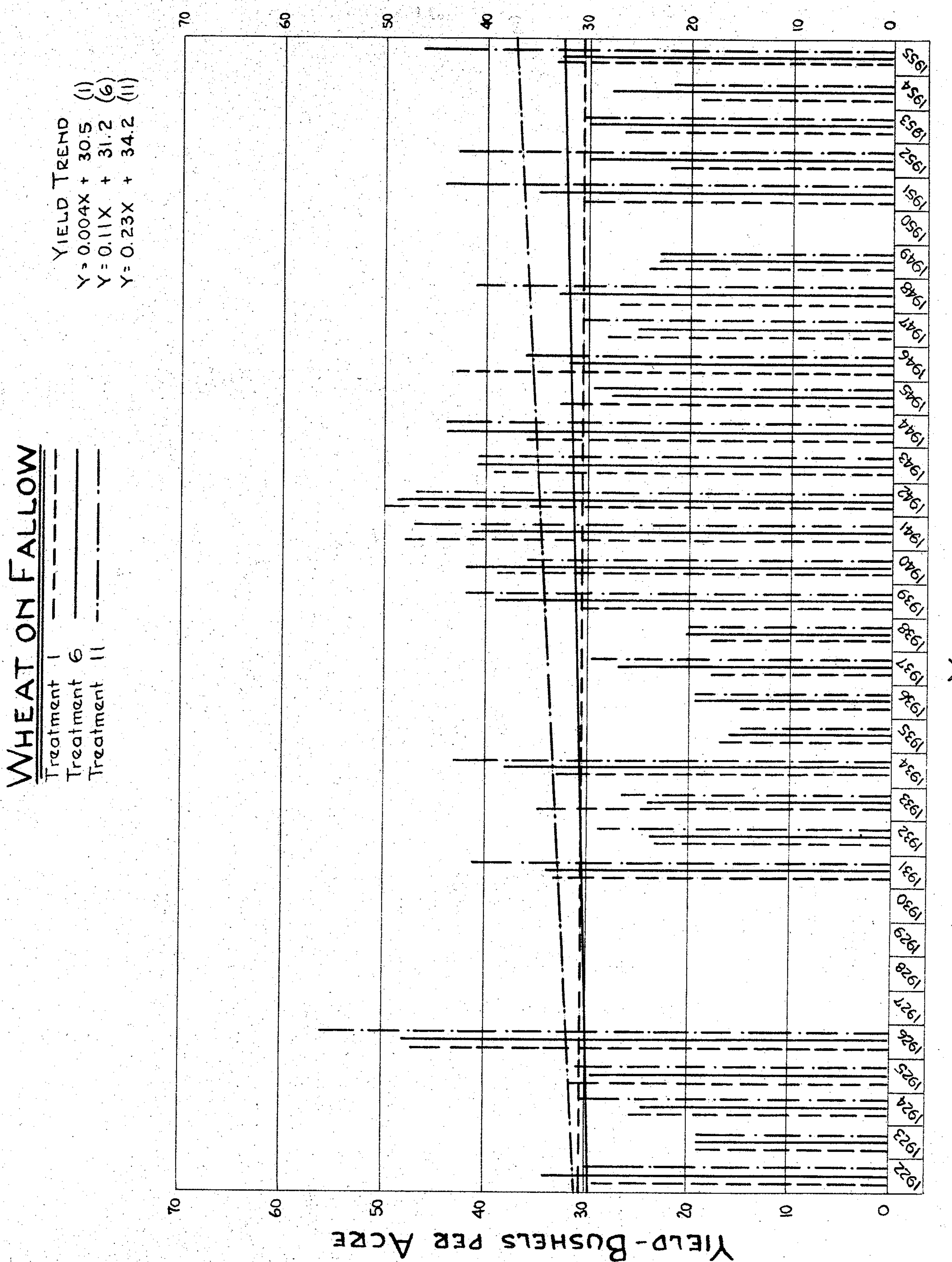


Figure 1

Appendix ii.

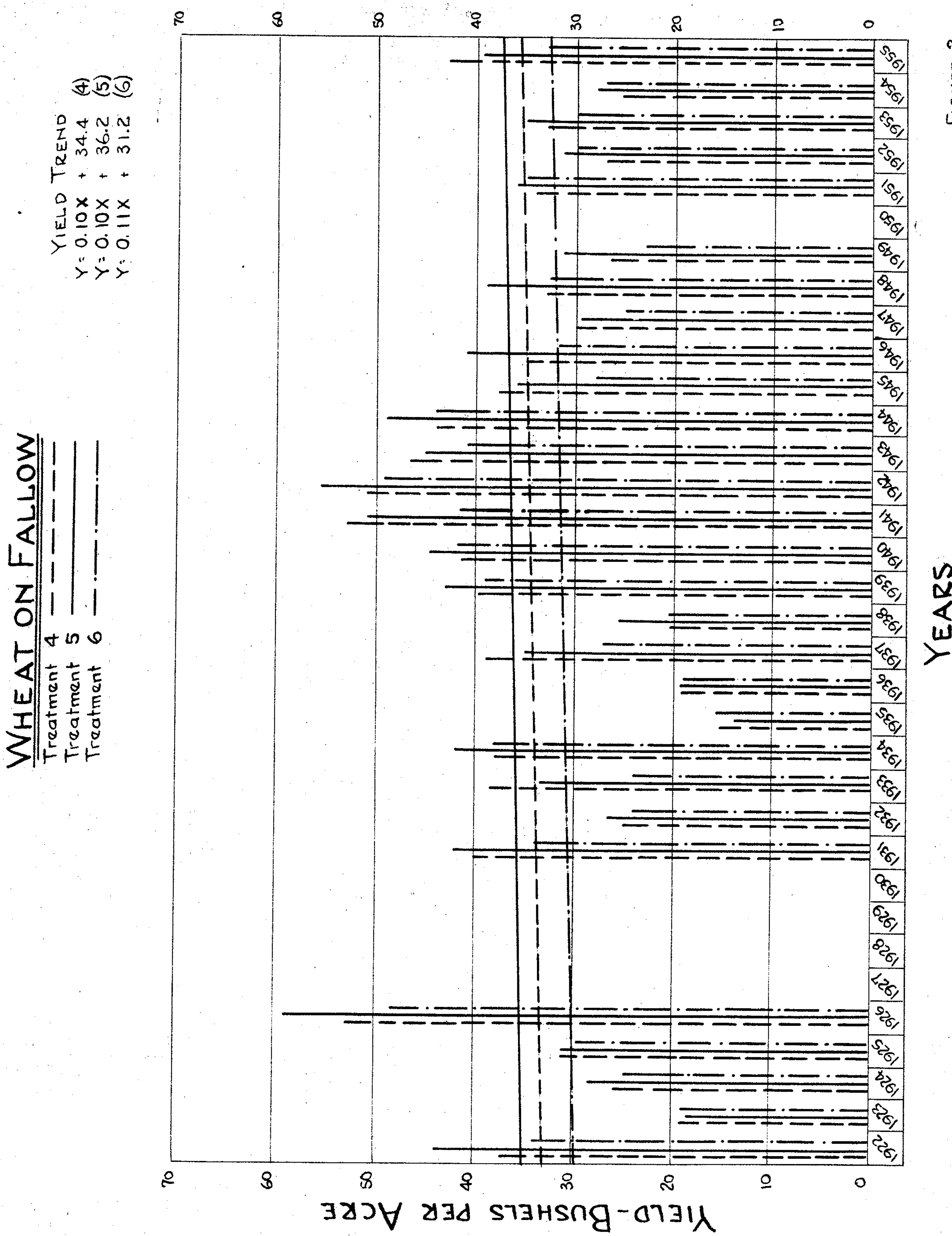
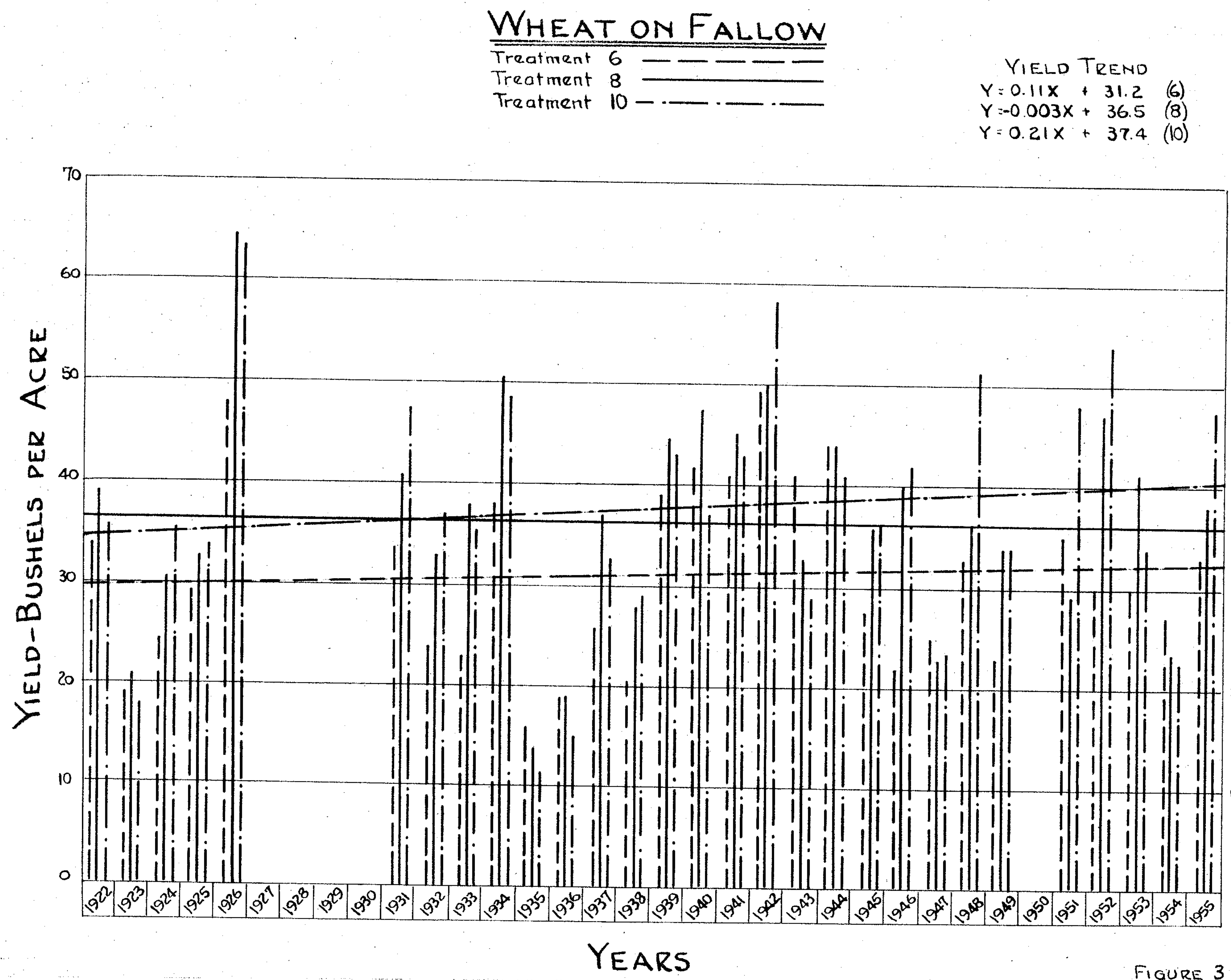


FIGURE 2


WHEAT ON FALLOW
Treatment 6
Treatment 8
Treatment 10
YIELD TREND
Y = 0.11X + 31.2 (6)
Y = -0.003X + 36.5 (8)
Y = 0.21X + 37.4 (10)
YIELD-BUSHELS PER ACRE
0
10
20
30
40
50
60
70
1922
1923
1924
1925
1926
1927
1928
1929
1930
1931
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941
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1955
YEARS

FIGURE 3

Appendix ii.

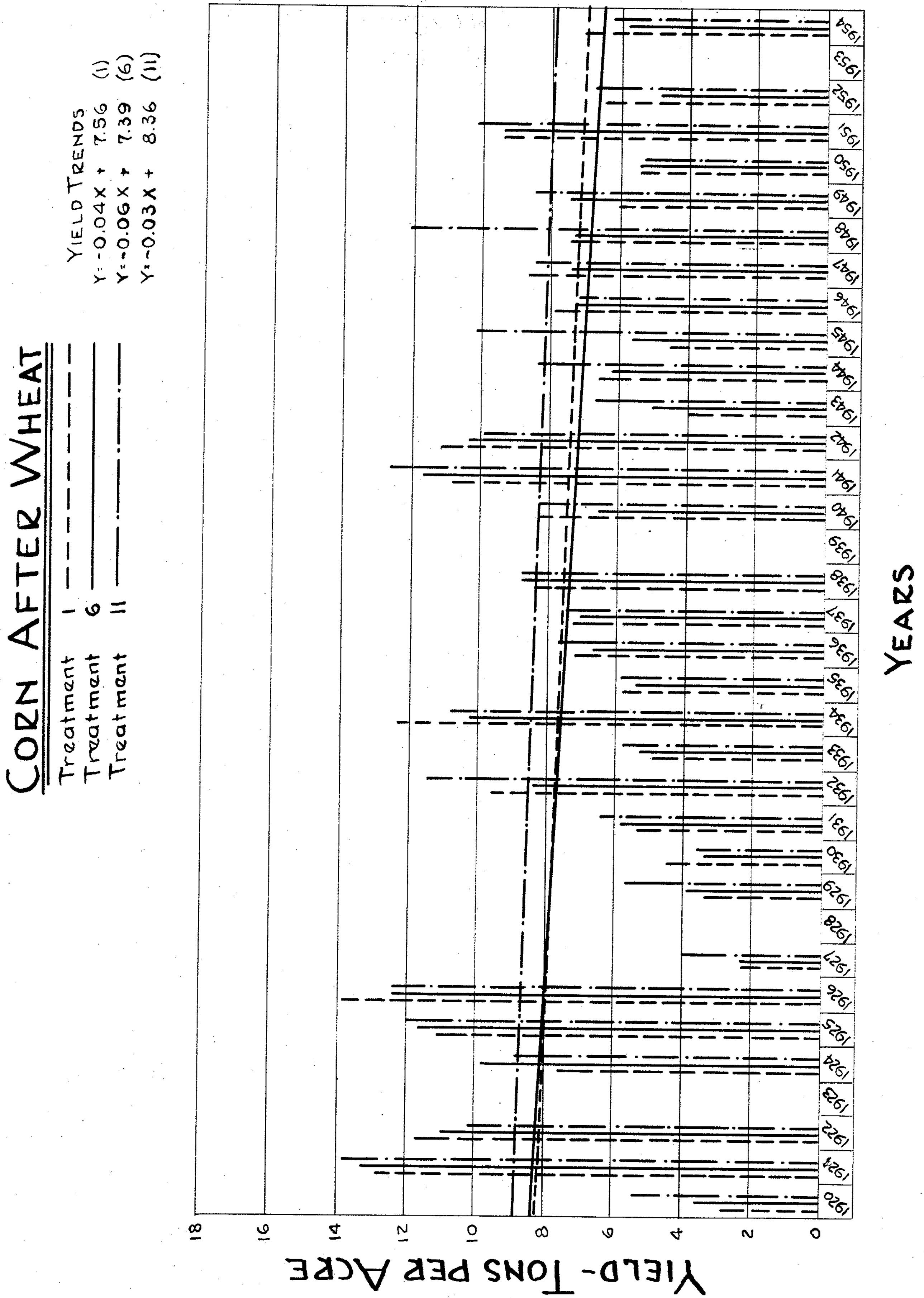

Figure 4

Appendix ii.

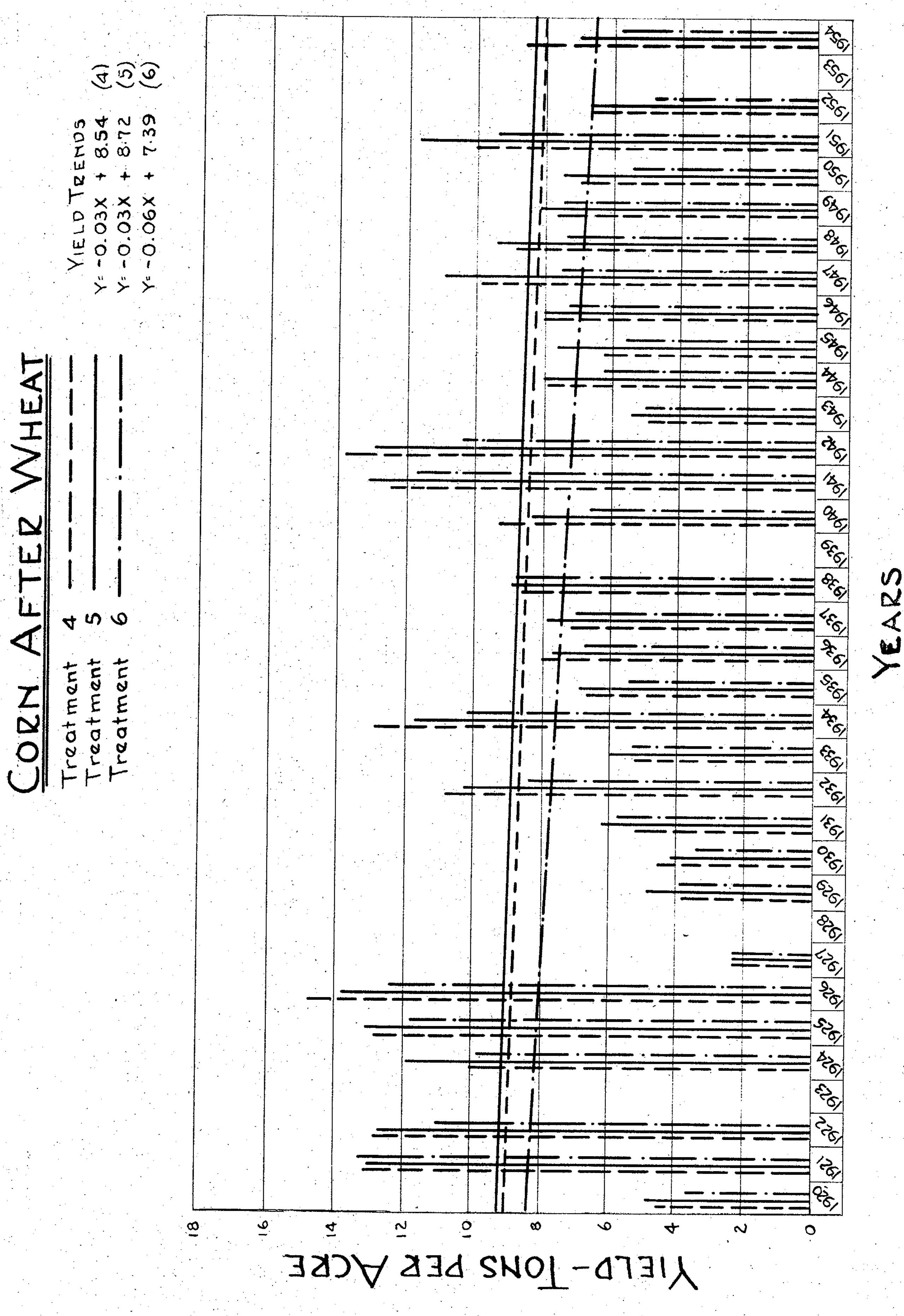

FIGURE 5

Appendix ii.

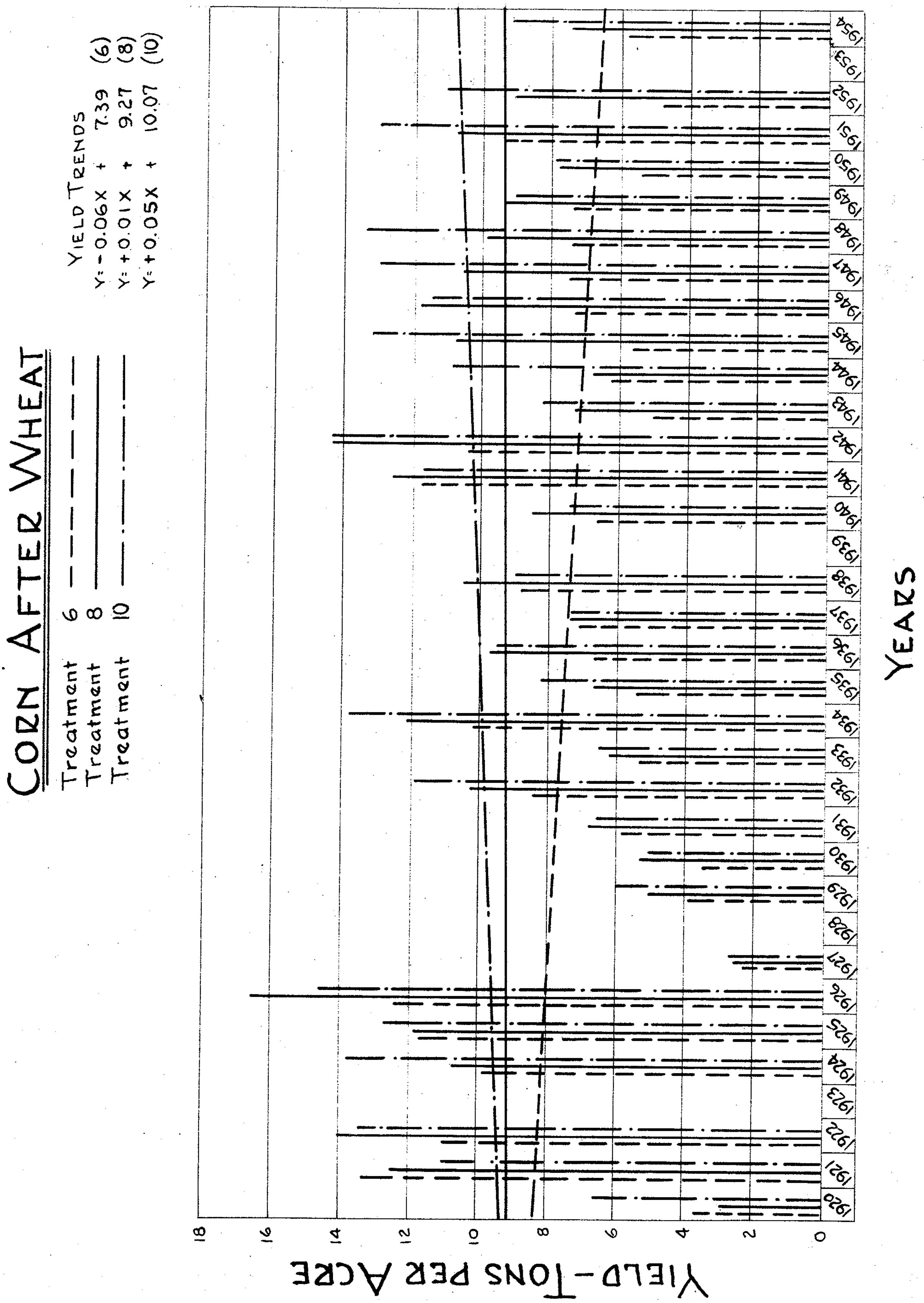

Figure 6

Appendix ii.

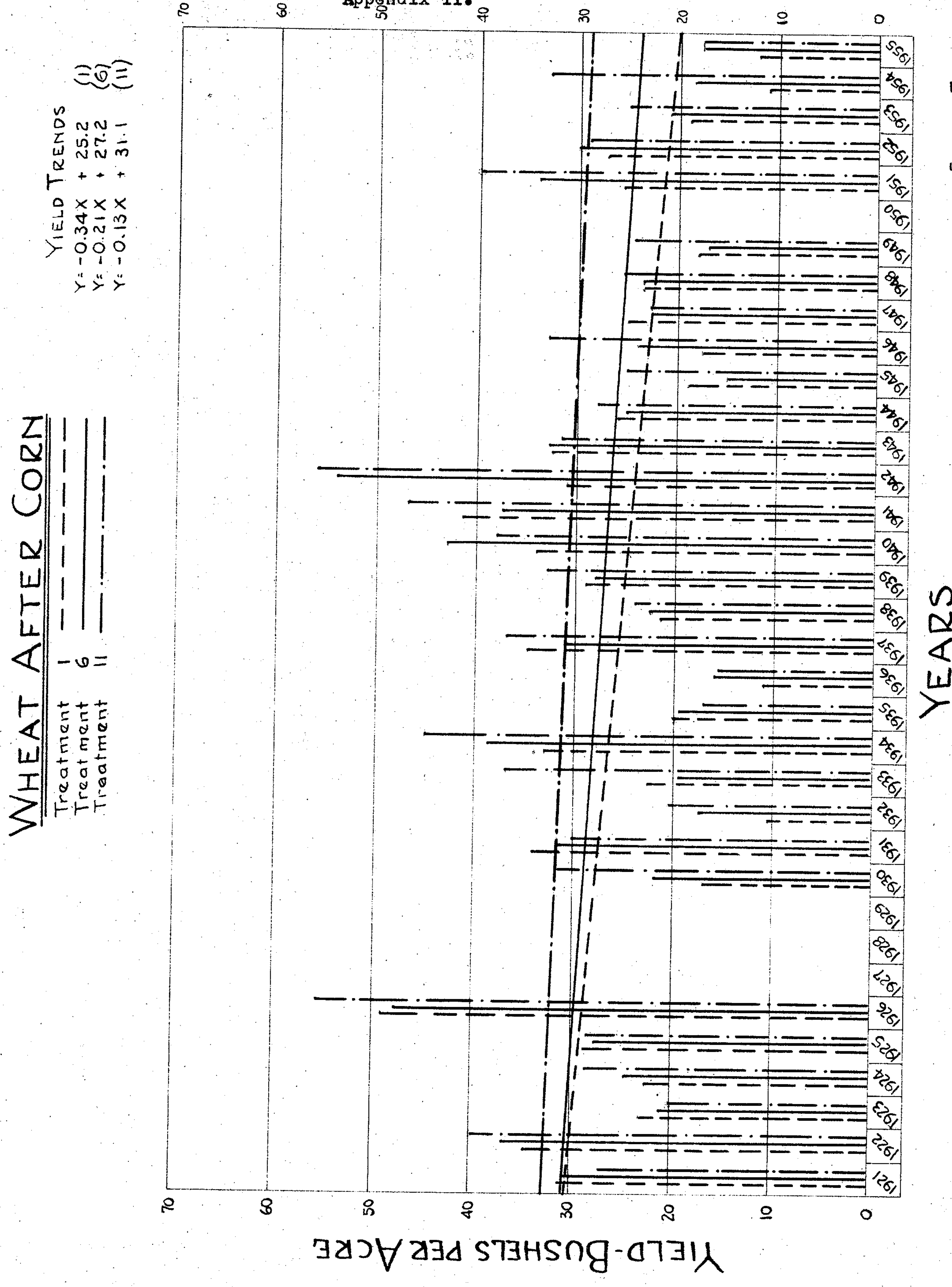

FIGURE 7

Appendix ii.

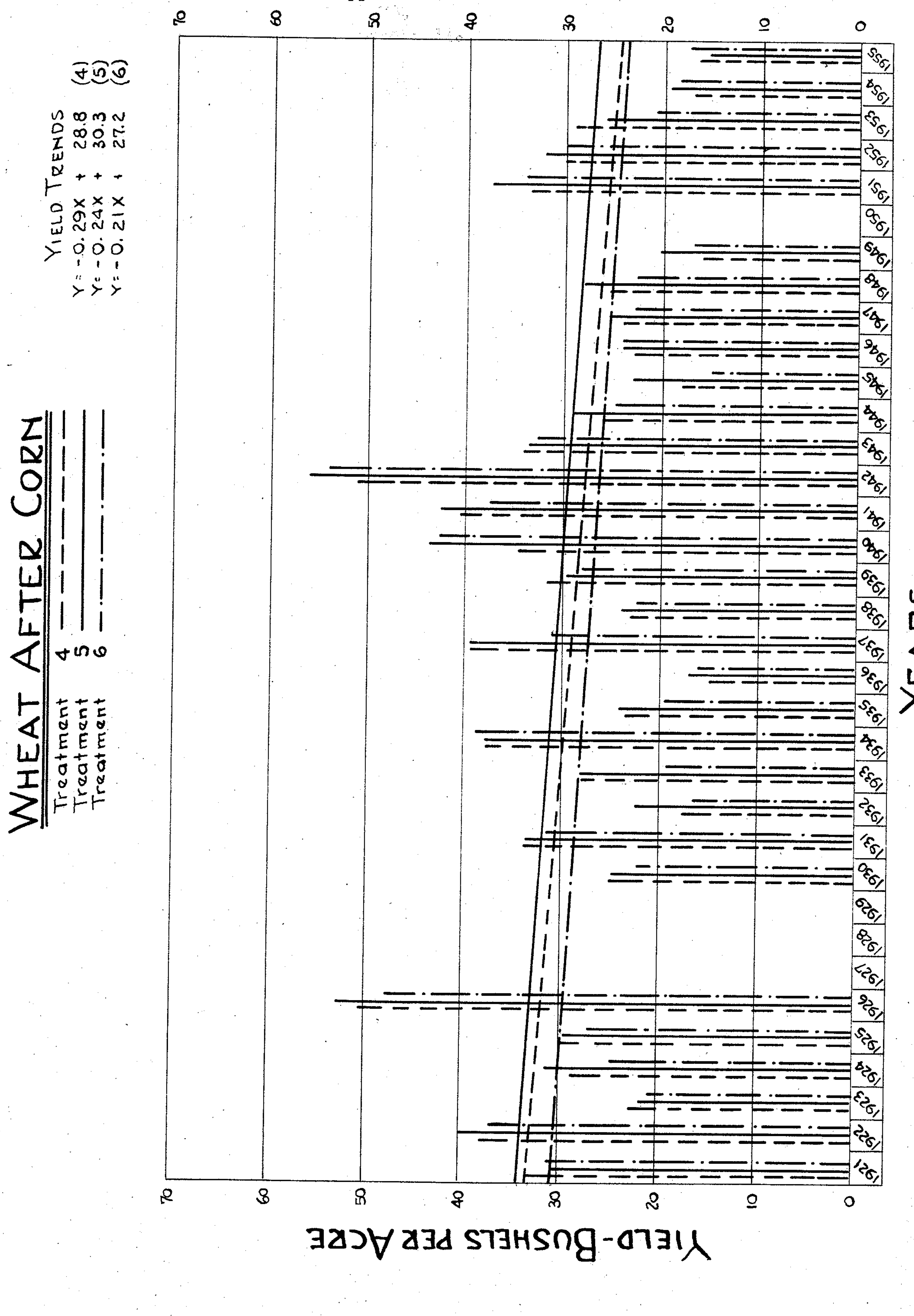

FIGURE 8

Wheat After Corn

Treatment	6	— — — —
Treatment	8	————
Treatment	10	—·—·—

Yield Trends

$Y = -0.21X + 27.2$ (6)
$Y = -0.04X + 34.0$ (8)
$Y = +0.18X + 35.2$ (10)

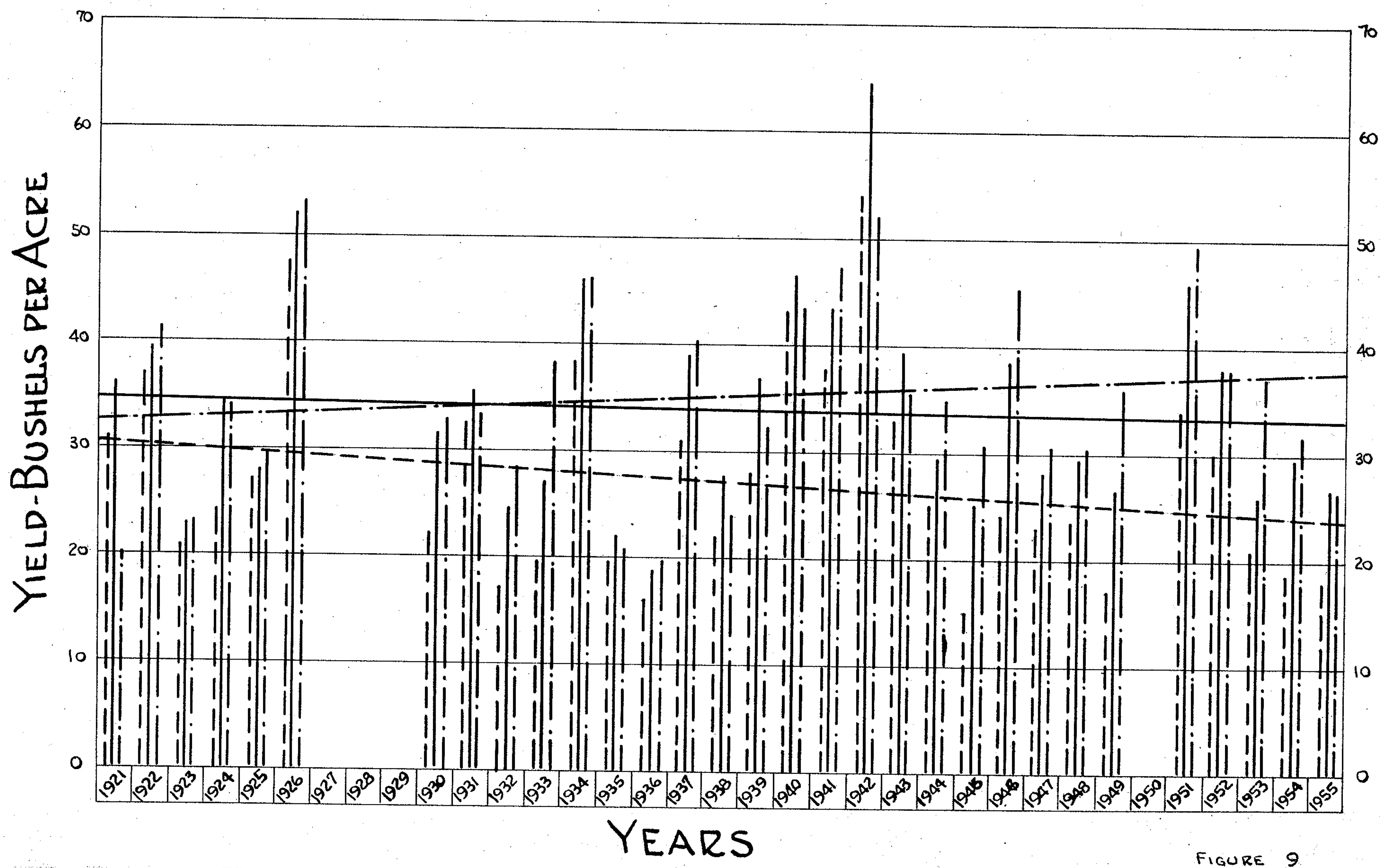

Figure 9

Appendix iii

Years as replication (wheat on fallow).

Variation	Degrees of freedom	Sum of squares	Mean square	F value	5%
Total	307	34196.21			
Years	27	17235.28	638.34	11.14*	1.57
Treatments	10	1495.05	149.5	2.61*	1.87
Years x Treatments (Error)	270	15465.88	57.28		

Coefficient of variability = 22.0%

Appendix iv.

Cycles as replication (wheat on fallow).

Variation due to	Degrees of freedom	Sum of squares	Mean square	F value	5%
Total	307	34196.21			
Cycles (replicates)	6	8430.61	1405.10	1.47	2.66
Ranges	3	2212.91	737.64		3.16
Cycles x ranges (Error a)	18	17235.28	957.52		
Treatments	10	1495.05	149.51	7.76*	1.99
Cycles x Treatments (Error b)	60	1156.05	19.27		
Ranges x Treatments	30	1239.02	41.30	3.06*	1.53
Cycles x Ranges x Treatments (Error c)	180	2427.29	13.48		

Coefficient of variability = 10.7%