A STUDY OF TRENDS IN YIELDS OF CROPS GROWN IN ROTATION, THE RESIDUAL EFFECTS OF FERTILIZER APPLICATIONS, AND THE RELATIONSHIP BETWEEN PLANT FOOD REMOVED AND THAT ADDED ON DUNMORE SILT LOAM SOIL

By

BARNEY STEWART HAWKINS

A Thesis Submitted to the Graduate Committee
In Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

in

Agronomy

Approved:

Dean of Agriculture

Head, Agronomy Department

Virginia Polytechnic Institute
1940

A C K N O W L E D G M E N T

The writer wishes to acknowledge with appreciation the assistance of Professor M. S. Kipps and other members of the Agronomy Department in planning and carrying on this investigation, and for their helpful suggestions in the preparation of this manuscript.

TABLE OF CONTENTS

INTRODUCTION

The economical production of crops should be the aim of those engaged in agriculture. Usually, the analysis of yield data from rotation experiments is based on the average yields produced. Average yields are necessary in the presentation of results of various plat treatments, but trend relationships may be used to advantage as a supplement to the average yields in interpretation of the data. Although the straight line yield trends are not applicable to all data, graphical presentations usually meet with greater reception than data presented in tables. These straight line trends over a period of twenty-five years indicate an increase or decrease in the productivity of the soil.

One of the important factors in the economical production of crops is the judicious use of fertilizers. In planning systems of farming and soil management where it would be advantageous to apply the fertilizer only once or twice during the rotation, it is important to know how long the fertilizer will have an effect on crop growth. The rate of exhaustion of a fertilizer varies according to the amount of application, soil and crop responses. A low rate of exhaustion occurs when applications of fertilizers are made on soils from which crop responses are slight; a high rate of exhaustion occurs when applications are made on soils from which responses are high. From an economic point of view the optimum rate of exhaustion will occur when the applications are low and the crop responses are high.

The work reported in the following pages was planned to study the straight line yield trends, the residual effects of fertilizers, and the estimated amounts of nitrogen, phosphoric acid and potash removed in harvested crops. Such a study should furnish valuable information concerning the rotation and fertilizer recommendations to be made for each crop.

EXPERIMENTAL

A. Purpose of Investigation:

The threefold purpose of this investigation is as follows: to determine the trend of the yields of corn, wheat, clover hay, and grass hay when grown in rotation with and without fertilizer; to study the residual effects of fertilizers which were applied five successive years previous to 1914; and to study the relationship between the amount of plant food added in fertilizers and that removed in harvested crops.

B. Materials and Methods:

The Virginia Agricultural Experiment Station has conducted without interruption, fertilizer and manure experiments on Dunmore silt loam soil since 1909. These experiments were conducted on four areas of thirteen one-eighth acre plats each. A regular rotation of corn, wheat, clover hay, and timothy and redtop hay has been employed so that each of these crops was represented each year.

During the first five years of the experiment, 1909-1913, the entire plat of one-eighth acre was fertilized as shown in Table II. However, in 1914 the plats were divided in half and the western half of each plat continued to receive fertilizer, the other half was left unfertilized. From the beginning of the experiment, two of the plats have never received a fertilizer treatment and were, therefore, considered as logical check plats when comparing the fertilizer treatments.

The amounts and sources of nitrogen, phosphoric acid and potash were as follows: 40 pounds of nitrogen derived from 13 percent dried blood from 1909 through 1933, and from 35 percent ammonium nitrate from 1934 through 1938*;

*Sulphate of ammonia was the source of nitrogen for plat 4 from 1909 to 1913 inclusive.

70 pounds of phosphoric acid from 16 percent superphosphate or from 32 percent raw rock phosphate; and 100 pounds of potash from 50 percent muriate of potash. All fertilizer applications were made annually in the spring to each crop except in the case of 16 tons of stable manure which were applied once in four years before corn.

During the experiment lime was applied to all plats at intervals of four years, usually before corn.

Data on crop yields from the various fertilized plats were obtained from the records of the Virginia Agricultural Experiment Station. These data were for the period from 1909 through 1938, but due to changes in the experiment only data of 1914 to 1938 inclusive were used in preparing yield trends of crops grown under various fertilizer treatments. However, in the study of residual effect of fertilizers applied prior to 1914, the data from 1909 to 1938 inclusive was used. This was possible because one-half of each plat received no fertilizer since 1913.

The straight line trends were calculated bythe method of least squares (17). In using this line, it is necessary to calculate but one variable which indicates a uniform upward or downward slope of the trend line. Such a line points out the general or average trend in yield over a number of years. Although not applicable to all yield data, it does have the advantage of being one figure which is relatively easy to understand.

Estimates of plant food removed in harvested crops were obtained by multiplying the total yields of crops grown in this experiment by percentages of nitrogen, phosphoric acid and potash contained in each crop harvested. These percentages, as shown in Table I, were taken from Morrison's Feeds and Feeding (18).

Table I.- The percentage composition of crops and their products in nitrogen, phosphoric acid and potash.*

Crops and Crop Products	N	P_2O_5	K_2O
	Percent	Percent	Percent
Corn, dent, well dried	1.55	0.644	0.396
Corn cobs, ground	0.37	0.046	0.444
Corn stover, medium in water	0.91	0.184	1.800
Wheat	2.10	0.989	0.528
Wheat straw	0.61	0.161	0.960
Clover and mixed grass hay, high in clover	1.54	0.391	1.788
Grass hay mixed, eastern states, good quality	1.12	0.391	1.632

*Analyses obtained from Morrison's "Feeds and Feeding".

RESULTS AND DISCUSSION

A. Yield Trends of Fertilizer Plats:

The average yields of crops, the direction and amount of yield trends of each of the fertilized plats are presented in Table II. Graphs showing plotted yields and straight line trends of the various crops for each of the fertilized plats are presented in Figures 1 to 15 inclusive. Separate base lines were used in the graphs in case of clover hay and grass hay, but the same base line was used to represent corn and wheat. The graphs cover the period from 1914 to 1938 inclusive.

Klages (13) used the straight line trend in the study of several rotations. Crops used in the rotations were: corn, wheat, oats, potatoes and peas. He stated that future yields cannot be predicted by use of the line trends, since the upward or downward trend cannot be expected to continue, due to the fact that a state of equilibrium in yields will be reached. He pointed out that such a position would be determined by the climatic conditions under which the crops were grown and by the soil changes induced by the cropping system. It was also shown that generally where high average yields were obtained, there was also a high upward trend, while low average yields had low upward trends, and in some cases, a downward yield trend. A comparison of closeness of fit between the straight line and parabola was also made by Klages, and he concluded that the parabola was not materially better than the straight line. The straight line was calculated by the method of least squares (17).

Weitz (27) presented the trend in combined acreage and total production of corn, wheat, oats and potatoes for the United States for the period from 1885 to 1924 inclusive. He showed that the total volume of production of these crops increased much more than the total acreage in these crops as a result of the rising acre-yields. It was pointed out that this was very

Table II - The average yields of corn and wheat in bushels and hay in tons per acre and their yield trends on the Rotation Experiment With Fertilizers from 1914 to 1938 inclusive.

Plat	Kind and amount of fertilizer	Crop	FERTILIZED PLATS		CHECK PLATS	
			Average Yield	Extremities of trend lines	Average Yield	Extremities of trend lines
2	Superphosphate[1]	Corn	47.80	46.15 - 49.33	42.13	44.68 - 39.78
		Wheat	19.99	14.02 - 25.50	12.20	12.60 - 11.84
		Clover hay	1.74	1.43 - 2.03	1.18	1.31 - 1.06
		Grass hay	1.92	1.28 - 2.50	1.38	1.18 - 1.56
3	Dried blood,[2]	Corn	57.25	55.48 - 58.88	44.35	48.96 - 40.06
	Superphosphate,[1]	Wheat	25.10	13.97 - 35.37	11.50	12.53 - 10.55
	Muriate of	Clover hay	2.34	1.16 - 3.44	1.25	1.27 - 1.23
	potash[3]	Grass hay	2.57	1.40 - 3.65	1.39	1.23 - 1.53
4	Sulphate of ammonia,[2]	Corn	42.48	35.84 - 48.62	35.40	39.17 - 31.92
	Raw rock	Wheat	12.00	7.14 - 16.49	8.05	7.18 - 8.86
	phosphate[1]	Clover hay	1.75	1.12 - 2.32	0.92	0.94 - 0.92
		Grass hay	1.90	1.63 - 2.15	1.17	0.91 - 1.41
5	Superphosphate,[1]	Corn	54.33	48.95 - 59.20	41.32	45.77 - 37.22
	Muriate of	Wheat	20.54	13.46 - 27.09	10.00	11.40 - 8.72
	potash[3]	Clover hay	2.00	1.30 - 2.65	1.04	1.02 - 1.07
		Grass hay	1.93	1.26 - 2.56	1.19	1.05 - 1.33
6	Muriate of potash[3]	Corn	39.30	40.01 - 38.63	32.92	37.53 - 28.65
		Wheat	10.75	13.66 - 8.06	7.17	6.80 - 7.50
		Clover hay	1.00	1.17 - 0.85	0.72	0.86 - 0.58
		Grass hay	1.14	0.82 - 1.44	0.80	0.74 - 0.85
7	Dried blood,[2]	Corn	41.74	43.17 - 40.42	33.12	36.41 - 30.09
	Muriate of	Wheat	11.13	8.83 - 13.25	7.63	7.90 - 7.38
	potash[3]	Clover hay	1.26	1.24 - 1.29	0.76	0.94 - 0.59
		Grass hay	1.42	1.05 - 1.75	0.76	0.69 - 0.84
8	Dried blood,[2]	Corn	40.75	44.05 - 37.70	36.98	45.82 - 28.82
	Superphosphate[1]	Wheat	15.16	14.29 - 15.97	8.87	10.38 - 7.47
		Clover hay	1.55	1.10 - 1.98	0.95	1.04 - 0.86
		Grass hay	1.55	1.20 - 1.88	1.03	0.92 - 1.14
9	Dried blood[2]	Corn	27.76	31.41 - 24.39	29.98	32.56 - 27.61
		Wheat	5.89	5.30 - 6.43	6.54	5.50 - 7.50
		Clover hay	1.06	0.69 - 1.42	0.73	0.77 - 0.69
		Grass hay	1.19	0.91 - 1.43	0.77	0.66 - 0.88

Table II - The average yields of corn and wheat in bushels and hay in tons per acre and their yield trends on the Rotation Experiment With Fertilizers from 1914 to 1938 inclusive.- Continued.

Plat	Kind and amount of fertilizer	Crop	FERTILIZED PLATS Average Yield	FERTILIZED PLATS Extremities of trend lines	CHECK PLATS Average Yield	CHECK PLATS Extremities of trend lines
10	16 tons manure[4]	Corn	59.30	61.55 - 57.25	39.19	47.20 - 31.80
		Wheat	23.65	20.11 - 26.91	8.82	10.77 - 7.02
		Clover hay	2.18	1.39 - 2.92	1.05	1.24 - 0.86
		Grass hay	2.11	1.35 - 2.83	1.08	1.06 - 1.11
11	16 tons manure[4], Raw rock phosphate[1]	Corn	56.82	43.64 - 68.99	29.61	33.64 - 25.89
		Wheat	21.70	8.71 - 33.69	5.77	4.24 - 7.19
		Clover hay	1.88	0.76 - 2.91	0.75	0.72 - 0.80
		Grass hay	1.77	0.66 - 2.81	0.76	0.55 - 0.95
12	4 tons manure	Corn	62.19	58.94 - 65.19	43.08	54.45 - 32.57
		Wheat	24.57	19.52 - 29.24	10.10	15.68 - 4.96
		Clover hay	2.59	2.16 - 2.98	1.35	2.03 - 0.73
		Grass hay	2.70	1.97 - 3.37	1.32	1.42 - 1.23
13	16 tons manure[4] Superphosphate[1]	Corn	58.88	64.76 - 53.43	43.72	55.10 - 33.22
		Wheat	25.06	21.25 - 28.57	8.45	10.77 - 6.29
		Clover hay	2.41	1.73 - 3.03	1.25	1.79 - 0.77
		Grass hay	2.26	1.63 - 2.85	1.17	1.21 - 1.13
14	Raw rock phosphate[1]	Corn	37.99	40.00 - 36.12	30.75	35.11 - 26.73
		Wheat	10.44	6.27 - 14.29	5.80	5.26 - 6.28
		Clover hay	1.28	1.10 - 1.45	0.81	0.97 - 0.67
		Grass hay	1.16	0.89 - 1.41	0.82	0.89 - 0.77
	Check-Average of two plats	Corn	32.50	36.40 - 28.90	32.50	36.40 - 28.90
		Wheat	6.91	5.71 - 8.03	6.91	5.71 - 8.03
		Clover hay	0.84	0.83 - 0.86	0.84	0.83 - 0.86
		Grass hay	0.97	0.73 - 1.18	0.97	0.73 - 1.18

[1] 70 pounds phosphoric acid.

[2] 40 pounds nitrogen.

[3] 100 pounds potash.

[4] Once in four years.

All applications were made annually on acre basis except where otherwise noted.

Fig. 1.

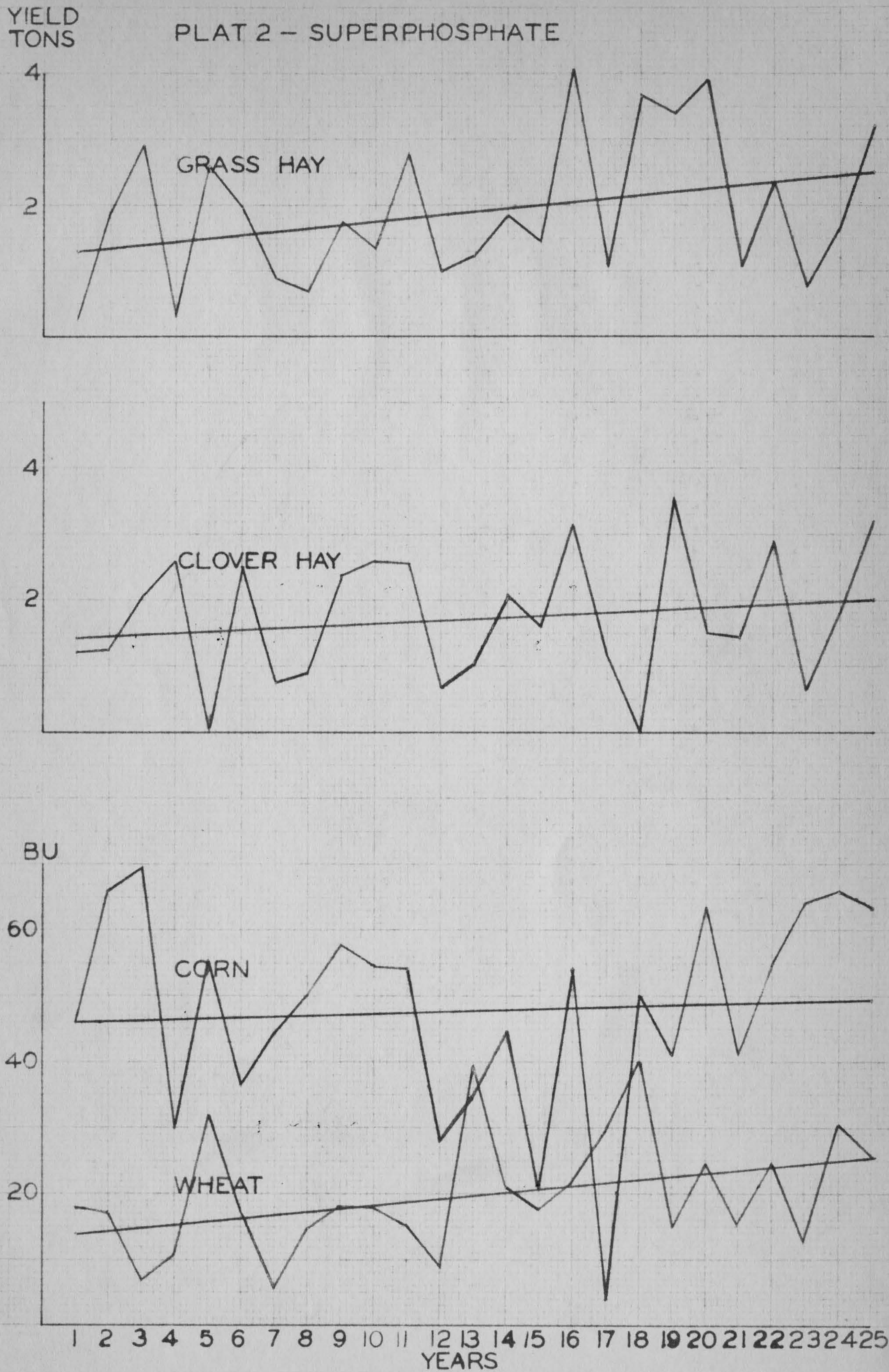

YIELD
TONS
PLAT 2 – SUPERPHOSPHATE
4
2
GRASS HAY
4
2
CLOVER HAY
BU
60
40
20
CORN
WHEAT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
YEARS

Fig. 2.

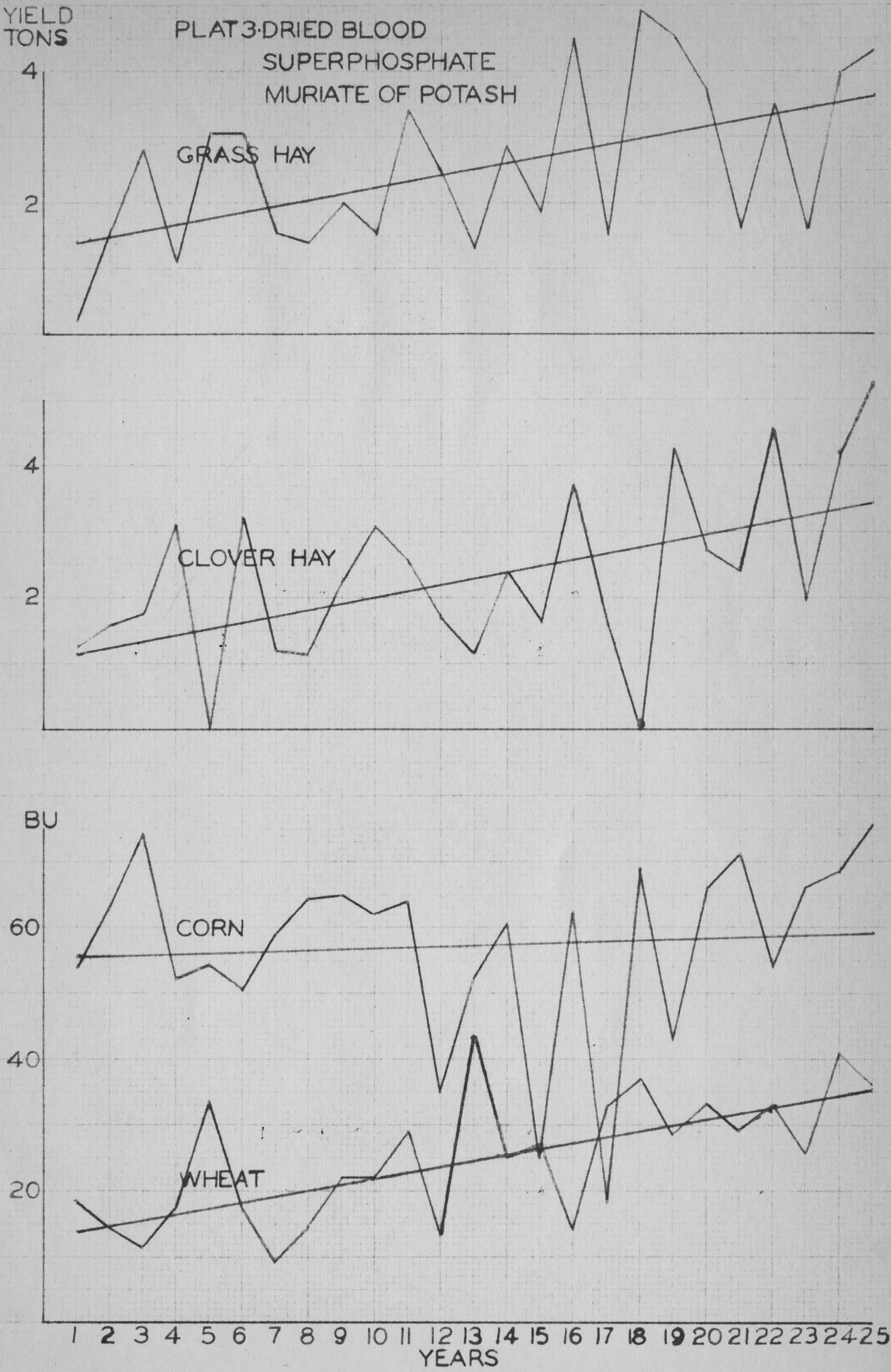
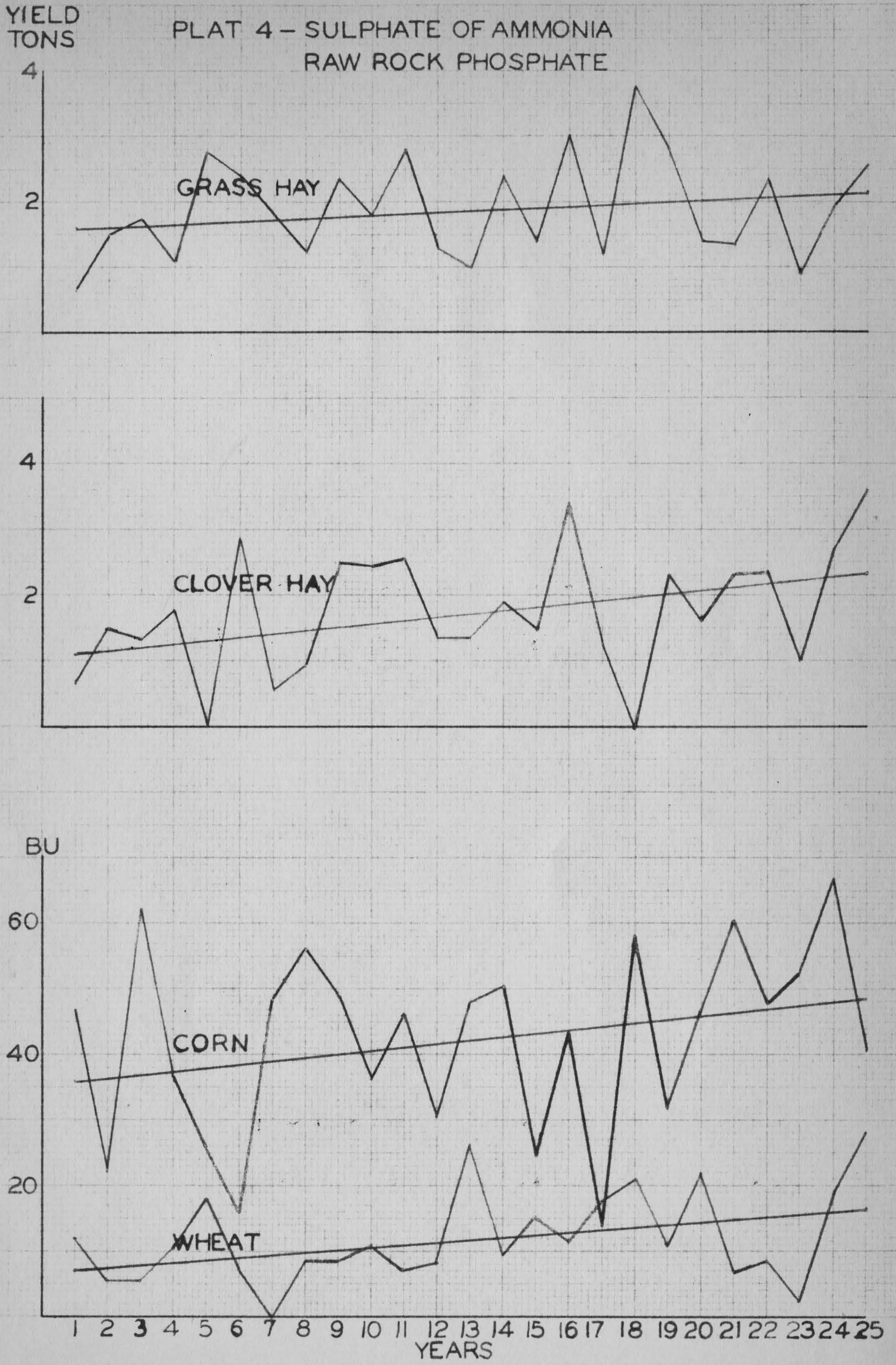

YIELD
TONS
PLAT 3·DRIED BLOOD
SUPERPHOSPHATE
MURIATE OF POTASH
4
2
GRASS HAY
4
2
CLOVER HAY
BU
60
CORN
40
20
WHEAT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
YEARS

Fig. 3.



YIELD
TONS
PLAT 4 – SULPHATE OF AMMONIA
RAW ROCK PHOSPHATE
4
2
GRASS HAY
4
2
CLOVER HAY
BU
60
40
20
CORN
WHEAT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
YEARS

Fig. 4.

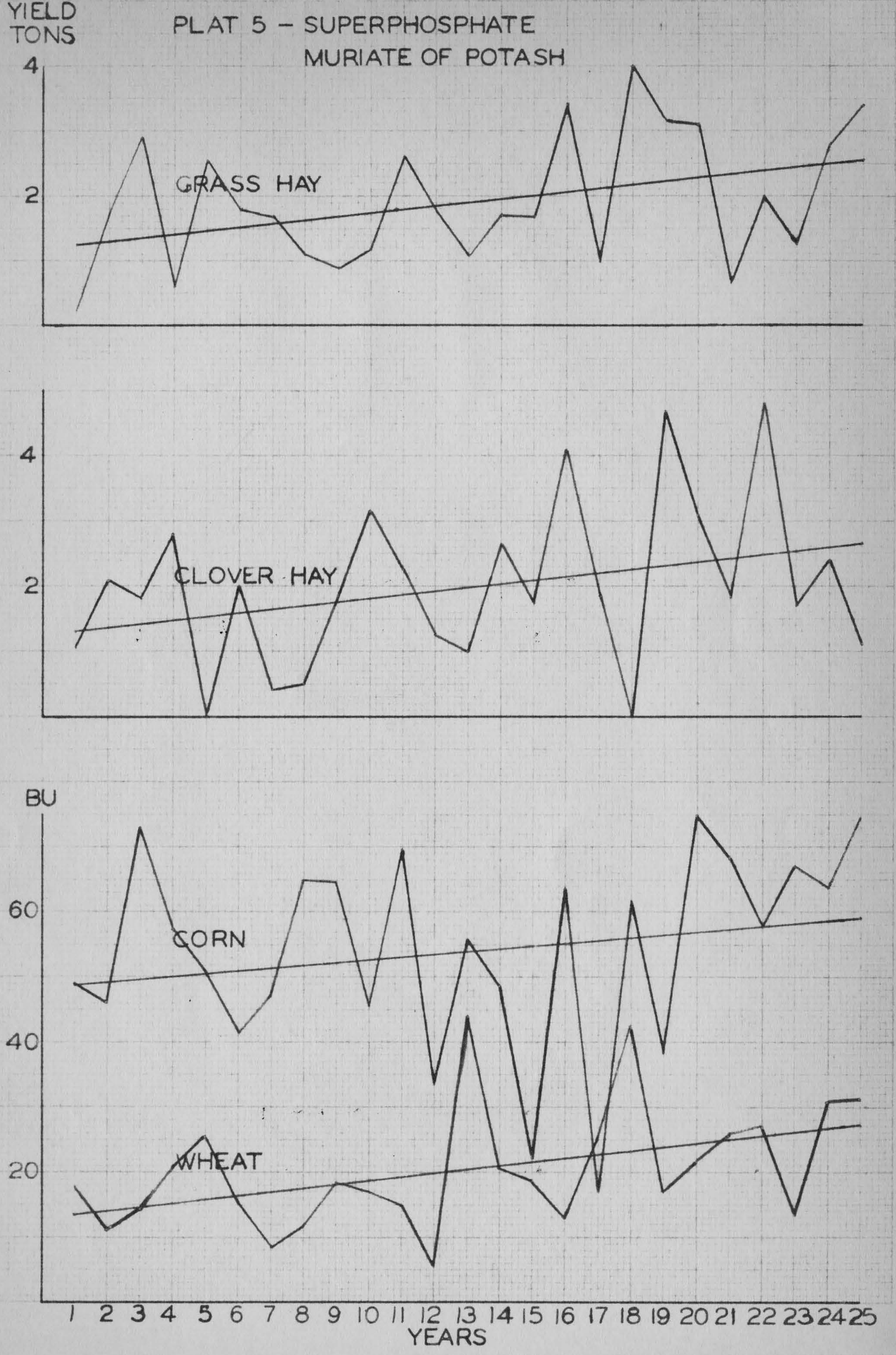
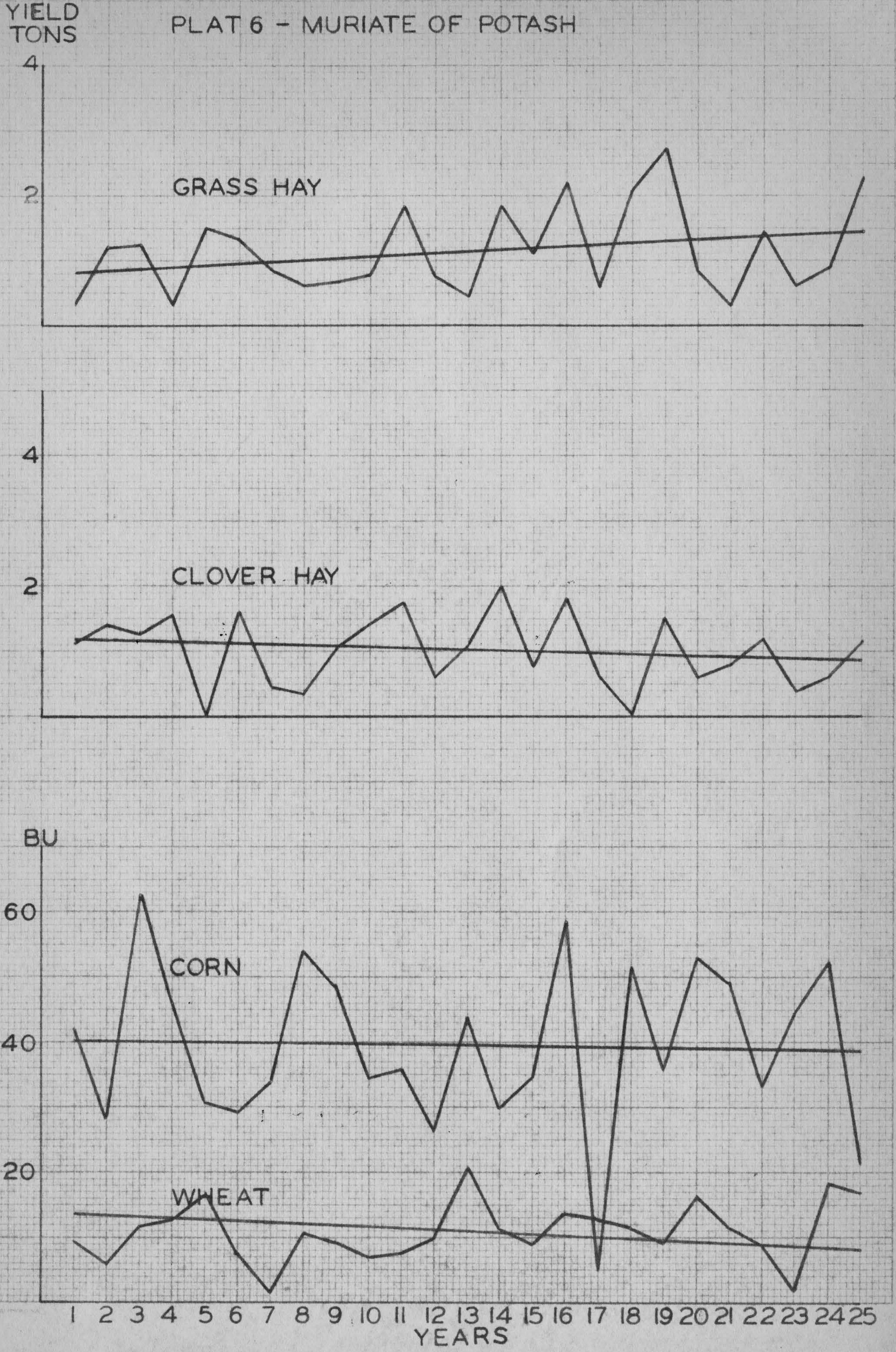
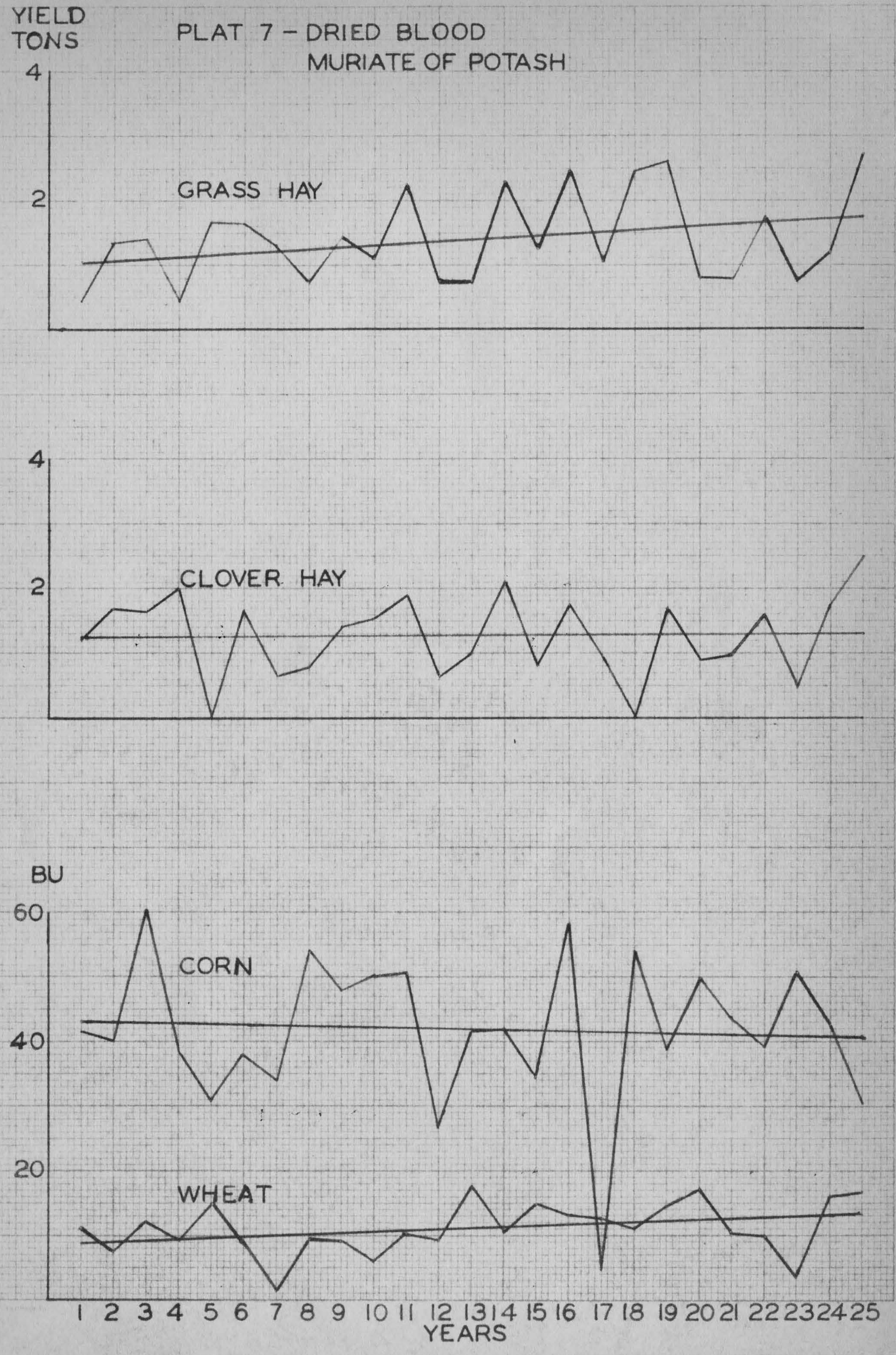

YIELD
TONS
PLAT 5 - SUPERPHOSPHATE
MURIATE OF POTASH
4
2
GRASS HAY
4
2
CLOVER HAY
BU
60
40
20
CORN
WHEAT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
YEARS

Fig. 5.



YIELD
TONS
PLAT 6 - MURIATE OF POTASH
4
2
GRASS HAY
4
2
CLOVER HAY
BU
60
CORN
40
20
WHEAT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
YEARS

Fig. 6.



YIELD
TONS
PLAT 7 - DRIED BLOOD
MURIATE OF POTASH
4
2
GRASS HAY
4
2
CLOVER HAY
BU
60
40
20
CORN
WHEAT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
YEARS

Fig. 7.

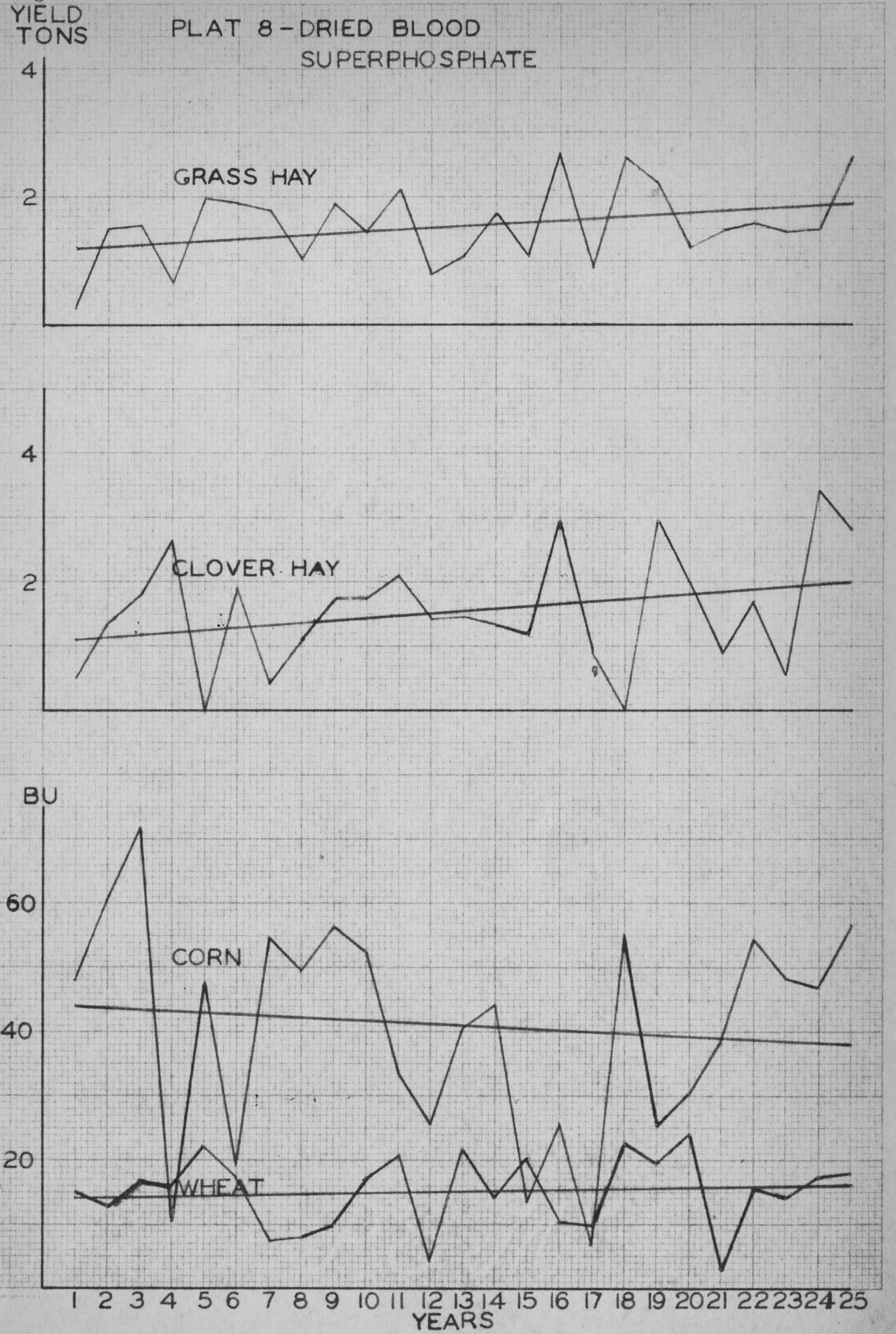

YIELD TONS
PLAT 8 - DRIED BLOOD
SUPERPHOSPHATE
4
2
GRASS HAY
4
2
CLOVER HAY
BU
60
40
20
CORN
WHEAT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
YEARS

Fig. 8.

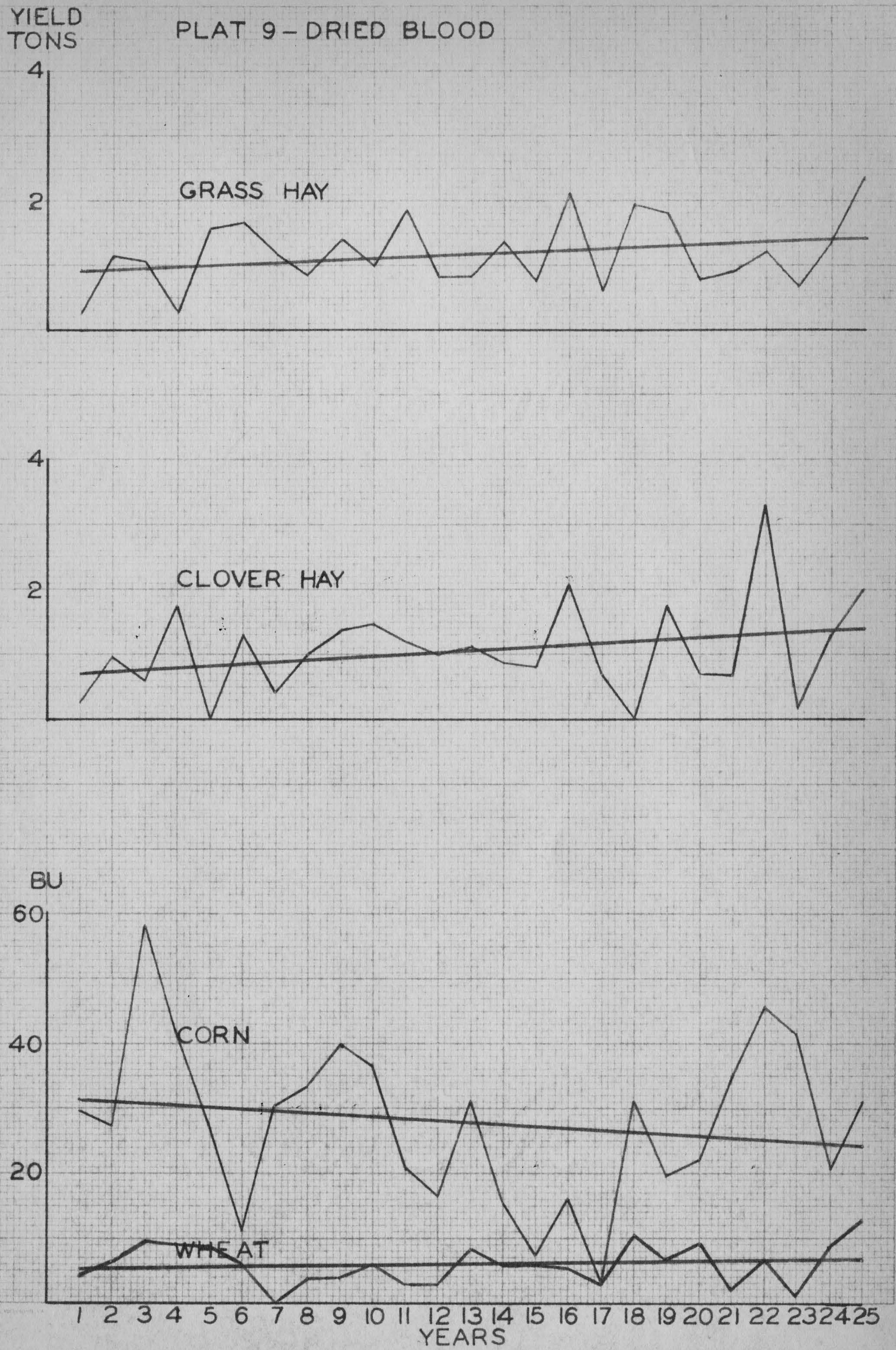

YIELD
TONS
PLAT 9 - DRIED BLOOD
4
2
GRASS HAY
4
2
CLOVER HAY
BU
60
40
20
CORN
WHEAT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
YEARS

Fig. 9.

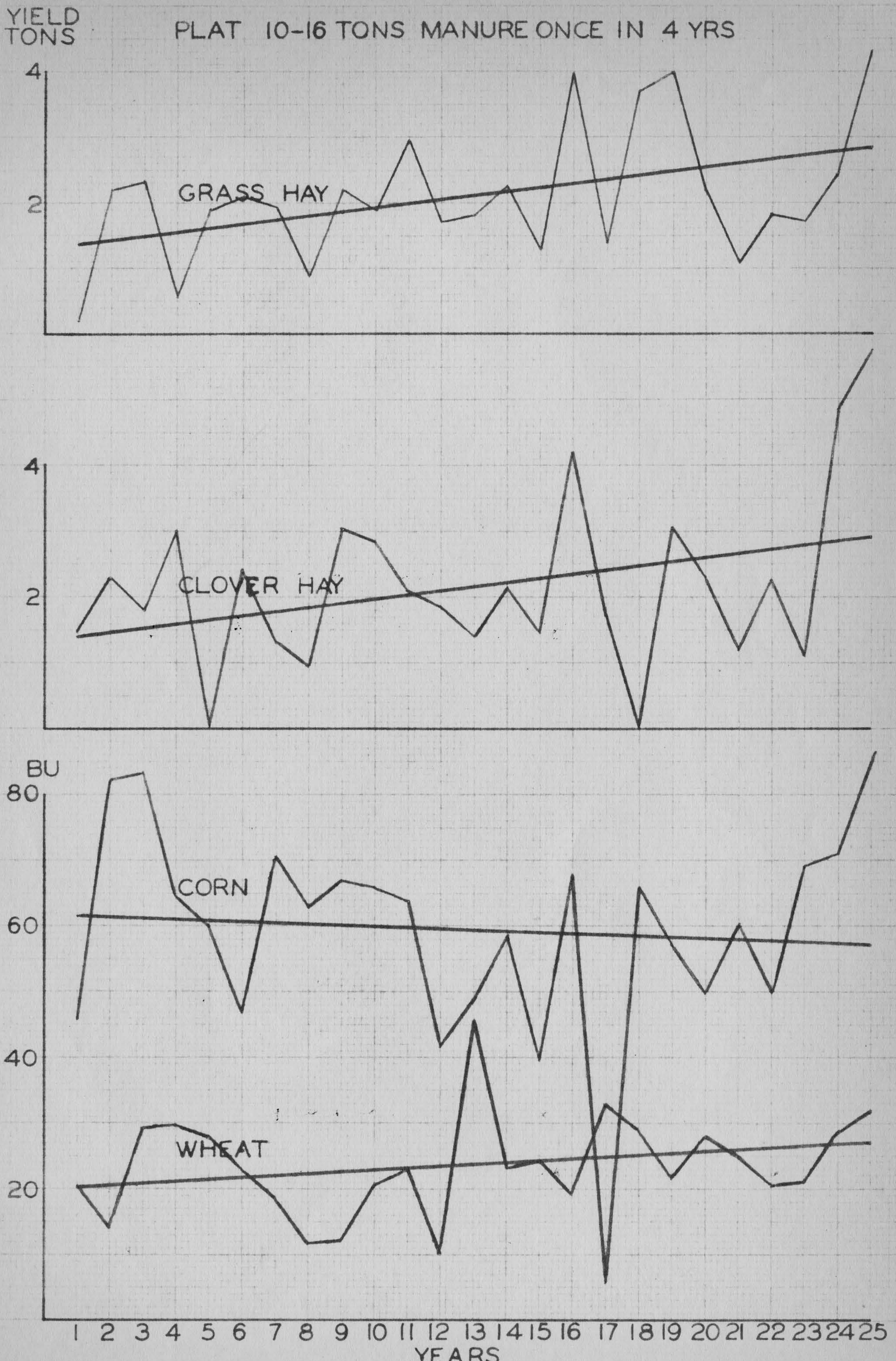

YIELD
TONS
PLAT 10-16 TONS MANURE ONCE IN 4 YRS
4
2
GRASS HAY
4
2
CLOVER HAY
BU
80
60
40
20
CORN
WHEAT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
YEARS

Fig. 10.

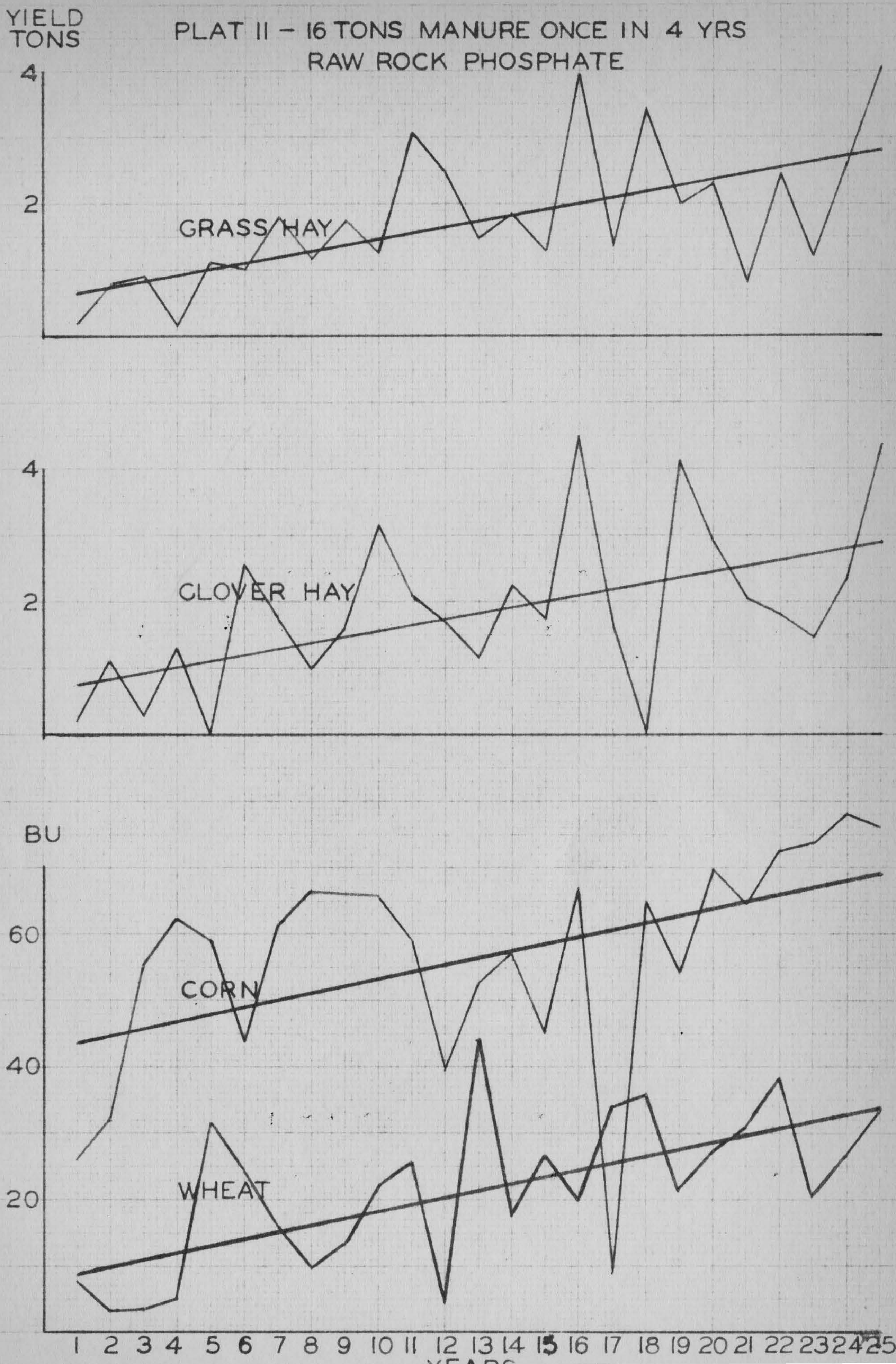

YIELD TONS
PLAT II - 16 TONS MANURE ONCE IN 4 YRS
RAW ROCK PHOSPHATE
4
2
GRASS HAY
4
2
CLOVER HAY
BU
60
40
20
CORN
WHEAT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

Fig. 11.

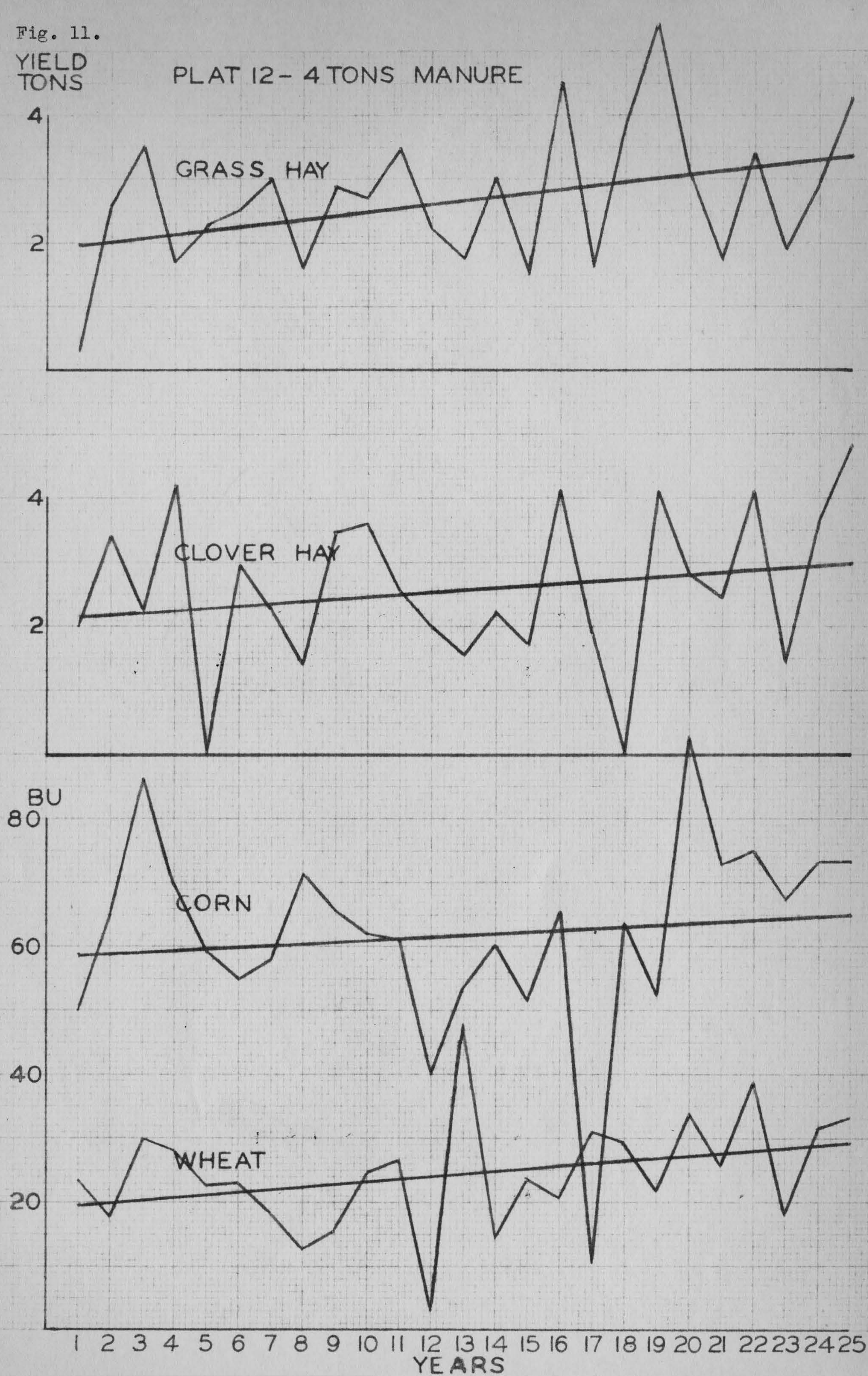
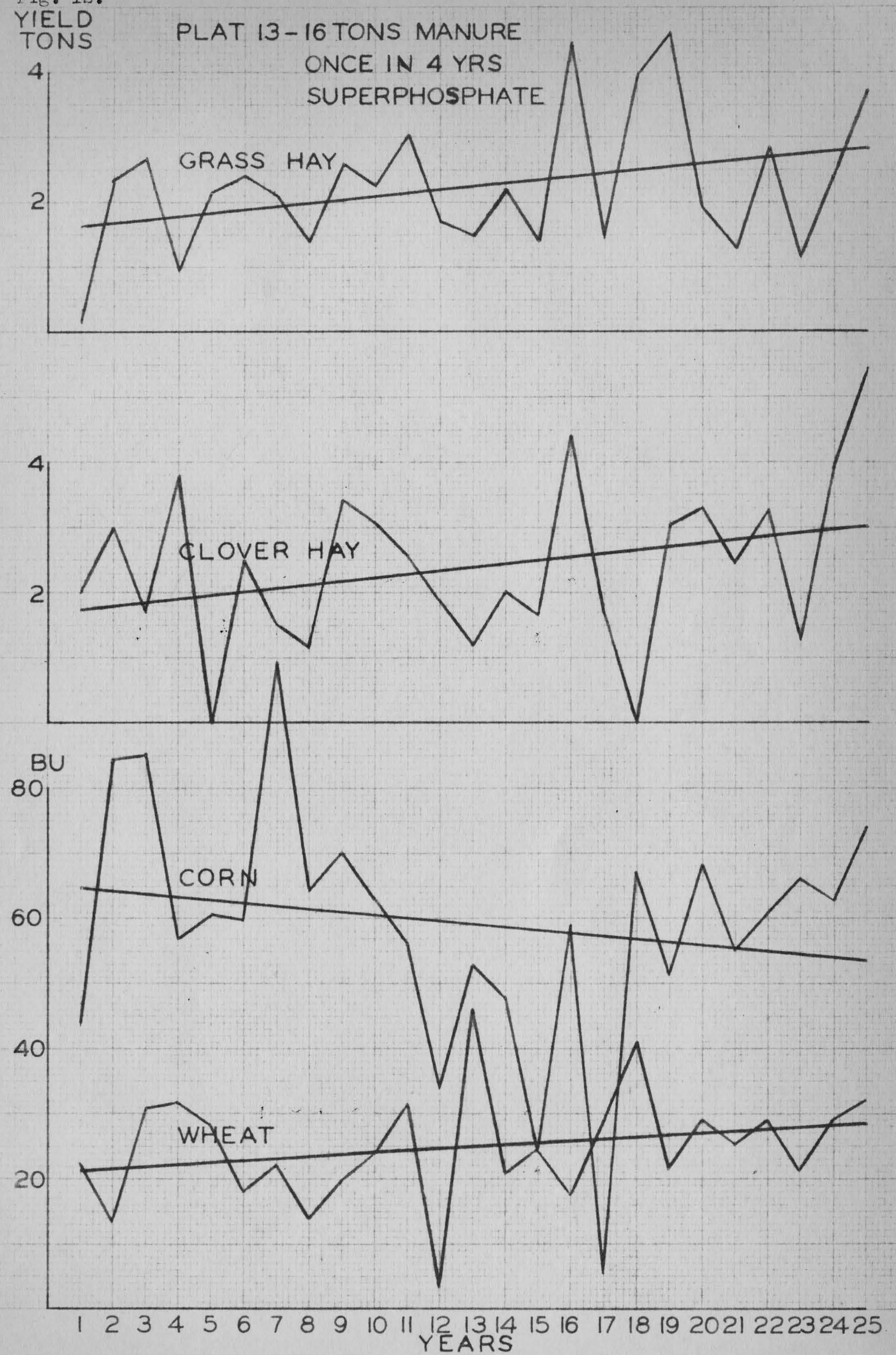
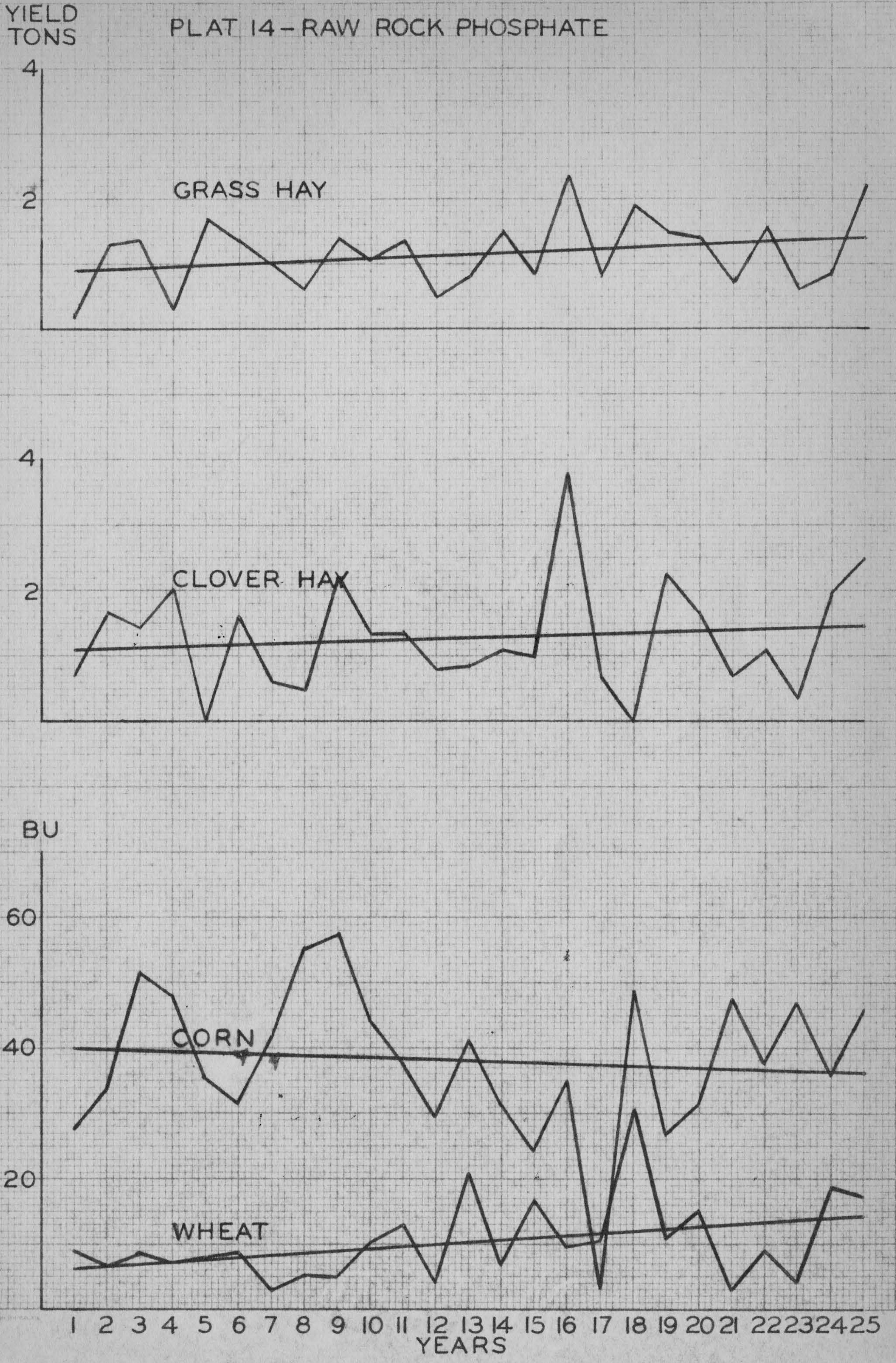

YIELD
TONS
PLAT 12- 4 TONS MANURE
4
2
GRASS HAY
4
2
CLOVER HAY
BU
80
60
40
20
CORN
WHEAT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
YEARS

Fig. 12.



YIELD
TONS
PLAT 13 - 16 TONS MANURE
ONCE IN 4 YRS
SUPERPHOSPHATE
4
2
GRASS HAY
4
2
CLOVER HAY
BU
80
60
40
20
CORN
WHEAT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
YEARS

Fig. 13.



YIELD
TONS
PLAT 14 - RAW ROCK PHOSPHATE
4
2
GRASS HAY
4
2
CLOVER HAY
BU
60
40
20
CORN
WHEAT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
YEARS

Fig. 14.

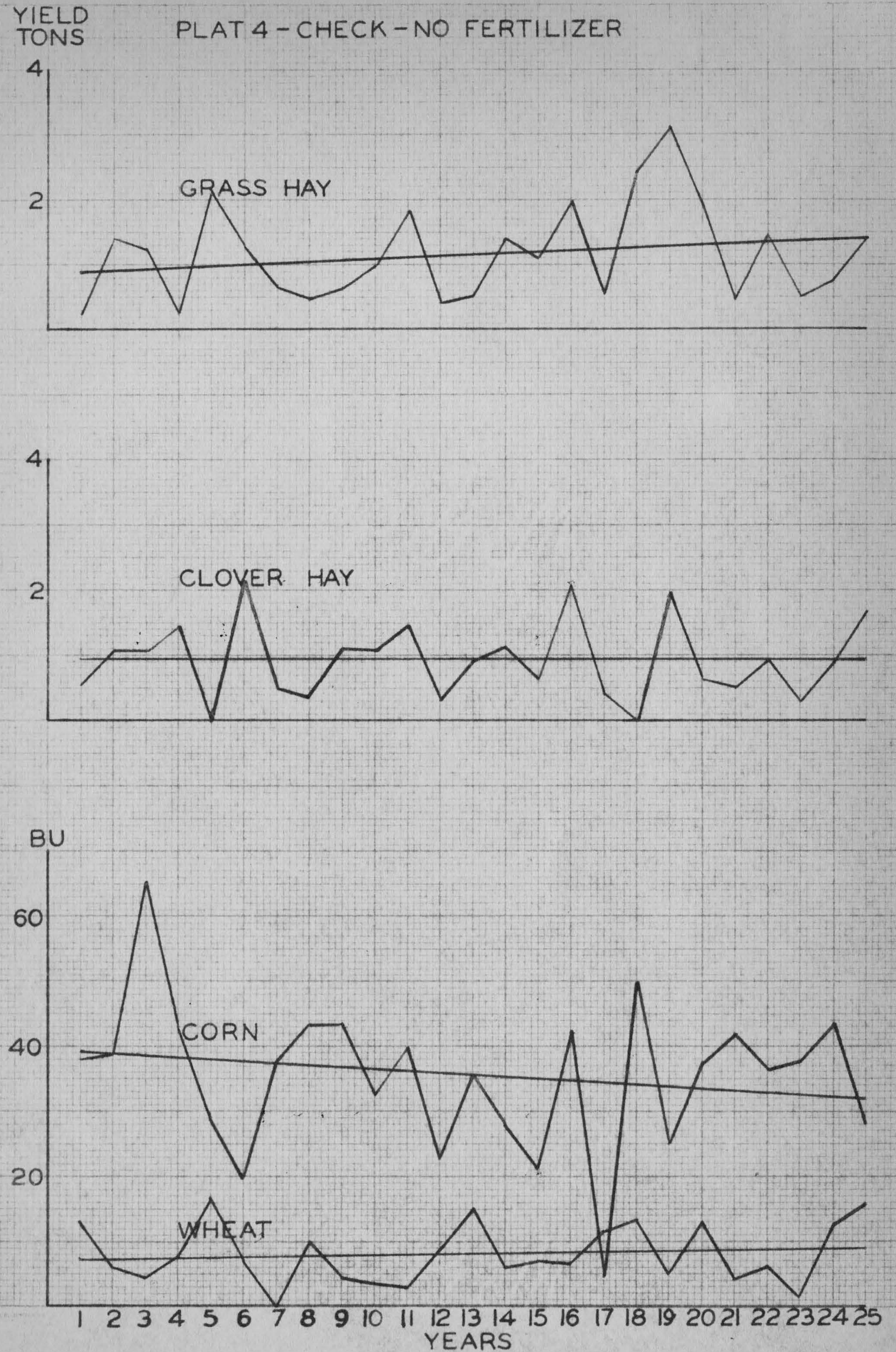
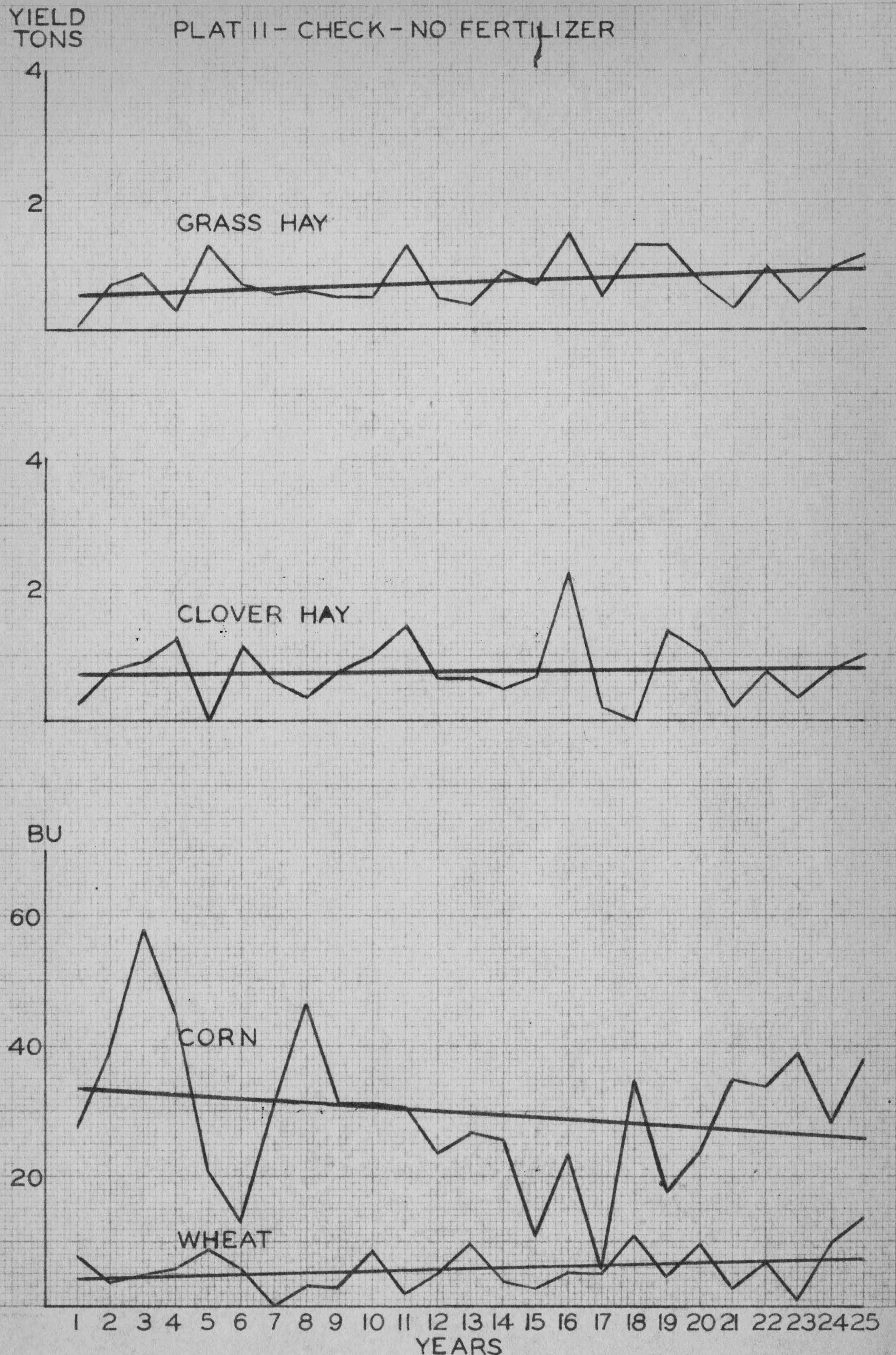

YIELD
TONS
PLAT 4 - CHECK - NO FERTILIZER
4
2
GRASS HAY
4
2
CLOVER HAY
BU
60
40
CORN
20
WHEAT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
YEARS

Fig. 15.


YIELD
TONS
PLAT II - CHECK - NO FERTILIZER
4
2
GRASS HAY
4
2
CLOVER HAY
BU
60
40
CORN
20
WHEAT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
YEARS

desirable, since the population of the United States was increasing and the most productive soils were already being cultivated.

From the various graphs, it may be seen that the most important plant food was phosphoric acid. When superphosphate was added, as shown in Fig. 1, the trend line was upward for each crop grown in the rotation. The average annual yield above that of the check plat was: corn, 15.30 bushels; wheat, 13.08 bushels; clover hay, 0.90 tons; and grass hay, 0.95 tons per acre. When raw rock phosphate was used, as shown in Fig. 13, the trend lines were upward except in the case of corn. However, the average annual increase in yields above the check plats was less than in the case of superphosphate, the increase was: corn, 5.49 bushels; wheat, 3.53 bushels; clover hay, 0.44 tons; and grass hay, 0.19 tons.

When muriate of potash was used in addition to superphosphate, as shown in Fig. 4, the yield trends for each crop were upward. However, the increase in yield over the yield of crops produced on the superphosphate plat was not materially greater for wheat and grass hay. Corn yields were increased 6.53 bushels per acre, per year, while the increase in clover hay was 0.26 tons.

White (28) in Pennsylvania, has shown the importance of phosphoric acid and potash in a grain rotation. For forty years, without the use of nitrogen, this treatment has maintained crop yields and organic matter content of the soil.

The addition of dried blood with superphosphate and muriate of potash produced upward trend lines for all crops in the rotation. These results are presented in Fig. 2. The increase in yields produced by a complete fertilizer as compared to that of superphosphate and muriate of potash was: corn, 2.92 bushels; wheat, 4.56 bushels; clover hay, 0.34 tons; and grass hay, 0.64 tons per acre per year.

When dried blood and superphosphate were applied without potash, as presented in Fig, 7, the trend for corn was downward, practically level for wheat, and upward for clover and grass hay. It is also interesting to note that superphosphate when used alone produced higher average yields for all crops grown in the rotation than when used with nitrogen.

From Fig. 3 it may be seen that the use of sulphate of ammonia and raw rock phosphate resulted in upward trends. Here also, the average yields of corn and wheat were below that of superphosphate alone. The yields of clover hay and grass hay were in each case the same. Results from plats 4 and 8, Figures 3 and 7, indicated that nitrogen did not increase yields when applied with phosphates.

The trend lines for crops grown on the plats which received only muriate of potash are presented in Fig. 5. The trend was downward for corn, wheat, and clover hay, but upward for grass hay. The average yields from muriate of potash were not very much greater than an average of the two check plats. This fact indicates that potash alone was not the limiting factor in crop production. The use of dried blood and muriate of potash, as shown in Fig. 6, resulted in a downward trend for corn, but upward trends for wheat, clover and grass hay. The addition of nitrogen did not materially increase the yields above those produced by muriate of potash alone.

Dried blood used alone, Fig. 8., produced slight upward trends for all crops except corn which was decidedly downward. However, the average yields of corn and wheat were below the average yields of the check plat. The yields of clover and grass hay were slightly higher than that of the check. The failure of the crops to respond to the nitrogen applications was probably due to the presence of a legume in the rotation.

Sixteen tons of manure per acre, applied once in four years, as shown by Fig. 9, resulted in high yields of all crops. The yield trend was upward for all crops except corn, which showed a slight decrease. The average yields were high as shown in Table II. Fig. 11 exhibits the trend lines of crops treated with four tons of manure annually. Upward trends for each crop were obtained. The average annual yields for the twenty-five year period were highest from this treatment with the exception of wheat, and here the yield is less than one bushel below the highest yield of wheat which was obtained on the plat which received a complete fertilizer. The fact that annual applications of manure produced highest yields of crops shows that small frequent applications were more valuable than large less frequent applications. This was probably due to the fact that more plant food was added than could be utilized by the crop to which the application was made. The excess was probably lost by leaching. In Fig. 10 is presented the trend lines for crops which received sixteen tons of manure once in four years, supplemented with raw rock phosphate. A rise in trend line is registered for each crop. The average yields were below those produced by a similar amount of manure not supplemented with phosphates. Yield trends from sixteen tons of manure once in four years, supplemented with superphosphate, are presented in Fig. 12. All trends are upward except in the case of corn. Superphosphate as a supplement to manure, has resulted in an increase of yields for all crops as compared to that of raw rock phosphate. However, the trend lines from the use of rock phosphate are upward at a greater degree than those from superphosphate. This is probably due to the slower rate of availability of phosphoric acid from rock phosphate. Superphosphate is readily available and the first applications would have an effect on the crop, whereas rock phosphate is very slowly available.

It would appear from the results of this experiment that plants secured very little phosphoric acid from rock phosphate. However, Wolkoff (30) stated that, "After phosphatic fertilizers are applied to the soil, the recovery of phosphorus from soil treated with double acid phosphate is no greater than the recovery of phosphorus from the same soil treated with ground rock phosphate, using 0.2 N nitric acid for the solvent in each case".

Comparing plat 11 which received manure and raw rock phosphate, and plat 13 which received manure supplemented with superphosphate, with plat 10 which received manure only, there is very little difference in yield which indicates that phosphates did not increase the yields when used with manure. However, this is probably due to the fact that the large applications of manure carried enough phosphoric acid to supply the needs of the crops. If small amounts of manure had been used, then phosphates probably would have increased the yields of crops because of the low phosphoric acid content of manure. Noll (20) at Pennsylvania Experiment Station found that 300 pounds of 16 percent superphosphate used with 6 tons of manure increased returns above the cost of phosphates about one dollar for each ton of manure used. He also found that the yields from superphosphate were higher than yields from rock phosphate when each was used with manure only or with manure and lime, or with nitrate of soda and muriate of potash. Bear (3) showed that superphosphate was superior to rock phosphate. However, he presented data to show that rock phosphate was more effective as a source of phosphoric acid than superphosphate if the soils were acid rather than if the reaction were approximately neutral. Kipps and Hutcheson (12) found that superphosphate produced higher yields of clover hay and wheat, but lower yields of corn than did raw rock phosphate, bone meal and basic slag. Also, when used as a supplement to manure, superphosphate exceeded the other phosphate carriers in the total pounds of corn, wheat and clover hay produced per acre.

Weir (25) pointed out that the supply of available phosphorus in the soil is more important than the total amount. Some soils may contain a very good supply, but still respond to phosphate fertilization. Other soils containing lower amounts of phosphorus may give no indication of phosphorus deficiencies. As an illustration, he said that, when a silt loam has had its original phosphorus supply reduced about one-half and is in need of phosphates, it is not necessary to add enough fertilizer to raise the phosphorus content to the original amount, but to fertilize sufficiently to enable the soil to furnish the phosphorus demanded by profitable crops. Hester and others (10), of the Virginia Truck Experiment Station, found that even in soils analyzing about 3300 parts per million of phosphoric acid, there was a response to phosphoric acid when added in fertilizers.

In Fig. 13 is shown the trend lines of crops which received raw rock phosphate. There was a slight upward trend for all crops except corn. A comparison of Figures 1 and 13 indicated that superphosphate was superior to raw rock phosphate in increases of yield and also rate of increase. This is in agreement with most of the literature previously cited.

An interesting comparison between fertilizers and manure may be obtained from yield data of plats 3 and 12 in Table II, and from Figures 2 and 11, which compare the complete fertilizer with four tons manure annually.

Sir E. J. Russell (21) in comparing farmyard manure and fertilizers, said that for the first few years the fertilizers considerably increased the fertility of the soil, but that after a time their effect began to decline. Manure was less effective in the beginning, but finally more effective than fertilizers. He indicated that crops to which manure is applied are less liable to suffer from seasonal factors and, therefore, exhibit less fluctuations in yield from season to season.

The complete fertilizer used on plat 3, and as shown in Fig. 2, has resulted in continued increase in yields as indicated by the straight line trends of the various crops. In wheat, clover and grass hay the yield trend has actually started at a lower point than the trends from the manure treatment and terminated at a higher level. This is contrary to Russell's idea that manure was finally more effective than fertilizers. There is very little difference in the seasonal fluctuations except possibly that corn and wheat varied more when manure was used. In most cases, there was a slightly higher average yield from manure applications than when fertilizers were applied. Where manure was applied in large amounts at less frequent intervals, as shown in Fig. 9, such was not the case.

Considering the rotation as a whole, applications of four tons of manure produced greatest increases in yields as indicated by the yield trends. Of the elements applied alone, phosphoric acid was far superior to potash and nitrogen. Potash and phosphoric acid were slightly superior to phosphoric acid alone in case of corn and clover hay, but not of wheat and grass hay. Nitrogen, phosphoric acid and potash, as compared with phosphoric acid and potash, produced higher yields of all crops. In both of the latter treatments, the yield trends were upward for all crops.

The results of this experiment indicate that phosphoric acid and potash should be added to the soil in fertilizers. Nitrogen is not as important, due to the fact that a legume is included in the rotation. However, all crops responded to nitrogen when applied in a complete fertilizer and produced higher average yields than where phosphoric acid and potash were used. The use of superphosphate alone resulted in increases over the check plat. The increases were: corn, 47 percent; wheat, 189 percent; clover hay, 107 percent; and grass hay 98 percent. Muriate of potash added to superphosphate increased the yields over superphosphate as follows: corn, 14 percent; wheat, 3 percent; clover hay, 15 percent, with grass hay remaining the same.

The complete fertilizer treatment increased yields over those produced by superphosphate and muriate of potash. The amount of increase was: corn, 5 percent; wheat, 22 percent; clover hay, 17 percent; and grass hay 33 percent.

B. Yield Trends of Check Plats:

A second series of graphs are presented in Figures 16 through 28 to show the straight line trends of the check plats which received applications of fertilizers from 1909 to 1913 inclusive, but have had no fertilizers added since that time. The data used in calculating the yield trends were for the years 1914 through 1938. The average yields of crops from this series of plats during this 25-year period is shown in Table II.

In Fig. 16 are presented the trends of crops which received superphosphate. All trends were downward except in the case of grass hay which was slightly upward. The average yields of all crops were higher than the yields of the check plat. The yields from raw rock phosphate, Fig. 28, were less than the yields of the check plat, and all trends were downward except in the case of wheat.

From Fig. 19, it may be seen that superphosphate and muriate of potash failed to increase the yields over superphosphate alone, Fig. 16. This indicates that superphosphate and muriate of potash had no greater residual effect than superphosphate.

The complete fertilizer treatment, as shown in Fig. 17, produced yields that were considerably higher than the check plat, but approximately equal to those produced by superphosphate alone. Trend lines for the complete fertilizer plat, Fig. 17, and for the superphosphate and muriate of potash plat, Fig. 19, were nearly parallel with the complete fertilizer yields being slightly higher.

The trends of yields from muriate of potash are presented in Fig. 20. These trends were level for grass hay and wheat, but corn and clover hay exhibited a distinct downward trend. When dried blood was used with muriate of potash, Fig. 21, average yields and trends were very similar to those of muriate of potash alone.

Fig. 16.

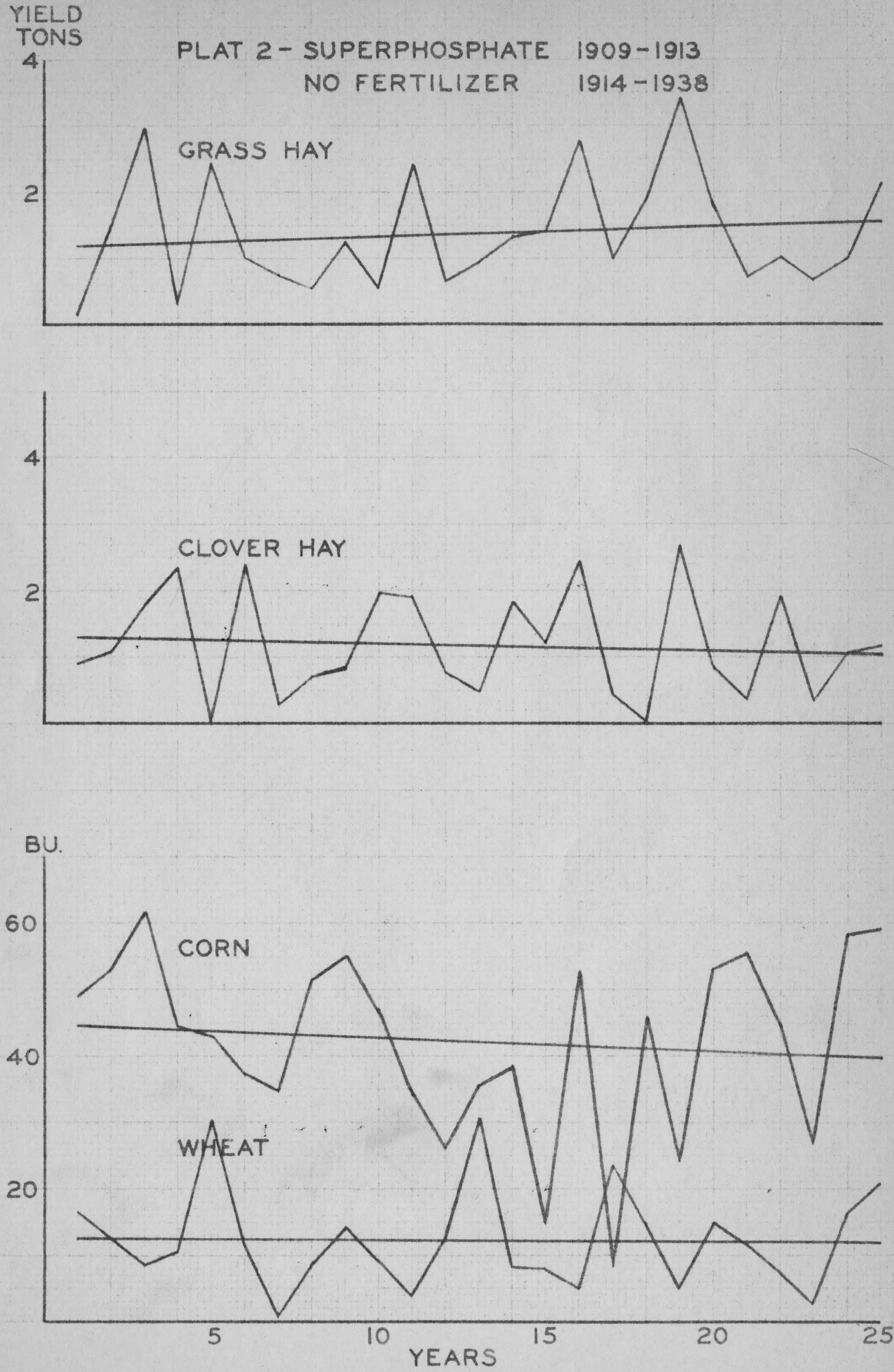

YIELD
TONS
PLAT 2- SUPERPHOSPHATE 1909-1913
NO FERTILIZER 1914-1938
GRASS HAY
CLOVER HAY
BU.
CORN
WHEAT
YEARS
4
2
4
2
60
40
20
5
10
15
20
25

Fig. 17.

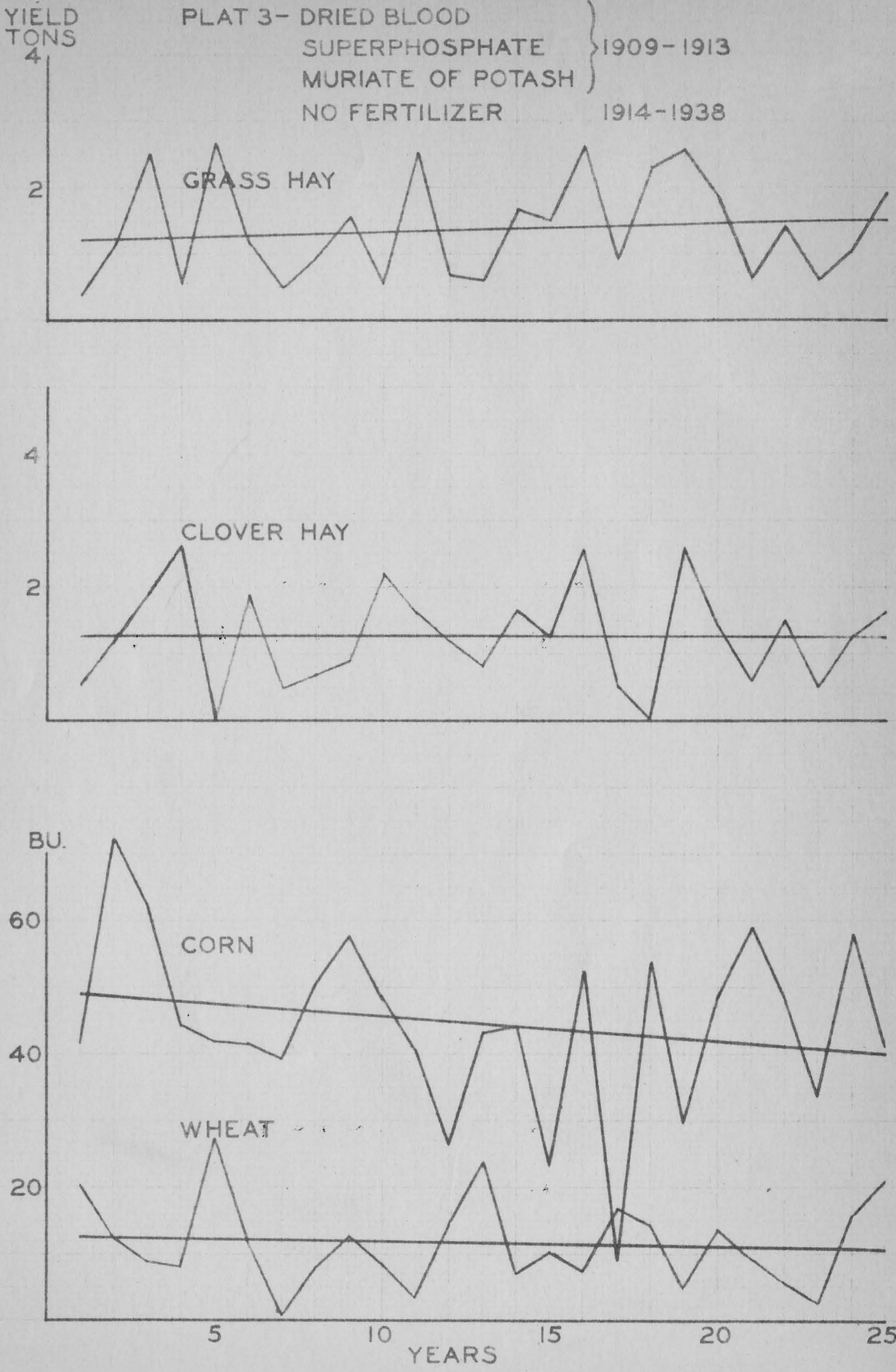
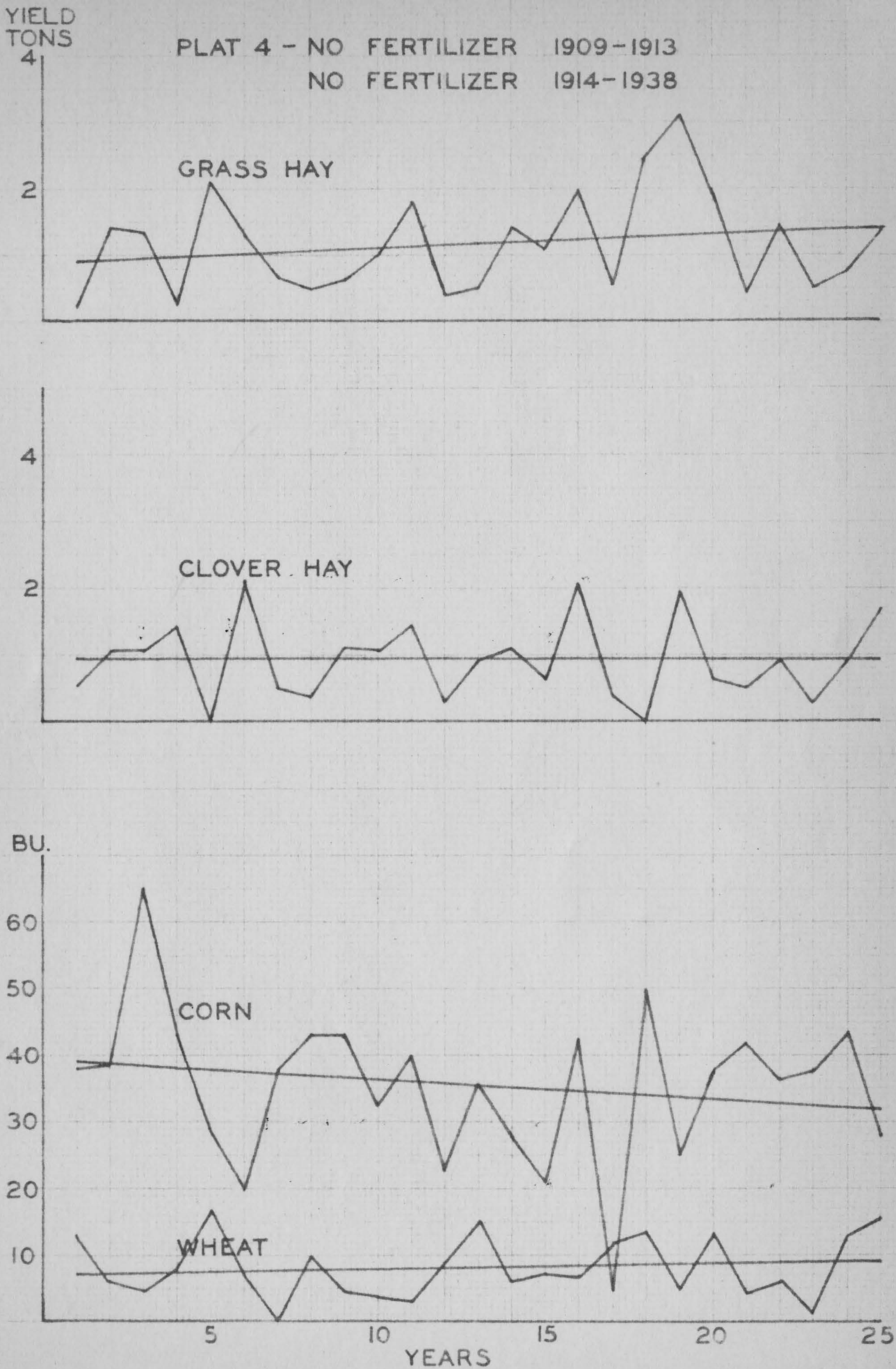

YIELD
TONS
PLAT 3- DRIED BLOOD
SUPERPHOSPHATE
MURIATE OF POTASH
1909-1913
NO FERTILIZER
1914-1938
GRASS HAY
4
2
CLOVER HAY
4
2
BU.
60
CORN
40
WHEAT
20
5
10
15
20
25
YEARS

Fig. 18.



YIELD TONS
PLAT 4 - NO FERTILIZER 1909-1913
NO FERTILIZER 1914-1938
GRASS HAY
4
2
4
2
CLOVER HAY
BU.
60
50
40
30
20
10
CORN
WHEAT
5
10
15
20
25
YEARS

Fig. 19.

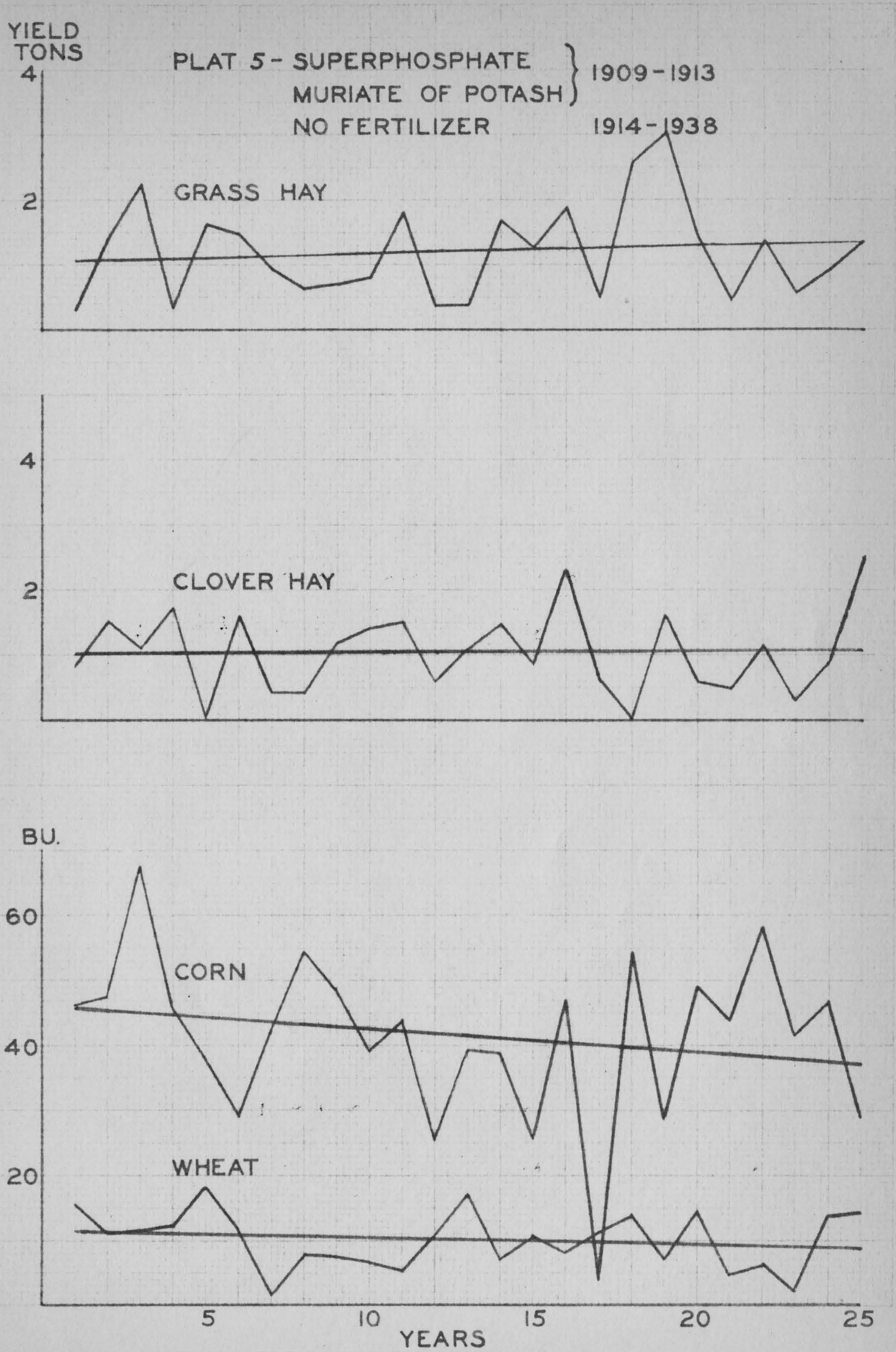

YIELD
TONS
PLAT 5 - SUPERPHOSPHATE
MURIATE OF POTASH
1909-1913
NO FERTILIZER
1914-1938
GRASS HAY
4
2
4
2
CLOVER HAY
BU.
60
CORN
40
20
WHEAT
5
10
15
20
25
YEARS

Fig. 20.

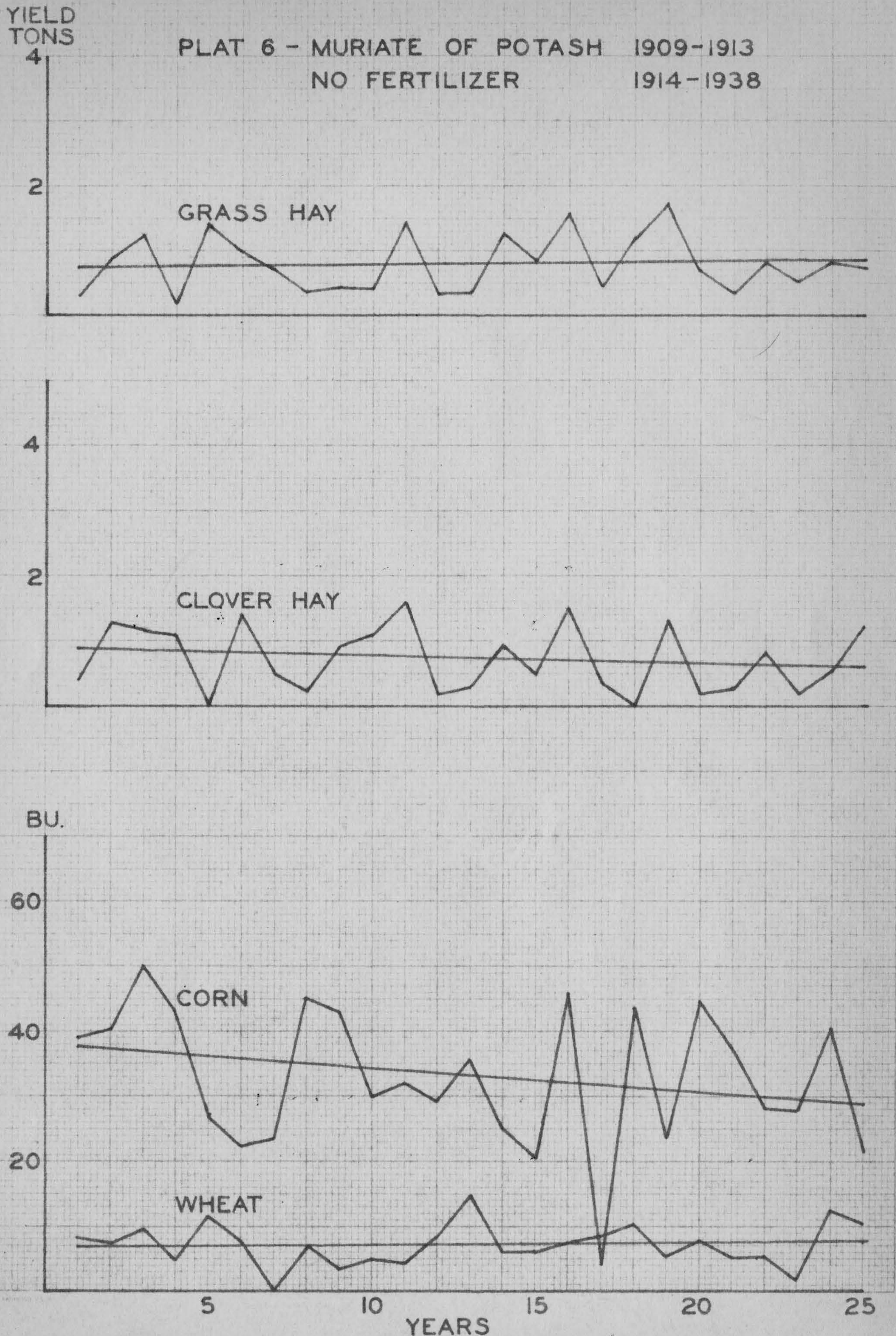

YIELD
TONS
PLAT 6 - MURIATE OF POTASH 1909-1913
NO FERTILIZER 1914-1938
4
2
GRASS HAY
4
2
CLOVER HAY
BU.
60
40
20
CORN
WHEAT
5
10
15
20
25
YEARS

Fig. 21.

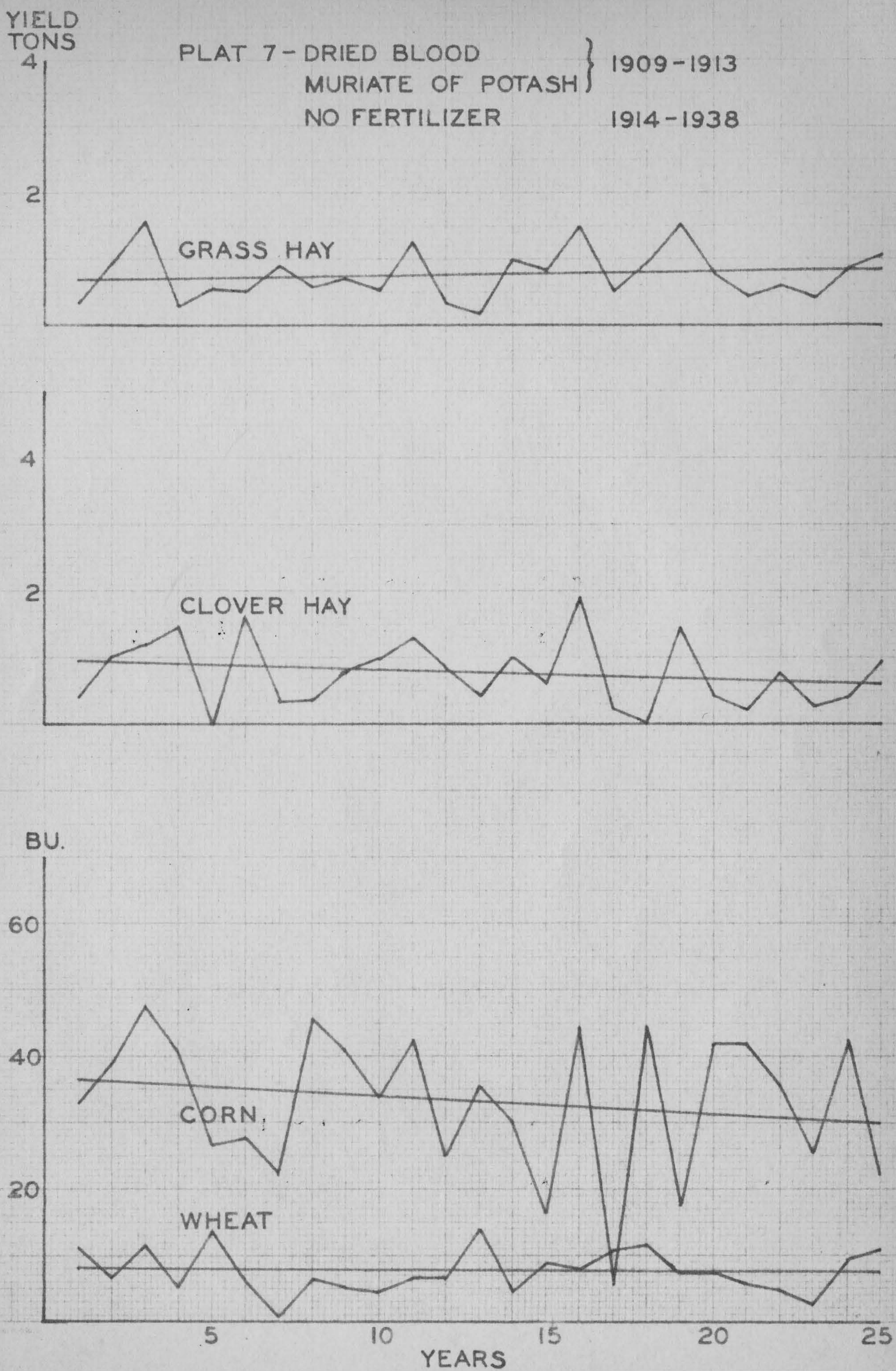

YIELD
TONS
PLAT 7 - DRIED BLOOD
MURIATE OF POTASH
1909-1913
NO FERTILIZER
1914-1938
GRASS HAY
CLOVER HAY
BU.
CORN
WHEAT
YEARS
4
2
4
2
60
40
20
5
10
15
20
25

Fig. 22.

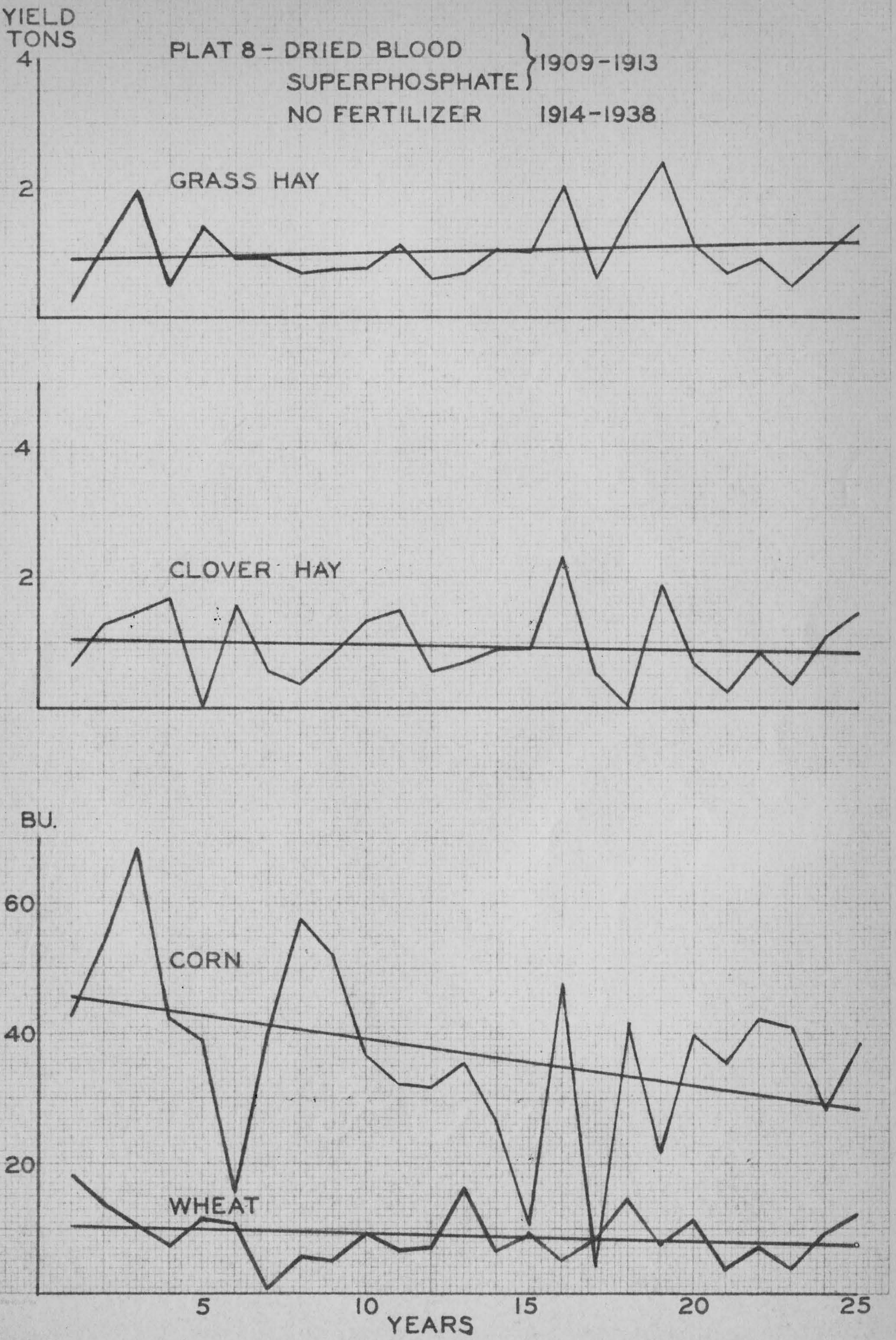

YIELD
TONS
PLAT 8 - DRIED BLOOD
SUPERPHOSPHATE
1909-1913
NO FERTILIZER
1914-1938
GRASS HAY
CLOVER HAY
BU.
CORN
WHEAT
4
2
4
2
60
40
20
5
10
15
20
25
YEARS

Fig. 23.

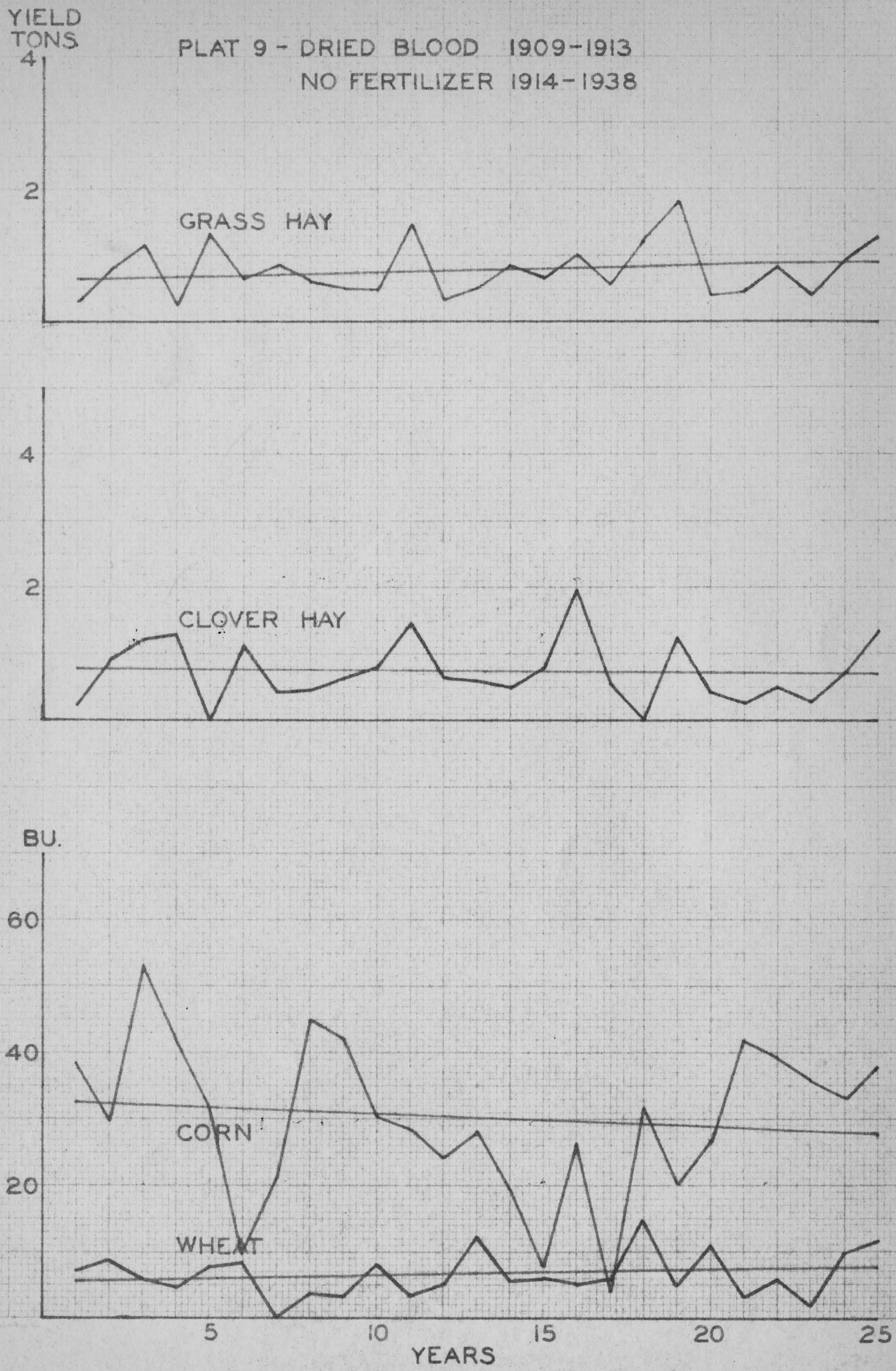

YIELD
TONS
PLAT 9 - DRIED BLOOD 1909-1913
NO FERTILIZER 1914-1938
4
2
GRASS HAY
4
2
CLOVER HAY
BU.
60
40
CORN
20
WHEAT
5
10
15
20
25
YEARS

Fig. 24.

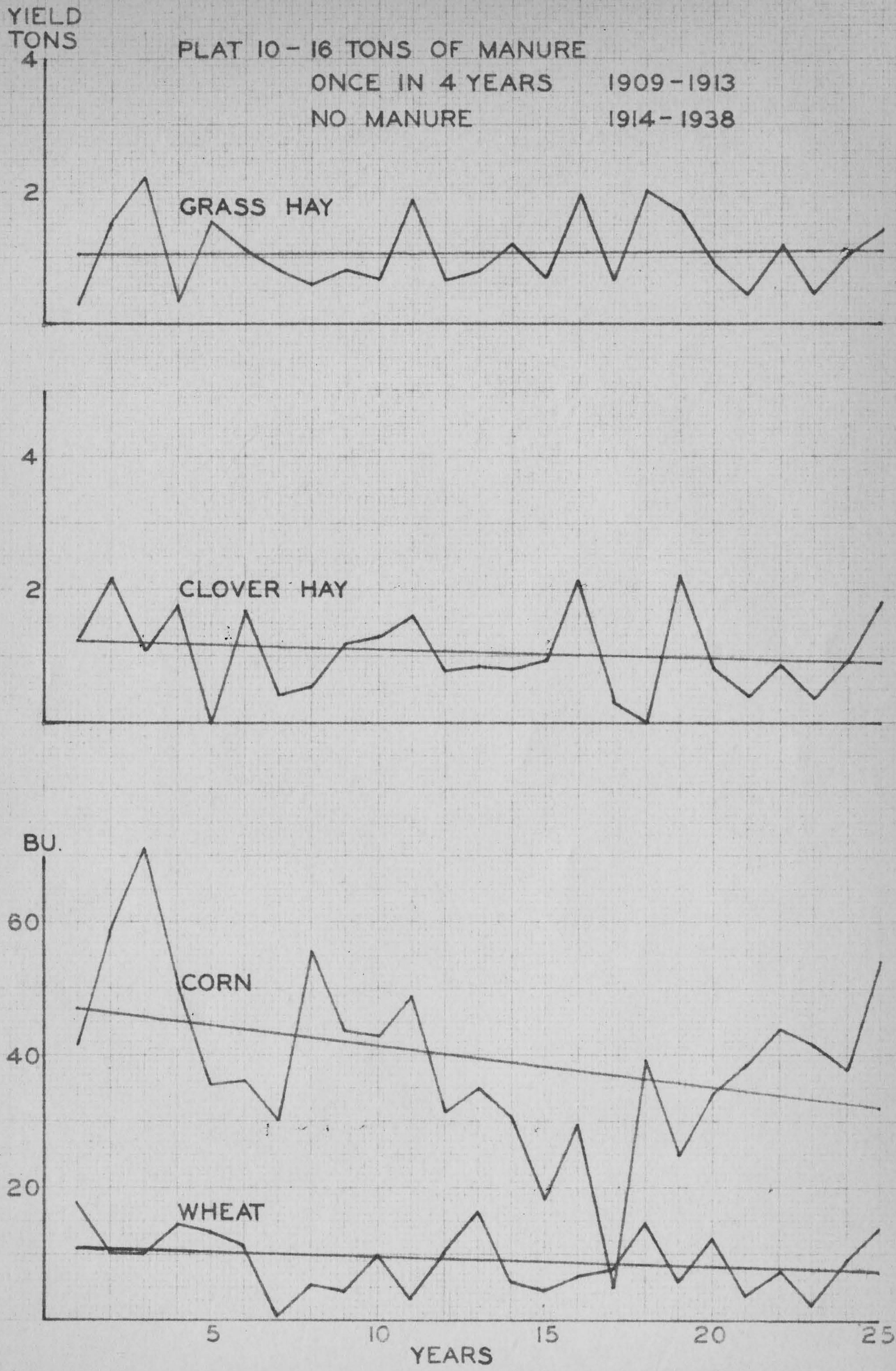

YIELD TONS
PLAT 10 - 16 TONS OF MANURE
ONCE IN 4 YEARS 1909-1913
NO MANURE 1914-1938
GRASS HAY
CLOVER HAY
BU.
CORN
WHEAT
4
2
4
2
60
40
20
5
10
15
20
25
YEARS

Fig. 25.

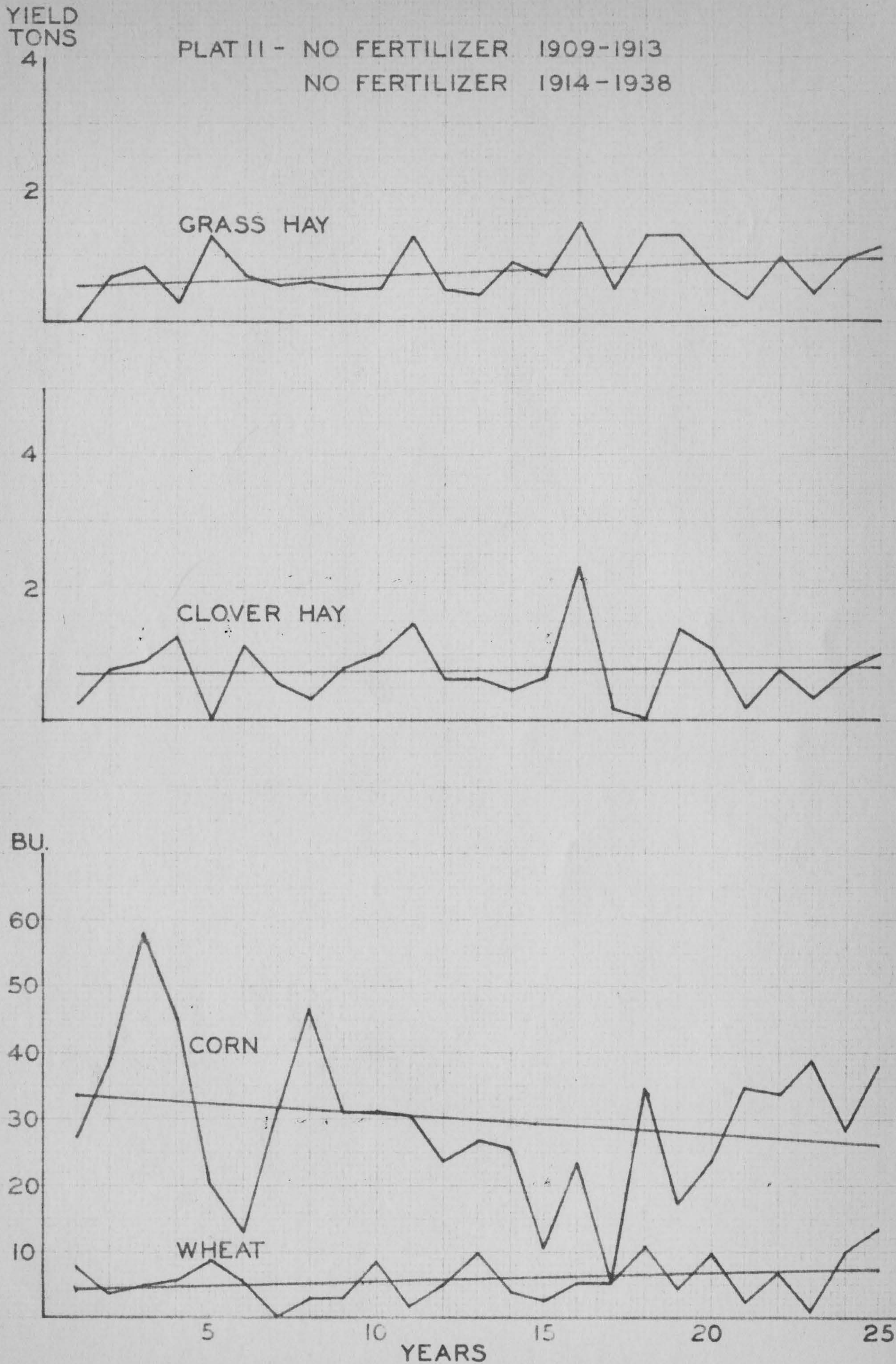
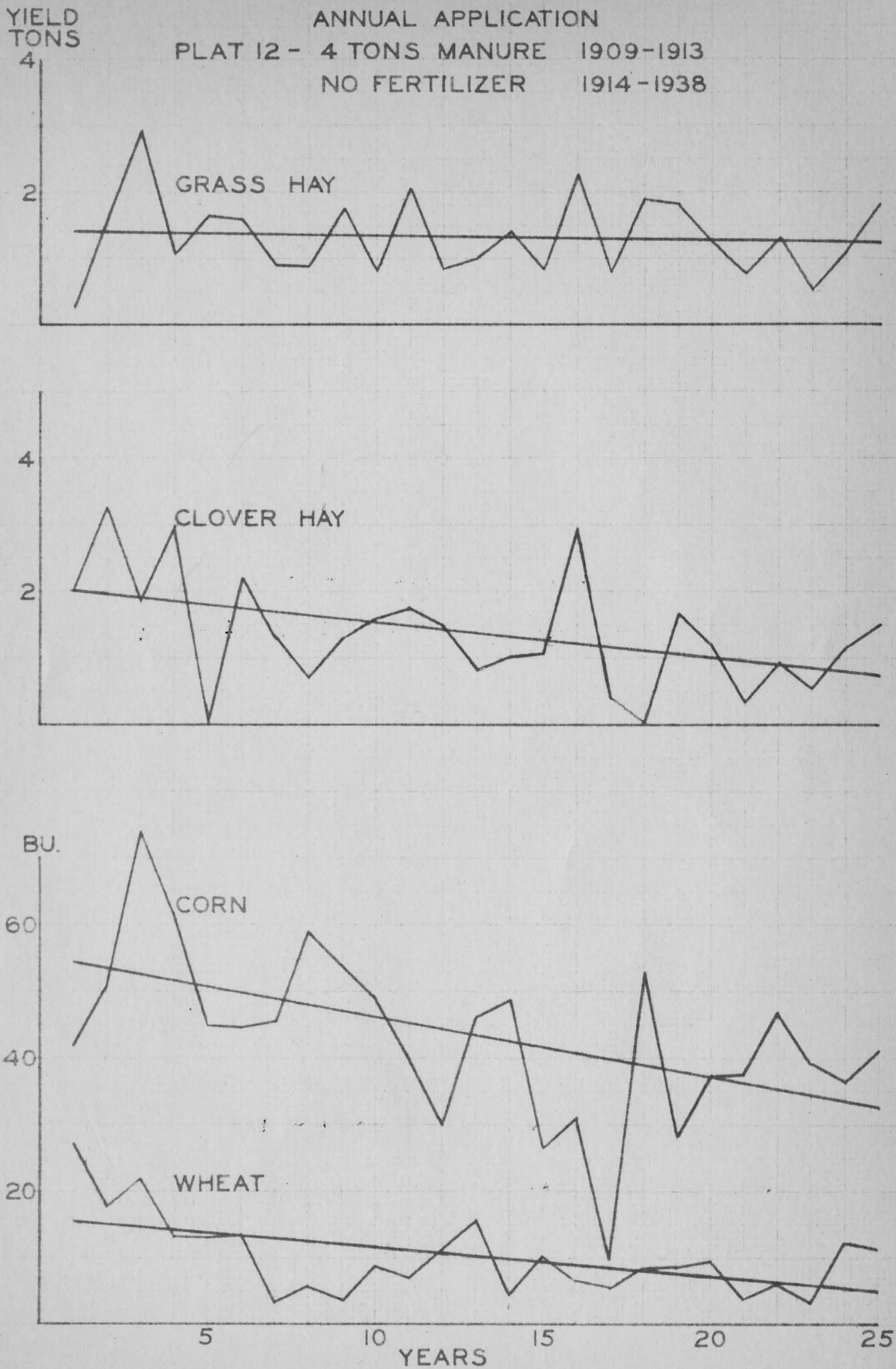

YIELD
TONS
PLAT II - NO FERTILIZER 1909-1913
NO FERTILIZER 1914-1938
4
2
GRASS HAY
4
2
CLOVER HAY
BU.
60
50
40
30
20
10
CORN
WHEAT
5
10
15
20
25
YEARS

Fig. 26.



YIELD
TONS
ANNUAL APPLICATION
PLAT 12 - 4 TONS MANURE 1909-1913
NO FERTILIZER 1914-1938
4
2
GRASS HAY
4
2
CLOVER HAY
BU.
CORN
60
40
20
WHEAT
5
10
15
20
25
YEARS

Fig. 27.

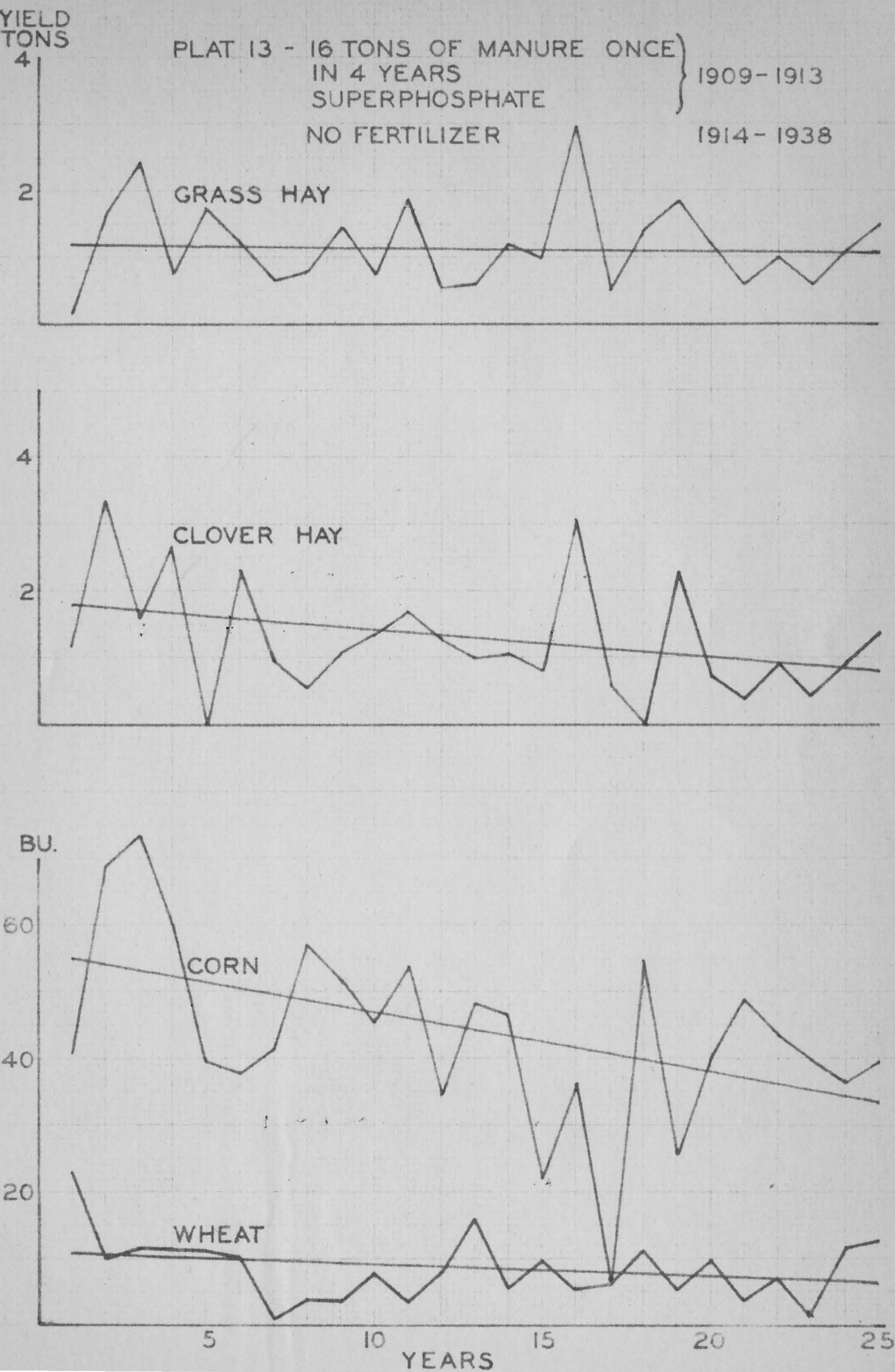
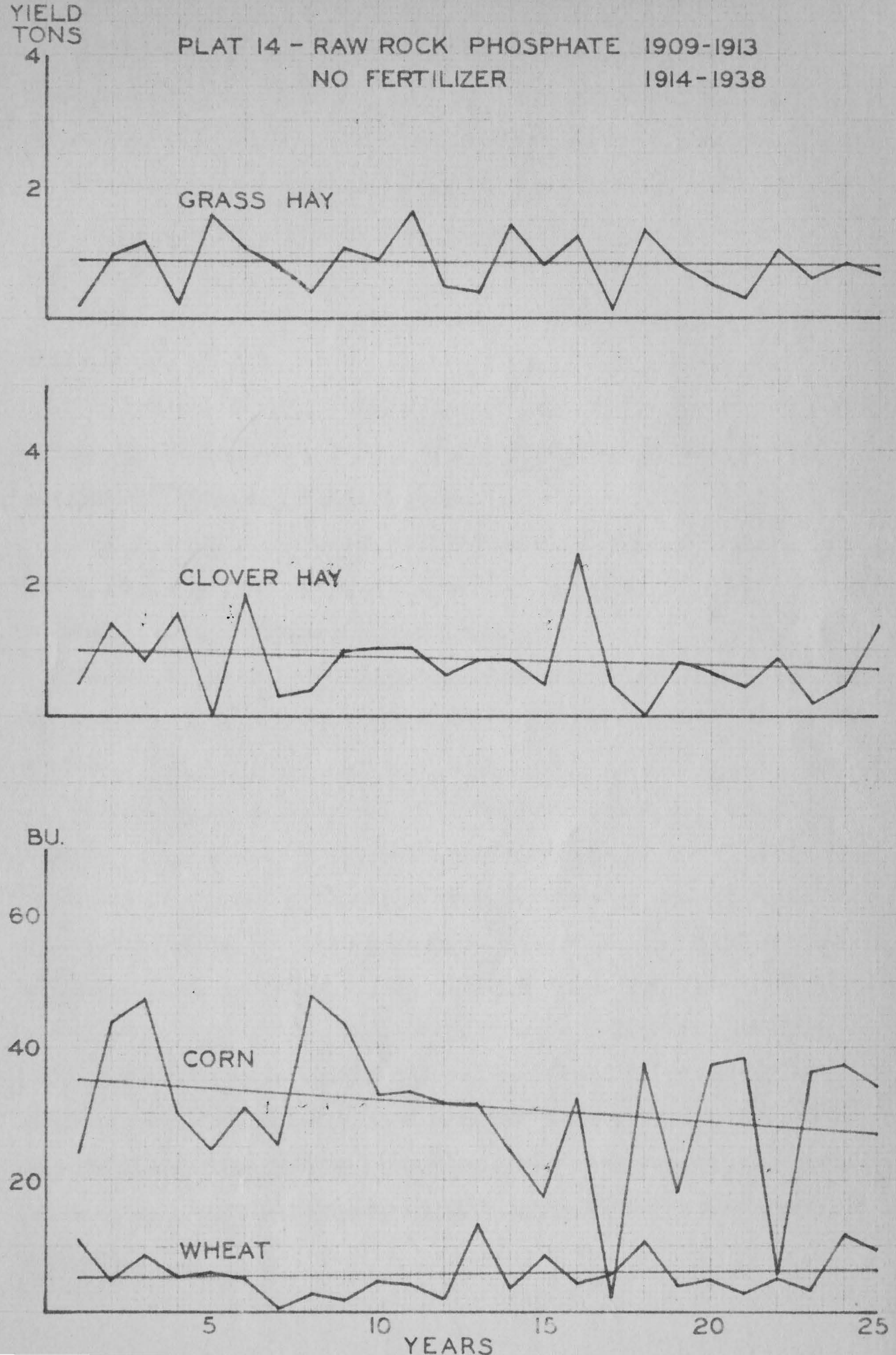

YIELD
TONS
PLAT 13 - 16 TONS OF MANURE ONCE IN 4 YEARS SUPERPHOSPHATE 1909-1913
NO FERTILIZER 1914-1938
GRASS HAY
CLOVER HAY
BU.
CORN
WHEAT
YEARS
4
2
4
2
60
40
20
5
10
15
20
25

Fig. 28.


YIELD
TONS
PLAT 14 - RAW ROCK PHOSPHATE 1909-1913
NO FERTILIZER 1914-1938
4
2
GRASS HAY
4
2
CLOVER HAY
BU.
60
40
CORN
20
WHEAT
5
10
15
20
25
YEARS

Dried blood and superphosphate, Fig. 22, produced lower yields than superphosphate alone. Trends of wheat and clover hay were slightly downward, with corn declining rapidly, but grass hay showed a slight upward trend.

The use of dried blood alone, Fig. 23, produced lower yields than the check plat. However, very slight upward trends were noted in the case of wheat and grass hay.

InFigures 24 and 26, respectively, are presented trends from the use of 16 tons of manure once in four years and 4 tons applied annually. The trend of grass hay from the former application was level. All other trends of both applications were downward. Higher average yields than the check were produced by all crops on both plats.

When superphosphate was used as a supplement to 16 tons of manure, once in four years, Fig. 27, yields were higher than when superphosphate was not used. However, all trends were downward.

The yields of plats 4 and 11, shown in Figures 18 and 25, were averaged and used as a basis for comparing the plats which received fertilizers prior to 1914.

Of interest is the fact that all check plats produced downward yield trends of corn. Trends for wheat were generally downward, but slightly upward trends were in evidence for the crops which were treated with muriate of potash; dried blood; raw rock phosphate; and the check plats 4 and 11 which received no fertilizer prior to 1914. Downward trends were dominant in the case of clover hay, as only the treatment of superphosphate and muriate of potash produced an upward trend. However, one of the check plats produced an upward trend. Grass hay trends were usually upward, but downward trends were produced by the following treatments: 4 tons manure annually; 16 tons manure once in four years supplemented with superphosphate; and raw rock phosphate.

C. Residual Effects of Fertilizers:

Residual or lasting effect of fertilizer and manure is very important. Weir (26) stated that the beneficial effects of manure on soils of the heavier type may be of long duration. In general, about one-half of the nitrogen in manure is rendered available during the first year, and about one-fourth of the phosphorus and potassium is used.

At Rothamsted, an experiment was conducted where fourteen tons of manure to the acre were applied for eight successive years. The land was then left in grass without manuring or fertilizing for fifty years. The yields were compared with those of a similar field on which no fertilization was made. The average increase in yields for each decade, resulting from the previous applications of manure, were 57, 24, 6, 15 and 28 percent respectively.

Miller (16) says that the plant nutrients in liquid manure are very quickly available to crops, while those in the dung become soluble at a slower rate. The opinion has been expressed that manure as drawn to the field on the average farm will yield about one-half of its nitrogen and potassium, and one-sixth of its phosphorus to crops during the first season. Unquestionably, the rate of availability will vary with climatic conditions and also with the richness of the manure itself. Proof that a large quantity of plant food remains in the soil after the first season is shown by the increase in growth of crops following a well-manured crop in a rotation. The organic content of manure is also undoubtedly of some value to the soil, especially when the supply of organic matter in the soil is limited.

Since the fertilized plats were divided in 1913, and one-half of each plat has received no fertilizer since that date, it is possible to study their residual effect.

In Table III is presented the average yields of crops grown on

Table III .- Average yields of crops grown on check plats from 1914 to 1938 inclusive.

Plat	Amount of fertilizer per acre applied annually from 1909 to 1913 inclusive	Corn	Wheat	Clover hay	Grass hay
		Bu.	Bu.	Tons	Tons
2	438 pounds superphosphate	42.13	12.20	1.18	1.38
3	308 pounds dried blood 438 pounds superphosphate 200 pounds muriate of potash	44.35	11.50	1.25	1.39
4	None	35.40	8.05	0.92	1.17
5	438 pounds superphosphate 200 pounds muriate of potash	41.32	10.00	1.04	1.19
6	200 pounds muriate of potash	32.92	7.17	0.72	0.80
7	308 pounds dried blood 200 pounds muriate of potash	33.12	7.63	0.76	0.76
8	308 pounds dried blood 438 pounds superphosphate	36.98	8.87	0.95	1.03
9	308 pounds dried blood	29.98	6.54	0.73	0.77
10	16 tons manure once in 4 years	39.19	8.82	1.05	1.08
11	None	29.61	5.77	0.75	0.76
12	4 tons manure	43.08	10.10	1.35	1.32
13	16 tons manure once in 4 years 438 pounds superphosphate	43.72	8.45	1.25	1.17
14	219 pounds raw rock phosphate	30.75	5.80	0.81	0.82
	Check - None*	32.50	6.91	0.84	0.97

* Average of two check plats.

check plats from 1914 to 1938 inclusive. Also shown is the amount of fertilizer applied prior to 1914. The average yields of plats 4 and 11 were used as a basis for studying the residual effect, since neither received any fertilizer before 1914.

A comparison of one treatment with another in percentage increase of yields is presented in Table IV.

Plats 10, 12 and 13, which received manure prior to 1914, produced crops with much higher average yields than the check. Of these manure treatments, the greatest residual influence was obtained from applications of four tons of manure annually. The yields from this treatment, plat 12, showed increases over the check of 10.58 bushels corn, 3.19 bushels wheat, 0.51 tons clover hay and 0.35 tons grass hay.

The percentage increase in yields from manure applied annually over 16 tons applied once in four years were: corn, 10 percent; wheat, 15 percent; clover hay, 29 percent; and grass hay, 22 percent. These results support the recommendation of using small, frequent applications rather than large, less frequent applications. Greater residual influence was exhibited where superphosphate supplemented 16 tons of manure than where the same amount of manure was used alone.

Applications of superphosphate prior to 1914 have resulted in much higher yields than were produced by the check plat. From the data in Table IV, it may be noted that the increases due to the use of superphosphate were:corn, 30 percent; wheat, 77 percent; clover hay, 40 percent; and grass hay, 42 percent.

Abbott and Conner (1) studied the effect of an application of superphosphate to a clay loam over a period of four years. The first year of the experiment the crop was a failure; the second year, the wheat yield was increased 6.4 bushels; the third year, the corn was increased 7 bushels; and

Table IV. Comparison of one treatment with another in percentage increase of corn, wheat and hay, grown on the plats which received no fertilizer since 1913.

Treatment	Corn	Wheat	Clover hay	Grass hay
	Percent	Percent	Percent	Percent
Superphosphate with Check	30	77	40	42
Superphosphate & Muriate of potash with Superphosphate	-2	-18	-12	-14
Dried blood, Superphosphate, and Muriate of Potash with Superphosphate and Muriate of Potash	7	15	20	17
Dried blood, Superphosphate, and Muriate of Potash with Check	36	66	49	45
4 tons manure annually with Check	33	46	61	36
16 tons manure once in 4 years with Check	21	38	25	11
4 tons manure annually with 16 tons Manure once in 4 years	10	15	29	22
Dried blood, Superphosphate, and Muriate of Potash with 4 tons manure annually	3	14	-7	5
Superphosphate with raw rock phosphate	37	110	46	68
Muriate of potash with Check	1	4	-14	-18
Dried blood with Check	-8	-5	-13	-21

the fourth year, the wheat was increased 1.6 bushels.

The Board of Agriculture for Scotland received a committee report (5) which proposed a scale showing the proportion of phosphate fertilizers left unused in the soil. It suggested that a scale cannot be more than an approximate indication of the rate of exhaustion of phosphates. Their scale showed that one-half of a superphosphate addition is left after the first season, one-fourth after the second season, and one-eighth after the third season. About two-thirds of the mineral phosphates added to the soil is left after one season; one-third after two seasons, and one-sixth after three seasons.

Gordon (7) reports that for plats receiving 50, 100, 150, and 200 pounds of superphosphate, respectively, the residual effect on the following volunteer crop of wheat for the three higher applications was sufficient to pay for the original cost of the applied phosphate.

Hartwell and Damon (9) of Rhode Island reported in 1915 an experiment covering twenty years from 1894 to 1913. During the first part of the experiment, various phosphates were applied on an equal cost basis. In 1902 applications were made to equalize the amount of phosphorus applied to each plat. No other applications were made until 1914. They considered the results of their work covering a period of nine years from 1905 to 1913 inclusive. The yields of various crops grown continued to show the effects of phosphates after nine years of cropping. Large increases in hay were secured in 1913 and also in turnips from the limed plats and, with the exception of rock phosphate on the hay, increases were also evident on the unlimed plats. There were no gradual decreases in the effects of the phosphates from year to year, but the increases were similar each year. Superphosphate was superior to rock phosphate in crop increases on the limed land, while rock phosphate was superior on the unlimed land. Results from such an experiment illustrate how important and long-continued the residual effects of phosphate treatments may be.

Baker (2) reported work from Indiana in 1924 on the residual effects of a single application of superphosphate and rock phosphate to a rotation of corn, wheat and clover. The effects had been studied for eight years. Taking the experiment as a whole, the residual effects of the superphosphate were larger than with the rock phosphate. For the first few years, the increases from superphosphate were larger than for the latter years.

Thorne (24) of Ohio reported a five year rotation of corn, oats, wheat, clover and timothy covering a period of twenty-three years when a chemical fertilizer was applied only to the wheat. The average increase per rotation above that of the check was wheat, 14 bushels; clover, 775 pounds; timothy, 405 pounds; corn, 8 bushels; and oats, 4 bushels. Thorne concluded "that a large part of the effect of the fertilizer or manure, ranging under ordinary conditions, from one-third to one-half the total effect is carried forward to crops following the one to which the treatment has been given."

Crop yields produced by rock phosphate, plat 14, were lower than those produced by the check plat. Under the conditions of this experiment the results indicate that raw rock phosphate had no residual influence.

Bear (3) at Ohio showed that despite the fact that rock phosphate supplied practically twice as much phosphoric acid as did the superphosphate treatment, there was no evidence that this residue was of any added value. The longer the experiment continued, the lower the yields on the phosphate rock plats were than those of the superphosphate plats.

Nagaoka (19) has reported the residual effects of phosphates upon rice grown on acid soil of a paddy field. He found that the increase in rice yields, due to the use of phosphates, were greatest the first year, decreasing the second and third years, but increasing the fourth year.

Plat 3 received a complete fertilizer from 1909 to 1913. When compared to the treatment of four tons manure annually, the yields from the fertilized plat showed an increase of 3 percent corn, 14 percent wheat, 5 percent grass hay, and - 7 percent clover hay. Both plats produced yields above the check plat.

Salter (23) reported that at the Ohio Experiment Station, only about forty percent of the entire effect of a single application of 500 pounds of a 4-16-4 fertilizer has been found to be realized during the year the fertilizer was applied. Thirty percent of the fertilizer was utilized by crops during the second year, seventeen percent during the third year, and twelve percent in the fourth year.

Bear (3) pointed out that, when fertilizers were applied in excess of crop needs, the residual effects were greatest in the case of soils which contained considerable amounts of clay or humus materials. Sands, being low in colloidal matter, allow the nutrients to leach out. This is in agreement with Weir's belief (26).

The residual effects of muriate of potash are shown from yields secured on plat 6. Here, the yields were approximately equal to those produced on the check plat which indicates no lasting effect. Corn showed 1 percent increase, wheat 4 percent, while clover hay and grass hay showed decreases of 14 and 18 percent respectively. However, Cooper and Wallace (6) in 1932 applied muriate of potash broadcast at the rates of 100, 200, and 400 pounds per acre to cotton. In 1935, the yields of seed cotton above that of the check were 504, 850, and 1007 pounds respectively.

Muriate of potash applied with superphosphate, plat 5, produced lower yields than when superphosphate alone was used.

The results secured on plat 9 indicate that nitrogen was either used soon after being applied or was leached from the soil. This plat received dried blood only and produced yields below those of the check plat in every case. The decreases in yield were: corn, 8 percent; wheat, 5 percent; clover hay, 13 percent; and grass hay, 21 percent. Further evidence that nitrogen had no residual effect can be found by observing the yields of plats 7 and 8. Dried blood and muriate of potash produced yields about equal to muriate of potash alone, and superphosphate applied with dried blood resulted in yields below those of superphosphate alone.

Collings (4) stated that many farmers have noted prolonged residual effects after applications of sodium nitrate which was sometimes observable several seasons after applications. This has been apparent on pasture land and in orchards. He says that the effect was probably due largely to a residual influence of the increased growth of the root systems of the fertilized crops, although it may have been due in part to bacterial fixation. Collings also stated that ammonium nitrate leaves no residue in the soil. On the other hand, the residual influences of superphosphate are noticeable for some years following their use.

The data in Tables III and IV show that residual effect was exhibited only by manure and by fertilizers which contained superphosphate.

D. Relationship Between the Amount of Plant Food Added in Fertilizers and that Removed by Harvested Crops:

In Table V is presented the total yields of crops grown on fertilized plats from 1914 to 1938 inclusive. In Table VI is presented the amounts of nitrogen, phosphoric acid and potash removed by the crops from the fertilized plats for the same period and the pounds of nitrogen, phosphoric acid and potash added in fertilizers. The difference between the amount added and the amount removed is also shown.

Dr. J. G. Lipman (14), Director of the New Jersey Experiment Station, stated that the cultivated crops in the United States removed in 1927 approximately 32.5 pounds of nitrogen, 12.5 pounds of phosphoric acid, and 30.75 pounds of potash per acre. He concluded that after due allowance is made for the nitrogen returned to the land in animal manures, for that fixed by bacteria, and for that brought down by rain and other atmospheric precipitation, there is still a net loss of 3,000,000 to 4,000,000 tons of nitrogen annually from our 300,000,000 acres of arable land. Lipman also estimated that the nitrogen in commercial fertilizer used replaced less than one-tenth of that lost by crop removal alone. In addition to this, Lyon and Buckman (15) stated that the loss of plant food through erosion is twenty times greater than that removed by crops. Lipman's figures also indicate a net loss through crop removal of nearly 2,000,000 tons of phosphoric acid, of which less than one-half is returned in fertilizers, and a net loss of about 5,000,000 tons of potash from this cause, of which only one-fifteenth is returned in fertilizers.

Highest yields of all plats were produced on plat 12 which received in the 25-year period an estimated 4,000 pounds of nitrogen, 2,000 pounds of

Table V .- Total yields of crops grown on fertilizer plats from 1914 to 1938 inclusive.

Plat	Amount of fertilizer per acre	Corn			Wheat		Clover hay	Grass hay
		Grain	Cobs	Stover	Grain	Straw		
		Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
2	438 pounds superphosphate	66,922	16,731	65,300	29,985	49,960	86,920	95,900
3	308 pounds dried blood 438 pounds superphosphate 200 pounds muriate of potash	80,149	20,037	84,620	37,654	68,660	117,160	128,520
4	200 pounds sulphate of ammonia 219 pounds raw rock phosphate	59,471	14,868	57,400	18,002	41,680	87,340	95,020
5	438 pounds superphosphate 200 pounds muriate of potash	76,059	19,015	73,720	30,811	52,140	100,280	96,560
6	200 pounds muriate of potash	55,019	13,755	57,400	16,129	28,400	49,920	57,360
7	308 pounds dried blood 200 pounds muriate of potash	58,431	14,608	58,800	16,694	35,260	63,260	70,920
8	308 pounds dried blood 438 pounds superphosphate	57,044	14,261	53,800	22,736	44,740	77,700	77,700
9	308 pounds dried blood	38,858	9,715	46,060	8,833	21,640	53,160	59,340
10	16 tons manure once in four years	83,021	20,755	90,520	35,473	75,440	108,900	105,620
11	16 tons manure once in four years 219 pounds raw rock phosphate	79,544	19,886	91,100	32,550	66,600	94,140	88,700
12	4 tons manure	87,069	21,767	96,560	36,862	76,660	129,540	134,780
13	16 tons manure once in four years 438 pounds superphosphate	82,431	20,608	100,660	37,590	80,860	120,380	113,160
14	219 pounds raw rock phosphate	53,184	13,296	54,060	15,667	32,000	64,080	57,960
	Check - no fertilizer*	45,505	11,376	48,720	10,371	21,210	41,960	48,320

* Average of two check plats.

Table VI.- Pounds of N, P_2O_5, and K_2O removed by the crops in the Rotation Experiment with Fertilizer, pounds of N, P_2O_5, and K_2O added by fertilizers and manure, and differences in amount added and that removed.

Plat	Nutri- ent	Crop removal of N, P_2O_5, and K_2O Corn*	Wheat**	Clover hay	Grass hay	Total	Amount of Nutrients Added by Fertilizers	Amount of Nutri- ents removed in ex- cess of those adde
		Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
2	N	1693	935	1339	1074	5041	....	5041
	P_2O_5	559	377	340	375	1651	7000	- 5349
	K_2O	1515	638	1554	1565	5272	....	5272
3	N	2086	1210	1804	1439	6539	4000	2539
	P_2O_5	681	483	458	503	2125	7000	- 4875
	K_2O	1930	858	2095	2097	6980	10000	- 3020
4	N	1499	632	1345	1064	4540	4000	540
	P_2O_5	496	245	342	371	1454	7000	- 5546
	K_2O	1334	495	1562	1551	4942	....	4942
5	N	1920	965	1544	1082	5511	....	5511
	P_2O_5	634	389	392	378	1793	7000	- 5207
	K_2O	1713	663	1793	1576	5745	10000	- 4255
6	N	1426	512	769	642	3349	....	3349
	P_2O_5	466	206	195	224	1091	....	1091
	K_2O	1312	358	893	936	3499	10000	- 6501
7	N	1495	566	974	794	3829	4000	- 171
	P_2O_5	491	222	247	277	1237	....	1237
	K_2O	1355	427	1131	1157	4070	10000	- 5930
8	N	1427	750	1197	870	4244	4000	244
	P_2O_5	473	297	304	304	1378	7000	- 5622
	K_2O	1258	549	1389	1268	4464	....	4464
9	N	1057	317	819	665	2858	4000	- 1142
	P_2O_5	339	122	208	232	901	....	901
	K_2O	1026	254	951	968	3199	....	3199
10	N	2187	1205	1677	1183	6252	4000	2252
	P_2O_5	711	472	426	413	2022	2000	22
	K_2O	2050	912	1947	1724	6633	4000	2633
11	N	2136	1090	1450	993	5669	4000	1669
	P_2O_5	689	429	368	347	1833	9000	- 7167
	K_2O	2043	811	1683	1448	5985	4000	1985
12	N	2309	1242	1995	1509	7055	4000	3055
	P_2O_5	748	488	507	527	2270	2000	270
	K_2O	2179	931	2316	2200	7626	4000	3626
13	N	2270	1283	1854	1267	6674	4000	2674
	P_2O_5	725	502	471	442	2140	9000	- 6860
	K_2O	2230	975	2152	1847	7204	4000	3204
14	N	1365	524	987	649	3525	....	3525
	P_2O_5	448	206	250	227	1131	7000	- 5869
	K_2O	1243	390	1146	945	3724	....	3724
Check ***	N	1191	348	646	541	2726	....	2726
	P_2O_5	388	136	164	189	878	....	878
	K_2O	1108	258	751	788	2905	....	2905

* Including cobs and stover.
** Including straw.
*** Average of two check plats.

phosphoric acid and 4,000 pounds of potash. The amounts of nitrogen, phosphoric acid and potash removed were 7055, 2270 and 7626 pounds, respectively. These figures indicate that more nutrients were removed in harvested crops than were added in fertilizers. Plat 10, which was treated with 16 tons of manure once in four years, received the same amount of nitrogen, phosphoric acid and potash as plat 12 which was treated with 4 tons of manure annually. However, less plant nutrients were removed in crops from plat 10.

Plats 11 and 13 received equal amounts of nitrogen, phosphoric acid and potash in manure and phosphates. However, the crops grown on plat 13, which received superphosphate and manure, removed more nutrients than crops grown on plat 11, which received raw rock phosphate and manure. Excessive amounts of phosphoric acid were added to each plat.

Plat 3 received a complete fertilizer with excessive amounts of phosphoric acid and potash. However, it failed to yield as much as plat 12 which received 4 tons of manure annually with none of the nutrients applied in excess.

Plat 5 received phosphoric acid and potash in excess without nitrogen being applied. The yields produced on this plat were approximately equal to the yields of the complete fertilizer plat. Superphosphate alone, plat 2, produced lower yields and, therefore, resulted in the removal of less nutrients than when used in combination with muriate of potash.

The fact that nitrogen is not the limiting nutrient is shown by the results secured on plat 9 which was treated with dried blood. This plat did not receive phosphoric acid or potash but received more nitrogen than the crops removed. The yields of corn and wheat produced on this plat were less than the yields of the check plat, but the yields of clover and grass hay were slightly higher on the check plat. Plat 7 also received an excessive amount of nitrogen. In addition, potash was applied in excess which resulted in yield increases over nitrogen applied alone. Neither plat 7 nor plat 9 received phosphoric acid, and yields produced by these plats were less than yields produced by the plat where superphosphate was used alone, plat 2. This fact indicates that phosphoric acid is the limiting nutrient.

An application of muriate of potash in excess, plat 6, did not materially increase the amount of nutrients removed by crops over the amount removed from the check plat. Further evidence that potash did not increase to a great degree the amount of nutrients removed, may be noted from the results secured on plat 5 which received superphosphate in addition to muriate of potash. The crops on this plat removed only 470 pounds of nitrogen, 142 pounds of phosphoric acid, and 473 pounds of potash more than the plat which received superphosphate only.

It is interesting to note that in most cases more phosphoric acid was added than was removed.

Van Alstine (31) reported that, from estimated additions and removals of phosphorus by plants, more phosphorus had been added to each treated plat than had been removed. Workers from Ohio reported that in no case had as much phosphorus been added in fertilizers as had been removed in crops. Russell (22) claims that only about 20 percent of the phosphoric acid added to soils is ever recovered. All plats which did not receive an application of some phosphate produced yields only slightly higher than the unfertilized plats. Excessive amounts of potash were applied on plats 5, 6, and 7, but these excesses failed to result in a much greater removal except on plat 5 which also received excessive phosphoric acid.

An interesting comparison can be drawn from plat 3, which received a complete fertilizer with excessive amounts of phosphoric acid and potash, and plat 12, which received four tons of manure annually with no excessive amounts of plant food. From plat 12 more nutrients were removed than added, but higher yields were produced than on plat 3 with its excessive minerals.

In Table VII is presented the total yields of crops grown on check plats from 1914 to 1938 inclusive.

The amount of nitrogen, phosphoric acid, and potash removed by crops from the check plats are presented in Table VIII. These plats were fertilized from 1909 through 1913.

More plant food was removed by crops harvested from plat 12, which received 4 tons manure annually, than from any other plat. These results indicated that manure had greater residual effect than mineral fertilizers. However, this high removal of plant food resulted from a few high yields at the beginning of the experiment. During the latter half of the 25-year period, yields from this plat dropped below those from plats 2 and 3. Plat 3, which received a complete fertilizer from 1909 through 1913, had large amounts of nitrogen, phosphoric acid, and potash removed. However, they were approximately the same as from plat 2, which received superphosphate, and this also indicates that superphosphate had more residual effect than either nitrogen or potash. By referring to trend lines for check plats 2 and 3 in Figures 16 and 17, it may be seen that the yields of wheat and grass hay after 25 years were highest on the superphosphate plat.

It is interesting to note that the crops grown on the plats treated with muriate of potash, dried blood and muriate of potash, and dried blood removed less plant food than an average for the check plats 4 and 11. These plats had received nitrogen and/or potash prior to 1914, but no superphosphate,

Table VII.- Total yields of crops grown on check plats from 1914 to 1938 inclusive.

Plat	Amount of fertilizer per acre applied annually from 1909 to 1913 inclusive	Corn Grain	Corn Cobs	Corn Stover	Wheat Grain	Wheat Straw	Clover hay	Grass hay
		Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
2	438 pounds superphosphate	58,979	14,745	55,320	18,306	33,120	59,240	68,840
3	308 pounds dried blood 438 pounds superphosphate 200 pounds muriate potash	62,087	15,522	54,000	17,258	30,980	62,660	69,320
4	None	49,559	12,390	52,940	12,080	24,100	46,180	58,520
5	438 pounds superphosphate 200 pounds muriate potash	57,851	14,463	49,100	15,208	27,300	52,080	59,600
6	200 pounds muriate potash	46,086	11,522	46,360	10,752	21,720	36,040	40,000
7	308 pounds dried blood 200 pounds muriate potash	46,367	11,592	45,680	11,443	21,680	38,040	38,240
8	308 pounds dried blood 438 pounds superphosphate	51,770	12,942	47,880	13,298	25,300	47,400	51,680
9	308 pounds dried blood	41,975	10,494	42,900	9,803	19,740	36,460	38,720
10	16 tons of manure once in 4 years	54,869	13,717	53,400	13,232	26,320	52,600	54,100
11	None	41,451	10,363	44,500	8,662	18,320	37,740	38,120
12	4 tons manure	60,311	15,078	57,940	15,155	31,400	67,720	66,060
13	16 tons of manure once in 4 years 438 pounds superphosphate	61,209	15,302	54,380	12,669	26,800	62,740	58,480
14	219 pounds raw rock phosphate	43,051	10,763	43,480	8,693	18,420	40,520	41,080

Table VIII.- Pounds of N, P_2O_5 and K_2O removed from check plats by crops in the Rotation Experiment with Fertilizers from 1914 to 1938 inclusive.

Plat	Nutrient	Corn*	Wheat**	Clover hay	Grass hay	Total
		Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
2	N	1472	586	912	771	3741
	P_2O_5	488	234	232	269	1223
	K_2O	1295	415	1059	1123	3892
3	N	1511	551	965	776	3803
	P_2O_5	506	221	245	271	1243
	K_2O	1287	388	1120	1131	3926
4	N	1296	401	711	655	3063
	P_2O_5	422	158	181	229	990
	K_2O	1204	295	826	955	3280
5	N	1397	482	802	667	3348
	P_2O_5	470	192	204	233	1099
	K_2O	1177	341	931	973	3422
6	N	1179	358	555	448	2540
	P_2O_5	387	141	141	156	825
	K_2O	1068	265	644	653	2630
7	N	1177	373	586	428	2564
	P_2O_5	388	148	149	149	834
	K_2O	1057	269	680	624	2630
8	N	1286	434	730	579	3029
	P_2O_5	428	172	185	202	987
	K_2O	1124	313	848	843	3128
9	N	1080	326	561	434	2401
	P_2O_5	354	129	143	151	777
	K_2O	985	241	652	632	2510
10	N	1387	439	810	606	3242
	P_2O_5	458	173	206	211	1048
	K_2O	1240	323	940	883	3386
11	N	1086	294	581	427	2388
	P_2O_5	354	115	148	149	766
	K_2O	1011	222	675	622	2530
12	N	1518	510	1043	740	3811
	P_2O_5	502	201	265	258	1226
	K_2O	1349	381	1211	1078	4019
13	N	1500	430	966	655	3551
	P_2O_5	501	169	245	229	1144
	K_2O	1289	324	1122	954	3689
14	N	1103	295	624	460	2482
	P_2O_5	362	116	159	160	797
	K_2O	1001	223	724	670	2618

*Including cobs and stover.
**Including straw.

which again indicates the importance of phosphoric acid in producing crops.

Plat 14 received raw rock phosphate before 1914, yet less plant food was removed than from an average of the check plats. This supports the theory that rock phosphate is very slowly available, and must be applied in large quantities to produce high yields of crops.

E. Nitrogen, Phosphoric Acid and Potash Removed by Various Crop Yields:

A third series of graphs are presented in Figures 29 to 32 inclusive, to show the amounts of nitrogen, phosphoric acid and potash removed by corn, wheat, clover and grass hay from the complete fertilizer plat. In all instances, the yields were arranged in ascending order regardless of the year produced. Attention is called to the fact that there were no recorded yields of clover hay for 1918 and 1931. Results are for the years 1914 to 1938 inclusive.

In Table IX is presented the estimated amount of plant food removed per acre by various yields of crops on a complete fertilizer plat. These figures were obtained by using the actual yields and multiplying by the percentage of nitrogen, phosphoric acid and potash found in each, as taken from Morrison's <u>Feeds and Feeding</u> (18). These analyses are shown in Table I. Morrison's (18) analyses are stated in percent of phosphorus and potassium. These figures were converted to phosphoric acid and potash by multiplying by 2.3 and 1.2 respectively.

Trend lines for yields and the plant food removed by corn, wheat, clover hay and grass hay grown in a rotation are shown in Figures 29 through 32. Lines for corn stover, corn cobs and wheat straw are not shown; however, the plant food removed by these by-products are included in Table IX.

Halligan(8) in 1912 presented figures showing the amounts of nitrogen, phosphoric acid, and potash removed by crops. He stated that a 50 bushel crop of corn would remove 63 pounds of nitrogen, 25 pounds of phosphoric acid, and 75 pounds of potash per acre in the grain, cob and stover.

Bear (3) found that a similar yield removed 62 pounds of nitrogen, 22 pounds of phosphoric acid and 64 pounds of potash.

Hopkins (11), Whitson and Walster (29), and Weir (26) also reported

Fig. 29.

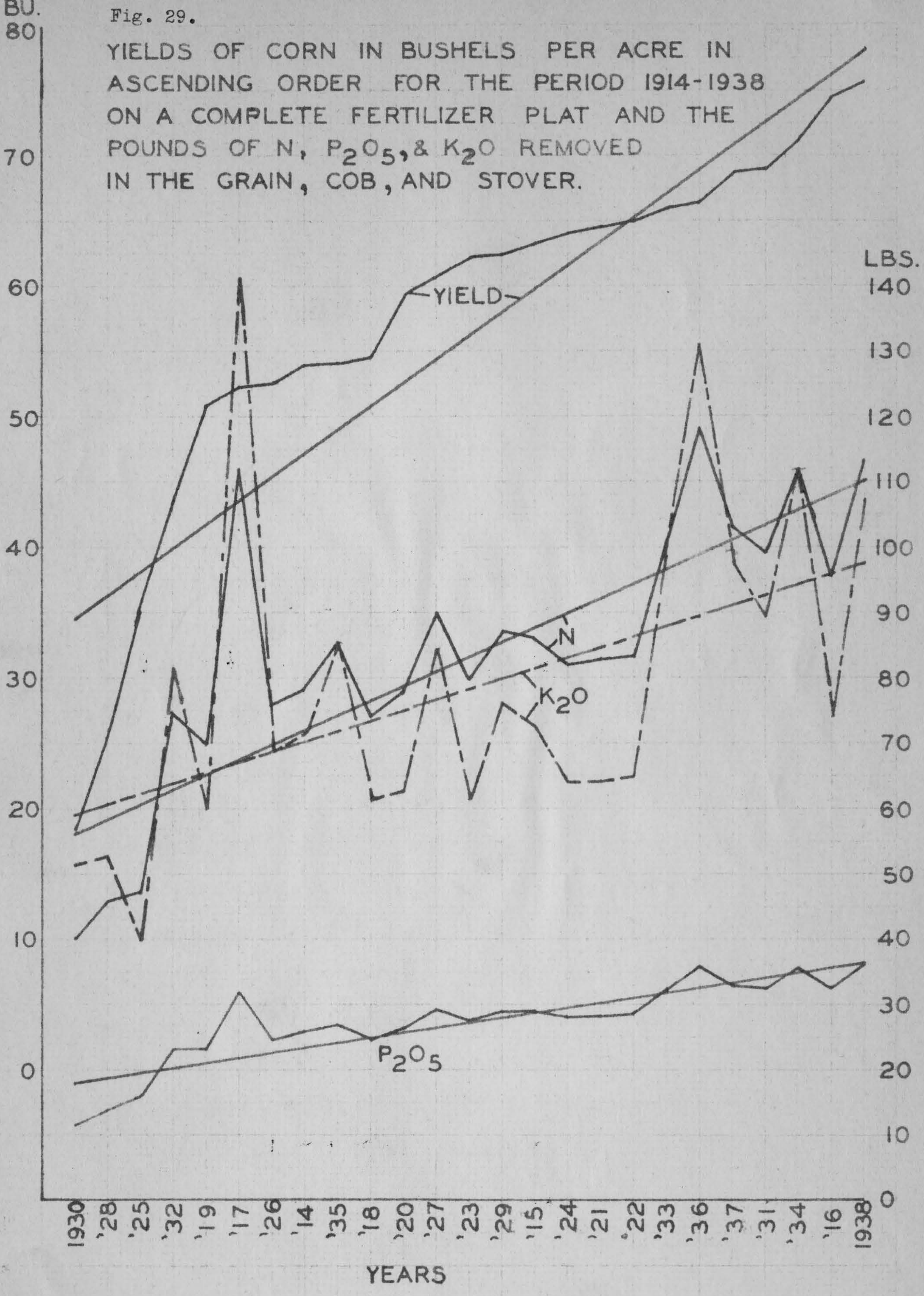

BU.
80
70
60
50
40
30
20
10
0
YIELDS OF CORN IN BUSHELS PER ACRE IN ASCENDING ORDER FOR THE PERIOD 1914-1938 ON A COMPLETE FERTILIZER PLAT AND THE POUNDS OF N, P2O5, & K2O REMOVED IN THE GRAIN, COB, AND STOVER.
YIELD
N
K2O
P2O5
LBS.
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1930
'28
'25
'32
'19
'17
'26
'14
'35
'18
'20
'27
'23
'29
'15
'24
'21
'22
'33
'36
'37
'31
'34
'16
1938
YEARS

Fig. 30.

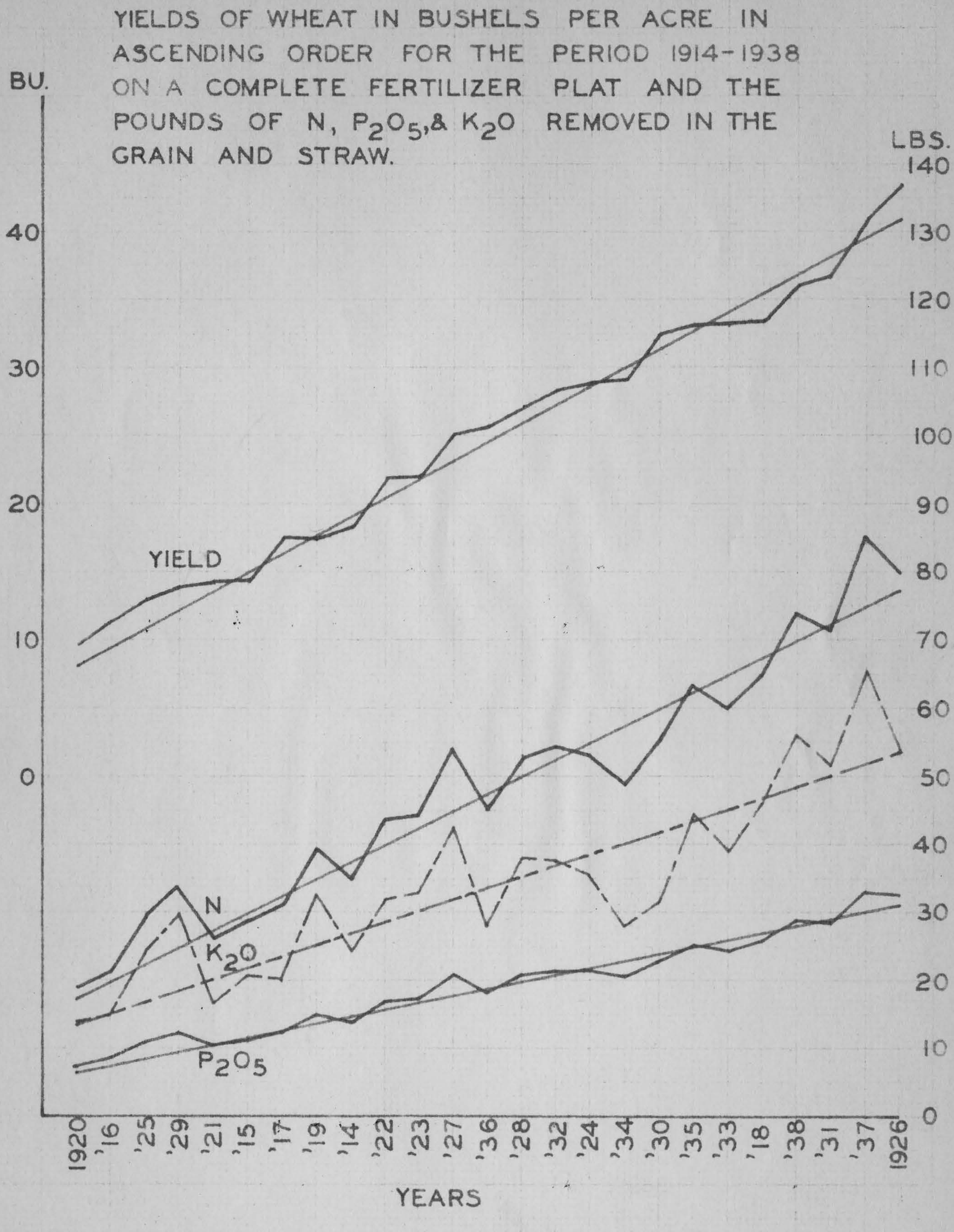

YIELDS OF WHEAT IN BUSHELS PER ACRE IN ASCENDING ORDER FOR THE PERIOD 1914-1938 ON A COMPLETE FERTILIZER PLAT AND THE POUNDS OF N, P_2O_5, & K_2O REMOVED IN THE GRAIN AND STRAW.
BU.
40
30
20
10
0
LBS.
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
YIELD
N
K_2O
P_2O_5
1920 '16 '25 '29 '21 '15 '17 '19 '14 '22 '23 '27 '36 '28 '32 '24 '34 '30 '35 '33 '18 '38 '31 '37 1926
YEARS

Fig. 31.

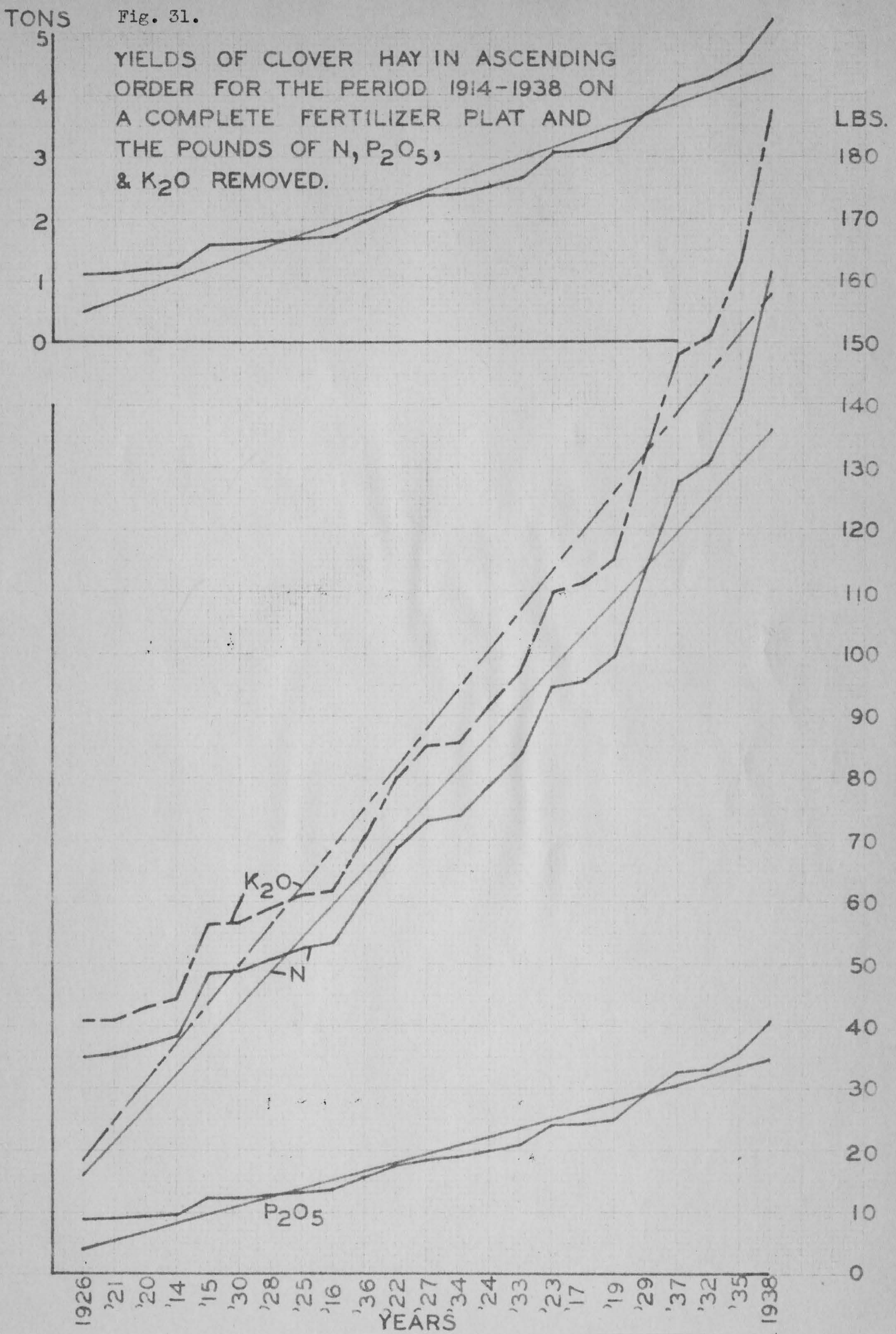
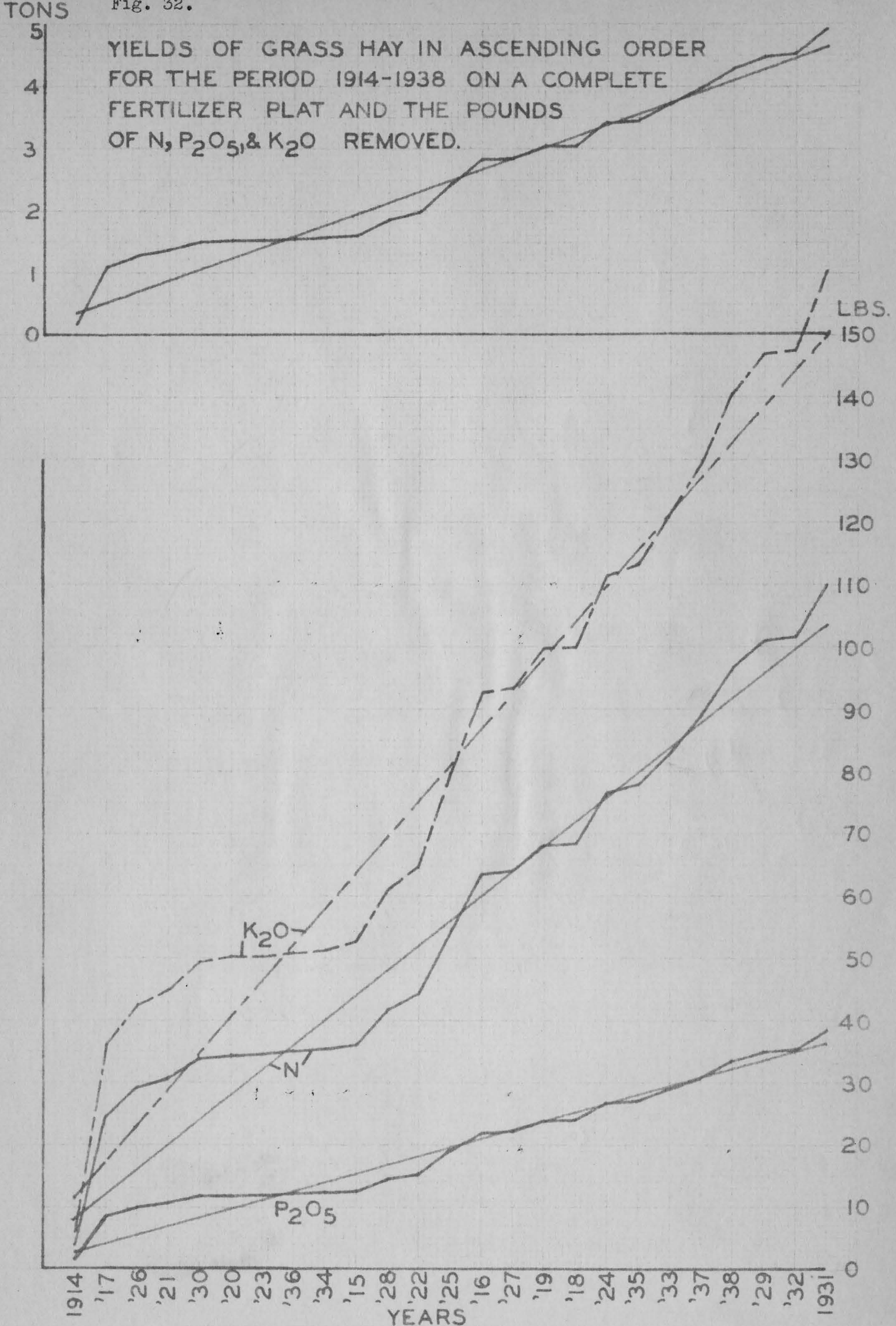

TONS
YIELDS OF CLOVER HAY IN ASCENDING ORDER FOR THE PERIOD 1914-1938 ON A COMPLETE FERTILIZER PLAT AND THE POUNDS OF N, P_2O_5, & K_2O REMOVED.
LBS.
K_2O
N
P_2O_5
1926 '21 '20 '14 '15 '30 '28 '25 '16 '36 '22 '27 '34 '24 '33 '23 '17 '19 '29 '37 '32 '35 1938
YEARS

Fig. 32.



TONS
5
4
3
2
1
0
YIELDS OF GRASS HAY IN ASCENDING ORDER FOR THE PERIOD 1914-1938 ON A COMPLETE FERTILIZER PLAT AND THE POUNDS OF N, P2O5, & K2O REMOVED.
LBS.
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
K2O
N
P2O5
1914
'17
'26
'21
'30
'20
'23
'36
'34
'15
'28
'22
'25
'16
'27
'19
'18
'24
'35
'33
'37
'38
'29
'32
1931
YEARS

Table IX.- Estimated amounts of plant food removed annually in pounds per acre by various yields of crops on complete fertilizer plat of Rotation Experiment with Fertilizers.

Corn, stover and cobs

Bu.	N	P_2O_5	K_2O
35.0	57.0	18.0	59.5
40.0	63.0	20.0	64.0
45.0	69.5	22.5	68.5
50.0	75.5	24.5	73.0
55.0	82.0	27.0	77.5
60.0	87.5	29.0	81.5
65.0	94.0	31.0	86.0
70.0	100.0	33.0	90.5
75.0	106.5	35.0	95.0

Wheat and straw

Bu.	N	P_2O_5	K_2O
10.0	21.0	8.0	15.5
15.0	30.0	11.5	22.0
20.0	39.0	15.5	28.0
25.0	48.5	19.0	34.0
30.0	57.5	23.0	40.0
35.0	66.5	27.0	46.0
40.0	75.5	30.5	52.5

Clover hay

Tons	N	P_2O_5	K_2O
0.5	16.0	4.0	18.5
1.0	31.0	8.0	36.0
1.5	45.5	11.5	53.5
2.0	61.5	16.0	71.5
2.5	76.5	19.5	88.5
3.0	92.0	23.5	107.0
3.5	108.5	27.5	126.0
4.0	124.0	31.5	143.5

Grass hay

Tons	N	P_2O_5	K_2O
0.5	11.0	4.0	16.0
1.0	22.5	8.0	32.5
1.5	33.5	11.5	49.0
2.0	45.0	15.5	65.0
2.5	56.5	19.5	81.0
3.0	68.0	24.0	98.0
3.5	78.0	27.5	115.0
4.0	90.0	31.5	130.0
4.5	101.0	35.5	146.0

the amounts of plant food removed by crops.

To estimate from the graphs in Figures 29, 30, 31 and 32, the amounts of nitrogen, phosphoric acid and potash removed by corn, wheat, clover hay or grass hay, select the desired yield on the straight line yield trend by referring to the figures on the left of the graph. Next, select the points directly under the yield on each straight line labeled N, P_2O_5 and K_2O. The figures on the right of the page opposite these points are the estimated number of pounds removed in harvested crops. This method was used in compiling Table IX.

Corn and wheat removed more nitrogen than potash, and more potash than phosphoric acid. Clover hay and grass hay removed more potash than nitrogen, and more nitrogen than phosphoric acid.

It is interesting to note that clover hay removed more nitrogen and potash than an equal yield of grass hay. The amounts of phosphoric acid removed are almost identical for each.

These figures are based on yields over a 25-year period and should be a good basis for making fertilizer recommendations.

SUMMARY AND CONCLUSION

Straight line trends for corn, wheat, clover hay and grass hay grown in a rotation were calculated by the method of least squares. Trends for fertilized and unfertilized plats were obtained for the 25 year period from 1914 to 1938 inclusive.

Upward trends of all crops were produced by the following treatments: superphosphate; dried blood, superphosphate and muriate of potash; sulphate of ammonia and raw rock phosphate; superphosphate and muriate of potash; 16 tons of manure once in four years and raw rock phosphate; and 4 tons of manure annually.

The highest average yields of corn, clover and grass hay were produced by the treatment of 4 tons of manure annually. The highest average yield of wheat was produced by a complete fertilizer.

An application of dried blood alone on corn and wheat produced lower yields than the check. The yields of clover and grass hay produced by dried blood were slightly higher than the check yields.

Superphosphate produced upward yield trends for all crops. These yields were considerably higher than the check.

Muriate of potash produced yields slightly higher than the check plat, but trends were downward except in the case of grass hay.

Superphosphate was far superior to muriate of potash or dried blood when single fertilizer carriers were applied to crops in the rotation.

Applications of superphosphate produced higher yields than applications of raw rock phosphate. The yield trends of crops were generally upward for both treatments but the trend rise was greater in case of superphosphate.

Phosphates used to supplement 16 tons of manure applied once in four years did not produce higher yields than manure alone.

Small frequent applications of manure produced higher average yields than large less frequent applications.

The trend lines for plats which received no fertilizer since 1913 were all downward in the case of corn. Wheat trends were downward except for treatments of muriate of potash; dried blood; raw rock phosphate; and the check plats 4 and 11 which received no fertilizer prior to 1914. Downward trends were dominant in the case of clover hay, as only the treatment of superphosphate and muriate of potash produced an upward trend. However, one of the check plats produced an upward trend. Grass hay trends were usually upward, but downward trends were produced by the following treatments: 4 tons manure annually; 16 tons of manure once in four years supplemented with superphosphate; and raw rock phosphate.

A study of the residual effect of fertilizers which were applied five successive years previous to 1914 was made.

Residual effect was exhibited only by manure and by fertilizers which contained superphosphate.

The residual effect of a complete fertilizer was greater than the residual effect of manure, except in the case of clover hay.

A study of the relationship between the amount of plant food added in fertilizers and that removed in harvested crops was made.

Plat 3 which received a complete fertilizer with excessive amounts of phosphoric acid and potash, failed to produce as high yields as plat 12 which received 4 tons of manure annually with none of the nutrients applied in excess.

Eight of the thirteen fertilizer plats showed more phosphoric acid added than removed by crops. More nitrogen was removed in crops than added in fertilizer from all plats except 7 and 9.

More potash was removed than added on nine of the thirteen plats.

The amount of nitrogen, phosphoric acid and potash removed by various yields was calculated for corn, wheat, clover hay and grass hay.

Corn and wheat removed more nitrogen than potash, and more potash than phosphoric acid.

Clover and grass hay removed more potash than nitrogen, and more nitrogen than phosphoric acid.

Clover hay removed more nitrogen and potash than grass hay, while both crops removed the same amountsof phosphoric acid.

BIBLIOGRAPHY

1. Abbott, J. B., and Conner, S. D. Results of cooperative fertilizer tests on clay and loam soils. Ind. Agr. Exp. Sta. Bul. 155. 1912.

2. Baker, W. G. Residual effects of acid phosphate and rock phosphate. Jour. Amer. Soc. Agron., 17: 172-186. 1925.

3. Bear, F. E. Soil Management. John Wiley and Sons, Inc., New York. 1927.

4. Collings, G. H. Commercial Fertilizers. P. Blakiston's Son and Co., Inc., Philadelphia. 1938.

5. Committee report on "Scales for compensation for manurial improvements under the agricultural holdings" to the Board of Agriculture for Scotland. Scottish Jour. Agr. 1: No. 2. 1918.

6. Cooper, H. P., and Wallace, R. W. Residual effect of potash on cotton. Annual Report, S. C. Agr. Exp. Sta. 1936.

7. Gordon, G. S. The residual effect of superphosphate. Jour. Dept. Agr. Victoria 16:610. 1918.

8. Halligan, J. E. Soil Fertility and Fertilizers. The Chemical Publishing Co., Easton, Pa. 1912.

9. Hartwell, B. L., and Damon, S. C. The comparative value of different sources of phoshorus. R. I. Agr. Exp. Sta. Bul. 163. 1915.

10. Hester, J. B., Carolus, R. L., and Blume, J. M. A study of the availability of phosphorus and potash and their influence upon vegetable crop production and fertilizer practices on Coastal Plain soils. Proceed. Soil Sci. Soc. Amer., 1; pp. 233-242. 1936.

11. Hopkins, C. G. Soil Fertility and Permanent Agriculture. Ginn and Company, New York. 1910.

12. Kipps, M. S., and Hutcheson, T. B. Fertilizer and manure experiments on Dunmore silt loam soil. Va. Agr. Exp. Sta. Bul. 317. 1938.

13. Klages, K. H. W. Trend studies in relation to the analysis of yield data from rotation experiments. Jour. Amer. Soc. Agron., 30: 624-631. 1938.

14. Lipman, J. G. The Menace of Overproduction. John Wiley and Sons, Inc., New York. 1930.

15. Lyon, T. L., and Buckman, H. O. The Nature and Properties of Soils. The Macmillan Co., New York. 1937.

16. Millar, C. E. Soils and Soil Management. Webb Book Publishing Company, St. Paul, Minnesota. 1929.

17. Mills, F. C. Statistical Methods. Henry Holt and Company, New York. 1924.

18. Morrison, F. B. Feeds and Feeding. The Morrison Publishing Company, Ithaca, New York, 1936.

19. Nagaoka, M. On the action of various insoluble phosphates upon rice plants. Bul. Col. Agr. Tokyo Imp. Univ. 6: 215. 1904.

20. Noll, C. F. Annual Report Pa. Agr. Exp. Sta. Bul. 367. 1938.

21. Russell, E. J. Plant Nutrition and Crop Production. University of California Press, Berkeley, Calif. 1926.

22. Russell, E. J. Soil Conditions and Plant Growth. Longmans, Green and Company, New York. 1932.

23. Salter, R. M. Fertilizer Review Vol. 6, No. 4, p. 10. 1931.

24. Thorne, C. E. The residual effect of fertilizers and manures. Monthly Bul. Ohio Agr. Exp. Sta. 2, No. 2. 1917.

25. Weir, W. W. Productive Soils. J. B. Lippincott Company, Philadelphia. 1920.

26. Weir, W. W. Soil Science. J. B. Lippincott Company, Philadelphia. 1936.

27. Weitz, B. O. The trend toward a more effective use of the land as shown by the yields per acre of certain crops. U. S. Dept. Agr. Bur. of Agr. Ec. Bul. 1458. 1926.

28. White, J. W. Soil organic matter and manurial treatments. Jour. Amer. Soc. Agron., 19: 389-396. 1927.

29. Whitson, A. R., and Walster, H. L. Soils and Soil Fertility. Webb Publishing Co., St. Paul, Minn. 1912.

30. Wolkoff, M. I. Relative availability of the phosphorus of raw rock and acid phosphate in soils. Soil Sci., 17: 39-56. 1924.

31. Van Alstine, E. The movement of plant food within the soil. Soil Sci., 6: 281-308. 1918.