1934

The Effect of Fertilizer Applications on the Quality and the Quantity of the Oil in Flaxseed

Clarence O. Stockland

THE EFFECT OF FERTILIZER APPLICATIONS ON THE QUALITY AND THE QUANTITY OF THE OIL IN FLAXSEED

A THESIS

SUBMITTED TO THE FACULTY

OF

SOUTH DAKOTA STATE COLLEGE

-- By --

CLARENCE O. STOCKLAND

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

June, 1934.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

The writer wishes to take this opportunity to express his gratitude to Dr. A. N. Hume for the suggestion of this problem, and to Prof. J. G. Hutton, under whose immediate direction the problem was carried out, for his many valuable suggestions and criticisms during every stage of its solution. The writer is also indebted to Dr. K. H. Klages, Prof. L. Fuhr and other members of the Agronomy Department for their advice and assistance.

Thanks are also due members of the Department of Chemistry and the Chemistry Experiment Station for the use of certain equipment which aided materially in the completion of the problem.

INTRODUCTION

A considerable number of economic seeds are characterized by the presence of oil instead of starch as reserve material. The flax plant produces an oil-bearing seed which yields either by pressure or by extraction an oil which is used chiefly in the manufacture of paints and varnishes, and in the manufacture of linoleum, oil cloth, printer's ink, and patent leather.

The oil obtained from flaxseed is known as linseed oil and is one of a class of fatty oils known as drying oil. When exposed to the air the oil absorbs oxygen, forming a compound known as linoxyn which constitutes the tough, elastic, and protective film that makes the oil so valuable to the paint industry.

Flax is grown in the United States chiefly for the oil content of its seeds. An important by-product of its crusher industry is linseed cake, which is rich in protein and has high commercial value as a live-stock food. The increasing demand for these manufactured products and the growing scarcity of linseed oil, due to the decreased acreage and yield of seed, has served to focus the attention of agriculturists as well as manufacturers on the cultivation of flax for the production of flaxseed and linseed oil.

Since flax production for linseed oil has received so much attention it is a matter of practical importance to ascertain, so far as possible, the cultural practices most favorable to the increase of quantity and quality of the crop. Such results can best be obtained by a combined agronomic and chemical investigation of the subject. This investigation has therefore been concerned with a study of the effect of different soil treatments on the production of seed, and a study of the oil from the standpoint of yield and quality.

HISTORICAL

Investigators of European countries are credited with the earliest researches involving the effects of fertilizer applications on the oil content of oil-bearing seeds. These studies, along with this country's more recent investigations, have shown that applications of commercial fertilizers may favorably or adversely affect the oil content of the seed and also influence the various constants of the extracted oil. Garner, Allard, and Foubert (1) have shown in fertilizer tests with cotton that the addition of a complete fertilizer yielded seed of a considerably higher oil content than the seed from the unfertilized land. Applications of nitrogen in increasing amounts lowered the percentage of oil, while increasing applications of phosphorus or potassium did not affect the oil content. They concluded that, "Under practical conditions climate is a more potent factor than soil type in controlling the size of the seed and its oil content", and, "Within ordinary limits the relative fertility of the soil appears to be a minor factor in influencing the size of the seed and its oil content."

O'Kelly, Hull, and Geiger (2) of the Mississippi Agricultural Experiment Station report that applications of fertilizer containing nitrogen and phosphorus alone caused a decrease in the oil content of cotton-seed as compared to the oil content of seed produced without fertilizer. The addition of potash to the fertilizer mixture increased the oil content and in practically all cases each successive potash increment produced a corresponding increase in the oil per ton of seed.

Bushey, Puhr, and Hume (3) have studied the influence of crop rotation on the oil content of flaxseed. They analyzed ten samples from ten different rotations and found them quite uniform in the percentage of

oil, there being a difference of only 2.1% in the oil content between the highest and lowest sample.

Stark (4), working with soybeans at the Illinois Agricultural Experiment Station, found that applications of limestone were followed by a decrease in the content of oil. He found that phosphorus, in most cases, still further decreased the percentage of oil while potassium showed a slight increase in percentage of oil. Expressed in number of pounds of oil gained or lost by the various treatments, it was found that manure gave an average increase of oil over no treatment amounting to 6.7 pounds per acre, while crop residues gave an average increase over no treatment of 26.4 pounds per acre. Limestone added to manure gave a further increase of 82.2 pounds per acre, and when applied with residues, the average gain for the limestone was 54.9 pounds per acre. Phosphorus applied in addition to manure and limestone resulted in an average loss of 4.3 pounds of oil per acre and phosphorus in addition to residues and limestone caused a gain of 2.7 pounds per acre. When potassium was added to residues, lime, and phosphorus, there was an average decrease of oil amounting to 2.8 pounds per acre.

Feller (5), of the New Jersey Agricultural Experiment Station, found applications of lime to the soil decreased the oil content of the soybeans in proportion to the amount of lime applied. Small applications of acid phosphate materially increased the oil content, especially when lime was applied with it. Applications of potassium resulted in a slight decrease in oil content.

Johnson (6), Minnesota, reports no consistent differences in oil content for three different cropping systems during the period of oil formation. Statistical comparisons of the oil content made from the twenty-

third day to maturity between the flax produced on a five and a three-year rotation and between a five-year rotation and a continuous cropping system gave a mean difference in favor of the five-year rotation of 0.56% and 0.97% oil. The comparison between the oil content of the seed from the three-year rotation and continuous cropping plots gives a mean difference in favor of the former of 0.42% oil.

Schuster and Graham (7), Delaware, present data to indicate that the composition of the soybean cannot be changed by soil treatment, maintaining that investigators must look to genetics for any improvement in soybeans as to oil and protein content. They found that single elements did not affect the composition of soybeans, but when applied in combination, they did. Nitrogen and phosphorus caused a very significant decrease in the oil content when applied on unlimed soil. Phosphorus and potassium, in combination, also caused a decrease in the oil content upon unlimed soil. A complete chemical fertilizer had no significant effect on the oil content upon either limed or unlimed soil. Manure caused a small significant loss in oil.

A careful investigation by Robinson and Cook (8) at Michigan shows that nitrogen added to combinations of potash and phosphorus fertilizers gives only slightly increased seed yields. Phosphorus alone did not increase the yield of seed over untreated plots but in combination with potash increased yields were obtained.

Ali Mohammad (9), working with flax in India, reports applications of sodium nitrate increased the height of the plants 5%, the average number of basal branches per plant 15%, and the yield of seed 6%, in comparison with complete fertilizers which increased the height of the plants 3%, the average number of basal branches 10%, and the yield of seeds 4%. Potassium

sulphate had no effect, while superphosphate had a deleterious effect except that it induced early flowering. None of the fertilizers had a significant effect on the percentage oil content of the seed.

The use of artificial manures was found by Eyre and Fischer (10) to occasion only a very slight variation in the oil content of linseed. The main effect has tended toward influencing the yields both of seed and of straw. The only significant increase in oil content was obtained from a combined superphosphate and potash treatment.

Gerken (11) presents data to indicate the yield of oil to be increased by fertilizer applications. He found applications of potassium and phosphorus, however, to be of no value without nitrogen.

Balashev (12) reports the beneficial influence of potash on flaxseed yields. He found nitrogen and potash fertilizers to rank first in order while phosphates are secondary in the fertilization of flax. In dry years he found the application of fertilizers to be ineffective or even injurious.

Mitrofanov (13), reporting on the results of fertility experiments conducted on non-chernozem soils, indicates that flax responds best to a complete fertilizer. Nitrogen with phosphorus seems to be the most effective combination. Heavy applications of nitrogen and phosphorus, however, had an injurious effect.upon the yield of the fiber and its quality. This seemed especially true of nitrogen. Additions of potash somewhat decreased this injury.

Balashev (14) finds flax very sensitive to an increase in the concentration of the soil solution and is therefore sensitive to mineral fertilizers. His investigations show that heavy applications of lime adversely affect the seeds. Phosphates act beneficially on heavy soils.

Nitrogen, and especially potassium are beneficial for light soils.

A summary of the data obtained by these investigators indicate that flaxseed may show considerable variability in composition as a result of differences in soil fertility and climates. It is apparent from a study of this material that fertilizer applications do affect the yield of oil. Some investigators have received increased yields of oil in response to treatments with potash and decreased yields with phosphorus. Others have achieved just opposite results. In combination with each other and with other fertilizers phosphorus and potassium have produced widely varying results. In the greater number of instances the application of fertilizers has tended more toward increases in yield of seed and straw than towards the increases in yield of oil.

PURPOSE OF INVESTIGATION

North Dakota, South Dakota, Minnesota, and Montana comprise an area which grew in 1932-33, 78.7% of the entire acreage of flax grown in the United States and Canada. In consequence, most of the investigation with flax has been done at stations within this area. The work which has been done has been concerned mostly with the development of disease resisting varieties with, perhaps, the least attention having been paid to the effects of cultural practices as affecting certain physical and chemical characteristics of flaxseed.

In this investigation the experimental work was divided into the following parts:

1. The effect of the application of fertilizers upon the length of the growing period.
2. The effect of the application of fertilizers upon the physical characteristics of the plants.
3. The effect of the application of fertilizers upon the yield of seed.
4. The effect of the application of fertilizers upon the quantity and drying properties of the oil.
5. The effect of the application of fertilizers upon the nitrogen content of the seed.
6. The effect of the application of fertilizers upon the presence of starch in flaxseed.

MATERIALS AND METHODS

The original plan of investigation was to obtain seed from a crop grown on station plots, having different fertilizer treatments. Such a procedure was begun and a crop planted in the spring of 1933 on plots at the South Dakota Agricultural Experiment Station, but due to the extremely dry conditions of that season, the crop did not mature seed and so had to be abandoned.

In order to proceed with the investigation, it was necessary to grow the crop in pots under greenhouse conditions. Although greenhouse conditions and methods are not strictly comparable to field conditions, it was possible to maintain an adequate moisture supply and to mature a crop yielding enough seed for analysis.

Only one variety of flax, Bison, was grown. This is a variety widely grown in South Dakota. It has a fairly tall growth habit, medium sized seeds, and has yielded well at this station.

SOIL:

The soil used in this experiment is described as Barnes sandy loam. It was taken from a field which had had no manural treatment for several years. Analysis of the soil shows it to contain: 5,351.9 lbs. nitrogen; 1,137.3 lbs. phosphorus; 16,246.9 lbs. calcium; 10,302.4 lbs. magnesium; and 13,284.2 lbs. of potassium per acre and to have a total water-holding capacity of about 46%. The soil was brought to a laboratory in early fall, allowed to air dry and was thoroughly homogenized before being put into the pots.

FERTILIZERS:

The elements applied as fertilizers were nitrogen, phosphorus, potassium, and magnesium. The nitrogen was supplied in the form of the

commercial fertilizer, sodium nitrate, at the rate of 350 pounds per acre or .735 grams per pot. Commercial acid phosphate was used to supply the phosphorus. This was applied at the rate of 300 pounds per acre or .63 grams per pot. The acid phosphate was ground in a mortar before weighing. It contains gypsum and about 20% P_2O_5 or 8.53% phosphorus. Potassium was added in the form of the pure salt, potassium chloride, at the rate of 300 pounds per acre or .63 grams per pot. The magnesium was supplied as the pure salt, magnesium chloride, at the rate of 200 pounds per acre or .90 grams per pot. These fertilizers were applied in dry form and thoroughly incorporated with the top two inches of soil.

PLAN OF EXPERIMENT:

Seventy pots in all were used. These were numbered consecutively from 50 to 119, and were divided into ten series of seven pots each. Nine different fertilizer treatments and a no treatment series were used as shown in the following table:

Table 1. System of Numbering and Treatment.

Series Number	Treatment	Pot Number
1	O	50 - 56
2	N	57 - 63
3	P	64 - 70
4	K	71 - 77
5	NP	78 - 84
6	NK	85 - 91
7	PK	92 - 98
8	NPK	99 - 105
9	Mg	106 - 112
10	MgP	113 - 119

In all tables the different treatments are designated by the symbol or symbols of the element or elements used in that treatment. For example, in Table I, above: No treatment is designated by the symbol O; nitrogen by the symbol N; phosphorus by P; potassium by K; nitrogen-phosphorus by NP; nitrogen-potassium by NK; phosphorus-potassium by PK; nitrogen-phosphorus-potassium by NPK; magnesium by Mg; and magnesium-phosphorus by MgP.

The seven pots of Series I received no treatment and so constitute the control series. The single elements and the combinations of elements as used in the investigation are outlined in Table I, above.

CONDITIONS OF GROWTH:

The flax was planted on November 14 with approximately twenty-five seeds to each pot. An excess of seed was planted in order to insure enough plants and to make for more even spacing when thinning out the plants. Eleven plants were allowed to develop and mature in each pot.

After planting, the soil in each pot was covered to a depth of one-half inch with 400 grams of pure quartz sand to serve as a mulch and to prevent cracking of the soil through evaporation.

The soil was kept at about 44% of its total water-holding capacity during the entire life of the plants.

The pots were shifted from time to time in order that they should not always occupy the same relative position in the greenhouse. Precautions were taken to keep the early temperature at about 50° F. in order that the seedlings would be encouraged to form a sturdy root system and not too rapid aerial growth. Such a temperature more nearly approximates early spring field conditions and also lessens the danger of damping off of the tender seedlings. As the plants developed, the temperature was allowed to

reach 68° to 72° F. This temperature was maintained throughout the later development of the plants. Near maturity the temperature often rose as high as 85° or 90° F. during periods of sunshine in the early afternoon. Artificial light was used when the number of hours of sunshine per day were limited. The artificial illumination was supplied by two 500-watt lamps.

DEVELOPMENT OF THE PLANTS:

Daily notes were taken in order to determine the effect of the various treatments on the daily increases in height of the plants. Notes were also taken to determine dates of flowering, boll formation, and date of maturity.

When all the bolls had become fully ripe and dry, they were picked and placed in manila envelopes which were left open so that they might be further dried in the laboratory. The crop was harvested on March 15, approximately 120 days after planting. When thoroughly air dry, the seeds were separated from the bolls by rolling gently between a piece of linoleum and a large rubber stopper. The bolls were counted at the time of harvesting and the number of seeds and the total weight obtained at the time of threshing.

OIL DETERMINATION:

The oil was extracted from the seed by means of anhydrous ether in a Bailey-Walker Extraction Apparatus. Five-tenths gram samples of seed in duplicate were weighed and ground in a mortar with a small amount of pure quartz sand. The samples were transferred to soxhlet thimbles, placed in weighing bottles and dried in a vacuum oven in an atmosphere of carbon dioxide gas at a temperature of 70° C. for sixteen hours or until a constant weight was obtained.

The water-free samples were transferred to extraction flasks and extracted for twenty hours with anhydrous ether. After extraction the ether was evaporated off and the oil allowed to dry for two hours in the vacuum oven in the presence of Carbon dioxide and at a temperature of 70° C. The weight of oil was determined by difference in weight of flask before and after extraction and drying.

IODINE NUMBERS:

The iodine numbers were determined according to the Hanus method (15) as outlined by the Association of Official Agricultural Chemists. An iodine monobromide solution was prepared by dissolving 13.615 grams of powdered iodine in 825 c.c. of glacial acetic acid. An amount of bromine equivalent to 13.615 grams of iodine was added to the solution.

The oil remaining in the flask after evaporation of the ether was dissolved in 10 c.c. of chloroform, 25 c.c. of the monobromide solution was added, the flasks were stoppered, and then allowed to stand for one-half hour with occasional shaking.

At the time the monobromide solution was being measured into the oil, the same amounts of chloroform and monobromide solution were placed in two other flasks to be carried along in the same manner with the oil as blank determinations.

At the end of the absorption period of thirty minutes, 10 c.c. of a 15% potassium iodide solution and 100 c.c. of water were added to each flask. (The addition of the potassium iodide, after absorption by the oil, gives a titration which may be calculated as though iodine were the only halogen present since iodine is titrated at the end.)

$$IBr + KI \rightarrow KBr + I_2$$

The unabsorbed iodine was immediately titrated with sodium thiosulphate.

$$2Na_2S_2O_3 + I_2 \rightarrow Na_2S_4O_6 + 2NaI$$

The amount of unabsorbed iodine subtracted from the total amount of iodine in the blank is equal to the iodine absorbed by the oil.

NITROGEN:

The nitrogen was determined by the ordinary Kjeldahl method.

STARCH:

Tests for starch were made by boiling in water ground seed from each series and examining under a microscope a drop of the solution which had been treated with a dilute iodine solution. Tests were also made by grinding seed from each series and noting the effect of a dilute iodine solution. Iodine solution was also applied to longitudinal sections of the seeds. All tests were made with the use of a microscope.

EXPERIMENTAL RESULTS

The Effect of the Application of Fertilizers Upon the Length of Growing Period

Under normal growing conditions the tendency of phosphorus is to hasten maturity. In our investigations this characteristic became apparent in a more rapid development of the plants than shown by any other plant food element used.

The most sturdy plants, during early development, were produced on the phosphorus treated series. Plants of the magnesium series appeared to lack the deep green color of the other series.

The phosphorus series began to flower on January 8 and were in full bloom by January 18. The series receiving no phosphorus began blooming on January 14, and all were in full bloom by January 30.

Boll formation began with the phosphorus series about January 18. The series receiving no phosphorus began to form bolls on January 25.

All the series receiving phosphorus had reached full maturity and were ready to harvest eight to ten days before the other series had become fully ripe. The nitrogen-potassium series was the last to ripen.

The Effect of the Application of Fertilizers Upon the Physical Characteristics of the Plants

DAILY INCREASE IN HEIGHT OF PLANTS:

Daily measurements of the increase in height were made each day from the twenty-fifth day after planting to maturity. The first measurements were made on December 11, when the plants ranged from 9 to 12 centimeters in height. The data obtained show greatly varied responses of the plants to the soil treatment.

In all cases where phosphorus was used alone or in combination with other elements, we find the most rapid increases in height.

Table II. Effect of Fertilizer Treatment on Increase in Height of Plants.

Series No.	Treatment	Av. Ht. Dec. 11	Av. Ht. Jan. 15	Av. Da. Increase Dec.11-Jan.15	Av. Da. Gain Over No Treat. Dec.11-Jan.15	Ht. at Matur.	Av. Da. Increase Dec.11-Matur.	Av. Gain Over No Treat. Dec.11-Matur.
1	O	9	53	1.26		87	1.12	
2	N	10	54	1.26	0.00	87	1.13	0.01
3	P	12	92	2.29	1.03	105	1.37	0.25
4	K	9	53	1.26	0.00	88	1.16	0.04
5	NP	12	90	2.23	0.97	109	1.43	0.31
6	NK	9	51	1.20	-0.06	88	1.16	0.04
7	PK	12	91	2.26	1.00	106	1.38	0.26
8	NPK	12	90	2.23	0.97	105	1.37	0.25
9	Mg	10	52	1.20	-0.06	86	1.12	0.00
10	MgP	12	92	2.29	1.03	108	1.41	0.29

(Height is expressed in centimeters.)

Examination of Table II reveals that phosphorus alone and phosphorus with magnesium chloride made the greatest daily increase in height. The average daily gain over no treatment in the case of phosphorus, and phosphorus with magnesium amounts to 1.03 cm. per day. The average daily gain over no treatment for the phosphorus-potassium series was 1 cm. For the nitrogen-phosphorus and nitrogen-phosphorus-potassium series, the average daily gain was .97 cm. over no treatment. Nitrogen with potassium, and magnesium chloride alone show a decrease in height over no treatment; the decrease in both cases amounting to -0.06 cm.

For the entire period, December 11 to maturity, phosphorus in

combination with nitrogen made the greatest daily gain, followed by phosphorus with magnesium and phosphorus with potassium. While the gain for phosphorus alone was greatest during the period December 11 to January 15, the gain was less for phosphorus for the entire period, December 11 to maturity, than for any combination with it excepting the nitrogen-phosphorus-potassium combination.

An idea as to comparative heights may be gained by examination of the following figures:

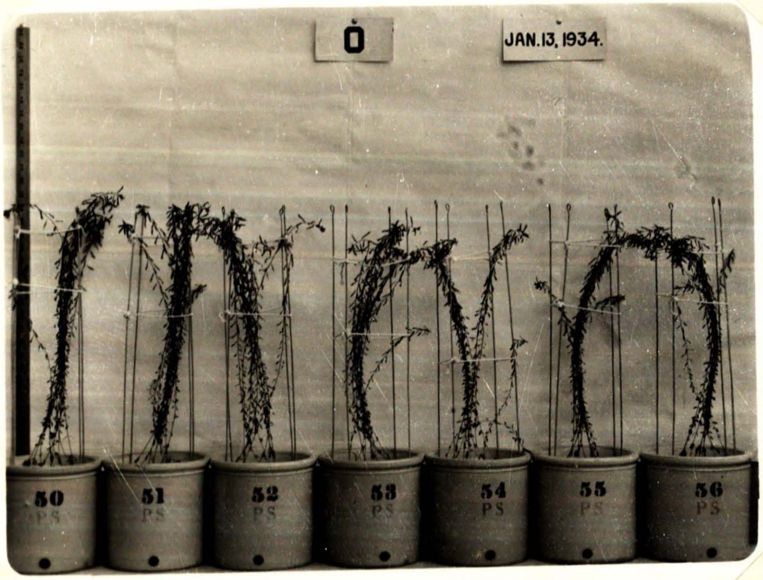


Fig. 1.

Figure 1 shows all the pots of the series receiving no treatment. The photograph was made on January 13, just before the series began to exhibit evidences of flowering.

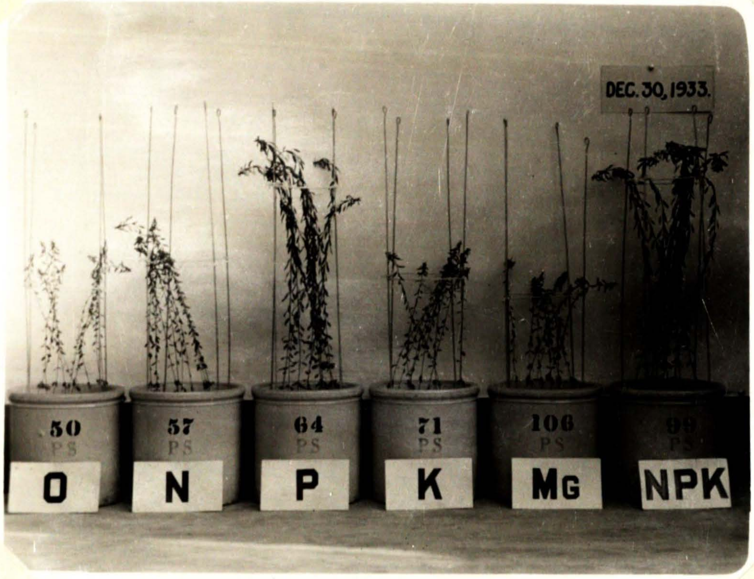


Fig. II.

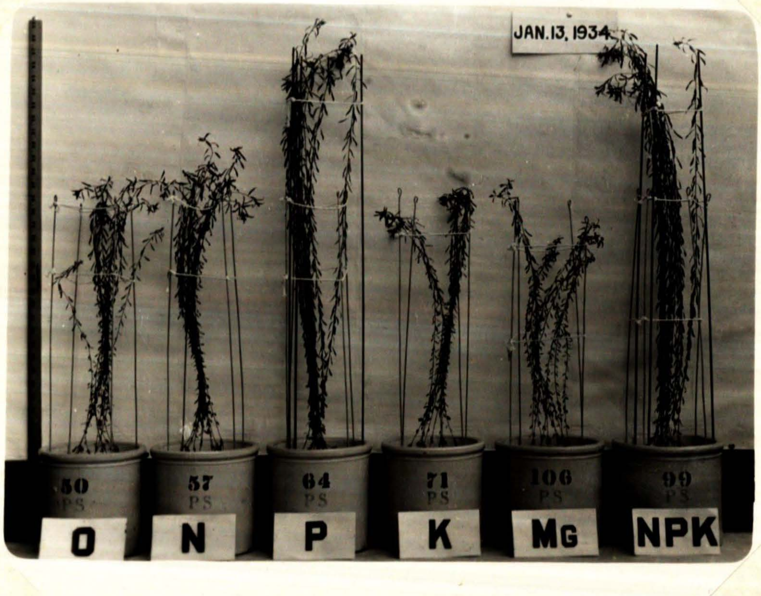


Fig. III.

Figures II and III show, for two different dates, the differences in height produced by each of the single treatments: nitrogen, phosphorus, potassium, and magnesium, as compared with a series receiving no treatment and a series receiving the nitrogen-phosphorus-potassium treatment.

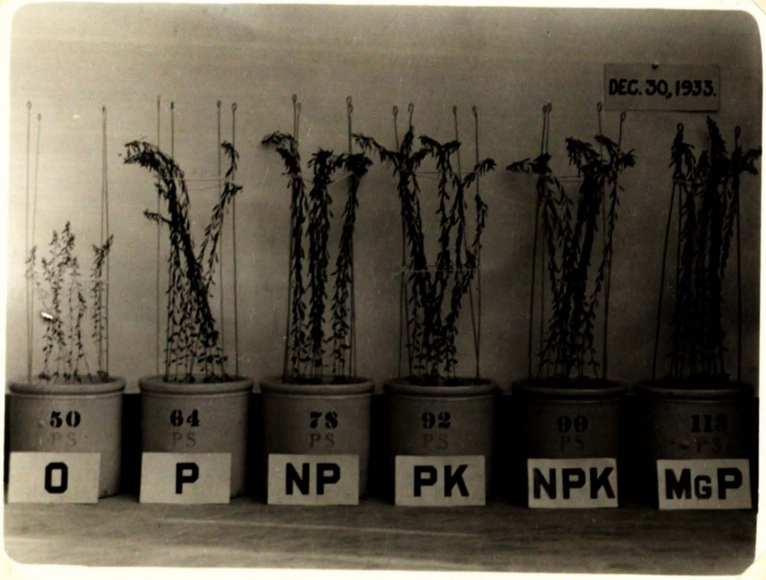


Fig. IV.

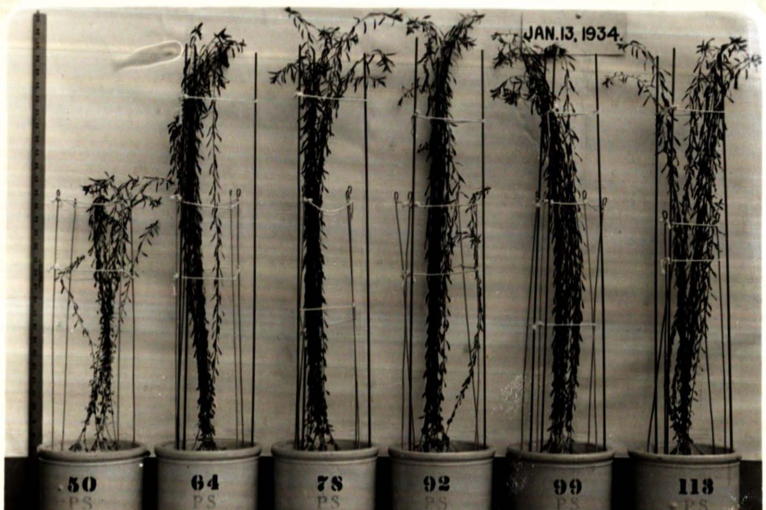


Fig. V.

Figures IV and V show, for two different stages of growth, the differences between a member of each series receiving phosphorus and a member of the no treatment series. The increase in height over no treatment is due in each case to the element phosphorus.

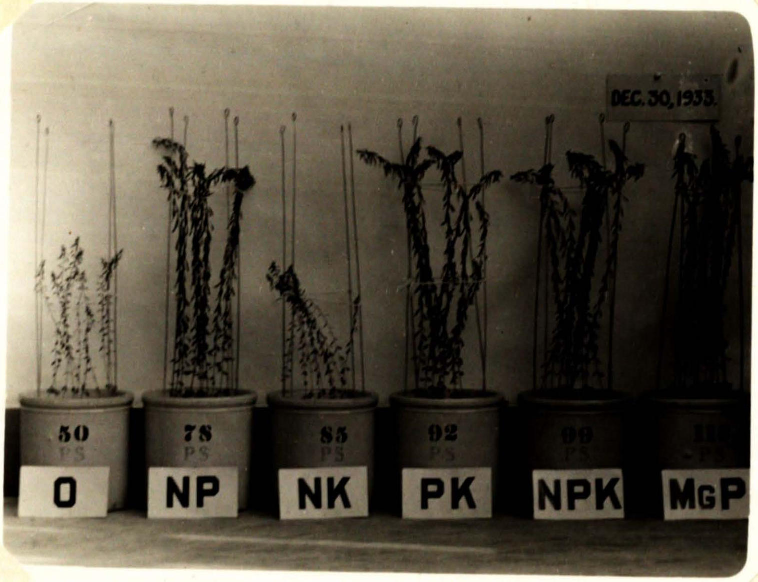


Fig. VI.

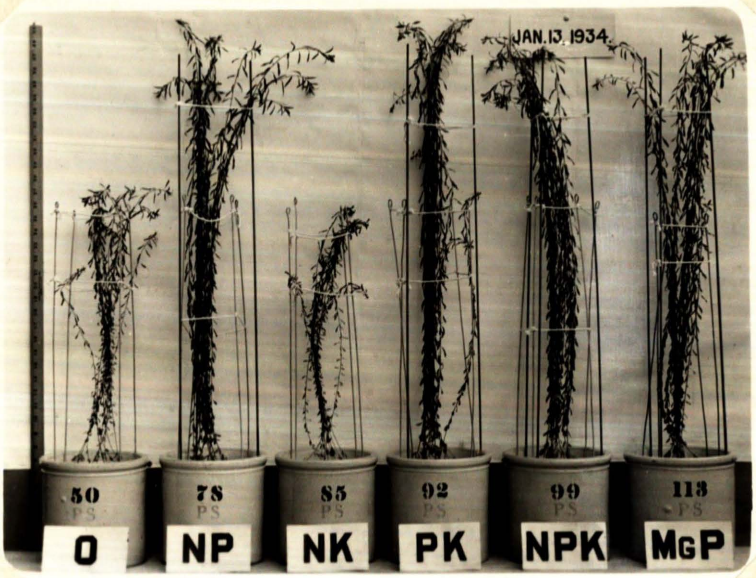


Fig. VII.

All the combinations of nitrogen with the other elements and of potassium with the other elements are shown in figures VI and VII for two different stages of development. It may be noted that the nitrogen-potassium series has decreased the height over that of no treatment. It is evident that the increases in height of the other combinations are due to the element phosphorus.

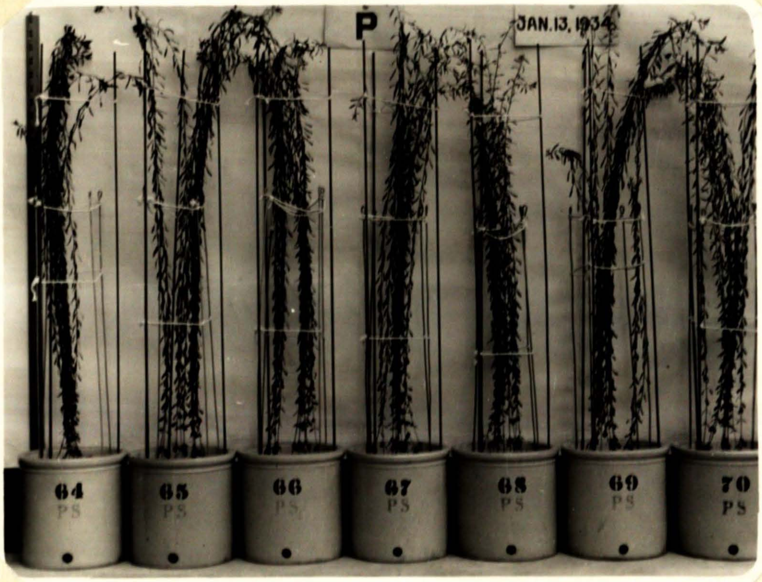


Fig. VIII.

The photograph, Figure VIII, shows all the pots of the series receiving phosphorus alone. This photograph was made on January 13, one week after the series had begun to bloom. Compare with the series of pots receiving no treatment, (Fig. I, Page 19).

Photographs, Figures II, IV, and VI, were made on December 30, at which time the plants ranged from 28 cm. in height in the potassium series to 51 cm. in the phosphorus series.

The second series of photographs, Figures I, III, V, VII, and VIII, were made on January 13, two weeks after the first series was taken. At this time the plants ranged in height from 49 cm. in the nitrogen-potassium series to 86 cm. in the phosphorus, phosphorus-potassium, and phosphorus-magnesium series. The series receiving no phosphorus had exhibited no evidences of flowering at this date. All of the series receiving phosphorus reached their maximum height on February 17. These heights varied from 105 cm. in the phosphorus and the nitrogen-phosphorus-potassium series to 109 cm. in the nitrogen-phosphorus series. The series receiving no phosphorus reached their maximum heights on about February 20. These

heights ranged from 86 cm. in the magnesium series to 88 cm. in the nitrogen-potassium and potassium series.

CORRELATION STUDIES OF THE FLAX PLANTS:

Table III shows a multiple correlation between (a) height of plants, (b) bolls per plant, (c) seeds per boll, (d) yield per pot, (e) seeds per plant, and (f) weight of 1,000 seeds.

Since all of these plant characteristics are correlated with yield, and since none of the values of "r" are below a .92, we may expect to find high correlations.

Table III. Multiple Correlation of Plant Characteristics.

	B Av. Bolls per Plant	C Av. Seeds per Boll	D Av. Yield per Pot in gm.	E Av. Seeds per Plant	F Wt. of 1,000 Seeds
A Av. Ht. Plants	.9677±.0143	.9503±.0218	.9789±.0094	.9746±.0113	.9566±.0191
B Av. Bolls per Plant		.9477±.0229	.9978±.0010	.9968±.0014	.9918±.0037
C Av. Seeds per Boll			.9684±.0140	.9685±.0140	.9286±.0310
D Av. Yield per Pot in gm.				.9987±.0006	.9939±.0027
E Av. Seeds per Plant					.9903±.0043

A study of Table III shows the close relationship that exists between the various plant characteristics involved. Especially high correlations are seen to exist between average bolls per plant and average yield per pot, and between average bolls per plant and average seeds per plant. A highly significant correlation exists between average yield per pot and average seeds per plant.

While the correlations in Table III may be considered as significant, they are not based upon a sufficient number of repetitions to warrant the drawing of generalizations or final conclusions.

The Effect of the Application of Fertilizers Upon the Yield of Seed

The results recorded in Table IV show that the application of phosphorus, either alone or in combination with other elements, produced marked increases in yield over that obtained from soil receiving no treatment and over those obtained from soils receiving treatment not involving the element phosphorus.

Table IV. Effect of the Various Fertilizers upon the Yield of Flax.

Series Number	Treatment	Total Yield in Grams	Average Bolls per Plant	Average Seeds per Boll	Weight of 1,000 seeds in Grams
1	O	4.0098	2.01	5.57	4.6621
2	N	4.4078	2.10	5.64	4.8278
3	P	12.8258	4.31	6.87	5.6228
4	K	3.5104	1.77	5.57	4.6309
5	NP	12.1222	4.29	6.70	5.4826
6	NK	2.9218	1.55	5.24	4.6821
7	PK	11.2638	4.18	6.37	5.4944
8	NPK	10.8108	3.90	6.77	5.3254
9	Mg	3.0094	1.55	5.49	4.6082
10	MgP	10.8836	3.78	6.98	5.3508

The increases in yield were due not only to the greater number of seeds produced but also to the greater weight of the individual seeds.

On the other hand, decreases in yield over that obtained from

the untreated soil were the results of applying magnesium alone, potassium alone, and nitrogen-potassium in combination.

These results are in substantial agreement with the results recorded in Bulletin 280 (16) in which field tests extending over a period of twenty years show phosphorus alone gave the largest increase in yield.

Table V. Effect of Certain Fertilizer Treatments on the Percentage Yield of Flax: No Treatment equals 100 per cent.

Series Number	Treat-ment	Per Cent Yield		
		Yield of Seed	Bolls per Plant	Seeds per Boll
1	O	100	100	100
2	N	109.9	104.5	101.3
3	P	319.9	214.4	123.3
4	K	87.5	88.1	100
5	NP	302.3	213.4	120.3
6	NK	72.9	77.1	94.1
7	PK	280.9	208.0	114.4
8	NPK	269.6	194.0	121.6
9	Mg	75.1	77.1	98.6
10	MgP	271.4	188.1	125.5

NOTE: The average number of seeds per boll is the average for all the bolls of each series.

From the results recorded in Table V it may be observed that the application of phosphorus alone gave the greatest percentage increase in yield, namely: 219.9%. It is also observed in whatever combination phosphorus was applied, it gave an increase in yield; nitrogen-phosphorus gave an increase of 202.3%, phosphorus-potassium gave an increase of 180.9%, magnesium-phosphorus an increase of 171.4%, and nitrogen-phosphorus-potassium

gave an increase of 169.6%. Nitrogen, when applied alone, increased the yield over no treatment by 9.9%, but when applied with other elements or combinations of elements, nitrogen reduced the yield. Potassium reduced the yield wherever applied. In the combination nitrogen-potassium, the yield was reduced 27.1% over no treatment. Magnesium alone reduced the yield nearly one-fourth over no treatment.

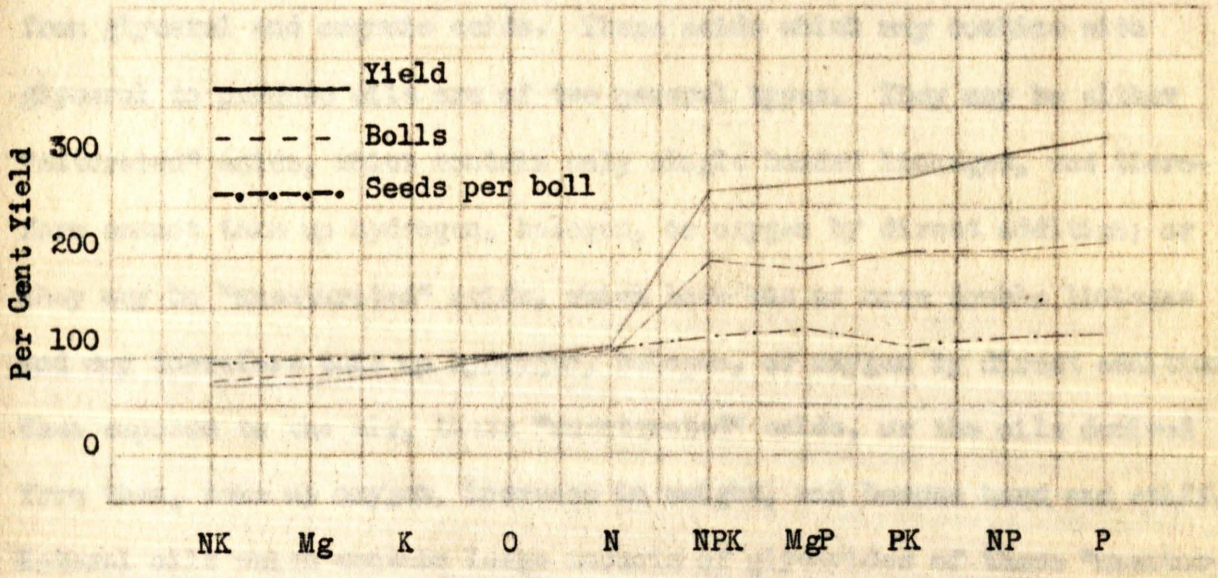


Fig. IX. The relation of fertilizer treatment to the yield of seed, number of bolls per plant, and number of seeds per boll. The data are given in percentage in order of their increasing or decreasing value from 100%, which is taken as the yield for no treatment.

The above figure shows graphically the relation of the several fertilizer treatments to the total yield, number of bolls per plant, and number of seeds per boll.

The Relation of the Application of Fertilizers to the Quantity and Drying Properties of the Oil

The value of flaxseed is determined by the per cent and quality of the oil contained. The quality of the oil is determined by its drying properties.

Oils are divided into two groups: drying oils, and non-drying oils. All vegetable oils contain esters or glycerides which are formed from glycerol and organic acids. These acids which may combine with glycerol to produce oils are of two general types. They may be either "saturated" acids, which contain only single bonded linkages, and therefore cannot take up hydrogen, halogen, or oxygen by direct addition; or they may be "unsaturated" acids, which have one or more double linkages and may therefore take up hydrogen, halogen, or oxygen by direct addition. When exposed to the air, these "unsaturated" acids, or the oils derived from them, take up oxygen, increase in weight, and become hard and stiff. Natural oils which contain large amounts of glycerides of these "unsaturated" acids are known as drying oils and are largely used in the manufacture of paints, varnishes, and linoleums. (17)

The principal unsaturated acids occurring in linseed oil are linoleic acid, $C_{17}H_{31}COOH$, and linolenic acid, $C_{17}H_{29}COOH$.

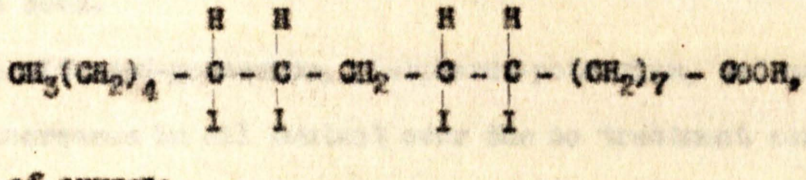
The quality of the oil is determined by the amount of these acids present in the oil since they determine the amount of oxygen which the oil is capable of absorbing.

The iodine absorption number is the per cent of iodine absorbed by the oil when subjected to the action of an iodine solution. Since an oil will abosrb oxygen and halogen alike, the iodine (halogen) absorption number becomes a measure of the "drying" properties of the oil.

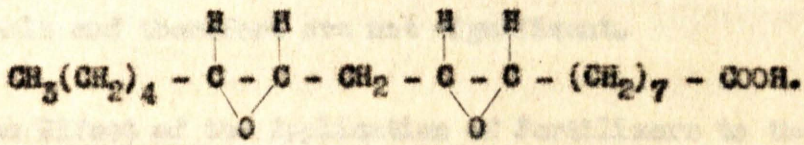
Linoleic acid, $C_{17}H_{31}COOH$, possesses two pairs of doubly linked carbon atoms as shown by the formula:

$$CH_3(CH_2)_4CH = CH - CH_2CH = CH(CH_2)_7COOH.$$

As shown by its structural formula this acid is capable of absorbing four atoms of halogen (iodine):



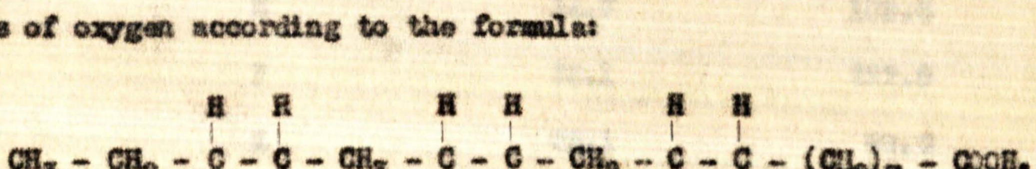
or two atoms of oxygen:



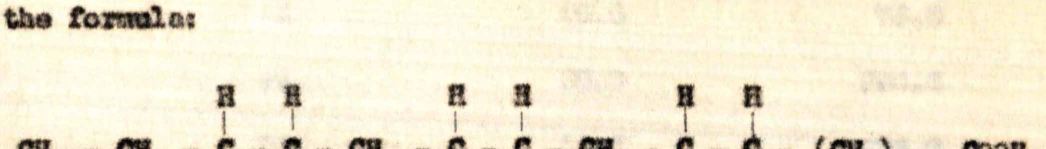
Linolenic acid, $C_{17}H_{29}COOH$, possesses three pairs of doubly linked carbon atoms:

$$CH_3 - CH_2 - CH = CH - CH_2 - CH = CH - CH_2 - CH = CH - (CH_2)_7 - COOH.$$

This acid will absorb six atoms of halogen (iodine) or three atoms of oxygen according to the formula:



and the formula:



OIL CONTENT:

The average oil content of Northwestern-grown flaxseed is approximately 40 per cent. The oil content of the seed produced in the greenhouse ranged from 34.7 per cent in the nitrogen series to 36.6 per cent in the nitrogen-potassium series. This is lower than the average for Northwestern-grown seed.

The nitrogen-potassium, phosphorus-potassium, and magnesium show marked increases in oil content over the no treatment series. The differences in oil content between all other series and the no treatment series are small and therefore are not significant.

Table VI. The Effect of the Application of Fertilizers to the Percentage Yield and to the Total Yield of Oil: The Total Yield for no Treatment Equals 100 Per Cent.

Series Number	Treatment	Oil Content of Seed Per Cent	Total Yield of Oil in Per Cent
1	O	34.8	100
2	N	34.7	109.8
3	P	35.1	322.8
4	K	35.1	88.3
5	NP	34.8	302.3
6	NK	36.6	76.6
7	PK	36.0	290.6
8	NPK	35.5	275.0
9	Mg	36.4	76.5
10	MgP	35.0	273.0

NOTE: Flax grown in North Dakota, South Dakota, Minnesota and Montana is known as Northwestern-grown seed.

While the per cent yield was not materially increased, a study of Table VI will show that the total yield of oil was much greater for each of the series receiving phosphorus than for any other series. When expressed on a per cent basis, with 100 per cent as the yield for no treatment, the yield for the series receiving phosphorus alone amounted to 322.6 per cent. On this same basis the yield for nitrogen-phosphorus amounted to 302.3 per cent; the yield for phosphorus-potassium was 290.6 per cent; the yield for nitrogen-phosphorus-potassium 275.0 per cent; and the yield for magnesium-phosphorus 273.0 per cent. The total yield for nitrogen was only 109.6 per cent. Potassium alone, magnesium alone, and the nitrogen-potassium combination all decreased the yield below that of the no treatment series.

The large increases and the decreases of oil are due, not to the percentage oil content of the seed, but to the increases or decreases in yield of seed. Since the producer is interested in the total yield of oil per acre, and the manufacturer is interested in the yield of oil per bushel or per ton, the data obtained should be of greatest interest to the producer.

IODINE NUMBERS:

No information is available upon which to base an explanation for the low iodine values obtained. During much of the growing period artificial light had to be used to supplement the small amount of sunshine received during the day. It is possible that the abnormal growing conditions are responsible for the low iodine values obtained.

The no treatment series gave the highest iodine number, while the phosphorus-potassium series gave the lowest iodine number.

Table VII. The Effect of the Various Soil Treatments on the Oil Content and Iodine Numbers of Flaxseed.

Series Number	Treatment	Oil Per Cent	Iodine Number
1	O	34.8	159.6
2	N	34.7	153.2
3	P	35.1	159.6
4	K	35.1	159.0
5	NP	34.8	152.7
6	NK	36.6	158.2
7	PK	36.0	151.1
8	NPK	35.5	151.2
9	Mg	36.4	156.0
10	MgP	35.0	154.3

Bushey, Puhr, and Hume (3) present data to show that the iodine numbers vary inversely with the oil content, the lower oil percentages having the higher iodine numbers and the higher percentages, the lower iodine numbers. A study of Figure X shows that the results of this investigation are not in accord with those obtained by Bushey, Puhr, and Hume.

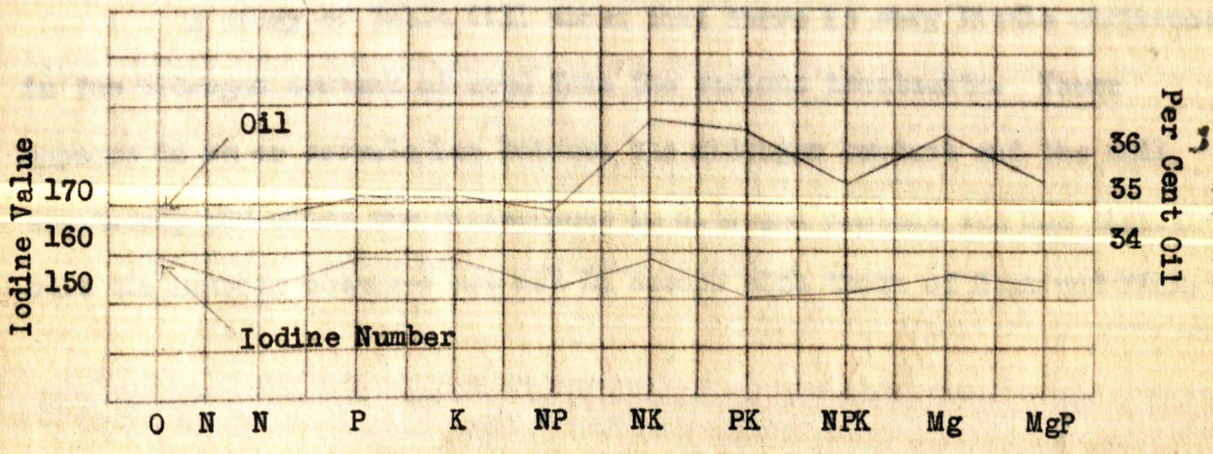


Fig. X. The relation of the various treatments to the oil content and iodine numbers of flaxseed. Data taken from Table VII.

The Effect of the Application of Fertilizers Upon the Nitrogen Content of the Seed

Haas and Hill (18) suggest the possible formation of fats from protein. Definite proof, however, of the origin of fats from proteins remains to be established.

Table VIII. A Comparison of the Percentages of Nitrogen and Oil in Flaxseed Under the Different Treatments.

Series Number	Treatment	Per Cent Oil	Per Cent Nitrogen
1	O	34.8	4.64
2	N	34.7	4.59
3	P	35.1	4.59
4	K	35.1	4.65
5	NP	34.8	4.58
6	NK	36.6	4.58
7	PK	36.0	4.64
8	NPK	35.5	4.59
9	Mg	36.4	4.66
10	MgP	35.0	4.59

A study of Table VIII shows that there is very little difference in the nitrogen content of seed from the various treatments. There appears to be no correlation between the nitrogen content and the soil treatment, and since the differences in nitrogen content are not significant the results obtained are not in accord with those of Haas and Hill.

The Influence of the Various Elements Upon the Presence of Starch in Flaxseed

According to Molton, Pelham, and Coe (19), starch is not a constituent of flaxseed. This assumption is also upheld by Haas and Hill (18) who show, in the case of almond seeds, that as they ripen to maturity the per cent of fat increases and the per cent of carbohydrates decreases.

Dilman (20) has begun a series of observations by means of microchemical tests of the changes that occur in the young flax seeds during the period of oil formation. He used the yellow stain, Sudan III, a specific for oil, in staining sections of seeds daily for several days after flowering.

He found the tissues of the cotyledons, three or four days after flowering, to contain many clear white grains or crystals which stained black with iodine, indicating that they were starch grains. The integuments of the seed and the seed coat also contained starch at this stage, no positive test for oil being obtained.

In seeds six days after flowering, he found green chlorophyll present in the cotyledons. These cotyledons stained distinctly with Sudan III but stained only slightly with iodine; thus indicating that the starch which was present in seeds three or four days after flowering had been converted into oil. He obtained no tests for oil before chlorophyll appeared, but he always obtained the test for oil after it had appeared.

It is evident from these observations that starch may be one of the chief sources of oils in oil-bearing seeds.

In this experiment a number of qualitative tests for starch were made as previously outlined. In the first of these tests .5 gram samples of seed from each series was boiled in 25 c.c. of water. After the solution

had cooled it was treated with a few drops of iodine solution (21). A drop of this solution was placed on a slide and examined under the low power of a microscope. Several drops of each solution were examined. Results in all cases were negative.

A few seeds of each series were ground in a mortar and treated with the same reagent as called for above. Examination under the microscope again produced only negative results.

A third test involved examination of longitudinal sections of seeds which had been split through the middle. A number of seeds from each series were thus examined, the iodine solution being applied to each seed individually. Examination under low power revealed the presence of a few scattered bodies in the seeds of flax that stained blue with the iodine solution. In some seeds so treated no stained bodies could be found, but the search was extensive to the extent of finding a few such bodies in seed from each series. Starch normally occurs in plant tissues in the form of microscopic granules composed of concentric layers. The bodies found in the flaxseed, however, were irregular in shape and possessed no definite concentric appearance. A review of a paper by Eckerson (22) suggests that the presence of the blue-stained bodies may be traced to amyloid, a storage hemi-cellulose, which, like starch, stains blue with iodine.

It has been shown by a number of investigators that as the oil content of the seed increases, the carbohydrate content decreases. Under normal growing conditions the mature seed contains very little carbohydrate material, and these are usually in the form of sucrose.

No conclusions are drawn from the results of the tests for starch.

SUMMARY

1. The application of phosphorus increased the yield of flaxseed as much as 3.2 times over that of the series receiving no treatment. In combination with nitrogen the yield was increased 3.1 times, with potassium it was increased 2.8 times, and with magnesium 2.7 times. The complete treatment increased the yield 2.7 times. Nitrogen alone increased the yield only slightly. All other treatments decreased the yield. The yield for nitrogen-potassium was only three-fourths that of the no treatment series.

2. The total yield of oil was increased proportionately to the yield of seed; 3.2 as much oil was obtained from the phosphorus series as from the no treatment series. The magnesium-phosphorus, nitrogen-phosphorus-potassium, phosphorus-potassium, and nitrogen-phosphorus yielded from 2.7 to 3 times as much oil as the no treatment series. The nitrogen gave only a slightly higher total yield of oil. The potassium, nitrogen-potassium, and magnesium series yielded less oil than the no treatment series.

3. Applications of phosphorus increased the weight of 1,000 seeds. The weight of 1,000 seeds from the series receiving phosphorus alone was increased 20.6 per cent over the weight of the seed from the no treatment series. The lowest increase in weight per 1,000 seeds for any phosphorus combination was 14.2 per cent. Potassium alone and magnesium alone decreased the weight of 1,000 seeds .7 and 1.2 per cent respectively.

4. Both the vegetative and seed producing stages of the flax plant were advanced six to eight days in all series where phosphorus was used. The nitrogen-potassium and nitrogen series were last to ripen.

5. The composition of the seed with respect to oil content, nitrogen content, and starch content was not significantly changed by the application of the phosphorus alone or in combination with other elements.

6. There is no apparent correlation between oil content and iodine value. The iodine value was not significantly changed by soil treatment.

LITERATURE CITED

1. Garner, W. W., Allard, H. A., and Foubert, C. L.
   1914. Oil Content of Seeds as Affected by the Nutrition of the Plant. Bureau of Plant Industry, Washington, D. C. Jour. Agr. Research 3:227-249.

2. O'Kelly, J. F., Hull, W. W., and Geiger, M.
   1933. Effects of Varying Amounts of Potash on Oil and Protein and on the Weight and Percentage of Cottonseed. Miss. Agr. Expt. Sta. Tech. Bul. No. 20, 8 p.

3. Bushey, A. L., Puhr, L., and Hume, A. N.
   1927. A Study of Certain Physical and Chemical Characteristics of Flaxseed and of Linseed Oil. S. Dak. Agr. Expt. Sta. Bul. 228, 11 p.

4. Stark, R. W.
   1924. Environmental Factors Affecting the Protein and the Oil Content of Soybeans and the Iodine Content of Soybean Oil. N. J. Agr. Expt. Sta. Jour. Am. Soc. Agron. 16:636-645.

5. Feller, C. R.
   1918. The Effect of Inoculation Fertilizer Treatment, and Certain Minerals on the Yield, Composition, and Nodule Formation of Soybeans. N. J. Agr. Expt. Sta. Soil Sci. 6:81-129.

6. Johnson, I. J.
   1932. The Relation of Agronomic Practice to the Quantity and Quality of the Oil in Flaxseed. Minn. Agr. Expt. Sta. Jour. Agr. Research 45:239-255.

7. Schuster, G. L., and Graham, J. M.
   1927. Effect of Various Fertilizers and Lime on the Composition of Soybeans. Del. Agr. Expt. Sta. Jour. Am. Soc. Agron. 19:574-576.

8. Robinson, B. B., and Cook, R. L.
   1931. The Effect of Soil Types and Fertilizers on Yield and Quality of Fiber Flax. Mich. Agr. Expt. Sta. Jour. Am. Soc. Agron. 23:497-510.

9. Ali Mohammad.
   1930. Effect of Fertilizers on the Growth and Oil Content of a Variety of Linseed (Linum usitatissimum L). Agr. Jour. India 25:471-86. (C. A. 25:4346[6]).

10. Eyre, J. W., and Fischer, E. A.
    1914. Oil Content of Flax. Southeastern Agr. College, Wye, Kent, England. Jour. Agr. Sci. 7:121.

11. Gerken, E. M.
1929. Experiment with Fertilizing Flax. Undobrenie i Uroshai (Fertilizers and Yields). No. 4:231-235. (C. A. 24:2225[7]).

12. Balashev, L. L.
1929. Flax and Mineral Fertilizers. Undobrenie i Uroshai (Fertilizers and Yields). P. 137-139. (C. A. 24:1925[5]).

13. Mitrofanov, A. S.
1930. Flax and Mineral Fertilizers. Undobrenie i Uroshai (Fertilizers and Crops). 2:86-93 (C. A. 25:1320).

14. Balashev, L. L.
1930. Summary of Results Obtained from Field Experiment with Fertilizers. XIII Fertilization of Flax. Trans. Sci. Inst. Fertilizers (Moscow) No. 69:5-46. (C. A. 25:1320[7]).

15. Association of Official Agricultural Chemists.
1924. Official and Tentative Methods of Analysis. Revised to July 1, 1924. Ed. 2:287. Washington, D. C.

16. Hutton, J. G.
1933. The Results of Twenty Years Complete Soil Fertility Tests at Brookings, S. Dak., S. Dak. Agr. Expt. Sta. Bul. 280, 19 p.

17. Thatcher, R. W.
Chemistry of Plant Life. 1st Ed. P. 132.

18. Haas and Hill.
1921. The Chemistry of Plant Products. 3rd Ed., 1:37, 43.

19. Molton, Pelham, and Coe.
Determination of Starch in the Presence of Interfering Polysacharids. Jour. Agr. Research 23:995.

20. Dilman, A. C.
1928. Daily Growth and Oil Content of Flaxseeds. Jour. Agr. Research 37:357:377.

21. Morrow.
1927. Biochemical Laboratory Methods. P. 227.

22. Eckerson, S. H.
Microchemistry. Tests for Membrane Substances. P. 10.