THE EFFECT OF FERTILIZERS ON THE YIELD AND QUALITY OF FIBER FLAX PRODUCED UNDER IRRIGATION

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Yesh Pal Puri

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APPROVED:

Redacted for privacy

Professor of Farm Crops

In Charge of Major

Redacted for privacy

Head of Department of Farm Crops

Redacted for privacy

Chairman of School Graduate Committee

Redacted for privacy

Dean of Graduate School

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INTRODUCTION

Flax, which supplies the raw material for the linen industry, is little known to most of the growers of the world. The production of it is considered specialized and is definitely limited.

Wherever this crop is grown, the growers face a great problem of maintaining the proper balance of nutrients in the soils. Deficiency and excess of any nutrient show adverse results on the yield and quality. Deficiency of nutrients may lower the yield of straw and fiber, but excess of nutrients such as nitrogen, would increase the yield of fiber and straw. However, excess of nitrogen would deteriorate the quality which reduces the market value of the fiber. The quality of fiber is more important than quantity and should not be sacrificed in favor of yield.

Quality is becoming more and more important in the fiber. The following factors have been considered under quality: strength, yield of hackled fiber, loss of hackled tow fiber, color, cleanliness and wax content of fiber. Seed quality includes oil content of seed and iodine number of oil.

Strength is an important consideration in the behavior of many materials used in manufacturing. This is commonly realized in such massive structural materials as steel, concrete and wood. It is equally important for flax textiles because fiber strength is related to the efficiency of such operations as hackling, spinning and weaving. Fiber strengths are frequently reported in terms of load per unit fineness, where fineness has the dimensions of mass per unit length. The tensile strength is one of the generally accepted measures of flax fiber quality which has been neglected in the industry and also by research workers. The grower who produces the fiber of high strength does not get a premium because this crop is not graded on this basis.

There is not much information available pertaining to strength of fiber. Whatever information is available comes from the research conducted in Europe, which is of little value under Oregon conditions. Some work has been done in Oregon and in some of the other states on fertilizer requirement of this crop, but all the experiments were conducted under non-irrigated conditions. Such fertilizer recommendations are of little or no value under irrigated conditions in order to maintain high yield of straw and fiber.

The objectives of this research were to study the effects of the different levels of fertilizer nutrients including minor elements under irrigated conditions on the yield and quality of fiber flax.

REVIEW OF LITERATURE

The fertilizer requirements of fiber flax appear to vary with the fertility level of the soil and its previous cropping system.

Lewis (23, p. 169-173) and Ince (18, p. 5-9) reported that excessive amounts of nutrients were not removed from the soil by the fiber flax. According to Deterre (9, p. 271-273), the fiber flax did not need high fertility requirement. It was also found that the application of excessive rates of fertilizer was deleterous to fiber flax quality. That was especially true with nitrogen.

Gross (14, p. 37-51) obtained no beneficial effects when nitrogenous salts were supplied in addition to potash salt, but explained that the experiments were conducted in an extremely dry year. Tobler (48, 47, p. 26-51, 208-214) stressed more on the importance of making anatomical studies of the bast cells when studying the effect of fertilizer. The shape of bast cells, which influence the quality of fiber, had generally been considered due to hereditary characters, but was more likely to be the result of soil nutrients.

Nitrogen

Bredemann and Fabian (2, p. 406-407) and Fabian (11, p. 18) found that a medium amount of nitrogen was needed for the best quality and yield of fiber. A smaller or a larger application of nitrogen would produce uneconomic returns. A deficiency of nitrogen caused short fine stems of fiber flax which contained little fiber, while excessive nitrogen in the soil tended to produce thick stems with lower fiber percentages and fiber of low quality.

In Western Oregon the soil is cold during the early spring and the level of available nitrogen is low in the soil because of low nitrification. Halverson (16, p. 868-875) studied the seasonal variation of nitrates in the Willamette Valley of Oregon and found that during winter and spring months the nitrification rate was low. Therefore, only traces of nitrates were present in the soil. The humid season breaks suddenly into summer and after this, moisture becomes the limiting factor, and the application of nitrogen in the spring was recommended. Powers (35, p. 755-763) also pointed out the necessity of nitrogen for early vegetative growth.

According to Week (51, p. 13-35), nitrogen alone caused inferior fiber formation and fiber of poor quality. But on the other hand, these bad effects might partly be improved with the application of P and K salts in combination with nitrogen.

Kleberger (21, p. 119-123) obtained increased yields of flax when nitrogen was applied in combination with other elements. Scheel (41, p. 489-523) got increased yield of fiber when nitrogen was applied, but line fiber percentage decreased and tow percentages increased. Scheel (41, p. 489-523) and Davin (8, p. 827) also found that excessive use of nitrogen causes a reduction in straw value, delay in maturity, and danger of lodging.

Robinson and Cook (39, p. 497-509) reported that nitrogen in the fertilizer mixture gave very little benefit. Nitrogen combined with potash and phosphorus fertilizers, gave no increased fiber yields and only slightly increased seed yields. The use of nitrogen seemed to increase the hackling percentages slightly, but lowered the strength. Neither of these measurements were significant.

Unpublished results of three years fertilizer trials in Western Oregon by Robinson and Nelson (40, p. 35) indicated that by the increase of nitrogen, the straw yield was increased, but line fiber at higher rates decreased.

Nelson (30, p. 41) (unpublished thesis) found that fiber flax was very sensitive to either a deficiency or an excess of nitrogen. A deficiency tended to produce short fine straw. An excess of nitrogen increased the straw yield, but lowered the quality.

Opitz (34, p. 61-116) stated that the good effect of nitrogen fertilizer on the yield and quality of fiber flax depended mainly upon the abundant and even water supply. Deficiency of water or irregular water supply diminished the effect of nitrogen. The maximum yields were obtained with small nitrogen applications. It was also found that seed yield and crude fat content were influenced slightly by the nitrogen application but much more by weather.

Milthorpe (29, p. 66) was of the opinion that nitrogen and phosphorus were two most important elements for flax. Satisfactory yields of straw and fiber were obtained only when both nitrogen and phosphorus were at high levels. Increasing the level of K did not greatly influence the development of the plant or its fiber. Na could apparently replace K. The level of Mg had a pronounced influence on dry weight, height, water content and fiber content. Superphosphate increased the total plant yield. Superphosphate decreased while $(NH_4)_2So_4$ increased the percentage and total yield of fiber. Superphosphate increased the fiber strength and coarseness of fiber.

Veltman (49, p. 12-23) reported that flax was sensitive to alkalies and required much water. To obtain the best fiber quality, a correct mixing ratio of N, K and Ca was essential.

Jordan, et. al. (20, p. 551-563) found that American hemp responded moderately to fertilizers, and nitrogen reduced the breaking strength of fiber.

Black and Vessel (1, p. 179-184) found that by employing nitrogen, phosphorus and potassium singly and in all combinations for hemp, nitrogen gave the most benefit, followed in order by phosphorus and potassium when alone.

Gupta (15, p. 16) reported that on jute there was particularly good response to increasing rates of nitrogen, and NH_4 appeared to be a better source of N than No_3. Omission of P from the nutrient solution produced the most adverse effect.

Potassium

Potash plays a very important role in the development of flax. There appears to be a definite relation to the fiber formation and improvement of the quality of fiber. Davin (8, p. 827) showed that potash increased the height of the plant and mentioned the work of others at the same institute, to prove that a large number of relatively small fibers with a very little decrease in the percentage of fiber in cross sections were correlated with increase in height. It was further stated that there was additional fiber in the extra height produced by the potash.

Bredemann and Fabian (2, p. 406-407) found that potash counteracts the deleterious influence produced by an excess rate of nitrogen fertilizer. Potash as a fertilizer did not produce any detrimental effect on the fiber and also did not increase the yield when applied on rich soil. Potash was especially beneficial when the soil was deficient in this nutrient.

Powers (35, p. 755-763) reported that potassium tended to increase the length and the value of fiber flax and that the potassium ion might play a catalytic role in synthesis of carbohydrates or function to keep simpler carbohydrates in solution until they could be deposited in the transforming bast fibers in the flax plant. Early planting and providing uniform moisture and nutrient supply with the aid of supplemental irrigation in Western Oregon tends to delay the maturity and increase the length and value of fiber flax.

Scheel (41, p. 489-523) found that by the application of potassium, the straw, fiber and seed yield was increased. This also increased the length of straw.

Krafft (22, p. 145) was of the opinion that chloride ion was beneficial to flax. Kleberger (21, p. 119-123, 158) obtained most satisfactory results with Kainite, but Tobler (47, p. 208-214) thought that potassium sulphate was the best. Steigerwald (45, p. 282-284) found that chemically impure salts of potassium and magnesium were better for seed yield than pure potassium chloride salts. For fiber yield, these salts behave quite opposite and for this, potassium chloride salts were the best. Robinson and Cook (39, p. 497-509) reported that potash in combination with phosphorus, gave increased yields of fiber and seed.

An increase in the iodine value of the oil was found by Schmalfuss (42, p. 65-66) when soil K had been more or less exhausted. Lewis (23, p. 169-173) thought that potassium could only be beneficial when the soil was deficient in potassium and phosphorus. The addition of either of these elements appeared to give no significant increase in yield.

A study of Willamette Valley soils by Stephenson and Schuster (46, p. 31) showed that little response was obtained from potassium application and their recommendations were for a program that would supply nitrogen, phosphorus and probably sulphur. Nelson (30, p. 41) reported that potassium did not improve yields and quality in any of the experiments. Therefore, K was not recommended for this crop in Western Oregon. Deterre (9, p. 271-273) found that potassium helped in the production of fine, regular, long fiber. Jakobey (19, p. 13-22) reported that the plant used large amounts of mineral nutrients in earliest stage of growth. Uptake of K, P_2O_5 and N reaches its maximum at blossoming time. The K requirement of fiber flax was nearly 50% higher than that of the oil flax.

Choudhery (6, p. 55-63) conducted a series of experiments on jute and found that there was no increase in growth or yield by the application of Kcl and superphosphate singly and in combination. Optiz, et. al. (32, p. 257-280) found that K manuring had good effects on most commercially desirable qualities of fiber flax, but the chloride ion was liable to cause damage.

Phosphate

The phosphate is not considered as effective as the K and N for this crop. It has a more indirect effect, or in other words, it acts in conjunction with other elements. Davin (8, p. 827) found that with the application of phosphate there was an increase in the percentage of fiber in the cross section, and in the fiber content of the flax plant, without causing any significant differences in the number and size of the fibers. Bredemann and Fabian (2, p. 406-407) stated that phosphate was slightly beneficial, but sometimes it lowered the fiber quality, producing more tow in proportion to line fiber and fiber strength was reduced. According to Deterre (9, p. 271-273), phosphorus increased resistance to lodging when applied as an optimum rate, but excess might cause coarseness in fiber. The findings of Scheel (41, p. 489-523) and Powers (35, p. 755-763) were contradictory to the work of Deterre, Bredemann and Fabian. It was found that phosphate improved the fiber. Scheel (41, p. 489-523) also reported that by the application of phosphorus, the seed yield was increased.

Robinson and Cook (39, p. 497-509) found that phosphorus, when applied alone, did not seem to increase the yield of fiber and seed over the untreated plots. In combination with potash, increased yields were obtained and also often increased the length of straw. Nelson (30, p. 12-41) reported that fiber flax did not respond to phosphate directly and recommended that phosphate should be applied to the legume in the rotation so that flax would be benefited indirectly. Opitz (33, p. 185-195), on the other hand, reported that for each addition of P_2O_5, there was a corresponding increase in yield of straw and seed. Small amounts of P_2O_5 gave more marked effect on the straw yield and large amounts decreased the straw yield.

Lewis (23, p. 169-173) was of the opinion that phosphorus should not be applied unless the soil was deficient in this element. The addition of this element did not appear to give any significant increase in yield.

Calcium

According to Robinson and Cook (39, p. 497-509) calcium (limestone) had only a slight beneficial effect on yields and it lowered the percentage of fiber in the straw. In most cases it also lowered the fiber strength and the hackling percentage, indicating a poor quality of fiber. Bredemann and Fabian (2, p. 406-407) found that recent application of lime gave detrimental effect on flax growth. Deterre (9, p. 271-273) reported that lime in excess gave short fiber and recommended that it should not be applied immediately before sowing the flax.

Magnesium

Robinson and Cook (39, p. 497-509) stated that magnesium, when applied with calcium, tended to remove the detrimental effect produced by calcium on fiber strength.

Minor Elements

Zinc

According to Smith (44, p. 99-100), zinc deficiency in flax causes die-back symptoms which occurred on heavy black soils. The use of zinc sulphate with normal superphosphate dressing to insure normal crop, was recommended. Millikan (28, p. 69-73) found that heavy rates of superphosphate, when applied in combination with 30 pounds per acre of zinc sulphate, caused a significant increase in the percentage of plants showing zinc deficiency symptoms, as compared to those receiving 30 pounds of zinc sulphate alone. However, this result was not considered conclusive because similar dressings of superphosphate, when applied, gave no significant effect on the incidence of zinc deficiency symptoms when compared with untreated plants. Walkley (50, p. 255-260) associated these conflicting results with the presence of zinc impurity in the super phosphate used. Riceman (38, p. 336-384) conducted experiments on zinc-deficient soil and found that oat plants which were treated with superphosphate, showed a discoloration characteristic of phosphorus deficiency. This was reduced by the addition of zinc, especially at lower levels of phosphate.

Piper (37, p. 199-206) and Millikan (27, p. 33-35) showed in the water culture experiments with cereals that this discoloration was not a characteristic of wheat or oats grown under conditions of zinc deficiency. In soils containing excessive zinc, Gall and Barnette (13, p. 23-32) reported that, although phosphate apparently did not change the toxic limits of replaceable zinc, it stimulated the growth of corn and cow peas on a sandy loam and a clay loam, while no effect was noted in a sand.

Millikan (26, p. 273-278) reported that heavy applications of phosphate, both with and without zinc sulphate, caused significant increase in the severity of zinc deficiency symptoms in flax. The effect of disodium phosphate was significantly greater than that of superphosphate. This difference was due to a much greater amount of zinc impurity in the superphosphate than in the disodium phosphate.

Boron

Clagett and Klosterman (7, p. 64-65) reported that a great majority of the early work on Boron in relation to flax culture, was dealt with symbiotrapism or the role of this element in the competition of the soil, in a soil containing considerable organic matter. Requirement of flax for Boron was shown in the early '30's by Shkolnik. It was found that about .5 ppm of Boron in sand culture stimulated the plant growth, whereas with no Boron, root growth was poor and resulted in early death of the plant. Over .5 ppm showed toxic effect. Other Russian workers have reported that in the absence of micro organisms, no Boron is needed, but these authors thought that these workers could be discounted, probably on the basis of use of impure chemicals or improperly washed medium of support.

Copper

Millikan (25, p. 113-116) reported that copper deficiency in flax causes chlorosis and retards the growth. Subsequent shortening of the internodes gave the plants a somewhat rosetted appearance. The leaves become puckered, slightly rolled along the edges, and very twisted. Growth finally ceased and the plants commenced to die from the top. These symptoms were similar to those described by Piper (37, p. 199-206).

Wax

According to Chelikin and Kamalava (5, p. 38-42), the flax and its waste products contained up to 2.5% of wax-like substances.

Bullis (3, p. 176-189) reported that the foreign flax fiber had lower wax content than the Oregon flax. It was found that wax content of flax fiber appeared in some seasons, to increase with maturity of the flax from which it was prepared, but this relationship was not consistant for three seasons in which this correlation was studied. This relationship may at times be complicated by other factors, such as soil or seasonal weather conditions. It was also stated that wax content of flax fiber definitely related to variety.

MATERIAL AND METHODS

An experiment was designed to determine the effect of different levels of fertilizer nutrients including minor elements under irrigated conditions on the yield and quality of the fiber flax.

Location and Type of Soil

Two experiments were established in the spring of 1955, one on Mr. Leo Michele's farm located five miles west of Jefferson, Oregon, and the other on Mr. Cox's farm located three and one-half miles west of Jefferson, Oregon. Two soil series were selected. The soil series on Mr. Leo Michele's farm was Chehalis, and on Mr. Cox's farm, Amity.

Chehalis series is a well drained Chehalis silt loam which is developed from recent alluvium on a flood plain. This is the best all-around soil in Linn County, Oregon, for general farm crops, especially flax, red clover, corn and wheat. Amity series is an imperfectly drained Amity silt loam which is developed from old silty alluvium on a terrace.

One variety of fiber flax with 14 fertilizer treatments and 6 replications was superimposed on both locations. The experimental plots on Mr. Cox's farm could not be harvested because the farmer invertedly harvested the crop. The data presented represents the crop from the experiments on Mr. Leo Michele's farm only. To have additional information on fertilizer response of flax, two varieties were planted on the East Farm of Oregon State College in the fall of 1956. This farm is located one mile east of Corvallis, Oregon. This experiment had 14 treatments and 6 replications for each variety. Unfortunately, this experiment was destroyed by a flood which covered the area with water and destroyed the plots.

Soil Test

Before the flax was planted, the soils were tested for phosphorus, potassium, calcium, organic matter, Boron and pH. The analysis of the soil samples were made by the standard methods (24, p. 1-8) currently being used in the Soil Testing Laboratory, Department of Soils, Oregon State College, Corvallis, Oregon. The results are shown in Table I.

Table I

Soil Analysis of Chehalis and Amity Soil Series

Soil Series	PH	LM Req't. T/A	P PPM	K ME/100g	Ca ME/100g	Mg ME/100g	B PPM	O.M. %	C.E.C. ME/100g
1. Chehalis									
Surface 6"	6.0	1½	54.2	1.21	13.60	10.76	0.77	3.22	28.90
Sub surface 12"	6.1	1	51.0	0.98	18.10	14.39	0.67	1.77	33.42
2. Amity									
Surface 6"	6.1	1½	62.0	0.86	11.70	6.99	0.80	2.27	22.87
Sub surface 12"	6.3	1	32.75	0.84	12.65	10.44	0.62	0.67	24.12

LM = Lime requirement
PPM = Parts per million
C.E.C. = Cation exchange capacity
O.M. = Organic matter

The soil analysis indicated the fertility level before planting the crop and it had no bearing on the treatments.

The previous crop history of Mr. Leo Michele's farm is given in Table II.

Table II

Previous Crop History

Year	Crop	Fertilizers Applied	Quantity Used
1952	Corn	16-20-0	400 pounds per acre
1953	Squash	6-20-20	300 pounds per acre
1954	Corn	6-20-20	130 pounds per acre

Establishment

A good seed bed was prepared just before planting. Holland Concurrent, a white flowering commercial variety, was used in the experiment. The experiment consisted of 14 treatments and 6 replications and was designed as randomized block. The first eight treatments were a 4 x 2 nitrogen and phosphorus factorial experiment. Plots were 30 feet long and 8 feet wide. The treatments are shown in Table III.

Table III

Fertilizer Treatments
with Rates of Application

Treatment Number	Treatments		Minor Elements (Pounds per acre)
1	N_0	P_0	
2	N_{20}	P_0	
3	N_{40}	P_0	
4	N_{80}	P_0	
5	N_0	P_{60}	
6	N_{20}	P_{60}	
7	N_{40}	P_{60}	
8	N_{80}	P_{60}	
9	N_0	P_{60}	$ZnSo_4$, $CuSo_4$ and Borax, 20 pounds per acre
10	N_{20}	P_{60}	$ZnSo_4$, $CuSo_4$ and Borax, 20 pounds per acre
11	N_{40}	P_{60}	$ZnSo_4$, $CuSo_4$ and Borax, 20 pounds per acre
12	N_{20}	P_{60}	K_2O, 60 pounds per acre
13	N_{20}	P_{60}	Borax, 20 pounds per acre
14	N_{40}	P_{60}	Borax, 20 pounds per acre

Nitrogen rates were 0, 20, 40 and 60 pounds of available nitrogen per acre applied as NH_4NO_3.

Phosphorus rates were 0 and 60 pounds of available P_2O_5 per acre applied as treble superphosphate. Twenty pounds of available sulpher was added to each plot and the source of sulpher was $CaSo_4$.

The source of K_2O was Kcl.

The source of zinc, copper and boron was zinc sulphate, copper sulphate and borax respectively.

The fertilizers were weighed and thoroughly mixed. They were broadcasted over their respective plots and disced in just prior to planting. The seed was drilled on the 10th of May, 1955. The crop was irrigated by overhead sprinklers on the 28th of May and on the 10th of June.

Harvest

The method of determination for yield, quality, physical and seed yield factors were as follows:

Pulled Flax

The plots were harvested when most of the leaves had fallen, which is considered to be optimum for best quality. An area 3 feet by 8 feet was pulled by hand from the center of each 30 foot by 8 foot plot. The pulled straw was shocked immediately after harvesting and it was exposed to sun for immediate drying and bleaching. Air-dry straw weights were recorded in grams for each plot.

Seed

Special threshing equipment called "whipper flax deseeding machine" was used to thresh the seeds from the fiber flax. The machine consisted of a pair of steel rollers, each of which was fastened to the end of a shaft. One roller was power driven, which in turn drove its twin roller by friction. By passing the tip ends of the straw between the rollers, the seed bolls were threshed without disturbing the parallelism of the straw. The seeds were cleaned in a small fanning mill customarily used for cleaning experimental seed lots. Weight of the seed per plot was recorded in grams and weight of deseeded flax was obtained by subtracting the weight of seed from the pulled flax weight.

Retting

Retting is the bacterial decomposition of the encresting substances which binds the fiber together and to the inner woody portion of the straw. Bacteria which are normally present on the straw helps in decomposition. Before retting, a string with an attached metal tag was tied around each bundle in order to maintain the identity of the plots during and after a retting process. The bundles were kept in an upright position in the tank and it was filled with cold water. The cold water was allowed to remain on the straw for four hours, after which it was drained. Fresh water, at a temperature of 92° F., without the addition of chemicals, was allowed to enter the tank. Throughout the retting process, 92° F. was maintained and this is an optimum temperature for development of retting organisms. Twenty percent of the water was replaced daily to lower the acidity, thus maintaining an optimum condition for the development of retting bacteria. As soon as the retting process was completed, the liquor was drained and the straw was rinsed with cold water in order to check further bacterial action. The tanks were drained and the straw was dried out in the open sunlight. After drying, the straw was stored until climatic conditions were favorable for the scutching process. The bundles were weighed in grams in order to obtain the weight of retted straw.

Scutching Process

Scutching is the process by which the woody material and short fiber from the long line fiber is removed. This is always done during a period of high humidity. All the samples were scutched in a commercial Van Hauewest machine under high humidity conditions. The speed of the beaters were kept constant for each sample in order to eliminate variation due to scutching speed. The scutched clean fiber is known as the line fiber and it was weighed immediately after scutching.

Percentage Yields

In this study, percentage of seed and fiber are based on the pulled straw weight and also percentage of line fiber on the deseeded straw weight. These were calculated by the following methods:

$$\text{Percentage of fiber in pulled flax} = \frac{\text{Line Fiber}}{\text{Weight of pulled flax (air dry)}} \times 100$$

$$\text{Percentage of fiber in retted flax} = \frac{\text{Line Fiber}}{\text{Weight of retted flax (air dry)}} \times 100$$

$$\text{Percentage of seed} = \frac{\text{Seed Weight}}{\text{Weight of pulled flax (air dry)}} \times 100$$

Quality

Wax Content

The wax determinations of the fiber were made by the Department of Agricultural Chemistry, Oregon State College, Corvallis, Oregon.

Method of analysis: The wax content was determined by extracting weighted samples of fiber with ether. After extraction, the ether was evaporated from the flask and the wax which remained was weighed and calculated as percent of the original fiber (4, p. 2).

Fiber Tensile Strength Testing Apparatus

Tensile strength was determined by using a power driven Scott Tensile Tester, Model D. H. Pendulum type, with a 50 kilogram maximum load. Before starting the strength tests, the fiber samples under test were kept in a controlled atmosphere room where all air conditioning, weighing and tensile testing took place. The average room conditions were maintained at a dry bulb temperature of 79° ± 3° F. and wet bulb temperature 68° ± 3° which made for a relative humidity of 56% ± 7%.

After three days exposure in a conditioned room, 10 samples were selected at random from the middle of the sample (hank of fiber). A section 10 inches long was then cut from the center of each sub sample for strength test. Each sub sample was constructed with a weight of 230 mg ± 20 mg as determined by the torsion balance and the actual weight was recorded. Each specimen was placed in Capstan "wrap around" clamps and tested in a flat bundle form. Ten determinations were made for each treatment. The breaking load was recorded in kilograms. All results are calculated and reported on the basis of load per unit fineness and are expressed in terms of Kg/g/cm.

Fiber Judging for Quality

The fiber was judged for quality by two judges, Mr. E. G. Nelson and Mr. D. W. Fishler, on the basis of cleanliness and color, and were rated 1 to 4 on the visual observations.

Color: 1. Bright, few or no greenish streaks.
4. Mostly greenish except at butt ends.

Cleanliness: 1. Absolutely no shives.
4. Numerous shives.

Hackling Test

The samples were hackled on a commercial hackling machine and were weighed on moisture free basis before and after hackling. The loss of weight in hackling on moisture free basis was noted. This is measured as the loss of hackled tow fiber. The hackled fiber yield on moisture free basis was also reported in grams per plot.

Seed Oil Content and Iodine Number

Oil content and iodine number were determined by tests conducted by the United States Department of Agriculture, Agricultural Research Service, Field Crops Research Branch, St. Paul, Minnesota.

There are two methods used for determining oil content: one is a dielectric method which requires a large sample of seed (75 grams). The other is a "small sample" technique which is considered quite reliable. Neither method is fully accepted as "official", but the investigators at Minnesota Research Station report that both are sufficiently accurate to place the samples in their relative order. In this study the small sample technique was used. These tests were run in duplicate and means of the tests were used in the statistical analysis.

Lab Analysis of the Straw for Total Fiber

Diameter Index of the Straw: Nelson and Sather (31) made a study of three different methods of measuring diameter of straw. The first measurement by the caliper was by use of a swing caliper which measured each individual straw. The second measurement consisted of a tying a string around a group of 50 straws and measuring the length in centimeters. The third was merely the weight of 25 centimeters of 50 straws. These measurements were all indexes and showed a high degree of correlation. The string measurement and the weight of 50 straws were considered so much more rapid than measuring the individual straw by the swing caliper method on the basis of their judgings. Circumference of 50 retted straws by the string method was determined and from this the diameter index was calculated.

Total Fiber Determination

The 50 straws from the diameter index determination were weighed on moisture free basis. These straws were scutched by Grant Lowry's small scutching machine in order to remove the woody portion from the fiber. These samples of fiber were boiled for 20 minutes in 1% NaOH. The samples were then washed with water in order to remove the shives from the fiber. Fiber was dried in an oven at 105° C. and weights were recorded. The percentage of total fiber was calculated.

$$\text{Percentage of total fiber} = \frac{\text{Weight of fiber (dry basis)}}{\text{Weight of 50 retted straws (dry basis)}} \times 100$$

The ratios of $\frac{\text{Weight of 50 retted straws}}{\text{Diameter index of 50 retted straws}}$ were also calculated and reported as ratios $\frac{\text{Weight}}{\text{Diameter}}$

Method of Analysis

The data were analysed by the analysis of variance as outlined by Immer (17, p. 157). The means were ranked by using the multiple range test developed by Duncan (10, p. 1-42) in 1955. The averages of each yield, quality and physical factors were computed and arranged according to their respective magnitude. These were underscored with lines as shown in Table VIII and these different lines give the sub-groups A, B, C, and D. These means are of statistical significance. The sub-group A contain treatment means which are significantly higher than the other sub-groups. The position of overlapping sub-groups ABC or ABCD, etc., were not determined.

Experimental Results

The conditions for flax production in the Willamette Valley in 1955 were fair except for insufficient rainfall during the critical growing period and the fiber flax yields were about average. The farmers who had facilities for irrigation produced a good crop. The experimental plots were irrigated in order to obtain full response of fertilizer. Weather conditions were ideal for harvesting and curing fiber flax.

Analysis of the Results

Summary of analysis of variances showing the mean squares for different yield, quality and physical factors are presented in Tables IV and V. The effect of the treatments were significant for retted flax, line fiber, percent of total fiber, hackled fiber, diameter index and seed yield.

Likewise, the treatment mean squares for pulled flax, deseeded flax, percent fiber in pulled flax, percent fiber in retted flax, percent of seed in pulled flax, oil content of seed, iodine number and fiber strength were highly significant.

There were significant differences for replications in the case of percent fiber in retted flax, cleanliness of fiber, diameter index, weight of 50 retted straws, ratios of $\frac{\text{Weight}}{\text{Diameter}}$ and iodine number of oil. The variation for line fiber, percent fiber in pulled flax and fiber strength were highly significant.

In the sampling technique for the determination of fiber strength, no significant variation within the sample was found, as shown in Table V.

Table IV

Summary of Analysis of Variances
Showing Mean Squares and Degrees of Freedom

Analysis for	Sources of Variation		
	Replication	Treatment	Rep. x Treat.
	Degrees of Freedom		
	5	13	65
Straw Yields			
Pulled flax	34,179.28	137,681.38**	45,311.10
Deseeded flax	22,015.50	62,814.00**	21,222.15
Retted flax	24,104.27	31,350.24*	14,904.66
Fiber Yield			
Line fiber	3,528.98**	2,475.49*	1,024.56
% fiber in pulled flax	4.89**	3.88**	1.20
% fiber in retted flax	9.43*	10.23**	3.47
% total fiber	32.90	36.04*	18.43
Quality			
Hackled fiber	518.02	824.01*	368.21
Hackled tow fiber loss	167.056	322.22	224.13
Color	0.056	0.288	0.241
Cleanliness	1.396*	0.548	0.364
Physical			
Weight 50 straws	67.053*	0.341	20.403
Diameter index	0.06*	0.041*	0.011
Ratios Weight / Diameter	20.663*	9.115	6.235
Yield			
Seed yield	2,698.554	3,606.824*	1,732.74
% seed in pulled flax	3.172	7.333**	2.525
Seed quality			
Oil contents	1.228	2.372**	0.787
Iodine number	15.146*	17.13**	5.815

*F value exceeds the 5% level of significance.
**F value exceeds the 1% level of significance.

Table V

Summary of Analysis of Variance
For Fiber Strength and Fiber Wax Content

Variation due to	Fiber Strength D.F.	Fiber Strength M.S.	Fiber Wax Contents D.F.	Fiber Wax Contents M.S.
Replication	5	3,291,510.46**	3	0.0217
Treatment	13	1,946,068.55**	13	0.0422
Rep x Treat	65	495,746.99	39	0.0268
Variation within sample	756	104,203.05		

* F value exceeds the 5% level of significance.
** F value exceeds the 1% level of significance.

To show the effect of nitrogen and phosphorus on pulled flax, line fiber, fiber strength and percent total fiber, the analysis of variance of 4 x 2 factorial design is given in Table VI.

The rates of nitrogen gave highly significant effect on the yield of pulled flax. Twenty pounds of nitrogen did not increase the yield significantly, but the increase of yield was significant at 40 pounds and 80 pounds of nitrogen. Response to phosphorus was not significant and no interaction between nitrogen and phosphorus was found.

Nitrogen application on the whole increased the yield of line fiber. Forty pounds of nitrogen was the optimum rate which increased the yield significantly over check and 80 pounds of nitrogen decreased line fiber yield over 40 pounds of nitrogen. Phosphorus did not show any significant effect on the yield of line fiber and the same was true with the nitrogen and phosphorus interaction.

The effect of nitrogen was highly significant and increment of nitrogen decreased the fiber strength significantly. At 80 pounds of nitrogen the decrease of fiber strength was highly significant. Effect of phosphorus was highly significant and decreased the fiber strength significantly. No interaction between nitrogen and phosphorus was noted.

No response of nitrogen and phosphorus was obtained in total fiber. The interaction between nitrogen and phosphorus decreased the total fiber which could be due to chance.

Table VI

Analyses of Variance of 4 x 2 Factorial Design of Nitrogen and Phosphorus on Pulled Flax, Line Fiber, Fiber Strength and % Total Fiber

	D.F.	Pulled Flax Mean Square	Line Fiber Mean Square	Fiber Strength Mean Square	Total Fiber Mean Square
Replication	5	40,157.00	2,525.47*	239,048.68**	35.676
Treatment	7	146,447.29*	16,357.64*	285,757.54**	54.609*
N	3	319,707.66**	5,081.35*	419,607.50**	1.50
P	1	43,802.10	204.188	537,432.10**	23.56
N x P	3	7,401.96	303.129	68,016.1	118.07**
N_0 Vs $N_{20} + N_{40} + N_{80}$	1	743,906.25**	1,757.00		
N_{20} Vs $N_{40} + N_{80}$	1	214,512.50*	1,020.1		
N_0 Vs N_{20}	1	1,908.16	2,773.5	4,695.88	
N_0 Vs N_{40}	1	724,537.50**	6,534.00*	66,776.23	
N_0 Vs N_{80}	1	680,066.70**	950.04	874,348.75**	
N_{20} Vs N_{40}	1	171,704.2	793.50	106,901.41	
N_{40} Vs N_{80}	1	701.17	12,467.04**	457,862.25**	
N_{20} Vs N_{80}	1			1,007,243.36**	
Rep x Treatment	35	47,680.91	1,169.80	50,663.94	17.803
Total	47				

* F value exceeds the 5% level of significance.
** F value exceeds the 1% level of significance.

The means for each yield and quality factors ranked by multiple range method are given in Tables VII and VIII. The position of overlapping sub groups ABC or ABCD, etc., was not determined. These may belong to A, B, C or may be a group by themselves. Only further experimental evidence would clarify the situation.

The averages of different fertilizer treatments for each yield and quality factors are given in Table VII with their ranking such as A, AB, ABC, D.

Treatment Responses

Yield

There was no significant response of potassium. The treatments of zinc, boron and copper slightly decreased the yield of pulled flax in all cases. Boron alone with 20 pounds of nitrogen and 60 pounds of phosphorus did not show any significant effect, but with 40 pounds of nitrogen and the same rate of phosphorus, the yield increased significantly, but only slightly more than with 40 pounds of nitrogen alone.

Each rate of nitrogen showed a pronounced effect on deseeded flax. At the rate of 80 pounds of nitrogen, the yield of deseeded flax was significant. Response to phosphorus was not measured. The effect of zinc, copper and boron mixture was not significant at all levels of nitrogen. There was also no effect of potassium. Boron alone at 40 pounds of nitrogen and 60 pounds of phosphorus increased the yield significantly and gave the highest yield.

Twenty and 40 pounds of nitrogen did not show any significant effect, but loss of weight in retting was more at 80 pounds of nitrogen. The mixture of zinc, boron and copper did not show any significant effect at 0 and 20 pounds of nitrogen with 60 pounds of phosphorus but at 40 pounds of nitrogen with 60 pounds of phosphorus, gave significant increase in yield. Potassium did not show any pronounced effect. Boron alone at 20 pounds of nitrogen and 60 pounds of phosphorus showed no significant effect, but at 40 pounds of nitrogen and 60 pounds of phosphorus gave the highest mean and decreased the loss of weight in retting.

Potassium did not show any significant effect on line fiber yield. The mixture of zinc, copper and boron at 40 pounds of nitrogen with 60 pounds of phosphorus gave significant effect than at 0 and 20 pounds of nitrogen. When boron applied alone at 20 pounds of nitrogen with 60 pounds of phosphorus gave no significant effect, but at 40 pounds of nitrogen and 60 pounds of phosphorus gave highest yield of line fiber. Phosphorus without nitrogen showed a detrimental effect.

Eighty pounds of nitrogen with and without phosphorus decreased the percent of fiber in pulled flax significantly. The remaining fertilizer treatments showed a significant increase.

Eighty pounds of nitrogen with or without phosphorus reduced the percent of fiber in retted straw, while the other treatments gave significantly high percentages of fiber.

The mixture of minor elements reduced the detrimental effect of nitrogen and phosphorus on percent total fiber yield, but showed detrimental effect when applied with 40 pounds of nitrogen and 60 pounds of phosphorus. Potassium with 20 pounds of nitrogen and 60 pounds of phosphorus increased the nitrogen percent total fiber yield as compared to the treatment of 20 pounds of nitrogen and 60 pounds of phosphorus. Boron alone gave increased percent total fiber as compared to treatments 20 pounds of nitrogen with 60 pounds of phosphorus and 40 pounds of nitrogen with 60 pounds of phosphorus.

<u>Quality</u>

At 20 and 40 pounds of nitrogen, the decrease in strength was not very marked as compared to 0 pounds of nitrogen, but 80 pounds of nitrogen decreased the fiber strength significantly. At 0, 20 and 40 pounds of nitrogen with 60 pounds of phosphorus, the averages fell in the same category, but 80 pounds of nitrogen with 60 pounds of phosphorus gave the lowest strength. Potassium did not show any significant effect. The mixture of zinc, copper and boron at each increment of nitrogen improved the fiber strength and at 40 pounds of nitrogen with 60 pounds of phosphorus gave the second highest mean of strength. Boron alone decreased the strength with increasing rate of nitrogen.

Nitrogen at 0, 20 and 40 pounds did not give any significant differences, but 80 pounds of nitrogen alone gave the very low yield of hackled fiber as was the case with 80 pounds of nitrogen and 60 pounds of phosphorus. Sixty pounds of phosphorus without nitrogen gave significantly low yield.

Response to potassium was not very noticeable. The mixture of zinc, copper and boron increased the hackled fiber yield. Forty pounds of nitrogen and 60 pounds of phosphorus with minor elements mixture gave highest yield of hackled fiber yield. Boron alone did not show any significant effect.

Physical Factors

The high rate of nitrogen, 40 and 80 pounds with 60 pounds of phosphorus gave significant increase and 20 pounds of nitrogen with no phosphorus gave significantly low diameter index. As the rate of nitrogen increased with phosphorus, the diameter index increased significantly. The response of potassium was not very significant. The mixture of minor elements (zinc, boron and copper) increased the diameter index significantly with increasing rates of nitrogen and 60 pounds of phosphorus. Boron alone, at 20 pounds of nitrogen and 60 pounds of phosphorus, slightly decreased the diameter, but did not show any effect at 40 pounds of nitrogen and 60 pounds of phosphorus.

Seed Yield and Oil Quality

Forty pounds of nitrogen gave the highest yield of seed and 80 pounds of nitrogen decreased the seed yield significantly. Phosphorus and potassium did not show any significant effect. The same response was obtained with the minor elements (zinc, boron and copper) mixture and boron alone on the seed yield.

Low rates of nitrogen up to 40 pounds gave a significant increase in percent of seed. At high rates of nitrogen, 80 pounds with and without phosphorus, decreased the yield significantly. The response of potassium produced the highest mean but not significantly different from other means. The mixture of minor elements (zinc, boron and copper) and boron alone, did not show any response.

Twenty pounds of nitrogen with 60 pounds of phosphorus gave the highest yield of oil and 20 pounds of nitrogen alone did not come to the same level. Eighty pounds of nitrogen with and without phosphorus gave a significant decrease. The range of means depicted that with increasing rates of nitrogen, the oil content of seed decreased significantly and 20 pounds of nitrogen with 60 pounds of phosphorus seemed to be the optimum rate of nitrogen. The mixture of minor elements (copper, zinc and boron) and potassium did not show any significant effect. Boron alone decreased the oil contents of seeds.

A very high rate of nitrogen, 80 pounds with or without phosphorus, decreased the iodine number of oil significantly. Forty pounds of nitrogen with 60 pounds of phosphorus gave significantly high iodine number. The mixture of minor elements (zinc, boron and copper) gave beneficial effect and increased significantly the iodine number at 20 pounds of nitrogen with 60 pounds of phosphorus. Potassium and boron alone did not give any significant response.

Table VII: THE EFFECT OF DIFFERENT LEVELS OF FERTILIZER NUTRIENTS INCLUDING MINOR ELEMENTS ON THE YIELD AND QUALITY OF FIBER FLAX

Treatment	YIELD: Pulled Flax Gms.	Deseeded Flax Gms.	Retted Straw Gms.	Line Fiber Gms.	% Fiber in Pulled Flax	% Fiber in Retted Straw	% Total Fiber	QUALITY: Fiber Strength Kg/g/cm.	Hackled Fiber Yield Gms.
1. $N_0 P_0$	BC 1928.33	ABCD 1365.00	ABCD 1156.33	ABC 190.83	A 9.9	A 16.48	A 28.41	A 2517.95	ABCD 106.91
2. $N_{20} P_0$	ABC 2101.67	ABCD 1426.67	ABCD 1222.33	ABC 200.13	A 9.5	A 16.39	B 25.50	ABC 2293.3	ABCD 113.59
3. $N_{40} P_0$	A* 2256.67	ABC 1473.33	ABC 1263.67	AB 219.17	A 9.7	A 17.18	A 30.91	ABC 2296.5	ABCD 117.75
4. $N_{80} P_0$	AB 2210.00	A 1570.00	AB 1270.17	C 170.83	B 7.7	B 13.39	A 31.17	C 2083.06	D 93.59
5. $N_0 P_{60}$	C 1828.33	D 1270.00	D 1091.17	C 174.67	A 9.5	A 15.97	A 30.45	ABC 2243.91	CD 96.09
6. $N_{20} P_{60}$	ABC 2011.67	ABCD 1380.00	ABCD 1186.00	ABC 208.17	A 10.3	A 17.44	B 25.59	ABC 2337.2	ABCD 115.42
7. $N_{40} P_{60}$	AB 2195.00	AB 1501.67	AB 1272.17	ABC 212.33	A 9.7	A 16.69	B 22.54	ABC 2253.49	ABCD 115.92
8. $N_{80} P_{60}$	A 2220.00	A 1565.00	ABC 1260.00	C 169.50	B 7.6	B 13.32	B 27.55	D 1804.91	D 93.25
9. $N_0 P_{60}$ Zn Cu B	C 1880.00	CD 1293.33	BCD 1110.83	BC 179.17	A 9.6	A 16.15	A 30.73	ABC 2365.3	ABCD 116.59
10. $N_{20} P_{60}$ Zn Cu B	C 1890.00	BCD 1301.67	CD 1105.50	C 175.83	A 9.3	A 15.88	A 28.88	AB 2456.58	BCD 98.25
11. $N_{40} P_{60}$ Zn Cu B	AB 2191.67	AB 1506.67	A 1279.17	A 223.33	A 10.2	A 17.48	B 27.22	A 2478.99	A 129.65
12. $N_{20} P_{60}$ K	ABC 2098.33	ABC 1480.00	ABCD 1242.00	ABC 204.33	A 9.7	A 16.46	A 28.92	ABC 2313.87	ABC 120.59
13. $N_{20} P_{60}$ B	AB 2153.33	ABC 1471.67	ABC 1258.50	ABC 210.50	A 9.8	A 16.65	A 31.04	ABC 2309.52	ABCD 114.59
14. $N_{40} P_{60}$ B	A 2260.00	A 1555.00	A 1304.33	A 225.83	A 10.0	A 17.23	A 29.84	BC 2167.04	AB 123.10

Treatment	QUALITY: Loss in Hackling Gms.	Fiber Judging: Color	Fiber Judging: Cleanliness	Wax Content	PHYSICAL FACTORS: Dia. 50 Straws cus.	Wt. 50 Straws Gms.	Wt. 50 Straws / Dia. 50 Straws	SEED YIELD & OIL QUALITY: Seed Yield Gms.	% in Pulled Flax	Oil Content	Iodine Number
1. $N_0 P_0$	42.43	2.17	2.33	2.99	BC 1.029	13.78	13.35	ABC 323.33	A 16.82	AB 36.78	AB 195.33
2. $N_{20} P_0$	49.60	2.42	1.67	3.01	C 0.905	17.58	15.87	ABC 330.67	A 16.13	ABC 36.60	AB 195.42
3. $N_{40} P_0$	58.27	2.17	1.92	2.86	BC 1.008	13.83	13.75	A 368.83	A 16.30	ABCD 36.57	AB 195.67
4. $N_{80} P_0$	35.93	2.75	1.67	2.77	B 1.056	13.02	12.06	C 293.67	B 13.41	CDE 35.57	BC 192.50
5. $N_0 P_{60}$	43.10	2.50	2.50	2.89	BC 0.971	12.75	12.83	BC 301.50	A 16.51	BC 36.92	AB 195.25
6. $N_{20} P_{60}$	43.60	2.00	1.92	2.87	B 1.045	14.04	13.37	ABC 321.50	A 16.05	A 37.13	AB 195.50
7. $N_{40} P_{60}$	57.10	2.25	2.08	2.73	A 1.214	20.37	16.57	AB 353.17	A 16.05	ABCD 36.42	A 195.83
8. $N_{80} P_{60}$	56.60	2.58	2.50	2.73	A 1.241	18.24	14.47	BC 297.83	B 13.45	E** 34.98	C 189.92
9. $N_0 P_{60}$ Zn Cu B	37.27	2.50	2.17	2.77	BC 0.997	12.89	12.70	BC 297.83	A 15.79	ABCD 36.53	AB 195.67
10. $N_{20} P_{60}$ Zn Cu B	43.27	2.17	2.42	2.86	B 1.098	14.49	12.70	ABC 313.50	A 16.57	A 37.07	A 196.00
11. $N_{40} P_{60}$ Zn Cu B	54.60	2.08	1.58	2.71	B 1.061	14.72	13.76	ABC 347.83	A 15.87	BCDE 35.85	AB 194.45
12. $N_{20} P_{60}$ K	63.93	2.42	2.08	2.85	BC 0.965	13.45	13.78	AB 354.33	A 17.11	AB 36.83	AB 195.33
13. $N_{20} P_{60}$ B	52.27	2.17	2.08	2.78	BC 0.992	13.12	12.99	ABC 334.83	A 15.50	ABC 36.62	AB 195.67
14. $N_{40} P_{60}$ B	46.93	2.50	2.17	2.67	B 1.055	14.27	13.52	ABC 348.00	A 15.35	DE 35.43	AB 193.58
	N.S.	N.S.	N.S.	N.S.		N.S.	N.S.				

* Significantly high ranking mean.
** Significantly low ranking mean.

Table VIII: Duncan's Multiple Ranges of Averages of Different Measurements of Fiber Flax Yields and Quality at 5% Level of Significance

Pulled Flax Means in Gms/Plot	Deseeded Flax Means in Gms/Plot	Retted Flax Means in Gms/Plot	Line Fiber Means in Gms/Plot	Percent Line Fiber in Pulled Flax	Percent Fiber in Retted Flax	Percent Total Fiber	Fiber Strength Kg/gm/cm	Hackled Fiber Yield Means in Gms/Plot	Diameter Index of 50 Retted Straws	Seed Yield Means in Gms/Plot	Percent Seed in Pulled Flax	Seed Oil Contents	Oil Iodine Number
1828.33	1271.67	1091.17	169.50	7.6	13.32	22.54	1804.91	93.25	0.905	293.67	13.41	34.98	189.92
1880.00	1293.33	1105.50	170.83	7.7	13.39	25.50	2083.06	93.59	0.965	297.83	13.45	35.43	192.50
1890.00	1301.67	1110.83	174.67	9.3	15.88	25.59	2167.04	96.09	0.971	297.83	15.35	35.57	193.58
1928.33	1365.00	1156.33	175.83	9.5	15.97	27.22	2243.91	98.25	0.992	301.50	15.50	35.85	194.45
2011.67	1380.00	1186.00	179.17	9.5 *	16.15	27.55	2253.49	106.91	0.997	313.50	15.79	36.42	195.25
2098.33	1426.67	1222.33	190.83	9.6	16.39	28.41	2293.30	113.59	1.008	321.50	15.89	36.53	195.33
2101.67	1471.67	1242.00	200.33	9.7	16.47	28.88	2296.53	114.59	1.029	323.33	16.05	36.57	195.33
2153.33	1473.33	1258.50	204.33	9.7	16.48	28.92	2309.52	115.42	1.045	330.67	16.08	36.60	195.42
2191.67	1480.00	1260.67	208.17	9.7	16.65	29.84	2313.87	115.92	1.055	334.83	16.13	36.62	195.50
2195.00	1501.67	1263.67	210.50	9.8	16.69	30.45	2337.20	116.59	1.056	340.83	16.30	36.78	195.67
2210.00	1506.67	1270.17	212.33	9.9	17.18	30.73	2365.30	117.75	1.061	348.00	16.51	36.83	195.67
2220.00	1555.00	1272.17	219.17	10.0	17.23	30.91	2456.58	120.59	1.098	353.17	16.57	36.92	195.67
2256.67	1565.00	1279.17	223.33	10.2	17.44	31.04	2478.99	123.10	1.214	354.33	16.82	37.07	195.83
2260.00	1570.00	1304.33	225.83	10.3	17.48	31.17	2517.95	129.59	1.241	368.83	17.11	37.13	196.00

* Means statistical significance.

DISCUSSION

Fiber flax is considered very sensitive to fertility levels of the soil. Proper fertility level of soil plays a vital role in maintaining the high yields and quality of the crop. Both are of value to growers and processors. It was found that under the conditions of this experiment, some fertilizer applications were beneficial to fiber flax.

Most of the flax fertility studies have been conducted under non-irrigated conditions in Oregon and fertilizer recommendations made on that basis are of little or no value under irrigated conditions. This study indicates that yield and quality were influenced by nitrogen, phosphorus, boron, and minor elements (Zn, Cu, B) in combination. Although the yield and quality of the unfertilized plots were quite high as compared to some of the other treatments which could be due to the high fertility level of the soil. This chemical analysis of soil also showed that over-all fertility level of soil was high. Phosphorus, on the other hand, did not show any beneficial effect on the fiber strength and produced coarse fiber.

Nitrogen

Nitrogen is considered very important element in development of fiber flax and a deficiency or excess of nitrogen show detrimental effect on the production. The results reported in this study indicate that low rates of nitrogen, such as 20 pounds per acre, did not increase the yield of pulled flax, deseeded flax, retted straw, line fiber, percent of total fiber, hackled fiber, seed yield, oil content and iodine number. In addition, the low level of nitrogen affected the physical characteristics of fiber flax. This was especially true in the case of diameter index of the straw and gave fine straw. This type of straw is difficult to process and most of the fiber is reduced to tow.

On the other hand, nitrogen at all levels did not show any effect on other physical factors such as weight of 50 retted straws and the ratio of $\frac{\text{Weight}}{\text{Diameter}}$. These determinations are mainly the physical factors by which a plant breeder can judge whether his breeding material is of high or low fiber content and also important in crop judging. Feaster (12, p. 43-47) recently has made a similar study and found that the correlations between percent fiber and stem weight, percent fiber and stem diameter, ratio of the $\frac{\text{stem weight}}{\text{diameter}}$ and percent fiber were negative for the plants with the monoecious straws of hemp.

In the present study, the correlations of the above mentioned factors were not made with the percent total fiber and nothing can be said whether thin straw or thick straw of flax would give high percentage of total fiber. Such an information would be of great value to the flax breeder, grower and processor. It would also help a great deal in crop grading.

By the application of nitrogen, even at low rates, fiber strength was affected, but the effect was not significant. This indicates that nitrogen is detrimental for fiber strength. This is only true when the fertility level of soil is high.

Nitrogen also did not show effect on other quality factors such as color, cleanliness and wax content of fiber. Color and cleanliness are very important factors in fiber judging and of a great value in the linen industry. There is no way to measure these factors quite accurately by mechanical means, although this can be determined by visual observations. Such determinations are affected by personal experience and other factors.

Oil content of seed and iodine number of oil are very sensitive for nitrogen application. As the rate of nitrogen increases, the oil content of seed decreases significantly. At 20 pounds of nitrogen with 60 pounds of phosphorus, the oil contents of seed did show significant increase. This beneficial effect can be attributed to phosphorus.

In order to procure high yields of pulled flax and deseeded flax, high rates of nitrogen can be applied, but there is a danger of lodging and straw of green color at very high rate, i.e., 80 pounds per acre. In this study, 40 pounds of nitrogen is moderate level of nitrogen in order to obtain economic yield of pulled flax, but very high nitrogen, no doubt, gives higher yield than 40 pounds. This rate of nitrogen shows other detrimental effects such as lodging, delay in maturity and straw of green color, which lowers the grade of the flax.

At 40 pounds of nitrogen per acre, high yields of line fiber, high percent of total fiber, percent fiber in pulled flax, percent fiber in retted straw and high seed yields are obtained. The fiber strength is also not affected significantly and it is not lowered to such a point that it would not justify its use. On this basis, 40 pounds of nitrogen seems to be the optimum rate for fiber flax production, but findings of Nelson (30, 41 p.) does not agree with this and recommended only 20 pounds of nitrogen per acre, but these experiments were conducted under non-irrigated conditions.

Very high rates of nitrogen, such as 80 pounds per acre, show detrimental effect in all the yield factors, except the deseeded flax. Very thick, green colored straw, delay in maturity, is produced and lodging also takes place. The yield of percentages and quality of the fiber is lowered very much and these detrimental effects would not justify the use of high nitrogen for fiber flax production. Such a high level of nitrogen is also detrimental to linseed production.

Phosphorus

The present study indicates that phosphorus does not play an important role in the development of fiber flax. This is true when the available phosphorus level of the soil is high. Phosphorus did not show any significant effect on the yield of straw, fiber and seed. It appears to increase the oil content of the seed and has some beneficial effect on the iodine number of oil. No analysis was made in order to determine the effect of phosphorus on seed yield and seed quality factors. Further study of this possible improvement of seed quality would be of real value because the sale of seed is an additional source of income to the growers.

On the other hand, phosphorus is very detrimental to fiber quality, which lowers the fiber strength and produces a coarse fiber and thick straw. In the current study, 60 pounds of phosphorus per acre was applied and this seemed to be a high rate of phosphorus on such soils which had a very high level of available phosphorus in the soil to begin with, so increase in yield or beneficial effects were not very likely. On this soil, a high rate of phosphorus is not justified and optimum level should be determined by further investigations at lower rates in combination with nitrogen.

Potassium

Potassium did not improve the yield, quality of fiber flax and seed significantly, because the exchangeable potassium was very high, that is, 966 pounds per acre initially. Such a high level of exchangeable potassium in the soil would not justify the use of potassium fertilizer. The data does show that potassium has some beneficial effect on percent total fiber. It means that this element plays an important role in total fiber production, but this fact should be confirmed by further trials. This nutrient should only be used on the soils where the deficiency occurs.

Minor Elements

Minor elements seem to play an important role in the development of fiber flax. Some very interesting results were obtained.

Borax, when used alone at the rate of 20 pounds per acre, combined with 40 pounds of nitrogen and 60 pounds of phosphorus showed some beneficial effect on the yield of line fiber, but detrimental effects on the quality of fiber. No noticeable effect was observed on increased seed yield and iodine number of oil.

Zinc sulphate, borax and copper sulphate, in combination, each at the rate of 20 pounds per acre, showed a very beneficial effect on yield and quality of fiber which is true only at 40 pounds of nitrogen and 60 pounds of phosphorus. This study indicates that either there is a deficiency of these minor elements in the soil or this crop shows more response to these elements in the presence of high rates of nitrogen. But these data do not give any conclusive information about profitable use of these elements. In order to determine the optimum rates of these elements, detailed experiments should be designed which would lead to definite conclusions regarding the use of these elements and rates.

Time, split application and placement studies of fertilizers can be another approach to increase the yield and maintain proper quality under irrigated conditions. Such a study would also be of great value for the flax which is planted quite early on cold soils in Oregon. At that time there is usually a deficiency of nitrogen which retards growth. A light application of nitrogen would be of advantage on most soils when the flax is planted early.

SUMMARY AND CONCLUSIONS

In 1955, an attempt was made to determine the effect of different levels of fertilizer nutrients including minor elements under irrigated conditions on the yield and quality of fiber flax.

Holland Concurrent variety of fiber flax with 14 fertilizer treatments and six replications were superimposed on two locations. In the field trials, randomized block design was used. The data of only one location were analysed in this study.

The yield characters studied were pulled flax, deseeded flax, retted flax, line fiber, percent fiber in pulled flax, percent fiber in retted flax, percent total fiber, seed and percent seed in pulled flax. Under quality the following factors were studied: fiber strength, hackled fiber, loss of hackled tow, color, cleanliness, wax content of fiber, oil content and iodine number of oil. The physical characters included the diameter index of 50 retted straws, weight of 50 retted straws and ratio of weight of $\frac{\text{50 retted straws}}{\text{diameter index of 50 retted straws}}$.

Fertilizer application was advantageous to the fiber flax production. Yield, quality and physical factor was influenced by the application of nitrogen. Low levels of nitrogen did not show any beneficial effect on the yield, quality and produced fine straw.

Nitrogen, at the rate of 40 pounds per acre, appeared to be the optimum rate in order to obtain high yield, quality of seed and fiber. This level did not show any deteriorating effect on the physical characters. High rates of nitrogen such as 80 pounds per acre, gave detrimental effect on yield, quality of fiber and seed. This level produced very thick, green colored straw and lodging also took place.

Phosphorus did not appear to increase the yield of straw, fiber and seed. It lowered the fiber strength significantly. It also produced thick straw and coarse fiber. This elements gave more beneficial effect on the seed quality when applied in combination with nitrogen.

Potassium did not play an important role in fiber flax development and only increased the yield of percent total fiber when applied with 20 pounds of nitrogen and 60 pounds of phosphorus. No significant results were shown on the yield of straw and fiber. It also did not effect the quality.

Minor elements (Zn, Cu, B) which, when applied with 40 pounds of nitrogen and 60 pounds of phosphorus treatment, gave very beneficial effect on the yield, quality and physical factors.

Boron alone with 40 pounds of nitrogen and 60 pounds of phosphorus, gave significant increase in the yield of straw and fiber, but lowered the seed yield and quality. It also showed detrimental effect on fiber quality.

Nitrogen, phosphorus, potassium and minor elements did not show any significant effect on the loss of hackled tow, color, cleanliness, wax content of fiber. The physical factors such as weight of 50 retted straws and ratio of $\frac{\text{Weight of 50 retted straws}}{\text{Diameter of Index of 50 retted straws}}$ were not effected.

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