SOME PHYSIOLOGICAL FACTORS INFLUENCING THE PRODUCTION OF FLAX FIBER CELLS

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Introduction

The early investigations upon fiber flax were in the main an attempt to obtain data on the influence of various fertility factors on yields of straw, seed and fiber. These studies conducted under different conditions resulted in conflicting interpretations. In the past decade investigations have continued in this field, but the investigators have tried to study it more from an anatomical viewpoint to determine just what occurs within the plants when they are grown and supplied with different so-called nutrients.

Following the excellent work initiated by the Irish Linen Industry Research Association, studies were made of the morphological characteristics of the fiber cells when grown under different conditions. This has involved the sectioning of many flax stems, the enlarging of these sections with the aid of a projection microscope, and measuring the cross-sectional area of the fiber cells. Previous results have shown that the percentage of fiber, as determined by the cross-sectional area of fiber cells in relation to the stem area, varies barely three per cent for plants of different varieties and for the average of mature plants grown under different conditions. However, a slight increase in the area of fiber cells combined with an increased area of stem and height would result in a much greater fiber yield per plant.

The work more recently reported has been in connection with plant breeding selection studies, and a few results have been reported

from field fertilizer plots under conditions where it has been impossible to control many factors which influence the development of the fiber cells within a plant. No results have been reported from replicated field plot treatments or plants grown in greenhouses where some controlled conditions were possible. Further, no experimental results based upon cross-sections have been reported where two or more fertilizer elements were applied in combinations.

This paper presents and discusses results from water and soil cultures grown under greenhouse conditions and plants grown under field conditions in replicated plots.

PREVIOUS WORK

Davin and Searle (4)[1] and Davin (3) have reported practically the only determinations of the areas of fiber cells from cross-sections of stems. They concluded that the percentage of fiber of the flax plant is inherited but failed to find any external characters of the plant with which the percentage of fiber was correlated. They showed that the number of fiber cells and size of the single fibers increased with the thickness of the stem irrespective of length. Results from two successive years' field work led Davin (3) to conclude that potash, if not in excess, causes an increase in the length of the flax plant, and superphosphate produces an increase in the percentage of fiber. This increase of the percentage of fiber due to phosphatic fertilizers was only 0.7 per cent but was significant, for among many thousands of

[1]Reference by number is to "Literature Cited", page 32.

flax plants examined in Ireland, the range of the variation in the percentage of fiber was only from 9.69 to 11.35 per cent or a difference of 1.66 per cent.

Renard (16) stated that he did not obtain, in the one year in which he grew flax in soil with different moisture percentages, such convincing results as secured by Davin (3) and one or two other experimenters. He found material differences in the inner structure of cross-sections of stems which were grown under similar conditions but did not obtain differences for area of fiber, wood, or pith cavity that were consistent for different races of flax or flax subjected to different moisture relations.

The cross-sections of flax stems studied by the different workers were usually taken in the middle of the stem at right angles to the length. Therefore it is desirable to show the relationship of the fiber cells within the steam at that point to other locations along the stem. Herzog (8) reviews very completely the previous literature regarding the length and thickness of fiber cells in relation to their position within the plant. His results show that the individual fibers, or the ultimate fiber cells, are longer in the upper than in the lower part of the plant, but the ultimate fiber cells are smaller in diameter at the apical than at the basal end of the plant. Some data, taken from Tammes (21), show that the number of fiber cells, as well as the number of fiber bundles, varies throughout the length of the plant. However, the latter is fairly uniform, but the number of fiber cells is highest in the median portion of the stem. Thus the relative yields of fiber determined at the median portion of a stem are higher than is

the true condition of the entire plant.

Field fertilizer tests with fiber flax have been in some ways conflicting, due probably in many cases to soil heterogeneity. Weck (25), Kleberger (10), and Kuhnert (12) obtained increased yields of flax with nitrogenous fertilizers when applied in combination with other elements and Scheel (18), Bredemann and Fabian (2), and Fabian (6) recognized that some nitrogen was necessary for best yields, but like Tobler (22) and the others emphasized the importance of not using too much of the nitrogenous fertilizer. Gross (7) obtained no beneficial effects from nitrogenous salts when supplied in addition to potash salts but attributed it to an extremely dry year when the experiment was conducted. Kulikova (13), experimenting with chemically pure single nitrogenous salts in soil cultures under somewhat controlled conditions, arranged the salts with regard to their beneficial effects on the development of flax plants in the following descending order of importance: KNO_3, NH_4NO_3, NH_4Cl, $(NH_4)_2SO_4$, $NaNO_3$, and $Ca(NO_3)_2$.

Davin (3), as previously mentioned, has shown an increase in the percentage of fiber in cross-sections and in the fiber content of the flax plant due to an application of phosphorus without causing any significant differences in the number and size of the fibers. Bredemann and Fabian (2) also have stated that phosphorus is slightly beneficial, but that sometimes it lowers the fiber quality. Mitrofanov (14) concluded that large applications of nitrogenous and phosphatic fertilizers lowered the fiber quality, and in order to obtain satisfactory yields it was necessary to employ a complete

fertilizer. Most authors attribute a great deal of importance to potash, and Davin (3) and Powers (15) have shown that it increases the height of the flax plants. Bredemann and Fabian (2) have stated that it counteracts the bad influence produced by an excessive quantity of nitrogenous fertilizer, and for a soil which is deficient in potash, an application is very beneficial. Scheel (18) obtained increased yields with potash fertilizers.

No one particular potassium salt results always in the greatest amount of growth. Kraft (11) states that the chloride acts favorably, and this is supported by the work of others. Kleberger (10) obtained the most satisfactory results with kainite, while Tobler (23,24) believed that acid sulphate was the best. Steigerwald (20) found that the chemically pure salt of potassium magnesium sulphate was better for seed yields than pure potassium chloride.

Most investigators believe that fiber flax does best upon a neutral to slightly alkaline soil but that a recent application of lime has a retarding effect upon the growth of the flax. Deterre (5) believes that lime in excess may give a short fiber.

Increased flax yields are usually attributed to varietal differences and to the effects produced by fertilizers. Hutchinson (9) concluded that there was little to be gained by applying fertilizer to flax when the crop was grown in a fairly rich clay loam soil and in regular rotation with other farm crops. Robinson and Cook (17) found that heavier types out-yielded lighter types of soil consistently and that applications of fertilizer to the lighter soil types did not cause them to give yields equal to untreated heavier soils.

EXPERIMENTAL PROCEDURE

Greenhouse Methods

Soil Cultures: In the first experiments sand cultures were used in triplicate. A sand known to be deficient in available plant fertilizer elements was used as a culture medium. To this medium were added the fertilizer elements in the form of a solution made up with distilled water. These elements were added in the quantities and proportions suitable for good growth of cereal crops because it was thought these proportions might be suitable for flax. Growth of flax under these conditions was satisfactory in most cases. The results shown in Table 1 were for plants grown in such sandy soil in a greenhouse in the winter of 1928. As indicated in the table, nitrogen was added to this prepared soil medium in such quantities as to allow the designation of low, medium, and high nitrogen content. Nitrogen was used in the form of potassium and calcium nitrates. Additional amounts of the solutions were added each week, and distilled water was poured over the soil when necessary.

A specially prepared soil consisting of approximately one-fourth sand, one-fourth manure, and one-half muck which was thoroughly mixed and screened was used in another greenhouse experiment. This experiment was run in triplicate. These soil cultures containing flax plants were placed under different periods of illumination. The periods were 10, 13 to 18, and 18 hours of light per day. The long days were obtained with the aid of artificial light from 1000 Watt electric bulbs. These bulbs located approximately four feet above the soil illuminated a soil

Table 1. Showing results obtained from plants grown in soil cultures in a greenhouse in 1928 and some measurements obtained from sectioning one plant from each treatment. Some soil cultures received different amounts of nitrates. Plants in other cultures grew in different periods of light each day. The percentage fiber from plants not sectioned was calculated from fiber yields obtained by scutching.

Treatment		Data from single plant sectioned						Data from plants not sectioned		
		Fiber per cent	No. of fiber cells	Area fiber sq. cm.	Area stem sq.cm.	Length stem cut,cm.	Yield of fiber cu. mm.	Average length cm.	Stem weight gm.	Per cent fiber
No	NO_3	5.94	203	33.9	570.0	64	28.65	57.3	.058	23.65
Low	NO_3	8.11	255	47.9	590.7	67	37.42	52.7	.061	21.20
Medium	NO_3	7.28	252	35.2	483.1	57	30.52	58.7	.070	21.55
High	NO_3	6.63	271	36.2	543.3	63	27.81	51.5	.083	19.27
Photoperiodism										
10	Hours	6.22	405	101.5	1633.1	66	125.55	83.7	.153	22.11
13-18	Hours	7.03	386	73.7	1065.1	94	85.24	78.2	.126	22.03
18	Hours	4.03	211	20.9	348.0	33	14.41	46.5	.059	24.27

area of approximately 12 square feet. The 13 to 18 hour illumination means that the plants when germinated received 13 hours of light each day. This period of illumination was increased approximately 30 minutes each week until it reached 18 hours of light where it was kept constant. With this increase from 13 to 18 hours of light, the plants grew under duration of light conditions similar to those they would have had if grown in a field during the regular growing season.

In 1930 flax was grown in a series of soil cultures in a greenhouse. This soil was different from the soil used in 1928. It was a sand loam upon which flax had previously been grown in a field. As the field flax had not yielded exceptionally well, it was thought the soil might be deficient in elements necessary for plant growth. The soil was well mixed before being put into two gallon crocks which were used in this particular experiment. Fertilizers were added to each crock at the rate of 350 pounds per acre or 1.225 grams per crock of 7000 grams of dry soil. The different fertilizer analyses used may be seen by reference to Table 2. This experiment was run in duplicate. The flax plants were watered whenever it appeared necessary.

Water Cultures: In 1931 plants were grown in a greenhouse in water cultures containing a few or all of the essential plant fertilizer elements in certain proportions. These proportions were those in which other workers had found cereals to grow well. The culture solutions were in three gallon crocks, and the number of plants per crock was approximately thirty. This allowed approximately 400 c.c. of solution for each plant, and as the plants were small, the solutions were only changed once at the end of the second week. The experiment

Table 2. Data from soil fertilizer cultures grown in a greenhouse in 1930. The treatments were duplicated and two stems from each treatment or culture were sectioned and the fiber measurements determined.

Treatment	Per cent fiber			No. fiber cells			Area of fiber cells			Area of stems			Yield fiber cu.mm.	Length stems cm.	Weight stems gm.
	1	2	Ave.	1	2	Ave.	1	2	Ave.	1	2	Ave.			
0-0-0	8.84	8.33	8.59	512	276	394	108.8	78.8	93.8	1208.9	947.1	1078.0	95.4	89.1	5.93
4-0-0	6.30	6.55	6.43	400	368	384	74.4	61.4	67.9	1182.4	943.9	1063.2	72.6	88.1	6.98
4-16-0	6.75	5.93	6.34	322	260	291	66.0	55.6	60.8	980.3	937.3	958.8	62.3	84.9	6.58
4-16-4	6.55	8.26	7.41	378	374	376	61.7	80.4	71.1	941.6	972.3	957.0	71.6	86.2	6.38
4-16-8	7.63	7.85	7.74	405	420	413	76.4	84.4	80.4	999.7	1074.5	1037.1	83.5	86.0	6.23
4-16-16	4.79	7.63	6.21	287	470	379	48.8	87.4	68.1	1020.7	1156.6	1088.7	74.9	89.5	7.48
0-0-8	6.73	7.87	7.30	384	388	386	66.7	66.1	66.4	990.6	843.5	917.1	71.3	90.4	6.43
0-16-8	7.83	8.10	7.97	414	456	435	80.1	89.1	84.6	1023.6	1101.1	1062.4	90.5	87.3	6.23
8-16-8	5.65	6.05	5.85	340	324	332	67.8	58.2	63.0	1201.0	964.0	1082.5	60.8	83.5	6.33
4-8-8	7.01	7.74	7.38	361	412	387	73.4	76.2	74.8	1047.6	982.9	1015.3	79.4	87.3	6.98
4-0-8	7.48	6.72	7.10	444	264	354	67.4	64.9	66.2	900.8	966.4	933.6	69.6	88.5	6.60
0-16-0	4.14	8.20	6.17	301	368	335	39.2	71.7	55.5	952.2	866.6	909.4	56.4	87.8	5.60

was terminated at the end of the fourth week. The nutrient solutions were made up as shown in Table 3. Tap water was used for the first and second series of water cultures because it was thought that the very small amounts of mineral impurities of this water would help to produce a better growth. However, none of these mineral impurities would be present in any case in a sufficient amount to cause an appreciable difference in the effect produced by the fertilizer elements which were being tested. In the third series of water cultures, distilled water was used. In all cases where flax was grown in water cultures, the plants were harvested at the age of four weeks. Only the living plants were measured and sectioned and the results, appearing in Tables 3 and 4, give the number of dead plants which were numerous in a few cultures.

Field Methods

The field experiments in 1931 were conducted upon a Hillsdale soil. A typical Hillsdale soil in its virgin condition is characterized by a surface layer of three to four inches of grayish-brown loam or sandy loam. Below this is a pale yellowish friable sandy loam ten to fifteen inches thick. This material then grades off into a yellowish-brown material from 18 to 24 inches thick, containing large quantities of clay that are still granular and friable. The upper horizon is acid in reaction and the soil is of average fertility.

The experimental field selected was one upon which no fertilizer had been applied for several years, and the field was thought to be deficient, as most Hillsdale soils are, in phosphorus and to some extent potash. Later, it developed from laboratory tests used to

Table 3. Showing the number of c.c. of salt solutions (1/M) added to each 12-liter jar water culture grown in 1931. Tap water was used for the first and second series but distilled water was used for the third series. Solutions were changed at the end of two weeks and the cultures were grown only four weeks. J.M.S. flax was grown in all jars. Data are given upon the average height of the plants, the number dead and alive at the completion of the experiment and the dry weights of the roots and tops.

No. Jar	$Ca(NO_3)_2$ c.c.	NaH_2PO_4 c.c.	KCl c.c.	$MgSO_4$ c.c.	Average height cm.	Number plants Alive	Dead	Weight roots gm.	Weight stems gm.
				FIRST SERIES					
1 N	62.4	---	---	180	6.76	29	0	.230	.450
2 P	----	216	---	180	6.03	30	2	.330	.280
3 K	----	---	216	180	5.66	28	1	.270	.260
4	----	---	---	---	6.32	30	0	.295	.280
5 PK	----	216	216	180	6.09	16	14	.295	.300
6 NPK	62.4	216	216	180	9.65	30	1	.845	.820
7 2NPK	124.8	216	216	180	11.83	18	11	.715	.780
8 NK	62.4	---	216	180	6.34	22	3	.195	.365
9	----	---	---	---	7.50	32	0	.110	.340
10 N2PK	62.4	432	216	180	17.13	26	0	.970	1.530
11 NP	62.4	216	---	180	9.88	25	2	.465	.570
12 NP2K	62.4	216	432	180	6.40	10	20	.355	.600
				SECOND SERIES					
1	30	400	400	180	10.12	26	2	.235	.690
2	60	400	300	180	16.26	33	0	.400	1.690
3	90	400	200	180	21.64	37	0	.670	3.250
4	120	400	100	180	25.09	37	0	.940	4.965
5	120	300	200	180	19.25	39	0	.590	2.695
6	120	200	300	180	13.77	27	5	.190	1.145
7	120	100	400	180	9.56	34	3	.200	1.010
8	60	300	400	180	11.33	32	3	.220	1.070
9	90	200	400	180	8.98	33	1	.160	.775
10	90	200	300	180	13.71	38	1	.320	1.580
11	75	250	350	180	9.92	16	15	.140	.790
12	105	250	250	180	17.48	33	0	.445	2.270
				THIRD SERIES					
	$Ca(NO_3)_2$ c.c.	KH_2PO_4 c.c.	$MgSO_4$ c.c.	Ratio					
1	31.2	43.2	480	1-1-8	11.82	9	20	.145	.550
2	31.2	345.6	60	8-1-1	11.72	15	17	.300	.880
3	249.6	43.2	60	1-8-1	11.10	21	18	.330	1.015
4	62.4	216.0	180	5-2-3	12.88	27	14	.430	1.190
5	93.6	129.6	240	3-3-4	15.96	37	3	.585	1.485
6	93.6	172.8	180	4-3-3	12.97	25	12	.440	1.180
7	31.2	172.8	300	4-1-5	12.58	22	16	.355	.965
8	156.0	172.8	60	4-5-1	10.23	9	23	.230	.580
9	124.8	43.2	300	1-4-5	16.86	27	7	.375	1.305
10	187.2	86.4	120	2-6-2	11.26	36	7	.450	1.145
11	62.4	86.4	360	2-2-6	13.46	28	11	.440	1.025
12	124.8	129.6	180	3-4-3	13.41	13	23	.305	1.030

	First Series	Second Series	Third Series
Date planted	March 28, 1931	April 28, 1931	June 3, 1931
Date harvested	April 27, 1931	May 29, 1931	July 1, 1931
Additional salts	10 c.c. iron tartrate 0.2% 5 c.c. MnCl 0.2%	20 c.c. iron citrate	20 c.c. iron citrate 3 c.c. $MnSO_4$ M/14 3 c.c. $HgBO_3$ M/5

Table 4. Showing the results with probable errors obtained from the first series of plants grown in water cultures in 1931. These cultures contained salts of nitrogen (n), phosphorus (P), or potassium (K) or combinations of these. Ten stems were sectioned from each treatment and measurements were taken upon the fiber content. The number of c.c. of salt solution used is given in Table 3. The area of fiber cells and stem area are magnified in area 67600 fold. The yield of fiber in cubic millimeters was obtained by multiplying the height of the plants by the unmagnified area of fiber. Probable errors were calculated by Bessel's formula using (N-1).

SEEDLING WATER CULTURE PLANTS

Treatment	Per cent fiber	No. of fiber cells per stem	Area fiber cells per stem sq. cm.	Area stem per stem sq. cm.	Average height mm.	Yield of fiber in cu. mm.
Tap Water	4.72 ± .18	93.8 ± 5.3	11.3 ± .7	244.6 ± 14.9	65.2 ± 1.1	1.108 ± .068
N	3.27 ± .24	94.6 ± 4.7	12.0 ± .7	374.7 ± 8.5	67.6 ± 1.2	1.217 ± .080
P	4.35 ± .17	81.3 ± 1.9	12.8 ± .5	296.5 ± 8.3	60.3 ± 1.1	1.146 ± .022
K	5.77 ± .18	87.5 ± 3.0	13.3 ± .6	232.2 ± 7.7	56.6 ± 1.4	1.132 ± .029
N-P	3.80 ± .21	116.3 ± 6.4	18.2 ± .9	481.1 ± 13.3	98.8 ± 1.8	2.668 ± .137
N-K	3.89 ± .37	96.9 ± 8.3	14.1 ± 1.4	363.7 ± 12.2	63.4 ± 1.5	1.331 ± .137
P-K	3.86 ± .26	94.9 ± 5.3	12.0 ± .8	316.1 ± 11.9	60.9 ± 2.0	1.096 ± .081
N-P-K	3.80 ± .14	113.6 ± 3.6	19.2 ± 1.1	508.7 ± 25.4	96.5 ± 1.8	2.702 ± .162
2N-P-K	4.18 ± .16	115.2 ± 3.8	23.1 ± .7	562.4 ± 22.8	118.3 ± 2.6	4.022 ± .148
N-2P-K	4.75 ± .26	150.4 ± 3.1	35.0 ± 2.3	735.7 ± 21.1	171.3 ± 4.6	8.908 ± .630
N-P-2K	3.08 ± .29	84.2 ± 7.4	12.7 ± 1.7	386.9 ± 12.7	64.0 ± 2.1	1.216 ± .165

determine acidity and available phosphorus that the soil was not deficient in calcium or available phosphorus.

There were 14 different fertilizer treatments applied to these field plots, and each treatment was replicated three times. The size of the plots was seven by three feet, and the applications of fertilizer were at the rate of 400 pounds per acre. At the age of 41 days when the young seedling plants were about 28 centimeters tall, they were selected for sectioning. Five plants, representing as near as possible the average size from each plot, were selected, measured, and preserved in a formalin-acetic-alcohol fixing solution for later sectioning. At that time there was no disease present in any of the plots, but a few weeks later wilt, Fusarium lini, appeared in the field and greatly affected the total yields from several plots. The wilt was not found to be correlated with any fertilizer treatment. The plants selected at maturity, age 92 days, for sectioning were not noticeably affected by the fungus disease, and it is believed the anatomical data are dependable. Five mature plants were selected from each plot, measured and preserved in a manner similar to that used for the seedling plants. The data, therefore, were obtained from 280 seedling and 280 mature plants; that is 20 plants were sectioned from each of the 14 treatments in the seedling stage, and 20 from each of the 14 treatments in the mature stage. In the case of the seedling stems, separate data were secured from each replicate plot. With the mature plants, 15 stems representing five stems from three separate replications or series, were bulked together. Therefore separate records were not

secured for the different replicates except the first series, which was worked up separately. The data showing the difference in methods for seedling and mature stems are seen in Tables 5 and 7.

Histological Methods

All of the plants for sectioning were killed and fixed in the formalin-acetic-alcohol solution, desilicated for three days in a ten per cent solution of hydrofluoric acid, imbedded in celloidin, and finally cut on a sliding microtome. The sections were cut approximately 40 microns thick. This procedure was somewhat similar to that used by Searle (19) but different in technique. The cross-sections were in some cases stained with phloxine, but methyl green proved generally more satisfactory. The celloidin matrix was not removed, as it helped to keep the sections intact. Where the methyl green stain was used, the sections were run through absolute alcohol before clearing in xylol, but with the phloxine stain the sections were run to 95 per cent alcohol and then cleared in carbol-turpentine and xylol. This prevented the loss of the celloidin matrix which would dissolve if absolute alcohol followed the treatment with phloxine stain.

The sections were enlarged with a projection microscope shown in Figure 1. The images were thrown on tracing cloth stretched over a glass table top and were focused by means of a handle h shown in Figure 1. With this apparatus the operator could measure the fiber cell area with a planimeter while keeping the image well focused by turning the focusing handle slightly to bring out details, which often varied from fiber bundle to fiber bundle within a section. The number of fiber cells per cross-section was counted, and the area of stem and

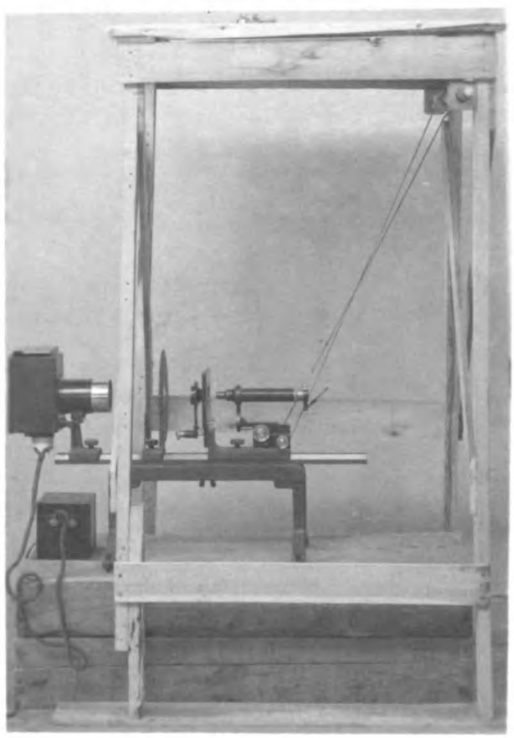

Figure 1. A side view of the projection microscope and table used for the enlargement of the flax plant cross-sections. A top view of the movable table top is shown in Figure 2. The fine adjustment of the microscope was operated by a handle at the right hand upper corner of the table.

Table 5. Data obtained from seedling stems which were grown in the field in 1931 in four different fertilizer series. Each result, with its probable error, is the average of five stems which were sectioned, or an average of 20 stems per treatment. The area of fiber and area of stem are in square centimeters magnified in area 67600 fold. Probable errors were calculated by Bessel formula using (N-1).

FIELD SEEDLING PLANTS

Series No. Treatment	Per cent fiber 1	2	3	4	Ave.	Number of fiber cells 1	2	3	4	Ave.
0-0-0	4.02±.10	4.37±.17	4.20±.23	3.70±.15	4.07±.08	186.8± 5.8	182.0 ± 6.7	217.2 ± 6.6	183.6±10.2	192.4 ± 3.8
4-0-0	3.92±.13	4.54±.32	6.60±.25	4.15±.24	4.80±.12	210.6± 9.4	176.4 ± 7.2	225.0±13.2	208.6 ± 9.6	205.2 ± 5.0
4-16-0	4.76±.21	4.50±.08	4.67±.05	4.91±.25	4.71±.08	221.2± 5.2	228.0 ± 6.6	240.8 ± 7.1	247.8 ± 9.2	234.5 ± 3.6
4-16-8	4.87±.18	4.72±.07	5.53±.09	4.60±.17	4.93±.07	223.2±11.1	215.4 ± 8.5	241.2±12.5	248.4±12.8	232.1 ± 5.7
4-16-16	4.44±.20	4.48±.19	4.72±.23	3.91±.21	4.39±.10	234.4± 9.5	231.6 ± 5.9	230.4 ± 8.5	226.8±13.2	230.8 ± 4.8
0-0-8	4.86±.13	4.05±.24	4.59±.10	4.18±.21	4.42±.09	199.4 ± 8.9	160.0 ± 8.1	223.0 ± 9.1	228.8±11.9	202.8 ± 4.8
0-16-8	3.86±.26	4.36±.14	4.37±.21	4.01±.26	4.15±.11	182.8± 9.5	219.2 ± 7.1	186.6 ± 7.7	217.2±12.7	201.5 ± 4.8
8-16-8	4.78±.20	4.11±.18	4.08±.18	4.02±.20	4.25±.10	222.6±11.7	230.4±12.2	221.8±10.3	211.2 ± 8.8	221.5 ± 5.4
4-8-8	4.04±.16	4.68±.38	4.90±.32	4.54±.06	4.54±.13	230.6± 4.6	247.6±19.2	249.4 ± 7.2	258.8 ± 9.9	246.6 ± 5.8
4-0-8	3.85±.15	4.62±.22	5.13±.33	3.65±.21	4.31±.12	183.4 ± 8.6	206.2 ± 5.3	220.6±18.2	202.6±14.4	203.2 ± 6.3
0-16-0	3.84±.19	lost	4.62±.15	3.71±.10	4.05±.09	198.2±10.1	lost	247.8 ± 8.2	219.8 ± 8.3	221.9 ± 5.1
$CaCO_3$ 2000	3.97±.23	4.98±.21	4.65±.22	3.83±.06	4.36±.10	188.4± 6.3	220.0 ± 5.6	191.8±13.7	231.6 ± 4.5	208.0 ± 4.2
$CaCO_3$ 4000	4.35±.18	4.53±.23	5.00±.31	3.53±.18	4.35±.12	214.2±15.7	204.8 ± 8.9	216.6±10.3	253.4 ± 6.9	222.3 ± 5.5
$CaCO_3$ 6000	3.63±.23	4.44±.31	4.08±.04	3.65±.10	3.95±.10	176.8 ± 9.2	171.0 ± 5.8	221.2±12.2	191.0±16.1	190.0 ± 5.7
	Area of fiber cells					Area of stem				
0-0-0	31.5±1.8	26.3± .6	45.6±4.1	40.5±1.6	36.0±1.2	789.1±51.3	609.6±26.4	1071.8±46.4	1125.6±66.2	899.0±24.8
4-0-0	34.3±3.0	34.7±3.1	76.2±7.0	42.4±3.1	46.9±2.2	868.2±59.8	766.9±47.0	1135.5±63.1	1036.2±64.1	951.7±29.5
4-16-0	46.0±1.1	32.3±1.5	53.8±2.3	63.4±4.5	48.9±1.3	989.9±69.6	721.7±36.5	1148.5±44.3	1297.4±81.1	1039.4±30.3
4-16-8	41.7±2.1	49.5±2.6	71.4±3.8	57.6±4.1	55.1±1.6	868.9±51.0	1050.9±61.9	1291.9±72.0	1252.5±67.7	1116.1±31.8
4-16-16	49.5±3.9	39.4±3.2	58.9±2.7	53.2±3.0	50.3±1.6	1111.7±60.8	875.9±48.9	1281.7±88.6	1375.7±65.1	1161.3±33.7
0-0-8	29.7±1.9	27.9±1.1	48.9±2.5	46.5±3.1	38.2±1.1	607.7±27.6	703.0±41.9	1059.2±34.2	1120.3±54.7	872.6±20.4
0-16-8	33.6±2.4	42.6±1.8	36.9±1.6	39.8±2.4	38.2±1.0	870.5±25.8	995.8±63.8	853.3±37.6	1004.9±48.9	931.1±23.1
8-16-8	43.4±3.3	45.1±3.8	65.4±3.7	65.0±6.2	54.7±2.2	897.7±37.3	1089.8±68.8	1631.8±29.8	1591.9±75.4	1302.8±28.2
4-8-8	46.7±3.3	48.4±5.9	53.2±3.1	52.0±1.8	50.1±1.9	1160.5±70.8	999.9±70.7	1113.6±64.8	1148.7±47.4	1105.7±32.1
4-0-8	34.3±3.4	41.3±1.8	74.4±4.9	43.1±3.4	48.3±1.8	880.6±72.4	911.4±53.9	1458.5±52.7	1173.9±50.4	1106.1±29.0
0-16-0	31.8 ± .8	lost	55.2±4.1	40.0±1.1	42.3±1.4	850.2±48.1	lost	1196.2±79.6	1087.6±46.5	1044.7±34.7
$CaCO_3$ 2000	41.7±2.2	43.5±2.7	38.1±1.5	45.9±1.8	42.3±1.0	1066.2±53.5	887.4±65.8	831.2±44.3	1195.1±32.0	994.9±25.2
$CaCO_3$ 4000	45.4±2.6	43.8±2.8	54.8±2.9	40.0± .8	46.0±1.2	1055.0±69.1	967.1±47.2	1103.4±31.6	1150.3±39.1	1069.0±24.4
$CaCO_3$ 6000	29.1±3.4	36.2±3.0	45.9±2.2	41.8±2.2	38.3±1.4	806.4±90.3	814.7±22.6	1127.4±54.7	1144.8±53.7	973.3±30.2

area of fiber were measured with the planimeter. Due to the fact that many sections were torn slightly in cutting or that the stain throughout the section was not uniform, it was necessary to have some means of calculating the fiber area of a section where it was impossible to measure the complete 360 degrees. This was possible by having the table top moveable, as shown in Figure 2; with a slight shift of the table top from one side to the other the image could be centered within a protractor and definite angles measured. All measurements were taken in duplicate, and at least two different measurements were taken from each stem. Where a reading was taken for a definite angle with the protractor, the result was calculated for 360 degrees, assuming as was usually the case, that the section had a symmetrical arrangement of the bundles. In a few stems it was found that there was 30 to 40 per cent more fiber on one side of the section than on the other, and if such stems had been measured for only 90° or a 150° and the results calculated for the area of the entire stem, undoubtedly an error would arise.

The greatest difficulty experienced in measuring the fiber cells was to distinguish them clearly in the seedling plants. In the mature stems the fiber bundles and cells were always distinct. In the seedling sections the thickening of the fiber cell walls had not proceeded very far, and there were many cells which were probably in a very early transitional stage, which made classification difficult. In the mature plants the cell wall thickening was so far along in its development that all cells could be distinctly classified as either fiber cells or parenchyma cells. That transitional cells exist with very little if any

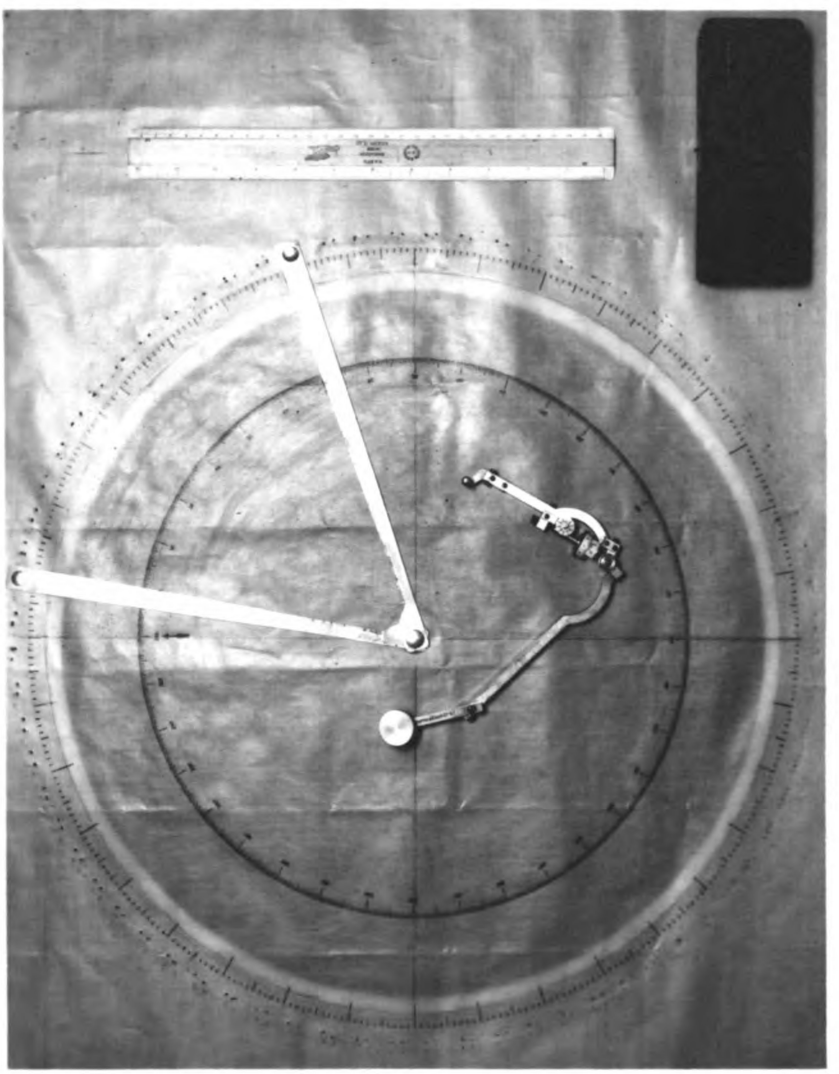

Figure 2. A top view of the movable table top showing the protractor and planimeter used in measuring the fiber cells and stem areas. The dark circular area inside the outer drawn protractor circle indicates the size of the hole in the table top which was covered with plate glass and tracing cloth through which the images were projected.

cell wall thickening may be seen from the results in which the fiber percentages of seedling stems average about four per cent, while in the mature plants the fiber percentages average eight to nine per cent. In Figure 3 it may be noted that in the seedling section the fiber cells are surrounded by parenchyma tissue, while in the mature stems this tissue has almost disappeared and the fiber cells have greatly increased in number.

THE ORIGIN OF FLAX FIBER CELLS

Strands of flax fiber cells are usually called bast fibers. This term is now understood to include all fibers outside the cambium layer, including phloem, pericycle and cortex fibers. The origin of the flax fiber cells has been somewhat disputed. Herzog (8 p.119) mentions earlier studies in which Tammes (21) attributes the fiber cells to primary cambium origin as sclerenchyma fibers of the pericycle, neither belonging to the cortex nor to the bast; Winter (26) disputes this. However, it seems as though the difference of opinion may be entirely due to differences in terminology. In several of the seedling sections studied by the writer the fiber cells showed plainly as pericycle fibers, Figure 3. In these sections the endodermis layer appeared distinctly as it would in root sections and definitely showed the fiber cells to be pericycle fibers. Figures 5 and 6 are photomicrographs of portions of cross-sections from flax stems and illustrate the variability in size, number and area of the fiber cells within different plants.

Figure 3. A photomicrograph of a seedling flax stem which shows a fairly distinct endodermis (E). Inside the endodermis may be distinguished the fiber cells, showing them to arise from the pericycle.

THE INFLUENCE OF DIFFERENT PERIODS OF LIGHT DURATION ON THE HEIGHT OF FLAX PLANTS

The results of flax plants grown under different periods of light in 1928 are shown in Table 1. The plants, as might be expected, responded very differently to varied light durations. Adams (1) grew four sets of flax plants exposed to light for 5, 10, 15, and 20 hours, and four additional sets exposed for 3, 6, 12, and 18 hours, respectively. These plants were measured at the age of 30 and 47 days, respectively, for the two series. Taller plants were produced under the longer periods of illumination. As Adams gave no additional data for older plants, it is impossible to tell if those with shorter light exposure did not finally grow taller than those having a longer exposure to light. The plants reported in Table 1 grown in an 18-hour light period per day grew the most rapidly as seedlings, but flowered and matured in 75 days without attaining any considerable height. Those grown in a 10-hour light period per day grew very slowly at the beginning, but eventually attained the greatest height and after 110 days started to flower, at which time the experiment was discontinued. The plants grown in a 13-18 hour light period per day grew at an intermediate rate and attained an intermediate height. Figure 4 shows plants 75 days old grown under different periods of light. The long-day plants had produced mature seed bolls and seed, the medium long-day plants were in flower and the short-day plants were still far behind in approaching maturity. However, the short-day plants finally exceeded all the other plants in height.

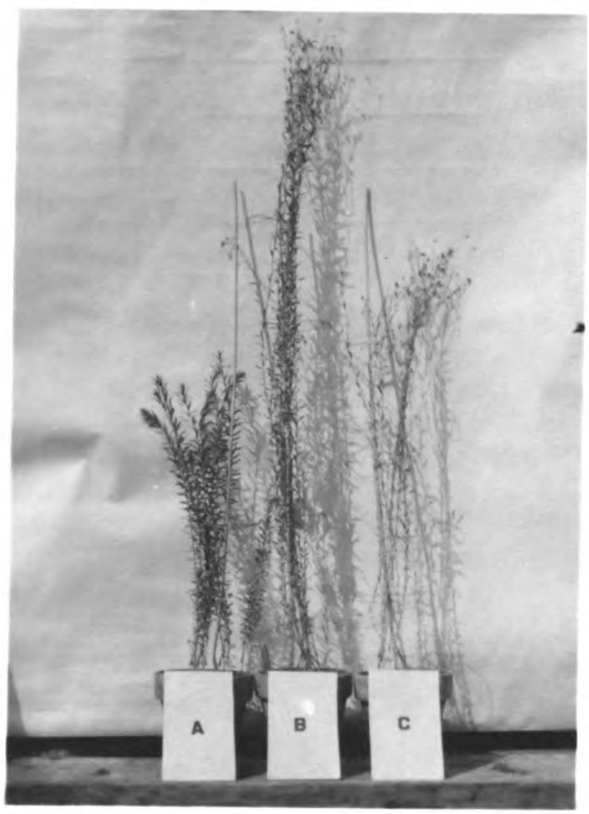

Figure 4. Flax plants all the same age, 75 days, grown in 1928 under different periods of light. The treatments were as follows: (A) 10 hours of light per day; (B) 13-18 hours of light per day; and (C) 18 hours of light per day. The plants in (C) have mature seed; the plants in (B) are in bloom; and the plants in (C) are very far behind in their development.

INFLUENCE OF DIFFERENT PERIODS OF LIGHT DURATION ON THE FIBER YIELD OF FLAX PLANTS

The flax plants grown under different periods of light duration gave very large differences in fiber yields, which is perhaps best shown by figures obtained by multiplying the cross-sectional area of fiber by the height of the plant. The plants grown in an 18-hour light period per day matured so quickly that they did not attain normal size and produced a small number and a very small area of fiber cells, and a low yield of fiber in cubic millimeters. The short-day plants yielded eight times as much fiber in cubic millimeters per plant as the long day plants. The plants which germinated in 13 hours of light per day and received additional light as they grew until at their maturity were receiving 18 hours of light per day developed normally. They had a high percentage of fiber, a good number of fiber cells and were plants of good volume.

INFLUENCE OF NUTRIENT CONDITIONS ON THE HEIGHT OF FLAX PLANTS

The tallest flax plants produce the greatest yields of fiber. However, plants may grow so tall that they lodge and make harvesting more difficult, if not resulting in a loss in yield. Such plants are also susceptible to attack by fungi.

Results are shown in Table 1 with plants grown in a greenhouse in 1928 in soil cultures to which different amounts of nitrate solution were added. Apparently the nitrate alone had little effect in increasing the height or cross-sectional area of the plants in this experiment. In Table 2, which shows results of soil cultures in the greenhouse in 1930, it is apparent that fertilizers produced little effect on height of plants.

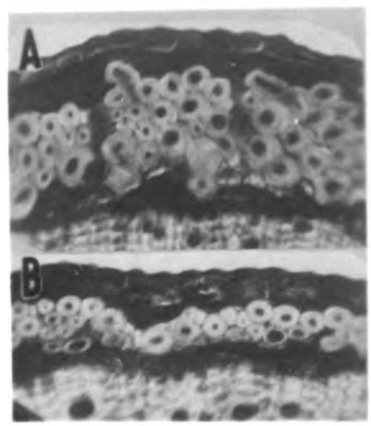

Figure 5. Photomicrographs of portions of cross-sections from flax stems of equal area and magnification showing in (A) a high percentage of fiber - 10.65, and in (B) a low percentage of fiber - 6.87.

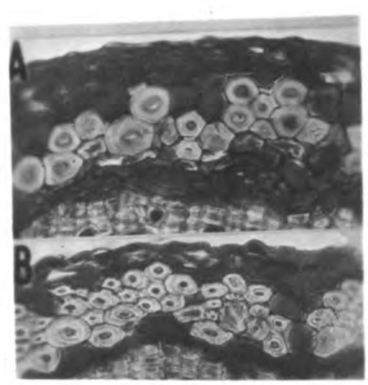

Figure 6. Photomicrographs of portions of cross-sections from flax stems of equal area and magnification showing in (A) a low number of large fiber cells - 339, and in (B) a high number of small fiber cells - 650.

In the water culture experiments the length of stem was greatest where three-salt cultures (particularly the 1.7-30.7-10.1* analysis in the first series, Table 4) were used instead of one-salt cultures. In the second series of plants grown in water cultures in 1931 in the greenhouse, the 2.5-28.4-9.4 and the 3.4-28.4-4.7 (jars 3 and 4, Table 3) treatments gave the greatest dry weights and height of plants. In the third series of plants grown in the greenhouse the same year in media containing different nutrient salts, the 2.6-9.2-6.1 and the 3.5-3.1-2.0 analyses (jars 5 and 9, Table 3) produced the highest yields of dry weights of tops and roots and the tallest plants. It is interesting that the cultures which yielded the best in the first and second series of water cultures, were cultures with very similar analyses, being very high in phosphorus and medium high in potassium. Two of the best yielding cultures (jars 4 and 5) of the third series resembled in their analyses those which yielded well in other experiments.

In Table 6 are shown the actual stem lengths of seedling and mature plants from replicated field fertility plots. A study of the seedling stem length shows that nearly all of the fertilizer treatments produce taller plants than the no-fertilizer treatment. The treatments containing nitrogen, particularly in combination with other elements, produced the tallest plants. However, the lengths of stems of the mature plants from different fertilizer treatments varied only from 66.0 to 75.8 cm. The differences in only a few cases are statistically significant. The relationship in height between the different fertilizer treatments in the mature stems is similar to that of the seedling stems, with the exception that the results of the 0-0-0 and

*The order of the fertilizer elements in analyses in this paper is N-P-K.

Table 6. Actual stem lengths in centimeters of the average of five seedling or mature stems for each of the four series of fertilizer treatments. The stems were plants grown under field conditions in 1931 and which were sectioned, the results of which are shown in Tables 5 and 7. The yield of fiber in cubic millimeters is given both for the seedling and the mature stems. Probable errors were calculated by Bessel's formula using (N-1).

FIELD PLANTS, 1931

Seedling stem lengths in cm.

Series No. Treatment	1	2	3	4	Ave.	Yield of fiber cu. mm.
0-0-0	20.1± .7	23.6 ± .6	29.6±1.0	22.5 ± .6	24.0 ± .4	12.8 ± .5
4-0-0	23.6±1.1	23.9 ± .5	28.4 ± .4	26.0 ± .7	25.5 ± .4	17.7 ± .9
4-16-0	27.1 ± .9	19.9 ± .6	29.0 ± .4	37.5±1.8	28.4 ± .5	20.5 ± .6
4-16-8	25.4 ± .8	22.5 ± .4	34.2±2.1	30.4 ± .7	28.1 ± .6	22.9 ± .8
4-16-16	24.8 ± .6	25.5±1.0	33.1 ± .5	38.4±1.4	30.5 ± .5	22.7 ± .8
0-0-8	18.4 ± .1	17.2 ± .4	25.9 ± .5	34.0±1.0	23.9 ± .3	13.5 ± .4
0-16-8	18.5 ± .4	23.0±1.3	26.2 ± .4	29.3 ± .9	24.3 ± .9	24.3 ± .4
8-16-8	23.2 ± .7	25.0±4.5	36.0±1.6	33.4±1.2	29.4±1.2	23.8±1.4
4-8-8	26.9 ± .9	26.5±1.2	30.1±1.4	34.0±1.1	29.4 ± .6	21.8 ± .9
4-0-8	21.1 ± .8	17.6 ± .6	32.3±1.5	27.9±1.4	24.7 ± .6	17.6 ± .8
0-16-0	21.9±1.2	17.9 ± .5	33.7±1.3	31.8±1.3	26.3 ± .6	16.5 ± .7
$CaCO_3$ 2000	23.3 ± .3	23.0±1.0	22.4 ± .8	29.8 ± .8	24.6 ± .4	15.4 ± .4
$CaCO_3$ 4000	23.4 ± .9	21.3 ± .6	29.1±1.3	29.1 ± .4	25.7 ± .4	17.5 ± .5
$CaCO_3$ 6000	19.4 ± .7	21.6±1.3	28.0 ± .5	23.2±1.5	23.1 ± .5	13.1 ± .6

Mature stem lengths in cm.

Series No. Treatment	1	2	3	4	Ave.	Yield of fiber cu. mm.
0-0-0	67.6±1.5	71.4±1.0	74.2 ± .3	75.8 ± .5	72.3 ± .5	149.3±4.0
4-0-0	67.6±1.1	61.4 ± .9	68.6±1.0	66.3±2.8	66.0 ± .8	120.8±2.8
4-16-0	71.9±2.9	68.1±2.8	75.4±2.7	71.8±1.9	71.8±1.3	123.6±3.8
4-16-8	79.6±1.8	74.8±2.1	74.9±1.1	70.2±1.4	74.9 ± .8	134.4±4.3
4-16-16	69.6±2.0	73.0±2.7	73.7±1.3	70.7±1.7	71.8±1.0	140.3±4.2
0-0-8	70.1±2.7	66.7±1.6	76.5±1.7	76.9±1.5	72.5±1.0	148.8±4.9
0-16-8	62.5±1.5	69.7±1.7	77.4±2.8	67.2±1.3	69.2±1.0	124.4±3.8
8-16-8	70.8±2.2	63.1±1.9	76.9±1.8	77.0±2.9	72.0±1.1	134.3±4.1
4-8-8	66.3±2.2	78.2±1.7	65.8± .9	77.2±5.9	71.9±1.6	129.8±5.3
4-0-8	74.2±2.6	72.4±2.1	75.6±1.8	81.2±1.2	75.8±1.0	180.4±7.2
0-16-0	74.7±1.1	69.2±2.8	78.6±1.0	75.3±1.6	74.5 ± .9	136.6±4.5
$CaCO_3$ 2000	60.6 ± .9	74.3±2.2	67.7±1.2	71.1±2.6	68.4 ± .9	119.4±4.5
$CaCO_3$ 4000	68.4±1.5	72.4±1.0	69.5±1.6	72.4±1.7	70.7 ± .7	118.4±3.5
$CaCO_3$ 6000	69.6±1.5	65.9±2.0	73.9±1.6	75.8±2.7	71.3±1.0	151.9±4.5

4-0-8 treatments are too high.

It is possible that some fertilizers, particularly nitrogen, would tend to produce more rapid growth in the seedling stages, resulting in a longer stem, but as maturity approached, plants fertilized with phosphorus and potassium would equal or even surpass the fast growing seedling plants. Nitrogen, whenever applied, produced marked increase in height in the seedling plants sectioned. In the mature plants from the same plots and treatments, the effect of nitrogen in early growth has been equalled or surpassed in some cases by phosphorus and potassium. Potassium, as mentioned earlier in the literature cited, has usually resulted in an increase in the height of mature plants.

INFLUENCE OF NUTRIENT CONDITIONS ON THE PERCENTAGE OF FIBER OF FLAX PLANTS

Under field conditions average yields of fiber seldom exceed 400 pounds per acre. If we think of this as a yield from mature stems with 8.5 per cent of fiber as measured by cross-sectional area, then an increase of one per cent of fiber per stem would actually be an additional yield of 47 pounds of fiber per acre, or 11.75 per cent increase in the total yield per acre. This would probably be the maximum obtainable, provided a fertilizer did not cause a greater height of plants, an increase in areas of stems, or an increase in the stand of plants per acre of ground. In the field experiments reported here, the greatest difference in percentage of fiber due to fertilizer treatment was 1.54 ± .17. In water cultures in the greenhouse experiments where conditions were such that greater variability could be secured, the potassium (K) culture yielded 5.77 ± .18 per cent fiber, and the NP2K

treatment with an excess of potassium yielded only 3.08 .29 per cent fiber. It is interesting to observe in Table 4 that plants grown only in tap water yielded a higher percentage of fiber, 4.72 .18 per cent, though they did not attain any great height.

Seedling flax plants grown under field conditions did not vary more than one per cent as between treatments, in percentages of fiber. A difference of approximately one-half per cent fiber, between any two treatments is statistically significant.

The percentage of fiber in the mature plants grown under field conditions was twice as great as it was in the seedling plants. This indicates that many cells surrounding the fiber cells, at the stage of the plants when the seedlings were measured, had not progressed far enough in their development to be called fiber cells, though later thickening of their cell walls took place. As in the seedling series, the mature stems did not show great differences in fiber percentages, as between the different treatments. For some reason not understood the check plot yielded next to the highest percentage of fiber and the results of the 0-16-0 fertilizer appear inconsistent with some of those obtained from the other plots. Statistically the data from all the field mature plants show significant differences only in one or two cases.

THE INFLUENCE OF NUTRIENT CONDITIONS ON THE NUMBER OF FIBER CELLS OF FLAX PLANTS

The percentage of fiber as determined in relation to cross-sectional area of stem is not always indicative of the fiber yield, because the plants may vary in diameter as well as in length. The

data on the production of fiber cells shown in Tables 1 and 2 are based upon too few sections per treatment to have any great significance. However, they serve in a way to indicate the trend and agree with some conclusions drawn from results which are obtained in other experiments.

The results with water cultures grown in 1931 show the necessity of having a complete solution for the best production of fiber cells. Cultures containing three salts - a complete solution - produced more fiber cells than one salt or two salt cultures, with one exception. The one exception was a complete solution containing an excess of potassium (NP2K) which was too toxic for the plants, retarding their growth and in many cases killing them. It cannot be said from these experiments whether potassium or nitrogen had a greater influence on the production of fiber cells, but it is definitely shown that potassium in excess decreases the number.

In Table 5, which shows the results obtained upon seedling plants grown in field replicated fertility plots in 1931, the number of fiber cells per stem is fairly constant, being similar to the percentages of fiber per stem. The results show that a difference of approximately 25 cells may be regarded as a significant difference, and nearly half of the treatments show an increase of 25 cells over the check plot. Fertilizers giving the greatest increase in number of cells per plant over the control are: 4-8-8, 4-16-0, and 4-16-8. The mature plants obtained from the same field replicated fertility plots in 1931, the results of which are shown in Table 7, indicate that no one treatment effected a significant increase or decrease in the number of fiber cells when compared with the check. The two lighter applications of calcium

Table 7. Data obtained from mature stems which were grown in the field in 1931 in the same four fertilizer series as shown in Table 5. Each result with its probable error in the first series is the average of five stems which were sectioned. Five plants from each of the remaining series were bulked together. The average is weighted for the mean of 20 plants. The area of fiber cells and area of stem are in square centimeters magnified in area 67600 fold. Probable errors were calculated by Bessel's formula using (N-1).

FIELD MATURE PLANTS

Series No. Treatment	Per cent fiber 1	Per cent fiber 2, 3, & 4	Per cent fiber Ave.	Number of fiber cells 1	Number of fiber cells 2, 3 & 4	Number of fiber cells Ave.
0-0-0	8.01 ± .59	9.75 ± .16	9.32 ± .16	451.6 ± 9.7	510.3 ± 14.0	495.6 ± 6.5
4-0-0	7.05 ± .12	9.55 ± .20	8.93 ± .09	348.2 ± 16.1	487.7 ± 14.4	452.8 ± 7.4
4-16-0	7.38 ± .34	8.79 ± .18	8.44 ± .12	401.0 ± 25.5	481.2 ± 15.3	461.2 ± 9.2
4-16-8	7.76 ± .25	8.10 ± .24	8.02 ± .12	498.4 ± 28.4	482.8 ± 14.3	486.7 ± 9.4
4-16-16	7.26 ± .47	8.69 ± .29	8.33 ± .17	400.2 ± 12.9	505.4 ± 11.1	479.1 ± 5.8
0-0-8	8.54 ± .33	9.24 ± .16	9.07 ± .11	516.2 ± 32.5	486.5 ± 9.5	493.9 ± 9.1
0-16-8	9.25 ± .40	8.04 ± .15	8.34 ± .12	439.4 ± 7.7	482.3 ± 12.9	471.6 ± 5.9
8-16-8	8.92 ± .18	8.53 ± .24	8.63 ± .11	459.0 ± 37.4	467.0 ± 14.1	465.0 ± 11.2
4-8-8	9.43 ± .11	8.05 ± .26	8.40 ± .12	382.2 ± 24.6	500.5 ± 23.1	470.9 ± 11.7
4-0-8	9.40 ± .67	8.84 ± .24	8.98 ± .20	538.4 ± 72.2	506.3 ± 12.6	514.3 ± 18.9
0-16-0	10.34 ± .29	9.30 ± .23	9.56 ± .12	485.2 ± 19.0	524.1 ± 18.9	514.4 ± 9.5
$CaCO_3$ 2000	8.81 ± .16	8.60 ± .21	8.65 ± .10	362.6 ± 16.0	487.0 ± 12.9	455.9 ± 6.9
$CaCO_3$ 4000	8.52 ± .55	8.98 ± .26	8.87 ± .18	454.2 ± 15.8	432.9 ± 12.8	438.2 ± 6.8
$CaCO_3$ 6000	8.31 ± .45	9.22 ± .14	8.99 ± .13	503.2 ± 32.9	480.0 ± 13.8	485.8 ± 10.2
	Area of fiber cells			Area of stem		
0-0-0	94.9 ± 8.6	154.6 ± 6.9	139.7 ± 3.7	1177.1 ± 42.8	1608.5 ± 83.2	1500.7 ± 37.6
4-0-0	82.1 ± 5.3	137.7 ± 4.6	123.8 ± 2.4	1178.2 ± 95.4	1452.7 ± 46.5	1384.1 ± 31.2
4-16-0	110.5 ± 5.6	118.4 ± 5.8	116.4 ± 2.9	1548.5 ± 136.1	1359.4 ± 69.7	1406.7 ± 45.5
4-16-8	108.2 ± 4.6	125.7 ± 8.0	121.3 ± 3.7	1397.2 ± 44.5	1536.4 ± 66.6	1501.6 ± 30.9
4-16-16	91.6 ± 5.5	145.6 ± 7.3	132.1 ± 3.5	1282.9 ± 81.6	1681.7 ± 64.1	1582.0 ± 34.5
0-0-8	150.7 ± 12.7	134.8 ± 6.1	138.8 ± 4.1	1742.5 ± 101.8	1467.3 ± 66.7	1536.1 ± 38.5
0-16-8	117.5 ± 8.5	122.8 ± 5.8	121.5 ± 3.3	1273.7 ± 78.9	1517.1 ± 52.3	1456.3 ± 30.1
8-16-8	133.0 ± 8.1	123.8 ± 6.2	126.1 ± 3.3	1502.8 ± 111.1	1470.3 ± 71.8	1478.4 ± 41.7
4-8-8	111.5 ± 10.0	125.5 ± 7.6	122.0 ± 4.1	1173.9 ± 95.7	1564.1 ± 85.3	1466.6 ± 44.0
4-0-8	140.4 ± 19.4	167.9 ± 8.2	161.0 ± 6.0	1456.9 ± 121.8	1932.8 ± 91.6	1813.8 ± 50.0
0-16-0	124.0 ± 9.8	123.8 ± 6.7	123.9 ± 3.8	1190.4 ± 75.2	1320.5 ± 61.5	1288.0 ± 32.6
$CaCO_3$ 2000	90.6 ± 12.1	127.1 ± 6.6	118.0 ± 4.2	1019.0 ± 122.1	1496.5 ± 80.4	1377.1 ± 46.3
$CaCO_3$ 4000	104.0 ± 6.9	116.3 ± 6.2	113.2 ± 3.2	1231.3 ± 65.8	1287.5 ± 47.5	1273.5 ± 26.3
$CaCO_3$ 6000	114.2 ± 8.1	154.0 ± 7.4	144.1 ± 3.8	1370.3 ± 53.8	1665.1 ± 72.7	1591.4 ± 34.2

carbonate resulted in the lowest number of fiber cells. Possibly an increased production of fiber cells depends on a definite ratio of the fertilizer ingredients or a proper balancing of the nutrient elements. In a few cases it appears that potassium did influence the production of fiber cells, but there were instances where just as large increases were secured from nitrogen or phosphorus.

THE INFLUENCE OF NUTRIENT CONDITIONS ON THE AREA OF FIBER CELLS OF FLAX PLANTS

At the beginning of the experiments reported here, it was not definitely known whether or not the yield of fiber from four to six-week old seedling plants would be representative of the future fiber development of the mature plants. The opinion of some flax breeders has been that there is a critical stage in the development of the flax fiber cells and this is the very early seedling stage. The data presented here show that in field seedling plants even 41 days old, the fiber cells are not far enough along in their development to distinguish more than one-third of them. The development and thickening of the fiber cell walls probably continue almost to the time of the plants' maturity. However, it is believed from results obtained that even though all the fiber cells in seedling plants cannot be distinguished, the number and area of the ones which can be distinguished is representative of the future fiber development when comparison is made between treatments.

The data on the area of fiber cells from plants grown in water cultures are shown in Table 4. In a number of cases treatments receiving one or more salts have a significantly larger fiber area as compared with that of plants grown in tap water. These increases seem

to be directly correlated with the increase in the area of stem and the number of fiber cells per stem. As the area of stem increases, the percentage of fiber as measured by cross-sectional area remains approximately the same, but an increase in the area of fiber is obtained.

Results obtained upon field grown seedling plants and presented in Table 5 show that a difference of approximately 6.5 square centimeters (magnified) in area of fiber cells is significant. Many of the treatments show even larger differences. The greatest increase above the check plot was caused by the 4-16-8 treatment. This amounted to 53 per cent. The areas of fiber cells in the mature stems are variable, but only one treatment, 4-0-8, appears to have caused a significant increase in area of fiber cells over the check plots. In both the seedling and mature plants the area of fiber cells is closely correlated with the area of stem. Therefore, fertilizers tending to increase the area of stem would also increase the area of fiber cells.

THE INFLUENCE OF NUTRIENT CONDITIONS ON THE STEM AREA OF FLAX PLANTS

The positive correlation between cross-sectional area of the flax stem and area of fiber cells has been mentioned. In general then, greater yield of fiber may be expected with such fertilizer applications as effect an increase in area of the stem. In the water culture experiment, the results of which are shown in Table 4, the area of the stem was the greatest, for complete solution treatments, and less for the one- or two-salt culture treatments. The area of the stem for seedling field plants increased with the application of fertilizer,

and the 8-16-8 application gave a 45 per cent increase over the check plot. The 8-16-8 application resulted in a slight reduction in area of stem, as compared with the check.

THE INFLUENCE OF NUTRIENT CONDITIONS ON THE YIELD OF FIBER IN CUBIC MILLIMETERS OF FLAX PLANTS

Naturally the large differences in percentage of fiber, area of fiber cells, and height of plants between the different water cultures shown in Table 4 produced large differences in the yield of fiber, expressed in terms of cubic millimeters per plant. The N2PK culture yielded approximately eight times as much fiber as the one- and two-salt cultures, and 2.25 times that of the 2NPK culture. The N2PK culture when calculated to the fertilizer analysis gives a 1.7-30.7-10.1 ratio. This is low in nitrogen but high in phosphorus and potassium. This represented a total salt concentration much higher than is probably the case in field soils, and the salts were probably in a more available form. The large increase in the yield of fiber in cubic millimeters obtained from several of the water cultures is due largely to the influence of the fertilizer salts on the average height of the plants.

In Table 6 a difference of four cubic millimeters is significant for most yields of fiber for the seedling field grown plants. This increase was obtained in all of the complete fertilizer plots when compared with the check treatment. The greatest increases were obtained with the 0-16-8, 8-16-8, 4-16-8, and the 4-16-16 treatments. The increase in yields of fiber in cubic millimeters with these three fertilizers averages about 80 per cent and is partly accounted for by the fact that the fertilizers produced taller plants.

The variability in the yield of fiber expressed as cubic milli-

meters per mature stem for different treatments, as shown in Table 6, is not due so much to the variability in the length of stems as to the area of fiber cells (see Table 7). The average probable errors for yield of fiber in cubic millimeters for these mature stems is 4.4; so it is necessary to have a difference of 20 cubic millimeters, or more, of fiber for the results to be significant. Such large differences between treatments were obtained in only a few cases. Additional data will have to be obtained to understand clearly this problem.

A FERTILIZER ANALYSIS FOR FLAX PLANTS

Results on seedling plants grown in water cultures and in the field are fairly comparable but the results on mature stems grown in the field are inconclusive. Nevertheless, application of some nitrogen upon the soil used in the field experiments seemed necessary for the best results with seedling plants, though the best results were usually where nitrogen did not exceed four per cent. The data for the field-grown mature plants were inconclusive. Fertilizers high in phosphorus, similar to a 3-28-9 (with one exception), gave the best results in the different series of water cultures. Potassium when applied as a single salt in water cultures gave the highest percentage of fiber in the series in which it was tested. When used in complete nutrient solutions it was present in the highest yielding cultures in concentrations as high as 9 to 11 per cent. In the field fertilizer experiments the best results were usually obtained with an eight per cent potassium treatment, while a 16 per cent treatment seemed to be too concentrated. This was also the case in the water cultures where the NP2K solution was so toxic that it killed some of the plants and resulted in a low percentage

of fiber in those that survived. From all of these results it seems probable that an analysis similar to a 4-16-8 is the most desirable for fiber flax under conditions where little is known regarding the soil requirements. Possibly the phosphorus percentage might be increased for better results but this will have to be tried out under field conditions.

SUMMARY

Photomicrographs from seedling flax stems prove definitely that the flax fiber cells arise from the pericycle.

Flax plants eventually attain the greatest height in short periods (10 hours) of light per day but elongate and mature the quickest in long periods (18 hours) of light per day. The short-day plants yielded eight times as much fiber as the long-day plants. Plants with a gradually lengthening seasonal daylight schedule (13-18 hours) had a high percentage of fiber, a good number of fiber cells, and were plants of good volume.

The height of a flax plant more than anything else determines how much fiber it contains. A complete nutrient solution was necessary in water cultures to produce the tallest seedling. Cultures lacking any one of the essential plant food elements for growth showed little difference from one another but did not grow as well as the complete cultures. Nitrogen, particularly in combination with other elements, produced the longest stems in field grown seedling plants, but results from these same fertility plots showed that plants fertilized with phosphorus and potassium equalled or even surpassed the nitrogen plots at maturity. Combinations of potassium and nitrogen seem to be desirable for best results.

Seedling field-grown plants gave the highest percentages of fiber with the following treatments, 4-0-0, 4-16-0, and 4-16-8. The percentage of fiber in the mature field-grown plants was twice as great as it was in the seedling plants but another year's results are necessary in order to determine the proper treatment. Some of the results substantiate the conclusions of other workers that phosphorus increases the fiber percentage and that nitrogen decreases it, but there were exceptions to this rule.

Results with water cultures show the necessity of having a complete solution for the best growth of the plant as well as the greatest production of fiber cells. The number of fiber cells increases after the plant is six weeks old. The number of fiber cells in field grown seedling plants increased with additions of fertilizers, but no significant increase or decrease was obtained in number of fiber cells in mature stems for any fertilizer treatment when compared with the check.

The area of fiber cells, as seen in cross-section, is closely correlated with the area of stem, and fertilizers tending to increase the area of stem and probably the number of fiber cells will increase the area of fiber cells.

Water cultures which produced the best yields of fiber were high in phosphorus and medium high in potassium. The 0-16-8, 4-16-8, 8-16-8, and 4-16-16 treatments gave the largest yields of fiber in cubic millimeters per stem for seedling field-grown flax plants. Mature field-grown plants gave the largest yields of fiber in cubic millimeters per stem with the following treatments: 4-0-8, $CaCO_3$ 6000 pounds, 0-0-0, and 0-0-8. Medium high yields of fiber in cubic millimeters per stem

were obtained with the treatments 4-16-16 and 4-16-8.

A study of the various cultures leads to the conclusion that a fertilizer analysis closely approximating a 4-16-8 is the most desirable for fiber flax where little is known regarding the soil requirements.

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