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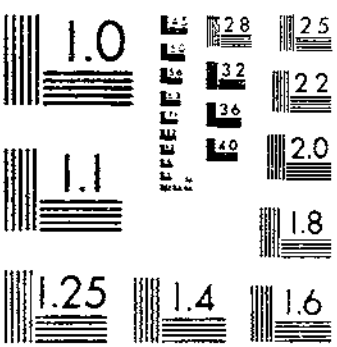
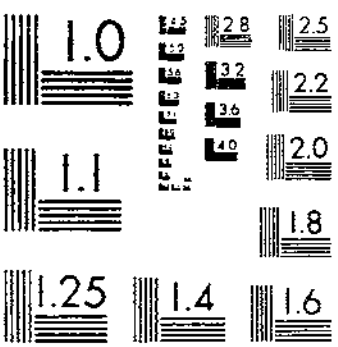


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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THE TIME TO HARVEST FIBER FLAX[1]

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CONTENTS

INTRODUCTION

Fiber flax is harvested at various stages, depending upon the climate in which it is grown and the purpose for which the flax is intended. It has generally been thought that fiber flax should be harvested early for fiber of the best quality and later for good seed. It has been said that the best fiber can not be obtained if good seed is produced and vice versa. Therefore the time to harvest may be considered a very important agronomic point in the yield and quality of the straw, fiber, and seed. In some localities the farmer can harvest at only one stage, due to climatic conditions which would prevent earlier or later pulling. In other sections the harvest, if desired, could be accomplished over a longer period of time; hence the maturity of the plant might be a determining factor in deciding when to begin to harvest.

The harvest stages of flax are called green ripe, yellow ripe, and full ripe. In the United States fiber flax may be harvested at all three stages, but it is rarely pulled at the green-ripe stage. This is, however, the common stage for pulling in Ireland and to some extent in western continental Europe, where the best quality of fiber is produced. Green ripe refers to the plant at an early stage after full bloom, when the stems and leaves are green. During this period the fiber separates easily and yields a very fine product, but the seed is entirely sacrificed. Yellow ripe refers to a later stage of develop-

[1] The experiments reported were carried on in cooperation with the Michigan Agricultural Experiment Station.

[2] The writer expresses his appreciation for assistance given and suggestions made by Lyster H. Dewey, senior botanist in charge, Office of Fiber Plants, Bureau of Plant Industry, and for the help of B. E. Hartsuch, chemistry department, Michigan State College, in performing the chemical work and making suggestions.

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ment when the stems and leaves have turned yellow because of loss of chlorophyll and many of the leaves have fallen off. Plants harvested at this stage have a medium-fine fiber which is stronger than that harvested at the earlier period. In the late yellow-ripe stage the seed is also obtained, which is an important source of revenue. Full ripe is what the name implies; the seed is fully developed and the plant is mature or dead. The fiber at this stage is said to be lignified and is difficult to separate from the wood. It has lost its silkiness, luster, and elasticity and has become of secondary importance to the seed. The seed is of very good quality, but little, if at all, better than that obtained in the late yellow-ripe stage. If the weather at harvest time is very wet, the plants will remain green, although the seed may be fully developed. This occurs sometimes in Michigan, but rarely in Oregon where fiber flax is grown. The dry harvest season in Oregon cures the flax to a beautiful yellow color, and there the bolls remain yellow even at the full maturity stage.

In the United States and Canada very little fiber flax has been pulled during the green stage in recent years because the maximum yield of seed has usually been desired, and the farmers have waited for a late yellow-ripe or full-ripe stage. Nearly all the American fiber-flax farmers pull their flax in the late yellow-ripe stage.

In selecting the time to harvest fiber flax in the United States and Canada, most farmers follow the rule of harvesting when one-third to one-half of the seed bolls are yellow to brown with fully developed brownish seeds. At this time the stems have usually turned yellow and the leaves have fallen off the stem two-thirds of the distance up from the ground. Experience shows that if flax is cut or pulled at this time immature seed will mature in the shock and the yield of seed will be as large as if harvested later. Further, the fiber will be of good quality under average climatic conditions, and this is considered the most profitable period for harvesting fiber flax under our economic system. If there is rainy weather at harvest time, flax is likely to make a "second growth," and this does not allow one to judge the stage of the plant very well by the color of the stem. The stem will remain green and the leaves that ordinarily fall off will remain or new leaves will be produced. In cases of this kind it is necessary to judge the maturity of the plant by the seed bolls. The seeds in the bolls rattle when they are hard and mature, and the harvest begins as soon as this becomes noticeable. Fiber-flax fields may have a red appearance when dead ripe, and it is desirable to pull before this stage is reached.

REVIEW OF LITERATURE

There has been little scientific investigation covering completely the time to harvest fiber flax. Tobler (*18*)[3] in the most recent scientific book on fiber-flax culture cites the more important research publications on this subject. Ivanow (*14*) made a number of chemical analyses of the vegetative parts of the plant (leaves, stems, and roots together) and also of the seed. These analyses, made at four different stages in the growth, showed an increase of the oil in the seed as it matured. A small decrease occurred in the percentage of ether extract and in the iodine number of the vegetative parts of the plant from

[3] Italic numbers in parentheses refer to Literature Cited, p. 21.

the seedling stage to the formation of flower buds. No data were given for the vegetative parts after flowering started. Starch and sugars also were studied by Ivanow, as he attempted to show the source of food used in the oil formation of the seed. Dillman (*9*) has made recent studies upon the oil content of the maturing seed of flax, and his results show a steady and rapid increase in the formation of oil in dry seeds from 7 days after flowering until 25 days after flowering, when a constant is reached. His work was conducted upon a seed-flax variety and does not give results directly applicable for fiber flax because in the field the flowers do not all blossom at the same time but over a period of several days, and information is desired regarding the oil content of immature and mature seed together as it is produced, pulled, and cured in the green and yellow stages.

Hutchinson (*13*) conducted the most extensive tests upon the production and quality of fiber harvested at different stages. His results showed that in general the latest date of harvesting gives the greatest yields of fiber and seed, but in certain tests the opposite results were secured. His results were based upon the averages of three plots for each stage, pullings being made once a week for four weeks. In certain years the delayed harvest resulted in more and stronger fiber, but there was little difference in the quality except in strength. He stated (*12*) that silkiness or oiliness is essential to spinning, as a dry, bare fiber yields a product of lower value.

Barker (*3*), Barker and Eyre (*4*), Eyre and Fisher (*10*) have brought forward evidence to discredit the view that ripening seed on the flax plant drains from the stem an oleaginous sap, thereby impairing the quality of the fiber resulting from such straw. They show that when flax is grown as a fiber crop and has come to the proper state for pulling, which is reached about three weeks after full flowering, the oil content of the seed has reached its maximum and the seed is developed sufficiently for use as a sowing seed.

It is thought by some that the amount of oil present in the flax fiber is an indication of quality. Fargher and Withers (*11*), writing about cotton, state:

> It is generally agreed that at the customary temperature of the spinning mill the waxes in the fiber become soft and semiliquid, and thus allow the proper working of the cotton. After spinning, the oil sets and cements the fibers. Spinning trials of Egyptian cotton deprived of its wax showed that the material behaves very badly in the drawing and spinning processes, giving an excessive amount of waste, irregular results, and showing a tendency to adhere to the rollers.

It has been stated by Anderson (*1*), Ruschmann (*17*), and others that the harsh fiber customarily obtained in the later stages is due to the lignifying of the cellulose in the fiber cells. According to the former (*1, p. 207*):

> Lignification increases with the age of the fiber, being most widespread in the fibers at the base of the stem. It increases as the stem matures, especially in the later stages of the stem's growth, and it is this fact that plays so important a part in determining the proper time for pulling the flax plant. Flax pulled too late is regarded as "harsh"; in other words it is lignified to a greater extent than is desirable. The lignification of the middle lamella and secondary wall interferes with the easy separation of the fibers from one another and renders the commercial fiber coarser.

Ruschmann (*17, p. T64*) makes the following statement: "The fully ripe plant should never be harvested, as the divisibility and spinning quality of the flax are greatly injured by increasing lignification."

Bradbury (*5*, *p.* 77) states:

> It has been generally experienced that when flax straw is pulled and retted in the green state the resultant fiber is finer and silkier than the straw pulled at a later and more matured stage, but the total yield in volume and weight of fiber is relatively smaller * * *. It consequently happens that when the plants are pulled at such an early period, the seed in the bolls is immature and too small in size and too light in weight for sowing.

Bredemann (*7*) and Opitz and Pander (*15*) present data showing the effect of early harvest upon the germination of the seed and the weight of 1,000 seeds. They show significant increases in the weight of 1,000 seeds and their germination between the green-ripe and yellow-ripe, and between the yellow-ripe and full-ripe stages of maturity.

Several workers (*7*, *8*, *15*, *19*), besides presenting results on the germination, percentage of oil, and weight per 100 seeds, have also determined the specific gravity of the seed; the iodine number, the saponification number, the refractive index, and the acid number of the oil; and the percentage of nitrogen and sucrose of seed flaxes harvested at different periods of maturity.

EXPERIMENTAL METHODS

In this bulletin are presented the results of three years' experiments upon flax plots harvested at different stages. Extensive notes were taken upon the appearance of the plants on different days in order that any harvest period might be duplicated another year. These notes are shown in Tables 1 and 2, which give the appearance of the plants on different harvest days in regard to color of the stems, presence or absence and color of the leaves, number of flowers, and size and color of the bolls and seeds from day to day.

The field from which the flax was obtained in 1926 was planted at the rate of 80 pounds of seed per acre with a force-feed, 20-disk type drill with 4 inches between the disks. The Saginaw variety of flax was used. This is a pure-line variety adapted to Michigan conditions. A strip 30 feet wide, with the drill rows running crosswise, was marked off; and on each day except Sundays, for a period of 30 days, a drill row of flax 30 feet long was pulled. Every other drill row was skipped in pulling, and 11 of these skipped rows were harvested on August 5, the last day, to check the soil heterogeneity.

TABLE 1.—*Appearance of flax plants on different days of harvest in 1926 as to color of stems, presence or absence and color of leaves, number of flowers, size and color of bolls, and condition and color of seeds*

Date of harvest	Stems		Color of leaves	Average number of flowers per plant	Bolls		Dry seeds	
	Color	Portion above root without leaves			Size	Color	Condition	Color
		Inches						
July 7	Green	8	Green	2	One-half full size	Green	Very immature and small	Greenish brown.
July 8	do	10	do	2	do	do	do	Do.
July 9	do	13	do	1	Two-thirds full size	do	Flakes	Green to greenish brown.
July 10	do	15	do	.5	do	do	do	Do.
July 12	do	17	do	.1	Three-fourths full size	do	Flat, immature, small to full size.	Do.
July 13	do	19	do	.05	do	do	do	Do.
July 14	do	20	do	.01	do	do	Immature, mostly full size, flat.	Do.
July 15	do	20	do	0	Full size	do	do	Do.
July 16	do	20	do	0	do	do	do	Mostly green, very few brown.
July 17	Turning yellow	20	Turning yellow	0	do	Turning yellow	Immature	Some gray flakes.
July 19	Yellow, 40 per cent	20	Few green	0	do	do	Maturing	Some reddish brown but mostly dark green.[1]
July 20	Yellow, 50 per cent	20	do	0	do	do	do	Do.
July 21	Yellow, 75 per cent	20	do	0	do	Yellow to brown, 75 per cent.	do	Light reddish brown, many tan, some green.
July 22	Yellow, 80 per cent	20	do	0	do	Yellow to brown, 80 per cent.	do	Do.
July 23	Yellow, 90 per cent	20	None green	0	do	do	do	Light brown, very few green.
July 24	do	20	do	0	do	do	do	Do.
July 26	do	20	Few green	0	do	Yellow to brown, 95 per cent.	do	Brown, some light colored.
July 27	Yellow	20	do	0	do	Yellow to brown	do	Do.
July 28	do	20	do	0	do	do	do	Do.
July 29	do	20	do	0	do	do	Nearly mature	Brown, no black.[2]
July 30	do	20	do	0	do	do	do	Do.
July 31	do	20	do	0	do	do	do	Do.
Aug. 2	do	20	None green	0	do	do	All mature	Dark brown, few black.
Aug. 3	Some dead	20	do	0	do	do	do	Do.
Aug. 4	Few green	20	Few green	0	do	do	do	Do.
Aug. 5	do	20	do	0	do	do	do	Do.

[1] A very marked difference in color of the seed occurred between July 20 and July 21. All seeds from plants pulled before July 20 had a greenish shade, and the seed obtained on July 21 and later had a brownish shade.

[2] A marked difference in color of the dry seeds occurred between the July and August pullings. The flax averaged 30 inches in height at maturity. The first blossoms were noticed on June 29.

TABLE 2.—*Appearance of flax plants on different days of harvest in 1927 as to color of stems, presence or absence and color of leaves, number of flowers, size and color of bolls, and condition and color of seeds* [1]

Date of harvest	Stems		Average number of flowers per plant	Bolls		Seeds			
						At harvest		After threshing (dry)	
	Color	Portion above root without leaves		Size	Color	Condition	Color	Condition	Color
		Inches							
July 5	Green [2]		2	One-third full size	Green	Watery	White	Extremely small, flat, uniform.	Dull, light brown, greenish brown.
July 7	do	8	.25	do	do	do	do	do	Do.
July 9	do	10	.13	One-half full size	do	do	do	do	Do.
July 11	do	10	.08	Two-thirds full size	do	do	Centers green	Not uniform in size	Do.
July 13	do	18	.04	do	do	do	do	Nearly full size	Glossy.
July 15	do	20	.03	Three-fourths full size	Turning yellow	Doughy	White	do	Greenish brown.
July 17	do	22	0	do	do	do		Full size, not completely filled.	All colors.
July 19	do	22	0	Fourth-fifths full size	do	do		do	Do.
July 21	Turning yellow	22	0	do	do	do	Green	Full size	Reddish brown.
July 23	do	22	0	Full size	do	do	do	do	Do.
July 25	do	22	.02	do	do	do	Turning brown	do	Do.
July 27	do	22	0	do	do	do	do	do	Brown. [3]
July 29	do	22	0	do	Nearly brown	Hard	Brown	do	Dark brown, very few dark green.
July 31	Yellow, 90 per cent	22	0	do	do	do	do	do	Do.
Aug. 2	do	22	0	do	Brown	do	do	do	Do.
Aug. 4	Yellow, 95 per cent	22	0	do	do	do	do	Uniform in size	Dark brown.
Aug. 6	do	22	0	do	do	do	do	do	Do. [4]
Aug. 8	do	22	0	do	do	do	do	do	Do. [4]

[1] The flax averaged 32 inches in height at maturity. The first blossoms were noticed on June 27.
[2] Leaves also green.
[3] Reddish tinge gone by July 27.
[4] One-tenth of 1 per cent black.

The flax, after being pulled, was spread out to dry for a day or two, then tied into bundles, and the seed bolls were wrapped in a sack to prevent any loss of seed. The bundles were stored in a dry room until late in the summer, when they were carefully threshed. The straw was then retted for 14 days in cold water. The retting was very slow, and it is certain that overretting did not occur, the length of time being primarily due to the lateness of the season. As the samples were rather small, they were well braked upon a small flax brake and the shives shaken out. Weighings of the fiber were then made, after which it was hackled, and the hackled fiber was used in the chemical determinations. Small amounts of the hackled fiber were cut into 15-centimeter lengths, conditioned at 65 per cent humidity, and weighed to one ten-thousandth of a gram. These, after reconditioning at 65 per cent humidity, were broken upon a hand-operating cloth-testing machine. The breaking strength in kilograms per gram of fiber was then determined for the length, 15 centimeters.

In the earliest harvested samples the seed was very carefully cleaned by hand, as the seeds were very light and an ordinary fanning mill would have blown them away. The other samples were cleaned by hand also, but not so much care was required, as the seeds were all mature.

As stated earlier, several rows of flax were skipped in harvesting and pulled on the last day, August 5. The yields for the different harvesting dates were figured in percentages of those for the skipped rows, which served as checks. The percentages were determined by dividing the actual yields by the corrected yields. The corrected yields were obtained by the method of straight-line interpolation between checks.

Gompertz's growth curves, referred to by Prescott (*16*), were fitted to these percentages as well as to the actual yields, as shown in the figures. The growth curves were fitted to the data by the method of grouping. The straw and fiber yields did not follow such a growth curve, so the best straight line was fitted to these data to show the lines of trend.

In 1927 a more extensive test was made on the time to harvest. Instead of harvesting one sample every day as in 1926, 10 samples were harvested from different sections of a large field every other day for 35 days and in addition on every fifth day an extra large area of flax was pulled. The individual samples taken every other day were drill rows 20 feet long. The next pulling, two days later, was the adjacent drill row, until 18 rows had been harvested side by side. Sections where the 18 rows were pulled were labeled from A to J, inclusive, and were widely separated in the field. The samples were dried in a greenhouse and then carefully wrapped separately in cheesecloth to prevent loss of seed until they could be threshed. The threshing of all samples was done by picking the seed bolls off by hand and crushing them between the fingers. All seeds that did not pass through a 1.651-millimeter diameter screen were picked out from the chaff with forceps and the seed weight or yield recorded. This proved to be a tedious procedure requiring a great deal of time, as there was a very large number of small, immature seeds. The straw, after weighing, was retted in warm water in three separate rets in which the straw from the first six, middle six, and last six

days of harvest, respectively, was retted together. The first and the second rets were normal, but the straw from the last six days of harvest did not ret well and remained in the water, which was changed a few times, for a month, and even then was not well retted but had lost considerably in weight. It was afterwards discovered that the retting tank used for retting the samples from the last six days contained some copper, which undoubtedly reduced bacterial growth.

The scutching was done upon a special Grant scutcher. This machine was designed for small-plot work, and its work was uniform and accurate. It had been found by previous scutching tests on samples of similarly treated and retted straw that the probable error for the average percentage of scutched fiber of 10 samples of similar straw worked on the Grant scutcher is less than one-half of 1 per cent. The fiber strength was determined from the scutched fiber in 1927, the method used in 1926 being followed.

In 1928 harvesting was done on only four separate days, which represented different stages of maturity. Each day that pullings were made the flax was divided into two separate lots. One lot of flax was spread loosely on wire screens in a cool barn to cure. The other lot of the same pulling was cured rapidly in a greenhouse. The temperature in the greenhouse was several degrees warmer than the atmosphere outside, although the windows of the greenhouse were open at all times. The flax, after being completely cured, was treated in a manner similar to that in 1926 and 1927. Special effort was made in 1928 to ret the flax similarly. The straw had its roots and panicles removed before retting. Samples representing all the treatments were retted together in a large glass jar. The ret required approximately eight days at a room temperature of 23° C.

In general the results in 1926, 1927, and 1928 agree very well. The general shape of the growth curves and the lines of trend that have been fitted each year to the data agree in nearly every respect.

YIELD OF SEED

Figure 1 shows graphs of the actual yields of seed in grams and the actual germination percentage of the seed of flax harvested at successive intervals in 1926 and 1927, to which Gompertz's growth curves have been fitted to show the trend of the results. The increase in yield of seed is fairly rapid, the maximum yield being reached about three weeks after full bloom. Tables 1 and 2, which present data on the appearance of the plant and condition of the seed on different harvest days, show that the seed is past the dough stage and is hard and brown at the end of the third week of harvest.

The data agree with those of previous workers in regard to the increase in the weight of the seed, but with the exception of Dillman (*9*) cover a greater period of time and cover it more intensively, as others have studied the seed from only three to five separate days, representing different stages. The growth curve for the increase in seed weight follows the same trend as the curve for the actual yield of seed, as would be expected. This is due to the fact that the increase in the yield (weight) of the seed is not so much an increase in the actual number of seeds as in the size and weight of the individual seeds.

Figure 2 shows that the percentage of oil [4] in the seed reaches its maximum very early and that the immature seeds contain a fairly

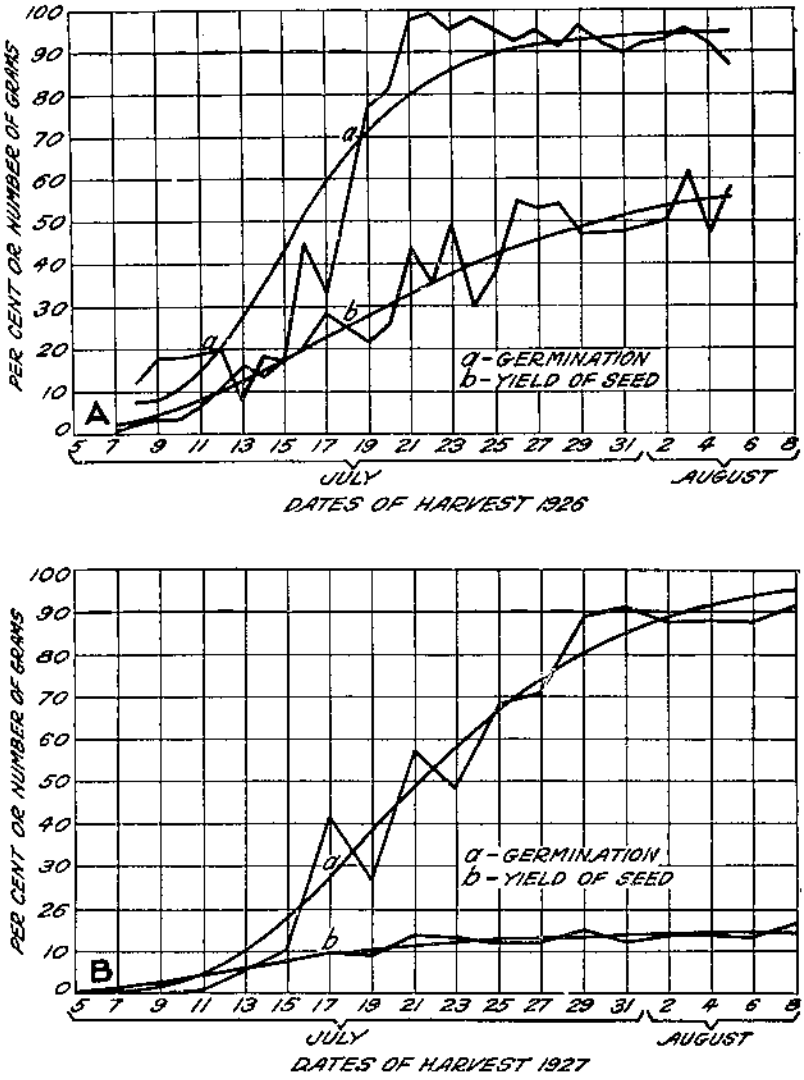

FIGURE 2.—Yield of seed in grains and percentage of germination of seed of flax harvested on different days in 1926 (A) and in 1927 (B). Gompertz's growth curves are fitted to show the trend of the data. The yield of seed in 1926 is from one plot, each plot being a drill row of flax 30 feet long, or $\frac{1}{484}$ of an acre. The yield of seed in 1927 is the average yield of 10 separate plots harvested each day. Each plot was a drill row of flax 20 feet long, or $\frac{1}{726}$ of an acre

high percentage of oil. The percentages in 1926 for the immature seeds are higher than in 1927, which tends to indicate that the harvest began at a later stage in 1926 than in 1927.

[4] Oil analyses of the seed were made by D. A. Coleman and H. C. Fellows, of the Bureau of Agricultural Economics, U. S. Department of Agriculture.

GERMINATION OF SEED

That the pulling began earlier in the plant's growth in 1927 is also indicated by the germination, which began with zero per cent in 1927 whereas in 1926 it was 12 per cent on the corresponding date. The

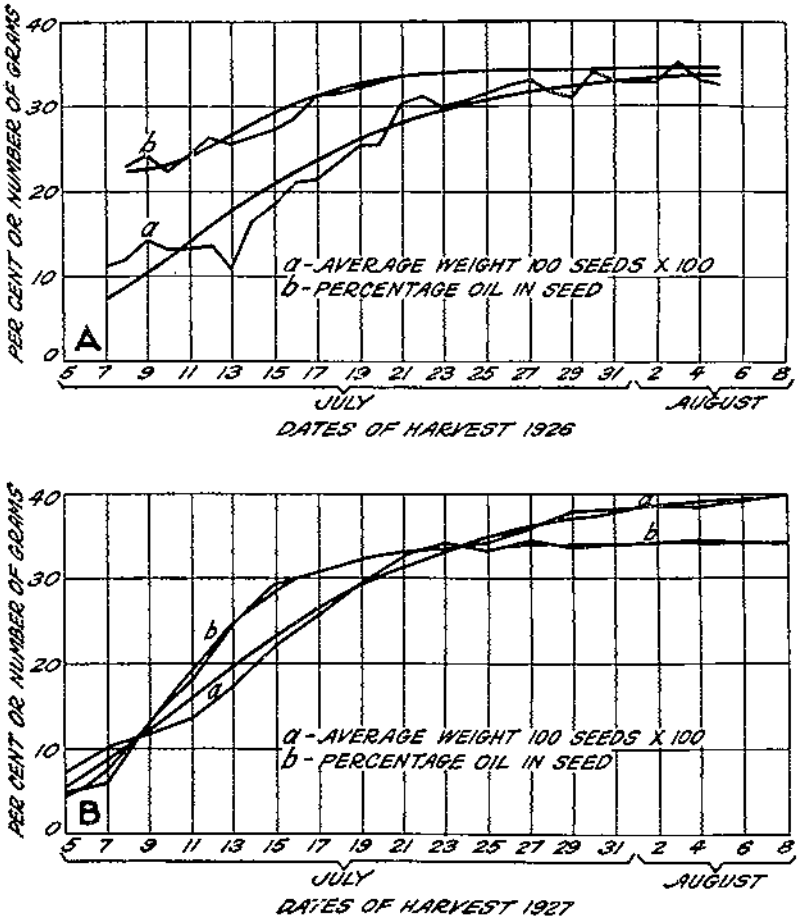

FIGURE 2.—Average weight per 100 seeds, multiplied by 100, in grams, and percentage of oil in air-dried seed of flax harvested on different days in 1926 (A) and 1927 (B). Gompertz's growth curves are fitted to show the trend of the data. The seed was obtained from one plot in 1926 and in 1927 from 10 separate plots harvested each day

actual germination data are shown in Tables 3, 4, and 6 for the years 1926, 1927, and 1928, respectively. The germination of the seed agrees with the results of several workers and shows that good germination may be obtained comparatively early in the harvest period from seed that is not fully mature, but which undoubtedly matures somewhat after pulling, while curing on the straw.

TABLE 3.—*Actual yields of straw, fiber, and seed and chemical determinations made on the fiber and seed of plots of flax harvested on different days in 1926* [1]

Date harvested	Straw			Seed		Germination		Fiber							
													Cellulose		
	Unthreshed	Threshed	Retted	Total weight	Weight per 100 seeds	Total seeds	Heavy seeds [2]	Oil [3]	Weight	Water	Ether extract [4]	Alcohol extract [4]	Alkali insoluble	Alkali soluble	Total
	Grams	*Grams*	*Grams*	*Grams*	*Gram*	*Per cent*	*Per cent*	*Per cent*	*Grams*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
July 7	447	378	283	0.78					85.1						
July 8	308	324	246	2.66	0.1190	12		22.93	67.2	6.39	2.41	4.05	63.71	26.14	89.85
July 9	483	388	292	3.35	.1408	18		24.07	81.5						
July 10	420	337	264	3.55	.1320	18		22.33	76.8						
July 12	435	355	270	10.22	.1372	20		26.21	82.6	6.08	2.38	3.92	67.14	26.40	93.54
July 13	481	383	297	16.14	.1060	8		25.59	82.5	5.96	2.13	3.65	56.86	27.71	84.57
July 14	432	345	265	13.34	.1661	18		26.32	71.9						
July 15	447	358	267	16.82	.1853	17		27.11	72.3	6.20	2.18	3.34	47.23	32.22	79.45
July 16	443	346	260	20.60	.2110	45		28.63	75.4						
July 17	486	381		28.49	.2143	33		31.08	88.4	5.93	2.28	3.41	40.74	32.84	73.58
July 19	351	279	214	21.82	.2540	77		32.22	62.4						
July 20	400	317	255	25.97	.2558	81		32.87	64.1	6.28	2.16	3.21	49.09	29.67	78.76
July 21	438	340	274	44.03	.3020	97	100	33.73	79.6	6.67	2.28	3.26	52.16	28.72	80.88
July 22	401	320	248	35.22	.3124	99	99	34.00	73.6	6.28	2.11	3.28	62.94	26.42	89.36
July 23	422	320	263	48.91	.3028	95	100	34.17	69.0	6.77	2.11	3.30	62.25		
July 24	344	286	226	30.16	.3070	98	100	34.14	77.6						
July 26	493	377	313	54.91	.3257	93	99	34.33	77.4	6.57	2.17	3.21			
July 27	429	323	254	53.15	.3315	95	100	34.43	81.4						
July 28	444	343	291	54.10	.3177	91	99	34.33	83.4						
July 29	404	308	258	47.05	.3125	96	98	34.32	91.9						
July 30	404	310	258	47.13	.3403	92	97	34.37	82.4						
July 31	426	318	255	49.20	.3296	90	95	34.45	75.4	5.36	2.07	3.35			
Aug. 2	433	341	283	50.45	.3290	93	99	34.48	82.2	4.67	2.45	3.70			
Aug. 3	423	307	256	61.88	.3510	95	91	34.50	74.5						
Aug. 4	351	261	222	46.60	.3300	92	95	34.50	61.4						
Aug. 5	428	320	268	57.55	.3267	87		34.40	77.8						
(5)	413	326	266	45.74	.3092	87		34.48	65.8						
(5)	420	323	271	56.67	.3362	92		34.42	86.3						
(5)	422	330	281	47.45	.3358	88		34.50	79.4						
(5)	407	335	276	35.56	.3068	85		34.38	79.4						
(5)	371	295	247	38.78	.3228	89		34.47	78.4						
(5)	479	373	317	58.88	.3328	82		34.45	94.2						
(5)	441	337	285	53.93	.3294	90		34.43	90.7						
(5)	343	268	223	40.71	.3418	91		34.29	74.9						
(5)	302	302	253	49.40	.3356	88		34.25	84.9						
(5)	392	294	248	51.38	.3158	87		34.51	65.4						

[1] Each plot was a drill row of flax 30 feet long, or 1/1356 of an acre.
[2] The germination of only heavy seeds, obtained by cleaning with a fanning mill.
[3] Wet basis. The seed used in the oil analysis had 5 to 5.5 per cent moisture.
[4] Dry basis.
[5] Rows used to check soil heterogeneity; harvested Aug. 5.

TABLE 4.—*Average yields of 10 samples of flax harvested in 1927*

Date harvested	Straw		Seed				Fiber		
	Unthreshed	Threshed	Total weight	Weight per 100 seeds	Germination	Oil [1]	Weight	Strength [2]	Hackling [3]
	Grams	*Grams*	*Grams*	*Grams*	*Per cent*	*Per cent*	*Grams*	*Coefficient*	*Per cent*
July 5	152	123	0.29	0.0713	0	4.96	27.17	137.3	42.77
July 7	157	118	.96	.1023	0	6.15	25.98	130.3	32.61
July 9	136	134	2.54	.1167	0	13.27	32.37	163.3	37.21
July 11	189	139	4.26	.1367	.6	18.10	32.07	148.8	35.89
July 13	183	129	6.06	.1756	5.6	24.84	33.22	142.2	37.64
July 15	167	121	7.75	.2230	10.2	29.39	28.04	123.0	39.89
July 17	175	125	9.68	.2570	42.0	30.72	34.10	178.8	46.87
July 19	166	117	9.05	.2955	27.2	32.29	30.06	207.8	46.21
July 21	205	144	13.02	.3382	57.4	32.81	36.28	225.1	43.96
July 23	206	147	13.69	.3341	48.7	34.07	35.37	213.5	38.53
July 25	175	121	12.56	.3433	68.2	33.21	30.29	207.9	45.65
July 27	169	122	12.52	.3607	71.1	34.53	29.26	179.2	40.72
July 29	192	140	15.01	.3784	89.2	33.05	36.84	151.4	28.89
July 31	183	141	12.29	.3827	90.8	34.07	34.90	149.1	30.49
Aug. 2	197	147	13.81	.3870	87.6	34.13	32.86	167.9	24.97
Aug. 4	209	151	13.86	.3843	88.1	34.40	30.35	158.9	24.54
Aug. 6	191	139	13.65	.3902	87.8	34.11	29.03	133.0	25.31
Aug. 8	224	163	10.41	.3962	91.4	34.32	35.17	173.3	21.10

[1] The percentage of oil in the seed represents an average of two determinations on the bulk of the air-dried seed of the 10 samples.

[2] The fiber strength is in kilograms per gram of fiber 15 centimeters in length. The probable errors of the strength are low; e. g., July 7, 128.40±6.07; July 21, 225.02±5.76; Aug. 4, 155.40±6.25. Each plot was a drill row of flax 20 feet long, or $\frac{1}{435}$ of an acre.

[3] The hackling percentage represents one determination on the 10 samples of fiber together.

The germination in 1927 (fig. 1, B) does not show such a marked increase at the beginning of the harvest as it does in 1926. (Fig. 1, A.) It is believed that there were probably two reasons. In 1927 a great deal more care was used in picking out seeds, including the mature ones, so that the percentage of germination in the early stages was lowered because of the larger proportion of immature seeds. The average germination of 1,000 seeds harvested each day from July 17 to 27, 1927, and tested later, was variable. Before this time it increased fairly uniformly and afterwards it was relatively constant. (Fig. 1, B.) It is not known exactly why these few days showed such a variability. Identical results were secured by a second germination trial. The only explanation that may be given is that when the straw was cured in a greenhouse the temperature was very warm. By reference to the United States Weather Bureau reports it was found that July 19 and 23 were clear, sunshiny days and that July 17 and 21 were cloudy and rainy. It is probable that the temperature and other

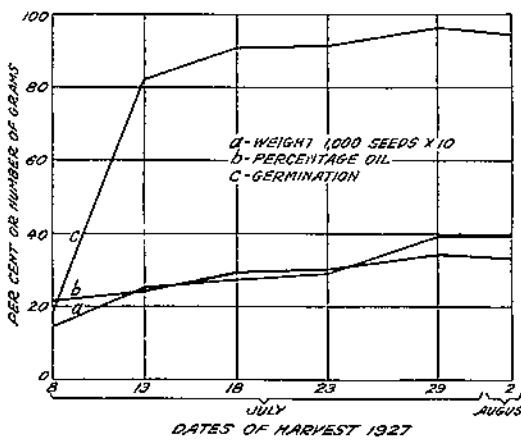

FIGURE 3.—Data from six large areas of flax harvested in 1927. The areas were of unequal size. The seed after threshing was cleaned on a fanning mill

physiological conditions in the greenhouse reduced the germination of the seed harvested on July 19 and 23. In Table 5 and Figure 3 data are given from the large samples of flax harvested at five different periods in 1927, in which the seed was cleaned with a fanning mill, removing a large number of light, immature seeds. The germination test of this seed showed a very high percentage of germination much earlier than the hand-picked samples harvested every other day in 1927, the results of which are shown in Table 4. The light seeds present in all early harvested samples partly account for the imperfect germination, as the germination data are from seeds selected at random. Samples of seed taken from July 21 to August 4, 1926, inclusive, showed a germination that averaged 99 per cent when cleaned of light seeds by an air current. This was in some cases a 10 per cent higher germination than that obtained from seeds selected at random and not fanned. (Table 3.)

TABLE 5.—*Data from large samples of flax harvested at different periods in 1927*

Date	Harvest stage	Germination	Weight per 100 seeds	Oil in seed [1]	Straw after retting	Fiber in retted straw	Quality of fiber
		Per cent	*Gram*	*Per cent*	*Per cent*	*Per cent*	
July 8	Green	19.6±1.4	0.1481±0.0031	21.63	79.47	28.90	Best of all samples; softest sample.[2]
July 13	do	81.4±1.1	.2517± .0044	23.92	75.25	24.34	Good.
July 18	Green to yellow.	90.8± .7	.2760± .0038	29.15	76.06	22.06	Fair; medium strength.
July 23	Yellow	94.2± .9	.2910± .0062	30.14	71.85	22.46	Fair; weakest of all samples.
July 29	do	96.4± .4	.3049± .0023	34.12	75.30	21.94	Harsh; fair strength.
Aug. 2	Dead ripe	94.4± .7	.3942± .0024	33.03	75.30	22.85	Harsh; strongest of all samples.

[1] The oil percentage of the air-dried seed was determined by the chemistry experiment station, Michigan State College.
[2] The fiber obtained on July 8 was judged the best of the six different days by the Smith & Dove Manufacturing Co., Andover, Mass.

Reports on the germination of the seed in 1928 are very interesting. The data given in Table 6 show how well the very immature seed will germinate when left on the straw and the straw is allowed to cure slowly. Only 7.3 ± 0.8 per cent of the seed from straw pulled on July 14 and cured in the greenhouse germinated, while 61.3 ± 2.0 per cent of the seed from the same sample of straw cured in a barn germinated.

TABLE 6.—*Data from flax harvested on different days in 1928 and cured in a cool barn or in a warm greenhouse*

Date of harvest	Harvest stage	Where the straw was cured	Weight per 100 seeds	Germination of seed	Straw after retting	Fiber of retted straw	Fiber strength [1]	Hackling	Ether extract [2]	
									Straw	Fiber
			Gram	*P. ct.*	*P. ct.*	*P. ct.*	*Coefficient*	*P. ct.*	*P. ct.*	*P. ct.*
July 7	Full bloom	In shade	[3] 0.0846	[3] 4.7	80.97	27.46	229.9±6.6	68.89	------	------
July 14	Late green	do	.1879±0.0047	61.3±2.0	82.65	24.43	243.5±8.5	64.06	------	------
July 20	Yellow ripe	do	.2378± .0014	82.6± .5	84.31	25.94	279.6±7.3	73.02	------	------
Aug. 3	Full ripe	do	.4037± .0036	89.6± .7	84.25	26.92	250.6±5.4	73.26	------	------
July 7	Full bloom	In sun	[3] 0.0814	0	82.70	28.59	190.4±6.8	56.00	1.41	2.15
July 14	Late green	do	.1568± .0004	7.3± .8	81.17	25.57	226.5±9.0	62.20	1.65	2.19
July 20	Yellow ripe	do	.2495± .0020	15.3± .4	83.06	27.96	288.4±7.0	73.15	1.64	2.38
Aug. 3	Full ripe	do	.3991± .0043	93.6±1.2	85.72	28.45	243.9±8.3	70.10	1.58	2.82

[1] Kilograms per gram of fiber, length 15 centimeters.
[2] Dry basis.
[3] Too few seeds for replicate test.

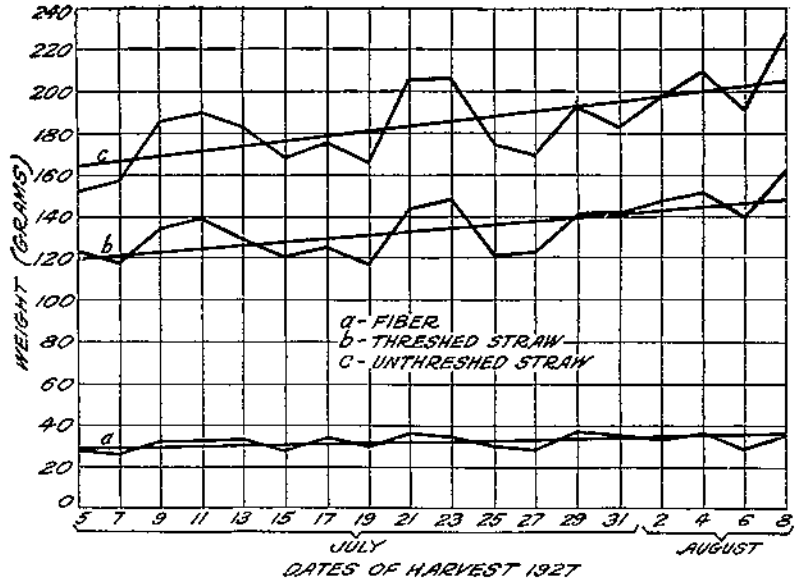

FIGURE 4.—Actual average yield (in grams) of unthreshed straw, threshed straw, and fiber from flax harvested on different days in 1927. Each day's yield is the average of 10 separate plots. The trends are shown by the best straight line fitted to the data. Each plot was a drill row of flax 20 feet long, or $\frac{1}{3634}$ of an acre

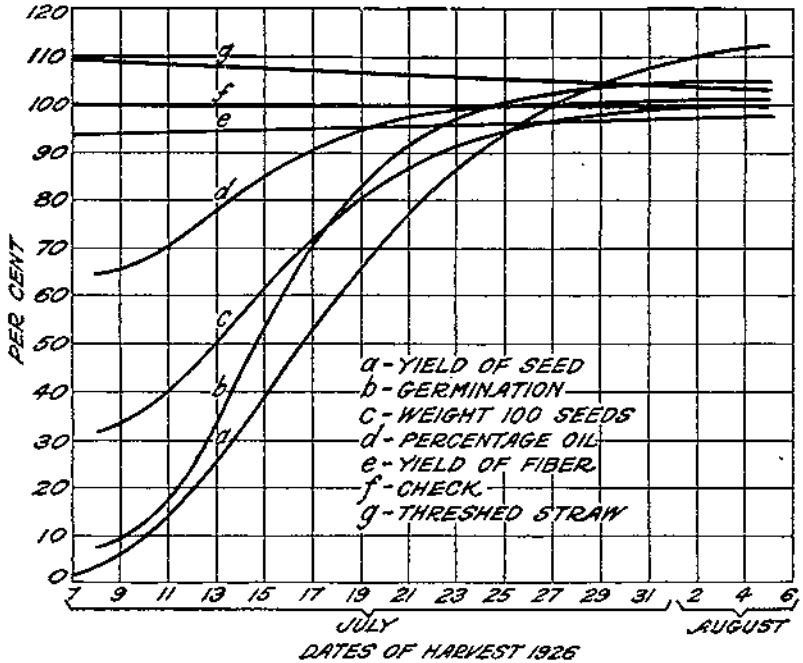

FIGURE 5.—Trends of data for different days of harvest in 1926 given as percentages of the last day's harvest taken as equal to 100 per cent

YIELD OF STRAW

The actual yields of straw in 1926 and 1927 are given in Tables 3 and 4, respectively, while that for 1927 is shown graphically in Figure 4. Figures 5 and 6 show the trend of the corrected yields of straw in 1926 and 1927, respectively. In 1926 (fig. 5) the yield of threshed straw decreased slightly, but the decrease was not significant, being only 6.43 ± 9.37 per cent. However, in 1927 the lines of trend (figs. 4 and 6) show a significant increase in the yield of both the unthreshed and threshed straw as the plant matures. The increase is partly accounted for by the fact that the seed develops on the plant with a slight extension of the panicle; but the plant also must increase in weight, as the threshed straw, too, shows an increase as the plant

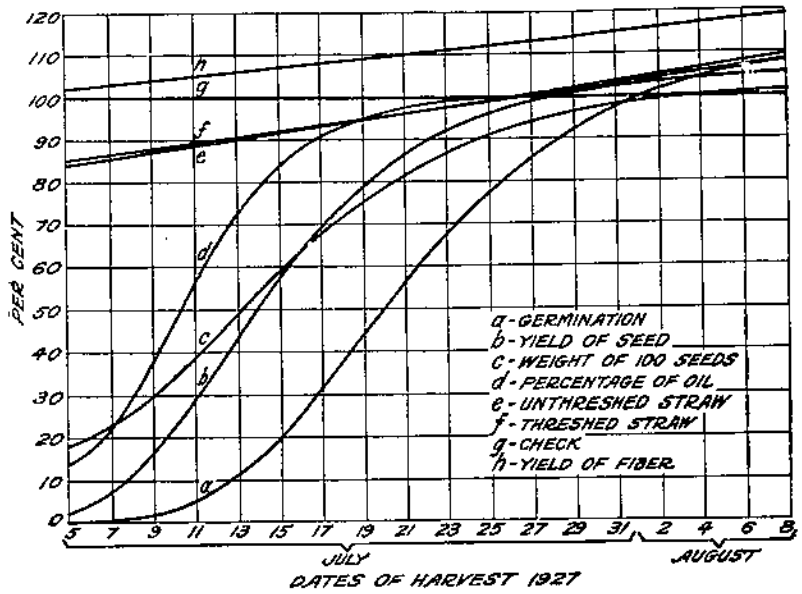

FIGURE 6.—Trends of data for different days of harvest in 1927 given as percentages of the data for the harvest of August 6 taken as equal to 100 per cent

matures. The increase in weight in the unthreshed straw is slightly greater than in the threshed straw, as is shown by the slope of the lines of trend. (Fig. 6.) It is possible that the yields of straw might follow a growth curve if the weights were taken from the seedling stage to maturity, but the results obtained here on the weights of plants after flowering had started did not seem to indicate or warrant the fitting of anything but a straight line. The increase in the weight of the straw apparently nearly reaches its peak at full bloom, and after that the increase is gradual and nearly constant.

YIELD OF FIBER

The yield of fiber in each of the two years that it was studied is shown, by lines of trend, to increase as the season advances. In 1926 the increase in the trend of fiber weight from the first to the last day is 3.65 ± 10.9 per cent (fig. 5), which is not significant; and in

1927 the increase in the trend of fiber weight from the first pulling to the last pulling is 17.79 ± 9.57 per cent (fig. 6), which is not significant. A significant increase would have agreed with what has been generally supposed from commercial results.

QUALITY OF FIBER

Although the yield of fiber increased somewhat, the quality did not improve very much except that in all three years the strength of the fiber, which is an important factor, increased with the lateness of the harvest. In 1926 the trend of the increase in strength throughout the period of harvest was gradual, but on some days the actual data varied considerably from the trend. Because of this variability in 1926, the average strength for 3-day periods was plotted (fig. 7), and the graph indicates a fairly smooth trend. In 1927 the strength of fiber increased up to July 21 and then decreased as the full-ripe or dead-ripe stage progressed. (Fig. 7.) It is believed that the low

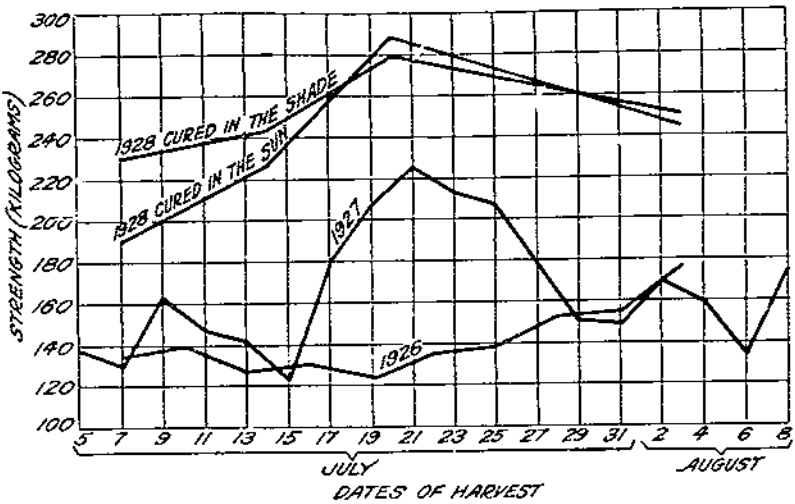

FIGURE 7.—Strength of fiber estimated as kilograms per gram of fiber 15 centimeters in length for different days of harvest in 1926, 1927, and 1928. In 1928, after harvesting a sample of flax, the sample was divided and one half of it was cured in the sun and the other half was cured in the shade

strength of fiber shown by the last six days' pullings is due somewhat to the poor retting; such a decrease is indicated, however, by the fact that the pullings of the middle six days, which were retted together, show an increase followed by a decrease that fits well with the later data. The scutched fiber tested for its strength was first conditioned under a constant 65 per cent humidity before weighing, after weighing, and before breaking.

In 1928 the strength of the fiber was low in the early stages of harvest, high in the middle period, and moderately high at the last harvest. These data are somewhat similar to those obtained in 1927. The two years together indicate that the strength may increase throughout the yellow-ripe period of harvest, later reach a maximum, and then decrease slightly during the full-ripe period. In 1928 the fiber after scutching was green in all samples of straw

cured in the shade and creamy yellow in all that had been cured in the sun. The fiber from the first two harvests was much finer and softer than that from the last two harvests.

In 1926 no record was kept of the hackling percentages, but in 1927 and 1928 these were recorded (Tables 4 and 6), and the percentages of hackled "line" were greatest in the middle or yellow-ripe stage and in the full-ripe stage. The results indicate that a small decrease in the hackling percentage may occur after the yellow-ripe stage, but further work is necessary to substantiate this. These percentages of hackling might be low in 1927 compared with the ordinary percentages of flax hackling, but the tow obtained in scutching is not usually considered in the hackling percentage. In the present case the hackling percentage represents the hackled line from the total yield of fiber. It is necessary to express it in this manner because the Grant scutcher used did not separate the line from the tow. The 1927 fiber did not appear consistent in the amount of "nature"[5] present, although there was not a great difference. The early samples contained slightly more nature than the later samples and this, with the good strength and good hackling percentage of the middle period of harvest, helps to prove that this stage is more favorable than the later stage for fiber of good quality.

To determine whether the fiber at the earlier stages of harvest is oilier than that at the later stages, as has been reported, both ether and alcohol extractions were made of samples of flax harvested on different days, as well as of the straw from which the fiber was retted and scutched. The data given in Tables 3 and 6 show very small differences between the early-harvested and the late-harvested samples, so that it is impossible to say whether the earlier harvested are oilier.

A number of cellulose determinations were made upon samples of fiber harvested on different days in 1926. (Table 3.) The hackled fiber was put in clear ammonium hydroxide (NaOH) solution, which separated out the soluble celluloses from the insoluble cellulose (*6*) under the particular conditions. The alkaline solution of cellulose contained the lignified cellulose, which is said to increase in amount in the later stages of harvesting. Besides the determinations of soluble and insoluble cellulose, data are given for the total cellulose in 1 gram of fiber. (Table 3.) The data in Table 3 are too few to give conclusive evidence of any increase or decrease in the cellulose content. The small differences may have been caused by nonuniform small samples of fiber, averaging 0.35 gram per sample, and more probably by the method of determination, which is not standardized for flax. As the results gave such small differences without a natural trend, the work was not repeated nor was a method worked out that applied especially to the problem.

The data obtained apply only to the green-ripe and yellow-ripe flax, as no determinations were made, for the full-ripe stage. They give low alkali-insoluble cellulose content and high alkali-soluble cellulose content in the early yellow-ripe period. Further work is needed on the cellulose content of flax fiber at different stages of

[5] A flax spinner's term used to designate quality, including feel, softness, life, resiliency, elasticity, and oiliness.

maturity, in order to draw more definite conclusions and to cover all three stages of harvesting.

Alpha-cellulose determinations were made upon six samples of flax fiber grown in 1927. The method used was that reported by the alpha-cellulose committee of the American Chemical Society.[6] The alpha-cellulose determinations for flax pulled on different days, expressed as percentages of dry weight of the fiber, are as follows: July 8, 76.5; July 13, 76.1; July 18, 76.3; July 23, 78; July 29, 79.5; and August 2, 80. These cover all three periods of harvest and indicate a small increase in the alpha-cellulose content of the fiber as the plant goes from the yellow-ripe stage to that of full-ripe maturity. The alpha-cellulose determinations made in 1927 are much higher than the alkali-insoluble cellulose determinations made in 1926. This is largely due to the difference in the method of determination and probably only slightly due to the better cleaning in the scutching and hackling in 1927.

DISCUSSION

Table 7 shows the actual figures of yields in 1927 as percentages of the yields of August 6. This date was selected as the standard, since it was near the end of the period of harvest and did not have a few abnormal high yields as found on August 8. All seven characters studied show an increase as the flax matures. The fiber weight appears high throughout, on account of a low yield of fiber on August 6. The growth curves and lines of trend shown in Figure 6 were calculated from the data in Table 7.

TABLE 7.—*Percentage yields in 1927 obtained by determining the average of 10 samples of flax for each harvest day as percentages of the average yield of August 6*[1]

Date	Straw		Seed				Fiber weight
	Unthreshed	Threshed	Total weight	Weight per 100 seeds	Germination	Oil[2]	
July 5	79.58	88.35	2.10	19.26	----------	14.54	93.59
July 7	82.19	85.04	7.00	26.21	----------	18.03	89.49
July 9	97.38	96.62	18.60	29.90	----------	38.90	111.50
July 11	98.95	99.56	31.20	35.03	0.68	53.05	110.47
July 13	95.81	92.45	44.40	45.00	8.37	72.82	114.43
July 15	87.43	86.62	56.77	57.15	11.61	86.15	96.69
July 17	91.52	89.64	70.92	65.86	47.83	90.06	117.46
July 19	86.91	84.18	66.30	75.73	30.97	94.66	103.54
July 21	107.32	103.30	102.00	84.11	69.59	96.19	124.97
July 23	107.85	105.89	100.33	85.62	55.35	99.88	121.83
July 25	91.62	87.13	92.00	87.98	77.57	97.36	104.34
July 27	88.48	87.99	91.71	92.43	80.97	101.23	100.79
July 29	100.52	100.93	109.98	96.97	101.59	98.65	126.90
July 31	95.81	101.65	90.07	98.07	103.41	99.88	120.22
Aug. 2	103.14	105.89	101.17	99.17	99.77	100.08	113.19
Aug. 4	109.42	108.55	101.56	98.48	100.34	100.85	125.21
Aug. 6	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Aug. 8	117.27	117.03	120.20	101.53	104.10	100.62	121.15

[1] The average yields of Aug. 6 were taken as 100 per cent.
[2] The percentage of oil in the seed was determined for only two samples for each day.

In Table 8 a comparison is made between the data for the different days and those for July 21. This day was used for purposes of comparison because it seemed to mark the turning point of the

[6] RITTER, G. J., CHAIRMAN. MODIFIED METHOD NO. 4 FOR THE DETERMINATION OF ALPHA CELLULOSE REPORTED BY THE ALPHA-CELLULOSE COMMITTEE OF THE AMERICAN CHEMICAL SOCIETY. [Unpublished.]

growth curves for a number of the characters. Table 2 shows that the condition of the plants on July 21 was very close to that when fiber flax is considered ready for harvest. The comparison was made by using Student's method (*2*) which gives odds for the significance of the differences in the data. Odds greater than 40 to 1 are often selected as representing significant differences and in Table 6 (odds more than 40 to 1 or less than 1 to 40) it is shown that on July 21 yields were greater than those on earlier days for germination and weight per 100 seeds, but that these increase significantly after July 21. The seed yield (and possibly the percentage of oil, had calculation been feasible) did not increase after July 21 but was significantly low before that date.

The data from the unthreshed and threshed straw and the fiber are somewhat variable. The standard, July 21, is in general equal to the period following and slightly better than the earlier period. Tables 7 and 8 indicate that flax harvested as early as July 21 gave yields that were near or at the maximum for all the characters studied except the germination of the seed and the weight per 100 seeds.

TABLE 8.—*Odds* [1] *showing significance of difference between average daily yields* [2] *and those of July 21 used as a standard* [3]

Date	Straw		Seed			Fiber weight
	Unthreshed	Threshed	Weight	Germination	Weight per 100 seeds	
July 5	61:1	6:1	9,999:1	9,999:1	9,999:1	344:1
July 7	3,332:1	1,110:1	9,999:1	9,999:1	9,999:1	9,999:1
July 9	61:1	22:1	9,999:1	9,999:1	9,999:1	81:1
July 11	8:1	2:1	9,999:1	9,999:1	9,999:1	61:1
July 13	132:1	61:1	9,999:1	9,999:1	9,999:1	61:1
July 15	666:1	344:1	9,999:1	9,999:1	9,999:1	9,999:1
July 17	13:1	8:1	163:1	100:1	9,999:1	2:1
July 19	61:1	81:1	908:1	3,332:1	1,428:1	81:1
July 21	(4)	(4)	(4)	(4)	(4)	(4)
July 23	1:1	1:2	1:1	18:1	1:2	2:1
July 25	13:1	18:1	8:1	1:37	1:48	18:1
July 27	156:1	100:1	8:1	1:163	1:327	666:1
July 29	3:1	1:1	1:3	1:9,999	1:9,999	1:1
July 31	18:1	1:1	4:1	1:9,999	1:9,999	1:1
Aug. 2	3:1	1:2	1:1	1:9,999	1:9,999	49:1
Aug. 4	1:2	1:5	1:1	1:9,999	1:4,999	1:3
Aug. 6	6:1	2:1	1:1	1:9,999	1:2,499	9,999:1
Aug. 8	1:5	1:10	1:22	1:9,999	1:9,999	1:1

[1] Obtained by Student's method (*2*).
[2] See Table 5.
[3] Odds of more than 40 to 1 (or less of than 1 to 40) may be considered as showing the results were not due to chance. Odds were not determined for the percentage of oil in the seed, as only two oil determinations were made for each day.
[4] Used as the standard of comparison.

Thus it has been shown that a number of characters in fiber flax reach simultaneously a maximum increase. These data would be of little value without a knowledge of their close correlation with the appearance of the plant at different stages. If the maximum yield of fiber and seed, the percentage of germination, etc., can be associated with the plant's morphological appearance, then the proper stage for pulling may be recognized in the appearance of the crop.

Tables 1 and 2 give data on the color of the stems, presence or absence and color of the leaves, number of flowers, size and color of

the bolls, and character of the seeds from day to day. Each year the harvesting started before flowering was over, when there were a few seed bolls about one-half their normal size and an average of two flowers per stem still in bloom. This stage is reached a little earlier than fiber flax is pulled in the United States and is therefore a good period at which to begin. According to the tables, the stems had turned yellow and the leaves had fallen off for two-thirds of the distance up the stems, about July 26 or 27. Comparing the condition of the seed bolls in the tables, it is seen that the harvest might have started as early as July 21, since the required number of bolls were then yellow. However, a few days later 50 per cent of the bolls would have turned from yellow to light brown, and thus this stage coincides in 1926 and in 1927 with the time when the leaves have fallen from the stems and the latter have turned yellow. Hence in central Michigan the harvest should start about July 26 or whenever the condition of the plants in the fields corresponds to the condition normally reached on that date. This date corresponds very closely to the average seasonal time of harvest at East Lansing, Mich., but is a week or 10 days earlier than the seasonal conditions in the "thumb region," the principal fiber-flax area of Michigan. There the harvest begins about August 1. In Oregon, where fiber flax is grown, the best flax is usually all pulled before August 1.

In Tables 3 and 4, which give the yields and analyses, the germination, percentage of oil yield, and weight per 100 of the seed are all low and on an upward trend before July 21. By that date some of the conditions have reached a maximum or very nearly a maximum, and the others increase only slightly thereafter. It would appear that as far as the seed is concerned the germination, percentage of oil, and weight per 100 seeds are all at their maximum by July 26 or a few days earlier. Though the trend of the total yield of seed still tends to rise after July 25, the rise is slight and mathematically insignificant (17.88 ± 12.52 per cent (fig. 7) in 1926); and it would be best to begin harvesting at about this time, especially if the acreage is large enough to make the work extend over several days. If the farmer has acreage requiring only one or two days to harvest, then a day or two later might be best as far as the germination and weight of the seeds are concerned.

Since the oil and cellulose content of the fiber show little or no correlation with the time of pulling, and only the strength of the fiber increases with later pulling, with a little loss in "nature," the data indicate that the best time to harvest, as far as the fiber is concerned, is at the yellow-ripe stage, or in the present case about July 25 or 26.

Pulling machines used for harvesting fiber flax in recent years seem to work better with flax full ripe to dead ripe. It may be possible to improve the machines so that they will work more efficiently in harvesting flax at earlier stages. Aside from the fact that the crop may yield a fiber of better quality if harvested early, it is usually desirable to harvest as early as possible to avoid danger of losses from bad weather, lodging, and diseases and to allow more time for the following processes of threshing, retting, scutching, and hackling, and thus secure a quicker financial return. In some localities, if the flax is harvested late, it is impossible to ret it under natural conditions until the following year.

The data here presented seem to justify the farmers of North America in their practice regarding the time of pulling fiber flax. No more favorable conditions for harvesting can be suggested than those already mentioned. Many farmers do not begin harvesting until the yellow stage of flax is well advanced, and with a large acreage this results in a very overripe condition before the harvest is ended. It would be better to begin harvesting earlier and to raise no more than may be pulled during the yellow-ripe stage.

SUMMARY

In order to determine the proper time to harvest fiber flax, observations were made during the summers of 1926, 1927, and 1928 with respect to the morphological appearance of the plants as correlated with the yields and certain other specified characters of the straw, seed, and fiber.

Determinations were made of these data on different days of the harvest for each of the three years, and the results are expressed in both tables and graphs. The changes in the various characters from day to day, as well as their relationships to one another, are likewise discussed in detail.

The conclusion is reached that fiber flax should be harvested during the yellow-ripe stage, in order to insure the best results in yield and quality of both the fiber and the seed.

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23

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