The Connecticut Agricultural Experiment Station, New Haven

Connecticut Fiber Flax Trials 1994-95

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Bulletin 946

October 1997

SUMMARY

Fiber flax cultivar trials were conducted in small plots at Mt. Carmel during 1994-95. In 1994 13 cultivars from the Czech Republic, Egypt, France, and the Netherlands were compared. In 1995 31 additional cultivars were included in the test. Sources included Canada, Lithuania, Poland, Russia, Sweden, Ukraine, and the United States. In 1994 yield of cleaned seed ranged from 78-676 lb/A. Yield of deseeded straw ranged from 2608-7065 lb/A; four Egyptian sources yielded the most seed and the least straw. Percent total fiber varied from 11.2-29.0% of deseeded straw. In 1995, a dry year, seed yield ranged from 183-1003 lb/A. Straw yield varied from 1832-4567 lb/A, a marked reduction from 1994. Total fiber ranged 19.4-31.7%. All of the French cultivars were at least 27% total fiber. Four Russian cultivars, two from the Czech Republic, two from the Netherlands, and two of unknown origin all had total fiber content of at least 27%.

In 1994 the French cultivars, Ariane and Viking, were planted on May 10, May 23, and June 6 with and without added N, P, and K. The 4-week delay in planting reduced straw yield of Ariane 56% and Viking, 34%. There was no consistent effect of added fertilizer. Total fiber content ranged 20-22.5% of deseeded straw for Ariane and 24.8-26.7% for Viking. Generally, total fiber content decreased slightly with later planting date. Seed yield was very low and it decreased with increasing planting delay. Added nitrogen decreased seed yield.

In 1995 Natasja, a Dutch cultivar, Ariane and Viking were sown at 35, 50, 75, and 100 lb/A. Seed yield was low and variable but tended to be highest at 75 lb/A. Straw yield decreased with decreasing sowing rate. Total fiber content was low for Ariane and Natasja, but was unaffected by sowing rate for all cultivars.

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Fiber flax, *Linum usitatissimum* (L.), the source of linen, is the world's oldest known textile fiber, in use for about 10,000 years. Bundles of long phloem or bast fibers are arranged in a ring between the bark and the inner woody core of the stem. When these bundles are separated the resulting long fibers can be spun into thread. Fiber flax came to America with the early colonists. In Connecticut it was grown commercially until about 1830 (Jenkins 1925). Weeds, the fatal flax wilt, flax from new farms in the West, and an abundance of relatively cheap cotton likely made it unprofitable for Connecticut farmers to continue to grow flax. Flax was grown commercially in the Willamette River Valley of Oregon until the 1950s. Elimination of the federal subsidy and very likely introduction of new synthetic fibers caused the entire industry to disappear in less than a decade.

Currently, in western Europe, commercial production of fiber flax occurs in France, Belgium, the Netherlands, Germany, England, and Ireland. In eastern Europe fiber flax is produced in Poland, Czech Republic, Romania, the Baltic countries, and several of the republics of the former USSR. Elsewhere, fiber flax is grown in China, Korea, Egypt, and Chile. Much of the flax fiber available for export comes from France, Belgium, the Netherlands, and China. The United States is viewed as an expanding linen market.

Work on the reintroduction of fiber flax began at The Connecticut Agricultural Experiment Station in 1992. Half-acre fields of the French cultivars Ariane and Viking were grown at Lockwood Farm, Mt. Carmel, and Valley Laboratory, Windsor. Small nursery trials were also done at each location. In 1993, a nursery trial of Ariane and Viking, with two planting dates, two levels each of nitrogen fertilizer and lime, was conducted at Lockwood Farm. Three farmers in four towns grew 132 acres. Test plots were established in two other towns with high deer populations. The results for 1992-93 were reported in Bulletin 932 (Stephens 1996c) and elsewhere (Stephens 1994, 1995).

This bulletin summarizes the results of flax nursery trials and large field experiments during 1994-95.

MATERIALS AND METHODS

Sites

Nursery trials in 1994-95 were conducted at Lockwood Farm, Mt. Carmel, on Cheshire fine sandy loam, a glacial till soil with moderate water holding capacity. No flax had been grown previously on the fields. Large field trials at Lockwood Farm in 1994 and 1995 were conducted on Yalesville fine sandy loam, another glacial till soil. Fiber flax was previously grown on both fields in 1993. Winter wheat or rye in 1994 preceded the 1995 trial. In 1994 fiber flax seed production was attempted in East Windsor and Ellington on Cheshire fine sandy loam, Agawam fine sandy loam, and Enfield silt loam, eroded phase. Both the Agawam and Enfield soils were outwash terrace soils. In 1995 flax was grown in Middlebury on Woodbridge fine sandy loam, a glacial till soil. Flax had not been previously grown in any of these fields. Corn preceded flax on the Agawam, Cheshire, and Woodbridge soils whereas woody nursery stock preceded flax on the Enfield soil.

Weather

Temperature and precipitation are measured throughout the year at Mt. Carmel and Windsor. The weather station at Mt. Carmel is about 14 miles southeast of Middlebury. The weather station at Windsor is about 8 miles west of the East Windsor-Ellington site. In both 1994 and 1995 the weather was generally dry during April and June (Table 1). In 1994 August and September had abundant rain. August 1995 was dry. Generally, 1994 was slightly warmer than 1995.

Soil preparation

Soil was plowed, disked and smoothed prior to

Table 1. Average monthly temperature (F) and monthly rainfall (in) at Mt. Carmel and Windsor during April-September 1994-95.

		Apr	May	Jun	Jul	Aug	Sep
		Temperature F					
Mt. Carmel	1994	51.0	57.7	71.6	78.3	71.1	64.5
	1995	47.6	57.3	68.2	76.2	73.4	63.8
Windsor	1994	50.6	57.3	70.3	76.6	69.5	62.8
	1995	46.8	57.4	69.3	76.1	72.4	62.4
		Precipitation in					
Mt. Carmel	1994	2.6	3.4	2.3	3.2	5.6	4.5
	1995	2.6	3.3	1.4	3.3	2.2	4.2
Windsor	1994	2.2	4.3	4.1	5.7	7.5	6.0
	1995	2.3	2.8	2.2	2.4	3.5	3.7

sowing. Added fertilizer was disked into the soil prior to the final smoothing. On soils where American grain drills with disk openers were used it was desirable to allow the soil to settle and firm for several days. Where European grain drills with floating shoes were used the final disking and smoothing generally occurred just before sowing. In both cases a smooth, pulverized seedbed was desirable.

Fertilization

Soil samples were analyzed by the Morgan soil test (Lunt et al. 1950). Available nitrogen was estimated and sufficient additional nitrogen was added to bring the total available nitrogen to 70 lb/A for normal culture or to the desired level for fertilizer trials. Small plots at Mt. Carmel received 112 lb/A of ammonium nitrate in 1994 and 120 lb/A in 1995. In 1995 the large fields at Mt. Carmel received 105 or 88 lb/A of ammonium nitrate; the large field in Middlebury received 100 lb/A of ammonium nitrate. In 1995 half of each small plot at Mt. Carmel received 17.8 lb/A of zinc sulfate as a spray on May 23, 1995.

Cultivars

In 1994, at Mt. Carmel and East Windsor-Ellington, two French cultivars, Ariane and Viking, were grown. Ariane is characterized as slow growing, semi-late flowering, late maturing, sensitive to zinc deficiency, resistant to lodging, slightly susceptible to Fusarium, very good fiber quality, and low seed productivity. Viking is characterized as fast growing, early flowering, average maturity, sensitive to zinc deficiency, average resistance to lodging, slightly susceptible to Fusarium, very good fiber production, and average seed production. Before flowering the development of Ariane is uneven; by maturity the crop is uniform. In 1995 the Dutch cultivar, Natasja, was also planted with Ariane and Viking. Natasja is characterized as slow growing, late to flower and mature, sensitive to zinc deficiency, resistant to lodging, slightly susceptible to Fusarium, and good production of both fiber and seed.

In the nursery trials of 1994 13 European and Egyptian cultivars were compared. Seeds of 43 American, Canadian and European cultivars were multiplied. In the 1995 nursery trials the 13 cultivars and selections of 1994 were tested again and 31 additional American, Canadian and European cultivars were added. Seed of 18 additional cultivars was multiplied at wide spacing.

Sowing

In small plots each drill was sown with a Precision Seeder with a special pickup disk modified to drop approximately 20-25 seed/4 inches of drill. Because the disk picked up a constant volume, variation in seed size affected stand density. Generally, smaller seed were sown more densely than larger. Seeding depth was 0.5-0.75 in.

In 1994 at Mt. Carmel and 1995 at Mt. Carmel and Middlebury, flax was sown in large fields with an American-built rear mounted 7-ft grain drill with 20 double disk openers and press wheels at 4-in spacing. Sowing rate in 1994 at Mt. Carmel and in 1995 at Middlebury was approximately 100 lb/A. In 1995, at Mt. Carmel sowing rates were 35, 50, 75, and 100 lb/A. In 1994, at East Windsor-Ellington, a rear mounted 3-m (9.9 ft) European drill utilized 19 floating tubes, each with a special shoe that split the seed stream and formed two drills at 3.5-in spacing. A set of springtooth tines smoothed the soil and covered the seed. Seeding depth was approximately 0.5 in. Sowing rate was 45-50 lb/A to enhance seed multiplication.

Experimental design

Small plots at Mt. Carmel were 3.3x19.8 ft (1x6 m) in 1994 and 3.3x16.5 ft (1x5 m) in 1995. Each plot contained 10 drills at 4-in (10-cm) spacing. Plots were separated by 3.3-ft (1 m) walkways. The randomized block design was replicated twice. The replications were sown April 21 and 27, 1994 and April 24-26, 1995.

In 1994 at Mt. Carmel the large field experiment included three sowings of Ariane and Viking at 2-week intervals in a randomized block design with three replications. Superimposed was a split-plot arrangement of six fertilizer treatments consisting of an unfertilized control, ammonium nitrate at 112 and 140 lb/A with or without 109 lb/A 0-46-0 and 83 lb/A 0-0-60, or the P and K fertilizers alone. Each fertilizer treatment was repeated three times. Sowing dates were May 10, May 23, and June 6. Individual sowing strips were 14 ft wide (two passes of the drill) plus a 3-ft buffer. Fertilized bands, perpendicular to the direction of sowing, were 28 ft wide with no buffer.

The large field experiment in 1994 at East Windsor-Ellington consisted of 20 and 10-A fields of Ariane and a 20-A field of Viking. Sowing occurred April 29-May 3.

At Mt. Carmel in 1995, Ariane, Natasja and Viking were sown at 35, 50, 75, and 100 lb/A in a randomized block with two replications. Individual sowing strips were 7 ft wide (one pass of the drill) plus a 4-ft buffer. Sowing occurred on April 27.

At Middlebury a 5-acre field was divided into thirds and Ariane, Natasja and Viking were planted on May 10. Each planting strip was about 1.4 A. Buffer strips about 8 ft wide bordered each plot.

Measurements and sampling

Stand density was measured on small plots in 1994 and 1995 and in the large field at Mt. Carmel in 1995. At two locations in each small plot and six in the large plots the number of stems in a 4-in (10 cm) segment of each drill was counted. In the small plots and the large field at Mt. Carmel height of the stem closest to the midpoint of the section was measured in 1995. On the large field at Mt. Carmel in 1994 length of three stems in each bundle was measured after harvest. Height and density were not measured on the large fields at East Windsor-Ellington in 1994 and at Middlebury in 1995.

Yield on the small plots was calculated from the inner 32.8 ft^2 (3 m^2) plot in 1994 and the inner 26.2 ft^2 (2.4 m^2) plot in 1995. In the large plots at Mt. Carmel in 1994 two 10.9 ft^2 (1 m^2) plots were harvested from each cultivar-planting date-fertilizer treatment plot for yield estimates. In 1995 in the large plots at Mt. Carmel a 3.3x7 ft (1x2.1 m) plot was gathered after pulling from six locations in each planting strip. The large fields at East Windsor-Ellington in 1994 and the large field in Middlebury in 1995 were not sampled.

Weed control

A tank mix of MCPA amine, sethoxydim (Poast) and crop oil concentrate was applied when the flax seedlings were 3-4 in tall. In 1994 small plots and the large field at Mt. Carmel were sprayed with a calibrated backpack sprayer. In 1995 the small plots at Mt. Carmel were also sprayed with a calibrated backpack sprayer. In 1994 at East Windsor-Ellington and in 1995 at Mt. Carmel and Middlebury the large fields were sprayed with tractor-drawn boom sprayers. MCPA amine was applied at 0.5 pt/A, sethoxydim at 0.5-1.0 pt/A, and crop oil concentrate at 2 pt/A in a spray volume of 12-15 gal/A.

Small plots at Mt. Carmel were sprayed May 28, 1994 and May 24, 1995. The large field at Mt. Carmel was sprayed June 3, June 8 and July 1, 1994. Weeds were not disked prior to the third sowing. Therefore, the same materials were applied on June 8, 2 days after sowing, in an attempt to kill advance weed growth.

At East Windsor-Ellington spraying occurred during May 31-June 2, 1994.

In 1995 the seeding rate experiment at Mt. Carmel was sprayed on May 31. The large field at Middlebury was sprayed June 6, 1995.

Pulling

Fiber flax is ready to harvest about 85-95 days after sowing when the seed capsules turn yellow-brown and at least the lower third of the stems is defoliated. In 1994 and 1995 small plots were harvested by hand pulling. On each end of the plot a 20-in headrow was pulled. Two outer drills on each side of the plot were pulled. The remaining six interior drills were pulled and all material was spread separately on the plot surface for retting.

In 1994 at Mt. Carmel samples of flax in the large field planted on May 10 were pulled by hand beginning September 1. Most of the remaining field was harvested with a self-propelled puller on September 13. Some of the plots planted on June 6 were harvested in the first week of October. In 1995 the entire large field was pulled on August 22. Average swath width was about 53 in. The puller laid the flax stems in uniform windrows with all the stems oriented perpendicular to the direction of travel. Within the windrow all stems had seed capsules at one edge of the windrow and roots at the other. Pulling commenced at the sides of the field and proceeded counterclockwise toward the center.

In 1994 at East Windsor-Ellington the original intention was to harvest all flax with a grain combine for the seed only. On August 8 and 23, 1995 attempts to combine standing green flax were unsuccessful. Therefore, during August 15-20 on 34 A flax was pulled with a self-propelled puller.

Deseeding

Deseeding (rippling) removes the ripe seed capsules from the flax stems. In 1994 and 1995 flax in small plots at Mt. Carmel was rippled 7-22 days after pulling. The stems were pulled through a ripple (large coarse comb) to strip the seed capsules. The air dried seed capsules were weighed and subsequently threshed by lightly crushing and rubbing over a ribbed rubber pad. The seed was cleaned by sifting and air blast separation to remove chaff, debris and empty seed. Air dried cleaned seed was weighed for yield determinations.

In 1994 deseeding was done at East Windsor-Ellington on 16 A of pulled flax with a French-built, tractor-drawn deseeder-thresher. A pickup drum lifted the windrowed flax from the ground and a pair of belts carried the flax between several pairs of steel and rubber rollers. The crushed capsules released the seed to a series of shaker screens. A coarse upper screen scalped stones and large debris. A finer middle screen removed stems and other debris but allowed the flax seed to pass. A fine bottom screen retained the flax seed but allowed soil and other fine particles to pass. The flax seed passed through an air stream for removal of chaff before transfer by auger to a grain tank. The flax straw passed through the machine, was inverted 180 degrees and returned to a windrow. Deseeding substituted for turning. Seed loss due to rain and birds was so great on the remaining 18 A that no attempt was made to deseed it.

On 16 A seed was removed from standing flax with a grain combine. On September 9-10 the fields were sprayed with diquat (1 pt/A) and X-77 spreader/activator (1 pt/100 gal spray) to kill and dry the flax and weeds. Combining was done without difficulty on September 13 and 19. Straw passing through the combine and the remaining stubble were unusable for long fiber production. In 1995 at Middlebury the flax was pulled and deseeded in one operation with a Russian-built, tractor-drawn puller-deseeder. Seed capsules were stripped from the pulled stems by a large revolving comb and were transferred to a wagon towed behind the puller-deseeder. The pulled flax was laid in a windrow. Pulling commenced at the edge of the field and proceeded clockwise to the center.

Retting

Retting is a mild microbiological decomposition that loosens the fiber bundles from the bark, the central woody core of the stem and from one another. Rain and dew supply moisture. Ideally, windrows are turned one or more times during the retting process to ensure uniform retting throughout the depth of the windrow.

During retting the color of flax straw changes from yellow green at pulling to golden brown and finally to silver gray. As the flax begins to turn silver gray it is checked regularly for completion of retting. Several dry flax stems are held together and broken repeatedly with the fingers. With a push-pull motion the woody stem segments (shives) are dislodged. When the shives separate cleanly and easily, retting is complete. Overretting weakens the fibers and allows them to break easily. Underretted flax is difficult to process. When retting is complete and the flax straw is dry, the flax is baled in round bales and placed immediately in dry storage.

In 1994 and 1995 windrows on small plots were turned by hand. In 1994 pulled flax in large fields at East Windsor-Ellington and in 1995 at Middlebury was turned with a French-built, self-propelled turner. A narrow pickup drum lifted the flax from the soil. A toothed belt carried the flax over the turner, inverted it, and laid it in a windrow. The first turning proceeded from the center of the field outward to the edges. Flax in large fields at Mt. Carmel was not turned in 1994 and 1995.

Bundling and baling

When retting was complete flax straw from each portion of the small plots was bundled separately by hand. On the large fields flax straw was baled with a round baler. Individual bales were approximately 4-ft diameter for ease of handling and transport. Stems in the windrowed flax were all oriented in the same direction. Baling was done with the roots pointing to the right of the direction of travel. Additionally, two strands of baling twine were inserted into the center of the bale so that each wrap of the bale was separated from the preceding wrap with two strands of twine. This aids unrolling of the bale at the processing plant. French flax balers are modified to reduce drum rotation speed and increase pickup speed. This provides a thicker wrap and reduces twine usage. Unmodified American balers may be used but twine usage will be increased.

Threshing

In 1995 seed capsules removed with the Russian puller-deseeder were threshed with a grain combine. The stripping of the seed capsules also removes flower buds, leaves and a small amount of green straw. If the seed capsules cannot be threshed soon after stripping it is necessary to dry them to avoid heating. This was accomplished by spreading the seed capsules in a layer on the floor of a well-ventilated barn and stirring them daily until dry. After threshing if seed moisture content was greater than 10% the seed was similarly spread out to dry and stirred several times daily. A large fan assisted the drying. If moist seed is allowed to heat, germination is drastically reduced.

Seed cleaning

Seed from the large fields in East Windsor-Ellington in 1994 and Middlebury in 1995 was cleaned in a large 4-screen cleaner with air separation to remove chaff, empty seed and dust after the final screening. Careful regulation of the air stream was necessary to avoid removal of sound seed. In 1994 each seed lot was cleaned about three times in order to remove the large amount of weed seed, especially seed harvested with the grain combine. Seed was stored in woven polypropylene bulk bags. In 1995 each seed lot was cleaned twice to remove chaff and light seed and bagged in polypropylene 1-bu (56 lb) bags.

Table 2. Stand density (stems/ft^2), stem height (in), yield (lb/A) of seed, straw, long fiber, and tow, and total fiber (%) of 13 fiber flax cultivars in small plots at Mt. Carmel in 1994.

Cultivar	Origin	Stand density stems/ft^2	Stem height in	Clean seed lb/A	Deseeded straw lb/A	Long fiber lb/A	Tow lb/A	Total fiber %
SL-789	Czech Rep.	251	26.2	198	7065	36	1551	25.2
SL-1288	Czech Rep.	195	24.8	78	5900	33	1179	23.1
Super	Czech Rep.	210	27.1	506	5523	102	799	18.3
Texa	Czech Rep.	242	25.1	325	6453	7	638	11.2
Giza 5	Egypt	92	20.0	656	2842	0	776	27.3
Giza 6	Egypt	130	18.8	676	2725	2	594	21.9
Giza 7	Egypt	163	18.4	621	2897	0	841	29.0
Giza 8	Egypt	108	18.9	576	2608	0	724	27.7
Argos	France	190	25.5	194	6257	53	1517	28.2
Ariane	France	212	26.6	196	5652	46	1310	24.0
Hermes	France	249	27.3	107	6092	114	1119	20.2
Viking	France	234	24.4	399	5129	34	1369	27.3
Bilanka[1]	NL?	215	28.5	402	5075	34	1224	24.8

[1] Probably Belinka from the Netherlands

Germination tests

Duplicate samples of 100 seeds were placed between moist blotters in a standard germination chamber in light for 14 hours at 86 F and in dark for 10 hours at 68 F. Germination counts were made after 7 days.

Fiber extraction

In 1994 and 1995 samples of flax straw from small plots and large fields were crushed by passing between a pair of fluted rollers, beaten (scutched) with a wooden scutching knife on an inclined scutching board, and combed (hackled) on a coarse hackle to remove short or broken fibers. The yield of long (line) fiber and short fiber (tow) was weighed separately.

RESULTS AND DISCUSSION

Some of the results from 1994-95 have already been reported (Stephens 1996a, 1996b). A more complete report follows.

Germination

In 1994 and 1995 germination occurred 5-8 days after sowing in both small plots and large fields. Where soil was dry at planting germination occurred soon after the first rain.

Zinc deficiency

No symptoms of zinc deficiency were noted in 1994 or 1995. There was no difference in response between small plots sprayed or not sprayed with zinc sulfate at Mt. Carmel in 1995.

Weed control

Weed control in flax sown at normal density in 1994 and 1995 was generally good. In small plots at Mt. Carmel extra light from the walkways favored henbit. In 1994 at Mt. Carmel weed control in the large fields was poor in the treatment sown June 6. Disking before sowing would likely have improved weed control. In 1994 at East Windsor-Ellington where flax was sown at reduced density, Pennsylvania smartweed, red root pigweed and ragweed resisted control. Although early germinating crabgrass was controlled by sethoxydim, large crabgrass became troublesome in one field at East Windsor after the flax foliage fell but before the flax seed was combined. In 1995 at Mt. Carmel weed control was poor where flax was sown at 35 and 50 lb/A. In both years one application of herbicide was insufficient to control weeds in the buffer strips between treatments. Three low density treatments were abandoned due to weeds. In 1995 at Middlebury where flax was sown at normal density weed control was good. However, one application was insufficient to control weeds in the border strips around each plot. Mowing before harvest was necessary.

1994-95 Cultivar Trials

STAND DENSITY. High stand density, 185 stems/ft^2, is desirable to control flax stem diameter and suppress weeds. In 1994 stand density ranged 92-251 stems/ft^2 (Table 2); in 1995 it ranged 58-231 stems/ft^2 (Table 3). Stand density was generally higher in 1994 than in 1995.

The seed disk in the planter picks up a constant volume of seed. In 1995 the disk was calibrated to drop 5-6 seeds/in of drill for seed weighing about 0.19 oz (5.5 g)/1000 seed.

Table 3. Stand density (stems/ft^2), height (in), yield (lb/A) of seed, straw, long fiber, and tow, and total fiber (%) of 44 fiber flax cultivars in small plots at Mt. Carmel in 1995.

Cultivar	Origin	Stand density stems/ft^2	Stem height in	Clean seed lb/A	Deseeded straw lb/A	Long fiber lb/A	Tow lb/A	Total fiber %
Cl-1059[1]	Canada	169	22.5	479	2273	67	380	19.7
FP-942	Canada	127	23.7	1003	2713	108	521	23.0
FP-943	Canada	210	20.8	746	2268	58	482	23.7
FP-944	Canada	177	22.5	623	2774	34	512	19.7
FP-945	Canada	135	24.1	974	2370	145	457	25.4
SL-789	Czech Rep.	231	25.4	183	3788	332	732	28.1
SL-1288	Czech Rep.	150	26.6	343	3606	453	506	26.6
Super	Czech Rep.	128	22.9	393	3298	336	503	25.4
Texa	Czech Rep.	225	28.0	432	4138	506	612	27.0
Giza 5	Egypt	58	19.8	490	1921	33	368	20.9
Giza 6	Egypt	63	21.1	519	1891	72	340	21.8
Giza 7	Egypt	86	18.4	510	1832	26	330	19.4
Giza 8	Egypt	90	20.0	482	1898	74	316	20.5
Argos	France	158	24.6	424	3654	491	668	31.7
Ariane	France	144	26.7	310	3529	421	569	28.0
Arione[2]	France?	141	27.2	190	3829	337	697	27.0
Hermes	France	176	27.5	222	3879	406	770	30.3
Viking(1)	France	141	25.9	197	3413	372	623	29.2
Viking(2)	France	136	26.3	521	3986	436	701	28.2
Baltucai	Lithuania	169	28.6	191	3508	241	578	23.5
Belinka	NL	76	26.1	501	2451	130	443	23.4
Bilanka[3]	NL?	145	24.4	692	3411	379	553	27.3
Cl-1381	NL	85	20.4	749	1895	44	369	21.3
Marina	NL	157	26.0	416	3911	150	916	27.4
Natasja(1)	NL	140	23.5	471	2807	215	491	25.0
Natasja(2)	NL	96	26.2	566	4041	130	844	24.4
Saskia	NL	131	25.0	215	2908	204	553	25.8
Vasa	Poland	119	26.7	616	3128	248	547	25.4
Aleksim	Russia	173	27.3	408	3589	293	707	27.9
Cl-629	Russia	118	22.7	738	2164	68	409	22.1
K-6	Russia	127	27.2	206	2831	139	539	24.0
Kram	Russia	164	27.9	412	4567	361	1013	30.0
Kvant	Russia	162	23.4	228	3143	152	558	22.6
M-8	Russia	177	28.6	161	3683	180	645	22.4
M-12	Russia	176	28.4	161	3772	384	701	28.8
Mogilevskij	Russia	187	26.1	306	3545	336	707	27.4
Orsanskij-2	Russia	209	27.8	356	3406	209	693	25.9
Priziv-81	Russia	132	27.5	252	2755	185	547	26.5
Tverca	Russia	172	29.1	351	3491	298	582	24.6
Henryk	Sweden	326	26.2	276	3664	125	738	23.5
Glukovskij	Ukraine	137	25.0	399	3091	174	501	21.7
Cl-1797	US	140	23.4	371	2659	108	452	20.9
E-68	Unknown	148	29.6	182	3562	441	539	27.5
Niva	Unknown	182	28.4	310	4122	345	796	27.6

[1] Cl = USDA flax collection, Fargo, ND
[2] Probably Ariane from France
[3] Probably Belinka from the Netherlands

Larger seed would be sown at lower density and smaller at higher density. The Egyptian seeds were large, hence low stand density. Seed from the Czech Republic was small, therefore, higher stand density. However, stand density is also affected by seed viability and seedling losses.

STEM HEIGHT. Under normal growing conditions fiber flax attains a height of 36-42 in. Dry weather in 1994 and 1995 reduced height growth. In 1994, sources from the Czech Republic averaged 25.8 in; France, 26.0 in; and Egypt, 19.0 in (Table 2). Bilanka, received from Egypt but probably Belinka from the Netherlands, was tallest, 28.5 in. In 1995 height ranged 18.4 in for Giza 7 from Egypt to 29.6 in for E-68 of unknown origin. Five cultivars from Canada averaged 22.7 in; Czech Republic (4), 25.7; Egypt (4), 19.8; France (6), 26.4; Netherlands (7), 24.5; Russia (11), 26.9 in.

In 1995 height of cultivars present in both years was slightly less than in 1994. Minimum acceptable long fiber length is 20 in (Personal communication, B. Metevier, Tex-Nord, Normandy). Because usable flax fiber extends from the root collar to the first branch, minimum acceptable stem height is 24 in. The Canadian and Egyptian sources are likely too short to be useful for long fiber production.

SEED YIELD. Yield of cleaned seed in 1994 was low. It ranged from 78 lb/A for SL-1288 to 676 lb/A for Giza 6 (Table 2). Sources from the Czech Republic averaged 277 lb/A; Egypt, 632; France, 224 lb/A. In 1995 seed yield ranged from 161 lb/A for M-8 and M-12 from Russia to 1003 lb/A for FP-942 from Canada (Table 3). Five sources from Canada averaged 765 lb/A; Czech Republic (4), 358; Egypt (4), 500; France (6), 311; Netherlands (7), 516; Russia (11), 325 lb/A. Although each seed capsule can contain 10 seeds, only rarely do all develop. Seed loss in the field before and during harvest also reduces the yield. In France the multiplication rate is 5 or 6 for normal density. That is, for every 100 lb of seed sown the expected seed yield is 500-600 lb. Clearly, the multiplication rate for most sources in 1994 and 1995 was low. Generally, the taller sources produced less seed than the shorter.

STRAW YIELD. A good yield of retted straw is about 6250 lb/A. In 1995 seed capsules and their stems of the fiber types comprised about 20% of the weight of flax straw. Therefore, a good yield of retted, deseeded straw would be about 5000 lb/A.

In 1994 yield of deseeded straw ranged from 2608 lb/A for Giza 8 to 7065 lb/A for SL-789 from the Czech Republic (Table 2). Average yield of the Czech cultivars was 6235 lb/A; Egypt, 2768; France, 5782 lb/A. Yield of the Czech and French cultivars was high; yield of the Egyptian was low. In 1995 deseeded straw yield ranged from 1832 lb/A for Giza 7 to 4138 lb/A for Texa (Table 3). Average yield for five Canadian sources was 2480 lb/A; Czech Republic (4), 3708; Egypt (4), 1856; France (6), 3715; Netherlands (7), 3061; Russia (11), 3359 lb/A. The Canadian and Egyptian sources resemble oil flax from which they probably were derived, that is, relatively high seed yield and low straw yield. The French and Czech sources were highest followed by the Russian and Dutch. The dry weather of 1995 greatly reduced straw yield compared to 1994.

FIBER YIELD. Fiber yield has two components, long or line fiber and short fiber or tow. The long fibers are derived from the long fiber bundles located between the outer bark and the inner woody core of the stem. The bundles extend from the root collar to the branches. Retting allows the fibers to separate from one another and from the bark and woody core. Extraction of the fiber requires removal of the bark and woody core. During crushing of the stems and removal of bark and woody core segments (scutching) some long fibers are broken, giving rise to tow. Overretting weakens the long fibers and renders them susceptible to breaking. Hand scutching is a relatively harsh treatment of fiber and probably increases the amount of tow. Long fiber comprises 21-24% of the weight of deseeded straw and tow, 10-13%. The expected yield of long fiber is about twice that of tow. In 1994, yield of long fiber was much less than tow (Table 2). This is probably the result of overretting. In 1995 yield of long fiber was greater, although less than tow in most cases (Table 3). Control of retting was better although hand processing likely increased the amount of tow during combing (hackling) of the fibers. Total fiber content may provide a better comparison of cultivars. Total fiber, as a percent of weight of deseeded straw, has an expected range of 31-37%. In 1994 total fiber ranged from 11.2% for Texa to 29.0% for Giza 7 (Table 2). The Czech cultivars averaged 19.4%; Egypt, 26.5%; France, 24.9%. In 1995 total fiber ranged from 19.4% for Giza 7 to 31.7% for Argos (Table 3). The Canadian cultivars averaged 22.3%; Czech Republic, 26.8%; Egypt, 20.6%; France, 29.1%; Netherlands, 24.9%; Russia, 25.6%. For sources tested in both years total fiber content was generally higher in 1995 than in 1994 except for the Egyptian sources.

1994 Planting Date and Fertilizer Trial

STEM HEIGHT. Stem height of Ariane generally decreased with later planting date (Table 4). For Viking stem height increased for the second planting on May 23. Viking was generally shorter than Ariane. There was no consistent effect of added fertilizer.

SEED YIELD. Seed yield was poor, 2-16 lb/A for Ariane and 3-22 lb/A for Viking (Table 5). Seed yield of both cultivars decreased with later planting. Added nitrogen decreased seed yield of both cultivars. Added phosphorus and potassium had no effect on seed yield of either cultivar. Some samples were pulled during September 1-12; on September 13 all remaining flax was pulled. Pulling occurred 99-133 days after planting. Some rippling did not occur until after the retted flax was bundled and placed in dry storage. Some seed loss may have occurred during retting or bundling and handling.

Table 4. Stem height (in) of Ariane and Viking fiber flax according to planting date and fertilizer treatment at Mt. Carmel in 1994.

	Treatment[1]	May 10	May 23	June 6
		Planting date / Stem height (in)		
Ariane	Check	36.4	37.6	33.4
	N	36.8	34.7	28.4
	N+	34.4	33.1	34.2
	NPK	36.6	30.2	34.4
	N+PK	35.0	32.2	27.6
	PK	35.0	33.2	27.6
Viking	No fert	31.8	33.2	27.1
	N	33.1	32.9	24.8
	N+	32.2	34.7	24.0
	NPK	31.5	37.1	26.4
	N+PK	29.9	34.4	25.9
	PK	30.7	32.7	25.6

[1] N=34-0-0, 112 lb/A; N+=34-0-0, 140 lb/A; P=0-46-0, 109 lb/A; K=0-0-60, 83 lb/A

STRAW YIELD. Deseeded straw yield of Ariane ranged from 1031-3823 lb/A; Viking, 1227-2931 lb/A (Table 5). Straw yield of Ariane decreased steadily with later planting date. Yield of Viking increased for the May 23 planting and then decreased. The effect of fertilizer was inconsistent; nitrogen decreased straw yield of Ariane in the latter two plantings. For Viking nitrogen increased straw yield in the first planting but not thereafter. Added phosphorus and potassium did not consistently affect either cultivar.

FIBER YIELD. The yield of fiber was low (Table 5). Total fiber, as a percent of the weight of deseeded straw, ranged from 3.2-10.1 for Ariane and from 3.1-15.1 for Viking. For Viking, percent total fiber decreased for the middle planting but then increased for the last planting. There was no consistent effect of fertilizer on either cultivar.

Large field plantings 1994-1995

1994 STRAW YIELD. At East Windsor-Ellington 34 of the 50 acres were harvested by conventional pulling. The retted straw was baled in 4-ft diameter round bales. The yield is shown in Table 6. This flax was sown at about 50 lb/A or half the density normally used. Good yield would be about 10 bales/A.

1995 SEED AND STRAW YIELD. In 1995 at Middlebury flax was sown at normal density (100 lb/A) and the yield of

Table 6. Yield of flax straw (4-ft round bales) at East Windsor-Ellington in 1994.

Cultivar	Acres	No. bales
Ariane	10	67
Ariane	8	53
Viking	16	79

Table 5. Yield (lb/A) of seed, deseeded straw, total fiber and fiber percent of Ariane and Viking fiber flax according to planting date and fertilizer treatment at Mt. Carmel in 1994.

Cultivar/ Treatment		May 10 Seed lb/A	May 10 Straw lb/A	May 10 Total fiber lb/A	May 10 Total fiber %	May 23 Seed lb/A	May 23 Straw lb/A	May 23 Total fiber lb/A	May 23 Total fiber %	June 6 Seed lb/A	June 6 Straw lb/A	June 6 Total fiber lb/A	June 6 Total fiber %
Ariane	Check	10	3653	820	21.8	11	3563	818	22.8	6	1838	391	18.3
	N[1]	10	3574	725	20.2	4	3168	700	23.6	2	1160	235	21.3
	N^+	10	3525	716	20.9	5	3340	710	21.2	2	1031	288	20.1
	NPK	7	3397	668	20.1	5	3012	651	21.2	3	1622	447	18.0
	N^+PK	10	3823	759	20.0	5	3046	674	21.7	2	1611	312	18.6
	PK	16	3434	735	22.2	11	3266	799	24.8	4	1467	273	23.6
Viking	Check	22	2456	640	26.0	9	2728	759	27.7	9	1811	443	25.7
	N	11	2663	765	34.5	4	2695	690	25.3	4	1541	373	25.1
	N^+	11	2864	647	23.2	8	2600	617	23.6	3	1227	295	22.9
	NPK	11	2504	582	23.1	4	2931	732	24.4	4	1770	432	24.7
	N^+PK	9	2383	579	24.5	5	2631	676	25.4	4	1888	531	24.9
	PK	16	2092	588	28.6	4	2747	820	29.6	4	1498	374	25.7

[1] N=34-0-0, 112 lb/A; N^+=34-0-0, 140 lb/A; P=0-46-0, 109 lb/A; K=0-0-60, 83 lb/A

cleaned seed and straw is shown in Table 7. Despite a relatively dry season, yield was good for Natasja. The reduced yield of Ariane was caused in part by trampling of the flax by deer. A portion of the plot was not harvested. The usual multiplication rate for fiber flax is 5-6; that is, 500-600 lb of seed would be obtained for each 100 lb sown. However, some seed was lost in harvesting as judged by the crop of volunteer flax seedlings. The method of harvest required that the seed be ripe and ripe seed capsules split open easily.

Table 7. Yield of deseeded straw (4-ft round bales) and cleaned seed (lb) of Ariane, Natasja and Viking fiber flax at Middlebury in 1995.

Cultivar	Acres	No. bales	Seed (lb)
Ariane	1.53	9.5	310
Natasja	1.45	11.75	596
Viking	1.45	10	522

1995 Sowing Rate Trial

STEM HEIGHT. Stem height of Ariane and Viking remained nearly constant over the range of seeding rates (Table 8). Stem height of Natasja tended to decrease with increased seeding rate.

STAND DENSITY. Stand density was low (Table 8). A sowing rate of 100 lb/A supplies about 185 seed/ft^2. Germination rate was over 90% for all cultivars. Seedling losses must have been great during the dry growing season. Stand densities at 35 and 50 lb/A were nearly identical. It was noted at germination that distribution of seed was erratic at those low seeding rates.

SEED YIELD. Seed yield was low and variable (Table 9). Yield of Ariane and Viking decreased at the highest seeding rate. Natasja had the highest seed yield at the highest sowing rate. Reduced stand density allows greater opportunity for branching and greater seed production. However, the stand density of Natasja was low even at the highest seeding rate.

STRAW YIELD. Yield of retted deseeded straw ranged from about 700 to nearly 3500 lb/A (Table 9). At high stand density a good yield would be 5000-5600 lb/A. The low density reduced yield. This is very apparent for Natasja which had the lowest density.

LONG FIBER YIELD. Yield of long fiber was low, 14-315 lb/A (Table 9). A good yield of long fiber would be 900-1000 lb/A. Yield was highest for Viking and least for Natasja. Long fiber yield was highest for all cultivars at a seeding rate of 75 lb/A.

TOW YIELD. Ordinarily, yield of tow is about half that of long fiber. However, at all seeding rates and cultivars tow was several-fold greater than long fiber. This is similar to the results from the small plots (Tables 2 and 3) and likely resulted from a combination of overretting and relatively harsh hackling (combing).

TOTAL FIBER PERCENT. Total fiber ranged from 17-28 % of deseeded flax straw. Viking was consistently highest and Natasja lowest. In general, fiber content increased with increasing seeding rate. However, Natasja had low density at all seeding rates, hence, low fiber content. In the 1995 nurs-

Table 8. Stem height (in) and stand density (stems/ft^2) of fiber flax sown at different rates at Mt. Carmel in 1995.

	Seeding Rate (lb/A)							
	35	50	75	100	35	50	75	100
Cultivar	Stem height (in)				Density (Stems/ft^2)			
Ariane	34.9	34.0	32.5	34.3	24	22	61	81
Natasja	31.8	25.5	28.4	26.8	17	22	33	33
Viking	33.2	33.3	33.2	30.0	23	27	54	85

Table 9. Yield (lb/A) of cleaned seed, deseeded straw, total fiber, and fiber percent of fiber flax sown at different rates (lb/A) at Mt. Carmel in 1995.

Cultivar	Ariane				Natasja				Viking			
Seeding rate lb/A	Seed lb/A	Straw lb/A	Total fiber lb/A	Total fiber %	Seed lb/A	Straw lb/A	Total fiber lb/A	Total fiber %	Seed lb/A	Straw lb/A	Total fiber lb/A	Total Fiber %
35	157	1936	448	22.8	113	1013	193	19.2	101	1424	367	25.3
50	123	1343	285	20.6	80	703	119	16.8	169	2359	655	27.6
75	149	3148	758	24.2	173	1599	331	20.8	186	3104	867	27.8
100	92	3463	852	24.5	203	1460	302	20.5	111	3325	943	28.4

ery trials (Table 3) total fiber percent was 28.0, 25.0 and 28.2 for Ariane, Natasja and Viking, respectively.

Seed Quality

Seed quality, as judged by appearance and germination tests, has been variable. Initially, one concern was that the hot and sometimes dry weather of summer affected seed quality. In 1994 at East Windsor-Ellington seed yield was low and the quality was poor. Ariane, harvested with a grain combine, had 22.5% germination. Viking, similarly harvested, had germination of 8.5% due to overheating of the seed. Previously pulled Viking deseeded with the French-built flax combine had germination of 30.5%.

In 1994 germination of seed produced in the planting date-fertilizer trial at Mt. Carmel was variable (Table 10). For both Ariane and Viking seed germination increased with later planting. However, only four treatments were tested for the planting of June 6. Recall that seed yield was low and generally decreased with later planting date for both cultivars (Table 5). Germination of Viking seed was clearly better than Ariane. Added fertilizer had no consistent effect on seed germination of either cultivar.

Table 10. Germination (%) of seed produced in the planting date-fertilizer trial at Mt. Carmel in 1994.

		Planting date			
Cultivar	Treatment	5/10	5/23	6/6	ALL
Ariane	Ck	28.2	47.8	78.5	43.8
	N	42.8			42.8
	N^+	19.0	50.3		29.4
	NPK	3.0	41.5		22.3
	N^+PK	19.0	9.0		16.5
	PK	35.9	31.1	80.5	38.7
Ariane		28.2	38.1	79.5	34.8
Viking	Ck	68.9	94.0	76.5	74.4
	N	69.2			69.2
	N^+	66.0	84.3		78.2
	NPK	53.3			53.3
	N^+PK	56.5	85.8	72.5	75.1
	PK	55.8			55.8
Viking		62.6	88.0	75.2	68.7
ALL		46.6	55.7	76.9	51.5

In 1995 the dates of pulling and rippling on the small plots, and the frequency and amount of rain were recorded. The days of exposure, frequency of rain and total amount of rain were determined. Days from planting to pulling ranged 83-101, days of exposure from pulling to rippling ranged 0-22, frequency of rain during exposure varied from 0-8 occasions with total rainfall of 0-5.48 in. Seed germination ranged from 9.0-96.0%. In general, exposure longer than 10 days resulted in decreased germination. However, increased time from pulling to rippling also increased the opportunity for increased frequency and amount of rain. Germination of seed removed the same day as pulling ranged 84.5-95.0%. Germination decreased after a single exposure to rain or after approximately 1.0 in of rain had occurred Figure 1). Clearly, prompt harvest of seed with minimal exposure to rain should result in highest seed quality.

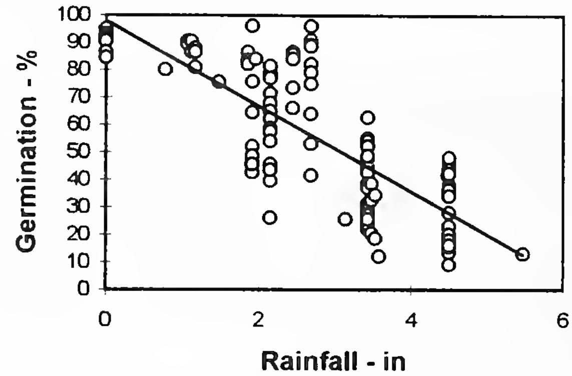

Figure 1. Germination (%) of 1995 Mt. Carmel flax seed according to rainfall (in) received between pulling and rippling.

In retrospect, seed quality of flax in 1994 from East Windsor-Ellington was compared against the weather records from Valley Laboratory in Windsor. Flax pulled August 20, 110 days from planting and deseeded September 3-6 with the tractor-drawn flax combine was exposed 14-16 days and received three occasions of rain for a total of 3.05 in. Average germination was 30.5%. Flax not pulled but harvested with a grain combine on September 13 was 143 days from planting and since August 20 had experienced six periods of rain totaling 3.82 in. Average germination was 22.5 percent. Very likely, delay in harvest and excessive rain were the causes of poor germination.

CONCLUSIONS

Planting date, weather, stand density, and stem height all influence yield. Clearly, delay in planting reduces yield. High stand density and greater stem height both increase yield. In a favorable year such as 1994 straw yield is acceptable. In an unfavorable season such as 1995 at Mt. Carmel straw yield is greatly reduced. Stem height is clearly reduced during a dry season. Seed quality is reduced by excessive delay in harvest and increasing exposure to rain after harvest.

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