EFFECTS OF FERTILIZERS ON YIELDS AND BREAKING STRENGTHS OF AMERICAN HEMP, *CANNABIS SATIVA*[1]

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AMERICAN hemp, *Cannabis sativa*, became a strategic crop with the outbreak of war. Production was increased from a prewar average of about 2,000 acres to 175,000 acres in 1943, and approximately 62,000 acres were grown in 1944. The prewar production centered largely in Wisconsin and Kentucky; and the acreage was increased in those states as well as in Illinois, Indiana, Iowa, and Minnesota.

The experience of prewar producers served as a general guide to production practices, but widely differing soil and climatic conditions presented many problems in the newer areas. This stimulated considerable research in production and processing methods. This paper describes experiments in which the effects of fertilizers on yields and breaking strengths of hemp fiber were studied.

The fiber of American hemp is a bast fiber, or soft fiber, and it has many desirable characters. When well retted, it is soft and readily spinnable. Acre yields are about twice those of flax, which is the other principal domestic soft fiber. Another important quality of hemp is its high breaking strength. Since adequate harvesting machinery and processing facilities are now available these characters may permit hemp to retain a more important place among the domestic fibers than it occupied in the prewar period. Such a result may well be predicated on improvements in production and processing methods which will result in larger yields of better quality fiber.

LITERATURE REVIEWED

Studies dealing with the effects of fertilizers on the yields and quality of hemp fiber are largely of European origin. Herzog (5)[3] summarized the results of these studies and showed that yield responses varied with soil and climatic conditions. Herzog states that in general fiber from hemp grown on peat soils was inferior in strength to that grown on mineral soils. Various fertilizers were not consistent in their effects on quality of fiber. In general, however, soil conditions are said by Herzog to have less influence on strength of fiber than other factors, particularly maturity of the plant and the extent of fiber processing.

The literature relating to the effects of fertilizers on hemp as it was produced and handled in this country prior to 1942 is meager. Several papers dealing with this subject have appeared recently.

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[3]Figures in parenthesis refer to "Literature Cited", p. 563.

Chapman (3) obtained large increases in yield of hemp straw from complete fertilizers applied on the plowsole.

Wilsie, Black, and Aandahl (7) and Black and Vessel (1) reported on series of fertilizer experiments conducted in Iowa in 1943 and 1944. Nitrogen gave the largest increases in yield in both years, followed by phosphoric acid. The response to potash was in general small, with some responses negative and some positive. No studies on fiber quality were reported.

The Iowa experiments also included one on peat soil at Crystal Lake, Iowa. Some seedlings on this soil gained an early advantage and grew tall and coarse. These shaded out other plants which remained stunted and were of no value for fiber production. Increasing the seeding rate from the normal 5 pecks to 11 pecks per acre increased the stand of desirable plants by only 2.3 plants per square foot.

Studies of the effects of fertilizers on fiber flax are more numerous than those dealing with hemp. In view of the similarity of the two crops, certain of these studies may appropriately be considered in connection with the work reported here.

Tobler (8, 9) stressed the importance of anatomical studies of the bast cells of flax when studying the effect of fertilizers. He stated that the shape of these cells which influences the quality of the fiber has generally been attributed to herditary characters but is more likely to be the result of soil nutrients.

Bredemann and Fabian (2) and Fabian (4), also working with flax, found that a medium amount of nitrogen is desirable for the best quality and yield of fiber and that either a smaller or a larger application would produce less valuable results. A deficiency of nitrogen is conducive to the production of short fine stems containing little fiber, while abundant nitrogen tends to produce thick stems with lower fiber percentages and fiber of a low quality. With abundant nitrogen the fiber cells were lacking in uniformity and they had large lumens.

Miller, Burton, and Manning (6) found that as flax stems increased in diameter the number of fibers, the number of bundles, and the number of fibers per bundle also increased. However, large stems had fewer fibers per unit of area than the small stems, and the individual fibers were coarser.

EXPERIMENTAL

Series of fertilizer experiments were conducted on mineral soils in Wisconsin and Illinois in 1943 and 1944. These experiments were uniformly arranged in factorial designs, thus permitting isolation of the effects of each fertilizer constituent and of the interactions among them. Other experiments in Indiana, and on peat soil at Coddington, Wis., followed different plans.

The hemp straw from each plot was dew retted, and, except for the experiment at Ladd, Ill., in 1944, the fiber was separated on a small reciprocating brake. The hemp straw from the experiment at Ladd, Ill., was processed in a commercial mill at that location. All tests of breaking strength were made on a Scott tester using spool clamps. The sample tested comprised fiber strands 25 cm in length, 0.2 to 0.7 gram in weight, and conditioned at 66% humidity. The breaking distance between centers of clamps was 7.5 cm.

EXPERIMENTS IN WISCONSIN AND ILLINOIS IN 1943

There were five experiments in this series in 1943. They were located on fields in relatively good state of fertility which were considered well adapted to hemp. All but one had been manured or had grown legumes or sod crops in recent years. Details of location, soil type, and cropping history are given in the first part of Table 1.

Nitrogen, phosphoric acid, and potash were applied, each singly and in all possible combinations, and the combined application was equivalent to a 3–12–12 analysis at 300 pounds per acre. Fertilizers were broadcast and disced in shortly prior to seeding hemp. There were five or six replications in each experiment. The data were treated by analysis of variance and are summarized in Table 2.

Mean yields of fiber ranged from satisfactory to quite high, and the increases due to fertilizer were moderate. It seems probable that the fields selected, by reason of good past management, were able to produce quite satisfactory hemp crops on the unfertilized plots. An exception should be noted in case of the Canniff field which was in hemp for the third successive year, and where fertilizer applications, particularly of nitrogen, were probably inadequate for maximum yields. Such increases as occurred were caused principally by nitrogen.

In all of the experiments, except that on the Canniff farm, the breaking strength of fiber from nitrogen-treated plots was lower than that from no-nitrogen plots. In two cases the reductions due to nitrogen were highly significant, and amounted to 7.3 and 9.5%, respectively. When the data were pooled and analyzed collectively, as shown in Table 3, there was a highly significant reduction in breaking strength caused by nitrogen which amounted to 4.4%. Omitting the data from the Canniff experiment, the mean reduction in breaking strength was 5.7%.

This effect was produced by only 9 pounds of nitrogen per acre. Because of the relatively good state of fertility prevailing on most of the fields, it is possible that this may have provided for more nitrogen than was needed in the early growth stages. If this is the case, it is indicated that even moderately excessive nitrogen applications may prove detrimental to the quality of hemp fiber.

In four of the five experiments the breaking strength of fiber from phosphate-treated plots was greater than that from no-phosphate plots although differences were not significant in any case. When the data were analyzed collectively (Table 3), there was an indicated significant increase in breaking strength caused by phosphoric acid. Potash did not affect breaking strength in any individual experiment nor in the experiments as a group.

EXPERIMENTS IN WISCONSIN AND ILLINOIS IN 1944

There were four experiments in the series of 1944, and by design the fields included a range in cropping histories and adaptability to hemp. Details of location, soil type, and cropping history are given in the second part of Table 1. The two fields listed first were in timothy sod the previous year, and they were spring plowed. Such a sequence is particularly unsuited to hemp with its high requirement for available nitrogen. The two other fields had grown legume crops in recent years and corresponded more nearly in fertility level to the fields used in 1943.

Fertilizers were applied as in 1943 in a factorial scheme, utilizing 0, 50, and 100 pounds of nitrogen, 0, and 30 pounds of phosphoric acid, and 0, and 20 pounds of potash per acre. There were four replications in each of the experiments in Wisconsin and two replications in the experiment on War Hemp Industries' field at Ladd, Ill. The data of the experiments are summarized in Table 4.

TABLE 1.—*Location, soil type, and cropping history of fields used for fertilizer experiments with hemp in 1943 and 1944.*

Name of cooperator	Location of field	Soil type	Cropping history
		1943 Fields	
W. Virchow	De Forest, Wis.	Carrington silt loam	Sweetclover, 1941; sweet corn, 1942
E. Keel	Juneau, Wis.	Miami silt loam	Corn, 1942; manured for hemp
R. Canniff	Beaver Dam, Wis.	Carrington silt loam	Hemp, 1941, 1942, and 1943
H. Newcomer	Mt. Morris, Ill.	Tama silt loam	Sweetclover, 1941; corn, 1942
H. Donaldson	Polo, Ill.	Tama silt loam	Sod to 1941; corn, 1942
		1944 Fields	
L. Wedig	Cuba City, Wis.	Dodgeville silt loam	Meadow, 1940–43; mostly timothy, 1942–43
War hemp industries	Ladd, Ill.	Tama silt loam	Meadow for years, mostly timothy
Wis. Exp. Station	Madison, Wis.	Miami silt loam	Legume-grass pasture, 1942; corn, 1943
P. Walsh	De Forest, Wis.	Clyde silt loam	Alfalfa, 1941; corn, 1942–43

TABLE 2.—*Effects of fertilizers on yields and breaking strengths of hemp fiber, experiments in Wisconsin and Illinois, 1943.*

Name of cooperator	Acre yield of fiber, pounds							Breaking strength of fiber, kgms per gram						
	Nitrogen		Phosphate		Potash		Mean	Nitrogen		Phosphate		Potash		Mean
	Present	Absent	Present	Absent	Present	Absent		Present	Absent	Present	Absent	Present	Absent	
W. Virchow	2,248	2,126	2,224	2,150	2,222	2,152	2,187	121.1	122.9	124.9	119.2	120.9	123.2	122.0
E. Keel	1,921	2,013	1,943	1,991	1,980	1,954	1,967	141.2**	152.4	149.5	144.1	147.7	146.0	146.8
R. Canniff	1,316	1,210	1,271	1,256	1,265	1,262	1,263	177.3	176.0	177.4	175.9	177.5	175.8	176.7
H. Newcomer	1,581	1,526	1,558	1,549	1,527	1,580	1,553	132.1**	145.9	138.4	139.5	141.5	136.4	139.0
H. Donaldson	1,489	1,462	1,498	1,453	1,472	1,478	1,475	135.8	141.4	141.0	136.2	138.9	138.3	138.6
Mean	1,711	1,667	1,699	1,680	1,693	1,685	1,689	140.2**	146.6	145.0*	141.8	144.1	142.7	143.4

*Differs from corresponding no treatment, $P = 0.05$.
**Differs from corresponding no treatment, $P = 0.01$.

TABLE 3.—*Analysis of variance for breaking strength of hemp fiber from five experiments in Wisconsin and Illinois.*

Source	DF	Variance	F value
Total	2,239	——	——
Experiments	4	171,735.23	121.99**
Blocks	23	2,559.17	1.82*
Treatments:			
N	1	22,348.79	15.87**
P	1	6,010.28	4.27*
K	1	1,049.69	——
NP	1	590.81	——
NK	1	334.65	——
PK	1	0.19	——
NPK	1	36.11	——
Exp. × treatments	28	1,203.24	——
Error	161	1,407.81	——
Sampling error†	2,016	742.60	——

*Significant, P = 0.05.
**Significant, P = 0.01.
†Ten determinations of breaking strength were made on the fiber from each plot. The sampling error is a measure of the composite variance among these determinations.

On the Wedig and War Hemp Industries' fields, where hemp followed spring-plowed timothy sod, the unfertilized hemp exhibited marked nitrogen deficiency. On both of these fields there were large and highly significant increases in yield from applied nitrogen, and the Wedig field responded to phosphoric acid as well. Inasmuch as yields increased progressively through the 0-, 50-, and 100-pound nitrogen applications, and as judged by yields and appearance of the crop with the heaviest treatment, it is doubtful if nitrogen at 100 pounds per acre more than met the requirements for satisfactory yields. Under these conditions no fertilizer element tested significantly affected the breaking strength of fiber.

The general character of growth on the Wedig field is shown in Fig. 1, and that on War Hemp Industries' field in Fig. 2.

On fields of the Wisconsin Experiment Station and the Walsh farm, fiber yields were not increased significantly by the nitrogen additions, while the Walsh field responded to application of phosphoric acid. It is probable that the treatments supplied more nitrogen than was needed for maximum fiber production. This is supported by data on losses in retting. On the Wisconsin Experiment Station field losses from green weight (calculated to dry basis) to dry-retted straw amounted to 17.0, 18.8, and 20.5% for the 0-, 50-, and 100-pound nitrogen additions, respectively. Corresponding figures on the Walsh field were 24.0, 26.6, and 30.2%. These figures represent losses of leaves in part, but they also reflect the generally more succulent type of growth on the niitrogen-treated plots. Linear trends in both cases were highly significant.

On both of these fields hemp fertilized with nitrogen at 100 pounds per acre had lower breaking strength than the hemp without nitrogen. The reduction on the Wisconsin Experiment Station field approached significance and on the Walsh field the difference was highly significant. Collective analysis of variance of the data from the two fields

TABLE 4.—*Effects of fertilizers on yields and breaking strengths of hemp fiber, experiments in Wisconsin and Illinois, 1944.*

Name of cooperator	Acre yields of fiber, lbs.								Breaking strength of fiber, kgms per gram							
	Nitrogen			Phosphate		Potash		Mean	Nitrogen			Phosphate		Potash		Mean
	0	50	100	0	30	0	20		0	50	100	0	30	0	20	
L. Wedig	300	785*	900**	562	772**	600	734	667	98.7	98.7	91.7	95.5	97.3	92.8	100.0	96.4
War Hemp Ind.	505	596	862**	626	683	700	609	655	80.6	88.4	82.7	84.5	83.3	82.3	85.5	83.9
Wis. A.E.S.	1,397	1,489	1,397	1,435	1,420	1,382	1,473	1,429	110.5	112.8	98.1	105.5	108.7	104.2	110.1	107.1
P. Walsh	1,137	1,191	1,115	1,092	1,206*	1,122	1,176	1,149	127.7	113.4	105.0**	114.9	115.9	117.7	113.1	115.4

*Differs from corresponding no treatment, $P = 0.05$.
**Differs from corresponding no treatment, $P = 0.01$.

shows a highly significant linear reduction in breaking strength due to the nitrogen applied. For the 100-pound application this amounted to 14.7%.

Nitrogen applications in the 1944 experiments were associated with general increases in stem diameter, although these were not large in all cases. In the experiment on the Wedig farm, mean stem diameters above the 0-, 50-, and 100-pound nitrogen treatments were 3.6, 4.7,

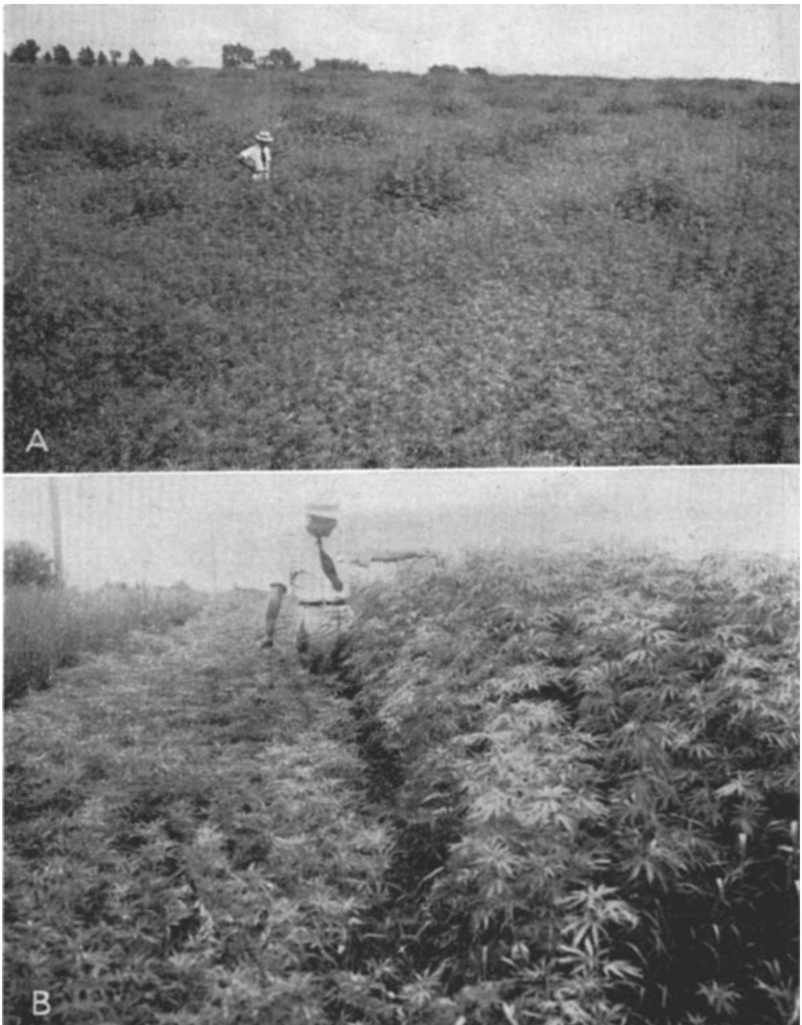

FIG. 1.—A, general character of growth of hemp on field on the Wedig farm adjoining experimental plots. B, experimental plots on the Wedig farm. *Right*, 100–30–0; *left*, 0–0–0.

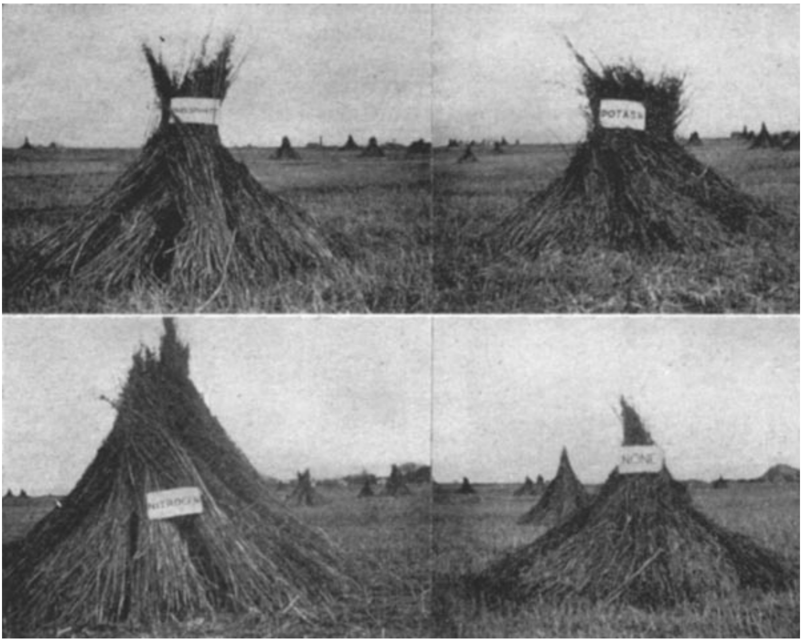

FIG. 2.—Shocks of retted hemp from equal areas of the experiment on War Hemp Industries' field at Ladd, Ill., showing the effects of fertilizers. *Upper left*, 0–30–0; *upper right*, 0–0–20; *lower left*, 100–0–0; *lower right*, 0–0–0.

and 5.1 mms, respectively. Corresponding data are not available for the experiment on War Hemp Industries' field, but stems sizes are known to vary in a similar manner. The lower dimension is too fine for most desirable hemp, while the upper limit is within the optimum range. On the other two fields, which were in better state of fertility, mean stem diameters of the unfertilized hemp were approximately equal to the maximum diameter of hemp on the Wedig experiment, and there were small additional increases as nitrogen was applied. This suggests that declining levels of breaking strength may be associated in part with stem diameters above the optimum range.

In most cases breaking strength of fiber was greater where phosphoric acid and potash were applied than where these minerals were not used, but differences were small and in no case significant.

Mean breaking strength of fiber from the 1944 experiments was lower than that from the 1943 experiments. This is probably the result of differences in conditions for growth or retting of the respective crops, and no explanation is advanced. Breaking-strength values within any given experiments are comparable because all plots were handled alike, although differences in composition induced by variable fertilizer treatments may have affected the character of retting. Comparisons between experiments may not be fully justified because of differences in times of harvest and exposure for dew retting.

EXPERIMENTS IN INDIANA

Four fertilizer experiments with hemp were conducted in Indiana in 1943. These were located on farmers' fields which had already received blanket applications of fertilizer. Details of location, soil type, and blanket fertilizer application are given in Table 5.

Experimental treatments including (a) no treatment, (b) 8-8-8 fertilizer at 500 pounds per acre, and (c) 8-8-8 fertilizer at 1,000 pounds per acre were superimposed on these fields. The treatments were made as surface applications shortly prior or subsequent to the time of seeding hemp. Data are recorded in Table 6.

In each case, as the fertilizer rate was increased, the stalks developed taller and coarser, and there were large increases in yield. In three of the experiments there was a progressive reduction in breaking strength of fiber with increasing fertilizer additions. There was one exception to this trend in the experiment on the Stevens farm. Here the fertilized plots produced stronger fiber than those without fertilizer, but as in the other experiments, the fiber was weaker where fertilized with 1,000 pounds than where 500 pounds per acre were applied. It is noteworthy in this connection that the unfertilized hemp on the Stevens field was exceptional in another respect. It attained an average height of only 3.5 feet, produced only 846 pounds of fiber per acre, and was a virtual crop failure.

Mean reductions in breaking strength in these experiments amounted to 1.4% for fertilizer at the lower rate and to 11.1% for the heavier application. Fiber from the fertilized plots was coarse, and this was particularly true with the heavy applications.

TABLE 5.—*Location, soil type, and blanket fertilizer applications on fields used for fertilizer experiments with hemp in Indiana in 1943.*

Name of cooperator	Location of field	Soil type	Blanket fertilizer application	
			Analysis	Acre rate, lbs.
Von Crow.....	Markle	Miami silt loam	3-12-12	350
Howard Bonham........	Warren	Miami-Crosby silt loam	2-12-6	300
George Spencer	Monticello	Parr loam	3-9-18	350
Jerry Stevens..	Remington	Carrington silt loam	3-12-12	250

While it is not possible in the Indiana experiments to attribute the reduction in breaking strength to any particular fertilizer constituent, it is perhaps pertinent that the heavier application supplied nitrogen at 80 pounds per acre. The methods of application should provide for more effective utilization of nitrogen than of the mineral elements of the fertilizer. Accordingly, it is a plausible assumption that the nitrogen of the 8-8-8 fertilizer was an important factor in reducing fiber strength in these experiments also.

TABLE 6.—*Effects of fertilizers on plant measurements, yields, and breaking strengths of hemp grown in experiments in Indiana, 1943.*

Name of cooperator	Method of fertilizer application	Acre rate of 8-8-8 fertilizer, lbs.	Number of replications	Plant measurements		Acre yields, lbs.		Breaking strengths, kgms per gram
				Height, ft.	Diameter, mm*	Retted straw	fiber	
Von Crow	Top dressed after seeding hemp	0	5	7.0	7.1	6,400	1,556	114.7
		500		7.7	6.3	7,100	1,755	109.2
		1,000		8.0	8.7	7,700	1,879	101.1
Howard Bonham	Broadcast on surface and disced in prior to seeding hemp	0	5	5.7	—†	5,220	1,381	110.1
		500		7.0	—†	7,480	1,630	100.8
		1,000		7.5	—†	8,520	2,315	87.6
George Spencer	Broadcast on surface and disced in prior to seeding hemp	0	3	4.5	4.0	4,660	1,452	111.6
		500		7.0	5.5	8,100	2,232	110.3
		1,000		8.0	7.1	8,620	2,178	103.5
Jerry Stevens	Top dressed after seeding hemp	0	3	3.5	4.0	3,560	846	111.7
		500		6.2	5.5	6,180	1,493	129.3
		1,000		7.0	7.1	7,480	1,829	113.6
Mean		0		5.5	5.4	5,173	1,349	112.1
		500		7.1	5.9	7,234	1,756	110.6
		1,000		7.7	7.8	8,088	2,062	99.7

*Measured 1 foot from butt ends.
†Not measured but known to increase with increase in fertilizer application.

EXPERIMENTS ON PEAT SOIL AT CODDINGTON EXPERIMENT FARM[4]

It is well recognized that hemp fiber produced on marsh soils is weak, and such soils are not recommended for hemp production. Marsh soils are characterized by their high content of nitrogen, and it was postulated that this might be at least partly responsible for the poor quality. Characteristically, hemp on these soils "thins itself out"; that is, some plants grow tall and coarse, while others, due to shading and competition, produce only short stunted stems. Hemp behaves similarly on mineral soils at high nitrogen levels, notably on old barnyards, feeding lots, etc.

In an experiment on peat soil at Coddington, Wis., in 1943, an abundance of phosphoric acid and potash was supplied in an effort to balance the nitrogen level. Fertilizers of 0–10–20, 0–20–20, and 0–10–30 analyses were applied at rates ranging from 500 to 2,000 pounds per acre. The hemp produced well with yields ranging from 1,780 to 2,265 pounds of total fiber per acre and averaging 2,053 pounds. However, the fiber had poor quality and its mean breaking strength was only 104.0 kilograms per gram. This compares with a mean breaking strength of 143.4 kilograms per gram for the fiber grown in experiments on mineral soils in Wisconsin and Illinois during the same year.

For the 1944 experiment, also at Coddington, treatments were designed to reduce the available nitrogen level as well as to supply minerals. A heavy sod of reed canary grass was plowed in late spring to raise the effective C:N ratio. Chopped straw was disced in on certain plots at 4,000 and 8,000 pounds per acre, respectively, to accentuate this effect further. Hemp was seeded the following day, thus insuring that the seedling stage of growth would coincide with active decomposition of this carbonaceous material. Except on unfertilized plots, the hemp received a blanket application of 2–10–20 fertilizer at 1,000 pounds per acre at time of seeding. Various minor elements were applied on duplicate plots, but since none of these had a consistent effect on yields or quality of fiber, the results are not reported in detail.

The essential data of the 1944 experiment are summarized in Table 7. The hemp made only moderate growth and showed evidence of nitrogen deficiency. Nitrogen deficiency was accentuated by the straw treatments, particularly the heavier rate. Stem diameters ranged from desirable diameters to too fine, and there was no selective self-thinning.

The mean yield on fertilized plots following spring-plowed reed canary grass sod was 1,113 pounds of fiber per acre and its mean breaking strength was 147.1 kilograms per gram. This yield, while reasonably satisfactory, was only a little more than one-half of the 1943 yield, but the fiber was of good quality. Its breaking strength was superior to that of hemp grown on mineral soils in any experiment in 1944 and to the mean breaking strength of fiber produced in the experiments of 1943. Straw at 4,000 pounds per acre depressed

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[4]Collaboration by A. R. Albert, Superintendent, Branch Experiment Station, Coddington, Wis., in this phase of the work is gratefully acknowledged.

the yield only slightly and the fiber was of good quality, but straw at 8,000 pounds per acre proved excessive.

TABLE 7.—*Plant measurements, yields, and breaking strengths of hemp grown on pea soil at Coddington, Wis., in 1944, following spring-plowed reed canary grass sod.*

Treatment	Plant measurements		Acre yields, lbs.		Breaking strengths, kgms per gram
	Height, in.	Diameter, mm	Retted straw	Fiber	
No fertilizer	57.5	4.2	4,673	1,012	156.7
2–10–20	62.8	4.7	5,791	1,113	147.1
Straw+2–10–20:					
4,000 lbs. per acre	64.0	4.4	5,924	1,032	145.3
8,000 lbs. per acre	50.0	3.2	2,850	388	138.3

This experiment was exploratory, and hemp was not grown concurrently in other cropping sequences. Thus the results cannot be regarded as conclusive; nevertheless, the character of growth and quality of fiber were widely different from those usually obtained on marsh soils.

DISCUSSION AND SUMMARY

There was little information regarding the effects of fertilizers on yields and quality of hemp fiber as produced in this country prior to 1943 when the acreage was greatly expanded. Research with flax indicated that abundant nitrogen might lower the quality of that fiber.

A series of fertilizer experiments with hemp was begun in Wisconsin and Illinois in 1943. The soils were in good state of fertility and responded only moderately to fertilizers. Nitrogen at 9 pounds per acre reduced the mean breaking strength of fiber by 4.4%.

The experiments of 1944 included two which responded markedly to nitrogen and two which gave no response. On the former fields nitrogen did not significantly reduce breaking strength, but on the latter nitrogen at 100 pounds per acre caused a mean reduction of 14.7% in breaking strength of fiber.

In experiments in Indiana increasing the application of 8–8–8 fertilizer through 0,500, and 1,000 pounds per acre increased the yield and caused general progressive reductions in breaking strength of fiber. For the 1,000-pound rate the reduction amounted to an average of 11.1%.

In an experiment on peat soil in 1943 heavy applications of mineral fertilizers produced high yields, but the fiber was of poor quality. In 1944, the level of available nitrogen was reduced by spring plowing a sod and applications of carbonaceous materials, and minerals were applied. The yield was only moderate but the fiber had good quality and breaking strength.

Abundant nitrogen causes a more leafy and succulent type of growth in hemp, and tends to increase stem diameter above the optimum range. These characters were associated with lower breaking strength of fiber in these experiments.