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Crop Rotation and Associated Tillage Practices for Controlling Annual Weeds in Flax and Reducing the Weed Seed Population of the Soil

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THE SOIL is one of the most important sources of weeds. Numerous investigators have estimated the weed seed population of agricultural soils in various parts of the U. S. and other countries, and have discovered that they are vast reservoirs of weed seeds. These reservoirs are partially depleted as seeds germinate and the plants winterkilled or destroyed by the farmer before more seed is produced. They are replenished as weeds are allowed to shatter their seeds, as the farmer sows weedy seed, or as seeds are brought in from other areas. Under conditions unfavorable for germination, certain seeds remain viable for many years so that when favorable conditions are restored they are able to respond. Furthermore, many seeds remain dormant for varying periods even under conditions favorable for germination.

It is obvious that those concerned with weed control should have directed some of their efforts toward limiting the build-up of seeds in the soil. This approach was most common prior to the introduction of 2,4-D and other current herbicides. Recommendations for "August plowing" and similar cultural practices to prevent weed seed production and stimulate fall germination have been made rather generally for the control of annual weeds. Such recommendations, however, have had too little experimental evidence to support them and have resulted largely from conclusions based on the apparent logic of theoretical considerations.

It seemed desirable to evaluate some of these cultural practices and determine their effectiveness by experimental trials designed for these objectives. A study was begun in 1946 and carried through 1955. It comprised two rotations and certain cultural practices made to the crop that preceded flax which was used as the test crop.

Data were obtained on the number of weed seeds in the soil at the beginning of the study and each time flax appeared in the rotation. Yields of flax and yields of the weeds in the flax were taken.

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REVIEW OF LITERATURE

That weeds are prolific seed producers is well known. Stevens (*13* and *14*)[2], Korsmo (*7*), and Salisbury (*12*) have reported on the number of seeds per plant in numerous weed species. In his latest paper on this subject, Stevens (*14*) compares the number of seeds per plant found by these three workers. Their data demonstrate the tremendous seed producing capacity of weeds. As an example, Stevens found 229,175 seeds on one large plant of pigweed (*Amaranthus retroflexus*) and 147 seeds on one late plant which was only 8 cm. high.

All weed seeds not harvested with the crop or removed in some other manner become part of the weed seed population of the soil. In view of the great capacity of weeds for seed production, it is not surprising that workers have found large numbers of weed seeds in the soil. In sampling plots involving various cultural practices at four locations in Minnesota, Robinson (*10*) found a range of 88 to 4,002 viable weed seeds per square foot of soil, 6 inches deep. Norris (*9*) sampled various fields in eastern Nebraska and found viable weed seeds ranging from 103 per square foot, 6 inches deep, in alfalfa to 848 in untilled fallow. In samples from the Rothamsted plots, Brenchley and Warington (*1*) found viable weed seed populations of approximately 45 million seeds per acre for 27 major species, 200 thousand for 19 minor species, and 113 million for the dominant species, poppy (*Papaver*). Sampling was confined to the upper 6 inches of the soil.

The viability of seeds in undisturbed soils has been studied by several workers. The study started by Beal in 1879 and continued by Darlington (*5*) is well known. In this study seeds, mostly weeds, were placed in sand in bottles and buried approximately 18 inches deep in soil. Bottles have been dug up at 5- or 10-year intervals and the seeds have been subjected to conditions suitable for germination. The latest sampling, conducted in 1950 (70 years after initiation of the study), showed 3 species still viable. It is interesting that such common weeds as pigweed (*Amaranthus retroflexus*) and black mustard (*Brassica nigra*), for example, showed viability after 40 and 50 years, respectively. Although this study does not give any indication of the ability of weed seeds to retain viability in the furrow slice, it does dramatically demonstrate their potential to survive.

Goss (*6*) reported on a study started by Duvel in 1902. This study followed the general plan of Beal. However, more species (107) were included and seeds were buried at three depths in sterilized soil in flower pots covered with a porous saucer. Pots were buried 8, 22, and 42 inches deep in soil. The experiment was conducted over a period of 20 years with 6 samplings during that period. Depth at which the seeds were buried had little effect on longevity. The seeds of weeds or wild plants survived better than those of cultivated plants.

Of the 107 species buried, 71 grew after 1 year, 61 after 3 years, 68 after 6 years, 69 after 10 years, 50 after 16 years, and 51 after 20 years. Goss makes the observation that "the seeds of most weeds, when ploughed under, will not perish during the period of any normal crop rotation."

Chepil (*3*) conducted viability studies in which he simulated the actual cropping practice of the region in which he was working (Saskatchewan, Canada). He planted weed seeds in sterilized soil in open-bottom trays, 12 inches square and 6 inches deep, and later placed the trays in the field. Trays were fallowed one year and cropped to barley or wheat in alternate years. Fallowing was simulated by turning the soil with a trowel several times during the season to a depth not exceeding 3 inches. Emerged seedlings were removed and counted at intervals throughout the period of emergence.

[2] Numbers in italics refer to Literature Cited, page 20.

From a total of 58 weed species, Chepil found 6 having seeds which had a life span not exceeding 1 year in cultivated soil. Eighteen species had a life span usually not exceeding 3 years, and the remainder of the species had seeds whose life span in cultivated soil exceeded 3 years. Many species had a relatively large proportion of seeds which were dormant, even under the most favorable conditions for germination, for periods longer than the duration of any practical rotation which might be used to rid the soil of weed seeds. Chepil concludes: "There is, therefore, little hope of ever being able to rid the land of some weeds and the general farm practice that is to be adopted must be of such a nature as to enable the farmer to attain the maximum possible control of these weeds."

Brenchley and Warington (*2*) found that fallowing for as much as 4 years reduced the viable weed seed population in the soil drastically but did not eliminate all of the seeds. The period of natural dormancy of most of the species with which they were working was determined to be from 4 to 9 years. They define a "naturally dormant seed" as one which will not start growth when placed in conditions favorable to germination. They found that when land is sown to wheat after a period of fallowing, the crop tends to be abnormally heavy and competes well with weeds. Some weed species were able to withstand the competition, however, and replenished the weed seed population of the soil by the time the first wheat crop was harvested.

Chepil (*4*) conducted a study to determine the effect of various cultural practices applied during a single fallow year on the viable weed seed population in the soil. Various cultural treatments were simulated in open-bottom trays 12 inches long, 6 inches wide, and 8 inches deep. Soils from the various trays were washed through a sieve in the fall following the simulated fallowing treatments and the number of viable seeds remaining was determined. Packing after each tillage operation was usually ineffective in stimulating germination of seeds in dryland soils. Moisture in addition to natural rainfall had no appreciable effect on germination nor on longevity of weed seeds in the soil. Periodic cultivation of the soils increased the emergence of seedlings and hence decreased the number of viable seeds recovered at the end of the fallow season. This increase in emergence was important only after June 30. "This was due to the fact that tillage brought up buried seeds to the surface after those originally on or near the surface had germinated, rather than to any other stimulating effect of cultivation on germination."

This latter statement of Chepil is supported by work of Robinson and Dunham (*11*). They compared two practices: (a) disking and harrowing 2 or 3 times before final seedbed preparation for soybeans, and (b) leaving the soil undisturbed until final seedbed preparation. The study was conducted for 3 years on land which had been fall-plowed. The results showed clearly that tillage prior to final seedbed preparation for soybeans did not stimulate the germination of weed seeds and, therefore, was of no benefit in weed control. Such tillage appeared to be harmful in the control of *Setaria*.

Much of the work cited thus far seems to indicate that, due to the great seed-producing capacity of weeds and the longevity of seeds in both cultivated and undisturbed soil, practical cultural practices can not be expected to solve all weed problems.

A very optimistic view of the benefits of crop rotation as a means of weed control is given by Leighty (*8*). He states in 1938 that crop rotation, accompanied by the use of pure seed, "is the most effective means yet devised for keeping land free of weeds." He further states that, of approximately 1,200 species of plants considered to be weeds in the United States, less than 30 are capable of surviving indefinitely on crop-rotated land. Most of the weeds

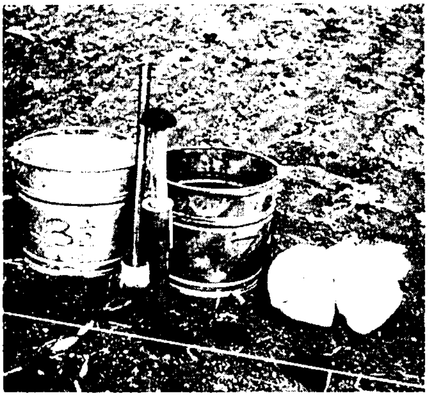

Fig. 1. Sampling equipment: Brass pipe sampling tube, lead-babbitt alloy mallet, pails for mixing cores from the tube at 3½- and 7-inch depths, and cloth sacks for composite samples.

Leighty mentions in this "noxious" group are perennials but a few annuals, such as wild oats and crabgrass, were classed as noxious. He states that "weeds, aside from the noxious species, are not a serious problem on a well-organized diversified farm," and that "indeed, there is little excuse for such a farm to be weedy."

MATERIALS AND METHODS

The trials to compare the effect of various tillage practices and crop sequences on flax and annual weeds were conducted from 1946-55 at Waseca, Morris, and Crookston, Minnesota. The soil types at the three locations were, respectively: Webster silty clay loam, Barnes silty clay loam, and Fargo silty clay loam.

The predominant weed species were *Setaria lutescens* and *S. viridis*. *Panicum capillare* and *Portulaca oleracea* were especially numerous at Waseca. *Echinochloa crus-galli*, *Polygonum convolvulus*, *P. pennsylvanicum*, *P. persicaria*, *Chenopodium album*, *Amaranthus retroflexus*, *Iva xanthifolia*, *Ambrosia artemisiifolia*, *A. trifida*, *Oxalis stricta*, and *Euphorbia maculata* were also present in appreciable numbers. *Sonchus arvensis* was prevalent at Crookston on all plots; but this species was not included in weed yields and counts since it is perennial.

Four-year rotations of corn-flax-alfalfa-alfalfa and oats-flax-red clover and timothy-corn were compared:

Year	Corn-preceding-flax rotation
1946	corn
1947	flax
1948	alfalfa
1949	alfalfa
1950	corn
1951	flax
1952	alfalfa
1953	alfalfa
1954	corn
1955	flax

Year	Oats-preceding-flax rotation
1946	oats
1947	flax
1948	red clover and timothy
1949	corn
1950	oats
1951	flax
1952	red clover and timothy
1953	corn
1954	oats
1955	flax

In 1946, 1950, and 1954 in the corn-flax rotation, normal tractor cultivation was compared with normal tractor cultivation *plus* hand hoeing the corn rows in the effect on flax and weeds the following year.

Hand hoeing was practiced to remove weeds that had escaped the cultivator, or had resulted from germination after the corn was laid by. At the time these trials were established, chemical methods of killing weeds in corn had not been developed to the point where they could be used for this purpose. In the fall, corn plants were cut and removed from all plots. Two methods of preparing a seedbed for flax were compared on both the "not hoed" and "hoed" treatments:

A. Corn stubble was disked and harrowed.

B. Corn stubble was plowed, disked, and harrowed.

In the oats-flax rotation, three treatments were compared:

A. Oat stubble was plowed and disked, and harrowed soon after oat harvest in August.

B. Oat stubble was disked and harrowed soon after oat harvest in August.

C. Oat stubble was plowed in September.

Individual plot sizes were 14 x 132 feet, except that the "hoed" and "not-hoed" corn plots were 14 x 66 feet. Rotations and treatments were replicated twice at each location.

Data obtained from each plot were yields of flaxseed, of flax straw, and of weed plants in flax at harvest time in 1947, 1951, and 1955. The number of viable weed seeds per square foot of soil, 7 inches deep, was determined in the spring of 1946, after flax harvest in 1947 and 1951, and in the spring of 1955.

Yields of flaxseed, of flax straw, and of weed plants were obtained from 6 square-yard quadrats on each plot. Weed plants were pulled, bagged, and dried in the oven. Yields are expressed on a dry weight basis. Flax was pulled, dried to a uniform moisture content, and threshed in a roller type, boll crusher machine. The lower 4 inches of the straw were cut off before straw yield weights were taken so that straw yields would correspond more closely with what could be obtained by cutting short with harvesting machinery.

Fig. 2. Washing soil samples through screens of different mesh to remove trash, stones, silt, and clay from weed seeds.

The number of viable weed seeds per square foot of soil was determined in the surface 3½-inch and in the 3½- to 7-inch layers.

A soil sampler of brass pipe was used, and fifteen plugs from this sampler removed ⅛ square foot of soil. (See figure 1.) Four separate sets of fifteen plugs each were removed from each plot, at each sampling date and at each depth. Each set of fifteen plugs was removed in a systematic arrangement lengthwise down the middle of each plot and the fifteen individual plugs were bulked. The surface 3½-inch and the 3½- to 7-inch layers of soil were taken and processed separately, making a total of eight bulked samples per plot per sampling date. The sums of the two soil layers are reported under Experimental Results.

The soil samples were placed in cold storage at 8° F. until they could be processed. The weed seeds were separated from the soil by washing in the apparatus developed by Robinson (*10*). (See figure 2.)

The small handful of weed seeds, trash, and gravel remaining from each washed sample was placed on a blotter in a germinator. Weeds were identified and counted by species as they germinated. When germination ceased, the sample was dried and stored and then placed in the germinator again. This procedure was repeated enough (at least four times) for each set of samples until it could be assumed that the number of dormant seeds remaining was not an important percentage of the total viable weed seed population. Alternating temperatures were also used to break dormancy during the germination periods.

EXPERIMENTAL RESULTS

The major measures of results in this experiment are:

(1) the number of viable weed seeds in the soil under each treatment, and

(2) the weed content and yields of flax following each treatment.

Number of viable weed seeds in the soil

The viable weed seeds each year of sampling at each location are reported in table 1. The data are grouped into grass and non-grass species and represent total numbers of viable seeds rather than those immediately viable. Since each sample was repeatedly placed under favorable conditions for germination until no appreciable number of seedlings resulted—and since the period over which these germinations were made was, in some instances, as long as 45 months—it was assumed that a reasonable estimate of the viable weed seed population was obtained.

It is apparent that there was considerable variation among stations and years. Part of the variation among years can be explained by the time of sampling, which was in the spring of 1946 and 1955 but after flax harvest in 1947 and 1951. Obviously many weeds may have shattered seed before the after-harvest samples were taken, thus invalidating comparisons with years in which samples were taken in the spring.

Two methods of presenting the data for treatments are used. They will be explained here.

First, in table 2, the data are means of three locations, expressed in percentage of the average number of seeds in all plots for the designated year at each location. Thus, the figure 71 in the column under "Grass species, 1947," in table 2 was calculated as follows:

The average of the grass weed seeds for all plots at Waseca in 1947 was 500. The number of weed seeds (averages of 2 plots) in the soil following corn that was hoed and later disked for flax was 300, which is 60% of 500. Corresponding percentages at Morris and Crookston were 119% and 33% respectively. The average of these percentages is 71. Averages of the three locations are used since in the analysis of variance, the interaction of locations x treatments was not significant at the 5% level.

In order to shorten the designation of treatments, a code was adopted which will be used for further references to them. In the corn-flax-alfalfa-alfalfa rotation the following code numbers are used—

C-1: weeds hoed in addition to tractor cultivation, not plowed, seedbed for flax prepared by disking and harrowing in the spring.

C-3: not hoed; weeds controlled by tractor cultivation only; seedbed prepared same as C-1.

Table 1. Viable weed seeds per square foot of soil, 7 inches deep, at Waseca, Morris, and Crookston, Minnesota in 1946, 1947, 1951, and 1955

Location	1946*	1947†	1951†	1955*
	grass species‡			
Waseca	444	500	490	561
Morris	912	608	506	177
Crookston	339	619	358	156
	non-grass species‡			
Waseca	439	222	555	200
Morris	505	484	1,615	196
Crookston	122	54	369	183
	total weeds‡			
Waseca	883	722	1,045	761
Morris	1,416	1,091	2,121	373
Crookston	461	673	726	338
Average	920	829	1,297	491

* Samples taken in the spring. † Samples taken in the summer. ‡ Average of all plots.

Table 2. Relative number of viable weed seeds in the soil in 1947, 1951, and 1955 following 7 treatments. (Data are means of 3 locations expressed in percentage of the average number of seeds for all plots each year at each location)

Treatments preceding flax sown in 1947, 51, 55	Grass species 1947	Grass species 1951	Grass species 1955	Non-grass species 1947	Non-grass species 1951	Non-grass species 1955	Total weeds 1947	Total weeds 1951	Total weeds 1955
Corn-flax sequence									
C-1 Corn hoed, disked for flax	71	62	61	92	98	122	78	86	85
C-3 Corn not hoed, disked for flax	141	125	100	94	82	92	127	97	97
C-2 Corn hoed, plowed for flax	73	88	75	108	134	105	84	118	87
C-4 Corn not hoed, plowed for flax	188	98	83	146	151	156	175	132	111
Oats-flax sequence									
0-1 Oat stubble plowed in August	62	110	81	112	97	74	77	102	78
0-2 Oat stubble disked in August	71	100	104	59	54	68	67	70	90
0-3 Oat stubble plowed in September	94	118	196	89	84	84	92	96	152
LSD at 5% level	63**	39*	45**	62	57*	92	47**	44	43*

* F significant at 5 percent level.
** F significant at 1 percent level.
The L.S.D. values are intended as measures of relative variability, not for determining significance between pairs of treatments.

Table 3. Viable weed seeds in the soil on plots in which the corn preceding flax was hoed. (Data are expressed in percentage of the weed seed numbers on corresponding not hoed plots)

Treatment	Grass species 1947	Grass species 1951	Grass species 1955	Non-grass species 1947	Non-grass species 1951	Non-grass species 1955	Total weeds 1947	Total weeds 1951	Total weeds 1955
C-1 Seedbed for flax disked	50	49	61	98	120	132	61	88	88
C-2 Seedbed for flax plowed	39	90	91	74	89	67	48	89	78
Average	44	70	76	86	104	100	54	89	83

Table 4. Viable weed seeds per square foot of soil, 7 inches deep, on plots in which the oat stubble was tilled in August preceding flax. (Data are expressed in percentage of the weed seed numbers on corresponding plots in which the oats stubble was plowed in September)

Treatment	Grass species 1947	Grass species 1951	Grass species 1955	Non-grass species 1947	Non-grass species 1951	Non-grass species 1955	Total weeds 1947	Total weeds 1951	Total weeds 1955
0-1 Stubble plowed and disked	67	93	41	126	115	88	84	106	51
0-2 Stubble disked	76	84	53	67	64	81	73	73	59
Average	71	88	47	96	89	84	78	89	55

Fig. 3. Germinating weed seeds contained in washed soil samples. The procedures followed are described in detail on page 7 of the text.

C-2; weeds hoed in addition to tractor cultivation, seedbed for flax prepared by plowing, disking, and harrowing in the spring.

C-4; not hoed; weeds controlled by tractor cultivation only; seedbed preparation same as C-2.

For the oats-flax-clover and timothy-corn rotation the code numbers are:

O-1; oat stubble plowed in August; seedbed prepared for flax by disking and harrowing in the spring.

O-2; oat stubble disked in August but not plowed; seedbed preparation for flax same as O-1.

O-3; oat stubble left undisturbed until September when it was plowed; seedbed preparation for flax same as O-1 and O-2.

In table 2, the data show that the total number of seeds in the soil was less following corn that had been hoed than corn not hoed. Likewise, there were fewer weed seeds where oat stubble had been disked or plowed in August than where it had been plowed in September. One exception occurred following the O-1 treatment in 1951.

Second, in tables 3 and 4, the data are percentages of the unhoed plots in the corn-flax sequence and of the September-plowed plots in the oats-flax sequence, respectively. Referring to the column under "Grass species, 1947," table 3, the figures were calculated as follows:

The actual number of weed seeds as an average of two replicates at three locations was: C-1, 410 seeds; C-3, 812 seeds; C-2, 422 seeds; C-4, 1,080 seeds; O-1, 359 seeds; O-2, 408 seeds; and O-3, 539 seeds. Thus in table 3, C-1 is 50% of C-3, and C-2 is 39% of C-4; and in table 4, O-1 is 67% of O-3, and O-2 is 76% of O-3.

Table 5. Number of viable weed seeds per square foot of soil, 7 inches deep, remaining in 1955 after 9 years of treatment. (Average of 3 locations)

Treatment	Grass species	Non-grass species	Total weeds
C-1	181	235	417
C-3	297	178	474
C-2	224	202	426
C-4	246	300	547
O-1	242	142	384
O-2	310	131	440
O-3	585	162	746

In these tables, the efficiency of the treatments in terms of the plots given no extra or August tillage may be compared. In table 3, the total number of weed seeds following hoed corn varied from 48% to 89% of the unhoed corn. In table 4, the number following after-harvest tillage of oats varied (with one exception) from 51% to 84% of the September-plowed plots. Plowing the corn land was somewhat more effective than disking in control of non-grass species. However, except in 1947, the opposite was true for the grass species. Disking oat stubble was more effective than plowing for control of non-grass species, but it tended to be less effective in control of grasses.

It is not valid to compare the data of one year with other years to show cumulative effects, because of the difference in sampling time each year. Table 5, however, shows the number of weed seeds remaining in the soil at the close of the experiment in 1955, ten years after it started. It is clear that, although hoeing or August tillage treatments reduced the weed seed population as compared to C-3, C-4, and O-3, none of the treatments was satisfactory. The

Table 6. Number, by individual species, of viable weed seeds per square foot of soil remaining in 1955 after 9 years of treatments. (Average of 3 locations)

Treatment	Foxtail-Barnyard grass	Lambs-quarters	Wild mustard	Purslane
	Surface to 7-inch depth			
C-1	127	17	122	88
C-3	254	12	65	87
C-2	190	16	110	69
C-4	172	13	207	71
O-1	180	8	79	43
O-2	211	7	67	45
O-3	428	17	85	53
	Surface to 3½-inch depth			
C-1	74	9	38	46
C-3	115	7	13	42
C-2	66	6	51	28
C-4	90	5	91	42
O-1	89	4	31	18
O-2	101	3	24	27
O-3	207	9	37	25
	3½- to 7-inch depth			
C-1	53	8	85	42
C-3	139	5	52	45
C-2	124	10	59	41
C-4	82	8	116	29
O-1	91	3	48	25
O-2	110	4	43	18
O-3	221	8	48	27

minimum number of 384 seeds per square foot, 7 inches deep, is sufficient to produce a heavy infestation of weeds.

From data reported in table 6, it is possible to determine the relative effectiveness of the tillage treatments on the most prevalent species.

Comparing hoed and not hoed treatments, foxtail-barnyard grass seed was reduced by hoeing in the corn and by disking the corn stubble for flax—but not by hoeing and plowing. Neither hoeing treatments reduced lambsquarters or purslane, and only hoeing corn and plowing for flax was effective against mustard. In the oats sequence there was some reduction of these species by each of the August tillage treatments, but these treatments were more effective against foxtail and lambsquarters than against wild mustard and purslane.

The soil samples were taken in two strata; from the surface to 3½ inches and from 3½ to 7 inches deep. Weed seed numbers did not differ appreciably between the two strata in most instances.

Weed content and yields of flax

The dry weights of weeds harvested with the flax and the yields of flax straw and flaxseed for each location, year, and treatment are reported in table 7.

The yield of weeds varied strikingly among years. In none of the plots hoed or given August tillage is there a marked trend toward a reduction of weeds in 1955 as compared to 1947. The proportion of weeds to flax straw by weight may give a better idea of the severity of the weed infestation than the actual weight. In table 8, this proportion is expressed in percentage for each year and each treatment, using the data for the "average of three locations" in table 7.

In 1955, weed weights were larger than straw weights for each treatment. In the preceding years, the percentage of weeds by weight varied from 16.6 to 54.3 on the hoed corn or the oat plots. Straw weights in 1955 were the lowest of the three years.

Fig. 4. Test plots, showing after-harvest tillage of oat stubble.

Table 7. Weed content and yields of flax following various tillage practices in crop rotations started in 1946 at Waseca, Morris, and Crookston, Minnesota

Treatment	Waseca			Morris			Crookston			Average of three locations			
	1947	1951	1955	1947	1951	1955	1947	1951	1955	1947	1951	1955	1947, 51, 55
					Dry weight of weed plants per acre, pounds								
C-1	1021	290	2154	1051	1335	2005	1233	294	2065	1102	656	2074	1277
C-3	2831	1157	3118	1911	1655	1661	1482	364	2723	2075	1059	2500	1878
C-2	288	774	2183	783	1581	1546	807	628	2074	626	994	1934	1185
C-4	1749	852	1463	1957	2647	2209	1228	779	2350	1645	1426	2007	1693
O-1	219	406	2812	1101	1452	1392	974	285	1570	765	714	1924	1134
O-2	267	399	2354	716	1016	2229	597	212	1379	527	542	1987	1019
O-3	728	794	2190	1100	1339	1305	748	280	1242	859	804	1579	1081
L.S.D. (.05)	538**	600	1254	744*	1642	1318	836	393	1963	414**	473*	766	330
Average	1015	667	2325	1231	1582	1764	1010	406	1915	1086	885	2001	1324
					Straw yield per acre, pounds								
C-1	2410	4910	1531	2083	3723	1572	1954	3219	1111	2029	3951	1404	2461
C-3	1545	4421	1637	1655	3092	1738	1179	3058	1009	1460	3523	1461	2148
C-2	2824	5148	2552	1792	2678	1727	1999	2923	1066	2205	3583	1782	2523
C-4	1970	5099	1650	1336	2649	1610	1403	2733	1324	1570	3493	1528	2197
O-1	2899	3620	2120	2173	2967	1474	2038	2627	744	2370	3071	1446	2296
O-2	2709	3388	1583	2086	3296	1107	1990	1979	761	2262	2887	1150	2100
O-3	2404	3743	1734	1917	3169	1302	1828	2213	929	2050	3041	1322	2138
L.S.D. (.05)	483**	1387	420**	898	645*	450	570	241**	444	389**	617*	217**	254
Average	2394	4333	1829	1863	3082	1504	1770	2679	992	1992	3364	1442	2266
					Flaxseed yield per acre, bushels								
C-1	21.8	18.0	15.4	18.5	16.3	16.3	16.0	19.2	11.1	18.8	17.8	14.2	16.9
C-3	14.4	19.4	16.0	18.2	13.2	16.7	11.4	17.3	9.7	14.7	16.6	14.1	15.1
C-2	24.9	19.3	19.1	18.8	11.1	16.5	20.7	17.2	13.3	21.5	15.9	16.3	17.9
C-4	18.5	18.1	15.5	12.4	9.8	13.2	15.1	16.3	12.4	15.3	14.7	13.7	14.6
O-1	26.5	16.1	20.2	20.7	12.1	14.8	17.1	13.4	8.3	21.4	13.9	14.4	16.6
O-2	25.9	15.5	12.5	21.9	16.0	11.7	17.9	10.4	7.9	21.9	13.9	10.7	15.5
O-3	23.7	16.8	15.3	18.5	16.9	13.1	17.1	12.0	9.7	19.8	15.2	12.7	15.9
L.S.D. (.05)	4.2**	5.8	4.2*	7.0	3.9*	3.9	8.8	3.3**	6.5	4.0**	3.3	2.5**	1.9
Average	22.2	17.6	16.3	18.4	13.6	14.6	16.5	15.1	10.3	19.1	15.4	13.7	16.1

* F significant at 5 percent level.
** F significant at 1 percent level.
The L.S.D. (.05) values are intended as measures of relative variability, not for determining significance between pairs of treatments.

Of the 9 trials reported in table 7, the hoeing treatments, C-1 and C-2, resulted in flax that was less weedy than the corresponding unhoed treatments, C-3 and C-4, in 16 of the 18 comparisons. C-1 and C-2 also resulted in higher flax straw and flaxseed yields in 15 of the 18 comparisons. The grand averages for treatments show that hoeing gave appreciably higher yields of seed and straw, and presumably gave higher quality straw and seed because of the lower weed content. The treatment in the corn-flax sequence giving the highest seed and straw yields and lowest weed yields was hoeing corn and plowing the corn stubble for flax.

In the oat-flax sequence, the amounts of weed plants did not differ appreciably among the three treatments. Rainfall during the year flax was sown and the preceding fall may be studied in table 9. A consistent relationship between weed plant yield and rainfall, or between flax yield and rainfall, is not evident. Probably differences in time of sowing, variety of flax, soil tilth, and the like between years and locations were more important factors affecting yield than were rainfall differences.

DISCUSSION

The effectiveness of the rotations and associated tillage practices on weed control was disappointingly small in this experiment. Although some tillage practices did reduce weed seeds in the soil and weed plants in flax, and did result in better yields of flax when compared to unhoed corn plots or those receiving no August tillage, the expected cumulative effects were not apparent. At the close of the experiment, about 400 weed seeds per square foot of soil, 7 inches deep, remained on the best treatments. These 400 seeds, if evenly distributed in the 7-inch layer of the soil, would provide 57 seeds per square foot of surface-inch. This is approximately the number of alfalfa seeds per square foot when sown at 10 pounds to the acre.

Table 8. Proportion of weeds to flax straw by weight

Treatment	Weight of weeds as a percentage of straw		
	1947	1951	1955
		(percent)	
C-1	54.3	16.6	147.7
C-3	142.1	30.1	171.1
C-2	28.4	27.7	108.5
C-4	104.8	40.8	131.3
O-1	32.3	23.2	133.1
O-2	23.2	18.8	172.8
O-3	41.9	26.4	119.4

The maintenance of the weed seed population cannot be blamed on the sowing of weed seeds in the oats, flax, clover, and alfalfa since the seed was known to be clean. The plots at all locations were on level land, so that a minimum of seeds was either washed in or blown in. The tillage and hoeing was done by experiment station help and supervised by the resident agronomist.

The working of the soil immediately following oat harvest kept weeds from going to seed and was planned to stimulate germination of seeds in the soil, thus removing them from the population. Any lack of success cannot be blamed on dry weather. In the two months, August and September, 7.08 inches fell at Waseca in 1946; 4.94 in 1950; and 6.53 in 1954. Corresponding figures for Morris are 4.15, 2.88, and 3.75 and for Crookston 5.84, 6.11, and 4.15. Of course dormancy could have been an important factor.

The most obvious reason for the failure to reduce the number of weed seeds significantly is twofold: (1) weeds matured and shattered seeds in the crops of the rotations where no special weed control was practiced, and (2) the large number of seeds produced by even a few weeds was sufficient to replenish those removed from the soil by germination.

Although the reduction of weed seeds in the soil was an objective of this study, the reduction of weed plants in the flax crop was also an important goal. Hoeing corn was more effective

Table 9. Fall precipitation for 1946, 1950, and 1954 and spring and summer precipitation for 1947, 1951, and 1955 at Waseca, Morris, and Crookston

Month	Precipitation (in inches)						
	1946	1947	1950	1951	1954	1955	Averages (long time)
Waseca							
August	1.20		2.73		3.58		3.40
September	5.88		2.21		2.95		2.84
May		2.45		4.14		1.15	3.59
June		5.52		6.28		4.59	4.57
July		1.91		3.78		3.29	3.25
August		5.22		5.52		1.85	3.40
September		3.73		6.19		1.47	2.84
Morris							
August	1.43		2.14		1.94		2.90
September	2.72		0.74		1.81		2.26
May		2.37		2.89		3.63	2.91
June		3.90		5.88		6.71	4.03
July		1.73		3.89		7.20	3.35
August		0.78		2.52		4.23	2.90
September		2.90		0.86		1.23	1.92
Crookston							
August	2.62		1.39		2.11		3.13
September	3.22		4.72		2.04		2.03
May		3.26		0.92		3.46	2.73
June		7.17		1.55		3.29	3.30
July		3.46		0.65		5.18	2.80
August		3.06		7.04		2.55	3.13
September		2.53		1.37		1.58	1.93

compared to unhoed corn than was after-harvest tilled oat stubble compared to September-plowed stubble. In fact, the amounts of weed plants in the flax following oats did not differ appreciably among the three treatments.

This may appear to be inconsistent with the data on weed seed numbers reported in tables 2, 4, 5, and 6 in which the August tillage treatments, O-1 and O-2, had fewer seeds than the September plowed treatment, O-3. However, weeds may have been less numerous on the August tillage treatments and consequently have grown larger because of less competition. On the average, flax following oat stubble plowed in August yielded 158 pounds more of straw and 0.7 bushel more of seed than flax following oat stubble plowed in September.

Comparing the corn and oat sequences, the best corn treatments, C-1 and C-2, resulted in appreciably higher seed and straw yields than treatments in the oat sequence. Weed plant yield was greater in the corn than in the oat sequence. These differences between a corn-flax and an oat-flax sequence cannot be attributed to residual fertilizer, since no fertilizer was used in these rotations. Since corn removes more water, nitrogen, and other nutrients than oats in late summer and fall, it is illogical to account for the difference on this basis. Better soil tilth for flax following the cultivated corn crop seems to be a logical explanation of these results. In soil sampling, the ground was hardest in the oat sequence and on unplowed treatments in both sequences.

Association of weed plant yield with rainfall is not clear. For example, the lowest weed yields were associated with above-average rainfall in 1951 at Waseca, with below-average rainfall in 1947 at Morris, and with below-average rainfall in 1951 at Crookston.

In order to study the relationship of weed plant yield with flax straw yield, and of weed plant yield with flax seed yield, correlation and regression coefficients were computed.

Correlation coefficients in 1947, 1951, and 1955 for weed plant and flax straw yields were .72, .06, and +.32, respectively. For weed plant and flax seed yields they were —.72, —.37, and +.30, respectively. The 1947 coefficients were signicant at the 1% level, but the 1951 and 1955 coefficients did not reach significance at the 5% level.

In order to determine the quantitative relationships between weed plant yield and flax straw yield, and between weed plant yield and flax seed yield, regression coefficients in the three years were computed. In 1947, 1951, and 1955, the coefficients for straw yield on weed yield were —.52, —.08, and +.27, respectively. For seed yield on weed yield in those same years, they were —.0047, —.0018, and +.0019, respectively. Only the 1947 coefficients were significant.

Undoubtedly several factors determined the relative growth of flax and weeds. Temperature, the incidence of rain at favorable or unfavorable times for the flax versus the weeds, and the viability of weed seeds are factors undetermined in this study that probably were important.

In general, the hoeing of corn and the August working of the oats plots increased yields of flax seed over unhoed corn plots and September-plowed oats plots, respectively. As an average of all locations and three years, C-1 yielded 1.8 bushels more than C-3; C-2, 3.3 bushels more than C-4; O-1, 0.7 bushels more than O-3; and O-2, 0.4 bushels less than O-3.

It must be concluded from this study that a crop rotation of corn-flax-alfalfa-alfalfa or oats-flax-red clover and timothy-corn continued over a ten-year period did not reduce the annual weed seeds of the soil appreciably and did not result in satisfactory control of annual weeds in the flax crop.

The hoeing of corn preceding flax in the first rotation and the August tillage of oat stubble in the second rotation

Fig. 5. Weeds in flax following oat stubble. Area left of center was plowed immediately after harvest; area at right was plowed in September.

Table 10. Number of weed seeds germinated in upper layer (0-3½ inches) and lower layer (3½-7 inches) of soil. (Total of all samples from 3 locations, 4-year period)

Weed species	Upper layer	Lower layer
Foxtail and barnyard grass	15,017	13,430
Lambsquarters and pigweed	1,102	1,023
Wild mustard	9,513	5,852
Purslane	5,339	5,269
Wild buckwheat	273	403

was helpful in reducing weed seeds in the soil. These treatments were also helpful in increasing the yields of flaxseed and straw.

It was expected that the better treatments might have a cumulative effect in reducing the weed seed population but this was not the case.

The experiment was not set up to study the germination of weed seeds. The only practical method of determining the number of viable weed seeds in the soil was to germinate them and count the seedlings. Because of a lack of uniformity in running these germination tests, caution is needed in summarizing the data and they are not included under experimental results. Nevertheless, the experience of germinating 58,944 seeds over a ten-year period provides some information incidental to the objectives of the experiment that may be of value to other investigators. The data represent the total number of seeds from all plots regardless of treatment, for three locations, and for the four years when soil samples were taken. These data can be broken down into seeds from 0 to 3½ and 3½ to 7 inches of soil and into seeds of six weed species.

It is possible to compare the number of seeds that germinated from each layer. Total numbers are given in table 10.

All soil samples were subjected to a minimum of four germination tests, but the intervals between tests were not uniform. The period from the first to the fourth test also varied with the year. The longest period was with the 1951 samples when 45 months elapsed between the first and fourth test. The shortest period occurred with the 1955 samples when improved methods of getting complete germination shortened the time to 18 months. It is, therefore, impossible to compare the number of seeds that germinated in the first test with later tests. It is possible, however, to compare the germination of species at the first, second, third, and fourth tests since all species were contained in a single sample.

The accumulated percent of total number of seeds that germinated in the first four tests by species is reported in table 11.

The data show that a relatively large proportion of purslane seed germinated shortly after the samples were taken. Mustard, oxalis, and wild buckwheat

Table 11. Cumulative percentages of total number of weed seeds that germinated in each test

Weed species	Test			
	1st	2nd	3rd	4th
	(percent germinated)			
Foxtail and barnyard grass	30.4	80.1	97.0	100.0
Lambsquarters and pigweed	36.4	80.0	95.6	99.0
Wild mustard	17.4	37.6	54.6	91.5
Purslane	70.1	92.8	97.8	99.8
Wild buckwheat	23.1	68.1	94.0	98.8
Oxalis	25.2	69.6	98	99.1

showed the longest dormancy; foxtail, barnyard grass, lambsquarters, and pigweed were intermediate. It must be remembered that the samples were stored inside.

SUMMARY

This study, begun in 1946 and carried through 1955, comprised two rotations, also certain cultural practices made to corn that preceded flax in one rotation and to oats that preceded flax in the other rotation. In the corn-flax sequence, a comparison of normal cultivation was made with similar cultivation plus hoeing to keep escaped weeds from going to seed. In a subdivision of this comparison, the corn stubble was plowed in preparation for flax in one instance and was surface-worked only in the other. In the second rotation, plowing or disking of oat stubble in August was compared with September plowing.

Both rotations included a legume—two years of alfalfa in the corn rotation and one year of red clover and timothy in the oats rotation. Data were obtained on the number of weed seeds in the soil each time flax appeared in the rotation and on yields of flax seed, flax straw, and the weeds in the flax.

A crop rotation of corn-flax-alfalfa-alfalfa or oats-flax-clover and timothy-corn continued over a ten-year period did not reduce the annual weed seeds of the soil appreciably, nor did it control annual weeds satisfactorily in the flax crop.

Although some tillage practices on crops preceding flax reduced weed seeds in the soil, reduced weeds in flax, and increased yields of flax when compared to unhoed corn plots or those receiving no August tillage, the expected cumulative effects of these treatments were not apparent. At the close of the experiment about 400 weed seeds per square foot of soil, 7 inches deep, remained on the best treatments.

In the germination of 58,944 weed seeds recovered in soil samples, a relatively large proportion of purslane (70.1%) germinated shortly after samples were taken; mustard, oxalis, and wild buckwheat showed the longest dormancy; and foxtail, barnyard grass, lambsquarters, and pigweed were intermediate.

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