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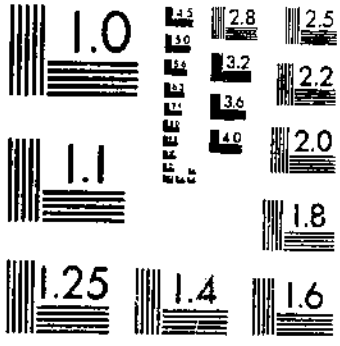

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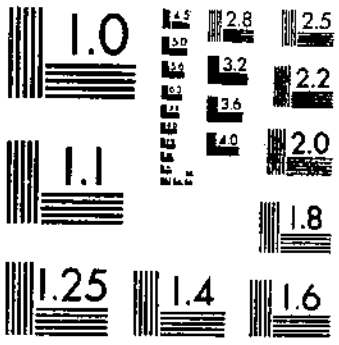

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Effect of Winter Cover Crops on Wireworm Injury to the Dry Lima Bean Crop[1]

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CONTENTS

INTRODUCTION

In southern California lima beans have been grown in many fields for 25 years or more. To maintain the productivity of the soil various agencies have advocated the planting of cover crops in the fall and plowing them under in the spring, late in March or in April. Many bean growers, however, have held the opinion that winter cover crops increase populations of the sugar-beet wireworm (*Limonius californicus* Mann.) (figs. 1 and 2).

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[2] The lima bean growers Grant Chaffee, Richard Bard, and Otto Kitchen and W. H. Treba, agronomist in the Soil Conservation Service, furnished land and equipment and assisted with the cultural operations in the experimental plots. The California State Emergency Relief Administration provided workers for preliminary studies in 1939; A. R. Melis, of the Soil Conservation Service, provided workers from the Civilian Conservation Corps in 1940–1941; Milton Miller, California Agricultural Extension Service, and Al Holland, farm advisor for Ventura County, gave helpful advice and cooperation. A. F. Howland and R. E. Campbell, of the Bureau of Entomology and Plant Quarantine, made the preliminary investigations, and G. L. Claypool, S. W. Stuart, V. L. Woolley, and A. Sattler assisted in the field work.

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FIGURE 1.—Poor stand of lima bean plants on the R. Bard farm in 1939. This field had never been planted to a cover crop.

FIGURE 2.—Barren area in lima bean field of A. Penkert, which was planted to barley the previous fall and plowed under in the spring. Soil samples taken in this area in 1939 showed an infestation of 4.6 wireworms per square foot.

Wireworms spread chiefly by flight of the adult beetles early in the spring. Studies from 1929 to 1935 by the author (*6*) [1] showed that in southern California the adults of the sugar-beet wireworm are most abundant early in March, at which time the eggs are deposited in the soil. Eggs laid in March hatch into wireworms that become large enough to cause considerable damage the following July, August, and

[1] Italic numbers in parentheses refer to Literature Cited, p. 20.

September. Under favorable conditions a small percentage of these wireworms become adults the next winter and emerge from the soil the following March. Most of the wireworms, however, feed for two summers before becoming adults, and under unfavorable conditions many of them do not mature for 3 years or more.

It seemed possible that cover crops might increase wireworm populations, by making conditions more favorable for survival and rapid development, as well as for egg laying. It was desirable, therefore, to determine the effect of plowing the cover crops under in February before the emergence of these adults. The early plowing under of the cover crops would not be expected to have much effect on the wireworm damage to the first crop of lima beans but would reduce the damage to subsequent crops.

Preliminary studies on the relationship between winter cover crops and wireworm infestations and their damage to the dry lima bean crop were begun in Ventura County, Calif., in 1938. An experiment on this relationship as affected by the type of cover crop and the time of plowing it under was conducted in this county from 1939 to 1944.

REVIEW OF LITERATURE

The importance of planting cover or green-manure crops to maintain soil fertility and to control erosion is generally recognized. A few workers, however, have been concerned over the possibility of a build-up of insect and disease populations following this practice. The subterranean habits of wireworms have made it difficult to obtain dependable information.

Thomas (*8*) reviewed literature on the effect of various cover-crop practices on wireworm abundance. Wilson (*10*) reported an increase in the population of *Melanotus communis* Gyll. in small field plots planted to summer cover of soybeans, and in plots in which weeds and grasses remained undisturbed. He found fewer wireworms in bare fallow plots and in those planted to cowpeas and velvet beans. Tenhet (*7*) stated that the sand wireworm (*Horistonotus uhleri* Horn) invariably infested soils deficient in humus, and that wireworm injury could be reduced by the incorporation of organic matter, especially by plowing under legume cover crops. Hawkins (*3*) recommended thorough cultivation in June to reduce the egg laying and hatching of the wireworm *Agriotes mancus* Say and the planting in July of green-manure crops such as crimson clover and buckwheat.

Pieters and McKee (*4*) stressed the importance of maintaining soil productivity and controlling soil erosion through the use of cover crops, and reported the effect on subsequent yields of turning under legume and nonlegume cover crops. Wessels and Hartman (*9*), after testing various cover crops and fertilizers over a period of 13 years to determine their effect on the production of various vegetables, concluded that legumes were not satisfactory for late sowing if the land was to be plowed early the next spring. They recommended seeding rye in late summer on land not planted to a market crop. Shirck and Lanchester (*5*), in studies of crop rotations over a 4-year period, found that sugar-beet wireworm populations increased rapidly when red clover and sweetclover were grown for more than one season. Alfalfa, sugar beets, and garden crops also tended to increase wireworm populations, whereas nonirrigated wheat reduced infestations by 50 percent in one season.

PRELIMINARY STUDIES

In the spring of 1938 a survey was made in Ventura County to obtain information on the effect of winter cover crops on wireworm damage to beans. Owing to many variable conditions that might have affected wireworm damage, the results were so confusing that in 1939 a more detailed study was made of groups of fields selected for uniformity. The fields in each group were on the same farm and appeared to be comparable except for the planting of different winter cover crops during the previous 3 years. The fields were from 8 to 30 acres in size.

The soil was sampled for wireworms before or soon after the beans were planted. Samples were taken about 20 feet apart by means of ⅛- and ½-square-foot metal forms. The composite sample from each field constituted a total of at least 5 square feet of soil surface. Samples were taken to a depth of 16 inches before April 15, when the wireworms were deep in the soil, and to a depth of 12 inches thereafter. The soil samples were sifted through a 12-mesh screen, so that the wireworms could be counted.

About 3 weeks after lima beans had been planted, the plants killed or injured by wireworms were counted in 100 to 600 10-foot strips of row selected at random. At this time both dead and wilted plants were pulled up and examined carefully for evidence of wireworm feeding.

The data obtained in the spring of 1939 are summarized in table 1. These results seem inconsistent in many ways, but in general the most wireworms and the greatest damage were in fields that had been planted to barley in the fall of 1936 or 1937. The fields were sufficiently large for outstanding differences in wireworm populations within the fields as well as between similar fields. Fields 18 to 22, for example, were adjacent to 8-acre fields that had been farmed for 30 years with no cover crops except for field 19. There was only 0.8 wireworm per square foot in field 21 as compared with 1.6 in the adjacent field on one side and 2.0 in that on the other side. As the wireworm populations before cover crops were planted were not known, it was not possible to determine changes in populations.

This survey indicated that the type of cover crop and the time of plowing it under in the spring may affect the next generation of wireworms. In earlier experiments reported by the writer (*6*), marked adults of the sugar-beet wireworm liberated in a fallow field on a warm day immediately flew some distance to piles of freshly cut malva used in adult-trapping experiments. Evidently adults prefer sheltered places either for protection or for egg deposition; therefore, when climatic conditions are unfavorable they can be expected to migrate to areas where there are cover crops. Consequently an increase in wireworms can be expected where cover crops are allowed to grow during the egg-laying season.

PROCEDURES

Plan of Experiment

In view of the preliminary findings, it appeared desirable to carry on an experiment in small field plots that could be planted to winter

cover crops and lima beans for several years without interfering with the growers' cropping practices. Three fields in Ventura County were selected for these tests—the Bard, the Soil Conservation, and the Chaffee. None of them had been planted to cover crops previously, and all were known to be infested with wireworms when the tests were begun in the fall of 1939.

TABLE 1.—*Effect of cover crops during the preceding winters on populations of the sugar-beet wireworm and injury to lima beans in 1939*

Farm and field No.	Winter crop			Wireworms per square foot	Plants per foot of row	Plants killed or injured by wireworms
	1936–37	1937–38	1938–39			
				Number	*Number*	*Percent*
Pettit:						
1		Barley	None	3.2	0.8	34
2		do	Barley	1.7	.7	23
3		None	Sweetclover	1.2	.9	19
Edwards:						
4	None	None	None	.9	1.2	12
5	Mustard	Barley	do	1.1	1.0	11
6	None	None	do	1.1	1.2	12
Balcom:						
7	Barley	Barley	Barley	[1] 2.4	.5	70
8	None	do	None	[1] 1.5		67
Thatcher:						
9	Mustard	Vetch	None	1.3	1.4	10
10	do	Mustard	do	.3	1.2	12
11	do	Fenugreek	do	2.0	1.3	11
12		Barley	Peas	2.5	1.2	12
13		Fenugreek	do	1.3	1.4	8
14		Mustard	do	3.6	1.0	10
15		Fenugreek	do	1.3	1.2	9
Penkert:						
16	Alfalfa	None	None	.4	1.0	7
17	do	do	Barley	.3	1.5	6
Borchard:						
18	None	None	None	1.1		
19	do	Barley	Barley	5.5		58
20	do	None	None	2.0		
21	do	do	do	.8		
22	do	do	do	1.6		
23	Barley	do	do	1.5		39
24	None	do	do	2.5		
Leonard:						
25	Barley	Barley	Vetch	2.3	1.1	24
26	Alfalfa	Alfalfa	Alfalfa		1.3	7
27	None	None	None		1.6	4
Noble:						
28	Sweetclover-rye.	None	None		1.5	8
29	None	do	do		1.8	9

[1] Wireworms per foot of row.

The cover crops consisted of barley (*Hordeum vulgare* L.), mustard (*Brassica alba* (L.)), sweetclover (*Melilotus indica* (L.)), purple vetch (*Vicia americana* Muhl.), and fenugreek (*Trigonella foenum-graecum* L.). Fallowing was included as a check. The fallow plots were kept free of weeds throughout the winter months. A few weeds, including malva, grew in some of the other plots. In this area barley, mustard, sweetclover, and vetch are commonly grown as green-manure crops in orchards and to a certain extent on bean and sugar-beet land. Because of its slow growth fenugreek had not been grown extensively in this area. All these crops and the fallow plots were arranged in randomized blocks. In the Soil Conservation field (fig. 3) four replicates were made of barley, mustard, sweetclover, and fallow treatments in plots 31 by 68 feet. All five crops and the fallow plots were included in the other two fields. There were four replicates in plots 38 by 110 feet in the Bard field and eight replicates in plots 40 by 120 feet in the Chaffee field.

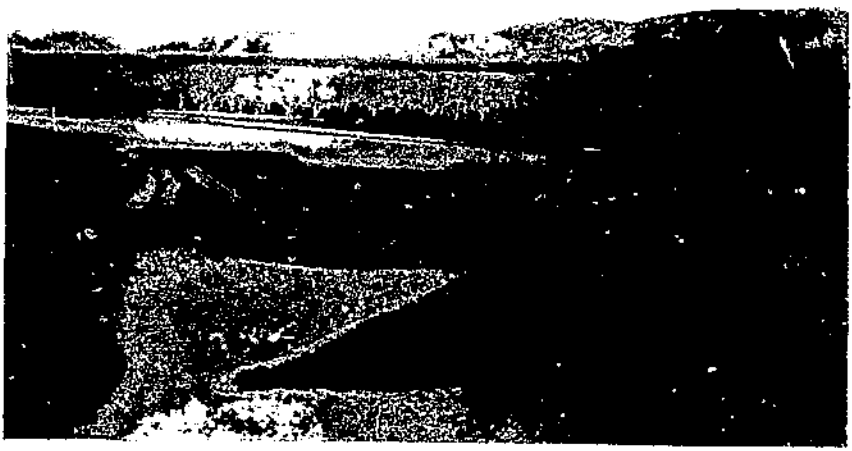

FIGURE 3.—Winter cover crops in experimental plots on Soil Conservation Service farm, Somis, Calif., 1942.

Arrangements were made to test the theory that cover crops plowed under late increased wireworms by providing favorable protection for the adults during the egg-laying season. The replicates, or blocks, were paired and a random block (all crops and the check) of each pair was plowed under about the third week in February, or before emergence of the adult females. The other block of each pair was allowed to remain standing until about the first of April, or until most of the beetles had emerged. The beetles were thus given an opportunity to select either fallow or cover-crop land in which to deposit their eggs.

The split-plot design of the experiment as outlined above was necessary, because the cover-crop plots were too small to be plowed individually. It is realized that this design was used at a considerable sacrifice of replication.

Description and History of Fields

The Bard field is located on Los Angeles Avenue, 3 miles west of Moorpark. It is 3 acres in size and has been planted to lima beans every year from 1936 to 1939. The owner reported that he had obtained a poor stand each year, and particularly in 1939, when wireworms destroyed two-thirds of the crop. The soil in this field is classified as Yolo fine sandy loam (Nelson and Dean 3).

The Soil Conservation field is off Los Angeles Avenue ½ mile west of Somis, on property leased by the Soil Conservation Service. The soil type in this 2.7-acre site varies from Rincon clay to Yolo fine sandy loam. Lima beans were grown on this site in the period 1936–1939. W. H. Von Treba, project supervisor, reported that because of wireworms there was a thin stand in this area in 1938 and again in 1939.

The Chaffee field of 5 acres is ¼ mile southwest of the intersection of Del Norte and Santa Clara Avenues, approximately 3 miles southeast of Saticoy, Calif. The soil varies from a Yolo fine sandy loam to Yolo sandy loam. Fordhook lima beans, which are marketed green, were planted in this field in 1936. The field remained fallow during the spring and summer of 1937, and was planted to sugar beets in the fall of 1937. Fordhook lima beans were planted again in 1939, and because of wireworms there was a thin stand, as well as several large barren areas in the field.

Cultural Practices

The plots were seeded to cover crops in the fall after the lima bean crop had been harvested. The barley was seeded at the rate of 100 pounds, mustard at 12 pounds, sweetclover at 20 pounds, vetch at 35 pounds, and fenugreek at 30 pounds per acre. The seed was broadcast and harrowed lightly into the soil. In 1939 the seed was planted between November 1 and 6, in 1940 between October 19 and 29, in 1941 between November 13 and 30, and in 1942 on November 9. It was necessary to irrigate the Bard and Chaffee fields in 1939 and again in 1940 in order to obtain a stand of plants. In 1941 and 1942 sufficient rain fell to enable the seeds to germinate and grow.

The cultural practices varied with weather conditions. The precipitation by months and years, together with soil temperatures, is given in table 2. Except for seasonal changes there were no outstanding differences in temperature. The rainfall, however, fluctuated widely, with a maximum of 34.5 inches for 1941 and a minimum of 9.38 inches for 1942.

In 1940 the blocks of cover crops designated to be plowed early or before adult emergence were plowed between February 19 and 21, and those designated for late plowing, between March 19 and April 15. In 1941, because of heavy rains, which totaled 22.8 inches during the period December 1940 through February 1941, early plowing was delayed until March 18–28. The heavy rains stimulated the growth in the Bard field and made it necessary to plow under the blocks of cover crops designated to be plowed late on March 20, whereas in the Chaffee and the Soil Conservation fields this operation was delayed until April 22. Less rain in 1942 made it possible to complete the early plowing in all fields between February 9 and 12 and the late

TABLE 2.—*Soil temperature and precipitation data, Ventura, Calif., 1939–44*

Month	Mean soil temperature at 4-inch depth (°F)						Precipitation (inches)					
	1939	1940	1941	1942	1943	1944	1939	1940	1941	1942	1943	1944
January		55.0	54.4	54.6	51.8	51.2	3.73	4.00	7.43	0.81	10.61	0.98
February		55.9	57.9	56.1	56.3	51.2	1.36	3.97	7.99	.54	3.14	7.03
March		62.4	62.1	62.1	59.2	60.6	1.62	.55	8.47	1.92	5.40	2.73
April		66.8	65.6	66.3	66.4	66.8	.24	1.76	4.06	3.03	.74	.99
May		72.7	78.0	73.3	72.2	71.7	.05	0	0	0	0	0
June		74.0	74.9	76.1	74.7	76.8	0	0	0	0	0	0
July		77.2	77.6	82.6	76.5	76.9	0	0	0	0	0	0
August		75.2	77.1	76.9	78.5	81.8	0	0	.06	.11	0	0
September	77.7	75.7	75.9	77.1	75.2	74.2	1.14	0	0	0	0	0
October	68.6	70.2	68.2	69.3	67.5	69.3	.06	1.53	.88	1.46	.49	0
November	60.7	59.4	62.5	58.7	60.0	55.7	.25	.18	.28	.25	.18	2.65
December	55.1	56.2	56.5	53.2	51.7	54.4	1.20	7.35	5.33	1.26	7.05	.82
Total or average	65.5	66.7	67.5	67.2	65.8	65.9	9.65	19.34	34.5	9.38	27.61	15.20

plowing by March 20 and 21. In 1943 also the plowing was completed on schedule, the early plowing by February 18 and 19 and the late plowing between March 25 and April 1.

All cover crops were plowed under to depths of 10 to 14 inches, and a special effort was made to turn each furrow completely over so that no portion of the crop was exposed to attract adult females. Several days after the plowing the fields were disked lightly to break up clods and to seal openings in the soil. Depletion of the soil moisture made it necessary to furrow out and irrigate the Bard and the Chaffee fields in April 1940 and 1942. No irrigation facilities were available in the Soil Conservation field.

The Chaffee field was discontinued in 1942 because of the owners' desire to plant winter vegetable crops.

In all fields lima beans of the King of the Garden variety were planted each year with four-row planters in rows 30 inches apart. The rates ranged from 80 pounds per acre in the Soil Conservation field to 110 pounds in the Chaffee field. The planting of beans in all fields was completed in 1940 between May 8 and 18, in 1941 between May 27 and June 2, in 1942 between May 23 and 27, in 1943 between May 18 and 22, and in 1944 between May 21 and 26.

The heavy soil in the Soil Conservation field retained moisture fairly well, so that it was unnecessary to irrigate the beans during the summer. The soil in the Chaffee field was also heavy, but because of the thickness of stand, irrigations were necessary in July of 1941 and 1942. The beans in the Bard field were irrigated in July 1942 and in August 1944.

Sampling Methods

The wireworm population in each plot was determined each year before beans were planted by taking at random twenty $\frac{1}{4}$-square-foot samples of soil to a depth of 16 inches, and sifting them individually with a hand soil sifter (Campbell and Stone 7) equipped with 12-mesh wire screen (fig. 4). The samples were taken with a soil auger approximately 6 inches in diameter. The first few samples each season were taken in 4-inch layers to a depth of 16 inches.

Figure 4.—Equipment and method for removing and screening soil samples to obtain data on wireworm populations.

Most of the wireworms were found in the upper 12 inches of soil. The samples were taken between late February and early April, before the eggs laid by the current season's beetles had had time to hatch. Therefore, all the wireworms were 1 year or more old. They ranged from $\frac{1}{4}$ to $\frac{3}{4}$ inch in length and were easily detected while the soil was being screened. In some years adults, especially females, were found in the samples taken earlier.

Yields were estimated on the basis of plants harvested from four rows, each 13½ feet long, or 0.01 acre, which had been staked out in the center of each plot (fig. 5) before the beans emerged. Shortly

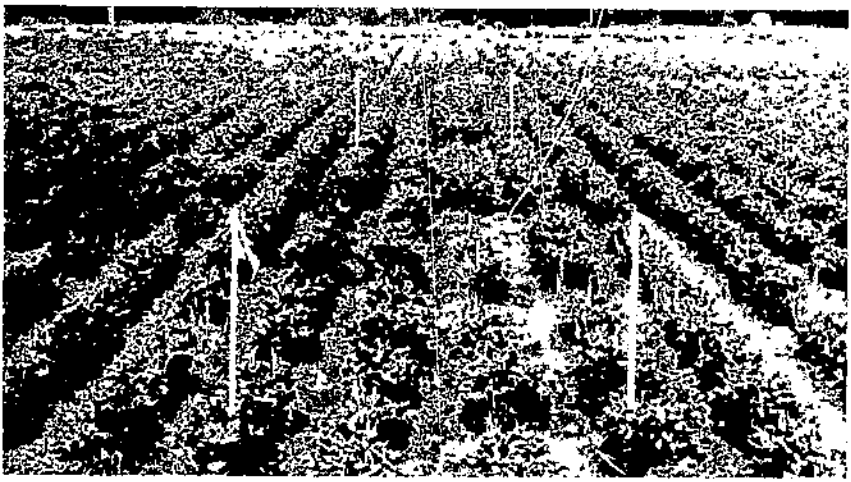

FIGURE 5.—A 0.01-acre area staked out in the center of a plot on which data on density of stand and yields of dry beans were obtained.

before the owners commenced harvesting, the bean plants from each area were pulled and counted and placed on a canvas so that they could be carried to a safe location for curing. The counts of the plants in each area at harvesttime provided information on the effect of wireworm populations on the density of stand. Generally the plants were pulled during the latter part of September, and were threshed by use of small power threshing machines before October 15.

RESULTS

WIREWORMS FOUND

Practically all the wireworms found in the experimental plots were sugar beet wireworms. However, three other destructive species were present in all fields. The most abundant was *Cardiophorus lecontosus* Lec., but only 54 individuals of this species were found during the 5 years, 27 being in the Bard field and 22 in the Soil Conservation field. A total of 32 *Limonius limicus* (Lec.) wireworms were found, 24 of which were in the Chaffee field and 1 in each of the others. *L. limicus* has been known to cause considerable damage to lima beans and other vegetable crops in some years. In a bean field adjacent to the Chaffee plots equal numbers of this species and the sugar-beet wireworm were present in the germinating beans.

Only 15 *Melanotus longulus* (Lec.) wireworms were found, 12 of which were in the Soil Conservation field which is surrounded by hill-type bean land. This wireworm is a major pest of lima beans on the drier hillsides. A single larva of *Anchastus cinereipennis* (Esch.) was found in the Soil Conservation field in 1940.

Records were kept of the number of sugar-beet wireworm adults found in the soil samples during the course of these studies. Usually most of the adults had emerged before soil sampling was begun. It is of interest, however, that the fewest adults, as shown in table 3, were in the fallow plots.

In 1940 there was about 1 wireworm per square foot in the fallow plots. This infestation decreased during the next 2 years to about 0.3 per square foot and increased slightly in 1943.

General Effects of Cover Crops

Of the five cover crops tested, barley grew the most rapidly and produced the densest stand. For this reason it proved to be the most difficult to turn under. Mustard ranked next to barley in this respect, reaching a height of 9½ feet in 1941 after heavy rains. The legume crops, sweetclover and vetch, provided good cover and reached a height of 3 to 4 feet when rains were adequate (fig. 6). Fenugreek made little growth in all years except 1941 and seemed unsuited for the type of soil in these fields. The best growth was obtained when the fields were irrigated immediately after the seeding early in November. When this practice was followed, the cover crops reached maturity by the middle of February.

TABLE 3.—*Number of adults of the sugar-beet wireworm taken by sifting 5 square feet of soil to a depth of 16 inches after each winter cover crop was plowed under*

Field and crop	1940	1941	1942	1943	1944	All years
Soil conservation:						
Barley	2	0	2	3	4	11
Mustard	1	0	0	0	0	1
Sweetclover	0	0	1	1	9	11
Vetch	0	0	0	0	0	0
Fenugreek	0	0	0	0	0	0
Fallow	0	0	1	0	1	2
Bard:						
Barley	2	3	11	1	27	44
Mustard	2	3	2	0	13	20
Sweetclover	1	1	9	3	3	23
Vetch	3	1	7	2	1	20
Fenugreek	2	0	7	0	10	19
Fallow	2	1	5	1	4	13
Chaffee:						
Barley	0	0	5			5
Mustard	1	0	5			6
Sweetclover	2	0	11			13
Vetch	2	0	11			13
Fenugreek	1	0	13			14
Fallow	1	0	1			5
Total	25	15	91	11	75	220

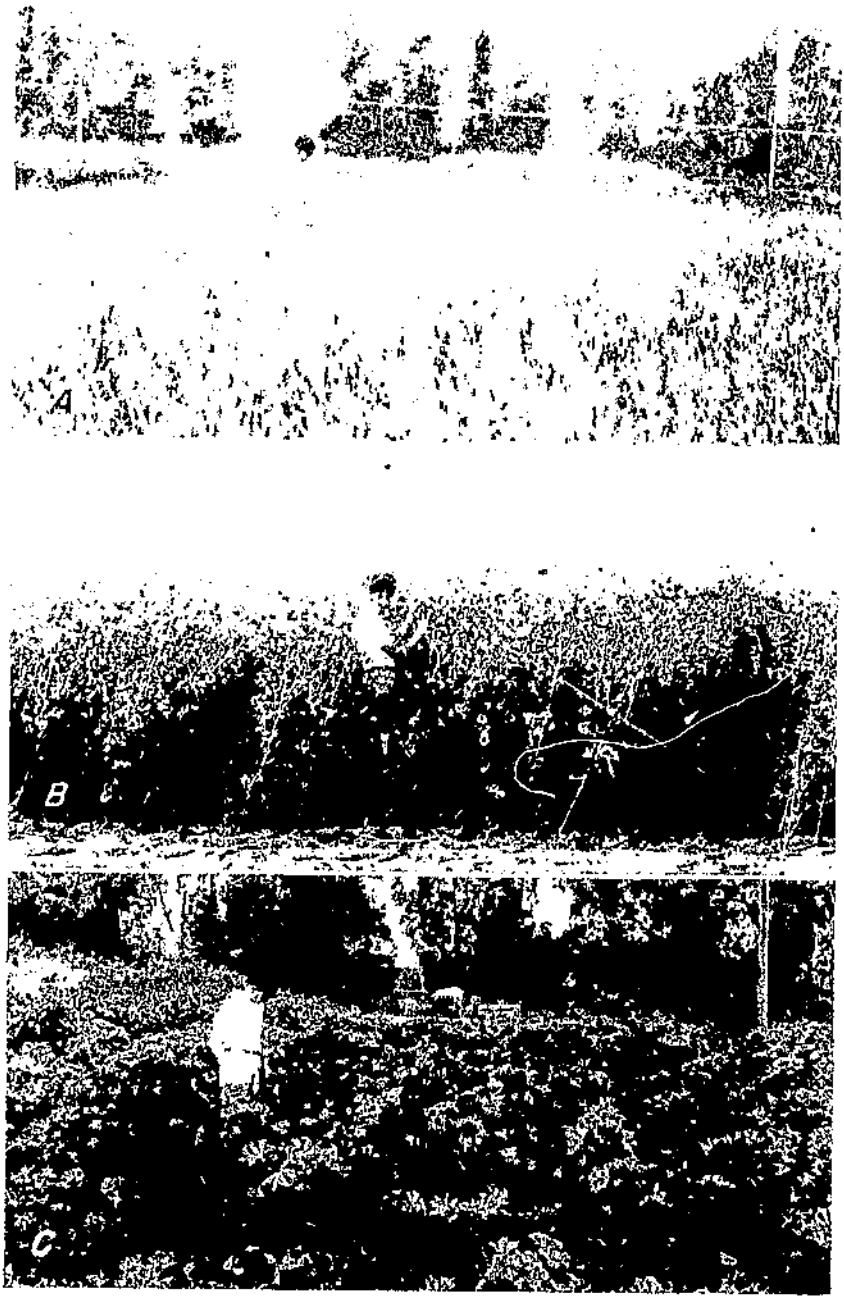

FIGURE 6.—Rank growth of winter cover crops on the Chaffee farm before being plowed under in April 1911: *A*, barley; *B*, mustard; *C*, sweetclover interspersed with malva.

The data obtained in each field on the over-all effect of the cover crops on wireworm populations and their damage to the lima beans are shown in table 1.

TABLE 4.—*Effect of winter cover crops on wireworm populations and their injury to the lima bean crop*

Field and cover crop	Number of wireworms per square foot of soil to a depth of 16 inches					Number of plants per foot of bean row at harvesttime					Yield of dry lima beans, sacks per acre				
	1940	1941	1942	1943	1944	1940	1941	1942	1943	1944	1940	1941	1942	1943	1944
Soil conservation:															
Barley	1.1	2.8	1.2	3.2	1.3	0.8	0.3	1.2	0.4	0.4	10.1	9.3	17.8	9.4	7.3
Mustard	1.0	.9	.7	1.4	1.0	.6	.4	1.0	.5	.4	14.6	11.8	20.8	8.7	6.3
Sweetclover	1.1	1.1	1.3	1.1	1.1	.5	.7	.8	.5	.3	15.9	21.4	15.1	12.4	8.4
Fallow	.9	.4	.2	.6	.6	.5	.9	1.0	.9	.4	11.4	23.7	18.9	19.9	9.1
Error [1]		1.5		1.7					.4						
Bard:															
Barley	1.8	2.6	1.2	4.2	2.5	.7	.6	.6	.3	.4	6.8	4.4	5.4	2.4	3.8
Mustard	2.0	1.5	2.1	2.0	1.8	.5	.7	.4	.7	.3	6.2	6.0	6.5	5.6	3.1
Sweetclover	1.5	1.7	1.5	1.5	2.2	.4	.6	.3	.6	.5	7.4	11.1	8.5	7.0	5.9
Vetch	2.7	1.0	1.6	1.7	1.0	.4	.7	.2	.5	.4	7.0	10.3	5.8	5.3	5.6
Fenugreek	2.7	1.3	1.4	2.1	1.1	.4	.6	.4	.3	.4	6.2	10.7	10.7	3.3	5.5
Fallow	1.5	.7	.6	1.2	1.1	.6	.7	.7	1.3	.5	9.1	9.0	16.3	10.5	5.1
Error				1.6				.2	.8			3.2	5.5	4.6	
Chaffee:															
Barley	.7	.3	2.0			1.0	1.0	1.3			13.3	11.4	13.3		
Mustard	1.0	.2	1.6			.8	.8	1.2			13.0	10.3	15.0		
Sweetclover	.9	.1	1.2			.7	.8	1.3			13.4	13.7	19.0		
Vetch	.8	.2	1.7			.8	.8	1.3			15.9	13.4	18.8		
Fenugreek	.8	.2	1.1			.8	.8	1.4			14.6	12.3	18.2		
Fallow	.9	.1	.1			.8	.9	1.7			14.1	12.9	20.2		
Error			.9					.2				1.9			

[1] Error indicates difference required for significance at odds of 19:1. Blanks indicate that the error was not significant according to the *F* test.

In the Soil Conservation field there were no significant differences between treatments in either wireworm populations or yields of dry beans in 1940 after the first planting. In 1941, however, after two consecutive plantings there was a significant increase in the wireworm populations of the barley plots over those in the fallow plots. Owing to this increase in wireworm numbers, there was extensive damage to the bean seed and plants, and the yields of beans in the barley plots were reduced. Apparently wireworms were not a factor in 1942, as excellent yields of dry beans were obtained in all cover-crop plots after heavy April rains. In 1943, after the third planting of cover crops, there was a marked increase in wireworm populations in the barley and mustard plots, and the yields of dry beans were reduced accordingly. The fallow plots, however, with consistently low wireworm populations, again gave the best yields. In 1944 low yields were obtained in the fallow as well as in the cover-crop plots, and it is possible that climatic and other factors were responsible.

From the wireworm populations recorded over the 4-year period it appeared that the barley plots were preferred most by ovipositing adults, and the fallow plots least. The wireworm populations of the mustard and sweetclover plots remained more or less constant, averaging about 1 wireworm per square foot.

In the Bard field in 1940 there were no significant differences between treatments in either wireworm populations or yields. In 1941, however, there was a definite decrease in the yield of beans in the barley plots, and the mustard plots also were low in yield. In 1942 the wireworm populations did not differ significantly; nevertheless, all crops gave a significant reduction in yield. In 1943, after four consecutive plantings of cover crops, the infestation in the barley plots increased to 4.2 wireworms per square foot, with the result that the average yield was the lowest obtained in these studies. In this year very poor yields were also obtained in the mustard, vetch, and fenugreek plots. The 1944 data show no significant differences between treatments in wireworm populations, numbers of plants, or yields of dry beans.

In the Chaffee field no significant differences between treatments were noted in wireworm population or in the density of stand in 1940 and 1941. The yields were nearly uniform in 1940, but in 1941 there was a reduction in yield in the mustard plots. The results obtained in 1942 are difficult to explain, as there was an excellent stand of beans in spite of marked increases in wireworm populations in all cover-crop plots, and exceptionally high yields were obtained in the cover-crop as well as in the fallow plots.

Effect of Time of Plowing

The effects of plowing the cover crops under in the latter part of February and about the first of April are shown in table 5 and figure 7. In general the early plowing tended to prevent the reduction in yield due to increased wireworm populations associated with cover crops.

In 1940 there were no significant differences among the early-plowed plots or among the late-plowed in either the wireworm populations or the yields of dry beans. This was anticipated, inasmuch as new-brood wireworms did not have time to develop after the experiment was started. More plants survived in the late-plowed barley than in the fallow plots, although the reason is not understood.

In 1941, after two plantings of cover crops, there were significant increases in the wireworm populations in the late-plowed sweetclover and barley as compared with the fallow plots, and significant decreases in the yield of late-plowed barley and mustard. There was no significant adverse effect of cover crops plowed under early.

In 1942, after three plantings of cover crops, there were significant increases in wireworm populations in all the late-plowed plots and corresponding decreases in yield. There were also significant increases in wireworms in the early-plowed plots except where sweetclover had been grown. The higher populations in the early-plowed plots were evidently due largely to the heavy rainfall in 1941, which delayed plowing until March 18, after the emergence of the adults. The yields in these plots in 1942 were good and exceptionally uniform. Thus when the weather was favorable for the bean crop the beneficial effects of the cover crops compensated for any damage caused by the higher population of wireworms.

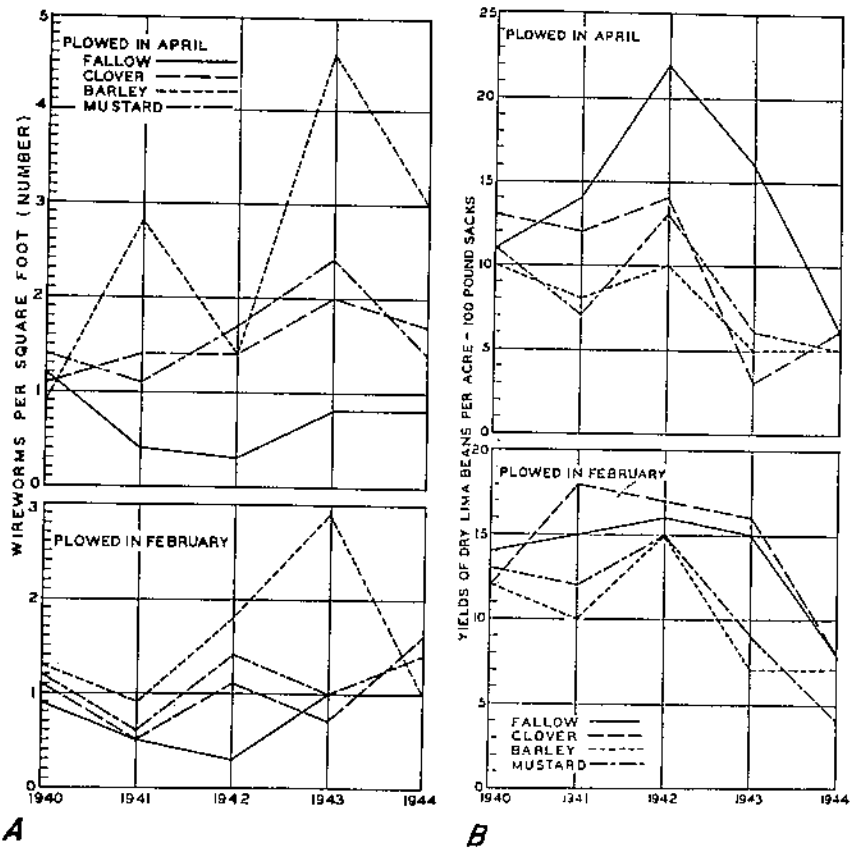

FIGURE 7.—*A*, Wireworms at least 1 year old, and *B*, yield of dry beans, in plots in which cover crops had been plowed under each year in February or April, 1940–44. In 1941, owing to heavy rains, the plots were not plowed until March 28.

In the winter of 1942–43 there were only eight replicates, four for early- and four for late-plowed cover crops, the experiments in the Chaffee field having been discontinued. As was generally true in previous years, the early-plowed plots had fewer wireworms and better stands than late plowed, and gave larger yields of dry lima beans. There were more wireworms in all the late-plowed plots than in any other year of the experiment. The stand of bean plants and the yield of beans were drastically reduced in all plots where the cover crop was plowed under in April.

No cover crops were planted in the fall of 1943; nevertheless, the usual data were obtained in the spring of 1944 to determine the carry-over effect of the previous four plantings. Except for the high wire-

TABLE 5.—*Wireworm population and damage to lima beans in the same plots each year from 1939 to 1944, after the plowing under of various winter crops in February and in April*

CROPS REPLICATED IN THREE FIELDS [1]

Season and crop	Wireworms per square foot		Bean plants per 0.01 acre at harvest		Yield of dry beans per acre	
	February	April	February	April	February	April
	Number	*Number*	*Number*	*Number*	*Sacks*	*Sacks*
1939–40:						
Barley	1.3	0.9	120	181	12	10
Mustard	1.2	1.4	115	113	13	11
Sweetclover	1.1	1.1	101	107	12	13
Fallow	.9	1.2	131	100	14	11
Error [2]				30		
1940–41: [3]						
Barley	.9	2.8	136	110	10	8
Mustard	.6	1.1	143	94	12	7
Sweetclover	.5	1.4	144	108	18	12
Fallow	.5	.4	153	141	15	14
Error		1.0		[4]		3
1941–42:						
Barley	1.8	1.1	176	215	15	10
Mustard	1.4	1.7	172	156	15	13
Sweetclover	1.1	1.4	173	149	17	14
Fallow	.3	.3	226	216	16	22
Error	1.0	.7				6
1942–43:						
Barley	2.9	4.6	77	49	7	5
Mustard	1.0	2.4	135	69	9	6
Sweetclover	.7	2.0	159	36	16	3
Fallow	1.0	.8	211	182	15	16
Error	1.5	1.8	39	59		5
1943–44: [5]						
Barley	1.0	3.0	90	53	7	5
Mustard	1.4	1.4	44	69	4	5
Sweetclover	1.6	1.7	72	68	8	6
Fallow	1.0	.8	91	80	8	6
Error		1.4				

See footnotes at end of table, p. 17.

TABLE 5.—*Wireworm population and damage to lima beans in the same plots each year from 1939 to 1944 after the plowing under of various winter crops in February and in April*—Continued

CROPS REPLICATED IN TWO FIELDS [1]

Season and crop	Wireworms per square foot		Bean plants per 0.01 acre at harvest		Yield of dry beans per acre	
	February	April	February	April	February	April
1939–40:	*Number*	*Number*	*Number*	*Number*	*Sacks*	*Sacks*
Vetch	1.7	1.2	116	114	15	11
Fenugreek	1.7	1.2	114	116	11	12
Fallow	1.0	1.2	132	115	13	11
1940–41: [3]						
Vetch	.3	.9	149	131	14	11
Fenugreek	.6	.8	139	117	13	11
Fallow	.5	.4	146	116	11	12
1941–42:						
Vetch	2.1	1.2	159	171	18	11
Fenugreek	1.3	1.2	164	222	17	14
Fallow	.3	.3	237	238	18	20
Error	.8	.8	48	35	..	..
1942–43:						
Vetch	2.0	1.4	161	25	9	2
Fenugreek	1.1	3.2	109	8	6	1
Fallow	1.0	1.4	249	204	9	12
Error	..	..	94	64	..	..
1943–44: [5]						
Vetch	.8	1.2	66	76	4	7
Fenugreek	1.5	.7	70	78	5	6
Fallow	1.3	1.0	101	85	5	5

[1] One field discontinued in 1942.

[2] Error indicates difference required for significance at odds of 19 : 1. Blanks indicate that the difference was not significant according to the *F* test.

[3] Because of excessive rains in 1941 none of the crops could be plowed under until March 28.

[4] The number of plants in the late-plowed fallow plots was significantly higher than the average for the barley, mustard, and sweetclover plots. Other differences were within the limits of experimental error.

[5] No cover crops planted in 1943.

worm population in the late-plowed barley, there were no outstanding differences in the result.

Vetch and fenugreek also may have caused an increase in wireworm populations (table 5), especially in 1942. There was no appreciable difference, however, between plots plowed under in February and in April.

To show more clearly the over-all effect of early and late plowing of barley, mustard, and sweetclover on wireworm populations, yields, and plant stand, the data from all fields in the years 1941–44 were averaged and are presented in figure 8.

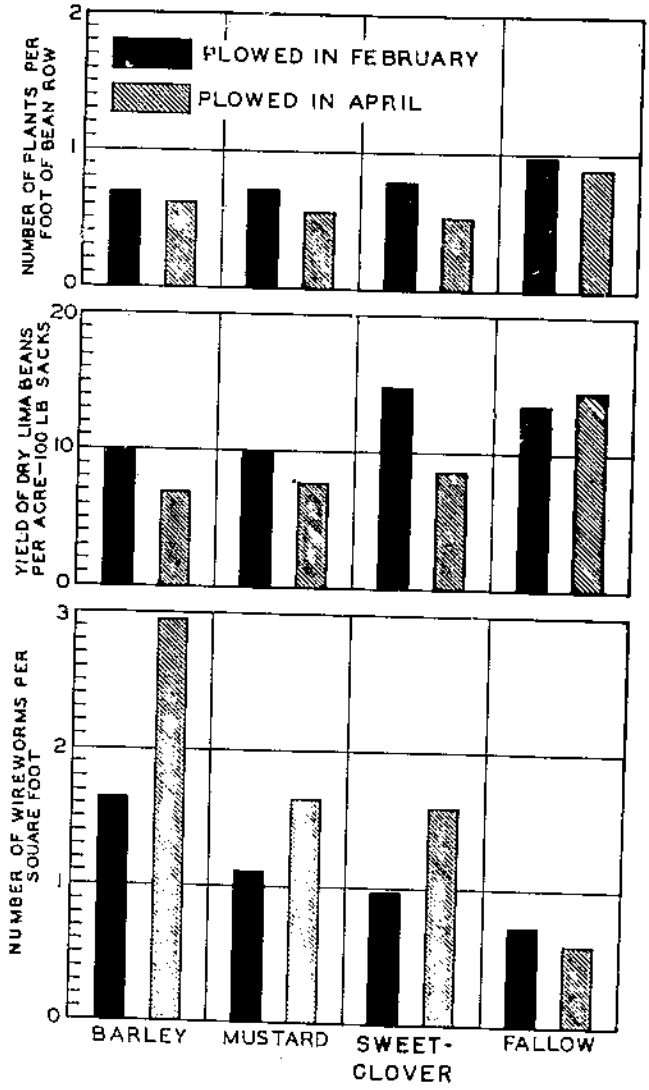

FIGURE 8.—Wireworm populations, plant stand, and yields of dry lima beans in plots in which winter cover crops were plowed under each year in February or in April, 1941–44.

This chart shows that the three cover crops tested were responsible for the build-up of sugar-beet wireworm populations and that these populations increased when the crops remained standing during the period of adult wireworm emergence. Despite the reduction in plants due to wireworms, equally as large yields of lima beans were obtained in the early-plowed sweetclover as in the lightly infested fallow plots. The increase in wireworm population due to sweetclover was apparently offset by the increased productivity of the soil. However, when the same crop was plowed under in April and the population increased

to 1.6 wireworms per square foot, the soil productivity was not sufficient to maintain satisfactory yields. The chart also shows that the continuous planting of barley greatly increased wireworm populations and that these plots and those planted to mustard were the least productive.

DISCUSSION

This experiment shows that adult wireworms are attracted to cover crops not only for shelter but also for oviposition. It is also apparent that the eggs deposited by the adults are less subject to desiccation when cover crops are available, especially if plowed under late in the season. Furthermore, the ample food aids survival and hastens the development of the larvae.

The beneficial effect of the cover crops was greatly reduced, especially in the Bard field, by the large numbers of wireworms feeding on the seed and roots of the lima bean crop. There was no appreciable difference in any year in yield of dry beans between the early-plowed plots except in 1943, when there was a tendency for the sweetclover and fallow plots to outyield the barley and mustard plots. In 1940 the late-plowed cover crops had not had time to increase wireworm populations sufficiently to decrease the yield. In 1941, 1942, and 1943, however, barley and mustard and, to a lesser extent, sweetclover plowed under late increased the wireworm population sufficiently, as compared with fallowing, to decrease the yield substantially. The wireworms in the fallow plots decreased between 1940 and 1942, and the yields increased accordingly.

Wireworms may have not been entirely responsible for the generally low yields that were obtained in the barley and mustard plots. Other research workers (Pieters and McKee 4) found that the turning under of a nonlegume cover crop decreased the yields of the following corn or cotton crops because of exhaustion of the soil nitrogen. Depletion of nitrogen in the barley and mustard plots may have caused some decrease in bean yields, but the extensive destruction of seed and plants by wireworms in these plots, especially in 1941 and 1943, cannot be ignored. During the period of these studies there was no significant difference in the yields of dry beans in vetch, fenugreek, and fallow plots. In most years, however, the fallow plots, because of usual low wireworm populations, produced the most beans.

SUMMARY

Studies were conducted in Ventura County, Calif., from 1939 to 1944, inclusive, to test the theory that winter cover crops plowed under late increased the population of the wireworms by providing protection for the adults during the egg-laying season. Preliminary studies made in 1938 had indicated that the type of winter cover crop and the time of plowing it under in the spring may affect the next generation of wireworms.

Three wireworm-infested fields were selected, and five cover crops—barley, mustard, sweetclover, purple vetch, and fenugreek—were used, with fallowing as a check. A randomized-block design was used, and one half of the blocks were plowed under early and the other half late in the spring. Soil samples were taken and sifted to deter-

mine the wireworm population before the current season's eggs had had time to hatch.

Practically all the wireworms found in the experimental plots were sugar-beet wireworms (*Limonius californicus* Mann.), although there were a few individuals of four other species.

In the plots that remained fallow during the winter, wireworm infestations were light and the stand of plants was good. The barley plots were preferred most by ovipositing adults, and the fallow plots least. Barley, mustard, and sweetclover were responsible for the build-up of wireworm populations.

With increases in wireworm infestations due to cover crops, there were corresponding decreases in the number of plants and usually in the yield of dry lima beans. The lowest yields were in the barley and mustard plots.

In general, early plowing tended to prevent the increases in wireworm populations and the consequent reduction in yields. This tendency was most outstanding in the early-plowed sweetclover plots where, despite the reduction in plants due to wireworms, equally as large yields of lima beans were obtained as in the lightly infested fallow plots.

The decrease in yields of lima beans in the barley and mustard plots may not have been due entirely to wireworms, but partially to depletion of nitrogen in the soil.

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