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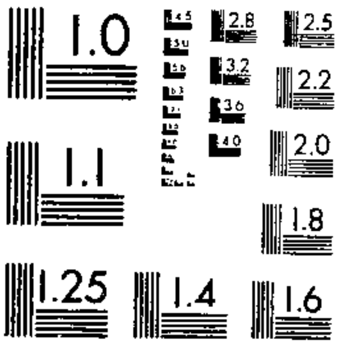

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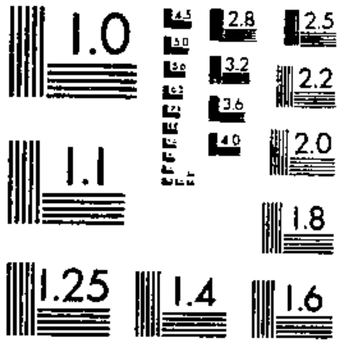

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Effect of Some Crop Rotations on Wireworm Populations in Irrigated Lands

by K. E. Gibson
M. C. Lane
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Technical Bulletin No. 1172
U. S. DEPARTMENT OF AGRICULTURE
In cooperation with the Washington
Agricultural Experiment Station

Contents

Washington, D. C. Issued January 1958

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. Price 15 cents

Effect of Some Crop Rotations on Wireworm Populations in Irrigated Lands[1]

By K. E. Gibson, M. C. Lane, W. C. Cook, and E. W. Jones,[2] *entomologists*, Entomology Research Division, Agricultural Research Service

A study of wireworm populations in relation to crop rotations was conducted at Prosser, Wash., from 1936 through 1946. This study was incidental to agronomic experiments begun in 1935 by the Washington Agricultural Experiment Station, the results of which were published by Nelson and Larson (*3*).[3]

The objective was to determine the effect of rotation length, of various crop sequences, and of certain individual crops on any variation in the numbers of wireworms from year to year and over a period of years. Some other pertinent facts have been brought out and are discussed later.

The wireworm population was comprised almost entirely of the two economic species most commonly found in irrigated lands—the Pacific Coast wireworm (*Limonius canus* Lec.) and the sugar-beet wireworm (*L. californicus* Mann.).

Procedure

Plan of Experiment

There were 102 rotation plots, each 0.1 acre in size, established on a Sagemoor fine sandy loam soil near Prosser. The Sagemoor series is the most extensive irrigated soil series in the Yakima Valley and occurs in large areas of the Columbia Basin of Washington. There were six 7-year, two 5-year, four 4-year, and five 2-year rotations, as well as five crops that were grown continuously. For each rotation there was a plot for each rotation year. These plots were placed side by side and crops were assigned to them in the same sequence as the rotation. The 7-year rotations consisted of 4 years of alfalfa seeded in wheat, followed by 3 years of row crops (corn, sugar beet, and potato) in varying sequences. The 5-year rotations consisted of 3 years of alfalfa, also seeded in wheat, followed by 2 years of row

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[1] H. P. Singleton and C. E. Nelson, of the Washington Agricultural Experiment Station, and C. A. Larson, H. P. Lanchester, and C. A. Amen, of the Agricultural Research Service, assisted in these experiments.

[2] Deceased August 3, 1955.

[3] Italic numbers in parentheses refer to Literature Cited, p. 19.

crops. The 4-year rotations were made up of 2 years of sweetclover seeded in wheat, followed by 2 years of row crops. The 2-year rotations consisted of various combinations of wheat, corn, sugar beet, or potato. The continuous crops were alfalfa, wheat, corn, sugar beet, and potato. The field-plot arrangement and the crops grown in each plot in 1935 are shown in figure 1.

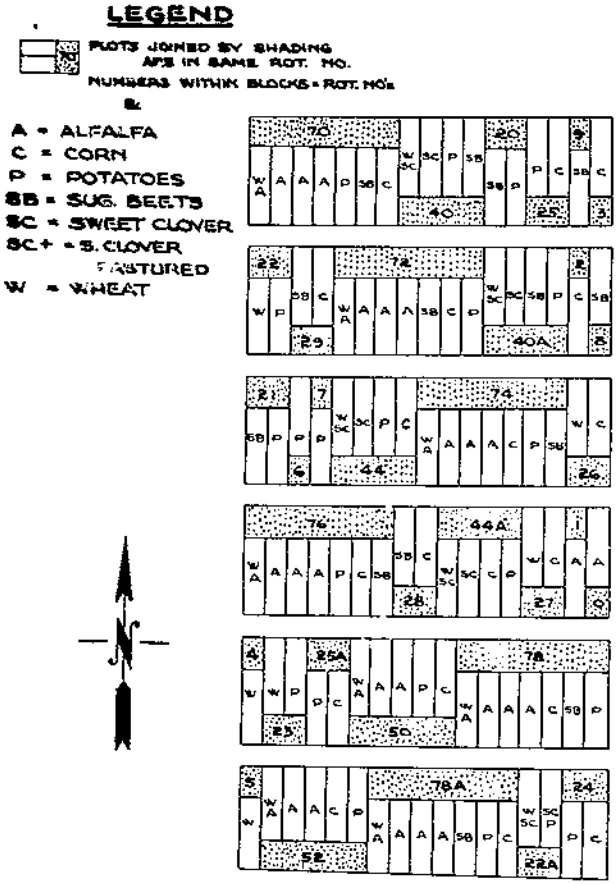

FIGURE 1.—Field-plot arrangement of various rotations of crops in 1935. Plots in the same rotation are joined by shading.

The five continuous crops and the five 2-year rotations were partially replicated in duplicate in this study. The plots of one replicate received 12 tons of barnyard manure per acre annually as fertilizer, while the other replicate received no fertilizer. A third partial replicate of the wheat-potato and corn-potato 2-year rotations was given additional treatments. Sweetclover was planted in the wheat and was plowed under as a green manure crop just before the potato crop was planted the next year. In the third set of corn-potato plots, 2.48 tons of chopped alfalfa hay per acre was applied annually as fertilizer.

None of the rotations were absolutely replicated; therefore, replication for wireworm counts had to be obtained indirectly. During each rotation, each plot grew every crop once in that rotation so the annual wireworm counts could be used to obtain replication in time. Thus, each year that all the plots were sampled contributed a partial replicate.

In addition to this replication in time, it was also possible to set up groups of plots for which the cropping history was the same for 2 or more successive years, such as potato following alfalfa or corn following alfalfa, in both of which there were three replicates each year (in different rotations).

Methods of Making Wireworm Counts

The wireworm populations were sampled by the methods described by Jones (*2*). Most samples were taken to a depth of 2 feet, and the soil was sifted through screens, the finest of which had 14 meshes per inch. The wireworms were removed, counted, and sorted to size; both larvae and adults were classified to species and the sex of the adults was determined.

Samples were taken annually in March. During the first 3 years a series of 23 plots, 1 from each rotation, was selected at random for sampling, and 20 1-square-foot samples were taken from each plot. It became evident that, while the method gave adequate samples of these particular plots, it did not give sufficient information regarding changes over the rotations as a whole. Therefore, the procedure was changed in 1939, and a set of 10 samples of approximately ¼ square foot each was taken with a 6-inch soil auger from each of the 102 plots. These samples did not yield adequate information regarding the individual plots but gave much better information regarding the various rotations than had been obtained earlier.

The sampling records of 1939–44 showed that, in March, about 73 percent of the wireworms were found in the top foot of soil. Accordingly, only the 7- and 4-year rotations were sampled to a depth of 2 feet in 1945 and only the 4-year ones in 1946. This sampling was done to obtain 7 years of records to a depth of 2 feet in the 7-year rotations and 8 years of such records for the 4-year ones. For comparisons with these rotations, the other wireworm population figures were increased proportionately in these years.

Annual Changes in Wireworm Populations

Since the arrangement of the plots or rotations was systematic rather than randomized and since the rotations were not replicated, it was highly important to know if the original distribution of the two species of wireworms over the experimental area was random. Obviously, the distribution would become systematized with the passage of time if the various crops and rotations affected the wireworm population. A simple analysis of variance of the population counts for 1936 showed that the variance between rows or between columns was of the same order of magnitude as that within them for each species of wireworm and for the total population, with no significant differences. This analysis indicated that the original wireworm distribution was random and counterbalanced the systematic arrangement of the rotations.

During the period of study there was a considerable fluctuation in the average wireworm population of the plot area. To determine if the change of base after the third year affected the averages seriously, the figures for the same 23 plots used for the first 3 years were averaged for the period 1939–46. This average ran slightly, but not significantly, higher than that for the whole series, so the averages for the two periods have been tabulated together in table 1 and plotted in figure 2.

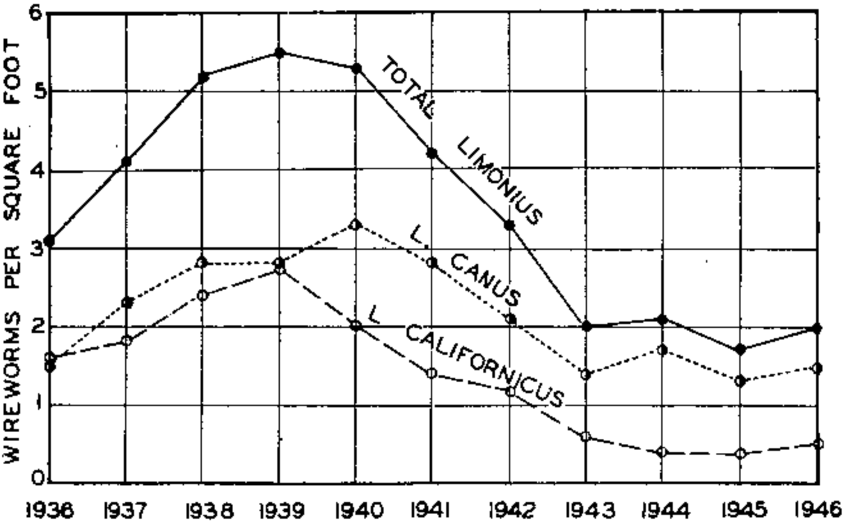

FIGURE 2.—Average populations of *Limonius* wireworms per square foot in rotation plots near Prosser, Wash., 1936–46.

TABLE 1.—*Average numbers of* Limonius *wireworms (adults and larvae) per square foot in rotation plots near Prosser, Wash., 1936–46*

Year	*L. californicus*	*L. canus*	Both species
1936	1.6	1.5	3.1
1937	1.8	2.3	4.1
1938	2.4	2.8	5.2
1939	2.7	2.8	5.5
1940	2.0	3.3	5.3
1941	1.4	2.8	4.2
1942	1.2	2.1	3.3
1943	.6	1.4	2.0
1944	.4	1.7	2.1
1945	.4	1.3	1.7
1946	.5	1.5	2.0
LSD—5% level	.9	1.2	1.6
1% level	1.2	1.6	2.1

The wireworm population of the plot area increased gradually during the first 4 years, reaching a peak between 1938 and 1940. After

1943 the population remained relatively stable. The curve of average abundance probably reflects the general effects of cropping practices on wireworms in that area. Before the plots were started, the entire field was in alfalfa. The change to the various combinations of truck and forage crops at first stimulated the production of wireworms. Later, as the short rotations were repeated and plots were left longer in single crops, the wireworm populations approached a state of equilibrium, reflecting what might be expected under the various rotations in that area. *L. californicus* made up about half the wireworm population until 1940 but declined greatly after that time. In 1946 only about a quarter of the wireworms present were this species. Although the population of *canus* was doubled by 1940, it subsided to about its original level after 1943. These population trends differ from those found by Shirck and Lanchester (*4*) in their studies in southern Idaho. In the Idaho area, *californicus* was the predominating species and remained so during the four seasons of study.

The steady and quite consistent reduction in the overall elaterid population in the Washington plots from 1939 to 1943 and the apparent leveling off from 1943 to 1946 may represent part of a cyclic trend. The population might have gradually increased again if the rotations had been carried on longer, but data are insufficient to establish this point.

In view of considerable fluctuations in wireworm populations during the period of study, there was a possibility that the heavier infestations during the early part of the study weighted the results unduly Accordingly, the population for each plot in each year was reduced to an index number based upon the average population of the whole series, and these numbers were used in comparisons of crops and rotations over the period. The comparisons obtained with the index numbers did not vary significantly from those obtained with actual population figures; so the latter are used exclusively in this paper.

Wireworm Populations in Rotations of Different Lengths

All the rotations contained combinations of the same crops, and rotations longer than 2 years included 2 or more years of a legume crop followed by 2 or 3 years of a cultivated crop. Sweetclover was the legume used in the 4-year rotations and alfalfa in the others.

Field studies over many years have indicated that *canus* can maintain itself well in cultivated crops, while *californicus* is more generally found in meadows, pastures, and irrigated grainfields where cultivation occurs only at rather long intervals. These differences, together with the fact that *canus* usually lays its eggs in bare soil while *californicus* prefers soil that is shaded by vegetation, should be kept in mind in following the discussion of this study.

The data on rotation length were analyzed by considering each rotation as a single series without regard to the number of plots, calculating the average population of each rotation and considering each year as a replication. This analysis showed that *canus* was the more abundant species in the continuous plots and 2-year rotations, while both species were present in apparently equal numbers in the 5-year rotations (table 2). *L. californicus* was also abundant in the continuous plots, largely because of the presence of alfalfa and wheat in the series, both of which furnished favorable conditions for this

TABLE 2.—*Average numbers of* Limonius *wireworms per square foot in rotations of different lengths, 1939–46*

Years of rotation	*L. canus*	*L. californicus*	Both species
7	1.3	0.9	2.2
5	1.6	1.6	3.2
4	2.2	1.2	3.4
2	3.0	.8	3.8
1	3.0	1.2	4.2
LSD—5% level	.5	.3	.7
1% level	.7	.4	1.0

species. Omitting these two crops, *californicus* averaged 0.5 per square foot in the remaining continuous plots, the smallest population in any length of rotation.

L. californicus was more abundant in the 5-year than in the other rotations. *L. canus* was more abundant in the shorter rotations, and since it was the more abundant species throughout most of the rotations, the total population of both species increased gradually as the rotations became shorter.

Effect of Continuous Cropping

A study of the effect of continuous crops on the wireworm populations should help explain the effect of crop rotations on them. The average populations of the two species for the 8-year period are given in table 3.

TABLE 3.—*Average numbers of* Limonius *wireworms per square foot in plots under continuous cropping, 1939–46*

Crop	*L. canus*	*L. californicus*	Both species
Wheat	5.2	2.4	7.6
Potato	7.1	.2	7.3
Corn	1.2	1.1	2.3
Alfalfa	.5	1.5	2.0
Sugar beet	1.1	.3	1.4
LSD—5% level	1.6	1.2	2.1
1% level	2.1	1.6	2.8

L. canus was more abundant in wheat and potato plots, less numerous in corn and sugar beets, and scarcest in alfalfa. *L. californicus* was most abundant in wheat and least so in potato and sugar-beet plots, while the infestation was intermediate in corn and alfalfa. Of these crops, wheat maintained large, sugar beet small, and corn intermediate populations of both species. The largest total populations were found in plots of wheat and potato.

A comparison of the wireworm populations in the manured and unmanured plots showed only one difference—populations of *canus* were larger in the plots of manured potato.

Wireworm Populations in the Various Rotations

Wireworm Populations in the 2-Year Rotations

In discussing the continuously cropped plots, it was shown that wheat and potato were favorable for *canus*, while corn and sugar beets were not. When these crops were combined into 2-year rotations, the wheat-potato sequences contained the largest populations of *canus*, while the sugar beet-corn ones contained the smallest. The other combinations, each containing one favorable and one unfavorable crop, supported intermediate populations of *canus*.

In the continuous plots, wheat maintained large, corn intermediate, and potatoes and sugar beets small populations of *californicus*. In the 2-year rotations, this species was found in fair numbers in the wheat-corn sequence but in very small numbers in all of the others. Populations of *canus*, *californicus*, and both species combined in the 2-year rotations are shown in table 4.

TABLE 4.—*Average numbers of* Limonius *wireworms per square foot in plots under the 2-year rotations, 1939–46*

Rotation	*L. canus*	*L. californicus*	Both species
Wheat-potato	4.0	0.8	4.8
Wheat-corn	2.1	1.5	3.6
Potato-corn	2.7	.6	3.3
Sugar beet-potato	2.9	.2	3.1
Sugar beet-corn	1.6	.5	2.1
LSD—5% level	1.3	.4	1.2
1% level	1.7	.5	1.6

Because of the dominance of *canus* in the entire series, the total wireworm population was largest in the wheat-potato rotation, smallest in the sugar beet-corn rotation, and intermediate in the others.

Each 2-year crop sequence was grown both with and without manuring, and the differences are shown in table 5.

The green manure used in the wheat-potato and the chopped alfalfa hay in the potato-corn rotations had about the same effect on the wireworm populations as the barnyard manure. Therefore, the data for the two types of treatment were averaged in this table.

In general, the use of manure increased the number of wireworms. This was most outstanding in the potato-corn and wheat-potato plots. In the sugar beet-potato plots, however, there was an increase in *canus* but a decrease in *californicus*, whereas in the wheat-corn plots the reverse was true.

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TABLE 5.—*Excess or deficiency in number of* Limonius *wireworms per square foot in manured as compared with unmanured plots in 2-year rotations, 1939–46* [1]

Rotation	*L. canus*	*L. californicus*	Both species
Potato-corn	*+1. 8	*+1. 1	**+2. 9
Wheat-potato	*+2. 2	+. 3	**+2. 5
Sugar beet-corn	+. 6	*+. 8	+1. 4
Sugar beet-potato	**+2. 7	**−1. 8	+. 9
Wheat-corn	−1. 2	**+1. 2	0
Average	**+1. 2	**+. 3	**+1. 5

[1] Departures marked with a single asterisk (*) are significant at the 5-percent level and those marked with a double asterisk (**) at the 1-percent level.

Wireworm Populations in the 4-Year Rotations

The 4-year rotations contained the following row-crop sequences. Potato-sugar beet, potato-corn, sugar beet-potato, and corn-potato, each following 2 years of sweetclover which was planted in wheat (table 6). These row-crop sequences made little difference in the population of *canus*, and only the sugar beet-potato sequence reduced the population of *californicus*. This rotation contained the smallest number of that species. The largest total number of wireworms was found in the corn-potato plots.

TABLE 6.—*Average numbers of* Limonius *wireworms per square foot in plots under 4- and 5-year rotations, 1939–46*

Truck crop sequence	*L. canus*	*L. californicus*	Both species
Following 2 years of sweetclover:			
Corn-potato	2. 6	1. 5	4. 1
Potato-corn	2. 2	1. 1	3. 3
Potato-sugar beet	1. 7	1. 4	3. 1
Sugar beet-potato	2. 3	. 7	3. 0
LSD—5% level	. 6	. 5	. 6
1% level	. 8	. 7	. 8
Following 3 years of alfalfa:			
Potato-corn	. 8	1. 7	2. 5
Corn-potato	2. 5	1. 3	3. 8
LSD—5% level	. 9	----------	1. 0
1% level	1. 4	----------	1. 4

Wireworm Populations in the 5-Year Rotations

In the two 5-year rotations, 3 years of alfalfa were followed by potato-corn or corn-potato. Since the legume history was the same in both rotations, any difference in wireworm populations must be correlated with the sequence of the truck crops. The largest total population was found in the rotation with the corn-potato sequence (table 6). Since the numbers of *californicus* were nearly the same in the two rotations, the larger total population in corn-potato was caused by a much larger one of *canus*.

The difference in the average populations of *canus* in the two rotations is quite striking. In order to examine this further, a new set of averages was made from the figures for each crop for the 8-year period. As shown in figure 3, the bar diagrams represent the average

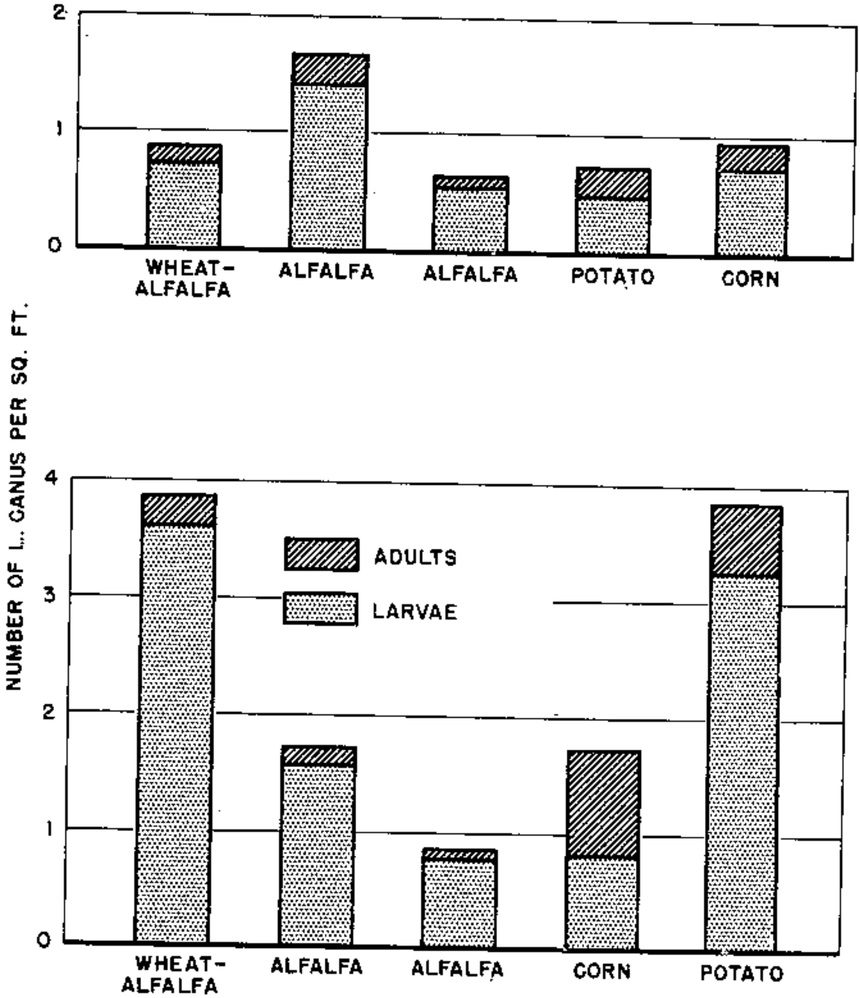

FIGURE 3.—Average spring populations of *Limonius canus* in soil in two 5-year rotations, 1939–46. The bar shows the *canus* population following the crop indicated.

canus populations in these crops in the order in which they occur in the two rotations. Only adults and larvae were present at the time of sampling in the spring. The crop named below each bar is that of the preceding year. For example, the bar labeled "potato" shows the *canus* population following that crop.

Populations of *canus* in the two rotations were about the same during the last 2 years of alfalfa, and when the alfalfa was plowed, the proportions of adults to larvae were about equal. When the first truck crop was potato, about half the larvae present transformed to adults; and from the eggs they laid, a slightly larger brood of larvae was produced in the following corn crop. The top section of figure 3 shows that for the entire rotation wireworms were most numerous the second year in alfalfa. This high population level apparently followed a rather heavy oviposition and good survival in the wheat-alfalfa. When corn was the first truck crop, the picture was quite different. All the larvae present transformed to adults the next fall, and a heavy new brood was produced in the following crop of potato. This stimulus to increase carried over into the wheat-alfalfa year, when population levels were about as high as in the year following potato.

This situation would indicate that the order in which truck crops are planted might be of considerable importance. In this particular case, population levels of wireworms were much lower in the sequence of alfalfa-potato-corn than in that of alfalfa-corn-potato.

Wireworm Populations in the 7-Year Rotations

The six 7-year rotations all started with wheat, in which alfalfa was seeded either in the stubble during August (1938–42) or in the young wheat in May (1943–45). The alfalfa was maintained for the next 3 years, then plowed and followed by 3 years of truck crops. The six rotations were the six different possible truck-crop sequences containing corn, potato, and sugar beet. The differences in total wireworm populations among the six rotations were relatively slight, varying from 1.9 to 2.9 per square foot, as shown in table 7.

TABLE 7.—*Average numbers of* Limonius *wireworms per square foot in plots under 7-year rotations, 1939–46*

Truck-crop sequence (following 4 years of alfalfa)	*L. canus*	*L. californicus*	Both species
Corn-potato-sugar beet	2.0	0.9	2.9
Sugar beet-corn-potato	1.3	1.0	2.3
Sugar beet-potato-corn	1.5	.8	2.3
Corn-sugar beet-potato	1.3	.7	2.0
Potato-sugar beet-corn	.8	1.2	2.0
Potato-corn-sugar beet	1.0	.9	1.9
LSD—5% level	.5	.4	.7
1% level	.7	.5	.9

The differences in populations of *californicus* were also slight, the only significant one being that the population in the corn-sugar beet-potato sequence was smaller than that in potato-sugar beet-corn (4th and 5th sequence in table 7). Populations of *canus* were very similar in four of the rotations. However, in the remaining two (corn-potato-sugar beet and potato-sugar beet-corn) the same tendency was noted as in the 5-year rotations. The largest populations followed corn and the smallest followed potato as the first truck crops after alfalfa, as shown below:

First truck crop after alfalfa:	*L. canus per square foot, number*
Corn	1.65
Sugar beet	1.40
Potato	.90
LSD—5% level	.35
1% level	.46

Wireworm Populations Following Various Sequences

In discussing the wireworm populations of the various rotations, it has been evident that the sequence of crops was of great importance. For example, in the 4-, 5-, and 7-year rotations, populations were larger where potato followed corn than where corn followed potato. In making a further analysis, crop sequences were obtained from the various rotations and the crop populations averaged. For example, the 2-year corn-potato rotation furnished two sequences—corn-potato and potato-corn. The other 2-year rotations each furnished two sequences. The corn-potato sequence occurred twice in the 7-year rotations, once in the 5-year, once in the 4-year, and three times in the 2-year series, making a total of 7 annual replications or 56 for the period 1939–46. In the same manner, replication was obtained for other crop sequences and the wireworm populations were averaged.

To determine the effect of any crop on the wireworms, it was necessary to subtract the population preceding that crop from the population following it. The significance of these differences was determined from all the replications obtainable. These population changes and the results of crop sequences are indicated in table 8.

In most cases two crop sequences could be found for each pair of crops, but this was not true of wheat-alfalfa where the alfalfa was planted in the wheat. This crop, in which the wheat probably furnished most of the wireworm food, differed in its reactions. If alfalfa had been planted alone, probably the results would have been quite different.

As with the continuous crops, potato was outstanding as a host crop for *canus*. In every case the population of this species was increased in crops following potato, irrespective of the crop which preceded potato. Furthermore, populations of *canus* decrease in any succeeding crop.

Any row crop immediately succeeding alfalfa was followed by increased wireworm populations of both species. Plots of corn and sugar beet appeared to maintain from small to moderate populations of *canus*. When these crops immediately followed alfalfa, the population increased; and when they followed potato, it decreased. When sugar beet followed corn or potato, populations of *californicus* were reduced. Because of the preponderance of *canus* in these plots, the total population of both species followed the trends shown for *canus* rather closely.

TABLE 8.—*Changes in* Limonius *wireworm populations following various crops in sequences, 1939–46* [1]

Sequence of crops	Replicates	*L. canus*	*L. californicus*	Both species
Wheat-alfalfa following:	*Number*			
Corn	24	0	0	0
Potato	24	−	0	−
Sugar beet	16	+	0	+
Corn following:				
Potato	56	− −	0	− −
Sugar beet	32	0	0	0
Wheat	16	0	0	0
Alfalfa	24	+	++	++
Potatoes following:				
Corn	56	++	−	++
Sugar beet	40	++	0	+
Wheat	24	+	0	++
Alfalfa	24	+	++	++
Sugar beet following:				
Corn	32	0	−	0
Potato	40	− −	− −	− −
Alfalfa	16	++	++	++
Wheat following:				
Corn	16	0	0	0
Potato	24	−	0	−

[1] Differences significant at 5-percent level are shown by + or − signs; at 1-percent level, by ++ or − − signs; nonsignificant difference by 0.

Alfalfa was a special case among the crop sequences, because it occurred only in series of 3 or 4 years in the rotation. Consequently, its effects could be demonstrated only by comparing the populations of wireworms in successive years. Populations present in the wheat-alfalfa year of the rotation were greatly reduced the second year and were more slowly reduced by 2 additional years of alfalfa (table 9). This crop had a definitely unfavorable effect upon populations of both species but did not eliminate either in 4 years. By the end of the fourth alfalfa year, *californicus* comprised half the total wireworm population. This was also the case when the rotations were started in 1935 (page 5). These data indicate that 3 or 4 years of alfalfa in a rotation reduced the total population to about one wireworm per square foot but would not reduce it much below that point.

TABLE 9.—*Average numbers of* Limonius *wireworms per square foot in plots of wheat-alfalfa and succeeding alfalfa crops, 1939–46*

Crop	*L. canus*	*L. californicus*	Both species
Wheat-alfalfa	2.1	1.1	3.2
Alfalfa, second year	1.4	.6	2.0
Alfalfa, third year	.8	.5	1.3
Alfalfa, fourth year	.6	.6	1.2
LSD—5% level	.5	.4	.5
1% level	.7	.5	.7

New Brood Production and Survival in Various Crops

Since the species of wireworms involved in this study have a larval period of 2 or more years, larvae of various ages may be in the soil at any one time. Larvae hatched from eggs in a current season are termed "new brood" and the older larvae, "old brood."

During the seasons of 1940 and 1941, studies were made of the production and survival of new-brood wireworms under wheat, potato, corn, sugar beet, and alfalfa. Eight plots of each crop, scattered among the various rotations, were sampled twice each season, 1/16-square-foot soil samples being taken each time to a depth of 1 foot. These samples were washed through a 60-mesh screen fine enough to retain newly hatched wireworms. The debris retained on the screen was carefully examined and the young wireworms were counted.

The first set of samples was taken late in June to determine the approximate number of new-brood wireworms hatched in the plots, while the second set was taken early in September as an indication of the number that survived the summer. No attempt was made to separate the larvae of the two species, and only the total new brood was considered. The results of the two seasons' work are summarized in table 10.

TABLE 10.—*Production and survival of new-brood wireworms per square foot of plot in various crops, 1940–41*

Crop	New brood in—		Surviving in September
	June	September	
	Number	*Number*	*Percent*
Wheat	2.8	2.0	71.4
Alfalfa	3.1	.9	29.0
Potato	9.6	2.7	28.1
Sugar beet	5.2	1.4	26.9
Corn	8.0	1.9	23.8
Average	5.7	1.8	35.8

In June, shortly after hatching, the larger new-brood populations were found in the potato and corn plots and the smaller ones in the wheat and alfalfa plots. In September the largest populations were still found in the potato plots, the next smaller were in the wheat and corn, and the smallest populations were in the alfalfa plots. Although the fall populations were rather widely divergent, there was little difference in the percentage survival on all except wheat. Wheat had the lowest spring population level of new brood but by far the highest percentage survival, and in the fall it ranked second only to potato in population.

Initial new-brood populations in alfalfa and sugar beet were comparable to those in wheat, but the summer mortality was much higher and the residual fall population smaller.

These figures on new-brood mortality and survival help to explain the relatively high population levels of wireworms often found in potato and wheat and the low levels in sugar beet and alfalfa.

Production of Adult Wireworms in the Various Crops

It was shown earlier in this bulletin that there were large differences in the numbers of wireworms present in the various rotations and crop sequences. A large population produced more adults than a small one; so in order to make valid comparisons the figures for total adults were treated to render them independent of the size of the total population. This was done by computing the ratios of the adults produced in one year to the larvae present in the same plot the preceding year. These ratios were expressed as percentages of the larvae present in any one year that transformed to adults in the following year.

The number of adults taken in the samples was rather small, so that to form a stable average it was necessary to combine many samples for the various crops and to compute the percentage of larvae that transformed for each crop and year. A total of 1,220 adults of *canus* and 553 of *californicus* was taken from 1939 to 1946. The numbers of *californicus* were so small in many plots that no significant differences could be found between crops or years. Sufficient numbers of *canus* were present to show significant differences between crops. The percentages of larvae transforming to adults under the various crops are shown in table 11.

Outstanding numbers of *canus* adults were produced in potato plots, while few were produced in second- and third-year alfalfa. In fourth-year alfalfa there were indications of an increase, probably resulting from the maturity of a brood of wireworms in alfalfa about 4 years after the truck crops.

The data for *californicus* are not shown but indicate that in plots of corn, potato, wheat-sweetclover, and sugar beet the percentage of adults was high, while in those of alfalfa and sweetclover it was low. As stated earlier, the differences were not significant.

TABLE 11.—*Percentage of larvae of* Limonius canus *that transformed to adults under the crop indicated, 1939–46*

Crop	Total adults found	Larvae transforming to adults
	Number	*Percent*
Potato	502	47.1
Wheat	157	25.9
Corn	237	24.8
Wheat-sweetclover	51	22.9
Sugar beet	125	19.6
Alfalfa, fourth year	23	18.4
Wheat-alfalfa	53	14.6
Sweetclover	22	9.0
Alfalfa, second year	38	8.5
Alfalfa, third year	12	3.3
LSD—5% level		17.9
1% level		23.8

There was also some indication that certain years were more favorable for adult production than others. Such years were 1940, 1941, 1945, and 1946. Probably the higher percentage of adults found in those years resulted from a brood that developed when a large number of eggs was laid in some one previous season.

Wireworm Injury to Potato Tubers

Each year 22 of the rotation plots contained potato, and a sample of the tubers was examined for wireworm injury at harvesttime. Each year from 1939 to 1944, a sack of 75 to 100 pounds of potatoes was examined from each plot yielding that amount or more, and the entire crop was examined where the yield was less than a sack. In 1945 two samples were taken in each plot, each sample consisting of all the tubers growing in 10 feet of the center row of each plot. Where the variation between the samples from the same plot seemed excessive, a second pair of 10-foot samples was taken. Where yields were low, more tubers were taken along the same row until at least 10 pounds were available for each sample.

The tubers were examined individually and classified as to whether or not they were injured by wireworms. The total weight and the percentage of tubers in each class were then obtained.

The results of the 1945 sampling were analyzed statistically, and it was found that, with two samples totaling from 10 to 25 pounds, variations in injury of about 19 percent were significant at the 5-percent level and of 26 percent at the 1-percent level. In the earlier seasons, much larger samples were taken, and the error was probably considerably smaller. The tuber injury varied greatly from year to year and was not entirely correlated with the wireworm populations present, as shown in table 12.

TABLE 12.—*Populations of* Limonius *larvae per square foot in rotation plots preceding potato and total injury to potato tubers, 1939–45*

Year	Larvae in preceding spring	Injury to tubers by weight
	Number	*Percent*
1939	4.2	55.3
1940	4.5	50.1
1941	3.3	35.3
1942	2.5	34.4
1943	1.8	22.0
1944	1.5	41.5
1945	.8	55.1
Average	2.66	41.96

The first 5 years of the study fall in line fairly well, when the relation of wireworm injury to the wireworms present in the spring is considered, but the last 2 are entirely out of line. This fact may result partially from the use of spring populations as a measure of the wireworms present. It is entirely possible for wireworm larvae to develop sufficiently from eggs laid in the spring to cause injury to potato in the same year, and this could have happened in 1944 and 1945. It is also possible for the weather during the summer to affect wireworm damage by holding the larvae in the potato hills or by forcing them out and down. Whatever the cause, 1944 and 1945 were years of outstanding injury to potatoes on these plots.

Wireworm injury varied greatly among the rotations. The average wireworm populations and the injury to the potato tubers in the various rotations are given in table 13.

There is no apparent relationship between wireworm populations and wireworm injury in the individual rotations. Considering only the rotation averages, there were somewhat fewer wireworms in the longer rotations, particularly those containing alfalfa, and the injury was definitely less.

TABLE 13.—*Wireworm populations and injury to potato tubers in 22 rotations containing this crop, 1939–45*

Rotation and truck-crop sequence	Wireworms per square foot	Tubers injured
	Number	*Percent*
7-year rotations (4 of alfalfa):		
Potato-sugar beet-corn	0. 9	23. 6
Potato-corn-sugar beet	1. 0	21. 5
Corn-sugar beet-potato	1. 3	37. 6
Sugar beet-corn-potato	2. 5	47. 6
Corn-potato-sugar beet	2. 9	43. 6
Sugar beet-potato-corn	2. 8	43. 0
Average	1. 9	36. 2
5-year rotations (3 of alfalfa):		
Potato-corn	1. 2	29. 1
Corn-potato	2. 3	45. 7
Average	1. 8	37. 4
4-year rotations (2 of sweetclover):		
Potato-sugar beet	1. 7	38. 9
Sugar beet-potato	2. 0	34. 2
Potato-corn	3. 7	35. 0
Corn-potato	4. 9	43. 5
Average	3. 1	37. 9
2-year rotations:		
Sugar beet-potato	1. 0	40. 9
Corn-potato	1. 4	41. 9
Wheat-potato	1. 8	52. 2
Corn-potato (manured)	2. 2	48. 1
Sugar beet-potato (manured)	2. 5	52. 7
Corn-potato (alfalfa hay)	2. 7	49. 8
Wheat-sweetclover-potato	4. 0	46. 2
Wheat-potato (manured)	4. 0	54. 4
Average	2. 5	48. 3
Unrotated potato:		
Not manured	4. 6	41. 2
Manured	6. 8	52. 3
Average	5. 7	46. 8
LSD—5% level	----------	14. 2
1% level	----------	18. 8

The smallest wireworm population and by far the smallest amount of injury to potato in the 7-year rotations occurred when this crop immediately followed alfalfa. When 1 or 2 years of other truck crops intervened, wireworm populations were larger and injury to potato tubers was considerably more.

A further grouping was made according to the crop planted the previous year, and the results are shown in table 14. Again, the wireworm population was smallest and resulting injury to the tubers was least when potato followed alfalfa. The most injury was found when potato followed wheat, whereas the largest populations of wireworms were in continuous potato plots. Apparently, wheat left the plots in a more favorable condition for egglaying adults.

TABLE 14.—*Wireworm populations and injury to potato tubers following various crops in rotation series, 1936–45*

Potato following	Plots	Wireworms per square foot	Tubers injured
	Number	*Number*	*Percent*
Wheat	2	2.9	53.3
Potato	2	5.7	46.8
Corn	7	2.6	45.7
Sweetclover	3	3.1	40.0
Sugar beet	5	1.9	41.6
Alfalfa	3	1.0	24.7

Although there does not appear to be any consistent relation between wireworm population and potato injury shown by these data, a grouping of the basic data according to the magnitude of the population, when plotted against wireworm injury on a logarithmic scale, gives a straight line with a rather gentle slope (fig. 4). An equation was fitted to these data by the use of least squares, which indicated that a

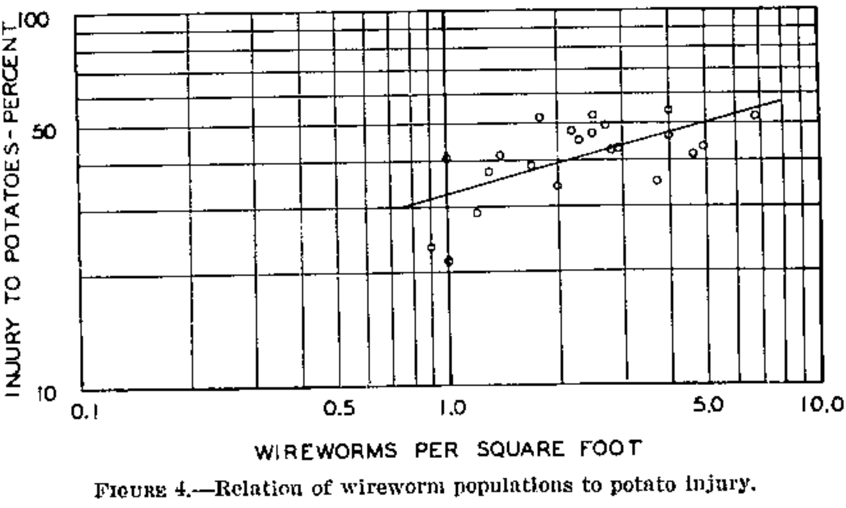

FIGURE 4.—Relation of wireworm populations to potato injury.

population of 1 wireworm per square foot would cause about 38 percent injury to potato tubers, while 10 worms per square foot would increase the injury to only about 50 percent. One worm to 2 square feet is capable of causing about 36 percent injury, showing the potentiality for injury of very small wireworm populations.

This information correlates well with the point brought out by Gibson (*1*), that with small populations the injury to potato tubers increases rapidly with relatively small increases in wireworm numbers and tends to level off as the population increases.

Summary

A study of wireworm populations in a series of crop rotation plots was conducted at the Washington Irrigation Experiment Station, Prosser, Wash., from 1936 through 1946.

Wireworm populations in the plots were estimated in March by sifting the soil and counting the larvae from either 1-square-foot (1936–38) or ¼-square-foot samples (1939–46) taken to a depth of 2 feet. These populations consisted almost entirely of the Pacific Coast wireworm (*Limonius canus* Lec.) and the sugar-beet wireworm (*L. californicus* Mann.).

There were six 7-year, two 5-year, four 4-year, and five 2-year rotations, as well as five crops that were grown continuously. These rotations consisted of 4 years of alfalfa followed by row crops of corn, sugar beet, and potato; 3 years of alfalfa followed by corn and potato or potato and corn; 2 years of sweetclover followed by 2 years of row crops; 2-year rotations of wheat, corn, sugar beet, or potato; and continuous crops of alfalfa, wheat, corn, sugar beet, and potato.

Wireworm numbers were largest in the continuous plots of wheat and potato and moderate to small in the plots of corn, alfalfa, and sugar beet. In the 2-year rotations, populations were largest in the wheat-potato plots, smallest in the sugar beet-corn plots, and intermediate in all the others. In the 4-year rotations, which included 2 years of sweetclover and 2 of truck crops, fairly high population levels were maintained. The lowest levels were in the 7-year rotations, which included 4 years of alfalfa.

Potato apparently favored the production and survival of *canus* but had the opposite effect on *californicus*. Alfalfa tended to reduce populations of both species, particularly *canus*, below the levels generally found in truck crops. Thus, the combination of 4 years of alfalfa, which reduced *canus*, and 3 years of row crops, which reduced *californicus*, resulted in the smallest total population in the entire series.

Rotations containing 4 years of alfalfa proved desirable. The most favorable position for potato in such a rotation was immediately following the alfalfa. Wireworm injury to potato tubers was greater when they followed other truck or row crops rather than alfalfa, even though populations were about equivalent. Short rotations and unrotated crops were undesirable, since large populations usually built up in them resulting in heavy damage to susceptible crops.

Adult production, particularly of *canus*, was large under potato plantings but appeared to be suppressed by both sweetclover and alfalfa. Production and survival of new-brood larvae seemed best in plots of wheat and potato. As a result, large populations were generally found in these crops.

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