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Controlling Perennial Weeds With Tillage

by

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The use of tillage for the control of perennial weeds is an old and well established practice. Previous to 1937 all perennial weed control by tillage in the Pacific Northwest used the standard recommendation of "black fallow" which involved tillage at least once a week to prevent any top growth of the weeds. Such a program, while effective, was extremely expensive; and this limited its use. Previous to 1935 a few experiments had been reported in the literature which indicated that delayed tillage, that is lengthening the intervals between tillage operations, might be a satisfactory means of eradication (1, 4)[2]. These experiments indicated a need for more widespread and thorough testing of delayed tillage to establish principles upon which an economical tillage program might be based.

In 1935 and 1936, experimental stations were established near Genesee, Idaho; Hays, Kansas; York, Nebraska; and Lamberton, Minnesota, to be operated jointly by the Bureau of Plant Industry, United States Department of Agriculture, and the respective state experiment stations to study the control of bindweed and other perennial weeds. A study of tillage methods was a major project at these stations. A preliminary report of the work at all of the stations was issued in 1939 (6) and a further preliminary report on the work at the Hays, Kansas, station was issued in 1941 (5). Preliminary recommendations for tillage control based on the results at Genesee, Idaho, were published in 1944 (2, 3). The complete results of the tillage trials at the Genesee station are reported in this bulletin. The work on bindweed which was the most comprehensive is discussed in Part I. More limited research on Canada thistle, white top, and Russian knapweed is reported in Part II. The studies of the several weeds are correlated and discussed in relation to a general tillage program in Part III.

[1] Agronomist, Idaho Agricultural Experiment Station and Agent U. S. Department of Agriculture.

[2] Numbers in parenthesis refer to "Selected References".

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General Description of the Area and Conditions

The research work was conducted in the Palouse along the Idaho and Washington border. This area is characterized by rolling hills with relatively gentle south and southwest slopes and relatively steep north and northeast slopes. The hills have a rather typical dune shape indicating the action of wind in their original formation. The soils are typically deep and fertile silt loams. The most common soil type is Palouse silt loam. The type of farming varies from one part of the region to another largely as a result of differences in precipitation. The western edge of the Palouse area which has an elevation of about 1700 feet and an average rainfall of slightly over 15 inches typically raises winter wheat in a fallow-wheat rotation. The eastern portion with an elevation of about 2500 feet and a rainfall of about 22 inches produces more diversified crops, but the most common rotation is field peas and winter wheat with occasional crops of barley, oats, sweet clover, and alfalfa. Fallow is occasionally included in the area, primarily for weed control purposes. A large portion of the Palouse area never produces cultivated crops. This complicates the weed problem.

The Palouse area is further characterized by a semi-continental type climate in which a large portion of the precipitation occurs during the winter months either as rain or snow. Summers are typically dry and mild with a relatively low humidity and maximum temperatures seldom exceeding 95 degrees Fahrenheit. The average growing season at Moscow, the nearest comparable weather station to the experimental area, has been 151 days. Weather conditions vary widely from year to year and during the period of the tests most of the extremes were encountered. During the 14-year period, the frost-free seasons varied from 67 to 201 days, the annual precipitation from 16 to 36 inches, the annual maximum temperature from 91 to 102 degrees, and the annual minimum temperature from 11 above zero to 30 degrees below. However, over the entire period, the average approached the long time norm as shown in Table 1.

Table 1. The annual precipitation and temperature at Moscow for the period 1936 to 1949[1]

Crop Year	Precipitation in Inches Annual	Precipitation in Inches May-Oct.	Mean Temperature Annual	Mean Temperature May-Oct.
1936-37	21.39	6.63	45.4	58.7
1937-38	19.91	5.29	49.2	61.8
1938-39	16.64	3.58	49.3	60.2
1939-40	19.09	11.26	50.3	61.4
1940-41	30.03	12.62	49.9	58.4
1941-42	19.94	6.94	46.6	58.3
1942-43	23.41	8.46	45.7	56.8
1943-44	16.12	5.07	46.8	59.5
1944-45	17.78	9.24	46.9	58.8
1945-46	23.57	7.34	47.6	58.2
1946-47	20.36	10.48	48.7	60.1
1947-48	36.47	12.99	46.2	59.1
1948-49	20.74	5.51	45.9	59.7
Average	21.96	8.11	47.6	59.3
50 year normal	21.75	7.39	47.2	58.6

[1] The crop year is taken from September 1 to August 31.

PART I

Bindweed

(Convolvulus arvensis L.)

Bindweed is one of the most widely distributed and destructive perennial weeds of the Pacific Northwest. It is particularly adapted to the non-irrigated wheat areas which receive from 15 to 25 inches of rainfall annually. The weed also occurs under lower and higher rainfall conditions and under irrigation. In many of these situations the areas involved are too large for the economical use of most chemicals, and tillage is one of the most promising methods of economical control.

The problem relative to tillage practices generally involves four questions: (1) when to begin cultivation, (2) how frequently to cultivate, (3) how deep to cultivate, and (4) how late into the fall cultivation should be continued. The research program on tillage started in 1936 was designed to answer these four questions. Separate experiments were conducted on each of these phases of the problem and each will be reported separately. The area used in these experiments was an 80 acre field located between Genesee, Idaho and Uniontown, Washington. The experimental area had a fairly uniform slope of about 10 percent to the south and west. The soil was Palouse silt loam, varying in depth from a minimum of 7 feet to a maximum of over 20 feet. Investigation indicated that the field had been uniformly infested with bindweed for more than 20 years when the experiments were started, and that some bindweed had been on the area for more than 30 years.

Time of Beginning Cultivations

ROOT RESERVE STUDIES

Materials and Methods. Root samples were taken from undisturbed bindweed at 2-week intervals throughout the growing season. These samples were analyzed for available carbohydrates to determine the weakest point in the life cycle of the weed when theoretically, cultivation should be most effective. The root samples from 5 square feet of soil were taken to a depth of 12 inches by screening and washing, the surface moisture was removed and the roots were then cut into approximately half-inch lengths and weighed. After the weighing they were placed in cheese cloth bags and dried with a forced draft of heated air until a constant weight was achieved at approximately 55°C. The roots were then stored and were later analyzed in the laboratory for reducing sugars, non-reducing sugars, starch and dextrins. All carbohydrates were expressed on a dry weight basis to eliminate the influence of the variability in dry matter content. For total available carbohydrates the total of these fractions converted to dextrose equivalents was used. Five samples were taken from each plot at each sampling date and these were handled individually until after the green weight of roots was determined. The samples from each plot were then composited for dry matter and carbohydrate determinations. These studies were started in 1937 and continued in 1938 and 1939. Root samples were also taken for the second foot depth at monthly intervals during 1938 to check on the validity of conclusions derived from the first foot samples.

Experimental Results. Considerable variability occurred in the date of first emergence and also the time at which recognizable growth stages in the bindweed were observed during the period from 1937 to 1939. For this reason, to obtain an average root reserve curve it was necessary to average the values at easily recognizable points in the life history of the bindweed and then average the dates at which these occurred. The average curve for the three seasons for total available carbohydrates is given in Figure 1. The data obtained from the second foot were the same as for the first foot with the exception that the changes in reserve levels were much smaller and hence only the first foot values are given. Figure 1 shows that there is a relatively steady drop in available carbohydrates for about a month after emergence in the spring. This corresponds to the early bud stage of growth which appears to be the weakest point in the life cycle of the bindweed. From this point reserves rose steadily for about 2 months until the first seeds were ripe and then dropped gradually for the balance of the season. On this basis it would appear that cultivation should be started about 1 month after first emergence in the spring, which, during the period from 1937 to 1939, averaged about June 1.

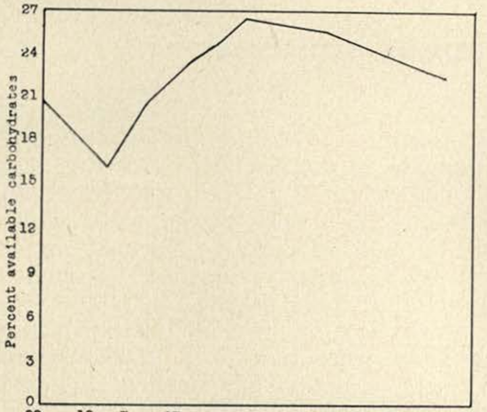

Figure 1. Trend of root reserves of undisturbed bindweed — 1 to 12 inch depth. Average for 1937-39.

EMPIRICAL TESTS

Materials and Methods. The best time to start cultivation for bindweed control in the field was determined on duplicate 1/20 acre plots on an area uniformly infested with bindweed. The plots which were to be started previous to August 1 were left undisturbed prior to starting, but those to be started after August 1 were cropped to winter wheat and the cultivation was started after harvest. The initial cultivations were made by plowing at a 6-inch depth; all subsequent cultivations were made at a depth of approximately 4 inches either with a duckfoot field cultivator or a rotary rod weeder equipped with a duckfoot shovel attachment at intervals of 8 days after emergence. When cultivations were delayed by rain and machinery breakdowns, cultivations were made as soon after the planned date as possible. These delays seldom exceeded 2 or 3 days. After the first season, cultivation was started 8 days after first emergence in the spring. Cultivation was continued each season until growth stopped in the fall, about November 1. A new series of plots was started each year that the experiment was conducted, but each series was continued until no further emergence occurred on any of the plots. By 1938 it was observed that border effects of as much as 15 feet occurred on the tillage plots and all plots started after 1938 were surrounded by strips 12 to 18 inches wide which were treated with sodium chlorate the fall before cultivation was started. This practically eliminated border effects. Seven dates of beginning cultivation were tested in 1937, 1938, and 1939 and three dates for the period 1940 to 1944. Data were taken on the number of days to emergence, the number of days between cultivations, the depth of cultivation, the type of implement used, the number of apparent "plants" per square yard, and the maximum length of vine growth of the plants at each cultivation.

Experimental Results. The data presented in Table 2 show that a delay of about 2 weeks after first emergence in the spring had some advantage over starting at first emergence, but the difference was only about two cultivations and 3 months which is not statistically significant. Waiting until June 1 had no advantage over starting at first emergence. Concerning the number of cultivations, the only significant difference was between beginning 2 weeks after emergence and beginning July 1. All dates after the start of the bindweed blooming required a significantly longer time for eradication than 2 weeks after emergence. From these data it appears that the best time to start cultivation is more closely associated with how it fits into the farm program than it is with root reserves. There appear to be three logical times to start cultivation as far as the availability of farm labor and machinery are concerned. These are; (1) after spring seeding is finished which is about 2 weeks after first emergence of the bindweed, (2) immediately after grain harvest, and (3) after fall seeding is completed, about November 1. Starting in 1940, only these three dates were tested to determine which might be the most desirable. Since two of these were included in the 1937 to 1939 experiments, comparisons of these two dates are available for the entire period of 1937 to 1944. The average data obtained for these three dates of beginning cultivation are given in Table 3. There was no significant difference in either the time or number of cultivations required for eradication among these three dates.

Table 2—The influence of seven dates of starting cultivation on the time and cultivations required to eradicate bindweed. Average of three experiments conducted from 1937 to 1939.

Time of beginning	Date Started	Date Eradicated	NUMBER OF Months	Cult.	Crops Lost
First emergence in the spring	4-28	11-7	30.3	31.0	3
May 1	5-3	9-27	28.8	30.3	3
Two weeks after emerg. in spring	5-8	8-17	27.3	29.2	3
June 1	6-1	12-6	30.5	31.3	3
At bloom	6-13	3-19	33.2	32.8	3
July 1	7-1	6-10	35.3	34.2	4
Immediately after grain harvest	8-6	8-7	37.0	30.8	3
LSD 5% level			5.3	4.4	

Table 3—The influence of three times of beginning cultivation on the eradication of bindweed.

	TIME OF BEGINNING Two weeks after spring emergence	Immediately after grain harvest	Late Fall	LSD 5% level
Average of four experiment 1940-43:				
Date started	5-2	8-17	10-25	
Date eradicated	2-18	3-4	10-7	
Number of crops lost	4	3	4	
Number of months for eradication	45.6	42.6	47.4	9.9
Number of cult. for eradication	39.5	41.2	39.4	8.6
Average for eight experiments 1937-44:				
Date started	5-5	8-11	....	
Date eradicated	7-23	2-4	....	
Number of crops lost	4	3	....	
Number of months for eradication	38.6	41.8	....	5.5
Number of cult. for eradication	34.9	34.8		6.1

DISCUSSION AND CONCLUSIONS

The data obtained from the field tests indicate that the study of root reserve trends is not an entirely satisfactory method of determining the correct time to start a tillage program on bindweed under non-irrigated conditions. This is probably due to two factors: (1) soil moisture exhaustion by delayed tillage and (2) the relative unimportance of the effect of delaying tillage on one cultivation where the total number of cultivations are as great as in the present study. A rapid rate of growth is desirable for fast food exhaustion, and, if soil moisture is depleted by delaying the initial tillage operation to the point that the growth rate is reduced for the following cultivations, a net loss in effectiveness might result. This apparently occurred when the initial tillage operation was delayed until the blooming period. The percentage available carbohydrates was reduced from approximately 21 percent to 16 percent which represents a loss of almost one-fourth of the total reserves in the first foot of soil. However, the reserves in the first foot of soil represents only a small portion of the total reserves available to the plant and hence this could not be expected to have a major influence on the number of cultivations required to starve the entire root system.

There is no appreciable difference in either the length of time or the number of cultivations required to eradicate bindweed with the dates tested. This indicates that the practical considerations of the most convenient time to start and the time of year a which final eradication occurs should determine the recommendation. The three dates tested during the period of 1940 to 1944 are all generally acceptable from the standpoint of convenience to the farm operator. The only major difference in these three times is the average date of eradication and the number of crops lost during the cultivation period. From this standpoint starting immediately after grain harvest has a distinct advantage. In these studies eradication was obtained much sooner and only three crops were lost when cultivation was started immediately after grain harvest while four crops were lost with the other two dates. Starting in late fall has a slight advantage over starting the following spring since eradication will be completed sooner, although in these studies the only difference was in being able to seed a fall crop if cultivation was started in late fall and having to delay for a spring crop if cultivation was not started until spring. Consequently it is concluded that cultivation should be started as soon after harvest as possible.

Frequency of Cultivation

ROOT RESERVE STUDIES

Materials and Methods. Two methods of attack were used in determining the effect of frequency of cultivation on root reserves. In the first method, a plot of bindweed was cultivated to a depth of 4 inches, and root samples were taken at 4-day intervals until the bindweed apparently had recovered from the cultivation. The method described for root sampling of undisturbed bindweed was used except that the depth of sampling was for the 1-foot depth below the depth of cultivation, i.e., the 5-inch to 16-inch depth. The root samples were taken from plots cultivated at three different times during the season, (1) emergence in the spring, (2) about July 15, and (3) about August 15. The plots in which sampling was begun in July or August had been cultivated at intervals of from 8 to 12 days after first emergence of the bindweed during the period preceding the sampling, in order to conserve moisture. This cultivation not only conserved moisture but reduced reserves in direct proportion to the amount of cultivation. While the lower reserve level in the later sampling dates reduced the magnitude of the changes in carbohydrates, this would be comparable to what would occur in a cultivation program, and was probably not sufficient to change the point at which the lowest level of reserves was obtained. These studies were conducted in each of the 3 years from 1937 to 1939.

In the second method the frequency of cultivation plots were root-sampled at the end of each cultivation season in the 1937, 1938, and 1939 experiments in an attempt to determine whether the same frequency of cultivation should be used in each season of cultivation. The root sampling was the same as was used in the first method except that the plots were only sampled at the end of the season. It was not possible to have the bindweed from all of the frequencies of cultivation at the same stage of growth at the time of sampling without interfering with the empirical tests. Consequently the wider frequencies of cultivation were not sampled necessarily at points in their reserve curves comparable to those from the narrower frequencies which were sampled between cultivation and emergence.

Experimental Results. The analysis of the trend of root reserves after cultivation showed striking differences, and, considering the differences in the time required to obtain a given growth stage, the curves were relatively constant from year to year. There were major differences among the three sampling periods in each year. As a consequence, the individual curves obtained for 1 year, 1938, are given. These are shown in Figure 2. The trend of root reserves after a cultivation made at first emergence in the spring was irregularly downward for 35 days after first emergence and then was steadily upward for the balance of the sampling period. This corresponds closely with the curve on undisturbed bindweed run at the same time. When the cultivation was made July 15 the reserve trend was sharply downward from about 4 days after first emergence until the low point was reached at 12 days after first emergence. After this low point, reserves increased rapidly for the balance of the sampling period.

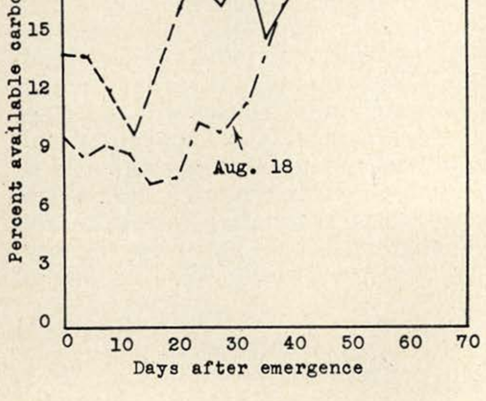

Figure 2. Trend of available carbohydrates in the roots of bindweed after 4-inch cultivations made at three dates in 1938. Root samples taken from the 5 to 16 inch depth in the soil.

When the cultivation was made August 15 the reserve trend was irregularly downward until 15 days after first emergence, then rose for 8 days, dropped slightly for 4 days, and then rose rapidly for the balance of the sampling period. These curves indicate that the best frequency of cultivation should be about 35 days after first emergence in the spring, 12 days after first emergence in mid-summer, and about 17 days after emergence in early fall.

The effects of the various frequencies of cultivation on root reserves at the end of the season are given in Figure 3. The 12 days after emergence frequency was the most effective in reducing carbohydrate reserves the first season of cultivation, and also the most effective at the end of the second season, although the differences were much less. At the end of the third season the 4 days after emergence frequency had the lowest level of available carbohydrates. It should be mentioned that the values for the narrower frequencies at the end of the third season are subject to considerable error due to the small amount of live roots in the soil at that time. In one experiment no live roots were

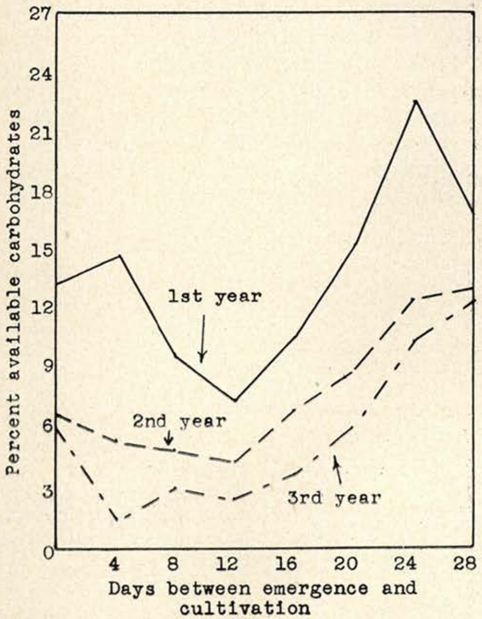

Figure 3. The influence of several frequencies of cultivation on the carbohydrate content of bindweed roots as measured at the end of each cultivation season. Roots taken from the 5 to 16 inch depth of soil. Average of three experiments, 1937-39.

found in four of the frequency plots. The data presented indicate that the frequency of cultivation should be 12 days after emergence the first year and that the frequency in days after emergence should be slightly narrower as cultivation proceeds.

EMPIRICAL TESTS

Materials and Methods. The best frequency of cultivation for bindweed control in the field was determined on duplicate 1/20 acre plots on an area uniformly infested with bindweed. The method described for the field tests of the best time to start cultivation was used in this experiment, except that all plots received their initial tillage at first emergence or 2 weeks after first emergence in the spring. The first experiment was started in 1937 using frequencies of cultivation at emergence and 4, 8, 12, and 16 days after emergence. During 1938 and 1939, 20, 24, and 28 days after emergence frequencies were also included. By 1940 it was obvious that the emergence, 20, 24, and 28 days after emergence frequencies were impractical and they were discontinued. The 4, 8, and 16 days after emergence frequencies were discontinued in 1941, but the 12 days after emergence frequency was continued until 1944 as a check for new frequencies under test. In 1940 three new frequencies of cultivation (14 days between cultivation, 21 days between cultivation, 14 days between cultivation the first year and 21 days for the balance of the cultivation time) were started. These frequencies were continued until 1944.

The study of the trend of root reserves after cultivation had indicated that the lowest point approximated the point at which 80 percent of the bindweed "plants" had emerged. From the data obtained in previous years, curves were derived which, assuming normal weather, would give the approximate period of time required for 80 percent emergence at any time during the season. These curves were used in determining when to cultivate in three frequency of cultivation experiments started in 1942, 1943, and 1944. Since the curve assumed normal weather, two fre-

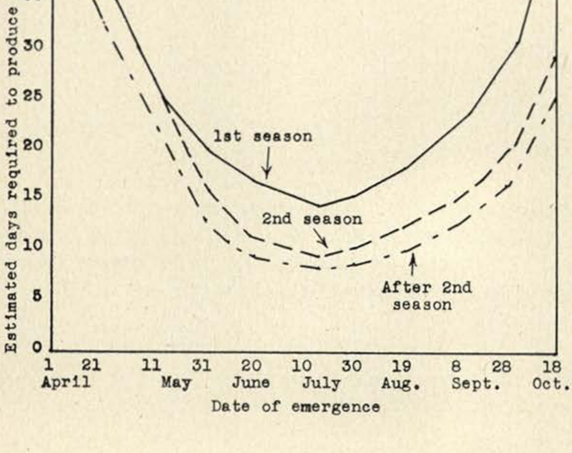

Figure 4. Curves used in determining when to cultivate theoretical frequency of cultivation plots.

quencies in addition to the theoretical frequency also were tested. These were 4 days narrower than the theoretical and 4 days wider than the theoretical which were assumed to allow for probable abnormal weather conditions and to serve as a check against possible errors in deriving the curves. The curves used in determining these frequencies are given in Figure 4.

Experimental Results. The data on the number of cultivations and the average density of the bindweed stand at each cultivation for the first five seasons of cultivation of each experiment are given in table 4. The data for the total number of cultivations required by each frequency in each experiment are summarized in Table 5 and the length of time required for eradication in Table 6. Since the days to emergence also is a variable in any experiment based on a certain number of days to emergence, Table 7 gives the average values for each of the first 3 seasons of cultivation for the 1938 and 1939 experiments both for days to emergence and the amount of growth produced between cultivations.

Table 4. The number of cultivations per year and the average density of the stand of bindweed at each cultivation for each frequency of cultivation experiment started from 1937 to 1944. Average of duplicate plots.

Cultivation interval	Number of cultivations					Ave. No. of plants per sq. yd. at each cult.				
	First year	Second year	Third year	Fourth year	Fifth year	First year	Second year	Third year	Fourth year	Fifth year
Experiment started in 1937:										
At emergence	24.5	30.0	25.5	7.5	0	......	1.3	0.1	0.1	0
4 days after emergence	15.0	17.0	13.0	2.5	0	......	8.4	1.3	0.02	0
8 days after emergence	12.0	13.0	11.5	0.5	0	......	15.4	1.8	0.02	0
12 days after emergence	9.0	9.5	9.0	0	0	......	23.9	1.6	0	0
16 days after emergence	8.0	8.0	8.5	1.5	0	......	31.8	5.0	0.04	0
Experiment started in 1938:										
At emergence	31.0	32.5	19.5	5.0	5.5	0.9	0.1	0.01	0.40	0.05
4 days after emergence	17.0	18.0	11.0	4.5	0.5	13.2	6.4	2.5	0.5	0.10
8 days after emergence	12.5	12.5	6.0	3.0	0	22.5	8.9	1.6	0.4	0
12 days after emergence	10.0	9.5	4.0	0	0	28.9	7.6	0.8	0	0
16 days after emergence	8.5	8.0	7.0	3.5	0	31.2	15.2	2.9	0.3	0
20 days after emergence	8.0	7.0	7.0	5.0	5.5[1]	23.3	17.5	4.2	2.3	1.0[1]
24 days after emergence	6.5	6.0	6.0	5.0	5.0[1]	33.9	23.1	10.6	6.3	2.4[1]
28 days after emergence	6.0	6.0	5.0	4.5	5.0[1]	30.6	22.7	11.8	9.4	3.6[1]
Experiment started in 1939:										
At emergence	32.0	19.0	6.5	0	0	0.1	0.5	0.1	0	0
4 days after emergence	16.5	13.5	6.5	3.0	0	9.8	4.0	0.7	0.05	0
8 days after emergence	13.0	12.0	8.0	2.5	0	13.9	7.1	2.2	0.03	0
12 days after emergence	10.0	9.5	7.5	0	0	19.9	10.0	2.8	0	0
16 days after emergence	8.0	7.5	6.0	3.5	2.5	18.4	9.4	4.1	0.6	0.01
20 days after emergence	6.5	6.5	5.5	6.0	5.5[1]	22.8	10.6	10.4	4.2	0.2[1]
24 days after emergence	6.0	6.0	5.0	5.0	5.0[1]	22.1	14.7	7.6	4.7	1.7[1]
28 days after emergence	5.0	5.0	4.0	5.0	5.0[1]	32.0	17.1	9.7	6.7	3.2[1]
Experiment started in 1940:										
4 days after emergence	12.0	9.0	6.0	3.0	0	8.4	5.0	0.6	0.01	0
8 days after emergence	9.5	8.0	5.0	3.5	0	9.0	4.2	1.2	0.05	0
12 days after emergence	8.0	8.0	5.0	2.0	0	11.3	4.9	1.5	0.02	0
16 days after emergence	7.0	7.0	5.5	4.5	1.0	13.6	7.4	3.6	0.05	0.01
20 days after emergence	6.0	6.0	6.0	5.5	4.0[1]	16.9	13.2	4.7	0.2	0.02[1]
14 days between cult. each year	10.5	10.5	12.0	9.5	2.5	11.6	4.8	1.3	0.1	0.01
14 days between cult. the first year then 21	10.0	9.0	8.0	8.0	5.0	12.3	8.6	3.3	0.3	0.03
21 days between cultivations each year	8.0	9.0	8.0	7.5	4.0	13.9	8.0	3.5	0.9	0.04

[1] Eradication not complete at the end of the fifth year.

Table 4—continued

Cultivation interval	Number of cultivations: First year	Second year	Third year	Fourth year	Fifth year	Ave. No. of plants per sq. yd. at each cult.: First year	Second year	Third year	Fourth year	Fifth year
Experiment started in 1941:										
4 days after emergence	10.0	13.5	11.0	8.0	0	9.4	3.9	0.2	0.02	0
8 days after emergence	10.0	12.0	8.5	6.0	0	10.6	6.1	0.2	0.01	0
12 days after emergence	8.0	8.5	7.0	4.0	2.0	12.1	6.3	0.9	0.1	0.02
16 days after emergence	7.0	7.5	7.0	6.5	3.0[1]	13.3	13.7	6.0	2.2	0.5[1]
20 days after emergence	6.0	6.0	5.0	3.5	2.5[1]	12.1	11.3	4.9	0.6	0.3[1]
14 days between cult. each year	11.0	13.0	9.5	4.0	0	5.5	5.1	0.8	0.01	0
14 days between cult. first year then 21	11.0	8.0	6.5	5.5	2.5	6.3	8.0	1.4	0.04	0.01
21 days between cult. each year	9.0	8.0	6.5	4.0	0.5	10.6	7.3	0.9	0.03	0.01
Experiment started in 1942:										
12 days after emergence	9.0	7.5	7.0	2.5	0	14.3	1.6	0.2	0.02	0
4 days before "theoretical"	8.0	8.5	5.0	4.5	0	17.3	4.6	0.4	0.05	0
At "theoretical"	6.0	8.0	7.5	4.5	3.0[1]	20.0	11.8	4.5	0.5	0.03[1]
4 days after "theoretical"	5.0	6.0	6.0	3.0	2.0[1]	22.0	12.1	4.1	0.03	0.04[1]
14 days between cult. each year	13.0	11.0	7.5	2.5	0	8.1	2.5	0.2	0.01	0
14 days between cult. first year then 21	13.0	7.5	5.5	3.0	0	10.5	6.3	0.7	0.04	0
21 days between cult. each year	9.0	7.5	5.0	0	0	11.3	1.6	0.03	0	0
Experiment started in 1943:										
12 days after emergence	8.0	9.0	7.0	1.0	0	18.8	6.8	0.09	0.01	0
4 days before "theoretical"	7.0	9.5	9.5	5.5	2.5	21.2	6.7	1.2	0.09	0.01
At "theoretical"	6.0	8.0	7.5	5.0	3.5	19.1	8.4	1.8	0.6	0.02
4 days after "theoretical"	5.0	6.5	7.0	5.0	4.0	19.7	9.8	2.7	0.5	0.01
14 days between cult. each year	10.0	12.0	10.0	7.0	0	15.1	5.0	0.4	0.02	0
14 days between cult. first year then 21	10.0	9.0	7.0	3 5	1.5	15.1	10.2	0.9	0.01	0.01
21 days between cult. each year	7.0	9.0	7.5	6.0	3.0	24.9	11.2	2.4	0.4	0.03
Experiment started in 1944:										
12 days after emergence	8.5	9.0	6.0	6.0	0	16.9	7.9	1.6	0.3	0
4 days before "theoretical"	7.0	9.5	8.0	6.0	0	19.6	6.4	0.5	0.01	0
At "theoretical"	6.0	7.5	6.5	7.0	6.0	25.9	17.5	2.9	0.2	0.01
4 days after "theoretical"	5.0	7.0	5.5	5.0	0	25.9	11.8	0.4	0.04	0
14 days between cult. each year	11.0	11.0	8.5	7.5	3.0	11.1	11.2	3.0	0.04	0.01
14 days between cult. first year then 21	11.0	8.0	6.0	5.5	0	13.8	10.1	0.8	0.02	0
21 days between cultivation each year	8.0	8.0	6.0	6.0	0	16.3	9.0	1.3	0.1	0

[1] Eradication not complete at the end of the fifth year.

Table 5. The total number of cultivations required to eradicate bindweed with several frequencies of cultivation started from 1937 to 1944. Average of duplicate plots.

Cultivation interval	Cultivation started in: 1937	1938	1939	1940	1941	1942	1943	1944	Ave. Comparative Cult.[1]
At emergence	87.5	93.5	57.5	......	......	......	......	......	80.7
4 days after emergence	47.5	51.0	39.5	30.0	42.5	......	......	......	42.6
8 days after emergence	37.0	34.0	35.5	26.0	36.5	......	......	......	34.2
12 days after emergence	27.5	23.5	27.0	23.0	29.5	26.0	25.0	29.5	26.4
16 days after emergence	26.0	27.0	27.5	25.0	36.0	......	......	......	28.6
20 days after emergence	......	37.5	28.0	27.5	......	......	......	......	32.7
24 days after emergence	......	45.5	36.0	......	......	......	......	......	42.6
28 days after emergence	......	43.5	40.0	......	......	......	......	......	43.7
14 days between cult. each year	......	......	......	45.0	37.5	34.0	39.0	41.0	39.0
14 days between cult. first year then 21	......	......	......	40.0	33.5	29.0	31.0	30.5	32.6
21 days between cultivation each year	......	......	......	36.5	28.0	21.5	32.5	30.5	31.8
4 days before "theoretical" [2]	......	......	......	......	......	26.0	34.0	30.5	29.7
At "theoretical" [2]	......	......	......	......	......	31.5	30.0	33.0	31.0
4 days after "theoretical" [2]	......	......	......	......	......	24.0	27.5	22.5	24.3

[1] Average cultivations determined as a percentage of comparable data for the 12 day frequency and reconverted to cultivations by multiplying by the long time average for the 12 day frequency.

[2] "Theoretical" frequency approximates 80 per cent emergence of the bindweed.

Table 6. The length of time in months required to eradicate bindweed with several frequencies of cultivation started from 1937 to 1944. Average of duplicate plots.

Cultivation interval	Cultivation started in: 1937	1938	1939	1940	1941	1942	1943	1944	Ave. Comparative months[1]
At emergence	41.0	41.5	29.5	......	......	......	......	......	41.3
4 days after emergence	35.0	39.0	35.5	28.5	40.5	......	......	......	37.8
8 days after emergence	33.5	29.0	35.5	29.5	41.5	......	......	......	35.8
12 days after emergence	30.0	23.5	30.0	32.0	40.0	35.5	32.5	39.5	32.9
16 days after emergence	34.5	38.5	42.0	44.5	59.5	......	......	......	46.3
20 days after emergence	......	66.0	65.0	56.0	53.0	......	......	......	62.9
24 days after emergence	......	100.5	77.5	......	......	......	......	......	109.5
28 days after emergence	......	106.5	101.0	......	......	......	......	......	127.6
14 days between cult. each year	......	......	......	47.5	35.0	33.5	39.0	46.0	36.8
14 days between cult. first year then 21	......	......	......	52.5	47.0	34.5	44.0	39.5	39.9
21 days between cultivation each year	......	......	......	51.5	39.0	28.5	45.0	45.0	38.3
4 days before "theoretical" [2]	......	......	......	......	......	29.0	48.5	39.5	35.8
At "theoretical" [2]	......	......	......	......	......	45.5	44.5	51.5	43.3
4 days after "theoretical" [2]	......	......	......	......	......	46.0	50.5	39.5	41.6

[1] Average number of months determined as a percentage of comparable data for the 12 day frequency and reconverted to months by multiplying by the long time average for the 12 day frequency.

[2] "Theoretical" frequency approximates 80 per cent emergence of the bindweed.

Table 7. The influence of eight frequencies of cultivation upon the rapidity of growth of bindweed. Average of two experiments started in 1938 and 1939.

Days between emergence and cultivation	Av. days to emergence			Av. growth in inches [1]		
	First year	Second year	Third year	First year	Second year	Third year
0	5.8	8.6	24.0	0.1	0.4	1.6
4	6.8	8.7	15.4	2.5	2.6	2.9
8	7.4	7.8	9.5	4.0	4.6	5.1
12	7.8	9.2	12.0	6.0	6.2	6.8
16	6.4	8.8	14.4	8.2	9.8	9.2
20	6.6	8.8	9.9	9.0	11.6	12.2
24	7.2	7.3	12.7	10.2	14.5	14.0
28	8.6	8.2	8.2	12.2	15.9	17.9
Average	7.1	8.4	13.3	6.5	8.2	8.7

[1] Average maximum vine length when cultivated.

The full range of frequencies from emergence to 28 days after emergence was tested in 1938 and 1939, and the average results from these two experiments are shown graphically in Figure 5. These experiments showed that any frequency narrower than

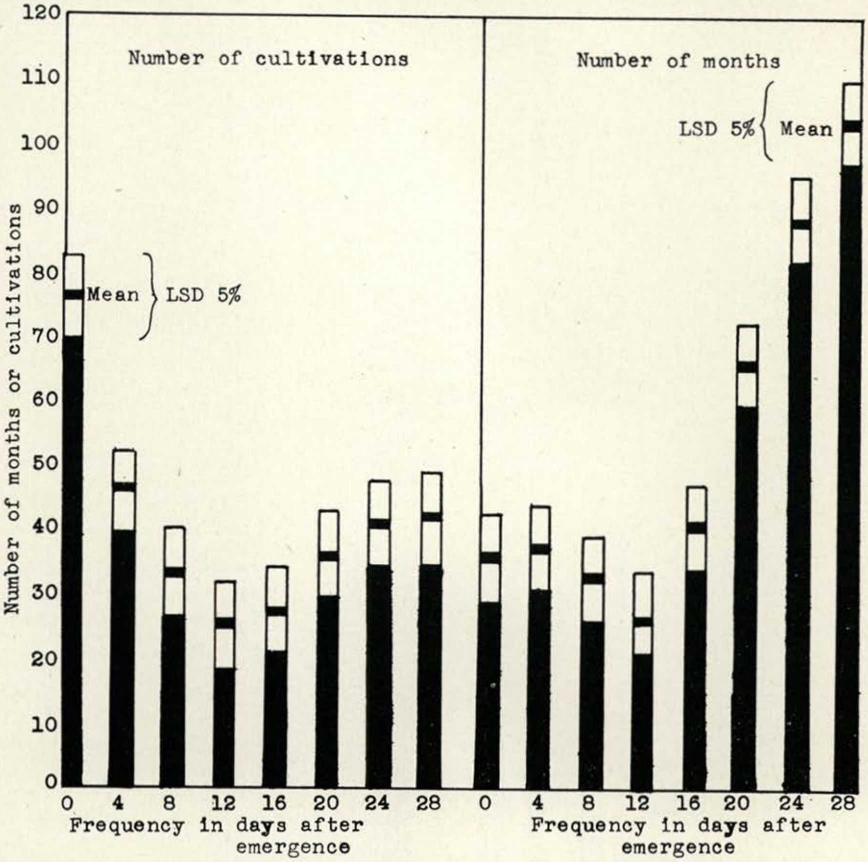

Figure 5. The influence of eight frequencies of cultivation on the time in months and the number of cultivations required to eradicate bindweed. Average of two experiments started in 1938 and 1939.

8 days after emergence or wider than 12 days after emergence required either more time or more cultivations for eradication than did the 12-day frequency. However, the difference in the number of cultivations between the 4-day and 8-day frequencies was not significant and the difference in time for eradication between the 12-day and 16-day frequencies was barely significant. Even when the data obtained in the 1937 experiment were included, as in Figure 6, these differences were either non-significant or barely significant. As a consequence the 4, 8, 12, and 16-day frequencies were continued for 2 more years to confirm the previous conclusion. The average data from the full five experiments are shown in Figure 7. On the basis of these tests it is evident that the 4-day interval required more cultivations than the 8, and the 8 required more time than the 12. It is also apparent that the 16-day frequency required more time than the 12. Hence it may be concluded that considering both the time and number of cultivations involved, 12 days after emergence is the most efficient frequency based on days after emergence that has been tested.

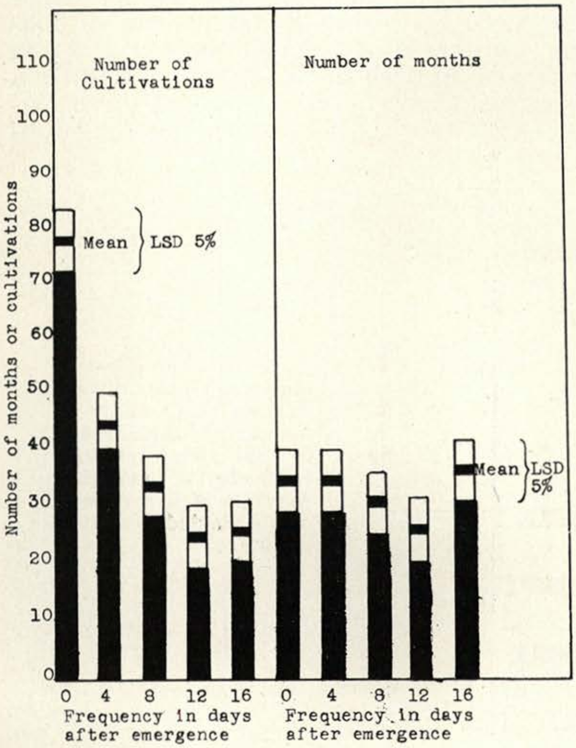

Figure 6. The effect of five frequencies of cultivation on the time in months and the number of cultivations required to eradicate bindweed. Average of three experiments started from 1937 to 1939.

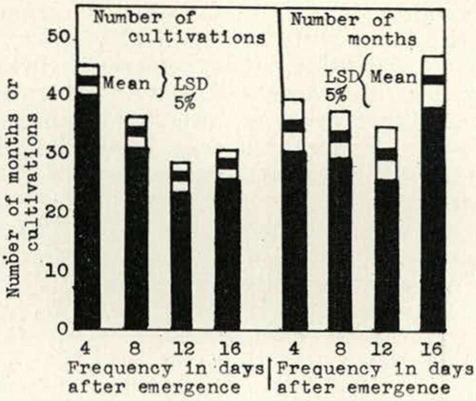

Figure 7. The effect of four frequencies of cultivation on the time in months and the number of cultivations required to eradicate bindweed. Average of five experiments started from 1937 to 1941.

A variable frequency of cultivation is more difficult to follow than a constant one. Hence two constant frequencies that might give results similar to the variable frequencies were started in 1940. These were: (1) cultivation every 14 days, which averaged about the same as 8 days after emergence; and (2) every 21 days, which averaged about the same as 12 days after emergence. A third frequency of every 14 days the first year and every 21 days thereafter also was included to provide for handling the large growth produced between wide frequencies in midsummer of the first year while bindweed stands were still dense. The data from these tests as compared to those from the 12 days after emergence frequency are shown in Figure 8. All three regular frequencies required significantly more cultivations for eradi-

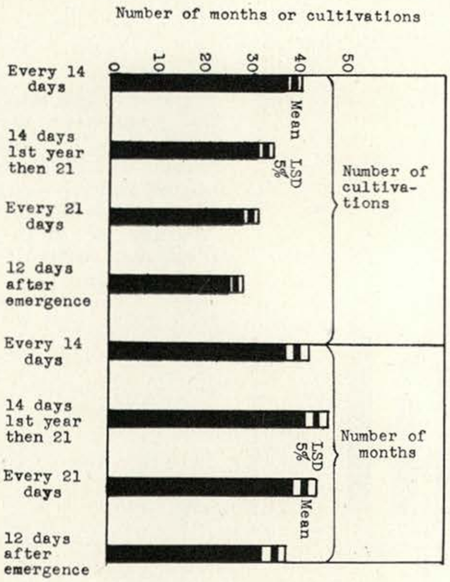

Figure 8. The effect of four frequencies of cultivation on the time in months and the number of cultivations required to eradicate bindweed. Average of five experiments started from 1940 to 1944.

cation than did the frequency of 12 days after emergence, and all except the 14-day interval required a significantly longer time to complete eradication. Even the difference in time between the 14 days between cultivations and the 12 days after emergence frequencies was nearly significant. It seems apparent from these data that 12 days after emergence is a better frequency of cultivation than any of the constant frequencies tested. Every 21 days was significantly better than the other set frequencies and would be the logical choice where a set frequency was desired.

The data obtained from the theoretical frequencies based on the 80 percent emergence curves are given in Table 8. The widest frequency tested, 4 days after the theoretical date of cultivation, required the least cultivation, however, this was not significantly fewer than the 12 days after emergence frequency. Both the theoretical and 4 days wider than the theoretical frequencies required a significantly longer time for eradication than did 12 days after emergence. The four days narrower than the theoretical frequency was not significantly different from the 12 days after emergence in either time or number of months required for eradication. The data suggests that during the period from 1942 to 1949 none of the theoretical frequencies were superior to 12 days after emergence.

Table 8. The influence of three intervals of cultivation based on root reserve curves on the eradication of bindweed. Average of three experiments started from 1942 to 1944.

Cultivation interval	Av. Days to emergence			Av. Days between cultivations			Av. growth in inches [1]			No. required for eradication	
	First year	Second year	Third year	First year	Second year	Third year	First year	Second year	Third year	Cult.	months
4 days before "theoretical"	7.4	8.2	10.3	21.9	17.2	16.4	9.6	7.0	5.1	30.2	39.0
At "theoretical"	7.6	8.4	10.5	25.7	20.8	20.4	12.3	8.9	8.2	31.5	47.2
4 days after "theoretical"	7.0	8.5	10.7	28.2	24.6	24.4	14.3	10.8	9.2	24.7	45.3
Check - 12 days after emergence	7.5	8.6	12.4	20.1	20.9	24.2	7.9	7.6	7.4	26.8	35.8
LSD 5% level										5.6	9.2

1 Average maximum vine length when cultivated.

It is apparent that studying the trend of root reserves after cultivation gives an excellent measure of the best frequency of cultivation provided the trend is determined during the critical period of the season. Bindweed is a relatively warm weather plant and, in the Palouse area, makes its most rapid growth during July and August. Growth is much slower in the spring months and somewhat slower in the fall than during mid-summer. As a consequence, a frequency determined from a reserve trend in the spring would be too wide in mid-summer and one determined in mid-summer would be too narrow in the spring and fall. However, all of the trend curves indicate that the rise in reserves after the low point is reached is much more rapid than the drop preceding the low point and hence a frequency too narrow is preferable to one too wide. This is particularly true in late July since the reserve curves indicate that a frequency 5 days too wide at this time of year may permit complete recovery from the last cultivation. As a consequence, the trend of reserves after cultivation during July determines the most effective frequency of cultivation. This curve shows that a frequency of 12 days after first emergence should be the most effective. This is the same frequency that was found to be the most effective in the empirical tests. The root samples taken at the end of the first season of cultivation also produced the same result.

It would appear from the root reserve data that the best frequency of cultivation should be wide in the spring, narrow in the summer, and again widen in the fall with the second season being narrower than the first and the third season narrower than the second. A constant frequency of cultivation fulfills the second requirement since emergence slows down and the frequency as measured by days after emergence narrows as the plants become weaker. However, since emergence is fastest during mid-summer and slowest in the spring the constant frequency has the narrowest frequency in days after emergence in the spring and the widest in mid-summer which is just the opposite of the desired situation. This may at least partially account for the fact that the 21 day frequency is much less effective than 12 days after emergence. The theoretical frequency of cultivation tests which met both requirements did not indicate that either requirement was of any great importance in a tillage program. It should be mentioned, however, that during the period of years covered by the tests of the theoretical frequencies of cultivation the growing seasons averaged both cooler and wetter than normal, and this would tend to delay the rate of emergence. As a consequence, the frequencies were probably too narrow, at least after the first season of cultivation. The data suggest that the frequencies may have been slightly too wide during the first season. However, it would appear that even in normal years, although some saving in the number of cultivation might be obtained with such a frequency, it would probably result in a greater length of time required for eradication. Apparently the most important factor in the effectiveness of any frequency of cultivation is how close it corresponds to the lowest point in reserves during the period of fastest growth.

The practical consideration of which frequency will handle best under field conditions and which provides for a margin of safety has considerable bearing on the recommendations that should be made. A constant frequency of cultivation has the advantage of permitting advance planning of field operations, which can be of considerable importance in following a cultivation schedule closely. A recommended frequency also should permit some margin of safety to allow for delays due to machinery breakdowns, and wet weather. A frequency of 21 days between cultivations allows no such margin of safety during the critical period in mid-summer but is entirely satisfactory at other seasons. The growth produced during mid-summer may be too large for easy cultivation. This could make a narrower frequency at this time more economical. Where moisture conditions are less favorable than in the Palouse area, a large growth may exhaust too much soil moisture and make a narrower frequency preferable. Since the growth rate seldom exceeds 1 inch per day it would be safe to assume that emergence occurred in the number of days corresponding to the depth of cultivation in inches. By adding 12 to the depth of cultivation in inches one should arrive at the number of days for a constant frequency of cultivation that should give excellent results. Using this method of calculation the frequency of cultivation would be every 16 days when cultivations are made at a 4-inch depth and every 18 days when cultivations are made at a depth of 6 inches. It is concluded that when a variable frequency of cultivation is possible, cultivations should be made 12 days after first emergence. When a set frequency of cultivation is desirable 21 days between cultivations is recommended with the suggestion that this be reduced to 14 days in July and August if the growth is too large to be economically handled or if better moisture conservation is desirable. If this change is undesirable, a frequency of cultivation of the depth of cultivation in inches plus 12 days may be used.

DEPTH OF CULTIVATION

Materials and Methods

The best depth of cultivation was determined by laying out duplicate plots and using three depths of cultivation. One twentieth acre plots were used for the 4- and 12-inch depths where field equipment was employed and square rod plots for the surface depth. A strip approximately 18 inches wide was treated with sodium chlorate around the borders of all plots to reduce border effects for these tests. For the 4-inch depth cultivation, a rotary rod weeder equipped with a duckfoot shovel attachment was used, except for the initial 6-inch plowing. For the 12-inch depth, a two-bottom 14-inch plow equipped with 16-inch shares was used in the cultivation. For the surface depth, cultivation was simulated by killing the plants to the surface with a generating type weed burner using gasoline for fuel. Preliminary tests showed that this type of burner did not kill below the surface of the ground. All operations were made at frequencies of 8 days after first emergence. Cultivation was started approximately 8 days after first emergence in the spring and continued until all plants were killed. Both the 4- and 12-inch depths were conducted in conjunction with the time of beginning cultivation experiments described previously and hence had common errors. The surface cultivation test, however, was conducted as a part of a frequency of burning test and hence has a separate error. The two tests were analyzed separately and the comparisons were made through the standard errors.

Experimental Results

The data obtained from these tests are summarized in Table 9. Since the depth of cultivation markedly influences the number of days to emergence and hence the days between cultivations, the values for these also are given. There was no significant difference in the number of cultivations required for eradication between the surface and 4-inch depths but the 12-inch required significantly less than the other two. There was a direct relationship between the depth of cultivation and the length of time required for eradication. The deeper the cultivations were made the longer it took for eradication. The difference between the surface and 12-inch depths was highly significant, whereas the differences between the surface and 4-inch and the 4- and 12-inch depths were not significant at the 5 percent level, although the former approached it closely.

Discussion and Conclusions

Wet soil delays cultivation more for deep cultivations than for shallow ones and hence the actual average frequency of cultivation for the first season of cultivation was 8.6 days after emergence for the surface depth, 9.4 days for the 4-inch depth, and 10.4 days for the 12-inch depth. According to the results obtained in the frequency of cultivation tests this should slightly favor the deeper cultivations, although the differences probably would not be great. It is probable, however, that the difference between the surface and 4-inch depths in the time required to kill would have been significant at the 5 percent level if both had received identical frequencies. The data suggest that the deeper the cultivations are made the fewer are required, but the longer it will take to obtain eradication. Assuming that cultivations at all depths can be made at equal cost the proper depth would be determined by the relative importance of the cost of cultivation and use of the land. However, the cost of cultivation rises rapidly with increasing depth. In these tests direct comparisons of relative costs were possible for the 4- and 12-inch depths and these showed approximately eight times the cost per cultivation for the 12- as for the 4-inch depth with the implements being used. This relationship would undoubtedly change with different implements and conditions but the deeper cultivations probably would always be the more expensive and hence the cost per cultivation would favor shallow cultivation. Deep cultivations would appear to be justified only when the added delay in the time for emergence is of considerable importance. This might occur at critical times in the farming operation such as during haying, harvesting, or seeding when it may be desirable to delay cultivations for an additional 10 days or more. By making a 12-inch cultivation instead of a 4-inch just before harvest, the cultivation interval could be shifted from 14 to 28 days between cultivations without serious effect on the final result. With the exception of these special conditions it is recommended that cultivations be made no deeper than is necessary to cut off all of the plants with the implement being used.

Table 9. The effect of three depths of cultivation on the eradication of bindweed. Average of three experiments started from 1939 to 1941.

Depth of cultivation	No. of cult. [1]		No. of months [1]		Av. of first Season of cult.		
	No.	Standard error	No.	Standard error	Days to emergence	Days between cultivations	Growth in inches
Surface	36.8	1.2	31.8	1.6	6.8	15.4	4.2
Four inches	36.0	2.4	39.5	3.8	8.2	17.6	5.8
Twelve inches	24.3	2.4	46.2	3.8	17.2	27.6	5.8

[1] Required for eradication.

DATE OF STOPPING CULTIVATION IN THE FALL

Three experiments were conducted from 1942 to 1944 to determine how late cultivation should be continued in the fall. In these tests duplicate 1/20 acre plots were layed out in a field uniformly infested with bindweed. All plots were plowed 6 inches deep 2 weeks after emergence in the spring. Subsequent cultivations were made at a depth of 4 inches with a rotary rod weeder equipped with a duckfoot shovel attachment at 14-day intervals. Five dates of stopping were tested in 1942 and 1944 and 6 dates in 1943. These dates ranged from August 15 to November 1. Growth normally stops in the Palouse area about November 1. The same procedure was used in subsequent seasons except that when emergence of the bindweed had not occurred during the 14 day period the frequency for that cultivation was changed to 28 days. Cultivation was continued on all plots until eradication was obtained with the exception of the August 15 date started in 1943. These plots were cultivated until the fall of 1949 and then abandoned.

Three experiments were conducted during the period 1937 to 1939 measuring the trend of root reserves under continuous cultivation. The method of sampling described for the trend of root reserves after a single cultivation was used except that sampling was started at first emergence in the spring and continued at 14-day intervals until growth ceased in the fall. This was continued until there were insufficient roots for analysis. Cultivations were all made at 4 inches at a frequency of 8 days after emergence from first emergence in the spring until growth stopped in the fall.

Experimental Results

The average data obtained on the number of cultivations and time required for eradication for the September 1 to November 1 dates are given in Table 10. There was no significant differences between the September 1, October 15, and November 1 dates and none between the September 15 and October 1 dates in the number of cultivations required for eradication. However, the October 15 date required significantly more cultivations than either the September 15 or October 1. The September 1 date required significantly more time for eradication than any other date. None of the other differences in time were significant but the November 1 date required the least.

The results obtained from the root sampling were similar for each experiment; but, since the growing seasons were different and eradication was obtained at different times, the results could not be averaged. As a consequence, only the fairly typical data obtained from the 1938 experiment are given. The curves of the percentage of readily available carbohydrates in the roots of the bindweed for the three seasons of cultivation on this experiment are shown in Figure 9. The curves for both the first and second seasons of cultivation dropped rapidly from first emergence in the spring until summer and then more slowly until about the 20th of September after which they rose for the balance of the season. In the third season the drop in reserves was slower in the spring, reached a low level by June 1, and then rose sharply until July 22 which was the last date that live roots could be obtained.

Discussion and Conclusions

It is apparent from the data obtained in this experiment that it is unnecessary to continue cultivation in the fall until growth stops. It is also apparent that under the conditions of these experiments that cultivation must be continued later than September 1 for best results. The time from August 15 to September 15 appears to be the critical period as far as this phase of a cultivation program is concerned. In the 1943 experiment where the August 15 date was included, the September 15 date required 46 months and 39 cultivations, the September 1 date 56 months and 42 cultivations, and the August 15 plots had received 50 cultivations over a period of 76 months when they were abandoned with 96 percent of the bindweed killed. There appears to be little difference in the dates after September 1, although considering both the number of cultivations and the time required for eradication October 1 seems to be preferable to the other dates.

The root reserve curves seem to indicate that, while root reserves are high in the upper levels of the soil and growing conditions are favorable, the rate of exhaustion is much faster than the rate of translocation of food from the lower roots, but that as reserves are reduced the rate of exhaustion is approximately equal to the translocation rate as long as growing conditions remain favorable. In the fall when growing conditions are less favorable the rate of translocation from the lower roots exceeds the rate of exhaustion and there is an actual increase in the reserves in the upper portions of the soil. The data from this experiment indicate that cultivations made during this period of slow exhaustion are relatively ineffective. Large amounts of growth are produced by bindweed during the fall months if cultivation is discontinued in September, but apparently this growth is incapable of producing sufficient carbohydrates for growth and storage. The difference between the October 1 and 15 dates might even indicate that the above ground parts of the plant are utiliz-

Table 10. The effect of five dates of stopping cultivation in the fall on the eradication of bindweed. Average of three experiments started from 1942 to 1944.

Date of stopping cultivation	Number of cultivations required	Number of months required	Av. date of eradication	Av. no. Crops Lost
September 1	42.3	56.7	2 - 10	5
September 15	38.2	46.7	4 - 10	4
October 1	38.3	43.3	12 - 28	4
October 15	45.8	47.3	4 - 28	4
November 1	42.2	41.7	11 - 10	4
LSD 5% level	5.6	8.6		

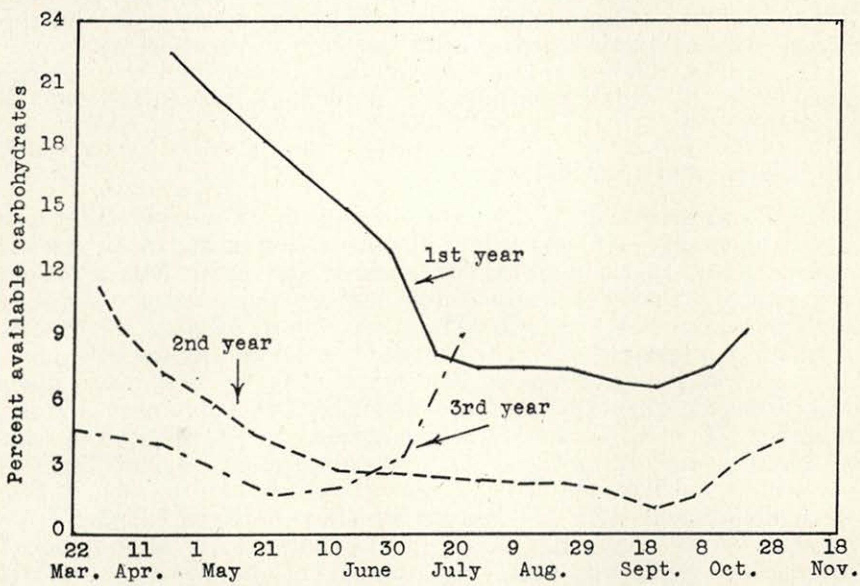

Figure 9. Trend of root reserves under continuous cultivation, 5-16 inch depth in the soil. Cultivation started April 21, 1938.

ing more food in respiration than they produce, hence this growth is an advantage in the cultivation program. Bindweed is a relatively long-day plant, and it is possible that in the latitudes of the Palouse area it requires approximately 12 hours of sunlight to manufacture sufficient food for its growth processes so that cultivation is unnecessary during the periods of the year when less than 12 hours of sunlight are obtained.

It is concluded that cultivation should be continued each season until at least September 15, but that it is unnecessary to cultivate later than October 1.

Summary

Tests were conducted on the eradication of bindweed by tillage during the period from 1936 to 1949.

The most efficient time to start a cultivation program on bindweed was just as soon after harvest as possible.

The most effective frequency of cultivation was 12 days after emergence of the bindweed. The best constant frequency of cultivation that was tested was every 21 days, but this was not so good as 12 days after emergence which averaged the same number of days between cultivations.

The depth of cultivation was not an important consideration since deeper cultivation required less total cultivations but more time for eradication. It was concluded that cultivations should be made only deep enough to cut off all plants at each cultivation with the implement being used.

October 1 was the best date to stop cultivation in the fall. Stopping before September 15 seriously interfered with eradication, and continuing beyond October 1 was of little if any benefit.

Studies of root reserve trends offered a satisfactory method of determining the frequency of cultivation and the best time to stop cultivation in the fall but were unsatisfactory as a means of determining the most efficient date to start cultivation.

Part II Canada Thistle, White Top and Russian Knapweed

Small areas of Canada thistle, white top and Russian knapweed were obtained for test purposes through the cooperation of farmers of the area. All three weeds were found in a single field about one mile north of Pullman, Washington, and the root reserve studies were conducted on that field. In order to use the equipment available it was desirable to have the cultivation tests as close as possible to the bindweed cultivation plots near Genesee. Areas of each weed were located within a mile of the bindweed plots and these were used in the cultivation tests. The Canada thistle and Russian knapweed were in one field adjacent to the bindweed area and the white top in a separate field on an adjacent farm.

CANADA THISTLE (Cirsium arvense Scop.)

Canada thistle is the second most important perennial weed in the Pacific Northwest. It is widely distributed in the heavier rainfall areas and under irrigation. It seldom occurs in large infestations but is usually confined to patches ranging in size from a single plant to a few acres. Since the areas are seldom large enough to justify special cropping methods, cultivation is one of the most widely used eradication practices on this weed.

Materials and Methods

The areas available for tillage trials on Canada thistle were small and isolated, hence the tests were restricted to studies of the best frequency of cultivation. Only constant frequencies were tested. In 1939 four frequencies were tested on single plots located in a single large patch. In 1940 five frequencies were tested on single plots in another large patch of Canada thistle. Initial cultivations were made by plowing 6 inches deep when the Canada thistle was about 5 inches tall, and subsequent cultivations were made with a duckfoot field cultivator at a depth of 4 to 5 inches. Cultivations were continued until growth ceased in the fall. When emergence had not occurred at the time a cultivation was due, the cultivation was delayed for 7 days so that the actual date of eradication could be determined.

During 1939 another large patch of Canada thistle was used to study the trend of root reserves after cultivation. The patch was kept cultivated at 14-day intervals from first emergence in the spring until June 2 at which time it was plowed 6 inches deep. After the plowing the area was sampled at intervals of about every 5 days for 77 days. The method of sampling was the same as that used for the trend of reserves after cultivation on bindweed except that only three samples were taken at each sampling date, and the depth was for the 7- to 18-inch level in the soil. Root samples were also taken in late August from the frequency of cultivation plots started in 1940 to determine the effect of the various frequencies on root reserves. Three samples were taken from each plot for the 12 inches below the depth of cultivation.

Experimental Results

The trend of the percentage of total available carbohydrates after cultivation is shown in Figure 10. The percentage of available carbohydrates decreased for a period of approximately 29 days after cultivation which corresponded to 13 days after emergence. After this reduction the reserves rapidly increased for 25 days, decreased for about 12 or 13 days, and then increased rapidly to the end of the sampling period. The second downward trend occurred at the bud stage of growth.

The number of cultivations and time required for eradication in the 1939 experiment are given in Table 11. This test showed very little difference in the length of time required for eradication with the frequencies tested, all giving eradication in about 4 months. The widest frequency, 28 days between cultivations, required the fewest cultivations. In 1940 the 7-day frequency was eliminated from the test and frequencies of every 35 and every 42 days were added. The results obtained from this test are given in Table 12. The percentage of available carbohydrates in the roots in late August are also given in this table. Eradication was somewhat more difficult in the test conducted in 1940 than in 1939; but two frequencies, every 21 days and every 28 days, still gave eradication in one season of cultivation. The other frequencies gave eradication during the second season. The 28-day frequency required the fewest cultivations, but it also required slightly longer for eradication than the 21-day frequency. This is the same result obtained in the 1939 experiment. The root samples taken in August showed a considerably lower percentage of available carbohydrates for the 28-day frequency than for the other plots.

Discussion and Conclusions

Both the root reserve studies and the frequency of cultivation tests indicated that a frequency of approximately every 28 days required the least number of cultivations for eradication. The average difference in the number of cultivations between the 21 and 28-day intervals, however, was only 1.5 cultivations. The average difference in the time required for eradication was only 2 weeks so there is probably little if any real difference in these two frequencies. The 21-day interval averaged 8 days after emergence and the 28-day 16 days after emergence; and, since the trend of reserves after cultivation indicated a frequency of 13 days after emergence, it is probable that the best frequency of cultivation was actually somewhere between the two. The average days to emergence in these tests was considerably longer than might normally be expected; hence the 21 day interval would probably be preferable. A 21-day interval gives an adequate margin of safety in the cultivation program. The data obtained in this experiment indicate that the best frequency of cultivation is approximately the same number of days after emergence as bindweed but that emergence is slower and hence cultivations can be made at somewhat wider intervals. The frequency of cultivation is not so critical with Canada thistle as it is with bindweed. It would appear to be desirable to use the same frequency of cultivation on both Canada thistle and bindweed where both weeds occur on the same farm. Where this occurs it is suggested that the frequency on the bindweed determine the frequency on the Canada thistle. Where Canada thistle occurs alone cultivations should probably be made every 21 days.

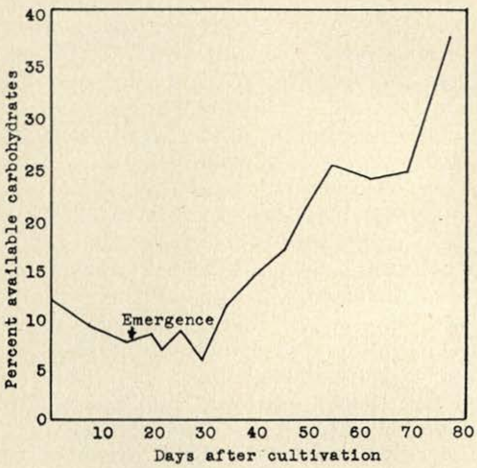

Figure 10. Trend of root reserves of Canada thistle after a 6-inch cultivation made June 2, 1939. Seven to 18 inch depth.

Table 11. The effect of four frequencies of cultivation on the eradication of Canada thistle. Single plots 1939 experiment.

Days between cultivation	Number required for eradication Cultivations	Days
7	18	122
14	9	122
21	6	115
28	4	122

Table 12. The effect of five frequencies of cultivation on the eradication of Canada thistle. Single plots 1940 experiment.

	Number required for eradication		Av. for first season of cultivation			Percent available carbohydrates at end of first season
Days between cultivations	Cult.	Days	Days to emergence	Days between Cultivations	Growth in inches	
14	11	367	13.4	14.6	2.1	18.82
21	7	136	14.5	22.7	2.9	16.43
28	6	156	15.2	31.2	3.6	11.72
35	9	469	16.5	39.0	5.3	15.42
42	8	469	17.0	45.3	7.1	19.56

WHITE TOP (Cardaria repens Boiss.)

White top is a serious weed in many parts of the Pacific Northwest. It occurs under widely varying conditions but is generally most common in the irrigated valleys. In most areas the infestations are small. This reduces the chances of using specialized cropping practices for eradication. The weed is generally difficult to control with chemicals, and cultivation could well be used under many circumstances.

Materials and Methods

Two areas of white top were available for test purposes. One area—a single large patch—was used to study the trend of root reserves after cultivation. This study was conducted in 1939 using the same methods described for determining the trend of root reserves after cultivation of Canada thistle. The other area was used to study frequency of cultivation. Duplicate 1/20 acre plots were used to test the effectiveness of four constant frequencies of cultivation. All plots were started with a 6-inch plowing made April 18, 1940. Cultivations were continued until November 1 of each season and started again the next spring as soon as the soil was dry enough to work. During the first two seasons of cultivation, all cultivations were made when due; but, in the third season, if emergence had not occurred at the time cultivation was due, then the cultivation was delayed for 7 days so that the actual date of eradication could be determined. Root samples were taken at the end of the first season of cultivation. The method described for determining the effect of various frequencies of cultivation on root reserves of Canada thistle also was used on the white top.

Experimental Results

The average data obtained from the empirical tests are given in Table 13. All of the plots were eradicated at essentially the same time which was near the end of the third cultivation season so that only the number of cultivations was of importance in this experiment. The number of cultivations required for eradication varied inversely with the frequency of cultivation with the widest frequency, 28 days between cultivations, requiring the least number of operations. The 28-day frequency also showed the least available carbohydrates in the roots at the end of the first season of cultivation.

The curve for the percentage of total available carbohydrates in the roots after a 6-inch cultivation is given in Figure 11. White top grows slowly during warm weather, and first emergence did not take place until 22 days after the cultivation. There was a small reduction in the reserve level from cultivation until first emergence. Following first emergence, reserves were depleted rapidly for about 12 days and then increased irregularly for the balance of the sampling period with a minor decrease occurring at 23 days after first emergence.

Discussion and Conclusions

Both the root reserve studies made at the end of the first season of cultivation and the final data on the number of cultivations required for eradication indicate that a frequency of cultivation of every 28 days was the most satisfactory for the control of white top. The 21 day frequency, which was second best, required an average of 5.5 more cultivations although the length of time required to effect eradication was approximately the same. The trend of root reserves after cultivation indicated a frequency of 34 days or 12 days after emergence. This trend of reserves was run too late in the season for the most rapid growth on the white top; hence the time to emergence was considerably longer than in the frequency of cultivation tests. The 21-day interval averaged 9.6 days after emergence for the first season of cultivation, and the 28-day 17.7 days after emergence. From this it might be suspected that the 21-day frequency was slightly narrow and the 28-day too wide. Since every 28 days was the widest interval tested, it is impossible to estimate the margin of safety involved in a 28-day frequency. It appears probable from the root reserve data that the margin would be small. In some cases considering the difference in the number of cultivations required, it might be preferable to use a 21 rather than a 28-day interval to insure an adequate margin of safety. It should be mentioned that white top becomes dormant during the summer months if soil moisture does not remain at a fairly high level. This summer dormancy seriously interferes with the cultivation program; and, under low rainfall conditions, a narrower frequency is justified to maintain adequate moisture. Under irrigation, summer dormancy of white top can usually be broken by irrigation, but under dry land conditions it must be prevented by cultivating at intervals frequent enough to conserve moisture. White top grows slowly and a frequency of every 21 days should be narrow enough to accomplish this.

It is concluded that where white top grows in conjunction with bindweed the frequency used on bindweed should control the frequency since the cultivation interval is more critical on bindweed than on white top. Where white top grows alone or

Table 13. The effect of four frequencies of cultivation on the eradication of white top. Average of duplicate plots. Single experiment started April 18, 1940, and completed in the fall of 1942.

Days between cultivations	Av. cult required for eradication	Av. for first season of cultivation			Av. percent available carbohydrates at end of first season
		Days to emergence	Days between cultivations	Growth in inches	
7	57.0	11.0	8.6	0.3	23.16
14	35.0	11.5	15.1	1.3	22.98
21	27.0	13.0	22.6	2.7	21.00
28	21.5	12.5	30.2	4.5	15.04

with Canada thistle, the frequency of cultivation should be either every 21 days or every 28 days depending upon the availability of moisture.

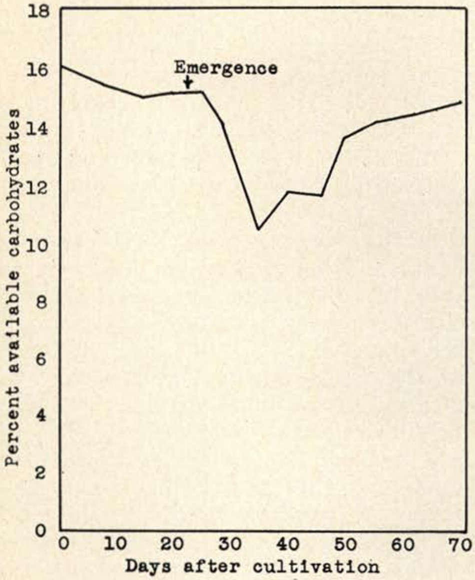

Figure 11. Trend of root reserves of white top after a 6-inch cultivation made June 2, 1939. Seven to 18 inch depth.

RUSSIAN KNAPWEED (Centaurea repens L.)

The total acreage of Russian knapweed in the Pacific Northwest is relatively small as compared to bindweed, Canada thistle, and white top. This acreage is generally composed of patches scattered throughout the area. It apparently is adapted to a major portion of the Pacific Northwest but the major concentrations occur in localized areas in the irrigated valleys. It is difficult to control with most chemicals, and cultivation is one of the major methods of eradication used.

Materials and Methods

Two relatively small areas of Russian knapweed were available for test purposes. Neither area was of sufficient size to permit adequate testing, but one area was used to study the trend of root reserves after cultivation, and the other was used for a frequency of cultivation test to obtain as much information as possible. Both studies were started in 1939. The method used in determining the trend of root reserves after cultivation of Canada thistle was used on the Russian knapweed with the exception that the area suitable for the test was exhausted at the end of 45 days of sampling, and the test had to be discontinued. The area devoted to the frequency of cultivation test was a single large patch, and this was divided into four parts with each receiving a different set frequency. These plots were root-sampled at the end of the first and second seasons of cultivation to measure the effect of the cultivation on root reserves. The procedure used on these plots was essentially the same as that for the Canada thistle.

Experimental Results

The data on the trend of total available carbohydrates in the roots are shown in Figure 12. The trend of reserves was irregularly downward from cultivation until the end of the sampling period 45 days later. Emergence was slow and required 22 days so that the reserves appeared to decrease for at least 23 days after first emergence.

The results obtained from the frequency of cultivation plots were of considerably more value than the root reserve trend. These data are given in Table 14. Both the 21- and 28-day frequencies required the same number of cultivations for eradication. The 14- and 21-day intervals required the least time which was considerably less than either the 7- or 28-day frequencies. Considering both the time and number of cultivations, the 21-day interval was the most efficient in this experiment. The data on the root reserves of the knapweed on these plots was somewhat contradictory. At the end of the first season, the 28-day frequency had the lowest level of reserves while at the end of the second season the 14-day interval was the lowest. However, the values were low on all plots at the end of the second season and the differences may not be significant.

Discussion and Conclusions

The empirical tests and root reserve data on Russian knapweed did not agree as well as on the other weeds studied. A number of factors may be responsible for these discrepancies. Russian knapweed stores a non-reducing sugar as its main food storage, and there was some difficulty in obtaining complete conversion of this material into reducing sugars in the laboratory. At the same time, pigments present in the roots of the Russian knapweed interfered with the reducing sugar determination. Although preliminary work largely eliminated these difficulties, they may have caused some trouble when differences were small. The areas used in this experiment were not entirely satisfactory; and this, no doubt, contributed to the problem. The trend of root reserves after cultivation gave a value of at least 23 days after first emergence for the most effective cultivation interval; the 21-day interval, which was the most saticfactory in the empirical test, averaged only 14 days after emergence. The 28-day interval, which was the second most effective, averaged 19 days between emergence and cultivation. The trend curve, however, was nearly level from 17 to 23 days after emergence, and it is possible that the actual low point in reserves came between these two sampling dates. If this is the case, the two tests would not be in serious disagreement. The data obtained on the effects of the various frequencies on the root reserves of the Russian knapweed might indicate that in Russian knapweed like in bindweed the frequency of cultivation should be narrower the second season than the first. This shifting frequency may explain the reason why the 21-day interval is more efficient than the 28. It would appear from the data obtained, that the frequency of cultivation is more critical on Russian knapweed than on Canada thistle or white top but perhaps less critical than on bindweed. As a consequence, where Russian knapweed occurs alone or with white top or Canada thistle, it should be cultivated every 21 days but where it occurs with bindweed the frequency required on the bindweed should be used.

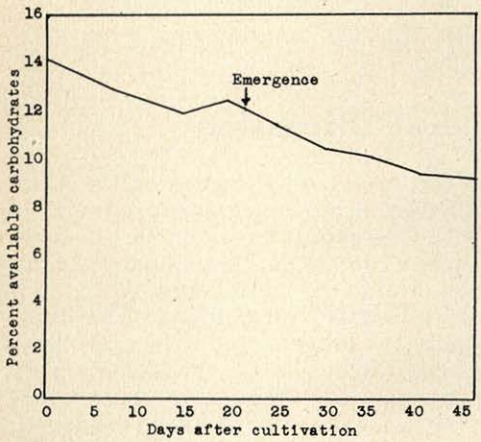

Figure 12. Trend of root reserves of Russian knapweed after a 6-inch cultivation made June 2, 1939. Seven to 18 inch depth.

Table 14. The effect of four frequencies of cultivation on the eradication of Russian knapweed. Single plot tests started May 5, 1939.

	Number required for eradication		Average of first and second seasons			Percent available carbohydrates at end of:	
Days between cultivations	Cult.	months	Days to emergence	Days between cultivations	Growth in inches	First Season	Second Season
7	47	25	5.9	7.5	0.8	16.89	4.15
14	24	17	7.1	14.6	3.5	14.36	3.39
21	16	17	7.6	21.7	5.5	14.59	4.70
28	16	27	10.0	29.1	10.8	11.69	5.92

Summary

Tests were conducted on the frequency of cultivation of Canada thistle, white top, and Russian knapweed during the period from 1939 to 1942. These tests were not so complete as those on bindweed; and, for this reason, the results reported on these plants are somewhat less definite.

The frequency of cultivation of Canada thistle is not critical, but an interval of every 21 days seems to be the most desirable in the absence of other serious perennial weeds.

The frequency of cultivation of white top is probably more critical than Canada thistle but less so than bindweed. It is suggested that, in the absence of bindweed and Russian knapweed where soil moisture is limited, a frequency of every 21 days be used on white top. An interval of every 28 days may be used where soil moisture is adequate to prevent summer dormancy.

The frequency of cultivation of Russian knapweed is more critical than white top or Canada thistle but less critical than bindweed. In the absence of bindweed a frequency of every 21 days is suggested.

Studies of root reserve trends offered a satisfactory method of determining the best frequency of cultivation of white top and Canada thistle but were not entirely satisfactory with Russian knapweed.

Part III General Discussion

The results obtained from the trend of reserves after cultivation of the four weeds studied indicate that the frequencies of cultivation of all of them with the possible exception of Russian knapweed are the same when based on days after emergence. The studies of bindweed, Canada thistle, and white top all indicated a frequency of 12 days after emergence. The Russian knapweed appeared to be slightly longer, but this may have been due to error. The three weeds which gave the same result vary widely in their characteristics as to temperature responses, time of flowering, rate of growth, and total growth produced. All, however, have deep, creeping root systems. All of these weeds because of their creeping root systems require a relatively long period of time for complete emergence to take place after a cultivation. As a consequence, the resulting root reserve curve is more a characteristic of a plant population than of a single plant. Since the development of the plant population is to a great extent determined by the creeping root system, all of these weeds might be expected to have similar root reserve curves after a cultivation. This appears to be the case with the weeds studied. The only major variable in the frequency of cultivation other than the number of days after emergence is the number of days from cultivation to emergence. This varies with the rate of growth. On the average, bindweed and Russian knapweed required the shortest time for emergence and Canada thistle and white top the longest. Ranked according to their speed of emergence during their fastest growth period, they would be bindweed, Russian knapweed, Canada thistle and white top. This is the same rank as the frequencies of cultivation when they were determined empirically. The indicated frequencies were: bindweed between 14 and 21 days; Russian knapweed 21 days; Canada thistle between 21 and 28 days; and white top 28 days. It is conceivable that, where weeds with deep creeping root systems are concerned, a relatively close estimate as to the best frequency of cultivation can be obtained by determining the days to emergence and adding 12 days.

It is perhaps questionable whether different frequencies of cultivation should be recommended for the different weeds. More than one kind of weed is frequently cultivated at the same time on a farm; and, where county, weed district, or custom units do the cultivation work on many farms, the possibility of error becomes rather large. This is particularly true where the work is done by untrained operators. A confusion in frequencies could cause a failure of the program. Cultivating white top at the bindweed frequency would be entirely satisfactory, but cultivating bindweed at the white top frequency could be disastrous. If a single set frequency is desirable, it would obviously have to be based either on the weed which is most abundant in the area or on the one which requires the narrowest frequency and preferably the latter. In the Pacific Northwest, bindweed is the most abundant and also requires the narrowest frequency of cultivation of any of the weeds studied. Therefore, where a single set frequency is desired, it should be based on bindweed.

There is a definite advantage in frequencies of cultivation which are a multiple of 7 days from the standpoint of farm planning since the cultivation is always due to start on the same day of the week. Where the number of days between cultivations is not a multiple of 7, cultivations will be due at various times during the week including Saturdays and Sundays. This would require a larger margin of safety in the recommendation, since cultivations due either on Saturday or Sunday often would be delayed until Monday. The margin of safety in the frequency should then be at least 1 day and preferably 2 days greater than where the cultivations can be set for early in the week. It would appear from the data obtained in these experiments that the best set frequency of cultivation of bindweed would be about every 16 days. This would permit a very small margin of safety during the critical summer period but would be fully adequate at other times during the year. Such a frequency, considering normal delays due to bad weather and other causes would require approximately 9 cultivations per season. A 14-day interval under the same conditions would require about 10 cultivations per season and a 21-day frequency about 7. The difference between the 14- and 16-day intervals would not seem to be justified on this basis. As a consequence where a given set frequency is desired for all creeping perennial weeds, it would appear that either the 14- or 21-day intervals should be used. Where moisture conditions are unfavorable and it is necessary to conserve moisture to insure rapid growth the 14-day interval would be preferable. Under more favorable moisture conditions a frequency of every 21 days would seem to be satisfactory. Under either of these schedules it would be possible to widen the interval by 14 days with a reasonable degree of security if first emergence had not taken place at the time the cultivation was due. Where a variable frequency of cultivation can be used, a frequency of 12 days after emergence should be fully satisfactory on all weeds studied and would probably give better results than any set frequency.

The data on bindweed indicated that the date at which cultivation should be started was more closely associated with farming practice than with any other single factor. Therefore, the same date could probably be used on all weeds. It would appear logical to kill the weeds as soon as possible and in order to do this cultivation should be started as soon as the land is available. This normally would be immediately after harvest.

No information was obtained on the proper depth of cultivation of Canada thistle, white top and Russian knapweed; but the similarity in the root systems of these weeds and in those of bindweed would indicate that they would respond much the same. Apparently the major factor in the lack of efficiency of deep cultivation is that the rate of emergence is slower from deep than shallow cultivations; hence it requires a longer period of time to exhaust a given amount of reserves. This is probably characteristic of the type of root system; hence all of these weeds probably would be eradicated more quickly with shallow cultivations than with deep ones. Deep cultivations could be used to advantage to delay emergence either in the establishment of a competing crop or to permit the completion of other farm work between cultivations. Other than this it would appear to be desirable to cultivate all at rather shallow depths, the actual depth being determined by the implement available.

The four weeds studied differ rather materially in their temperature requirements for growth. White top is a cool weather plant; bindweed does best in warm weather. Both Russian knapweed and Canada thistle are intermediate but tend to be more like bindweed than white top. This difference could have a material effect on the proper date to stop cultivation in the fall. Bindweed cultivation may be stopped as early as September 15 although October 1 appears to be preferable. No tests were conducted on the other weeds; but, from their growth characteristics, it could be assumed that white top should be cultivated until at least October 15 and preferably November 1 if a deep cultivation is not made in late fall. Where wet soil may prevent late cultivation, a deep cultivation may be justified at the end of the cultivation season on this weed. Both Canada thistle and Russian knapweed should probably be cultivated until October 1 but it appears questionable whether cultivation later than this would be necessary.

The length of time required for eradication varies with the amount of stored food available and the relative speed of exhaustion. Root samples taken on the four weeds indicated that bindweed stored the largest amount of food. White top, Russian knapweed, and Canada thistle follow in the order given. The empirical tests indicated that when growing conditions were similar approximately three seasons of cultivation were required for the eradication of bindweed and white top, about two for Russian knapweed and one for Canada thistle. Under other conditions these values would change. The condition and previous history of a particular weed infestation largely determines the amount of stored food. The area used for the bindweed studies had been poorly farmed and infested for at least 20 years at the time the experiments were started and probably had a much higher level of reserves than normally would be the case; hence the normal length of time required for eradication would probably be less than that found in these experiments. The same may be true for the white top. It is believed that the Russian knapweed was carrying approximately a normal level of root reserves and the Canada thistle may have been slightly below normal. Weather conditions appear to be the major factor in the length of time required for eradication with any particular cultivation schedule. During the period from 1936 to 1949, the number of cultivations required for eradication remained relatively constant from year to year; but the length of time varied widely depending upon weather conditions. During this period, annual precipitation varied from about 16 to 36 inches, and the experiments started in the wet years always required the longest period for eradication. As an average of eight experiments, the 12 days after emergence frequency required 26.4 cultivations and 32.9 months for eradication. The number of cultivations had a coefficient of variability of 8.8 percent and the months 15.5 percent. In a number of the experiments, years was significant for time but not for the number of cultivations. In only two cases was the year x treatment interaction significant for either time or cultivations. Apparently the only major effect of bad weather is that cultivation is delayed and it takes longer to perform the required number of cultivations. This assumes, of course, that the cultivations are made as soon as possible after the date due. During the 14-year period, cultivations were delayed as much as 2 weeks by bad weather without any apparent effect on the number of cultivations required for eradication.

GENERAL SUMMARY AND CONCLUSIONS

Tests were conducted on the eradication of bindweed by tillage from 1936 to 1949 and of Canada thistle, white top and Russian knapweed from 1939 to 1942.

Bindweed tests included studies of the time of beginning cultivation, frequency of cultivation, depth of cultivation, and how late to cultivate in the fall. Only frequency of cultivation studies were made on the other weeds.

The most effective variable frequency of cultivation of bindweed was 12 days after first emergence. The same frequency of cultivation appears satisfactory for the other weeds studied. The most effective set frequency of cultivation tested on bindweed was every 21 days but this was not so good as the variable frequency. The best set frequency of cultivation for Canada thistle was between 21 and 28 days, for white top every 28 days, and for Russian knapweed every 21 days.

The depth of cultivation was not an important consideration in the cultivation of bindweed, and it is recommended that cultivations be made only as deep as is necessary to cut off all plants with the implement being used.

October 1 was the best date to stop bindweed cultivation in the fall.

Studies of root reserve trends were a satisfactory method of determining the frequency of cultivation of bindweed, white top, and Canada thistle but were not entirely satisfactory with Russian knapweed. Root reserve studies with bindweed were valuable in determining when to stop cultivation in the fall but were unsatisfactory as a means of determining when to start cultivation.

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This bulletin presents the results obtained from one phase of a comprehensive weed research program conducted coopera-

tively by the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering, Agricultural Research Administration, U. S. Department of Agriculture; the Idaho Agricultural Experiment Station; and the Washington Agricultural Experiment Stations. A major portion of the field work on this project was conducted at a special field station located between Genesee, Idaho and Uniontown, Washington.