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In Coöperation With

DIVISION OF CEREAL CROPS AND DISEASES
BUREAU OF PLANT INDUSTRY
U. S. DEPARTMENT OF AGRICULTURE

Results of Bindweed Control Experiments at the Fort Hays Branch Station, Hays, Kansas, 1935 to 1940

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Results of Bindweed Control Experiments at the Fort Hays Branch Station, Hays, Kansas, 1935 to 1940 [1]

F. L. TIMMONS[2]

INTRODUCTION

Field bindweed *(Convolvulus arvensis)* has been recognized as a serious weed pest in central and western Kansas for more than thirty years. The first experiments with the control of this weed in Kansas were conducted in 1907 and 1908 on a farm near Victoria, Ellis county, under the direction of A. M. Ten Eyck of the Kansas Agricultural Experiment Station, Manhattan. Experiments involving the use of salt, cultivation and smother crops to control bindweed were started at the Fort Hays Branch Station in 1915 by R. E. Getty, who was then in charge of Forage Crops Investigations. The results of these experiments conducted over a period of years were reported in 1923 by Call and Getty.[3] Experimental work with bindweed control was continued as a part of Forage Crops Investigations until 1930.

The investigations reported in this publication were started July 1, 1935, as a cooperative project between the Kansas Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture. The experiments have been conducted on a 130-acre tract of bindweed-infested land lying adjacent to the Fort Hays Branch Experiment Station. Five years of results have been obtained from most of the experiments.

The purpose of this bulletin is to make available the more important and useful data secured in these experiments, together with such interpretations and recommendations as the facts seem to justify. The conditions under which the experiments were conducted are described in order that the reader may be better able to judge the application of the results and recommendations to his own locality.

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1. Fort Hays Branch Station, Kansas Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture, coöperating. Contribution No. 31, Fort Hays Branch Station.
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3. Call, L. E., and Getty, R. E. The eradication of bindweed, Kan. Agr. Expt. Sta. Circ. No. 101, 1923.

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The chemical analytical phases of the regional coöperative bindweed project, of which the work at Hays is a part, are conducted coöperatively with the Iowa Agricultural Experiment Station, Ames, Iowa, and W. G. Gaessler, research associate professor, Plant Chemistry Subsection, Iowa Agricultural Experiment Station, should receive special acknowledgment for the analytical data on root reserves herein reported.

EXPERIMENTAL CONDITIONS

SOIL TYPE

The experimental area consists, for the most part, of level to slightly rolling upland.[4] large ravine which is subject to overflow of runoff water cuts through one corner and along one side of the area and has been used for a few experiments of minor importance. The soil is typical of those found in a large part of west central Kansas. The surface 6 to 15 inches is a medium heavy, relatively dark, silty clay loam. The subsoil is heavier, more compact, and lighter colored. The soil has excellent moisture-holding capacity and is capable of producing high yields of crops under favorable moisture and other climatic conditions. It appears to be particularly well adapted to the growth of bindweed, which competes vigorously with crop plants in the presence of either an abundance or scarcity of soil moisture and persists under the most unfavorable climatic conditions.

CLIMATIC CONDITIONS

Precipitation.— The average annual precipitation for the six-year period, 1935 to 1940, during which the experiments reported here were in progress, was 19.42 inches as compared to the 73-year average of 22.59 inches. The precipitation was below average in every one of the six years except 1940, when 64 percent of the total for the year was received after July 1 and therefore had little effect on the results obtained in 1940.

Temperature.— The dry seasons experienced since the bindweed-control project was established were characterized also by abnormally high summer temperatures. Maximum temperatures of 100° F. or higher were reached on 27 days in 1935, 54 days in 1936, 32 days in 1937, 33 days in 1935, 31 days in 1939, and 17 days in 1940. In years with normal or above normal rainfall, temperatures of 100° F. or higher usually do not occur on more than 10 to 15 days during the summer.

The combined effect of deficient moisture and unusually high summer temperatures resulted in conditions extremely unfavorable for crop production throughout. the period. Yields of summer growing smother crops were far below average every year, while average yields of small grain crops were produced only in 1936 and 1938.

BINDWEED GROWTH

Bindweed is known to have been present on a considerable portion of the present control project more than 30 years ago. It continued to spread under a farming practice of continuous grain and feed crop production and when the experimental work was undertaken in 1935 the infestation on the land subsequently used was complete and remarkably uniform.

Numerous excavations have shown the bindweed at Hays, in general, to be relatively shallow rooted. In upland soil very few roots have been found below six feet and over 70 percent of the total weight of roots in the top six feet of soil was in the surface two feet, On overflow bottomland in a ravine running through the project the bindweed roots were found to penetrate deeper. Also the total amount of root growth was greater and the proportion of the total at lower levels somewhat greater. The amounts of bindweed roots at different levels and the percentage of the total to a depth of six feet for both upland and bottomland soil on the bindweed project at Hays are given in Table 1.

TABLE 1.—*The weight of bindweed roots at different soil levels at Hays, Kan.*

SOIL DEPTH.	Upland (av. 4 tests).		Bottom land (av. 4 tests).	
	Grams dry wt. per cubic ft. of soil.	Percent of total.	Grams dry wt. per cubic ft. of soil.	Percent of total.
First foot	1.82	42.8	2.77	38.8
Second foot	1.28	30.1	1.63	22.8
Third foot	.52	12.2	.99	13.9
Fourth foot	.25	5.9	.77	10.8
Fifth foot	.22	5.2	.56	7.8
Sixth foot	.16	3.8	.42	5.9
Totals	4.25	100.0	7.14	100.0

Due to a more limited capacity for storage of food reserves it would be expected that the relatively shallow rooted bindweed on upland at Hays would be more easily eradicated by cultivation or smother crops than bindweed under more favorable soil moisture conditions where the roots penetrate 15 to 25 feet and have been found at even greater depths.

A bindweed root was traced to a depth of 23 feet 1½ inches at Manhattan, Kan., by Dr. J. C. Frazier, of the Kansas Agricultural Experiment Station staff, who will publish on this work later. The plant grew from seed in April, 1937, and was excavated in late July, 1939. Bindweed roots were excavated to a depth of 20 feet at Lincoln, Neb.[4] It was estimated that only one-half of the total weight of roots was in the upper five feet and only one-fourth of it was in the upper two feet. The weight of bindweed roots per cubic foot of soil in an irrigated field at Davis, Cal.,[5] was found to be undiminished at the depth of five feet and roots were present, in important amounts at a depth of 14 feet. Bindweed roots were excavated to a depth of 17 feet at Cherokee, Iowa,[6] where an average of 40 percent

5. Bioletti, Frederic T. The extermination of morning-glory. Cal. Agr. Expt. Sta. Cir. 69, 1911.

4. Kiesselbach, T. A., Petersen, N. F., and Burr, W. W. Bindweeds and their control. Neb. Agr. Expt. Sta. Bul. 287, 1934.

6. Bakke, A. L., Gaessler, W. G., and Loomis, W. E. Relation of root reserves to the control of European bindweed. Iowa Agr. Expt. Sta. Res. Bul. 254, 1939.

of the roots was found below the 24-inch level, and the total yields of roots ranged from 2 to 3 tons per acre or more. Reports from California and Iowa indicate that intensive cultivation must be continued at least a year longer to eradicate bindweed than has been found necessary at Hays. Farmers have found the same to be true in some sections of Kansas where bindweed is known to be much deeper rooted than at Hays.

The growing season for bindweed at Hays averages about seven months. Emergence in the spring usually begins early in April and growth continues until November or until minimum temperatures of 20° F. or lower occur. Freezing temperatures above 20° F. appear to retard bindweed growth, but do not injure the vines.

Normally the period of heaviest bloom in the vicinity of Hays is from May 15 to June 15 and mature seed is produced from June 15 to July 15. In infested small-grain fields bindweed seed usually matures before harvest. Under favorable conditions bindweed continues to bloom and produce seed during August and September, though less profusely than earlier. In the dry seasons during the course of the experiments reported herein bindweed has become dormant in late June or July in nearly every year and usually has started new growth in late August or early September after the first fall showers.

EXPERIMENTAL PLAN

The experiments undertaken at the beginning of the project were designed to provide information on all of the important phases of the bindweed control problem. They covered a broad field of investigation, including root reserve studies, different frequencies, times of beginning and depths of cultivation, the use of competitive or smother crops, rate, date and method of applying sodium chlorate, and other chemical treatments of various kinds. Ten of the experiments have been conducted in a similar manner on cooperative weed research projects in Minnesota, Nebraska, Idaho, and to some extent in certain other states.

Each experiment is started on new land every year and the experiments once begun are continued to completion. Those involving intensive cultivation or chemical treatments are usually completed in two or three years while those making use of competitive or smother crops are continued four or more years. All of the different treatments have been replicated two or more times in each experiment. The experimental plots have ranged in size from one rod square for chemical treatments to one-twentieth acre or larger for cultivation and competitive cropping experiments.

EXPERIMENTAL RESULTS

EFFECT OF BINDWEED UPON CROP YIELDS

The yields of nine different crops were determined each year from 1936 to 1940 on bindweed-infested land and on adjacent noninfested land, both of which were cultivated, seeded and otherwise handled in exactly the same manner. Preparation of the seedbed and time and method of planting were in accord with what is generally considered good farm practice in the region. The average yields for the five-year period are shown in Table 2. Grain and forage yields of the different crops were reduced from 20 to nearly 90 percent by bindweed competition. Small-grain crops produced more nearly normal yields on infested land than did the summer growing crops, probably because the former made a considerable growth early in the spring before bindweed emerged while the latter were forced to compete with bindweed throughout their growing seasons.

TABLE 2. The effect of bindweed on the yield of crops at Hays, Kansas, 1936 to 1940

CROP.	Average yields, 1936 to 1940. Grain. Bushels per acre. Non-infested.	Grain. Bushels per acre. Infested.	Grain. Percent reduction due to bindweed.	Cured forage. Tons per acre. Noninfested	Cured forage. Tons per acre. Infested	Cured forage. Percent reduction due to bindweed
Barley	23.6	15.9	32	...	...	...
Oats	29.9	22.1	26	...	...	...
Rye	12.5	10.0	20	...	...	...
Wheat	11.3	6.5	42	...	...	...
Corn	2.7	.9	67	1.2	.5	57
Kafir	13.2	2.0	85	2.7	.9	66
Milo	14.0	1.5	89	2.1	.9	56
Sorgo				1.8	.8	56
Sudan grass	...	...	...	1.6	.5	66

The yields of crops were unusually low during the course of the experiment, particularly corn and sorghums because of deficient moisture and extremely high summer temperatures. It is possible that in more favorable seasons the reduction in yields would be less than in this experiment. This has not been observed to be the case, however, in those seasons in which moisture supplies were more nearly normal.

EFFECT OF INTENSIVE CULTIVATION UPON BINDWEED ROOT RESERVES

Numerous experiments and observations have shown that when bindweed-infested land is cultivated repeatedly at frequent intervals, the plants are eventually killed. It is believed that the reason they are not killed at once is because of the reserves of food stored in their roots and that they finally die only when this supply has been exhausted. Chemical analysis has shown that these reserves consist largely or almost entirely of starch, sugar, and closely related compounds herein referred to as readily available carbohydrates.

One of the studies included in the present investigation was designed to determine the effect of repeated cultivation on root reserves. Plots were accordingly laid out in the spring of each year and cultivated eight days after each emergence of bindweed (every two to three weeks) until all plants were dead. Samples of the bindweed roots were taken from the 6 to 18-inch soil level when the experiments were started and every two weeks thereafter. After their

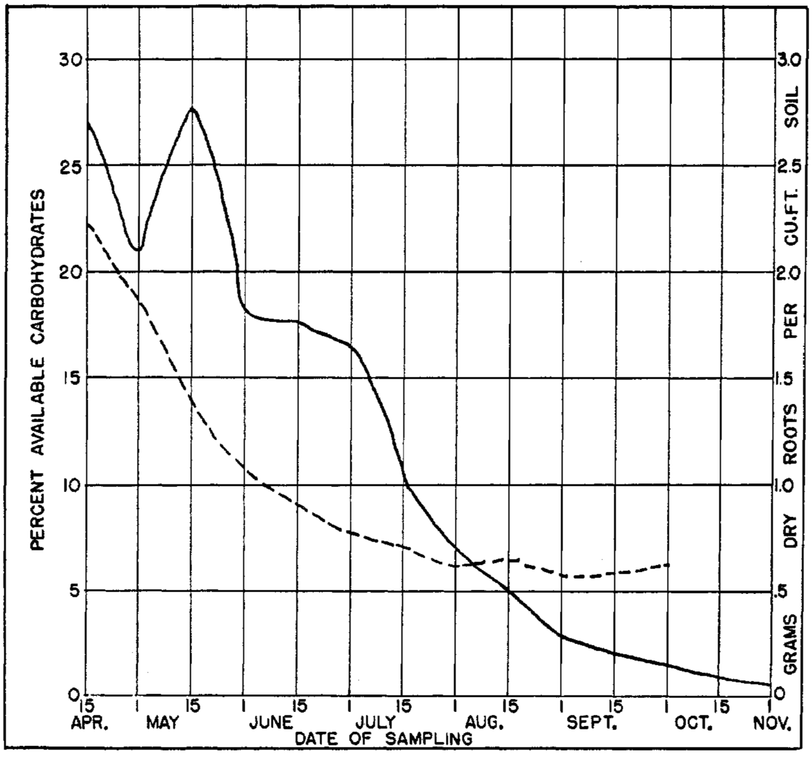

FIG. 1.—Effect of intensive cultivation on the amount of living root material and on the percentage of root reserves of bindweed. Average, 1936 to 1939. The solid line shows the grams of dry roots per cubic foot of soil. The dotted line shows the percent of readily available carbohydrates in the roots.

removal from the soil the roots were washed, killed immediately in an electric oven, dried, weighed and analyzed for food reserves. The average trends of the amount of dried bindweed roots per cubic foot of soil and the percentage of root reserves (readily available carbohydrates) during the growing season are shown in Figure 1.

The percentage of readily available carbohydrate reserves declined rapidly from the beginning and this decline continued until about July 1 each year, after which it remained about the same. The amount of living roots decreased slowly at first and then more rapidly after July 1 and this decrease continued until all plants were dead. By the end of the season approximately 95 percent, on the average, of the roots in the surface 18 inches of soil had died. The curve for root weight is not shown beyond the first year. Complete eradication was usually accomplished by the middle of the second year of cultivation and nearly always by the end of the second year. These results support the belief that in order to kill bindweed by cultivation the supply of root reserves must be exhausted.

FREQUENCY OF CULTIVATION

Seven different experiments have been conducted to compare the effectiveness of cultivating bindweed at different intervals after emergence. These have included cultivating immediately after the bindweed appears above the surface of the ground, 4 days after it emerges, 8 days after, 12 days after, 16 days after, 20 days after, and 28 days after. The average interval between cultivations during the first year was 9.1 days for those plots cultivated immediately after the bindweed emerged, and correspondingly greater for the others. The number of cultivations necessary to kill the bindweed and also the average number of days between cultivations for seven experiments conducted from 1935 to 1939 are given in Table 3. Only

TABLE 3.—*The relation of frequency of cultivation to the number of cultivations required to kill bindweed at Hays, Kansas, 1935 to 1939*

Interval between emergence and cultivation, number of days.	Number of days between cultivations, first year in each experiment.		Number of cultivations required to eradicate bindweed.	
	Range.	Average.	Av. of 7 expts., 1935 to 1939.	Av. of 5 expts., 1937 to 1939.
0	4–17	9.1	32.7	35.2
4	8–21	13.2	23.4	25.2
8	13–24	18.4	18.7	20.0
12	18–27	21.8	16.5	17.1
16	21–32	25.6	15.7*	17.0*
20	24–39	29.0	....	17.2*
28	32–43	37.0	....	16.4*

* Eradication not complete in some experiments. More cultivations will be necessary.

five of the intervals were tested in all experiments, but all seven intervals were included in five experiments conducted from 1937 to 1939.

Bindweed was eradicated by the fewest cultivations and therefore with the least expense when cultivated 12 days after each emergence. This meant cultivating about every three weeks on the average, although in some cases the interval between cultivations was only slightly more than two weeks. An average of 16½ cultivations only was required to kill bindweed by this method, or approximately half the number required when the bindweed was cultivated each time at first emergence. Nearly 19 cultivations were required when cultivated 8 days after emergence and 23 were necessary when 4 days' growth after emergence were allowed. All plots cultivated 12 days or less after emergence were nearly always free of bindweed by the end of the second season.

Bindweed was eventually eradicated when cultivation was delayed 16 or even 20 days after emergence. However, it was always necessary to continue the cultivation into the third season and sometimes into the fourth year in order to accomplish eradication and there was no saving in cultivations as compared with the 12-day plots. Where cultivation was delayed until 28 days after the bindweed appeared above ground, eradication was not accomplished even where the treatment was continued four years.

During the first few months of intensive cultivation bindweed usually emerged in from 4 to 8 days after each cultivation. As the plants became weaker later in the season and in the second year, and when growth was retarded by cool fall weather, the time required for emergence was often as much as 12 to 15 days. This means a corresponding difference in the interval between cultivations for the most efficient results. It is generally impractical, however, to take such variations fully into account in a control program.

On the basis of the results from these experiments, it appears that the safest and most feasible plan is to cultivate once every two weeks during the first three or four months or as long as the bindweed continues to emerge vigorously within 6 to 8 days after cultivation. After the plants have become weakened and require 10 days or longer to come up after being cut off, the cultivation interval can safely be lengthened to three weeks. This plan allows a margin of safety for delays which frequently occur due to wet soil conditions and other causes.

TRENDS OF ROOT RESERVES AFTER CULTIVATION

A study of the trends of food reserves in bindweed roots after a single cultivation and after a period of cultivation explains why good results are obtained from allowing bindweed to grow 8 to 12 days after each first emergence (2 to 3 weeks between cultivations) and also why unsatisfactory results are secured when cultivation is delayed as long as 20 or 28 days after emergence (4 to 5 weeks between cultivations). Ten experiments after a single cultivation and five experiments after 2-month cultivation periods were conducted during 1936 to 1940. In these experiments root samples were taken from the 6- to 18-inch soil levels at the time of cultivation (or last cultivation in the series), and at frequent intervals thereafter, the

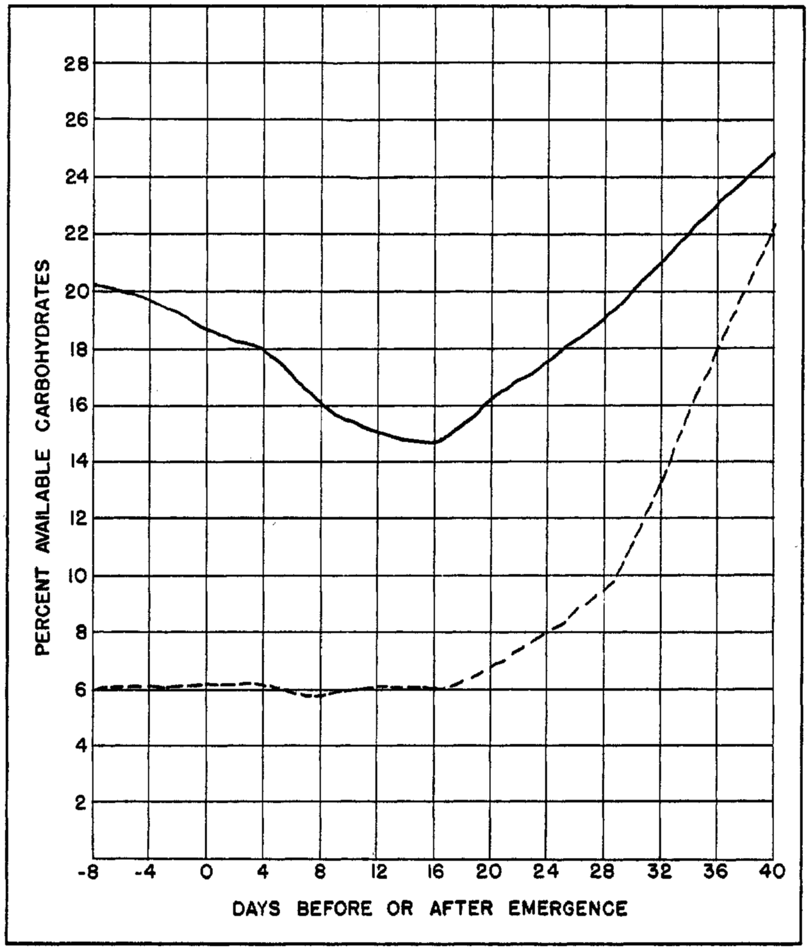

FIG. 2.—Graphs showing the trends of food reserves in bindweed roots after single cultivations and after two-month fallow periods. Average, 1936 to 1940. The solid line shows the averages for the single cultivations and the dotted line shows the average after two-month fallow periods.

plots in the meantime receiving no further cultivation. The root samples were washed immediately after removal from the soil and killed in an oven, dried, weighed and analyzed for food reserves. The trends of these reserves are shown in Figure 2.

After a single cultivation in previously untreated bindweed where root reserves were at a high level the percentage of carbohydrates decreased slowly until about four days after first emergence of the bindweed. Following this the decrease was more rapid and continued for a period which varied from 8 to 20 days after first emergence in the different experiments and averaged about 16 days in all 10 experiments. Immediately after this low point was reached there was a rapid increase, indicating that from about 16 days after first emergence (24 days after cultivation) bindweed is able to produce not only the carbohydrates needed for growth but also a considerable surplus which is stored in the roots for future use.

Following the last cultivation of 2-month cultivation periods which had reduced root reserves to a low level, the percentage of carbohydrates fluctuated between narrow limits and averaged unchanged in the five experiments for about 16 days after first emergence of the bindweed (24 days after cultivation). Apparently, during this time the reserves in the 6- to 18-inch sampling zone were being replenished from reserves in deeper roots as rapidly as they were being drawn from the surface roots in the production of new growth. Following this the reserves began to increase at a rate that was even more rapid than after a single cultivation, which shows how rapidly bindweed can recover from intensive tillage treatment if cultivation is interrupted too long.

The trends of bindweed root reserves after cultivation emphasize two important points that were also brought out in the results of the frequency of cultivation experiments, namely, (1) bindweed can be eradicated just as quickly and with fewer cultivations by cultivating every two to three weeks or more often but, (2) any delay that extends the time between cultivations to more than three weeks will permit the bindweed to recover rapidly and repeated delays may mean that the benefit from cultivation previous to that time will be entirely lost.

TIME OF BEGINNING CULTIVATION

Five experiments in which cultivation treatments were started at first emergence of the bindweed and May 1, June 1, July 1, August 1, and September 1 each year were begun during the years, 1936 to 1940. All plots have been cultivated eight days after each first emergence of the bindweed until all plants were dead. Four of the experiments have been completed and the results are given in Table 4.

There was little difference in the number of cultivations required to eradicate bindweed under the treatments started at different times during the year, the average number varying from about 16 to 18. The slight saving in cultivations for the June 1 date was offset by the greater difficulty encountered with heavy bindweed vine growth which was usually present by June 1. The vines and undecayed roots made it difficult to cultivate thoroughly and economically under the wet soil conditions that have frequently prevailed in June.

TABLE 4.—*Relation of time of beginning cultivation to the number of operations required to kill bindweed, Hays, Kansas, 1936 to 1939*

Approximate date of beginning cultivation, first year.	Number of cultivations required to eradicate bindweed in experiments started in:				
	1936.	1937.	1938.	1939.	Average.
First emergence in spring	17	13	22	20	18
May 1	18	13	20	18	17.3
June 1	14	11.5	20	17.5	15.8
July 1	17	14.5	20.5	16.5	17.1
August 1	16	13	20.5	15	16.1
September 1	17.5	14	18.5	12*	....

* Eradication not complete. More cultivations necessary.

The best time to begin cultivating to eradicate bindweed apparently is largely a question of freedom of the land from a crop or trash or excessive vine growth, of soil moisture for growth of the bindweed, and of convenience with respect to other farm work. There appears to be no advantage in plowing or cultivating bindweed-infested land when it is too dry for growth. If the bindweed doesn't grow, there is probably little exhaustion of root reserves. There are two periods in the year that seem to be favorable for beginning cultivation. One is in the spring within two or three weeks after bindweed growth starts, and the other is as soon following small-grain harvest as there is sufficient moisture to promote bindweed growth and permit thorough tillage. When moisture following small-grain harvest is sufficient for bindweed growth it is considered best to start the cultivation treatment immediately rather than delay it until the following spring. This has considerable advantage as in some cases eradication will be completed by the end of the following season and thus the use of the land will be lost for only one year. In other cases, where bindweed will require more than two full years of cultivation to eradicate it, beginning after small-grain harvest may prevent the loss of the use of the land for a third year.

DEPTH OF CULTIVATION

Seven different depths of cultivation and combinations of depths were compared in four experiments conducted during 1936 to 1940. The results are summarized in Table 5. Plowing to depths of 8 and 12 inches to begin with did not reduce the number of subsequent 4-inch duckfoot cultivations necessary to eradicate bindweed. On the average, approximately 19 cultivations were required in each case. Plowing repeatedly to depths of 8 and 12 inches gave eradication with approximately two and five fewer operations, respectively, in two experiments, but the reduction in number was not nearly enough to offset the greater cost of the deep tillage. Plowing twice a year, just before harvest and again in late fall, to depths of 8 and 12 inches resulted in no saving in cultivations in the one experiment in which they were tested. Bindweed emergence was delayed only two days on the average by an 8-inch plowing and only four days by a 12-inch plowing, as compared with a 4-inch cultivation.

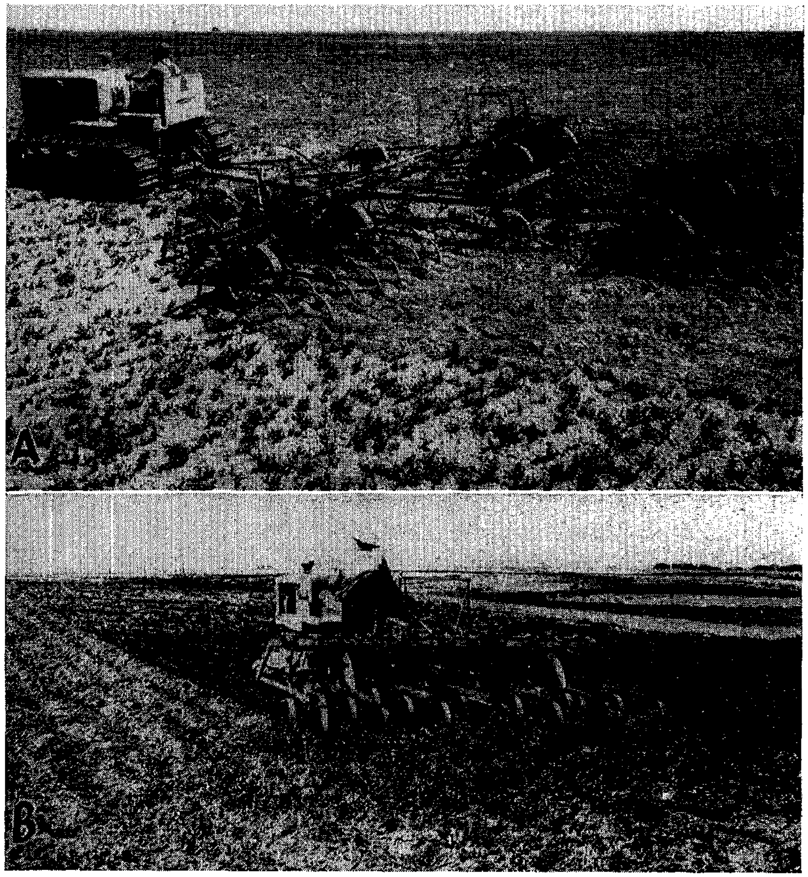

FIG. 3.—(A) Cultivating bindweed on a demonstration field at the Fort Hays Branch Station. (B) A typical view of bindweed vine growth when cultivation is not started until June 1 or when allowed to grow too long between cultivations. Such growth interferes with later cultivations, especially if the plants are plowed under.

From these results it appears that there is little advantage in cultivating deeper than four inches to eradicate bindweed in the relatively heavy soil at Hays. In light soils somewhat deeper cultivation may sometimes be necessary, especially during dry periods to facilitate thorough work.

TABLE 5. *Relation of depth of cultivation to the number of cultivations required to kill bindweed at Hays, Kansas, 1936 to 1938*

Depth of cultivation (inches).		Number of cultivations required to eradicate bindweed.			Number of days between cultivations; average first year in 2 Expts.
Original.	Subsequent.	Average 4 Expts., 1936 to 1938.	Average 2 Expts., 1937 to 1938.	1 Expt., 1938.	
4	4	19.3	21.0	23.5	17.4
8	4	18.7	20.0	21.5	17.5
12	4	19.4	19.8	21.0	18.1
8	8	....	17.8	19.5	20.0
12	12	....	15.0	17.0	21.7
4	4 and 8 (1)	....	....	21.0	....
4	4 and 12 (2)	....	....	21.5	....

(1) Plowed to depth of 8″ just before harvest and again as the last operation in the fall of each year.

(2) Plowed to depth of 12″ just before harvest and again as the last operation in the fall of each year.

There has usually been considerable difficulty at Hays in using a duckfoot or blade weeder after a deep plowing at the beginning of the cultivation treatment because of undecayed bindweed roots and other vegetation in the loose soil that is left, Best results were obtained by starting with a duckfoot cultivation or shallow plowing so that in subsequent operations the sweeps or blades worked against a hard plow sole rather than in loose soil.

Shallow cultivation during the early part of the eradication treatment also encourages a large number of the bindweed seeds near the surface to germinate so that the seedlings may be killed. Several years of shallow cultivation are apparently necessary before all of the seeds near the surface are germinated. An average of 134 bindweed seedlings per square rod emerged in the spring of 1940 on two plots at Hays that had been cultivated four inches deep with a duckfoot during 1938 and 1939.

When land is plowed 8 to 12 inches deep at the beginning of the cultivation treatment the large numbers of bindweed seed which are usually present in the surface are buried so deep in the soil that they probably do not germinate for many years, but will germinate and possibly reinfest the land in later years when they are brought to the surface by other deep cultivations. In one experiment at Hays there was an average of 15 bindweed seeds per square foot in the surface foot of soil, three years after the cultivation treatment was started and one year after all bindweed plants were dead. The number of seeds was greatest in the plots that had been plowed 8 and 12 inches deep to begin with and a greater proportion were below a depth of four inches.

It seems reasonable to suppose that after land has been cultivated shallow for one year and most of the bindweed seeds near the surface have germinated, an occasional deep plowing in order to bring the deeply buried seeds to the surface so that they will germinate and be killed would be desirable. On the other hand, it would not seem desirable to plow the land much deeper than it had previously been plowed since it became infested with bindweed; such deep plowing would mean increased difficulty with deeply buried seed.

OTHER CONSIDERATIONS IN CULTIVATING TO ERADICATE BINDWEED

It is essential that all bindweed plants be cut off by each cultivation if complete root starvation is to be accomplished. A duckfoot cultivator or homemade duckfoot or blade weeder makes an excellent implement for cultivating bindweed when the sweeps or blades have sufficient overlap and are properly sharpened. A rod weeder is also a satisfactory tool. Occasional use of a moldboard plow or oneway is sometimes necessary or advantageous. The disk, springtooth harrow and the lister are unsuitable for bindweed work since they almost invariably leave uncut and uncovered bindweed vines which continue to feed the roots and thus retard or prevent eradication.

The lateral roots of bindweed usually extend from 6 to 10 feet in the soil beyond the last plant that is visible on the surface. For this reason it is important that the cultivated area extend at least a rod beyond the visible margins of the infestation. Where the bindweed infestation extends beyond the field into a permanent fence row, roadway, pasture or other place where it cannot be included in the cultivated area the bindweed outside the field should be eradicated with chemicals before an intensive cultivation treatment is started in the field. Eradication work on highways, railroad right of ways, etc., should proceed ahead of beginning intensive cultivation on adjoining farm land. Any bindweed plants left outside of the cultivated area will continue to supply food to the roots for a distance of about ten feet into the area and prevent their eradication no matter how long the cultivation treatment is continued. This important fact is too often overlooked.

ERADICATION OF BINDWEED WITH THE HOE

For city dwellers and others who do not have the use of a field cultivator, a hoe is often a satisfactory substitute. In experiments at Hays thorough hoeing at regular intervals of two weeks or less during the growing season has been as effective as has other methods of cultivation. Also hoeing every two weeks has been just as effective as hoeing every 10 days or every week both when the plants were cut off just below the surface and when they were cut three inches deep. When the intervals between hoeings was longer than two weeks the results were not satisfactory.

It is believed advisable to hoe once every 10 days during the first three or four months in order to provide a margin of safety for unusual vigor of the bindweed under certain conditions and for delays that might occasionally prevent hoeing on the scheduled date. After the bindweed has become weakened, as shown by its failure to produce vigorous new growth, the intervals between hoeings can safely be lengthened to two weeks. Eradication can usually be accomplished as quickly with a hoe as with field cultivators, but hoeing must be done somen-hat more frequently. This is accounted for by the generally shallower cultivation and the quicker emergence of the bindweed. The number of hoeings necessary to completely eradicate bindweed will vary from 20 to 40, depending upon the age and vigor of bindweed, soil moisture conditions and the thoroughness with which the work is done.

Cutting off all plants at each hoeing operation is just as essential as when cultivation is done with field implements and for the same reasons. Plants that escape have an opportunity to replenish their root reserves before the next hoeing and death is accordingly delayed. If any bindweed plants are left, outside of the hoed area resuits will not be satisfactory.

Hoeing is the best method of eradicating bindweed around trees, shrubbery and other ornamental plantings where the use of chemicals usually kills all other vegetation as well as bindweed. It is probably the most economical method for farmers who have only small patches of bindweed in the garden, lawn, or other place convenient to the buildings and especially for city property owners who usually have small patches, only, and often not accessible to farm machinery. Several cities in Kansas have used hoeing programs so successfully during the last three years that they have eliminated nearly all bindweed from parks, alleys, parkings and other city-owned property.

COMPETITIVE CROPS

One of the most important results obtained from the experiments at Hays is the discovery that good crops can be grown on bindweed-infested land and the bindweed eradicated at the same time by merely intensifying the methods of crop production now in use by progressive farmers in the region. A year of intensive fallow reduces the stand of bindweed 85 to 90 percent, after which crop competition and intensive cultivation (every two to three weeks) between harvest and seeding completes the kill in from two to four more years. The crop yields are comparable with those on noninfested land and the number of extra cultivations required is no greater than when bindweed is cultivated continuously until it is eradicated before a crop is planted.

It has also been found possible to eradicate bindweed in three to five years at Hays by cultivating intensively between harvest and seeding of crops grown every year. This practice is not considered generally practical, however, in the region where summer fallow increases crop yields. As was pointed out, on page 9, bindweed ordinarily reduces crop yields from 20 to 90 percent. A full year of fallow to reduce the stand of bindweed and store moisture in the soil is necessary to prevent a considerable reduction in crop yields.

Success with competitive crops in eradicating bindweed is strictly dependent upon close attention to several important essentials. The intensive cultivation treatment (every two to three weeks) must be maintained during all fallow periods and during the intervals between harvesting and seeding crops until all bindweed plants are dead. Good stands of crops without skips or thin spots are absolutely necessary. Quick emergence of seed after planting and rapid growth of crops are important. Only close-drilled crops should be used.

SMALL-GRAIN COMPETITIVE CROPS

Experiments comparing nine different methods of growing wheat and two methods of growing rye have been started at Hays, each year since 1936. All experiments are continued four years or longer; therefore, those started in 1938 and in later years have not been completed. The 11 different treatments are outlined and the more important results from experiments started in 1936, 1937, 1938, and 1939 are presented in Table 6.

EXPERIMENTAL TREATMENTS

All of the treatments except No. 2, No. 10, and No. 11 begin with a year of fallow and all except No. 10 and No. 11 include one or two years of fallow during the four-year course of the experiment. In all treatments except No. 11 the land is cultivated 10 days after each first emergence of bindweed or every two or three weeks during fallow periods and is cultivated immediately after crops are harvested and at intervals of two to three weeks until the next crop is seeded. In treatment No. 11, which is considered a noneradication check method, a wheat crop is grown every year and the land is plowed or onewayed about August 1, cultivated again September 5 to 10, and seeded to the next crop September 20 to 25. In all treatments except No. 5, No. 7, No. 9, and No. 11 the crop is drilled October 5 to 10 instead of the normal wheat-seeding date of September 20 to 25 in order to permit one more late season cultivation.

Treatment No. 1, which begins with two years of intensive fallow followed by two crops of wheat, usually results in eradication of bindweed by the end of the second year of fallow and before the first crop of wheat is planted. It therefore serves as a check, or control, with which to compare the other treatments in which wheat or rye is seeded before bindweed has been completely eradicated. Treatment No. 2 is a variation of No. 1 in that sorgo is drilled about July 1 of the first year instead of cultivating throughout the season as in No. 1. Treatment No. 3 consists of a rotation of alternate fallow and wheat while No. 4 includes two years of wheat after the first year of fallow before the land is fallowed a second time. In all four treatments the wheat is drilled October 5 to 10.

TABLE 6.—*Number of years required to kill bindweed by a combination of tillage and cropping with winter wheat and winter rye, Hays, Kansas, 1936 to 1940*

Treatment No.	METHOD AND CROP.	Number of years required to eradicate bindweed in Expts. started in:				Number of bindweed plants per square rod, October, 1940, in Expts. started in:			
		1936.	1937.	1938.	1939.	1936.	1937.	1938.	1939.
1	Fallow 2 years; wheat 2 years; seeded October 5 to 10	2	2	2	2	0	0	0	0
2	Cult. May 1 to July 1; drill sorgo; fallow second year; wheat 2 years; seeded October 5 to 10	2	....	2	*......	0	....	0	20
3	Alternate fallow and wheat; seeded October 5 to 10	2	....	3	*......	0	....	0	42
4	Fallow 1 year; wheat 2 years; seeded October 5 to 10; fallow 1 year	....	3	*......	*......	0	0	2	31
5	Fallow 1 year; wheat seeded September 20 to 25 and harvested for hay in May each year thereafter	2	3	*......	*......	0	0	1	59
6	Fallow 1 year; wheat 3 years; seeded October 5 to 10	2	3	*......	*......	0	0	6	80
7	Same as No. 6 except wheat seeded September 20 to 25	2	*......	*......	*......	0	1.2	28	95
8	Fallow 1 year; rye 3 years; seeded October 5 to 10	2	*......	*......	*......	0	.3	37	113
9	Same as No. 8 except rye seeded September 20 to 25	2	*......	*......	*......	0	.3	12	95
10	Wheat every year; seeded October 5 to 10; intensive cultivation between harvest and seeding	4	....	*......	*......	0	....	63	139
11	Wheat every year; plowed or one-wayed August 1; cultivated September 5 to 10; seeded September 20 to 25	*......	....	*......	*......	254	....	389	205

* Eradication not complete by October, 1940.

In treatment No. 5 the land is fallowed one year and seeded to wheat September 20 to 25. After the first year the wheat is harvested for hay May 20 to 25 each year and the land cultivated intensively until seeding time September 20 to 25. The wheat could probably be pastured off instead of being cut for hay with about equal results. The purpose, here, is to determine whether taking the crop off early and thereby affording an opportunity for early plowing while there is moisture in the soil and before the bindweed has made much growth in the wheat makes it easier to kill the bindweed than when wheat is allowed to ripen and plowing is delayed until about July 1.

Treatments No. 6, No. 7, No. 8, and No. 9 are all quite similar and are designed to compare wheat and rye drilled at both the normal and delayed dates of seeding in a rotation of one year of fallow and three crops. Wheat is used in No. 6 and No. 7 and rye in No. 8 and No. 9.

Treatment No. 10 differs from the first nine methods in that the land is never fallowed, but is cropped to wheat every year, and is different from No. 11 in that an attempt is made to eradicate bindweed by plowing immediately after harvest and cultivating every two to three weeks until the delayed date of seeding, October 5 to 10.

EXPERIMENTAL RESULTS

The results given in Table 6 are complete for the experiments started in 1936 and 1937, but are not complete for those started in 1938 and 1939. Bindweed was killed by all treatments except No. 11 in the experiment started in 1936. In fact, with all methods except No. 10, the bindweed was all dead by the end of the second year. Four years were required to eradicate the bindweed with treatment No. 10 which, it will be remembered, consisted of growing a crop of wheat every year with intensive cultivation between crops.

Treatments No. 2, No. 3, No. 10, and No. 11 were not included in the experiment started in 1937. In this experiment all methods of growing wheat after one or two years of fallow in which the wheat was seeded late (October 5 to 10) or was harvested early for hay eradicated the bindweed in two to three years. These were treatments No. 1, No. 4, No. 5, and No. 6. Treatments No. 7, No. 8, and No. 9, in which wheat seeded early and rye seeded both early and late were used as crops, were less successful but had reduced the bindweed so much by the end of four years that the few surviving plants could have been easily eliminated by spot treatment with sodium chlorate.

In the experiment started in 1938, the bindweed was eradicated in two to three years by the most intensive treatments No. 1, No. 2, and No. 3 and had been reduced to a very small number in three years by treatments No. 4, No. 5, and No. 6. Wheat seeded early (except when cut for hay) and rye (treatments No. 7, No. 8, and No. 9) were somewhat less effective, as they had been also in the 1937 experiment. Treatment No. 10 was still less effective, but had reduced the stand of bindweed about 85 percent in three years as compared with the original stand, while treatment No. 11, the non-eradication check treatment, still had a heavy stand of bindweed.

In the experiment started in 1939 none of the methods except the two years of fallow (treatment No. 1) had completely eliminated bindweed by October, 1940, but the reduction in stand under the different treatments ranked them in about the same order as to effectiveness that they had maintained in earlier experiments. This latter experiment, of course, and also some of the treatments started in 1938 have not been conducted long enough to determine what the final result will be.

The number of experiments that have been completed are not sufficient to permit final conclusions. The results do, however, suggest certain tentative conclusions. On this basis it appears that one may reasonably expect that bindweed at Hays can be eradicated in two years by intensive fallow (treatment No. 1); in three years by alternate fallow and wheat (treatment No. 2); in three to four years by a year of fallow and two or three crops of wheat with intensive cultivation between crops (treatments No. 4, No. 5, and No. 6); and in four or more years by a system of growing wheat every year with intensive cultivation between harvesting and seeding (treatment No. 10). Over a four-year period these various methods have required about the same total number of cultivations to eradicate bindweed, control annual weeds and prepare the ground for seeding even though some of them have resulted in eradication of the bindweed much sooner than others. Since the cost is about the same in each case a good measure of their relative practicability would appear to be the amount of grain that is produced during the course of the treatment.

YIELDS OF COMPETITIVE CROPS

Treatment No. 10, consisting of wheat every year, produced only approximately one-half as much grain in four years as those which began with a year of fallow. The year of fallow reduced the vigor of bindweed and the stand 85 to 95 percent and thus largely eliminated its competitive effect on the subsequent crops. Those treatments which began with a year of intensive cultivation (fallow) followed by three crops of wheat or rye produced considerably more grain during the four years than did treatments which involved two years of fallow and only two crops. This is in agreement with the results of long continued experiments on the Dry Land Agriculture Project at the Fort Hays Branch Experiment Station. In these latter experiments a rotation of one year of fallow and three years of wheat has produced higher yields than rotations of one year of fallow and two years of wheat or of alternate fallow and wheat. Any of these rotations can usually be expected to outyield a rotation of two consecutive years of fallow and two years of wheat.

SUGGESTED COMBINATIONS OF WHEAT AND INTENSIVE CULTIVATION

When judged from the standpoint of crop returns from the land as well as economy and dependability in eradication of the bindweed, the following plan for bindweed-infested land may tentatively be suggested for the region of Hays: fallow one season from about

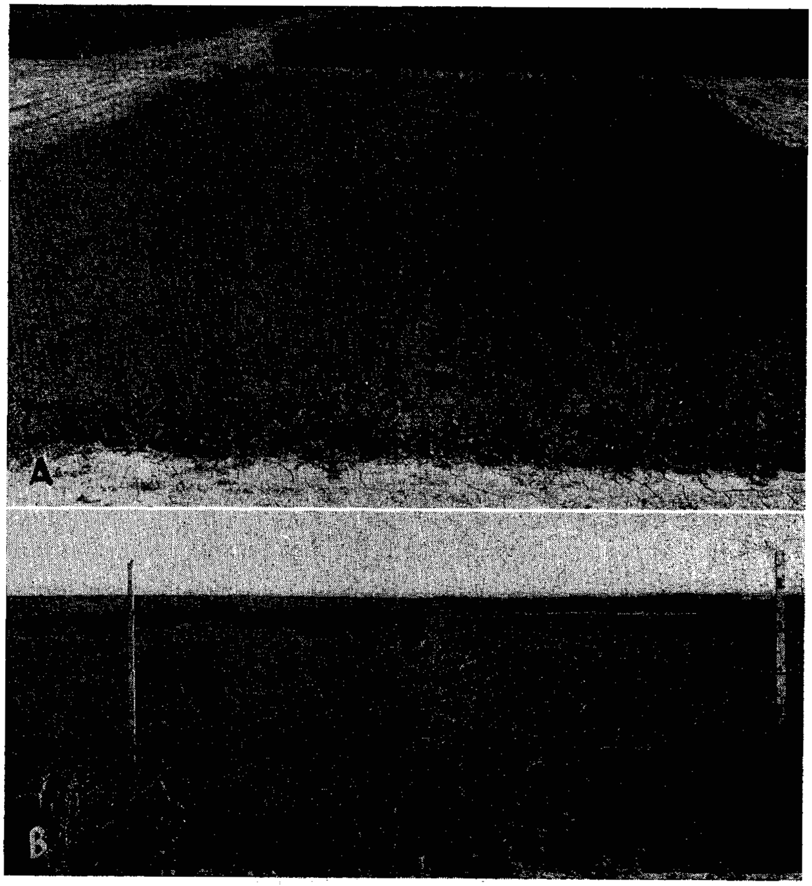

FIG. 4.—Small grain on bindweed-infested land. (A) Land not fallowed before seeding (foreground) and after one year of fallow (background). Note the stunted grain on the nonfallowed land and the bindweed plants in the grain. (B) A close-up view of wheat (left) and rye (right) seeded after one year of fallow. Note the vigorous growing crop and the few surviving bindweed plants.

May 1 to about October 5, cultivating every two weeks during the first three or four months and every three weeks from then until the wheat is seeded in early October. Then grow three crops of wheat, plowing the land as soon as possible after each harvest and cultivate every two or three weeks thereafter until seeding time about October 5. By delaying seeding until early October and cultivating the bindweed immediately before seeding, it is possible to reduce the amount of bindweed growth made in the wheat during the fall and also prevent it from maturing seed before harvest the next year. A good job of cultivation, in which all bindweed is cut off, is essential. A duckfoot cultivator is suitable for this purpose.

In the western one-fourth of Kansas, where a system consisting of a year of fallow and two crops of wheat or one consisting of alternate fallow and wheat are recognized practical methods of growing wheat on noninfested land, they will also probably be among the most practical on bindweed-infested land. The only modifications of the usual farming methods that appear to be necessary are immediate plowing after harvest and thorough cultivation every two to three weeks during the fallow season and between crops. Also the date of seeding wheat would need to be advanced into September in this area, but should be somewhat later than the normal date.

It is believed that, even in more humid regions in the state where summer fallow is not ordinarily practiced, a year of fallow will be helpful to reduce quickly the competitive ability of the bindweed and give the crop an immediate advantage. Exceptions to this may be found on rolling land where erosion would cause serious soil losses from bare fallowed fields. A system of cropping every year, but with intensive cultivation between crops, might be advisable under such conditions.

An extremely important point in connection with the seeding of wheat and also other crops on land that has been cultivated intensively for bindweed control is management of the land in such a way as will insure a good seedbed and a good stand. With frequent cultivation there is often a tendency for the surface soil to become loose and dried out to a depth of several inches if special precautions are not taken or if ample rains are not received at seeding time. To avoid these conditions cultivation should be more shallow as the time for seeding approaches. After the final cultivation and just before seeding the crop, the land should always be packed with a subsurface packer, or a similar tool. In dry seasons at Hays, a packer has been used after the last three or four cultivations previous to seeding wheat with beneficial results. By means of the shallow cultivations and the use of the packer, it is usually possible to hold the moisture near the surface so that the seed can be drilled into it and prompt germination be assured.

SUMMER COMPETITIVE CROPS

Experiments comparing annual summer growing competitive crops have been started every year since 1936 at Hays. The tests have been limited to sorgo (cane), Sudan grass, and foxtail millet. All crops, including the sorgo, were seeded in close-drilled rows with a grain drill. Other crops such as soybeans, drilled corn, sunflowers and hemp, which have been tested elsewhere, are not adapted to western Kansas and have not been used.

The three crops have been compared in two different combination methods with intensive cultivation which extend over a period of four years. The first method consists of intensive fallow for one full season and until about July 1 of the second year, at which time the crop is seeded. After the first year the various crops are grown every year with intensive cultivation in the spring until July 1, when the crop is drilled. The second method is the same as the first except that the full season for fallow at the beginning is omitted and the crops are seeded the first year and every year thereafter following intensive cultivation during the early part of each season up to July 1. A third method, which is a variation of the other two, has been included for comparison. In this method the intensive cultivation treatment is started following small-grain harvest instead of in the spring as in the other two and is continued until July 1 of the second year, when sorgo is drilled. Sorgo is seeded every year thereafter following early season cultivation until about July 1 as in the first two methods. In all three methods, the land is cultivated 10 days after each first emergence of the bindweed or every two to three weeks when it is not in crop. The seeding of crops is delayed somewhat later than is the normal practice, in order to weaken the bindweed as much as possible by the intensive cultivation and to insure prompt germination and rapid growth of the crop.

A fourth method of growing sorgo, which is commonly used in the region of Hays, was included in the tests as a noneradication check treatment. In this method the sorgo is drilled about June 1 each year on land that has not been previously cultivated, except as necessary to prepare it for seeding. This preparation has consisted of plowing, disking, and harrowing just before seeding.

All experiments have been conducted on upland. Sorgo has been grown on bottomland by method No. 2, however, and the results are included for comparison with the upland plots.

The experiments started in 1936 and 1937 have been continued four years and are considered complete. The important results from these two experiments and those obtained thus far from the experiment started in 1938 are given in Table 7.

When sorgo was grown every year on land previously fallowed one full season and until July 1 of the second year (method No. 1), the bindweed was eliminated in each of the three experiments. In each case eradication was complete at the end of the second year. The one and one-half years of intensive cultivation greatly weakened and thinned out the bindweed and the close-drilled sorgo completed the kill.

Sudan grass grown in the same way also completely killed the bindweed in all of the experiments, but in two of them (those started in 1937 and 1938) eradication was not complete until sometime during the third season. That is, somewhat more time was required than for sorgo. Millet failed in most cases to smother out the few

TABLE 7.—*Number of years required to kill bindweed by a combination of tillage and cropping to sorgo, Sudan grass and millet and the yield of these crops on upland at Hays, Kansas, 1936 to 1940*

Method No.	Crop (close-drilled).	Cultivation method.	Number years required to eradicate bindweed in Expts. started in: (1).			Number bindweed plants per square rod, October, 1940, in Expts. started in:			Average yields cured forage; tons per acre in Expts. started in:		
			1936.	1937.	1938.	1936.	1937.	1938.	1936.	1937.	1938.
		Fallowed 1 year, then cultivated from about May 1 to July 1, and the crop seeded each year thereafter.									
1	Sorgo		2	2	2	0	0	0	1.8	1.3	1.1
1	Sudan grass		2	2.5	2.5	0	0	0	1.1	.9	1.0
1	Millet		4	*	*	0	2.6	.4	1.0	1.0	.9
		Cultivated from about May 1 to July 1, and the crop seeded each year.									
2	Sorgo		3	3.5	*	0	0	1.2	.6	1.2	.9
2	Sorgo (bottom land)		......	2.0	3	......	0	0	......	5.5	5.2
2	Sudan grass		3	3.5	*	0	0	.1	.4	1.2	1.2
2	Millet		*	*	*	31	2	.5	.9	.9	1.1
		Cultivated after barley harvest and from about May 1 to July 1, and the sorgo seeded each year thereafter.									
3	Sorgo after barley		3	3.5	*	0	0	5.3	.5	1.3	.7
4	Sorgo	Plowed and seeded about June 1 each year (only 1 cultivation)	*	......	*	32	......	168	.7	......	.4

* Eradication not complete by October, 1940.
(1) An average of two plots in each experiment.

surviving bindweed plants that remained after the one and one-half years of intensive cultivation at the beginning and even permitted bindweed seedlings to become established in the crop.

When sorgo was drilled about July 1 every year on land that had been intensively cultivated since spring, but had not been fallowed a full season at the beginning (method No. 2), the bindweed was killed in three years in one experiment and three and one-half years in another. In the third experiment started in 1938, a few bindweed plants still remained on the plots in October, 1940, after three years of treatment. Sudan grass was equally effective, but millet did not give eradication in any of the experiments. Sorgo on bottom land was more effective than on upland, probably because of the greater supply of soil moisture and the heavier growth of crop.

Method No. 3, in which sorgo was seeded on land intensively cultivated since barley harvest the previous year, was slightly less effective on the average than method No. 2. The method (No. 4) in which the land was cultivated only once each year just before drilling sorgo resulted in a considerable reduction in the stand of bindweed in three or four years, but did not appear to be an effective or practical means of complete eradication. It is, however, a common method of holding bindweed in check in many localities.

The total yields of cured hay during the course of the experiments averaged somewhat higher for the first method under which the land was fallowed one and one-half seasons before the first crop than in the second method in which a crop was grown every year after early season cultivation periods. Hay yields were unusually low on upland throughout the course of the experiments, ranging from only one-fifth to one-third of those on bottomland.

On the basis of these results it appears that fallowing one full season and until about July 1 of the second year before drilling sorgo or Sudan grass is the most practical plan for eradicating bindweed and growing a summer forage crop in the region of Hays. This method has eradicated bindweed one year earlier on the average and has tended to give higher yields than a system of growing crops every year after intensive cultivation previous to seeding, but without a full season of fallow. In more humid regions growing a crop every year would be more advantageous from the standpoint of erosion control and possibly crop yields. The surprising effectiveness of this method on overflow bottomland at Hays indicates that it would be suitable under conditions of abundant soil moisture.

On the basis of results so far secured, millet cannot be recommended. It should be remembered, however, that the seasons during which these experiments were conducted have been abnormally dry. It is possible that millet would prove somewhat more effective in normal seasons though there is no reason to believe this crop will ever prove as satisfactory as sorgo or Sudan grass.

As with winter wheat, it is important that the cultivations be thorough but as shallow as possible as the time for seeding approaches,

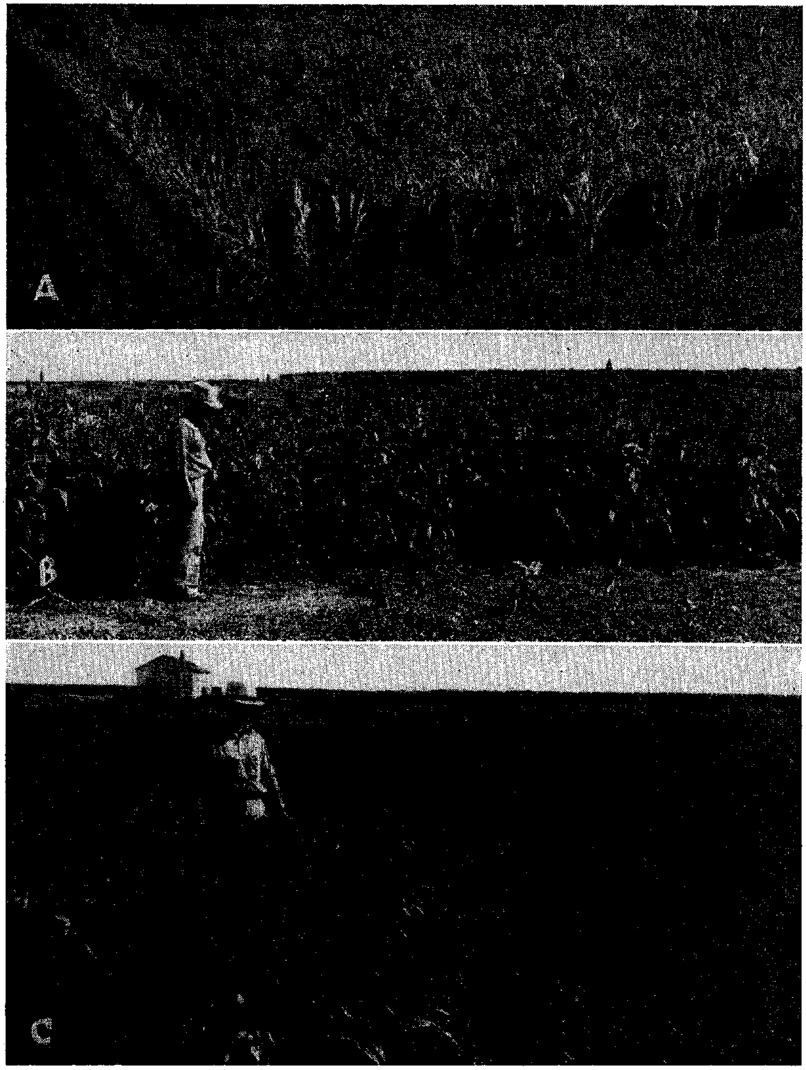

FIG. 5.—Sorgo on bindweed-infested land. (A) Upland; grown every year after intensive cultivation from about May 1 to July 1 (method No. 2). The crop was nearly always stunted by drought, but the bindweed was killed in three to four years. (B) Overflow bottomland; grown as in (A). The crop made a rank growth and the bindweed was killed in two to three years. (C) Upland, but seeded after one and one-half years of intensive cultivation (method No. 1). Sorgo (left) killed the bindweed in two years, but millet (right) was not effective.

and that the land be thoroughly packed with a subsurface packer or similar tool immediately following the last cultivation before drilling the crop in order to insure a good stand.

PERENNIAL AND BIENNIAL COMPETITIVE CROPS

None of the perennial or biennial legume or grass crops are adapted to upland conditions at Hays and do not make a satisfactory growth on clean land, much less compete with bindweed vigorously enough to eliminate it from infested land. According to reports from other states, alfalfa has shown considerable promise as a smother crop for bindweed under conditions of abundant soil moisture, which promotes a vigorous season-long growth of the crop. Alfalfa is grown successfully on bottomland at Hays but not on upland. However, repeated failures to obtain a satisfactory stand of alfalfa at Hays during the unfavorable seasons since 1935 have prevented tests with that crop up to this time.

It has been observed that bindweed patches do not spread readily into established stands of buffalo grass. On the other hand, four years of observations under pasture conditions and fifteen years under lawn conditions indicate that buffalo grass will not crowd out the bindweed after the latter becomes established in either situation.

No experiments have been conducted at Hays with other lawn grasses in competition with bindweed.

CHEMICAL TREATMENTS

SODIUM CHLORATE

A large number of different chemical compounds and mixtures have been used at Hays to determine their effectiveness in eradicating bindweed. Sodium chlorate has been the most satisfactory chemical for general use. Others that were effective and are recommended for certain limited use are common salt and carbon bisulphide. Many other chemicals tested have been found entirely unsatisfactory while some have shown some promise and are being tested further.

The use of weed-killing chemicals of unknown composition or properties and which have not been tested and approved by the Experiment Station should be avoided. Some of these are poisonous to persons handling them and to livestock that eat the sprayed vegetation.

METHOD OF APPLICATION

Sodium chlorate has given approximately the same results at Hays whether applied dry or as a spray solution consisting of one pound of chemical per gallon of water. The two methods have been compared during five years in divided and single applications with about equal average results. Therefore, the choice of the method to use is largely a matter of the safety, economy, and convenience in the particular situation. Data comparing the two methods are given later. (Table 8.)

An important advantage of the dry method is reduction of the fire hazard. When applied dry, most of the chemical comes into immediate contact with the soil, whereas with spraying much of it adheres to the vegetation. Also there is more danger of chlorate adhering to clothing when applied as a spray.

Warning.*—When clothing, dry vegetation of any kind, unpainted boards, and similar inflammable materials are wetted with sodium chlorate solution and allowed to dry they may be ignited easily by friction, sparks, or the heat of the sun, and will burn violently with intense heat. Cases have been reported in which operators were severely or even dangerously burned in this way.* Consequently, when sodium chlorate is applied as a spray, all precautions against fire should be taken. Rubber boots should be worn while spraying and spraying equipment should be kept well painted. Dry applications are not entirely free of fire hazards, particularly when vegetation is wet with dew or rain. Care should be taken so there is no opportunity for the chemical to collect on vegetation or in clothing such as in trouser cuffs or pockets, nor to be spilled in or around buildings where there is inflammable litter that will burn. Gloves should not be worn while handling chlorate, nor should smoking be tolerated. Sodium chlorate is poisonous to animals when consumed in considerable quantity, therefore, livestock should not be allowed to range over areas that have been treated recently.

It is usually more economical to apply sodium chlorate in the dry form than as a spray. The cost of handling and hauling large quantities of water is eliminated and distributing equipment necessary for dry applications is much less expensive than spraying equipment. Mechanical dry chlorate spreaders may be purchased for $25 to $48 that will treat infested land as rapidly as power spraying outfits costing from $200 to $400. In using mechanical dry chlorate spreaders it is important that they be recalibrated frequently to correct for changes in atmospheric conditions, soil conditions or changes in speed of operating, all of which affect the rate at which the chemical is distributed. Care should be used also to prevent skips between swaths with the spreader.

About 85 percent of the sodium chlorate used in Kansas in recent years has been applied dry because of the greater safety and economy. There are situations, however, where the spray method is more satisfactory. Along fence rows, steep road shoulders, ditch banks, and similar places mechanical spreaders cannot be operated effectively and a uniform distribution of the chemical can be obtained most easily with a sprayer. If spray equipment is lacking, the chlorate may be distributed by hand, but care and considerable skill is required to obtain uniform distribution in this way.

Sodium chlorate is leached directly downward into the soil by surface moisture and spreads laterally very little or not at all. For this reason, uniform distribution of the spray or of the dry chemical over the infested area, is absolutely necessary for best results. In all chlorate applications the treated area should include a border strip of 6 to 10 feet beyond the visible limits of the infestation in order to kill lateral roots that nearly always extend several feet from the last surface shoot.

RATE OF APPLYING SODIUM CHLORATE

The amount of sodium chlorate required to eradicate bindweed depends on a number of factors, including soil fertility, age of the infestation, depth of root penetration and the amount of rain and

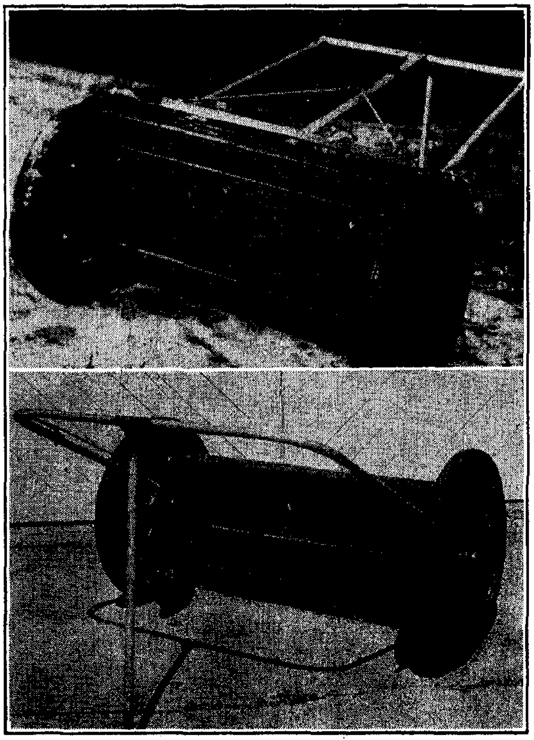

FIG. 6.—Mechanical spreaders for distributing sodium chlorate. Such spreaders provide more uniform distribution of dry sodium chlorate than hand applications and should be used wherever possible.

snowfall received after the application. The influence of these factors and probably others make the results from sodium chlorate treatments quite variable and difficult to predict.

Different rates of applying sodium chlorate, both dry and as a spray, were compared in experiments conducted at Hays each year from 1935 to 1939. Atlacide, a weed-killing mixture consisting in part of sodium chlorate, was included in these experiments. The average percentages of bindweed survival are given in Table 8 for all comparable rates of application in five experiments and separately for three of the experiments conducted from 1935 to 1937 and two started in 1938 and 1939.

In the first three experiments, conducted from 1935 to 1937, three pounds of sodium chlorate per square rod killed over 95 percent of the bindweed and appeared to be the optimum dosage since it was as effective as any heavier rate. In two experiments started in the dry falls of 1938 and 1939 all rates of treatment were much less effective. In this case the higher rates up to five pounds per square rod gave better results than lower rates. Atlacide was not as effective as sodium chlorate at the same rates of application. Nearly twice as much Atlacide as chlorate was required to produce an equivalent kill.

TABLE 8.—*Rate of applying sodium chlorate and Atlacide at Hays, Kansas, 1935 to 1939*

RATE OF APPLICATION POUNDS PER SQUARE ROD.	Average percentage survival of original stand of bindweed on upland and bottom land.		
	3 Expts., 1935 to 1937.	5 Expts., 1935 to 1939.	2 Expts., 1938 to 1939.
Sodium chlorate dry:			
2	16.1	27.5	44.6
2½	9.7	......	......
3	4.5	12.9	25.6
4	4.9	10.2	18.1
5	7.1	7.8	12.4
6	......	......	17.9
Sodium chlorate spray:			
2	20.3	29.1	42.3
2½	8.2	......	......
3	5.3	13.9	26.7
4	3.8	10.6	20.8
5	......	......	13.2
6	......	......	23.5
Atlacide spray:			
3	22.9	26.2	31.1
4	16.8	18.3	29.0
5	......	......	28.8
6	......	......	32.6

The information available indicates that applications of 3 to 4 pounds of sodium chlorate per square rod will prove the most practical for the first application on average upland soils. On bottomland or other low places and on unusually fertile soils rates of 4 to 5 pounds per square rod appear advisable. Where Atlacide is used the rate should be at least one-half greater than for sodium chlorate.

It is usually necessary to apply some additional chlorate the following year to complete the kill. This necessity cannot entirely or even generally be avoided by increasing the rate of the orginal application. The most economical plan is to use a rate for the first application that can usually be depended upon to reduce the stand of bindweed 90 percent or more and then apply chemical where needed the following year to eradicate the surviving plants.

Bindweed patches located on old stack bottoms, in barnyards, feedlots or heavily manured areas in fields are nearly always extremely difficult to eradicate with sodium chlorate. The amount of chlorate required to eradicate bindweed in such areas is often many times the normal rate of application due to the action of the organic matter. Cultivation or hoeing is usually a more satisfactory method of eradicating bindweed under these circumstances.

TIME OF APPLYING SODIUM CHLORATE

Results from experiments in which sodium chlorate has been applied at different times in the year have been variable, probably because of seasonal differences and the large number of factors involved. In these experiments applications have been made on 10 different dates each year using 2½ pounds per square rod on all dates except in 1939, when the rate was 4 pounds per square rod. The results are given in Table 9. As an average of the four experiments, chlorate treatments in October gave the best kills, while those made in November, September, August, and July averaged only slightly less effective. Treatments made June 1 or earlier gave much poorer results in 1936 and 1939 and were considerably less effective as an average of the four experiments. Similar results have been reported from other states.

TABLE 9.—*The relation of date of application to the effectiveness of dry chlorate treatments at Hays, Kans., 1936 to 1939*

DATE OF APPLICATION (1).	Number of surviving bindweed plants per square rod in experiments started in: (2).				
	1936.	1937.	1938.	1939.	Average.
April 1 to 15	253	5.5	.4	147	102
May 1	361	16.5	34	270	171
June 1	229	3.5	17	153	101
July 1	79	2	19	78	44
August 1	65	1	28	155	62
September 1	70	5.5	9	77	40
September 15	48	1.5	28	104	45
October 1	31	.5	9	71	28
October 15	....	3	3	81	29(3)
November 1	58	6	32	103	5[illegible]
Untreated checks	633	534	620	648	609

(1) The rate of application was 2½ pounds per square rod on all plots in 1936, 1937, and 1938 and 4 pounds per square rod on all plots in 1939.
(2) An average of two plots for each date.
(3) Corrected on the basis of other dates in the same experiments.

The results indicate a considerable range in time during the year when chlorate applications can be made with about equal chances of success. Within this range the months of September and October usually provide the most favorable conditions for chlorate treatments. It is desirable that chlorate treatments be made as early in the fall season as possible so that enough rain will be received to leach the chemical to an effective depth in the soil before winter.

During July and August bindweed is often dormant and it is difficult to locate the limits of the infestation. High temperatures increase the fire hazard in using chlorate and heavy rains resulting in loss of chemical and poor kills are more likely to occur than in the fall. Applications in the spring should always be avoided because

FIG. 7.—Results from applications of 2½ pounds of sodium chlorate per square rod at different times during the year. (Upper left corner: May 1. Upper right corner: June 1. Lower left corner: October 1. Lower right corner: November 1.)

of the probability of heavy losses of chlorate due to excessive leaching from heavy rains and perhaps to decomposition of the chlorate under the conditions of abundant moisture and high temperatures.

METHODS OF WORKING DRY CHLORATE INTO THE SOIL

As an average of five experiments, each in a different year, broadcasting dry sodium chlorate on the surface without tillage has given as good results as any of four methods of working the chemical into the soil. The data from this experiment are given in Table 10. In three of the five years (1937,1938, and 1939) there was a slight advantage for disking the chlorate in. Plowing the chlorate under did not increase its effectiveness while plowing the land previous to application made uniform distribution of the chemical difficult and resulted in poorer kills of bindweed. The grain drill as an implement for applying chlorate proved to be wholly unsatisfactory in practice since it could not be adjusted to feed the chlorate at a constant rate.

Also the chlorate severely rusted all metal parts of the drill and made the wooden parts dangerously inflammable.

The results of these experiments are corroborated by observations made at many places in Kansas. They indicate that no advantage is likely to be gained by working dry chlorate into the soil except where the surface of the treated area is so smooth and devoid of vegetation that the chemical may be blown or washed away, and where necessary to reduce the poison hazard to livestock. In such cases, a light working with a disk, drill or similar tool after the chemical is applied gives sufficient protection. Where water pressure is available near buildings thorough sprinkling immediately after the chemical is applied is believed to be a desirable practice.

TABLE 10.—*The relative effectiveness of different methods of applying dry sodium chlorate at Hays, Kansas, 1935 to 1939*

METHOD OF APPLICATION.*	Average number of surviving bindweed plants per sq. rd.		Percent survival of original stand of bindweed.	
	5 Expts., 1935-'39.	3 Expts., 1935-'37.	5 Expts., 1935-'39.	3 Expts., 1935-'37.
Broadcast on surface; no tillage	88	28	11.9	4.1
Broadcast and disked in	94	14	10.9	1.4
Broadcast, plowed under and disked	71	27	10.4	4.3
Broadcast on land that had been plowed and disked	100	47	14.4	6.7
Drilled in with a grain drill	....	42	....	4.6
Untreated checks	890	858	112.0	122.0

* The rate of application was 2½ pounds per square rod on all plots in 1935, 1936, and 1937 and 3½ pounds per square rod on all plots in 1938 and 1939.

Plowing the land immediately after a chlorate application is not only a useless expense but is likely to interfere with best results. Chlorate-treated areas should not be disturbed by plowing, listing or other deep tillage until after any necessary retreatments have been made, all surviving bindweed plants have been eradicated and the land is ready to go back into cultivation with the remainder of the field.

FOLLOW-UP SODIUM CHLORATE TREATMENTS

Complete eradication of bindweed has seldom been accomplished by the first year's treatment with sodium chlorate even when the rate of application was heavy. Usually additional applications to surviving plants were necessary the following year and occasionally in later years. There has been no advantage at Hays from follow-up treatments made before August or September of the year following the original applications. Bindweed plants have continued to die for a year and in some cases for nearly two years after the original chlorate treatment without any additional applications.

The surviving plants should be retreated with sodium chlorate as soon as they begin to recover from the effects of the original treatment, but generally not before. Recovery is evidenced by a change from the characteristic pale yellowish-green vine growth of chlorate-sick plants with small widely scattered leaves, to more vigorous growth with larger leaves having a deeper green color. Recovery of surviving plants begins earlier in years of heavy rainfall, and in eastern Kansas is reported to take place as early as May or June in some years.

The method of follow-up treatment with sodium chlorate depends upon the number of bindweed plants that survived the original treatment. When there are less than about 30 plants per square rod and they average three feet or more apart it is usually more economical to treat each plant individually than to retreat the entire area. In that case, a teaspoonful of dry chlorate is sifted over an area about 6 inches in diameter around each plant or the plant may be sprayed thoroughly with a chlorate solution. If by excavation in the treated area it is found that nearly all bindweed roots, including laterals, have been killed to a depth of 12 inches or more by the original treatment the surviving plants should be treated individually even though there are as many as 50 per square rod.

Complete area retreatment with a mechanical spreader or a spray machine is recommended where the survival of bindweed is 10 percent or more of the original stand and where the lateral roots are still alive in the surface foot of soil. The rate of retreatment should vary from 1 to 4 pounds per square rod, depending upon the vigor and thickness of the surviving stand of bindweed.

At Hays, cultivation has not proved to be an economical method of completing the eradication of bindweed after chlorate treatment. As an average of three experiments 13 cultivations were required to eliminate surviving plants from land that had been treated with sodium chlorate as compared to 19 cultivations necessary to eradicate bindweed from untreated land. Cutting off surviving plants with a hoe at intervals of two to three weeks will eventually kill them if continued long enough.

OTHER CONSIDERATIONS IN THE USE OF SODIUM CHLORATE

Sodium chlorate is destructive to nearly all forms of vegetation and when applied in sufficient amount to eradicate bindweed kills crops and garden plants, shrubs and small trees that are rooted in the treated area. Large trees are usually not killed by such treatments. Chlorate also renders the soil practically sterile to all plant growth for from one to three years, depending upon the rate of application, the type of soil, the amount of rainfall received after the treatment and possibly other factors. The detrimental effects on crops and ornamental plants are evident for from two to five years after the final application. These detrimental effects limit the use of sodium chlorate for bindweed control largely to uncultivated areas such as roadsides, railroad right of ways, fence rows and wasteland.

The cost of eradicating bindweed with sodium chlorate usually ranges from 30 to 45 cents per square rod or about $50 to $75 per acre. This is at least ten times the cost of eradication by intensive cultivation or smother cropping on areas large enough to use these methods. Furthermore, the productivity of the soil is usually increased by intensive cultivation rather than decreased as in the case with chlorate. For these reasons, it is usually not desirable to use sodium chlorate on cropland except for eradicating very small isolated or widely scattered patches of bindweed. Many landowners are cultivating small patches of one-fourth acre or less with homemade implements or using a hoe in preference to treating with sodium chlorate. The principal advantage of sodium chlorate treatment is that the infested area requires attention but once or twice a year during the eradication process while with cultivation the area must be gone over every two or three weeks for two growing seasons.

SALTING BINDWEED

Common salt (sodium chloride) was the first chemical to be used successfully in controlling bindweed in Kansas. Experiments at the Fort Hays Branch Experiment Station during the 13-year period 1913 to 1925 showed the optimum rate of treatment to be 20 tons per acre at first, followed by a second application to any plants missed by the first treatment. Twenty tons to the acre amounts to almost one pound to the square foot, or a layer about one-fifth of an inch thick. The stand of bindweed left after lighter applications of salt varied from 15 percent for the 16-ton treatment to 75 percent for the 8-ton treatment.

These results indicated that salting treatments are effective when made anytime during the growing season but that the most favorable time is in the spring as soon as the bindweed has emerged. The limits of the infestation can then be determined and there is not sufficient vine growth or other vegetation to interfere with uniform distribution of the salt. When treatments are made later in the season all excess vegetation should be removed, leaving only enough to hold the salt in place and prevent shifting by wind or runoff water. No advantage was found for cultivating the land just previous to salting. Plowing soon after treatment definitely decreased the kill.

INJURIOUS EFFECTS OF SALT

Salting as a method of eradicating bindweed has the serious disadvantage of leaving the soil sterile and not capable of profitable crop production for many years. The yields of wheat at Hays in 1939 on areas that had been treated with salt 20 years previously at the rates of 8, 12, 20, 24, and 28 tons per acre were 15.0, 6.2, 7.4, 3.3, and 2.4 bushels per acre, respectively, compared to 17.2 bushels per acre on untreated land in the same field. Salted spots are objectionable from the standpoint of appearance and tillage, as the soil acquires a whitish color and a sticky structure like gumbo. The greater the rainfall the sooner the salt is leached from the soil. In western Kansas there are areas salted 15 or more years ago that are still bare or are growing only Russian thistles.

Heavy applications of salt will kill the largest trees even when the treated area is several feet from the trunk and in some cases when only a relatively small part of the root system extends into the salted soil.

RECOMMENDATIONS FOR THE USE OF SALT

The use of salt for bindweed control should be restricted to permanent fence rows, railroad right of ways, irrigation and drainage ditches and ditch banks, roadsides, around buildings, oil wells or petroleum bulk or supply stations and other areas where more or less permanent sterility of the soil is desired or not objectionable or where sodium chlorate is a fire hazard. An important advantage of salting bindweed is that it prevents, for many years at least, the re-infestation of the land from bindweed seeds which are nearly always present in considerable numbers in infested soil. Water should not be run through irrigation ditches that have been treated with salt until all of the salt has been dissolved by surface moisture and absorbed into the soil. Failure to observe this precaution may result in serious damage to crops on which the water is used. Salt should be hoed into the surface soil or dissolved and leached into the soil by artificial watering when it is used on sloping land or in watercourses in order to prevent it from being carried out onto an adjoining field or other productive land by runoff water.

Salt should not be used on cultivated land, within the feeding zone of tree roots or anywhere that its effects on the soil would interfere with future plantings for landscaping and beautification purposes. Sodium chlorate is preferable to salt wherever permanent soil sterility is not desirable since the detrimental effects of the chlorate persist in the soil for a much shorter period. At the present prices for "bindweed salt" delivered at various points in Kansas, the cost of eradicating bindweed is about the same with salt as with sodium chlorate.

ERADICATING BINDWEED WITH CARBON BISULPHIDE

Experience at the Fort Hays Branch Experiment Station with carbon bisulphide has shown it to be effective in eradicating bindweed when used during warm weather on soil that is moist—not muddy—from the surface down to a depth of at least 12 to 14 inches. Treatment with carbon bisulphide immediately kills all plant and animal life in the soil within the zone of penetration but does not injure the productivity of the soil for more than a few weeks. The treatment is very expensive, ranging from $1.50 to $2 per square rod or $240 to $320 per acre. This limits its use for bindweed control in Kansas to small areas in special locations where the advantage of immediate eradication and of the ability to grow valuable garden or ornamental plants on the soil within a few weeks after treatment outweighs the disadvantage of the much greater cost.

Carbon bisulphide is a liquid about one-fourth heavier than water and evaporates readily, forming a gas about 2½ times heavier than air. *The fumes from carbon bisulphide are highly explosive. Fire of any kind should be kept entirely away from the material at all times. The precautions in handling it should be the same as for handling gasoline.*

METHODS OF TREATMENT

Tools necessary in applying carbon bisulphide consist of a sharpened iron prod for making holes, a 2-foot length of one-half inch galvanized pipe with a funnel and measuring cup attached for measuring and pouring the liquid, a teakettle or similar convenient container to be used in pouring the liquid into the measuring cup and a wooden tamper. *Metal or metal-shod tampers should not be used because of the danger of explosions caused by sparks.* Probe and funnel-pipe sets can be purchased from manufacturers of carbon bisulphide at a cost of about $2.50 or can be made by local blacksmiths. An automatic hand applicator designed for labor economy which probes the hole and injects the carbon bisulphide in one operation is also on the market.

Experience in Idaho[7], where carbon bisulphide has been used extensively, shows that it can be successfully used on nearly all types of soils except those that are loose or gravelly and those that are extremely heavy. Carbon bisulphide should be applied only to land where the soil is moist from the surface down to a depth of 12 to 14 inches. All vegetation should be cleaned off of areas to be treated. The chemical is placed in holes 6 to 8 inches deep in staggered rows 18 inches apart. Two ounces of the material are applied in each hole, at which rate approximately 2 gallons per square rod are required. Each hole should be thoroughly tamped immediately with a wooden tamper after application. Care should be taken to treat several feet beyond the farthest plant in an infested area to prevent a fringe of regrowth around the outside of the patches. The treated area should be left undisturbed for three or four weeks after treatment except for occasional watering with a sprinkler during the first 10 days to keep the surface soil sealed and prevent escape of the carbon bisulphide gas.

The land should be turned over rough with a plow or spade three or four weeks after treatment. Bindweed crowns and short lengths of top roots are frequently left alive near the surface. These should be lifted out of the soil with a spade or shovel and destroyed or left exposed so that they will dry out and die. The land should be stirred twice more at intervals of 10 days or two weeks, after which crops or ornamental plants may safely be planted. A careful watch should be maintained for bindweed seedlings as the seed is not destroyed by the treatment.

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7. Spence, H. L., Jr. Eradicating perennial weeds with carbon bisulphide. Idaho Ext. Bul. 106, 1937.

RESULTS IN A BUFFALO GRASS LAWN

Carbon bisulphide treatment was successfully used to eradicate bindweed from a buffalo grass lawn at the Fort Hays Branch Experiment' Station in the summer of 1940 with only temporary injury to the grass. The sod was thoroughly watered by sprinkling three days previous to treatment and watered moderately three days aftertreatment and at intervals thereafter. The bindweed crowns that remained alive were removed to a depth of 5 or 6 inches with a dandelion digger. The buffalo grass showed a temporary browning effect, but regained its normal color and vigor within a few weeks.

Watering the sod heavily the next day after carbon bisulphide treatment greatly reduced the effectiveness in killing bindweed. The killing effect on bindweed was satisfactory when watering was delayed either three days or a week after treatment, but injury to the grass was greatly increased in the latter case.

A further study of the method is needed, but the limited experimental evidence available indicates that it is possible with the use of special care to eradicate the deeply rooted bindweed from a lawn or pasture by the use of carbon bisulphide without destroying or permanently injuring the stand of grass.

CROPS FOR CHLORATE-TREATED LAND

Sodium chlorate treatment has been used for bindweed control on cropland in Kansas only on small patches in most cases. Nevertheless, the total area of farm land in the state treated with chlorate exceeded 1,900 acres in 1939 and was slightly more in 1938, according to statistics compiled by the Kansas State Board of Agriculture.[8]

Chlorate-treated land should be planted to a suitable crop as soon as all bindweed plants have been eradicated, usually the second or third season following the original treatment,. Crops should not be planted until all bindweed has been killed on each infestation. Otherwise the land may become reinfested from the few surviving plants that remain.

It is important to know what crops will grow best on chlorate-treated land from which bindweed has been eradicated in order to increase the return from the land, reduce soil erosion and to provide the strongest possible crop competition for bindweed seedlings that might otherwise reinfest the area as soon as the residual effects of chlorate in the soil have been reduced sufficiently to permit plant growth.

Two experiments have been conducted at the Fort Hays Branch Station to study the duration of the detrimental effects of sodium chlorate in the soil and the relative tolerance of different crops to these effect's. Applications of sodium chlorate at rates of 2½ and 5 pounds per square rod were made on strips of noninfested land in September, 1935, and again on new strips in September, 1936. Ten

8. Yost, T. F. Summary of bindweed situation and progress of eradication in 1939. Kan. Bd. of Agr. Rpt. Vol. 59, No. 237, June, 1940.

different crops were planted each year thereafter across the treated strips and adjoining strips of untreated land and the yields determined separately for the different treatments. The relative total yields of the various crops on chlorate-treated land during the 5- and 4-year periods of the experiments are given in Table 11 as percentage of the total yields of the crops on untreated land.

The sorghums and corn produced more nearly normal yields on treated land than did the small grains. Surface-drilled sorgo and Sudan grass were injured less by chlorate than row crops planted with a lister, probably because the more shallow root development in the former absorbed less of the chlorate that had been leached to deeper soil levels. The rank of the different crops in decreasing tolerance to the effects of chlorate in the soil was sorgo, Sudan grass, milo, corn, kafir, oats, rye, sweet clover, barley, and wheat.

TABLE 11.—*The effect of residual sodium chlorate in the soil on yields of different crops at Hays, Kansas, 1936 to 1940*

CROP.	Yields on chlorate-treated land in percent of untreated check plots.*			
	Percent of total yields, 1936-'40; sodium chlorate applied Sept. 21, 1935.		Percent of total yields, 1937-'40; sodium chlorate applied Sept. 1, 1936.	
	2½ pounds per sq. rd.	5 pounds per sq. rd.	2½ pounds per sq. rd.	5 pounds per sq. rd.
Barley	48	18	24	16
Oats	82	41	65	36
Rye	69	29	51	8
Wheat	40	17	30	3
Corn	86	51	66	45
Kafir	74	34	67	50
Milo	86	40	87	81
Sorgo (drilled 8-inch rows)	108	81	87	76
Sudan grass	96	69	74	88
Sweet clover	56	29	38	4

* Grain yields only for barley, oats, rye and wheat; grain and forage yields for kafir and milo and forage yields only for corn, sorgo, Sudan grass and sweet clover.

Close-drilled sorgo and Sudan grass appear to be definitely superior to all other crops for planting on chlorate-treated land not only because they produce a greater return but also because of the vigorous competition they afford bindweed seedlings during the growing season and their ability to prevent soil erosion. Row sorghum is a second choice provided cultivation after the crop is planted is thorough enough to destroy all bindweed seedlings. Oats is a fairly suitable crop if the land is plowed immediately after harvest and cultivated occasionally during the remainder of the season to destroy annual weeds and bindweed seedlings. Flax and most perennial grasses are known to be highly tolerant to the effects of sodium chlorate and might be suitable in eastern Kansas although it is doubtful if they would be as satisfactory as close-drilled sorgo or Sudan grass.

The detrimental effects of sodium chlorate on crops diminished from year to year following the treatment but were still apparent in the yields of barley and wheat after three to five years. On the other hand, the yields of the different sorghum crops were reduced for only two years following applications of five pounds of sodium chlorate per square rod and for only one year following applications of 2½ pounds per square rod. It is believed that the detrimental effect of chlorate on crops was more severe and persisted over a greater length of time in these experiments, conducted on a rather heavy soil during abnormally dry years, than would be the case on a lighter soil or under conditions of greater rainfall.

CONTROL OF BINDWEED SEEDLINGS

BINDWEED SEED AND THE SEEDLING PLANT

The problem of preventing reinfestation from the large number of bindweed seeds frequently contained in previously infested land is nearly as important as that of eradicating the original stand. Bindweed seed has a hard, thick outer coat or shell that is impervious to water and causes a considerable percentage of the seeds to lie dormant in the soil many years before germination. The number of bindweed seeds remaining in the soil after eradication of the old plants is believed to vary considerably with (1) eradication tillage methods, (2) age of the infestation or number of seed crops produced, and (3) climatic conditions and ability of the bindweed plant to produce seeds. Some infestations have been known never to produce seeds. It is believed that the soil in some infested areas is heavily populated while that in other areas contains very few bindweed seeds. Generally speaking, the longer bindweed is allowed to remain on land the more serious will be the seedling problem after eradication has been accomplished.

In observations at the Fort Hays Branch Experiment Station on land that had been infested many years seedlings continued to emerge in large numbers for five to eight years after the original bindweed had been eradicated. A thick stand of bindweed seedlings came up in the spring of 1928 on one field from which all old plants had been eliminated in 1920. An average of 66 seedlings per square rod emerged in the spring of 1940 on an area that had been free from old bindweed plants since 1936 and on which no seed had been produced since 1935. Bindweed seedling emergence tends to be heaviest in early spring, but may take place at any time during the growing season when the soil is moist within one or two inches of the surface.

A newly emerged bindweed seedling has two bluntly heart-shaped leaves notched at the top resembling those of a seedling radish. These remain attached at the base of the vine for several weeks and serve as an easy means of distinguishing a seedling from an old plant after the seedling has developed several of the characteristic arrow-shaped bindweed leaves. A bindweed seedling one month old can be killed by cutting it off once to a depth of three or four inches with a

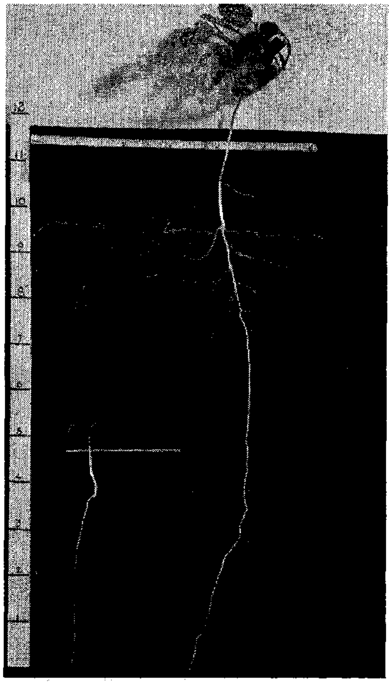

FIG. 8.—Bindweed seedlings at different stages of development. The small seedling is one week old and the large seedling is six weeks old. The units shown are inches. (Photograph courtesy Dr. J. C. Frazier, Kan. Agr. Expt. Sta., Manhattan, Kan.)

hoe or other cultivation implement,. Younger seedlings are killed as easily as the seedlings of other plants when uprooted or cut off by any kind of a farm tool.

Studies made by Dr. J. C. Frazier[9] of the Kansas State College at Manhattan show that the average bindweed seedling at the age of six weeks has developed a root system 12 inches deep with a lateral spread of seven inches. Seedlings at that age usually cannot be killed by an ordinary cultivation four or five inches deep, but will nearly always send up new shoots from below that depth. Obviously

9. Frazier, J. C. Unpublished data of the Botany Department, Kan. Agr. Expt. Sta., Manhattan, Kan.

any successful method of controlling bindweed seedlings must not let them grow more than a month between cultivavtions when the land is not in a good stand of close-drilled or inter-tilled crop.

CONTROL OF SEEDLINGS IN CULTIVATED FIELDS

In an experiment begun at the Fort Hays Station in 1937 both wheat and sorghum grown continuously or in rotation with fallow were effective in preventing reinfestation of the land by bindweed seedlings where good stands of crop were obtained and where the cultivation was thorough enough to destroy all annual weeds once a month in the intertilled crop and between harvest and seeding. On the other hand, when the stand of the crop was thin or spotted, or the land was allowed to remain in stubble after harvest without cultivation during the remainder of the season, or when the sorghum row crop was cultivated indifferently, many bindweed seedlings were able to establish themselves so that ordinary cultivation did not kill them.

Fields from which bindweed has been eradicated should be given careful attention under a system of superior farming practice for an indefinite period of years. Close-drilled sorghums and small grain crops appear to be the most suitable for this purpose, but row crops are usually satisfactory if thoroughly intercultivated. When the stand of close-drilled crop is thin or spotted it should be destroyed early in the season and the land prepared for other crop or it should be plowed immediately after harvest and closely observed for bindweed plants that may have established themselves.

The number of extra cultivations required for bindweed seedling control that would not otherwise be necessary to destroy annual weeds usually does not exceed two or three each season. The cost of these extra cultivations is small, but the danger of reinfestation if they are omitted is great. This was demonstrated on one area on the bindweed control project at Hays in 1940. A portion of a field which had been free from bindweed since 1937, but which had a uniform emergence of seedlings in the spring of 1940, was not cultivated until June 15 and was given a second cultivation August 15. The seedling plants had established themselves and spread so rapidly that in October there was almost a complete stand of bindweed that would require at least a year of intensive cultivation to eradicate (see Figure 9). Another portion of the same field was cultivated for the first time May 15 when the bindweed seedlings were about a month old. The plot was given four additional cultivations during the season at intervals of about a month and when wheat was seeded in early October there were no bindweed plants. A third part of the field was cultivated May 15 and again June 1, at which time it was listed for kafir. The crops were cultivated only twice during the season, but this was sufficient to prevent any bindweed seedlings from becoming established. Thus two extra cultivations in one and three in another meant the difference between a field free from bindweed and one almost completely reinfested.

The growing of perennial crops eliminates extra cultivation costs but is likely to extend the time during which bindweed seed will remain dormant in the soil as compared to land that is stirred frequently under annual crop production. Alfalfa, where it is adapted, is probably the most suitable perennial crop for controlling bindweed seedlings. Since alfalfa is not adapted to upland soil at Hays its effectiveness in controlling bindweed has not been tested there.

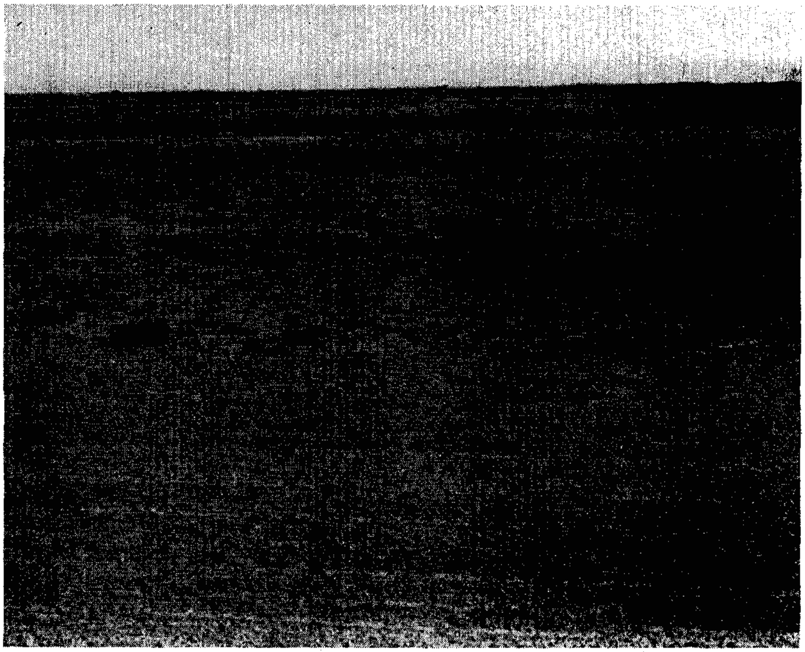

FIG. 9.—View showing in the background a full stand of bindweed developed from seedlings in one season on a field that had been cultivated only twice, and in the foreground, a portion of the same field which had been cultivated five times during the season and was free from bindweed at wheat seeding time in early October.

There is still a possibility that an occasional bindweed seedling will survive crop competition and escape destruction by cultivation even under the most carefully planned and persistently followed cropping system. For this reason, it is important that a careful watch be maintained for many years on all previously infested fields for individual bindweed plants or small patches. These can be eradicated with little difficulty or expense by treatment with sodium chlorate if they are found and treated before they are more than a year or two old.

CONTROL OF SEEDLINGS ON UNCULTIVATED LAND

The control of bindweed seedlings on chlorate-treated land in uncultivated areas, such as fence rows and roadsides, presents a somewhat different problem than that in cultivated fields. The length of time during which seedlings will continue to emerge on uncultivated land is believed to be much less since seeds have usually not been buried deeply by cultivation but remain near the surface subject to conditions which encourage germination. A considerable percentage of the bindweed seed on chlorate-treated land in uncultivated areas apparently germinates and the seedlings are killed while the effects of the chlorate treatment are still present in the surface soil. On the other hand, some seedlings do emerge in many cases after the effects of the sodium chlorate are diminished and unless control measures are taken frequently reinfest the land. Where salt has been used to eradicate bindweed in uncultivated areas there is usually no seedling problem since the land remains sterile to all plant growth for many years.

All areas on uncultivated land from which bindweed has been eradicated by chemical treatment should be closely inspected several times during each season and any seedling plants found given a light application of sodium chlorate. Inspection of such areas should be continued until no bindweed plants are found for two seasons. Constant vigilance and persistent effort to kill seedling plants are the price that must be paid to keep previously infested land free from bindweed and prevent the difficult and expensive job of eradication from having to be done over again.

The necessity for being constanly on guard against reinfestation from seedlings on land that has once been infested with bindweed emphasizes the importance of farmers and other landowners being careful to avoid bringing bindweed seed on their land in livestock feeds, crop seed, garden or flower seed, balled evergreen trees, or fill-in dirt from infested land. It also emphasizes the advantage of starting eradication treatment on infested land without delay in order to prevent further spread to new land and stop the production of bindweed seed that will remain in the soil for many years as a constant threat to reinfest the land whenever an opportunity is afforded.

SUMMARY

Results from experiments in the control of field bindweed *(Convolvulus arvenis)* at the Fort Hays Branch Experiment Station, 1935 to 1940, are presented together with recommendations for their application in central and western Kansas. This period of years has been drier than may normally be expected in the Hays territory and it may be that modifications in the methods and practices suggested here will be found advisable with moisture conditions somewhat more favorable.

Grain and forage yields of nine different crops grown with methods comparable to average farm practice were reduced from 20 to nearly 90 percent by bindweed competition. Wheat and other small grains produced more nearly normal yields on infested land than sorghums and other summer growing crops.

Intensive fallow usually eliminated the bindweed in two seasons or less and proved more dependable and much lees expensive than eradication by chemicals.

Cultivation 12 days after each first emergence eliminated bindweed with 16½ operations as an average of seven experiments, compared with 33 cultivations when cultivated immediately after they emerged, which until recently has been the commonly accepted practice, This means a reduction of one-half in the cost of eradication by cultivation methods.

Cultivating 8 days after emergence required 19 cultivations, and 4 days after emergence required 23 cultivations for eradication. When 16 days or more of top growth were allowed, no saving in cultivations resulted and the time necessary for eradication was lengthened one or more years. The best plan for practical use appears to be to cultivate every two weeks during the first three or four months of the treatment or until the bindweed has been weakened and emerges more slowly, after which the interval can be safely lengthened to three weeks.

The two most favorable times for beginning cultivation considering all factors appear to be in the spring soon after bindweed growth started and after small grain harvest as soon as sufficient soil moisture is present to promote bindweed growth and permit thorough tillage.

No advantage was found for cultivating bindweed deeper than necessary to cut off all plants well below the surface at each operation. The optimum depth in the medium heavy soil at Hays was four inches. After eradication is complete and bindweed seed near the surface has been germinated, there is probably an advantage in gradually increasing the depth of plowing to bring deeply buried seed to the surface where they will germinate and the seedlings can be killed.

Hoeing every 10 days to 2 weeks eradicated bindweed as quickly as other forms of cultivation and appears to be a good method for use in cities and on small patches near farm buildings or around trees where field machinery is not available or cannot be used.

One year of intensive fallow and three crops of wheat seeded in early October each year after intensive cultivation between harvest and seeding, eradicated bindweed in from three to four years and proved to be a practical plan for the region of Hays. Alternate fallow and wheat and a rotation of one year of fallow and two years of wheat also appear to be good methods for use in western Kansas. This requires no change in methods already followed by progressive farms in growing wheat other than timely and thorough cultivation at approximately two-week intervals when the land is not in crop.

Close-drilled sorgo seeded about July 1 after 1½ years of intensive cultivation always eliminated the bindweed in two years. Sorgo drilled each year about July 1 after thorough cultivation from about, May 1 to seeding time required one or two years longer to accomplish eradication and tended to produce lower yields of forage. However, this appears to be an excellent method for use under conditions of abundant soil moisture, especially where soil erosion is an important consideration. Sudan grass was nearly as effective as sorgo under both methods, but millet was not satsifactory. Smother crops should never be pastured and cultivation should begin immediately after the crops are harvested.

The use of competitive crops in combination with intensive cultivation promises to be the most economical method of controlling, or eradicating bindweed on large areas of infested land. Thorough tillage and strict attention to essential requirements are, however, positively necessary for success.

Sodium chlorate proved to be the most satisfactory chemical for general use in treating bindweed. The cost of chlorate treatment averages about ten times that of intensive cultivation. This and the undesirable residual effects of chlorate restricts its use largely to small patches and to uncultivated areas.

Because of the fire hazard when sodium chlorate is *applied as a spray, rubber boots should be worn and care taken to prevent clothing or wooden equipment from being soaked by the solution. Gloves should not be worn while handling chlorate and care should be used to prevent the dry chemical from collecting in clothing, such as in trouser cuffs or pockets, and from being spilled in or around buildings where there is inflammable litter that will burn.*

The results were approximately the same whether sodium chlorate was applied dry or as a spray solution. About 85 percent of this chemical used in Kansas in recent years has been applied dry because of the greater safety and economy of that method.

Experimental results with date and rate of chlorate treatments were quite variable from year to year and probably will be somewhatdifferent for other parts of the state than at Hays.

In the experiments at Hays, September and October have been found the most favorable months for sodium chlorate treatments. Treating in the spring and early summer gave the poorest kills. Results elsewhere have uniformly indicated that late summer and fall is generally the preferable time of the year.

Three to four pounds per square rod have, in general, given the most economical results on upland at Hays. Four to five pounds should probably be used on bottomland or on unusually fertile soils. It is not generally practical to apply enough chlorate at one application to completely kill all bindweed. The most practical method is so far as possible to apply enough at the first application to kill 90 to 95 percent of the bindweed and follow up a year or more later with such applications as may be necessary to complete the job.

Follow-up treatments with sodium chlorate in the second season have usually been necessary regardless of the rate of the original application. Best results were obtained when the retreatment was not made until the surviving bindweed plants showed signs of recovering from the original application. This does not usually occur before September of the following year in western Kansas, but may take place as early as May or June under conditions of heavy rainfall.

No advantage was found for cultivating dry sodium chlorate into the soil except where necessary to prevent shifting of the chemical by wind or runoff water on steep slopes or areas that were devoid of vegetation. Shallow cultivation was best for this purpose. Plowing the chlorate under was undesirable since this operation interferes with uniform distribution. A grain drill is not suitable for applying sodium chlorate. Satisfactory dry chlorate applicators can be purchased for $25 to $48.

Common salt was effective in eradicating bindweed when applied at the rate of one pound per square foot (about 20 tons per acre), but it destroyed the productivity of the land for 20 years or longer. Salting treatments are as expensive as sodium chlorate and should not be used except on areas such as railroad right of ways, irrigation and drainage ditches or ditch banks and permanent fence rows, around buildings, oil wells, petroleum bulk stations, etc., where more or less permanent sterility of the soil is desirable or where sodium chlorate treatment is a fire hazard.

Carbon bisulphide was effective in eradicating bindweed where conditions were favorable. Its practical use is limited to areas where the advantage of eliminating bindweed immediately and planting the land to garden crops or ornamentals within a few weeks justifies the extremely high cost, which ranges from $1.50 to $2 per square rod. *Carbon bisulphide is highly inflammable and explosive; therefore, fire of any kind should be kept away from the material at all times.*

Close-drilled sorgo and Sudan grass were the best crops for planting on chlorate-treated land. The crops in order of decreasing tolerance to chlorate in the soil were sorgo, Sudan grass, milo, corn, kafir, oats, rye, sweet clover, barley, and wheat.

Bindweed seedlings continued to emerge in large numbers for at least five to eight years after the original stand had been eradicated. Both wheat and sorghum grown continuously or in rotation with fallow were effective in preventing reinfestation of the land by bindweed seedlings where good stands of crop were obtained and where the cultivation was thorough enough to destroy all annual weeds once a month in intertilled crop and between harvest and seeding.

All areas on uncultivated land from which bindweed has been eradicated by chemical treatment should be inspected several times a season for several years and any seedlings found given a light application of sodium chlorate or the entire root system dug up while the plant is young.

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