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THE NATURE, ECOLOGY, AND CONTROL OF CANADA THISTLE
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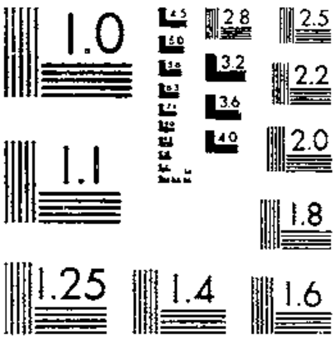

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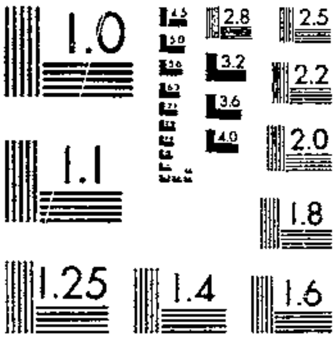

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386 THE NATURE, ECOLOGY, AND CONTROL OF CANADA THISTLE

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CONTENTS

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THE NATURE, ECOLOGY, AND CONTROL OF CANADA THISTLE

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HISTORY AND DISTRIBUTION

Canada thistle (*Cirsium arvense* (L.) Scop.) is an aggressive perennial weed throughout the northern half of the United States (*9*).[1] Infestations of this weed cause severe yield losses in cultivated fields, in pastures, on rangelands, and in lawns and gardens. It is established in forest and other watershed areas and on roadsides, riverbanks, and ditchbanks. In many of these places it produces seeds abundantly. Its many seeds and its horizontal root growth enable Canada thistle to spread easily and rapidly.

C. arvense is indigenous to Europe, western Asia, and northern Africa (*8*) and is known by a variety of common names throughout the world. The most often used are Canada thistle, creeping thistle, California thistle, field thistle, and cursed thistle (*4, 9, 25*). Canada thistle may have become the popular name in the United States because of the tradition that Frenchmen introduced it into Canada for feeding swine (*10*) and that from there it spread to the United States. No evidence to support this tradition was found. According to Hansen (*12*), Canada thistle was first introduced to North America as an impurity in crop seeds in two Canadian provinces, Quebec and Ontario. It was likely introduced at various times and places with agricultural seeds brought by early colonizers since Dewey (*10*) reported it to have been spread throughout the greater part of Europe by the middle of the 18th century. He also reported it to be found in western Asia, northern India, Australia, and New Zealand in 1901. He cites reports of 1900 that showed it to be in all States of the United States bordering on, or north of, the 37th parallel.

The rapid spread of Canada thistle has continued since that time. Man has been a very active agent in its dispersal (*14*) by planting seeds of contaminated forage and small grains. By 1952 it was reported to infest more acreage than any other noxious weed in a four-State area of Montana, Idaho, Oregon, and Washington.[2] Blankenship (*5*) in 1901 reported it to be rare in Montana, in only five small patches. Heikes[3] in 1956 reported 625,000 acres infested in Montana.

[1] Italic numbers in parentheses refer to "Literature Cited," p. 31.

[2] Dwyer, C. H., and Others of the Noxious Weed Control Task Force of the Land Subcommittee, Columbia Basin Interagency Committee. NOXIOUS WEEDS IN THE COLUMBIA BASIN. 1952. [Mimeographed.]

[3] Heikes, E. E. THE WEEDS. Mont. Ext. Serv. Newsletter 3, 2 pp. 1956.

By 1901 most of the 31 States that had reported infestations of Canada thistle had declared it to be a noxious weed (*5*). This did not deter its advance throughout the area of its adaptation as indicated by the increasing acreages. In 1957 it was listed as a noxious weed in the seed laws of all States of the United States except Alaska, Arkansas, Hawaii, and New Mexico (*33*).

Canada thistle is well adapted to productive, deep, well-aerated soils where temperatures are moderate. It grows under a wide range of moisture conditions but grows best under 16 to 30 inches of rainfall or under irrigation. Poorly aerated soils or high water tables limit the growth of Canada thistle (*4, 25*).

GENERAL METHODS AND MATERIALS

The nature, ecology, and control of Canada thistle were studied at Bozeman, Mont., from 1953 to 1965. The studies involved plants growing in natural infestations, on both croplands and noncroplands, and plants cultured from roots from different locations. A variety of plot layouts were used. Treatments involving combinations of cropping, cultivation, and herbicide sprays were compared on large plots on which regular farm-type cultivators, sprayers, and other equipment were used. Evaluation of herbicides and comparisons of growth habit were conducted on square-rod plots. Effect of treatments on Canada thistle and records of growth habit were usually determined by stem counts of Canada thistle plants on permanent quadrats. Evaluation of chemicals was usually determined by stem counts or by estimates of control, comparing treated and untreated or check plots.

Soils in the experimental areas were dark-brown silt loams, well drained, and highly productive. Moisture was provided by 16 to 19 inches of rainfall annually and irrigation once or twice each summer. Details of some of these studies may be found in other publications (*16, 17, 18, 19, 23*) and later in this report as the results are discussed.

DETAILED PROCEDURES, RESULTS, AND DISCUSSION

Nature of the Plant

The studies at Bozeman show that Canada thistle (fig. 1) is distinguished from other thistles by its horizontal branching roots, by its erect stems branching toward the top, and by its characteristic of growing in circular patches, with each new patch usually consisting of only one clone. The stems grow erect from 24 to 48 inches, arising from numerous buds on the horizontal roots. Stems of different clones vary from ribbed to smooth, often with a row of spines below the leaves. Stems are usually green but may be brownish to reddish purple on some clones or in certain locations. The leaves are usually dark green, deeply lobed, and ruffled on the margin, with spines around the margin and at the tip of lobes. Leaves occasionally are found to be smooth on the margins with no spines or very short spines. Leaf surfaces are glabrous to hairy. Flowers are borne at the apex of stems. These stems are terminal or arise from leaf axils and branch sev-

FIGURE 1.—Canada thistle (*Cirsium arvense* (L.) Scop.), including part of the extensive root system. Inset shows details of a flower and seeds.

eral times. The flowers are mostly purple or blue with various shades; occasionally they are white.

Root System and Carbohydrate Storage

Canada thistle has an extensive system of fibrous absorbing and branching horizontal roots (*14*)[4] (fig. 1). These roots contine to grow each season and contain an abundance of stored food that gives perennial life to the plant. Such roots repeatedly initiate vigorous new shoots that are very competitive. The food reserve of Canada thistle enables it to initiate new shoots for about 1½ growing seasons despite repeated cultivations that prevent production and transfer of new food to the roots (*27*).

Canada thistle roots were sampled extensively at Bozeman to determine the normal trend of carbohydrate reserves and to compare root development of 10 ecotypes grown at a common site. The ecotypes were obtained from 10 locations in Montana, Idaho, Washington, and Wyoming and were established by planting a 1-foot-long root section of each on August 1, 1956. In 1958 after the plants were well established, root samples were obtained on four replicates of each ecotype at three soil depths. The average root yield of all ecotypes, determined by their ovendry weights, showed 54 percent of the roots in the 3- to 9-inch layer, 30 percent in the 9- to 15-inch layer, and 16 percent in the 15- to 21-inch layer (table 1). Hence, 84 percent of all roots found to a depth of 21 inches were within 15 inches of the surface. As the length of life of a stand increases, a greater percentage of roots would possibly be found below 15 inches. Although roots in some soils have penetrated

[4] GRIFFIN, C. W. A MORPHOLOGICAL AND HISTOLOGICAL STUDY OF THE UNDERGROUND ORIGINS OF CANADA THISTLE. Unpublished Masters Thesis. Botany Department. Copy on file, Library, Mont. State Univ. 1934.

TABLE 1.—*Root yields of 10 Canada thistle ecotypes at 3 soil depths, Bozeman, Mont., 1958*

Ecotype[1]	Ovendry weight of roots from 18- by 18- by 6-inch soil samples at 3 depths			Total weight
	3 to 9 inches	9 to 15 inches	15 to 21 inches	
	Grams	*Grams*	*Grams*	*Grams*
LW	10.91	5.86	4.55	21.32
FM	7.84	5.53	2.57	15.94
G3	7.01	5.88	2.60	15.49
G4	7.70	4.88	2.71	15.29
G1	8.65	3.55	2.62	14.82
G2	7.61	4.83	1.22	13.66
AI	7.10	3.71	1.84	12.65
PW	7.39	2.82	1.51	11.72
YM	6.19	3.24	1.68	11.11
FI	6.34	3.27	1.29	10.90
Total weight	76.74	43.57	22.59	142.90
Average weight	7.67	4.36	2.26	4.76
Percentage of total weight	53.7	30.5	15.8	100.0

[1] The ecotypes were designated by letters and numbers according to place of origin as follows: LW, Laramie, Wyo.; FM, Fergus County, Mont.; G1, G2, G3, G4, Gallatin County, Mont.; AI, Ada County, Idaho; PW, Prosser, Wash.; YM, Yellowstone County, Mont.; FI, Fremont County, Idaho.

20 feet, most roots develop about 3 to 12 inches beneath the surface (*14, 25*).

Available carbohydrates in root samples at Bozeman increased as the depth of sample increased. The food reserves in Canada thistle are stored mainly as inulin (*34*). These reserves vary with the season, in a manner characteristic of other perennial weeds (*1, 25*). The low point of carbohydrate root reserves, as described by Welton, Morris, and Hartzler (*34*), was about June 1, when flower buds had begun to appear.

In another study at Bozeman, roots were sampled approximately weekly from April until October for 2 years. The carbohydrate reserves decreased from early spring to the lowest points measured, on June 6, 1954, and June 30, 1955. From these dates on through the season reserves generally increased until September when the carbohydrate content leveled off (fig. 2).

Weather records show that mean temperatures were 2.4° and 2.0° F. above normal in April and May, respectively, 1954, and were 4.3° below normal in April and 0.6° above normal in May 1955. Lower temperatures in 1955 probably caused the delay in utilization of carbohydrates and plant development that

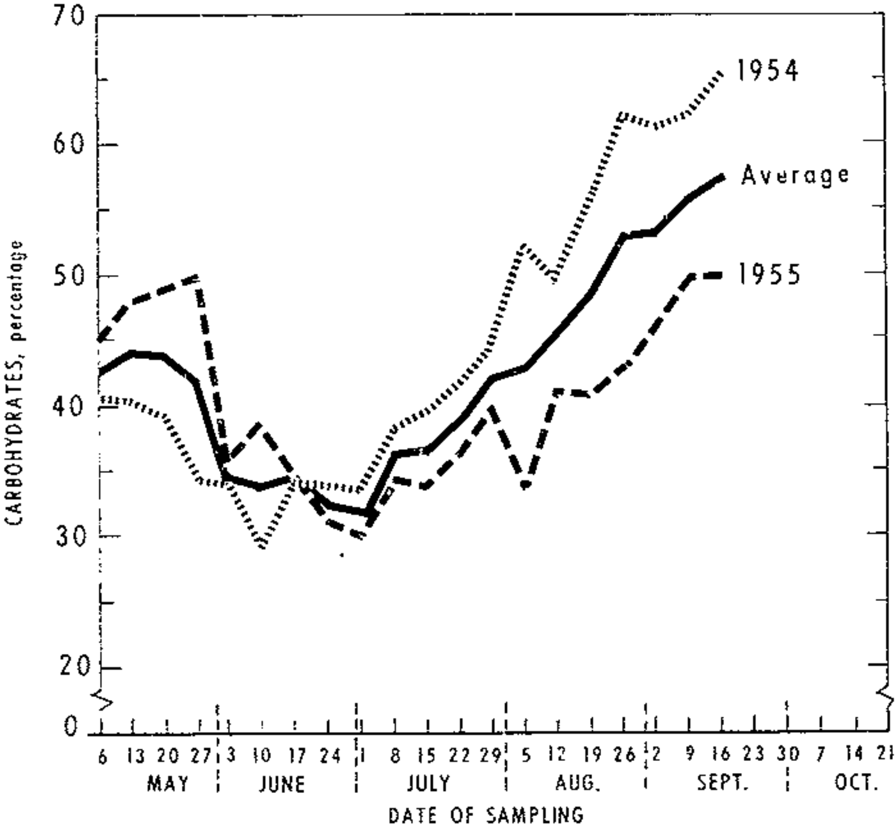

FIGURE 2.—Trends of carbohydrate reserves in Canada thistle roots as percentage of ovendry weight, Bozeman, Mont., 1954 and 1955.

occurred that year. A comparable early bud stage of growth occurred June 17, 1954, and June 23, 1955. The occurrence of bud stage after the low point of reserves in 1954 and before the low point of reserves in 1955 may have been caused by an interaction of the growing conditions and the influence of photoperiod on flowering.

Shoot Development

Herbaceous shoots of Canada thistle normally emerge each spring after soils and air temperatures have warmed considerably (table 2). In a study of whitetop (*Cardaria draba* (L.) Desv.) at Boise, Idaho, shoot emergence began in March when mean temperatures were 35° F. and was completed in late March and April when mean weekly temperature never exceeded 47° (*15*). In a study of Canada thistle at Bozeman, shoot emergence did not begin until mean weekly temperatures were 42° or higher and shoot emergence was greatest when mean weekly temperatures were at least 46° (*19*). By comparison, shoot emergence of European bindweed (*Convolvulus arvensis* L.) was reported to begin later in the season at warmer temperatures than either whitetop or Canada thistle (*27*).

The general population of Canada thistle plants varies considerably in appearance and growth characteristics (*4, 9*). At Bozeman, shoot emergence of 10 different clones or ecotypes was recorded in 1959 (*19*). An ecotype LW, from Laramie, Wyo., emerged at least 10 days earlier than several other ecotypes, its shoot growth preceded that of the others, and it matured earlier (table 3). Thus, because of its earlier establishment, the LW ecotype might be expected to be more competitive in such crops as spring wheat. About two-thirds of the shoots of all ecotypes emerged between May 1 and May 15, when the mean temperature was 46° F.

After shoot emergence of Canada thistle, the rosettes enlarged horizontally, covering and shading the ground. Vertical shoot growth began increasing rapidly about 3 weeks after emergence. Under the climatic conditions at Bozeman, the most rapid vertical growth occurred from June 16 to June 29, 1959, with an average growth of 3 centimeters per day (table 4). This is a comparable period to that in which root reserves were lowest in 1954 and 1955 (fig. 2).

Flowering and Seed Production

Canada thistle has been reported to be normally dioecious: that is,

TABLE 2.—*Shoot emergence of whitetop in the spring at Boise, Idaho, and of Canada thistle at Bozeman, Mont.*

Whitetop at Boise, Idaho, 1952			Canada thistle at Bozeman, Mont., 1959		
Time interval	Mean temperature	Emergence of shoots	Time interval	Mean temperature	Emergence of shoots
	°F.	*Percent*		*°F.*	*Percent*
March 17 to 24	35	20	April 14 to 20	36	0
March 25 to 31	44		April 21 to 28	42	3
April 1 to 7	41	80	April 29 to May 6	46	27
April 8 to 15	47		May 7 to 15	49	46
			May 15 to 29	46	24

TABLE 3.—*Shoot emergence of 10 Canada thistle ecotypes in the spring, Bozeman, Mont., 1959*

Ecotype [1]	Shoots emerged on [2, 3]—				Shoots per square foot, May 29, 1959
	Apr. 21, 1959	May 1, 1959	May 11, 1959	May 15, 1959	
	Percent	*Percent*	*Percent*	*Percent*	*Number*
LW	4.0	38a	95a	97a	5.5
G1	0	12 bc	75ab	83 b	6.8
AI	2.0	14 b	63 bc	77 bc	5.0
G2	0	6 c	63 bc	82 b	4.5
G4	0	6 c	53 cd	83 b	6.9
FI	0	4 c	52 cd	79 bc	4.5
YM	0	4 c	51 cd	76 bc	5.1
FM	0	8 bc	42 cd	58 d	5.2
PW	0	4 c	35 d	67 cd	3.2
G3	0	6 c	34 d	63 d	3.2
Average	0.6	10	57	76	5.0

[1] See footnote 1, table 1, page 4, for origin of ecotypes.
[2] Duncan's Multiple Range Test, P=0.05. Values with different letters are significantly different at the 5-percent level.
[3] 100 percent emergence on May 29, 1959.

staminate flowers that produce only pollen are borne on one plant and pistillate flowers that produce the seed on another (fig. 3). This characteristic was investigated among the 10 ecotypes described above. Eight of the ecotypes bore pistillate flowers that were observed each year but apparently never produced pollen and depended upon an external source for pollen to produce seed. Pistillate flowers that were covered to prevent external pollen from the florets in 1959 and 1960 produced no seed. Although most of the seeds are borne on the pistillate plants, an occasional seed was found on the staminate plants in these studies.

TABLE 4.—*Shoot growth of Canada thistle, Bozeman, Mont., 1959*

Time interval	Days	Mean temperature	Degree days [1]	Vertical shoot growth [2]		
				Total	Daily	
	Number	*°F.*	*Number*	*Cm.*	*Cm.*	*Percent*
May 5 to June 4	30	46	162	18	0.60	0.5
June 5 to 15	11	62	188	21	1.90	1.6
June 16 to 19	4	65	80	13	3.14	2.6
June 20 to 29	10	61	156	29	2.92	2.4
June 30 to July 6	7	61	109	18	2.63	2.2
July 7 to 13	7	62	119	12	1.68	1.4
July 14 to 20	7	71	183	7	1.03	.8
July 21 to 27	7	72	191	2	.27	.2
July 28 to August 3	7	67	155	2	.22	.2
Total	90		1,343	122		
Average		63			1.61	

[1] An arithmetic accumulation by days of daily mean temperature in degrees above 45° F.
[2] Each number is the average for 20 plants.

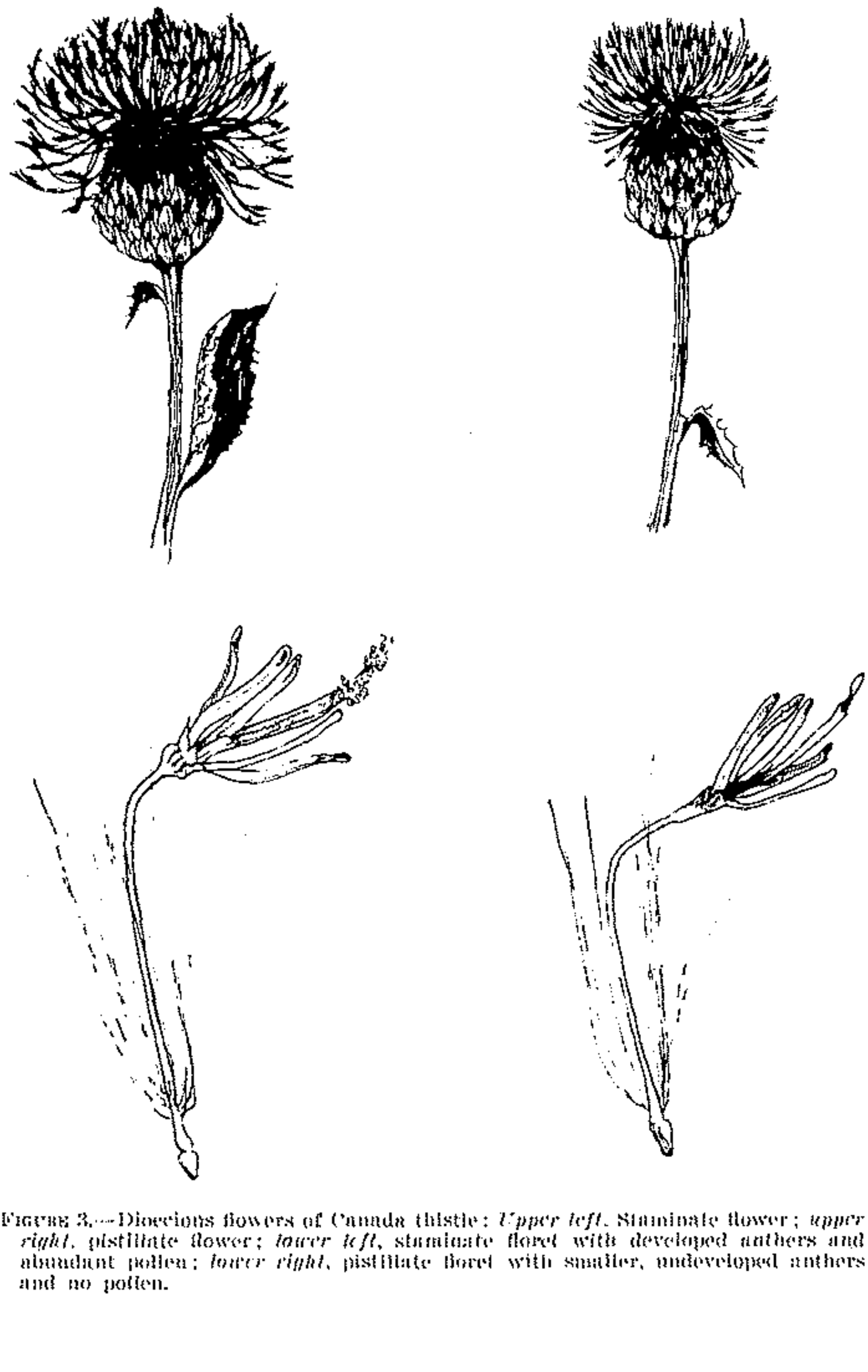

FIGURE 3.—Dioecious flowers of Canada thistle: *Upper left*, staminate flower; *upper right*, pistillate flower; *lower left*, staminate floret with developed anthers and abundant pollen; *lower right*, pistillate floret with smaller, undeveloped anthers and no pollen.

Thus, florets on staminate plants were occasionally perfect, bearing both pollen and seed: this indicates that the species is imperfectly dioecious, as reported by Bakker (*4*) and Lund and Rostrup (*22*).

Staminate and pistillate flowers are easily distinguished in the field by the abundant pollen on the staminate flowers and, as the seed matures, by the voluminous pappus on the pistillate flowers to transport the seed. The pappus, although present on staminate plants, is relatively undeveloped as compared to the pappus on pistillate plants. Flowering occurred from July 1 into August. According to Linck and Kommedahl (*21*), Canada thistle is a long-day plant; they found no flowering in plants under light for 8 or 12 hours but found considerable flowering under light for 18 hours.

In our studies large quantities of viable seeds were produced under favorable conditions where staminate and pistillate plants were planted within 50 feet of each other (*19*). However, in studies in the Netherlands yield of seed was low and seeds were dispersed by the wind for only short distances up to 1 kilometer (*4*). Hayden in Iowa (*14*) reported little seed production unless staminate and pistillate flowers were within 20 to 200 feet of each other.

Seed size varied considerably among different ecotypes of Canada thistle in our studies (table 5) (*19*). The largest seed was found on LW and was equivalent to approximately 298,000 seeds per pound; the smallest seed was found on FI and was equivalent to 677,000 seeds per pound. The types sampled probably do not actually encompass the entire range of variation in this characteristic. The number of Canada thistle seed per pound has previously been reported as 283,000 (*30*).

Viability of Canada thistle seed was quite high in several germination tests (*8, 14*). In one study 50 to 80 percent of the newly harvested seeds germinated (*19*). Goss (*11*) showed that some Canada thistle seed remained viable when buried in the soil for as long as 20 years. Viability was greater for seed buried at 42 inches than for seed buried at 8 or 22 inches.

TABLE 5.—*Average weight of 100 seeds of 8 Canada thistle ecotypes, 1958–60*

Ecotypes [1]	Average weight of 100 seeds in— 1958	1959	1960	3-year average weight of 100 seed [2]	Seeds per pound
	Gram	*Gram*	*Gram*	*Gram*	*Number*
LW	0.165	0.150	0.141	0.152a	298,420
GI	.082	.096	.107	.095 b	477,470
YM	.093	.095	.096	.095 b	477,470
AF	.098	.090	.090	.093 b	487,740
PW	.070	.099	.103	.091 b	498,460
FM	.087	.095	.084	.089 b	509,660
G4	.085	.087	.090	.087 b	521,380
FI	.066	.063	.073	.067 c	677,000
Average	.093	.097	.098	.096	492,330

[1] See footnote 1, table 1, page 4, for origin of ecotypes.
[2] Numbers bearing different letters differed significantly.

We found that new seedlings established slowly and seem to be quite sensitive to shading or competition. They usually survive and become established on newly plowed ditchbanks or disturbed grazing or noncropland areas where for a time plant competition is limited. These results agree with those of Bakker (*4*) who reported that Canada thistle seedlings died when light intensity fell below 20 percent of full daylight and development was delayed at 60 to 70 percent of full daylight.

Nature of the Problem

Canada thistle propagates by roots and is very aggressive in any field because of this characteristic. However, the plant is also a threat to other areas because of its seed production, which is its major means of spreading from farm to farm, and from farms and roadsides to our ranges and watershed areas (*4, 12, 14*).

Canada thistle causes serious yield losses in spring-sown small grains, peas, row crops, and pastures and is obnoxious in many other situations. It is well adapted to growing with spring wheat and grows with this crop perhaps more often than with any other. The difference in adaptation of Canada thistle to spring wheat and alfalfa hay cropping programs was clearly shown in two of our experiments reported in 1958 (*16*) and 1959 (*23*). The percentage of Canada thistles increased progressively in continuous spring wheat cropping, but decreased in alfalfa mowed for hay (table 6). Other investigators have reported alfalfa, perennial forage grasses, and winter wheat to be the most effective competitive crops in controlling Canada thistle (*32, 35*).

The effect of Canada thistle on the yield of spring wheat was measured by the author in several farmers' fields in Gallatin County, Montana, 1953–55 (*17*). Randomly located patches were chosen in these fields where yield samples could be obtained at four different levels of Canada thistle infestation by proceeding along an individual drill swath into the thistle patch.

Although the levels of yield varied among the different fields, the patterns of yield reduction were similar when the numbers of Canada thistles present were similar. For example, yield reduction was about 60 percent each time 25 thistle shoots per square yard were present (fig. 4). This was the usual level of infestation found throughout the center of the patch, with a sparse infestation toward the outer edge. Where only two shoots per square yard were present, the rate of yield reduction per shoot was greater than the rate at higher densities because thistle plants were more vigorous and larger.

TABLE 6.—*Canada thistle survival in two cropping programs*

Cropping program	Survival of Canada thistle in—				
	1953	1954	1955	1956	1957
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Continuous spring wheat	100	143	158	182	192
Alfalfa mowed for hay	100	60	11	9	1

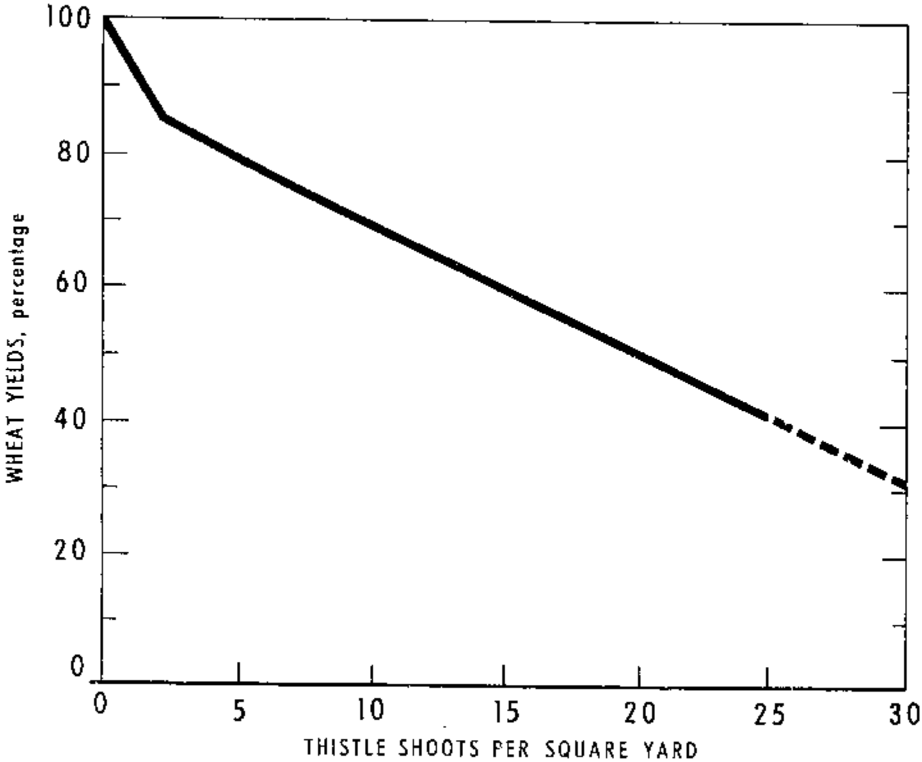

FIGURE 4.—Yield reduction in wheat caused by different levels of Canada thistle infestation in Gallatin County, Montana, 1953–55.

Control Measures

The foregoing description indicates several characteristics of Canada thistle that are typical of weedy species and that enhance its persistence and spread. Because of these characteristics and the prevalance of Canada thistle, control measures have been extensively sought over the past 100 years. The methods of control developed fell into three broad categories—cultivation practices, cropping programs, and chemical treatments.

Some consideration has been given also to biological control since there are several natural enemies of Canada thistle (*9*). However, only recently has this work resulted in promise of an active biological agent that will control thistles. Harris (*13*) in Canada conducted feeding trials on (*Haltica carduorum Guer.*), a leaf-feeding beetle that was found in Europe. Results of these studies were encouraging and the beetle was taken into California for further feeding studies.[5] Since these feeding studies have indicated no danger to crops, this beetle has been released in California, Idaho, Montana, Oregon, and Washington

[5] HAWKES, R. B. HOST SPECIFICITY STUDIES ON HALTICA CARDUORUM (GUER. (COLEOPTERA: CHRYSOMELIDAE)). U.S. Dept. Agr., Agr. Res. Serv., Ent. Res. Div. 1965. [Mimeographed leaflet.]

for further field studies of its adaptation and effectiveness in control of Canada thistle.

Cultivation

Cultivation practices have been developed to starve Canada thistle roots by repeatedly destroying the new shoots and leaves (*27, 31*). Over the years many variations in the starvation process have been suggested; one was hoeing periodically in row crops (*10, 12*). Early writers (*12, 25*) stated that starvation must be begun as soon as shoots appear above ground. This practice became known as the "black" fallow system. Later studies indicated that depletion of root reserves was greater and fewer cultivations were necessary if the new thistle shoots were destroyed about 8 to 10 days after emergence (*27*). This practice of delayed cultivation has become an effective control of Canada thistle. The land should be cultivated to a depth of 3 to 4 inches every 21 days (*27*). All writers emphasize the necessity of destroying all shoots at each cultivation so that no new food is stored.

Cropping

The effectiveness of competitive crops in control of Canada thistle was recognized as early as 1846 (*29*). Mowing Canada thistle at the early bloom stage or mowing repeatedly at various intervals has also been effective (*34*). Alfalfa has been one of the best competitive crops when mowed at least twice each year for hay (*6, 9, 26*). Different forage crops vary in their ability to compete with Canada thistle; also, moisture conditions and fertility of these crops influence their ability to compete (*32*). Alfalfa grown for hay and clipped at the bloom stage was very effective in control of Canada thistle in our investigations at Bozeman (*16, 17*).

Chemicals

Salt (NaCl) was one of the earliest chemicals recommended to control Canada thistle (*10, 29*). A brine solution was applied to the thistle foliage and brine or dry salt was applied to the soil. Dewey (*10*) stated that "Salting thistle plants every week or two during two successive growing seasons in pastures where sheep have access to them, usually destroys them." This practice apparently was popular since it was recommended by Detmers (*9*) many years later.

Sodium ($NaAs_2O_3$) and calcium arsenite ($Ca(As_2O_2)_2$) were the most effective of several chemicals tested by Detmers (*9*) in 1927. Reports of tests in 1928 (*2*) indicated that 180 pounds per acre of sodium chlorate applied in the fall killed the Canada thistle but did not injure oats planted the next spring. Workers in Ohio recommended 400 to 480 pounds per acre (*35*). Tests with sodium chlorate in Idaho (*20*) showed that at least 640 pounds per acre was needed to eliminate Canada thistle and that moisture conditions, soil type, and organic matter greatly affected sodium chlorate treatments. This chemical seems to be the first to achieve widespread use to control perennial weeds. Hulbert, Bristol, and Benjamin (*20*) reported about 8,000 pounds used on 18 acres in Idaho in 1927 and 1,147,392 pounds used on 2,028 acres in 1930.

Carbon bisulfide (CS_2) came into use about the same time as sodium chlorate. Although quite costly, carbon bisulfide was widely accepted for use on patches of Canada thistle (*28*) on croplands. Because of the very short residual life of carbon bisulfide, crops could be planted 2 to 3 weeks after the treatment.

A new growth regulator type herbicide 2,4-D (2,4-dichlorophenoxyacetic acid) appeared in 1944 and was immediately tested to control Canada thistle (*3*, *24*). Researchers generally classed Canada thistle as intermediate in response to 2,4-D. It required repeated treatments for effective control (*24*.) Bakke (*3*) reported 70-percent control in 1 year with a treatment of 1 or 2 pounds per acre applied at the early bud stage and a second treatment to control regrowth in September. A summary of results of several 2,4-D experiments to control Canada thistle (*24*) indicated that 2,4-D was more effective than 2,4,5-T (2,4,5-trichlorophenoxyacetic acid) and about equally as effective as MCPA (2-methyl-4-chlorophenoxyacetic acid).

Combinations of Cultivation, Cropping, and Chemicals

As indicated by the work previously cited, specific cultivation practices, cropping programs, or chemical treatments to control Canada thistle have been developed. However, with the development of selective sprays, a combination of these methods into farming programs is the most practical way to control extensive infestations of Canada thistle on farmlands. Such combination methods were found by the author to control whitetop very effectively (*15*), and some combination methods to control Canada thistle have also been investigated and reported from South Dakota (*7*).

Three experiments designed to evaluate cultivation, cropping, and chemicals, alone and in several combinations, were conducted in Montana and Idaho from 1953 to 1960, in selected fields where a dense natural infestation of Canada thistle occurred.

Experiment 1 was begun in 1953 and consisted of 16 treatments involving cultivation, cropping with wheat, forage grasses, alfalfa, corn, potatoes, and peas as crops, and selective spraying with 2,4-D and MCPA. The plots were established in a fairly uniform infestation of Canada thistle on 5 acres of highly productive silt loam soil on the Montana Agricultural Experiment Station. The treatments were randomized and replicated four times on plots 33 feet wide and 80 feet long (1/16 acre).

Experiment 2 was conducted in cooperation with the Idaho Experiment Station. The efforts of Hugh C. McKay in this work are gratefully acknowledged. It was also begun in 1953 and consisted of 11 treatments similar to those of experiment 1. These 1/10-acre plots were located near Newdale, Idaho, on a 5-acre field densely infested with Canada thistle. The soil was a silt loam typical of the Upper Snake River Valley area. Grain and potatoes had been grown in this field for many years before the experiment was begun. Small grains had been grown in this field the 4

CAUTION

If herbicides are handled or applied improperly, or if unused parts are disposed of improperly, they may be injurious to humans, domestic animals, desirable plants, pollinating insects, fish, or other wildlife, and may contaminate water supplies. Use herbicides only when needed and handle them with care. Follow the directions and heed all precautions on the container label.

previous years, resulting in a low state of fertility.

Experiment 3 was begun in 1955 on a leased site of variable silt loam soil near Bozeman, Mont., and consisted of 8 treatments. Small grains had been grown in this field the 4 previous years and the field was heavily infested with wild oats as well as Canada thistle.

The plots of all three experiments were large enough to be farmed with regular field equipment. A duckfoot cultivator with rigid shanks and 16 inch sweeps with 3-inch overlap was used. All plots were plowed in the spring the 1st year and in the fall each year thereafter. Chemicals were applied with a tractor-mounted sprayer with a 20-foot boom consisting of two 10-foot sections. Treatments were continued for 5 years to assess their long-time value in eradicating Canada thistle.

All wheat plots were irrigated once each year at Bozeman and twice each year at Newdale. Alfalfa, corn, and potato plots received additional irrigations as needed.

The perennial grass and alfalfa plots were seeded without companion crops, and were mowed once during the year of seeding. The hay plots at Newdale were fertilized with 30 pounds of nitrogen and 100 pounds of phosphate fertilizer (P_2O_5) per acre in the seedling year.

The Canada thistle population was sampled in June each year by counting the shoots within permanent square-yard quadrats. Original counts were made the 1st year of each experiment, before treatments were made. The effect of treatments on control is presented each year as the percentage of that original count.

Samples to determine wheat and forage yields were taken from the same quadrats in which the thistles were counted.

Control of Canada thistle by several of the cultivation, cropping, and chemical treatments was excellent. There was a definite economic advantage in combining fertilizer and 2,4-D treatments in wheat infested with Canada thistle as well as an advantage in control of Canada thistle (table 7; fig. 5).

The data presented on Canada thistle survival in tables 7, 8, and 9 were obtained in early June each year before annual spraying or mowing or cultivation. The data represent the effect of control measures taken the previous years.

EFFECT OF SPRING WHEAT CROPPING, CULTIVATION, NITROGEN FERTILIZER, AND 2,4-D SPRAY ON CONTROL OF CANADA THISTLE AND YIELD OF WHEAT.—The stand of Canada thistle in spring wheat was effectively reduced with annually repeated treatments of 2,4-D alone in all three experiments (table 7). 2,4-D was much more effective the 1st year of treatments at Bozeman than at Newdale; however, during the 2d, 3d, and 4th years the trend was about the same at both locations; and by the 5th year survival of Canada thistle was much the same for similar treatments in spring wheat at all locations.

Applications of nitrogen alone at Bozeman resulted in an increased growth of Canada thistle and an increased yield of spring wheat; however, applications at Newdale resulted in no appreciable change in growth of Canada thistle but resulted in an increased yield of wheat (table 7). The previous cropping history of these locations probably contributed to this difference in growth of Canada thistle. (See p. 13.) Wheat responded well to nitrogen at Newdale and moderately well at Bozeman. By comparison, wheat

[illegible] cropping, nitrogen fertilizer, [illegible] seeded to spring wheat each year and [illegible] treated the same but [illegible] 2,4-D [illegible] stage.

[illegible] experiment [illegible] 2,4-D [illegible] control of Canada [illegible] spring [illegible]

[illegible] wheat [illegible]

[illegible]

[illegible] yield was lower from this [illegible] treatment in these ex[illegible] than in experiment 1. A [illegible] oats appeared in experi[illegible] 1st year, but these were [illegible] from the plots and were no [illegible] problem. The wild oat prob[illegible] a limiting factor in a [illegible] spring wheat cropping [illegible]. If present, then wild oats [illegible] controlled early in the pro[illegible] or the program must be dis[illegible] crop rotation begun. [illegible] thistle was more sensitive [illegible] 2,4-D during the 1st year in both experiments at [illegible] than at [illegible] (table 7).

[illegible] experiment 1 the combination [illegible] wheat cropping with 2,4-D [illegible] greater control of [illegible] 2,4-D spraying with

TABLE 7.—*Effect of spring wheat cropping, cultivation, nitrogen fertilizer, and 2,4-D spray on control of Canada thistle and yield of wheat*

Experiment		Nitrogen fertilizer	2,4-D spray	Canada thistle infestation in [2]—				Spring wheat yields for—					Annual wheat yield	
No.[1]	Crop or cultural treatment			2d year	3d year	4th year	5th year	1st year	2d year	3d year	4th year	5th year	Average	Average increase [3]
		Lb./acre	*Lb./acre*	*Percent*	*Percent*	*Percent*	*Percent*	*Bu./acre*	*Bu./acre*	*Bu./acre*	*Bu./acre*	*Bu./acre*	*Bu./acre*	*Bu./acre*
1	Spring wheat	50	3/4	8	2	1	4	56	60	52	70	44	56	28
2	do	90	[4] 2	99	25	8	3	77	77	48	35	([5])	[6] 59	37
3	do	50	3/4	23	6	1	3	30	31	20	15	41	27	12
	Average			43	11	4	3	54	56	40	40	43	47	26
1	Spring wheat	50		115	214	255	338	63	48	29	30	15	37	9
2	do	90		165	136	169	142	73	56	28	22	([5])	[6] 44	22
3	do	50		90	245	189	160	27	23	11	12	21	19	3
	Average			123	198	204	213	54	42	23	21	18	33	11
1	Spring wheat		3/4	14	2	1	6	54	66	48	44	27	48	20
2	do		[4] 2	152	125	57	33	30	35	20	29	([5])	[6] 29	7
3	do		3/4	30	23	21	15	21	29	19	12	31	22	7
	Average			65	50	26	18	32	43	29	28	29	33	11

1	Spring wheat (check)		119	146	156	218	49	38	22	20	12	28	0
2	do		196	219	170	168	30	23	19	16	5	22	0
3	do		113	253	219	122	29	13	6	9	23	15	0
	Average		143	206	182	169	36	25	16	15	18	22	0
1	1st, 3d, and 5th years—cultivation; 2d and 4th years—spring wheat.	3/4	([7])	([7])	0	1	([5])	55	([5])	59	([5])	[6] 28	6
3	do	3/4	0	2	4	2	([5])	42	([5])	28	([5])	[6] 19	0
	Average		([7])	1	2	1	0	49	0	44	0	24	3
1	No crop—no cultivation.	2	28	49	39	25	([5])	([5])	([5])	([5])	([5])	([5])	......
1	do	-----	136	188	142	152	([5])	([5])	([5])	([5])	([5])	([5])	......
2	1st year—cultivation; next 4 years—spring wheat.	3/4	8	1	([7])	([7])	0	80	48	40	([5])	[6] 42	20

[1] Identical treatments compared in separate experiments: (1) Bozeman, Mont., begun in 1953; (2) Newdale, Idaho, begun in 1953; (3) Bozeman, Mont., begun in 1955.

[2] Percentage of original infestation first year. Data are averages of 10 counts on 4 replications, 3 by 3 feet.

[3] Compared with spring wheat check.

[4] Rate increased to 3 pounds per acre after 1st year.

[5] No crop grown or no yield sample obtained.

[6] Average computed using 4 years instead of 5.

[7] 0.5 percent or less.

no cropping, indicating that control of thistles with 2,4-D was enhanced by spring wheat competition.

In all three experiments, repeated cultivation to control Canada thistle was effective. On the average, 1 season of cultivation involving six or seven operations eliminated 98 percent of the Canada thistle.

Comparing yields of the spring wheat check treatments for 2 years at Newdale with the yields after 1 year of cultivation shows a 17 bushel yield advantage for 1 year of cultivation and 1 year of wheat over 2 years of wheat. Production costs for one crop and 1 year of cultivation would be considerably less than costs for 2 years of cropping. Also, control of Canada thistle was 98 percent with cultivation and cropping compared to an actual increase in infestation with continuous spring wheat cropping.

Effect of forage cropping, cultural practices, nitrogen fertilizer, and 2,4-D spray on control of Canada thistle.—Alfalfa consistently controlled Canada thistle when mowed twice each year (table 8). The only variation in the trend among the three experiments occurred at Newdale where Canada thistle showed a slight increase during the year of alfalfa establishment. In experiments 1 and 3 there was a slight increase of Canada thistle during the 6th year of alfalfa. This increase has often been

Table 8.—*Effect of cropping, cultural practices, nitrogen fertilizer, and 2,4-D spray on control of Canada thistle*

Experiment No.[1]	Treatment: Cropping practices	Treatment: Nitrogen fertilizer	Treatment: 2,4-D spray	Canada thistle infestation in[2]— 2d year	3d year	4th year	5th year
		Lb./acre	Lb./acre	Percent	Percent	Percent	Percent
1	Alfalfa forage crop and mowing twice each year.			14	5	([3])	0
2	Alfalfa grass mixture and mowing twice each year.			121	11	11	([3])
3	do			46	17	16	5
	Average			60	11	9	2
1	Forage grass and mowing	25	3/4	13	3	([3])	0
2	do	80	[4] 2	19	8	3	3
3	do	40	3/4	102	25	5	([3])
	Average			45	12	3	1
1	Potatoes 1st year; silage corn continuous other years.	80	3/4	18	0	0	0
3	Silage corn continuous	80	3/4	7	6	1	4
1	Grass seeded in rows for seed production and sprayed 8 weeks after emergence 1st year; sprayed once each year for next 4 years.	25	1	19	2	4	2

[1] Identical treatments compared in separate experiments: (1) Bozeman, Mont., begun in 1953; (2) Newdale, Idaho, begun in 1953; (3) Bozeman, Mont., begun in 1955.

[2] Percentage of original count made the 1st year.

[3] 0.5 percent or less.

[4] Rate increased to 3 pounds per acre after 1st year.

observed. As the alfalfa stand is thinned and weakened by age, Canada thistle begins to invade. For this reason and because alfalfa yields are lower in stands 5 years old or older, alfalfa fields normally should be rotated to other crops after 4 or 5 years.

Forage grass that was mowed to simulate pasturing and sprayed with 2,4-D was about as effective as alfalfa and mowing in controlling Canada thistle (table 8). Silage corn was an effective competitive crop for control of Canada thistle since a 2,4-D treatment as well as inter-row cultivation was possible. Actual elimination of Canada thistle occurred in experiment 1 with potatoes and cultivation the 1st year and silage corn and cultivation and spraying the following 4 years.

EFFECT OF CERTAIN ROTATIONS, CULTURAL PRACTICES, AND CHEMICAL SPRAYS ON CONTROL OF CANADA THISTLE AND YIELD OF CROPS.—In general, each cropping, cultural, or spraying practice was equally effective when combined into a rotation or farming program to control Canada thistle (table 9). Alfalfa or grass forage crops that were mowed or the grass sprayed with 2,4-D and mowed for 3 years each reduced Canada thistle so that later crops of potatoes, peas, or wheat were little affected by thistle competition.

Yields of peas were generally satisfactory when sprayed with MCPA, although the control of Canada thistle was temporary and somewhat erratic at the rates used. MCPA at ¼ pound per acre controlled Canada thistle less effectively than at ½ pound per acre, but ½ pound per acre injured the peas more as shown by visual symptoms. However, the yields of peas did not differ significantly when either ¼ or ½ pound per acre was applied. Perhaps the injury caused by the higher rate was offset by better weed control. The very low yield of peas in the 3d year was a result of severe damage from 2,4-D contamination of the MCPA spray that year.

Several combinations of cropping, cultivation practices, and spraying effectively controlled Canada thistle. Consistency with followup treatments and well-managed competitive crops increased control. Derschied (7) reported similar results in a series of similar combinations of control measures in 1961.

ECONOMIC ADVANTAGE OF NITROGEN FERTILIZER AND 2,4-D SPRAY USED TO CONTROL CANADA THISTLE IN SPRING WHEAT FIELDS.—Increased yields and net returns from spring wheat crops fertilized with nitrogen and sprayed with 2,4-D were spectacular (table 10). The cost of nitrogen or 2,4-D, or both, was deducted from the yield increases above the check for four treatments on spring wheat. The net increased return from nitrogen and 2,4-D in spring wheat ranged from 13.5 to 39.5 dollars per acre, assuming the price of wheat at $1.00 or $2.00 per bushel, respectively. Nitrogen alone or 2,4-D alone also resulted in profitable returns. These data emphasize that such treatments not only control Canada thistle but also are economically profitable.

YIELD OF SPRING WHEAT AS AFFECTED BY TIME OF TREATMENT OF CANADA THISTLE BY HANDWEEDING OR 2,4-D SPRAY.—As shown in figure 4, spring wheat yield losses, caused by competing Canada thistle plants at various levels, generally increased directly in proportion to the increase in density of the infestation. Early removal of Canada thistle competition from spring wheat by handweeding or 2,4-D

TABLE 9.—*Effect of certain rotations, cultural practices, and chemical sprays on control of Canada thistle and yield of crops*

Experiment No.[1]	Year of treatment	Treatment: Crop	Treatment: Cultural practice	Treatment: Spray: Herbicide used	Treatment: Spray: Rate of application	Canada thistle infestation in[2]—: 2d year	3d year	4th year	5th year	Crop yields for—: 1st year	2d year	3d year	4th year	5th year
					Lb./acre	*Percent*	*Percent*	*Percent*	*Percent*					
1	1st	Spring wheat		2,4-D	3/4									
	2d to 5th	Alfalfa	Mowing			7	1	1	1	[3] 57.0	[4] 2.0	[4] 4.2	[4] 5.5	[4] 2.6
1	1st to 3d	Grass pasture	do	2,4-D	3/4	--	--	--		-----	-----	-----	-----	-----
	4th	Spring wheat		2,4-D	3/4	--	--	--		-----	-----	-----	-----	-----
	5th	Peas		MCPA	1/4	17	7	5	8	[4] .8	[4] 2.4	[4] 2.3	[3] 48	[3] 50
2	1st to 3d	Alfalfa	Mowing			--	--	--	--	-----	-----	-----	-----	-----
	4th	Potatoes				98	21	3	7	[4] 1	[4] 4.6	[4] 4	[4] 11.5	[5]
2	1st	None	Cultivation (4 times).	2,4-D	2	--	--	--	--	-----	-----	-----	-----	-----
	2d to 5th.	Spring wheat	Nitrogen fertilizer.	2,4-D	3	1	1	1	1	[5]	[3] 90.4	[3] 59	[3] 42	[5]
2	1st	Spring wheat		2,4-D	----	--	--	--	--	-----	-----	-----	-----	-----
	2d to 4th.	Alfalfa grass mixture.	Mowing		----	--	--	--	--	-----	-----	-----	-----	-----
	5th	Potatoes				76	90	30	4	[3] 30	[4] 1	[4] 4	[4] 4	[5]
1	1st & 3d	None	Cultivation		----	--	--	--	--	-----	-----	-----	-----	-----
	2d & 4th	Winter wheat		2,4-D	3/4	13	2	1	2	[5]	[3] 64	[5]	[3] 46	[5]
1	1st to 5th	Peas		MCPA	1/4	40	52	71	20	[3] 71	[3] 63	[3] 11	[3] 40	[3] 43
1	1st to 5th	do		MCPA	1/2	22	27	39	6	[3] 64	[3] 56	[3] 14	[3] 44	[3] 42

[1] Treatments compared in separate experiments: (1) Bozeman, Mont., begun in 1953; (2) Newdale, Idaho, begun in 1953.
[2] Percentage of original infestation 1st year.
[3] Bushels per acre.
[4] Tons per acre.
[5] No crop grown or no yield sample obtained.

TABLE 10.—*Increased net return from spring wheat in fields treated with nitrogen fertilizer and 2,4-D spray to control Canada thistle*

Treatment	Cost of treatment per acre [1]	Yield of spring wheat per acre [2]		Net annual increased return per acre from spring wheat after considering costs of nitrogen and 2,4-D if wheat sold for—		
		Average annual	Increase over check	$1.00 per bushel	$1.50 per bushel	$2.00 per bushel
		Bushels	*Bushels*			
Nitrogen + 2,4-D spray	$12.50	48	26	$13.50	$26.50	$39.50
2,4-D spray—no nitrogen	3.00	33	11	8.00	13.50	19.00
Nitrogen—no spray	9.50	33	11	1.50	7.00	12.50
No nitrogen—no spray (check)	0	22	......	0	0	0

[1] Average cost of applying fertilizer or spray—$1 per acre each; average cost of nitrogen per acre (63 pounds at 13½ cents per pound)—$8.50; average cost of 2,4-D spray per acre—$2.

[2] Average of 3 experiments, with 4 replications each.

effectively minimized the yield loss in two experiments at Bozeman, 1958 and 1959 (table 11).

In 1958 Thatcher spring wheat was seeded with a 6-foot, 12-hole cereal drill in an area of fairly heavy Canada thistle infestation (15 to 25 shoots per square yard). Nitrogen fertilizer at 50 pounds per acre had been broadcast over the plot area before seeding. Plots were handweeded and 2,4-D was applied on different days after wheat emerged.

The procedure in 1959 was similar to that in 1958 but more treatments were tested. The level of Canada thistle infestation was lower in 1959, varying from 8 to 15 shoots per square yard, and the infestation was in a field that had been fallowed and cultivated twice in 1958. These factors probably contributed to the higher wheat yields in 1959.

With all treatments to control Canada thistle, wheat yields decreased as the time from emergence to treatment increased (table 11), showing the effect of thistle competition on wheat. In 1958 with a moderate to heavy infestation of Canada thistle, handweeding 16 days after emergence increased the yield 21.7 bushels per acre over the check, a 2½-fold increase. 2,4-D treatments at 1 pound per acre at the same time increased the yield 12.9 bushels per acre over the yield of the check. However, yield increased less when 2,4-D was applied 30 days after emergence of the wheat, and yield did not increase when 2,4-D was applied 37 days after emergence.

Results in 1959 with a lower level of thistle infestation also showed that with all treatments wheat yields decreased as the time from emergence to treatment increased. There was a trend toward increased yield when amine 2,4-D was applied 37 days after emergence. 2,4-D applied 46 days after emergence of wheat tended to cause a decrease in wheat yield. The ester formulation of 2,4-D apparently injured wheat more than the amine formulation.

In 1959, wheat yields were not significantly greater when 2,4-D was applied 16 days after wheat emerged than when it was applied 30 days after wheat emerged. This would indicate a greater injury to wheat by 2,4-D when it was applied at the early date than when it was applied at the later date. The

TABLE 11.—*Spring wheat yields as affected by time of treatment of Canada thistle by handweeding or 2,4-D, Bozeman, Mont., 1958 and 1959*

Time of treatment			Wheat yields for treatments in [1]—						
Days after wheat emergence	Stage of plant development of—		1958			1959			
	Wheat	Canada thistle	Hand-weeded	2,4-D amine [2]	Check	Hand-weeded	2,4-D amine [3]	2,4-D ester [3]	Check
			Bu./acre	*Bu./acre*	*Bu./acre*	*Bu./acre*	*Bu./acre*	*Bu./acre*	*Bu./acre*
16	4 to 6 leaf	Just emerged or 8-leaf rosette.	36.7*	27.9*	15.0	50.9*	43.5*	39.8	36.7
30	Fully tillered	Early bud (21 inches)	30.0*	24.2*	15.0	45.7*	43.8*	39.2	36.7
37	Very early boot	Late bud (30 inches)		19.9	15.0	42.2*	40.6*	35.1	36.7
45	Mid-boot	First bloom				41.9*	35.2	29.2	36.7
Average			33.4*	24.0*	15.0	45.2*	40.8*	35.8	36.7

[1] *—Significantly different from check at 5-percent level.
[2] Applied at the rate of 1 pound per acre.
[3] Applied at the rate of ¾ pound per acre.

greater competition of Canada thistle on the later date and the fact that 2,4-D was less injurious on the wheat then apparently offset this greater 2,4-D injury on the early date. The data for 1958 did not indicate this early injury; however, the heavier infestation of Canada thistle in the 1958 plots than in the 1959 plots may have accounted for these different results.

EVALUATION OF CHEMICALS FOR CONTROL OF CANADA THISTLE ON NONCROPLANDS.—Several investigations of promising herbicides to control Canada thistle were conducted near Bozeman from 1958 through 1963. The site of these plots was an old infestation of Canada thistle on a fertile silt loam soil on experiment station lands. Individual plots were 1 square rod and borders were sterilized with sodium chlorate to prevent border effects of adjacent treatments. Sprays were applied with compressed-air knapsack sprayers at the rate of 40 gallons of water per acre. Pellets or granules were broadcast on the plots by hand. Effects of treatments on Canada thistle were determined by visual estimates or by shoot-count comparisons with a check plot in each replication.

An extensive series of comparisons was begun in 1958 with applications made on April 30 before Canada thistle emerged, on June 12 at its early bud stage, and on July 2 at its first bloom stage.

Several soil sterilants applied in April controlled Canada thistle for the full season the first year (table 12). Monuron (3-(*p*-chlorophenyl)-1,1-dimethylurea) at 80 pounds per acre was the most effective. No Canada thistle was found on August 20, 1958, or July 1, 1959, in plots treated with monuron in 1957, but some was found on June 1, 1960. In fact, Canada thistle was the only plant in these plots in 1960. Simazine (2-chloro-4,6-bis(ethylamino)-*s*-triazine) at 16 pounds per acre and fenuron (3-phenyl-1,1-dimethylurea) at 40 or 80 pounds per acre also controlled Canada thistle the 1st year, but after 2 years Canada thistle had recovered considerably on these plots also.

Because Canada thistle often recovers in a year or two after soil sterilants have been applied, the value of these chemicals in controlling Canada thistle or other deep-rooted perennials is limited. Unless the soil is kept sterile by repeated treatments for a long time, the perennial weed is usually the first plant to reinvade the treated area. Selective or semisterilant herbicides are therefore more desirable, especially those that allow grass to establish while they control Canada thistle. 2,4-D, dicamba, and picloram demonstrate this in later experiments. (See also tables 14 and 15.)

Although single treatments at low rates of 2,4-D resulted in limited control of Canada thistle (tables 12 and 13), repeated treatments at low rates resulted in moderate control. 2,4-D at high rates of 40 or more pounds per acre resulted in excellent control of Canada thistle when applied November 8, 1962 (table 13). The timing of such applications is important since results in experiments begun earlier in the season were not satisfactory. For example, 50 and 100 pounds per acre applied on October 1, 1953, or May 1 or July 1, 1955, did not control Canada thistle at all, as determined 1 year after treatments. This is probably a result of the breakdown of 2,4-D at the higher temperatures in the summer and early fall. Perennial grasses such as Kentucky bluegrass and bromegrass were also damaged more severely by 2,4-D applied in November. Results

TABLE 12.—*Control of Canada thistle as influenced by date of application and chemical applied, Bozeman, Mont., 1958 and 1959*

Date of application and chemical	Rate of application	Control of Canada thistle on—			
		Aug. 20, 1958	July 1, 1959	June 1, 1960	July 25, 1960
April 30, 1958	*Lb./acre*	*Percent*	*Percent*	*Percent*	*Percent*
Monuron	80	100	100	91	---------
Fenuron	80	98	96	50	---------
Fenuron	40	96	80	26	---------
Polychlorobenzoic acid	40	95	97	94	---------
Simazine	16	97	95	50	---------
Sodium chlorate	1, 120	65	67	14	---------
Ethyl *N*,*N*-dipropylthiolcarbamate	50	30	2	0	---------
Sodium *N*-methyldithiocarbamate	150	47	32	0	---------
Sodium *N*-methyldithiocarbamate	100	25	9	0	---------
June 12, 1958, and October 12, 1958					
2,4-D	2	89	35	42	---------
2,4-D	4	76	69	59	---------
2,4-D	8	88	56	53	---------
2,4-D	20	63	75	48	---------
June 12, 1958, and July 8, 1959					
Amitrole	8	99	87	99	70
Amitrole	4	100	89	90	82
2,3,6-TBA	8	96	92	99	58
July 2, 1958					
Fenuron wettable powder	40	100	100	100	---------
Fenuron pellets	60	100	100	100	---------
Fenuron pellets	40	100	99	100	---------
Fenuron pellets	20	100	97	98	---------
2,3,6-TBA	30	99	100	100	---------
2,3,6-TBA	20	100	100	100	---------
2,3,6-TBA	10	100	98	99	---------
MonuronTCA	280	100	98	97	---------
MonuronTCA	180	99	93	90	---------
MonuronTCA	140	62	85	52	---------
July 8, 1959					
Borate, 2,3,6-TBA [1]	436	---------	---------	---------	97
Amitrole-T	4	---------	---------	---------	97
Amitrole	4	---------	---------	---------	96
Fenac + 2,4-D	4+2	---------	---------	---------	95
Fenac Na liquid	4	---------	---------	---------	95
Fenac pellets	4	---------	---------	---------	88
2,3,6-TBA	20	---------	---------	---------	87
2,3,6-TBA pellets	20	---------	---------	---------	74
2,3,6-TBA	10	---------	---------	---------	35

[1] Borate (B_2O_3)—39 percent; 2,3,6-TBA—8 percent.

of treatments with MCPA at 40 pounds per acre were about equal to results with 2,4-D (table 13).

Amitrole (3-amino-1,2,4-triazole) at 4 pounds per acre controlled Canada thistle well for 1 season when treatments were applied in June 1958, in June 1961, or in July 1962 (tables 12 and 13). Amitrole damaged most species present, including grasses; however, not all grasses were destroyed at this rate. Amitrole-T (3-amino-1,2,4-triazole plus ammonium thiocyanate) tended to be more effective than amitrole; however, because of insufficient comparisons, amitrole-T was not considered conclusively better. The average control of Canada thistle by seven separate treatments of amitrole at 4 pounds per acre was slightly more than 90 percent as determined 1 year after treatment.

From 1958 to 1962, 2,3,6-TBA (2,3,6-trichlorobenzoic acid) was included in seven treatments and was generally very effective. At 10 pounds per acre the average control 1 year later was 85 percent; at 20 pounds per acre the average control 1 year later was 95 percent. This chemical showed a long residual activity in the soil and was quite toxic to perennial grasses. However, as the toxicity decreased, perennial grasses tended to invade plots before Canada thistle. Applications of 2,3,6-TBA made in November were as effective as, or slightly more effective than, treatments in April, May, or June.

Dicamba (2-methoxy-3,6-dichlorobenzoic acid) controlled Canada thistle effectively in several experiments in 1961, 1962, and 1963. Rates tested were from ½ to 20 pounds per acre, and single applications of

TABLE 13.—*Control of Canada thistle by chemicals applied, Bozeman, Mont., 1961 and 1962*

Date of application and chemical	Rate of application	Canada thistle control on—		
		June 1, 1962	June 26, 1963	June 26, 1964
June 20, 1961	*Lb./acre*	*Percent*	*Percent*	*Percent*
Dicamba	10	99	99	---------
Dicamba	20	100	100	---------
2,3,6-TBA	20	89	58	---------
2,3,6-TBA	10	80	50	---------
Amitrole-T	4	98	74	---------
Amitrole-T	2	87	8	---------
Amitrole	4	99	70	---------
Fenac	4	87	84	---------
Fenac+2,4-D	4+2	82	75	---------
2,4-D amine	2	70	39	---------
2,4-D acid	4	70	16	---------
2,4-D acid	2	35	0	---------
July 16, 1961				
Dicamba	10	99	100	---------
Dicamba	20	100	100	---------
2,3,6-TBA	20	98	66	---------
2,3,6-TBA	10	82	51	---------
Amitrole-T	4	98	45	---------
Amitrole	4	90	10	---------
Fenac+2,4-D	4+2	98	21	---------
2,4-D acid	4	70	0	---------
2,4-D acid	2	35	0	---------
2,4-D amine	2	34	14	---------

TABLE 13.—*Control of Canada thistle by chemicals applied, Bozeman, Mont., 1961 and 1962*—Continued

Date of application and chemical	Rate of application	Canada thistle control on—		
		June 1, 1962	June 26, 1963	June 26, 1964
July 3, 1962	*Lb./acre*		*Percent*	*Percent*
Dicamba	10	--------	99	53
Dicamba	5	--------	99	40
Dicamba	2	--------	83	10
Dicamba	1	--------	77	4
2,3,6-TBA	15	--------	96	97
2,3,6-TBA	10	--------	78	98
Amitrole-T	4	--------	93	65
Amitrole	4	--------	83	20
2,3,6-trichlorobenzyloxypropanol	15	--------	82	66
2,3,6-trichlorobenzyloxypropanol	10	--------	63	40
2,4-D	1	--------	10	0
November 8, 1962				
Dicamba granules	20	--------	99	100
Dicamba liquid	10	--------	99	100
Dicamba granules	10	--------	89	95
Dicamba granules	5	--------	70	75
2,3,6-TBA liquid	20	--------	95	100
2,3,6-TBA liquid	10	--------	94	100
2,3,6-trichlorobenzyloxypropanol	20	--------	100	100
2,3,6-dichlorothiobenzamide	20	--------	100	98
Fenac granules	10	--------	98	95
Fenac granules	5	--------	94	100
Fenac granules	2½	--------	82	45
2,4-D acid	40	--------	98	95
2,4-D acid	20	--------	99	50
MCPA granules	40	--------	99	92
Atrazine wettable powder	40	--------	92	98
Atrazine wettable powder	20	--------	80	68
Isocil (wettable powder)	20	--------	87	98
Fenuron pellets	20	--------	63	95
Fenuron pellets	30	--------	22	95
Linuron wettable powder	20	--------	38	15

5 to 10 pounds per acre to the foliage in early July almost completely eradicated Canada thistle. Applications of 5 or 10 pounds per acre in November were slightly less effective (table 13). Applications of 4 pounds per acre on July 3, 1963, in a mixed stand of bromegrass, Kentucky bluegrass, and Canada thistle effectively controlled Canada thistle (table 14). The grasses were not damaged and provided strong competition.

Picloram (4-amino-3,5,6-trichloropicolinic acid) controlled Canada thistle effectively in experiments in 1962 and 1963 (tables 14, 15, 16, and 17). In these tests picloram at ¼ pound per acre controlled Canada thistle more effectively than 2,4-D at 4 pounds per acre in other experiments, and at rates of 1 or 2 pounds per acre, picloram controlled Canada thistle 98 to 100 percent, as determined 1 year or more after treatment.

Picloram was toxic to most species present. Perennial grasses were

TABLE 14.—*Control of Canada thistle by dicamba and picloram applied, Bozeman, Mont., July 3, 1963*

Chemical and rate of application (lb./acre)	Estimated control on [1]—			
	Oct. 22, 1963	June 25, 1964	July 22, 1964	Sept. 22, 1964
Picloram:	*Percent*	*Percent*	*Percent*	*Percent*
½	100	99	97	90
1	100	100	100	100
2	100	100	100	100
4	100	100	100	100
Dicamba:				
½	94	80	20	10
1	80	85	25	10
2	84	80	25	25
4	99	98	90	75

[1] Data are averages of 3 replications.

severely damaged at rates of 2 or 4 pounds per acre. Picloram at ½ pound per acre gave control of thistle about equal to 4 pounds per acre of dicamba (table 14). Although perennial grasses were damaged badly at 2 or 4 pounds per acre of picloram, a heavy stand of cheatgrass and wild oats volunteered on these plots the season after treatment. Winter applications of picloram on the soil seemed just as effective as summer or foilage applications.

Canada thistle infesting a winter wheat field was treated with various rates of picloram, June 6, 1962 (table 17). Individual plots 20 by 30 feet were sprayed with a portable sprayer with a 10-foot boom at a rate of 10 gallons of water per acre. Canada thistles were in the early bud stage of growth and wheat was in the early boot stage. Treatments were randomized and replicated in four complete blocks.

Picloram controlled Canada thistle effectively as estimated 14 and 25 months after treatment. Fourteen months after treatment with 1 pound per acre, 98 percent of the

TABLE 15.—*Control of Canada thistle by chemicals applied at different rates, Bozeman, Mont., July 2, 1963*

Chemical	Full rate of application	Canada thistle control on—							
		Oct. 22, 1963, after full or part rate of herbicide was applied				June 12, 1964, after full or part rate of herbicide was applied			
		1	½	¼	⅛	1	½	¼	⅛
	Lb./acre	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Dicamba	9	95	91	69	66	83	75	83	80
Picloram	9	100	100	100	100	100	100	100	100
2,3,6-trichlorobenzyloxypropanol	18	90	66	69	60	95	68	55	20
Fenac	18	90	97	68	51	99	65	25	10
Trifluralin	18	7	19	39	38	40	10	0	0
Dicamba+2,4-D	4+½	78	61	54	38	85	63	50	35
Fenac+amitrole	4+½	28	73	75	49	90	60	40	20

TABLE 16.—*Control of Canada thistle by chemicals applied, Bozeman, Mont., Nov. 29, 1963*

Chemical	Chemical formulation	Rate of application [1]	Control June 25, 1964	Comments June 25, 1964
		Lb./acre	*Percent*	
Picloram	Potassium salt	2½	100	Everything dead except Kentucky bluegrass and wild barley.
		5	100	
		10	100	
Fenac	Na liquid	2½	63	Ground bare at 10 pounds per acre. No annuals present.
		5	90	
		10	97	
Dicamba	Amine	5	98	Little residual apparent. Fanweed and prickly lettuce still growing, even at highest rate. Perennial grasses not injured.
		10	85	
		15	97	
2,4-D	Amine	10	98	Heavy residual apparent. Ground practically bare. Few perennial grasses present.
		15	100	
		20	100	
2,4-D	Acid	40	94	Very little residual, as shown by germinating prickly lettuce, storksbill, and other annuals.
MCPA	Acid	20	91	Few annuals present. Little injury to dandelion and perennial grass.
		30	96	
		40	100	
2,6-dichlorothiobenzamide.	Wettable powder	10	98	Only Canada thistle remaining.
		20	99	
Prometone	Liquid	20	75	Only Canada thistle remaining; plants are chlorotic.
		40	65	

[1] Active ingredient.

Canada thistles had been killed. Injury symptoms were still evident in surviving thistles and in the barley and red clover grown the year after the treatments. Barley yields increased on all plots treated with picloram and 2,4-D; however, lodging was severe on the plots treated with 1 and 2 pounds per acre of picloram.

SUMMARY

Canada thistle is an aggressive perennial weed growing in the northern half of the United States and many other countries. It is well adapted to productive cultivated soils, especially where spring cereals are grown. It is a weed of roadsides, ditchbanks, rangelands, pastures, and forests, and is spread and introduced into new areas by the wind and by man when he plants contaminated forage and small-grain seeds.

In studies of its life history at Bozeman, Mont., Canada thistle was found to be an imperfectly dioecious plant producing large quantities of viable seed. Seed size

TABLE 17.—*Control of Canada thistle by picloram and 2,4-D applied, Bozeman, Mont., June 6, 1962, and barley yields obtained the following year*

Chemical	Rate of application	Control on—		Barley yield Aug. 22, 1963
		Aug. 22, 1963	July 6, 1964	
	Lb./acre	*Percent*	*Percent*	*Bu./acre*
Picloram:				
Potassium salt	¼	66	27	42.1
Do	½	85	60	42.9
Do	2	99	99	[2] 43.3
Picloram ester	1	98	82	[2] 44.6
2,4-D ester	½	40	25	41.5
Check		0	0	18.8

[1] Data are averages of 4 replications.
[2] Severe lodging caused by picloram.

of strains randomly chosen at 10 locations varied from 298,000 to 677,000 seeds per pound.

Newly germinated Canada thistle seeds require considerable light and usually become established on disturbed areas of pastures or croplands where competition is limited during the seedling stage.

Once established, Canada thistle was very persistent because of propagation from underground roots and its ability to survive from stored reserves of the roots. The normal trend of reserves was somewhat like that of other perennial weeds, with carbohydrates decreasing for 5 to 6 weeks after new shoots emerged in the spring. The carbohydrate reserves then increased until September and remained about constant until freezeup in October. The first herbaceous shoots of Canada thistle emerged in the spring when mean weekly temperatures were 42° F. These shoots varied considerably in appearance as did the leaves, which were from deeply lobed with many spines on the margins to no lobes and few spines. The most rapid shoot growth was in June when mean temperatures were from 61° to 65°.

Because of the aggressiveness and the wide distribution of Canada thistle, all kinds of control measures have been sought, including cultivation, cropping, chemicals, and biological agents. Cultivation and cropping alone and in combinations with chemicals to control Canada thistle were tested in three separate experiments in Montana and Idaho from 1953 to 1959. Several were found to be effective and practical.

The data from these three experiments show that 2,4-D controlled Canada thistle more effectively when competitive crops such as wheat, pasture grass, or silage corn were grown than when no crops were grown. Combining 2,4-D spray with spring wheat cropping effectively controlled Canada thistle and also increased yield of wheat substantially over a 5-year period. In two of the three experiments, the addition of nitrogen fertilizer not only increased the Canada thistle stand but also maintained wheat yield at a high level. In the other experiment, nitrogen did not substantially increase the Canada thistle stand but did maintain wheat yield at a high level. 2,4-D controlled Canada thistle in spring wheat more effectively the first 4 years when nitrogen fertilizer was added than when it was not; however, the difference was not so great the 5th year.

From the standpoint of net crop return and control of Canada thistle, the combination of 2,4-D spray and nitrogen fertilizer was best in a series of spring wheat treatments.

Alfalfa that was mowed twice each year for hay very effectively controlled Canada thistle; the average control was 98 percent in three experiments.

Effective control of Canada thistle also resulted in infested plots where perennial forage grasses were grown. These plots were sprayed with 2,4-D and mowed for hay twice each year.

Various rotations or combinations of forage crops, spring wheat, corn, or potatoes showed that combinations of effective measures summarized here were satisfactory as farm programs to control and eliminate Canada thistle.

One season of cultivation, begun by June 1 and repeated every 21 days, eliminated an average of 95 percent of the Canada thistle in separate experiments.

MCPA effectively controlled Canada thistle in peas and yields were quite satisfactory; however, only a small percentage of thistles were actually killed by this treatment.

Canada thistle was found to reduce wheat yields about 50 percent at infestation levels of 20 to 25 thistles per square yard. Such yield loss was prevented with early control of Canada thistle in two experiments. Spring wheat yields from plots handweeded or sprayed with 2,4-D 16 days after wheat emergence averaged 54 percent more than yields from untreated plots. Wheat yields were increased significantly by handweeding and 2,4-D in plots treated 30 days after wheat emerged, but not in plots treated 37 days after wheat emerged. Wheat yields were greater in handweeded plots than in plots treated with 2,4-D on the same date. This indicated the advantage of early elimination of the competitive effect of Canada thistle and the injurious effect of 2,4-D on the wheat on the respective dates of treatment.

On noncropland, Canada thistle was effectively controlled for 1 season with 2,4-D at 2 to 4 pounds per acre. A second treatment of 2,4-D on Canada thistle regrowth the same year resulted in better control as determined by survival the following year. A competing stand of perennial grass usually developed in plots treated with 2,4-D for Canada thistle control. Certain other chemicals such as 2,3,6-TBA, amitrole, amitrole-T, and fenac controlled Canada thistle fairly well with single applications, but were generally quite toxic to all associated plants, including perennial grasses. Dicamba applied at the bud stage of growth at 5 to 10 pounds per acre generally effectively controlled Canada thistle. This chemical was much less damaging to the grasses present than 2,3,6-TBA, amitrole, or fenac, and was considered to be a more desirable treatment for many noncrop situations.

The most effective chemical tested was picloram at 2 or more pounds per acre, which eliminated Canada thistle consistently. Control by picloram at one-half pound per acre was 85 percent in two experiments and at 1 pound per acre was 98 to 100 percent in three experiments. Time of application seemed to have little influence on the effectiveness of picloram treatments. Perennial grasses were generally quite tolerant to picloram at 1 pound per acre or less.

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