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CANADA THISTLE AND RUSSIAN KNAPWEED AND THEIR CONTROL

BY CHARLES F. ROGERS

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CANADA THISTLE AND RUSSIAN KNAPWEED

SUMMARY

Canada thistle and Russian knapweed, two of the worst weeds known to agriculture, are found associated with all crops and almost every kind of soil, and in every agricultural region of Colorado. Their distributions in Colorado are shown in Figures 2 and 11.

Canada thistle has characteristic stems and leaves which together with its extensive perennial root system make identification easy. Its leaves, stem, flowers and fruit are shown in Figure 1.

The Canada thistle has large horizontal roots where food is stored for use in the replacement of the above-ground parts of the plant and for the extension of the root system. Shoots are sent up from buds on the roots as often as the tops are killed.

The shoots that come up in the spring are formed early in the winter, and grow during the time the ground is frozen.

Roots of Canada thistle can grow horizontally thru ordinary soils as far as 20 feet in one season. A single horizontal root grows in a given direction for 2 to 4 feet and bends down as shown in Figure 3. Another root arises at the bend, and continues the course of the mother root.

Under normal conditions roots of the Canada thistle live in the soil for two seasons. When the tops are destroyed by cultivation or other treatments, this time may be shortened or extended.

Vertical roots of the Canada thistle have been found 22½ feet below the surface of the ground. They absorb most of the water and mineral nutrients for the leaves and stems. The kind of soil in which the Canada thistle is growing has much influence upon its development. Sandy and hard-pan soils are least favorable, and moist clay is most suitable to the growth of roots and tops of the Canada thistle.

Russian knapweed described in this bulletin, has shown no definite association with soil types in Colorado. It is usually found upon land once planted with imported Turkestan alfalfa seed.

The presence of the seed of this weed in alfalfa seed imported from Russian Turkestan has given the knapweed its name and made probable its establishment in every place where Turkestan alfalfa seed has been planted.

The horizontal roots of Russian knapweed are similar to those of Canada thistle, but they are shallower, more fibrous, have less

storage region in each root, and have more roots near the surface of the soil. The vertical roots penetrate deeply into the soil, in some instances to the water table. The length of life of the roots of Russian knapweed is probably the same as that of the Canada thistle.

Excepting for a number of minor differences the noxious characteristics of the Canada thistle and Russian knapweed are the same. Both plants are among the most persistent of the perennial weeds of Colorado.

When these pests are allowed to grow unmolested, they make so dense a stand that almost no plants can compete with them.

Both the knapweed and the thistle damage hay by making the hay difficult to eat, or unedible. They damage pasture by invading the sod and crowding out good forage.

Viable seeds of the Canada thistle are produced wherever the staminate and pistillate plants are growing near each other. Seeds with high percentage of germination have been collected from several places in northern Colorado.

The seeds of Canada thistle and Russian knapweed can travel great distances. Those of Canada thistle are often carried by a strong wind to places far removed from the old plants. If seeds of either Russian knapweed or Canada thistle fall into flowing water they endanger the land below them.

These two pests travel in impure seed, for Canada thistle is a common impurity of commercial seeds of many kinds. The most abundant, important and dangerous impurity in the Turkestan alfalfa seed released from the Denver Customhouse in March, 1928, is Russian knapweed seed. None of this alfalfa seed should be planted before a purity test has been made by the Colorado State Seed Laboratory.

The best way to keep any perennial weed out of a locality is to use *clean seed*, to clean all farm machinery before it leaves the place where it has been used, and to prevent flowering and seed production of all infestation.

Fresh manure is a common source of weed infestation because seeds of many weeds are not killed by passage thru an animal. Manure should be allowed to decompose before it is spread upon the land.

Prevention of weed infestations by the use of clean seed, clean hay and well-rotted manure, together with the elimination of seed formation, is the cheapest way to keep free from weeds of any kind.

The natural increase in the size of an infestation due to the yearly extension of roots is from 6 to 20 feet a year.

The surest means of protection from an existing infestation is eradication, but if this is not possible, the patch should at least be treated separately. No roots should be dragged to other parts of the field or farm. Complete isolation of the infestation is the first step toward its elimination when conditions for eradication are suitable.

Proper control measures for perennial weeds assist in ultimate extermination. They should consist of the prevention of seed formation by mowing and spraying, the burning of mowed weeds, separate, clean cultivation of infestations, clean fallow at intervals, crop rotation, and smother crops.

The general principles upon which eradication measures are based are starvation of the roots or the direct killing of the roots.

The roots of perennial weeds can be starved when such practices as clean cultivation or fallow, spraying and smothering are properly and consistently carried out.

There are numerous commercial sprays with varying value sold in Colorado. Perennial weeds can be smothered by using either crops or dried material. Smother crops should be quick, vigorous, consistent growers, and should be able to hold the weed in check at all times.

Straw, manure and stack bottoms can be used on small patches. Any one of these smothering materials must be kept moist so that decomposition will be active, and it must be kept deep enough to prevent stems from penetrating thru to sunlight.

Sheet metal and paper have been used successfully on very small patches of perennial weeds. Cost of material makes this method prohibitive for large areas.

Direct killing is a way of eradication of perennial weeds which depends upon a sudden death of the roots and tops of the plant.

Some sprays are claimed to be powerful enough to almost entirely eradicate a plant in a single treatment. This has not been found to be the case with any of those tried out at the Colorado Experiment Station. Sodium chlorate has, however, given more promise than any of the others.

Digging out of very small patches or of seedlings proves a sure way to eradicate perennial weeds.

Killing the roots underground avoids the danger of spreading the roots about by dragging, and is further advantageous in that a single treatment often suffices.

Carbon disulfide has been found to be a useful and reasonably certain method for eradication of small infestations in a short time. It is not practicable for large areas, but is recommended where it

is desired to *protect* large areas of weed-free land. Carbon disulfide cannot damage the soil and its poisonous effects are temporary.

Salt is expensive to purchase, and hard on the soil. It will kill out any vegetable life when it is applied at the rate of 2 pounds to the square foot. When it cannot be washed out by flooding, it permanently injures the soil. It is particularly valuable in keeping weeds out of feedlots and other untillable land.

CANADA THISTLE AND RUSSIAN KNAPWEED

By Charles F. Rogers*

The "Canada thistle," one of the worst weeds known to agriculture the world over, has for some time been a resident of every agricultural region of Colorado, but it has not been given the attention its abundance in the state merits. A more recent immigrant to the Rocky Mountain States is the Russian knapweed, which at present infests chiefly alfalfa fields or areas once planted to alfalfa, for it has been introduced in imported Turkestan alfalfa seed. It too has been found in every important agricultural region of Colorado, but it is not well known because of its close association with alfalfa and its relatively recent discovery in the state.

Because of the numerous inquiries for information on these two weeds, and the samples sent in to the College and Experiment Station for identification, this bulletin has been prepared to acquaint the people of Colorado with the Canada thistle and the Russian knapweed. The plants are described and illustrated to show their distinguishing characteristics so that those who are not familiar with this thistle and knapweed can recognize them. The principles and methods of prevention, control and eradication given in this bulletin are based upon experience with the Canada thistle and other perennial weeds during the last 200 years in Europe and America. Altho experiments upon the control and eradication of the Russian knapweed as yet have not been conducted extensively in this country and none have been completed in Colorado, the habits of this new pest are so similar to those of the Canada thistle that the methods which are effective for the prevention, control or eradication of the thistle are almost certain to be effective upon the Russian knapweed as well.

THE CANADA THISTLE

The Canada thistle (*Cirsium arvense*, (L.) Scop.) also known as creeping thistle, field thistle, cursed thistle, and by many other local names thruout the world, is an introduced perennial that propagates itself by both seed and perennial roots.

Detmers† in Ohio says that "The Canada thistle is readily

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The writer wishes to thank Dr. L. W. Durrell for assisting with the manuscript, the preparation from original material of Figures 1, 4, 9 and 10, and for copying from Lund and Rostrup (loc. cit.) Figures 3, 5, 6, 7 and 8. Much credit is also due Ira Hatfield and Miss Anna M. Lute for generous assistance with the manuscript.

†Detmers, Freda: Canada Thistle, *Cirsium arvense* Tourn. Field Thistle, Creeping Thistle. Ohio Agric. Exp. Sta. Bul. 414:1-45. Nov., 1927.

distinguished from all other thistles by its deep green, intensely spiny leaves, small heads of flowers bourne in clusters, by growing in patches and by its horizontal branching root."

DESCRIPTION

LEAVES AND STEM.—The leaves and stem of this thistle are distinguishing characteristics. The erect, ribbed, spiny stems arise from the numerous buds and knobs of the horizontal roots. They are usually green, but in places where exposure to light is great, they are often brown or purple near the base. The leaves are normally dark green and shiny on the upper surface, with a white hairiness on the under surface, especially if the leaves are young and vigorous. The blade of the leaf is long and narrow, and the lobes are terminated with spines as shown in Figure 1-A. The edge of the leaf has several orders of lobes, and is sometimes so "ruffled" that it appears almost ragged. The leaves are sessile, that is they have no "stem." Sometimes the base of the blade clasps around the stem, giving it the appearance of being more spiny than it really is. The stem is often much branched, with the higher branches more vigorous. These in turn are branched several times, and bear flower heads at their tops. (Fig. 1-B.)

Shoots sent up from the roots in the late summer or fall, seldom develop stems above the ground, but remain as flat rosettes of leaves (Fig. 3). Here they are protected from the early frosts and often keep alive long after the stalks have been frozen. All shoots, including the flowering stalks, first appear in the rosette stage.

FLOWERS AND FRUIT.—The numerous purple heads are much alike on all the plants of the Canada thistle. They are 2/5 to 3/5 of an inch in diameter, and 1/2 to 3/5 inch long. The pollen is produced by one plant and the seed-bearing parts are on another plant that has a separate root system. The staminate flowers have a sterile ovary with a poorly developed style and stigma. In the pistillate plants the stamens remain undeveloped, but the stigma matures and the ovule grows normally which means that only those plants, in which the egg develops, can mature seed. This explains the common idea in many localities that the Canada thistle produces no seed. It is entirely possible that this is true, because if only one kind of plant, either the staminate or the pistillate, is growing isolated from other Canada thistles, fertilization cannot take place. The staminate flowers can of course bear no fruit, and without the pollen from them, the pistillate plants remain unfruitful. It is known, however, that when the two plants are growing close enough together there is plenty of fruit. Viable seed was collected within 4 miles of Fort

Fig. 1.—Drawing of the details of the leaves, stems, heads and flowers of the Canada thistle.

A.—A lower leaf and a section of the stem.
B.—Top of a flowering stalk which shows arrangements of heads.
C.—Pistillate flower.
D.—Staminate flower.
E.—Seeds from the center and edge of the head.
F.—Canada thistle seed with pappus or down.

Collins late in the summer of 1927, and was shown to have a high germination test almost immediately after collection.

Lund and Rostrup* who observed this pest more than 60 years ago in Denmark, state that both the staminate and the pistillate plants produce close to 10,000 flowers on a single stalk in a season. Only a small proportion of the seed ever matures into ripe fruit, but even with this there is always an abundance of good seed, whenever the conditions are favorable.

Under normal conditions of sunlight and moisture in Colorado the flowering will start in June and continue until August. Many of the stalks will have some heads open with light brown "down" floating away on gusts of wind, while other heads are purple with fresh flowers. The two kinds of plants can be distinguished by the mature heads, or by the freshly opened flowers which are shown in Fig. 1. The petals of the pistillate flowers are shown in Figure 1-C, to be much smaller than those of the staminate flowers (Fig. 1-D). The staminate flowers have petals 1/5 to 7/25 of an inch long, whereas those of the pistillate flowers are only 3/25 to 1/5 of an inch long. When the staminate flowers open, they give off a strong perfume much like vanilla, but the pistillate heads have more the odor of the "thistle rust" which will be discussed later.

Then too, there is a difference between the mature heads. When the flowers fade, the pappus, shown close to the tube of the flowers in Fig. 1-C and D, begins to grow in the pistillate head and becomes twice its original length. The pappus in the staminate head, however, is not quite so long at first and does not grow after the flowers fade. The mature seed-bearing heads therefore look much larger and are more fluffy than the faded pollen-bearing heads. The "down" is a light-brown color in the heads which contain seeds, but it does not show plainly thru the dried petals of the staminate heads, which remain a dirty brown and never open up after the flowers have died.

Figure 1-F shows a seed attached to the pappus. The larger thread-like branches are covered with minute "hairs" which increase the carrying power of this contrivance for dissemination. When the seeds are still in the head and the "down" is moist, all the branches are drawn together with their ends pointing upward. As they dry out, the branches spread, and the finest divisions stand straight out. Several repetitions of this movement serve to pull the seed from its position and drag it out to where the wind can easily carry it away.

The seed is 1/10 to 1/8 inch long, and about 1/25 of an inch

*Lund, Samsфe, and E. Rostrup: *Marktidselen, Cirsium arvense.* D. Kgl. Danske Vidensk. Selsk. Skr. 6, Raekke 10:148-318. 1901.

thick. Those that grow in the center of the head are straight, but they become more curved as they are found nearer the edge. (Fig. 1-E.) When ripe the seeds are tawny.

OCCURRENCE AND HABITS OF GROWTH

ASSOCIATION WITH CROPS.—Crops in general do not have much effect upon the growth of the Canada thistle or upon the Russian knapweed. The Canada thistle thrives in small grains, gets along well in cultivated crops as ordinarily managed, survives almost any kind of pasturing including good sod, and can hold its own for a time in competition with smother crops. It does not spread rapidly in sod, and is seriously checked by continued trampling, but in cultivated or grain crops, unless given constant attention, it quickly gets the upper hand and spreads rapidly by horizontal roots.

ASSOCIATION WITH SOILS.—To the same degree that the Canada thistle infests most crops, it may be found on all soils except peat. Brenchley* records that in 812 fields observed, this thistle was dominant 125 times, and held a higher rate of occurrence per 100 fields than any other weed. In the Central and Northern States it grows most luxuriantly on limestone soils where water is abundant. The thistle has been found in dry places in Colorado and has persisted for more than 25 years on unirrigated land in the city of Fort Collins. On extremely wet soils with a high water table, the growth is weak, and the root development is poor and shallow. This relation is discussed more fully under the root system.

RANGE

DISTRIBUTION IN COLORADO.—The writer has seen the Canada thistle growing in several places about Grand Junction and Montrose and had a report of it from Del Norte, which was later verified by a specimen. The thistle has been seen growing along the railroad right-of-way in Salida, and is known from specimens to be in the upper and lower parts of the Arkansas Valley. Specimens have been sent to the College from Weld County and the pest has been located in at least four large areas close to Fort Collins. Because no survey of the state has been made to discover all the regions it infests, it is not possible to give every location, but in view of the time it has been known to be in Colorado, this thistle is certainly more widely distributed than the map in Figure 2 indicates. It has not been generally recognized by the people of Colorado as one of the worst weed menaces to their agriculture.

DISTRIBUTION OVER THE WORLD.—Every agricultural region in

*Brenchley, Winifred E.: Weeds of Farm Land. 1920. X. plus 239 pp. illus. New York: Longmans, Green and Co.

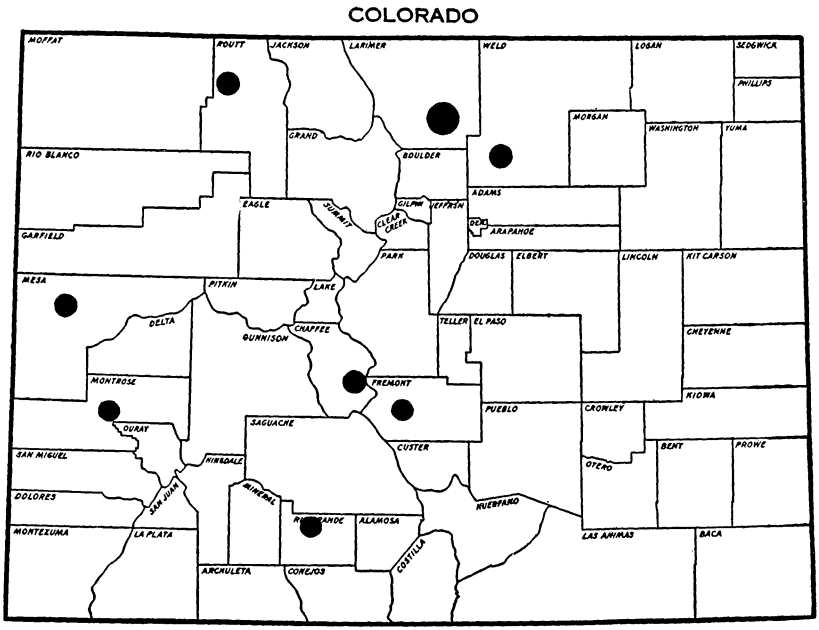


Fig. 2.—Map showing the known distribution of the Canada thistle in Colorado.

the United States, north of the line from Virginia to central California is infested to some degree with the Canada thistle. In the Dakotas and in Canada, stringent legal measures are in force which require that the plant be destroyed wherever found. In these regions seed formation is more common, general development is more vigorous, and infestations are larger and more numerous than in Colorado.

Every agricultural country that has imported seed from Europe is troubled with this most destructive weed. New Zealand and South Africa have struggled with it because the first few plants were not eradicated as soon as they got started.

Uses

Almost any plant can be used in some way, and the Canada thistle is no exception. When the shoots and roots are taken early in the spring before the leaves have pushed thru the surface of the soil they are tender and tasty, and can be used in the same ways as asparagus. Both the shoots and roots are reported to have been eaten in Russia, and by the Indians in this country. When in flower, the fragrant perfume attracts insects, and the nectar is considered in some places to make good honey.

Root System

Horizontal Roots.—The tops of the Canada thistle die down

to the ground after the first heavy freeze, but the roots remain alive during the winter. There are many horizontal roots which lie parallel to the surface of the soil at depths which depend upon the nature and the moisture content of the soil. They are most commonly found from 6 to 12 inches below the surface. Figure 3 shows the interrelation of the roots and how they bend downward after they have grown horizontally for several feet. These horizontal roots together with the vertical roots are the storehouse for the food made by the leaves during the summer, and the most important means of extension of the plant in the soil. Usually they grow horizontally for 2 to 4 feet before making the wide bend into the subsoil. Almost always a new horizontal "regenerative root" arises at the bend, and takes the same direction as the mother root. A number of feet farther on, it too will bend down. This may be repeated several times during a season, so that the spread of the Canada thistle thru the soil is rapid. It is sometimes as much as 20 feet in a season, when the growing conditions are favorable.

Certainly the horizontal roots are the most important part of the plant when control measures are to be considered. The horizontal roots are largest at the bends, and bear most of the stalks upon the sharper parts of these curves, as is shown in Figure 3. There are almost no small roots that come off from the horizontal roots, and absorption from the upper levels of the soil is largely limited to the fibrous roots that are found upon the underground portion of the stem and the very young horizontal roots. The horizontal roots, are, therefore, practically unable to live independently of the vertical roots which descend into the subsoil when they have a full load of tops to support.

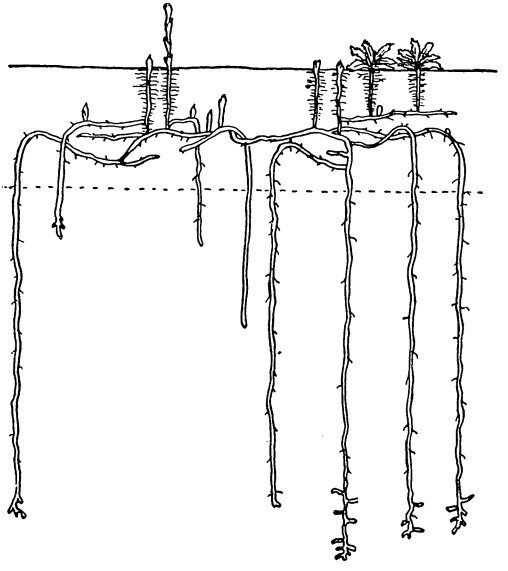


Fig. 3.—Diagrammatic sketch of root system of the Canada thistle.

VERTICAL ROOTS.— The vertical roots grow into the subsoil according to the nature of the soil and the need for water and mineral nutrients. After the roots assume the vertical position, they have an abundance of small branches for absorption. It is upon these parts of the plant that the upper roots and the aerial portions depend for their general vigor and continued extension, because this region together with its functions of absorption, is one of the chief places for storage. Figure 4-A is a cross section of a root of the Canada thistle which shows its cellular structure and the wide ring of large storage cells where the food is kept and changed into the forms in which it can be most easily used. The diagram of the thistle root in 4-B gives a simpler picture of the relative proportions of the storage region "S" to the conducting or vascular region "V."

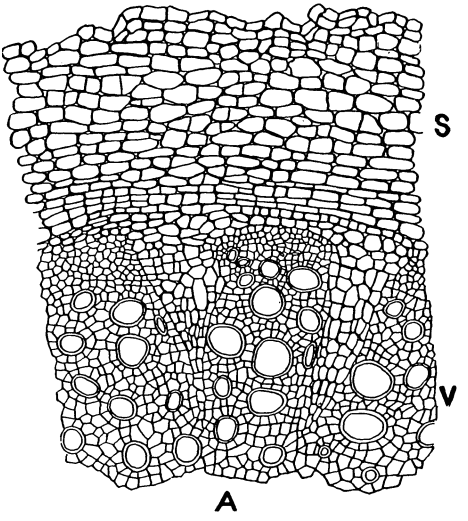
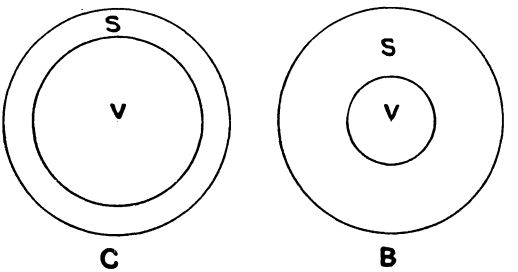


Fig. 4.—A.—Cross section of a root of the Canada thistle showing the conduction and storage regions. "S" is the storage region of the root. "V" is the vascular or conducting tissue.



B. and C.—Cross section of roots of the Canada thistle and Russian knapweed showing the relative conduction (V.) and storage (S.) regions of each.

DEPTH OF PENETRATION OF ROOTS.—Unless the water is far down the roots frequently reach the water table. A depth of more than 8 feet was reported from Denmark by Lund and Rostrup*, and excavations made by the author in Iowa and Colorado showed that depths of 7½ to 9 feet are common. One digging in the dry region of the steppes of southeastern Russia found the ends of roots of the Canada thistle at a depth of 22½ feet below the surface. The root is fairly uniform in size thruout its vertical length.

EFFECT OF SOIL UPON THE ROOTS.—The kind of soil in which the roots grow greatly modifies their development, and consequently their absorptive and storage capacity. Unfavorable conditions in the subsoil always result in a poor growth of tops and a weak root system. Hard-pan soils, gravel, sand or a high water table decrease the depth and retard the rate of penetration of the roots. If the root tip is destroyed during its growth by striking marly soil, a stone, or other obstacle, branches are usually sent out to continue the same direction of growth. Gravel or sand affects roots in much the same way as does hard-pan or marl. The effects of different soils upon root growth are shown diagrammatically in Figures 5 and 6. Moist clay always seems to furnish the best medium for development of perennial weeds. In Figure 5-A is seen a root of the Canada thistle growing in clay which is underlaid with marl. The tufted branches indicate the level of the hard-pan. Much better development is evident in Figure 5-B because the soil in this case is a soft homogeneous clay, but is underlaid at a considerable depth by marl, at which level the branches always become tufted When gravel is covered by a thin layer of clay, the roots take the position shown in Figure 5-C. The roots form in the soft soil, but cannot penetrate the rough gravel. If the hard-pan is at the surface, the roots have many small short branches, as is shown in Figure 6-A and B, but if the layers below are soft and moist, a root will sometimes find its way into the more favorable regions and help support the plants above. Sandy soils, however, give little comfort to perennial roots

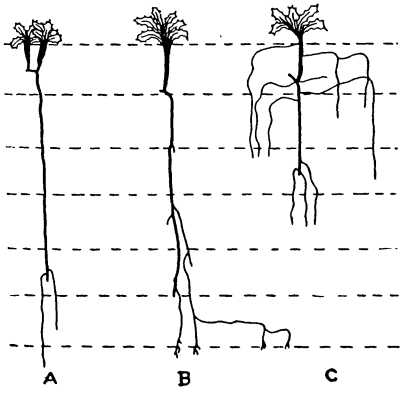


Fig. 5.—Development of the roots of the Canada thistle in clay.
A. and B.—Clay underlaid with marl.
C.—Clay underlaid with gravel.

*Loc. cit.

of this kind, for they remain shallow, short and weak (Fig. 6-C). It can be clearly seen that the kind of soil upon which the Canada thistle is growing is a large factor in the vigor and resistance of the plant to efforts at control, and has a major role in the means employed for complete extermination.

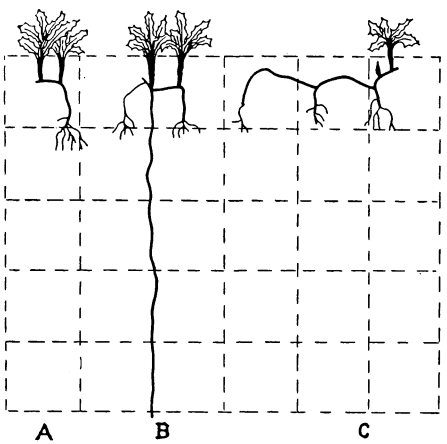


Fig. 6.—Effects of hard and sandy soils upon the development of the roots of the Canada thistle.
A. and B.—Hard-pan near the surface.
C.—Development in sand.

SIZE OF ROOTS.—The size of the roots has the same relation to different soils as does the extent of the root system. Clay furnishes the best medium for development of individual roots as it does for the whole plant. Roots ¾ inch in diameter have been taken from moist, soft clay by the author. These diameters were found at the bends of the roots where they start into the subsoil. Below the bend the roots slowly taper downward, but they are fairly uniform in size thruout their vertical length unless they are stopped by unfavorable soil, or by a high water table. The coarser and harder the soil, the smaller the roots are likely to be. The decrease in diameter in places where there is high water table, sand or hard-pan, is partly due to starvation of the roots because of the poor top growth, and partly due to the frequent branching that occurs when the tips die and new tips are formed. Roots in sand never becomes more than ¼ inch in diameter, and the proportion of the storage to conducting tissue is smaller than when the roots are large, and the leaves are sending down an abundance of surplus food for storage.

LENGTH OF LIFE OF ROOTS.—Altho the Canada thistle is a perennial plant, its roots, unlike many of the woody plants, do not live indefinitely, for they pass thru a definite life cycle. New roots keep taking the place of those that die, and the infestation seems to remain the same when it is really being constantly renewed.

A root which is formed early in the spring will reach its full development the same summer, but probably will not produce flowering stalks. The shoots it sends up will have many leafy stems, and will assist in the accumulation of the reserve supply of food and energy to be used the next spring. These tops die down to the root

in the winter unless they are infected with the "thistle rust," in which case the lower end of the underground part of the stem will probably live over winter, and send up sickly shoots the following spring.

During the second season for the root, it produces large flower stalks. In the meantime young roots have been growing out from the old one, and have penetrated the soil in all directions. During the summer of 1929, therefore, the greatest activity of the 1928 root is reached. It quickly falls into decay after the death of the tops and in the spring of 1930 the root will be nothing but a dead black form with a shredded string in the center, which was the conducting tissue. Roots which are hindered by smothering or by other interference, do not follow this cycle so closely, and are usually longer lived because their normal development has been interrupted.

NOXIOUS CHARACTERISTICS

Those characteristics of a plant that make them noxious are not in themselves undesirable. The very habits that make a grass form a good lawn or pasture are noxious when exhibited by the Canada thistle or the Russian knapweed. Persistence, capacity to spread, either by root or by seed and density of growth, may or may not be advantageous. In the Canada thistle and Russian knapweed they are decidedly troublesome.

PERSISTENCE.—Something of the life history of the Canada thistle has already been presented. One of its worst characteristics is its ability to retain its hold upon life, and the soil in which it is established. There is no record of an area infested with this plant ever having died out from natural causes, and the records of the successful attack upon the thistle by man are altogether too few. Many fields and even whole farms have been abandoned, because the Canada thistle had got the upper hand in the struggle. A field near Ontario, Iowa, has been infested with this thistle for 40 years, and efforts have been made to check the invasion, but it has spread steadily. This persistence is accounted for by the large amount of food stored in the roots.

CAPACITY TO SPREAD.—Coupled with this persistence is a great capacity to spread. The natural increase in the size of an infestation has already been explained. This in itself is one of the worst characteristics of the Canada thistle.

When small sections of roots are broken from the main system they have phenomenal powers of regeneration. The roots of this pest have, as do many other perennial weeds, the capacity to form in a short time a whole new plant from a fragment of root that is supplied with food, and which is more than 6 weeks and less than 2

seasons old. Figure 7 shows a small section of root that was broken off and dragged in the early summer from the original infestation. During the remainder of the growing season, it sent up a stalk from near one end, and produced many horizontal roots. The infestation from this small piece is already more than 9 feet across. Instead of being unusual this is the common occurrence in fields where the areas covered by perennial weeds are plowed or cultivated at the same time as the thistle-free ground. If they are not exposed to direct sunlight, or to desiccating winds, these detached sections of roots can live for some time in a rather dry soil.

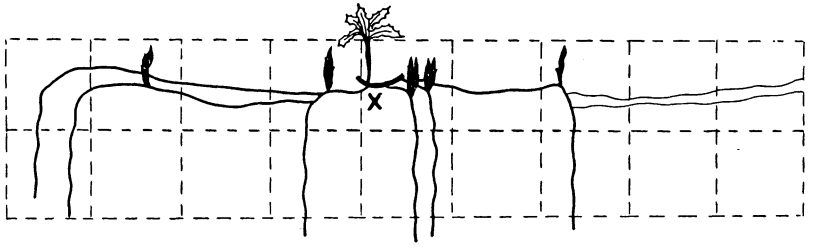


Fig. 7.—Growth during one season of a root system from a section of a root. X.—Original section of root.

When conditions become favorable for regeneration, the buds quickly develop, and grow into astonishingly large and healthy plants for the apparent amount of reserve in the fragment of root. As soon as the leaves unfold above the surface of the soil, the new system quickly becomes self-supporting. The reserve food in the old root, however, is soon used up either in the extension of the roots, or in the production of new shoots. Deep cultivation thru patches is therefore unwise because of the great danger of spreading the pest, without doing serious damage to any established plants. Natural extension of 20 to 40 feet a year under favorable conditions, gives sufficient cause for anxiety, but the vitality of the pieces of root makes it necessary to use methods that do not drag the roots over weed-free land.

Any noxious plant that spreads by wind-blown seed is likely to become a serious pest. The most rapid and widespread natural means of dissemination of the thistle is by its parachute-provided seed. This characteristic of the thistle makes it a constant menace for many miles in all directions from the place where viable seeds are produced. The seed may be shaken loose by the wind and dropped into flowing water which irrigates land many miles away. Infestation commonly caused by dissemination of seed by either wind or water, are inexcusable, for it is entirely possible to prevent seed formation by cutting the stalks when the flowers begin to open.

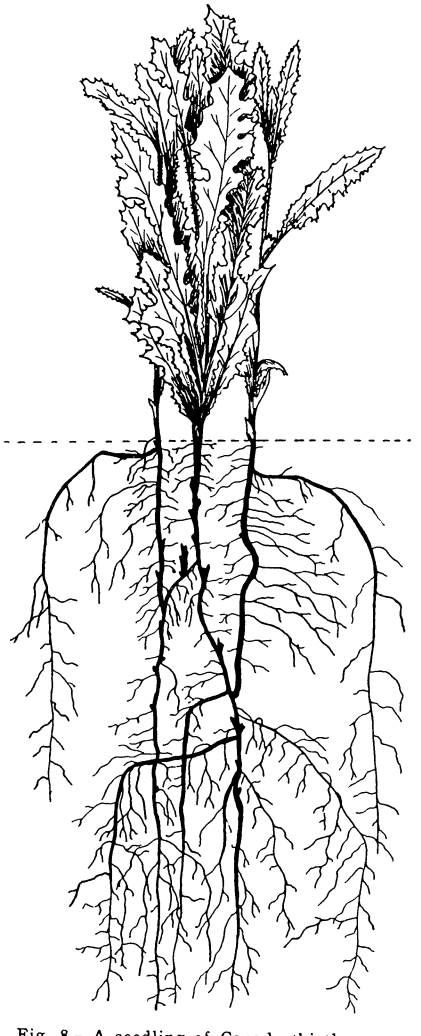


Fig. 8.—A seedling of Canada thistle grown in sand for 10 months. Note the development and formation of buds upon the bends of the roots.

Some of the seeds will germinate the same year they are matured, but most of them will not grow until the following spring. Those that do start late in the summer will become not more than 6 to 10 inches high, and some will fail to live over the winter. When the seeds germinate in the spring, however, they grow quickly into large plants with stalks 20 to 24 inches tall. Except that they are unlikely to flower the first year, they can in no way be distinguished from an old plant. Lund and Rostrup* allowed a seedling to grow in sand for 10 months. The box which held the sand was nearly 3 feet deep, practically as long and about a foot wide. They broke the box apart to expose the roots in their natural position. The development of the roots in the sand is shown in Figure 8. If development like this can take place under such unfavorable conditions, it can readily be seen what will happen in the field.

Impure seed is one of the easiest and most common means of introduction of the Canada thistle into a new region. It is found in clover seed more frequently, in Alsike clover, and in uncleaned grains from infested fields. It occurs in most kinds of seeds.

One of the easiest ways to carry the seed from place to place in a locality is on and in farm machinery. Wagons, hay racks, threshers or combines are good carriers because the seeds shatter out of the heads and collect in the cracks and on the non-moving

*Loc. cit.

parts of the machinery. They rattle out during moving, or are dumped out when the thrashers or combines are cleaned before starting a new run, instead of being left at the place where the previous job was completed. A few moments spent in the prevention of spread of weeds from one field to another will save probably years of effort on the same or on a neighboring farm which previously had been free from the pest. The spread of any weed in this way, when prevention is so easy, can find no excuse whatever.

When the seeds of Canada thistle are fed in grain most of them pass thru the animal without injury and are able to grow when they are spread upon the land in fresh or undecomposed manure. At the time the grain is thrashed many viable seeds are of course blown out with the straw from infested fields. After being used for bedding, the straw with its load of thistle seed is carried to the field again. Poor hay which contains mature thistle plants is sometimes fed to animals. Many of the mature seeds remain in the hay, and return to the field in the manure. These means of dissemination add to the noxious characteristics of the Canada thistle by increasing the ways in which it becomes dangerous.

DENSITY OF GROWTH.—When the Canada thistle has become well established, the shoots come up so thickly that the soil is completely covered. If this happens in grain fields, the young grain is choked out or seriously checked in its growth. Thistles in a pasture are usually so completely left alone by livestock that the spiny plants grow unmolested. The edible pasture plants are, therefore, crowded out and the pest more strongly entrenched than ever. Ordinary practice in the cultivation of corn holds the thistle down for a while in the spring. After the corn is laid by, the thistles can sometimes so nearly overtake the corn that it grows little after the last cultivation.

The growth of the Canada thistle is much greater in full sunlight than in full or even partial shade. Altho it never flowers when completely shaded, its capacity to compete successfully with other herbaceous plants is nearly as great in the shade as it is in well-illuminated locations.

PRESENCE IN HAY AND PASTURE.—Canada thistles which grow in hay meadows are usually kept under control and are unlikely to mature much seed. They are, however, present in the dried hay where their coarse leaves and stems would make poor forage even if they were free from spines. Hay which has many thistles in it is useless for fodder, and has little value as bedding. It is dangerous to use it as a fertilizer because the heads, even tho cut green, are probably full of seed which can grow when the manure is spread upon soil.

Pasture land infested with the Canada thistle is sure to be unevenly grazed. Wherever there is a stalk of the thistle, the grass is left by the livestock, and of course is eaten more closely elsewhere.

The roots do not thrive in sod nearly as well as in broken ground. If the pasture is heavily overgrazed, the thistles may be eaten also, but they are taken unwillingly, and only because they cannot be separated from the grass. This kind of treatment weakens the sod, giving the advantage to the thistle which will quickly take full possession of the land.

NATURAL ENEMIES

FUNGI.—Many parasitic fungi are found on the Canada thistle. One of them, commonly known as the "thistle rust" (*Puccinia suaveolens* Pers.) does more damage to the thistle than all the rest of the fungous diseases combined. Like the other rusts this one has alternate generations, but unlike many of them, both generations are found upon the same plant. This results in a perennial mycelium in the plant, and in the continued production of both kinds of spores, the uredospores and the basidiospores. Early spring infection causes a sudden increase in the rate of growth until the flowers are about to open; then the whole stem withers and dies. The fungus invades and travels along the roots. It sometimes attacks every shoot along a new root with a result that none of the shoots grow into strong or normal appearing plants. The stems die down to the ground level in the fall, but the lower part of the infected underground stem lives over winter. Because of the presence of buds under the scales of the underground stems, shoots from them appear earlier than from healthy roots. The shoots are light green, slender and frail. They grow faster than the other stalks but die just before the flowers open.

As much as 30 percent of a patch can be infested at one time with this disease. It frequently limits the activity of the plant, but does not entirely kill it out. Uredospores are plentiful in pustules on the leaves and stem of the Canada thistle. They produce a second less virulent infection. The third crop of uredospores is often so late that infection from this crop becomes barely visible before the tops are killed by frost. The open pustules give off a characteristic odor which is similar to that of the pistillate flowers of this thistle.

INSECTS.—Of the many insect parasites upon the Canada thistle, only a limited number do any appreciable damage. The Painted Lady butterfly prefers the Canada thistle to any other plant. At times there is so severe an outbreak of this insect that the whole plant is defoliated. If the second crop of larvae are not plentiful,

the new shoots that come up in July and August after defoliation of the first stalks will not be affected and no permanent injury will result. This insect (*Pyrameis cardui*, L.) is characteristically marked with white or yellow spots on the forward parts of its brown wings. The body is 3/5 to 1 inch long and the wing spread is from 2½ to 3 inches. The mature larva is slightly more than an inch long, and has a dull yellow band down the front.

There are two footless grubs which attack the thistle. One of them, the *Dasynea gibsoni*, Felt., causes one side of the head to break out after the grubs have consumed much of the receptacle and many young seeds. This insect is known as Canada thistle midge. It is closely related to the clover seed midge. The footless grub of a yellow fly damages the heads without any evidence of injury showing on the outside. Most of the seeds in an infested head are destroyed by this insect parasite. Damage done by insects varies much according to the prevalence of the insect.

BIRDS.—One of the most consistent destroyers of the seed of the Canada thistle is the goldfinch. Its diet consists to a remarkable degree of thistle seeds. Some of the seeds are probably uninjured by passage thru the bird, so that eating does not destroy all of the seeds consumed. A large proportion of them, however, are digested. Other birds, most of them closely related to the goldfinch, consume small quantities of thistle seeds.

RUSSIAN KNAPWEED

Russian knapweed (*Centaurea picris, Pallas.*) is not well known generally thruout the United States because of its rather recent introduction, and because as yet it is limited to the parts of the country which have used alfalfa seed imported from Russian Turkestan. This weed is one of several "knapweeds" which are so named because of the heavy gray hair or nap on the stem. This nap is especially noticeable when the plants are young. The plant is called "Russian knapweed" because of the source from which it came into this country.

Its natural enemies have not appeared in numbers sufficient to be of any importance in the control of the weed by destruction of either the tops or the root system.

DESCRIPTION

Russian knapweed may be distinguished from other weeds in Colorado by its characteristic lilac-colored flowers in small round heads, by the tough, dark-brown or black perennial roots, and by the rather shredded appearance of the mature plant when seen alone.

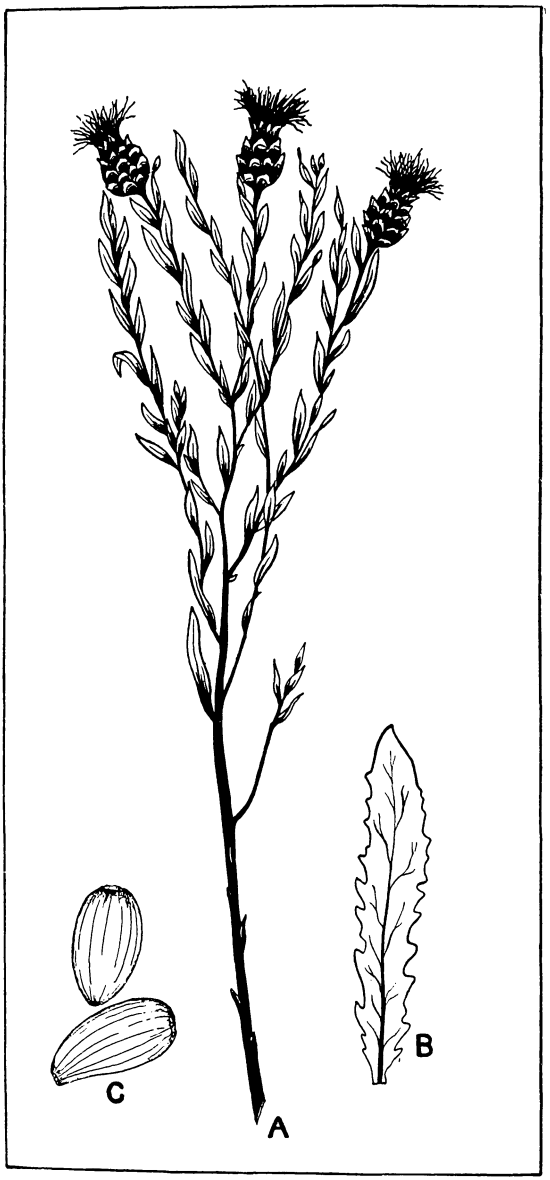


Fig. 9.—A.—The stem, leaves and heads of the mature Russian knapweed.
B.—A leaf of a young plant.
C.—Seeds of the Russian knapweed.

LEAVES AND STEMS—The leaves on a mature stem are small, narrow, with smooth surfaces and edges, and without a pronounced midrib or petiole. The ends of the blade have a rounded point. Short, stiff hairs cover the leaf and stem so that they feel sticky to the touch, and irritate the skin when brushed across the hand or face. The leaves get smaller as they approach the head (See Figure 9-A).

The upper parts of the stems of the mature plants have the same hairy roughness as the leaves. The whole stem is hard and practically inedible when dried in hay. The young stems are covered with a long, soft gray nap which remains upon the lower part of the stem. It does not appear on the branched parts of the flower stalks where the leaves are small. When the nap is removed from the lower part of large stems, a dark-brown or purple color is visible, and continues down to the underground

part of the stem which is much the same color as the true roots that lie horizontally at a short distance below the surface of the soil. The leaves on the upper end of the underground part of the stem are dark, pointed scales, but close to the root these almost disappear and are replaced by fine roots.

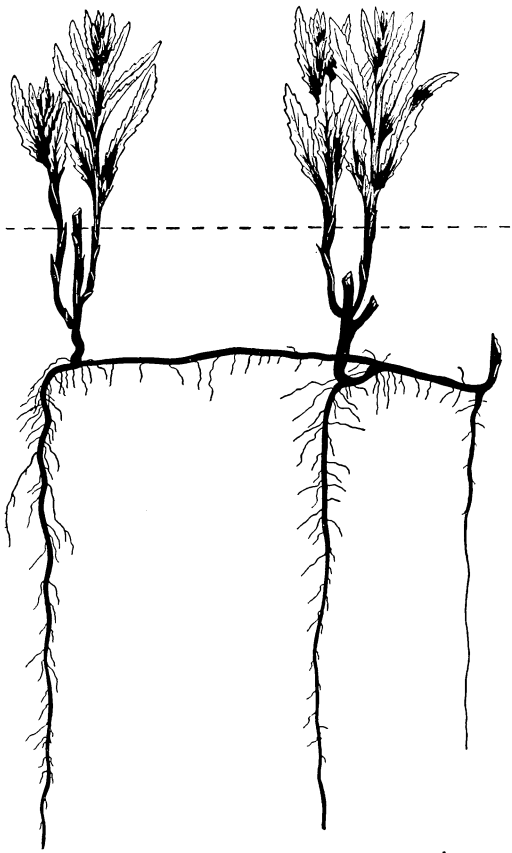


Fig. 10.—A portion of the root system and young shoots of the Russian knapweed.

When the Russian knapweed comes up in the spring the first leaves are large, gray-green and much longer than wide with rounded teeth along the edge of the blade. (Fig. 9-B.) The same long nap that covers the young stem is found upon these young leaves, which are so different from the leaves on the upper part of the stem that one who is unfamiliar with the pest, could easily mistake the young shoots of Russian knapweed for some other kind of plant. Young shoots and their relation to the roots are shown in Figure 10. The young leaves vary greatly in shape, but when the stem is densely pubescent and attached to dark-brown, tough, perennial roots, there is little question that the plant is the Russian knapweed, altho the final proof depends upon the flowers and fruit.

FLOWERS AND FRUIT.—The appearance of small, round, single heads of lilac flowers upon rather long stems, will establish the identity of the Russian knapweed if the leaves, stems and roots leave room for doubt. The heads are never more than ⅜ to ½ inch in diameter, and are usually almost spherical. The lack of thorns, and the size of the heads make it possible to distinguish the plant from any thistle. The single heads on long stems furnish an addi-

tional distinction from the Canada thistle. When the flowers are open, they give off a characteristic, rather pleasant odor.

The seeds of Russian knapweed are a chalky light gray, and are marked longitudinally by inconspicuous fine lines. Some of the seeds are slightly curved, altho most of them are wedge-shaped, as is shown in Figure 9-C. Fully developed seeds have been found in all the mature heads of Russian knapweed collected by the writer in Colorado. Seed production by this plant is therefore a very real danger to the localities where this pest is already established.

OCCURRENCE AND HABITS OF GROWTH

Turkestan alfalfa seed imported directly from Russian Turkestan is responsible for the introduction of the pest and for most of the present infestations in Colorado.

ASSOCIATION WITH CROPS.—Up to the present time at least, the Russian knapweed has been or can be associated directly with Turkestan alfalfa seed. When the alfalfa is replaced by a cultivated crop, the pest is discovered often for the first time, growing luxuriantly in patches of almost any size and number. Its similarity to alfalfa in height and the way in which it blends with the leaves, stems and flowers of alfalfa make its detection unlikely by the casual observer of a field, even at close range. Its resistance to cultivation and its capacity to get along with almost any crop makes it as indifferent as the Canada thistle to the kind of crop with which it is growing. When in competition with other weeds in waste places, it can easily hold its own and spread rapidly thru them. Sod seems to have no effect whatever upon the Russian knapweed, for it has been known to spread steadily and rapidly in otherwise good sod pastures where the common wild morning glory was killed out and the Canada thistle was making no headway.

ASSOCIATION WITH SOILS.—The great variety of soils upon which the writer has found rank growths of this weed indicates that there is no soil which is most favorable to its development, unless it be damp clay, where moisture is likely to be abundant, and where the soft earth permits easy penetration of the roots. Equally strong, numerous and menacing infestations have been found on other kinds of soil, but they are not more vigorous, nor do they spread faster than in clay. The slight advantage in clay soil cannot even suggest that the pest is to be more definitely associated with a certain soil than with a certain crop. Its appearance in alfalfa is due to its presence in imported alfalfa seed. The Russian knapweed seems to be able to survive almost any crop in any tillable soil in Colorado.

RANGE

DISTRIBUTION IN COLORADO.—Requests for identification of Russian knapweed and for control measures come to the Experiment Station and the College in increasing numbers. Locations of the numerous infestations known to exist in Colorado are shown on the map in Figure 11. Near Montrose and in the valley of the Gunnison river, Russian knapweed has been found in several places. It is known to be widely distributed over the San Luis Valley. Patches of this pest have been found from the New Mexico line as far north as Hooper and Saguache. A specimen for identification recently came from the San Juan Basin. Knapweed was formerly thought to be limited to the southern and western parts of Colorado because no specimens had been sent from the central and northeastern agricultural regions of the state. During 1927 and the first months of 1928, however, numerous locations have been found in Weld, Larimer and Morgan counties.

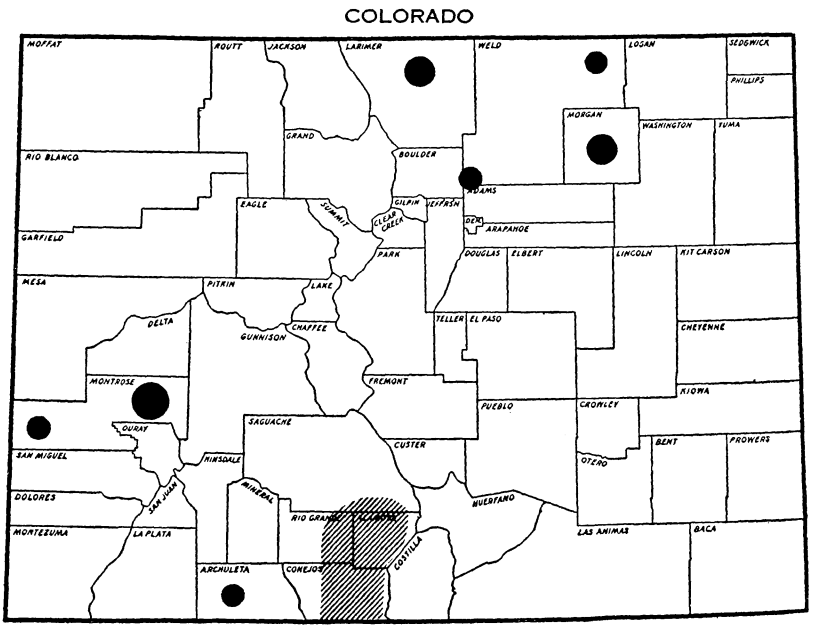


Fig. 11.—Map showing the known distribution of the Russian knapweed in Colorado.

In every case of questions about this pest, alarm has been expressed at its persistence, its capacity to spread and the damage it does to the crops which are planted upon infested land. There is now little doubt about its existence generally over Colorado, and it has been reported from all the states that bound Colorado. Where

imported Turkestan alfalfa seed has been planted there is every reason to believe that infestations of Russian knapweed had a chance to get started because the seed of this pest is almost always present as an impurity. It may have failed in some places to become permanently established, but if alfalfa seed from Turkestan is used repeatedly Russian knapweed is almost certain to take possession of the land upon which it is sowed.

Prevention is far cheaper and better than control or eradication. Only seed that has been cleaned and tested for purity should be used whenever a crop is to be planted.

ROOT SYSTEM

The root system of this pest has never been as carefully investigated as has that of the Canada thistle, but the similarity between the two makes a detailed description of the roots of Russian knapweed unnecessary.

HORIZONTAL ROOTS AND EXTENT OF THE ROOT SYSTEM.—The horizontal roots of Russian knapweed are all of practically the same dark-brown to black color. They are covered by fine absorptive roots which grow out in all directions. The horizontal root is not large except at the rather sharp downward bend where the root expands to be ¼ inch or more in diameter. Frequently a number of shoots arise close together along the outside of the bend and grow up into a clump of plants. A vertical root under a group of stems can be easily mistaken for a tap root. Near the bend another root starts a horizontal course for a few feet before it too bends down. In the region where no shoots or bends are found, the fibrous roots are few, but near the shoots the absorptive roots are abundant. The horizontal roots in this plant are shorter than in the Canada thistle. This is probably responsible for the somewhat slower rate of increase in the size of infestations of Russian knapweed when the two plants are under the same conditions.

VERTICAL ROOTS AND DEPTH OF PENETRATION.—Altho the vertical roots of Russian knapweed have numerous large branches, the main root continues in a generally vertical direction with the deviations necessary for an easy path. In one place where the water table was high, the whole root was traced. It was found that it tapered uniformly from the vertical bend to the water line, but did not extend into the water. A number of small branches were sent out horizontally just above the level of the water, probably for the purposes of absorption. Under ordinary circumstances, however, when the water level is low, the roots of the Russian knapweed penetrate into the subsoil and are uniform in size thruout most of their length. The limit of their power to go down into the soil

has not yet been found, but their vigor above ground and resistance below the surface to most treatments are good indications of a deep and extensive root system. A small part of a root system is shown in Figure 10. This pest thrives upon dry as well as irrigated land, so that its root system must be both wide and deep.

SIZE OF THE ROOTS.—So far as the writer is aware, there has been no study of the effects of soil upon the behavior of the roots of Russian knapweed, or of the soils upon the size of the roots. Observations of the sizes of roots of this pest on the Wetern Slope near Montrose, in several places in the San Luis Valley, and in northern Colorado, have failed to indicate any difference between the sizes of the roots in different soils or under different conditions. In all places the diameter of the root at the downward bend was a little more than a quarter of an inch. The thickness of the horizontal root in all cases varied with age, but the maximum was approximately constant. Figure 4-C shows the relative amount of storage region in the root of Russian knapweed, compared with the conducting system. It is plain from Figure 4-B and 4-C that there is a greater reserve region in the roots of the Canada thistle than in those of the knapweed.

This deficiency of storage region in a single root, however, is probably more than balanced by the greater number of roots in the upper layers of the soil, which are sometimes completely matted with the dark-brown roots of Russian knapweed. There is every evidence that the food stored in the roots of this pest is equal in quantity and availability to that of any other plant of the same general nature.

LENGTH OF LIFE OF ROOTS.—The length of life of the roots of the knapweed is not exactly known. Excavations of its roots indicate that the life cycle of this plant is practically the same as that of the Canada thistle. This point, however, will have to be proved by further observation.

NOXIOUS CHARACTERISTICS

Perennial weeds with habits in common have also many similar noxious characteristics.

PERSISTENCE.—The persistence of Russian knapweed has already classed it as one of the most feared weed pests in Colorado, even tho it has been established for a much shorter time than many others. Land that is overrun by the knapweed is useless for all time unless some direct, consistent and effective attack is made upon the pest. It easily survives most methods of cultivation and, if driven from much-used places, takes refuge in out-of-the-way corners.

CAPACITY TO SPREAD.—The capacity of Russian knapweed to spread by natural means is not as great as that of the Canada thistle because of its lack of a distributing device, but this disadvantage is more than made up by the vitality of the roots and their capacity to form new plants.

There are many fields in Colorado infested with Russian knapweed in which the small infestations over the field are definite proof that some operation of cultivation or preparation of the land reached the roots and dragged fragments of them into new locations. The vitality of these fragments is one of the greatest sources of danger in the spread of the knapweed over a field. The natural increase of a single infestation is great enough without the sudden appearance of new patches caused by the dragging of roots when the soil is plowed, harrowed or floated.

Impure Turkestan alfalfa seed has been responsible for the introduction of this pest into Colorado and many parts of the United States. Uncleaned grains from fields in which the knapweed is growing, or irrigation water which carries the seed, are constant menaces to weed-free land. Because seeds cannot be wind-blown for any distance, artificial means of dissemination are the chief causes of new infestations, and because these artificial means of dissemination can be entirely controlled, the spread of Russian knapweed in impure seed seems to be utterly inexcusable.

In March, 1928, there was released from the Denver Customhouse approximately 50,000 pounds of Turkestan alfalfa seed, imported from Russia. About 25,000,000 seeds of Russian knapweed were brought in with this alfalfa seed. This is enough to produce a perfect stand on at least 5,000 acres of land. Ten percent of the shipment was stained red to indicate that it was a variety of alfalfa not adapted generally to the conditions of the United States. Much of this alfalfa seed was not sold during 1928, and will be on the market in succeeding years. Anyone who intends to use Turkestan alfalfa seed, should look at large samples to learn if part of it has been stained red. In that case every prospective purchaser should examine closely a considerable quantity of it on paper for conspicuous, light-grey, wedge-shaped seeds. Whether or not any are found, before the seed is planted a 4-ounce sample should be sent to the Colorado Seed Laboratory at Fort Collins, for a test of its purity. If any seed of Russian knapweed is found, the alfalfa should NOT be planted. This weed is so serious a menace that no precautionary measure is too great to take, in order to protect weed-free land from infestation by one of Colorado's most noxious weed immigrants.

Fresh manure from animals that have been fed hay or grain containing seed of the knapweed, or bedding that has in it the

mature heads of the pest, contains viable seeds of the weed. It will increase the damage already done by the pest if the fresh manure is placed upon the soil. Dangers of this kind have already been discussed under the Canada thistle and prevention measures are suggested later in the bulletin.

DENSITY OF GROWTH.—When the knapweed grows unmolested, it makes a perfect soil cover and eliminates all other vegetation. Even when controlled in part by cultivation, there is a constant battle between the farmer and crop on one side, and the weed on the other, in which the weed often gains the victory. The Russian knapweed's combination of persistence and density of growth makes it one of the most noxious weeds in the state.

PRESENCE IN HAY AND PASTURE.—The stiff stems and rough leaves of the knapweed are almost inedible when dry. The presence of much of the pest in hay seriously decreases the feeding value of the hay and lowers the market price. As well as being inedible, it menaces the land of every purchaser. Hay that contains Russian knapweed should not be salable, because of the danger of spreading the weed by seed in the hay.

Pastures infested with the knapweed cannot carry the regular grazing load because it is not eaten freely even when green, and it chokes out desirable forage plants as fast as it spreads. Because of its close association with alfalfa, and its capacity to make pastures almost useless, it is particularly serious in alfalfa fields and pasture lands where grazing is heavy.

PREVENTION, CONTROL AND ERADICATION OF PERENNIAL WEEDS, SUCH AS CANADA THISTLE AND RUSSIAN KNAPWEED

The following discussion of methods of prevention, control and eradication of perennial weeds is general, but the Canada thistle is mentioned more frequently because of extensive work that has been done upon it.

Whenever work is done on weeds, it should be with the purpose of ultimate extermination of the plant attacked. There are three ways in which weeds may be handled; by the prevention of infestations, by the proper control of existing patches, and by the complete eradication of the pest. The best way is to keep the land free from weeds by consistent and vigorous prevention measures. They may seem useless, expensive, irksome and without result, but they are cheaper and far less annoying than the attention demanded by control or eradication measures for weeds.

Control of weeds is largely a matter of sanitation which prevents the spread of the pest into other places, and the rapid increase in size of the already-existing infestation. Methods of eradication frequently differ from those used for control, more in degree or intensity of application than they do in the principles upon which their successful use is based.

The first of these, prevention, must be practiced constantly; and the second, control, is to be considered as a prevention measure until the time comes when extermination is practicable.

PREVENTION MEASURES

The most satisfactory of all control measures for any pest is the prevention of infestation. Study of the habits, life history and general characteristics of a plant help to determine the most economical and effective means of control, and give the best ways for keeping a region free from a weed.

CLEAN SEED.—The cheapest and most effective means of protection from any noxious weed is the use of clean seed. It is unnecessary for anyone in Colorado to plant any kind of impure seed, for the State Seed Laboratory at the Agricultural College is equipped to analyze seed samples and to identify impurities in them. Any seed that contains thistle or knapweed, should be rejected by the purchaser, and pure seed obtained from a dependable source.

Along with the use of clean seed goes the need for care in cleaning farm machinery when it is to be moved from place to place. Many kinds of seed are known to have been carried from one farm to another in the dried mud on machinery. During harvest the seeds rattle out of the bundles of grain, collect on the racks, or in

the thresher and are carried to new locations. Combines usually carry a load of weed seed from one job to another, and scatter some all along the way. Protection from infestations due to this kind of spread is easy, simple and many times worth the inconvenience caused by a few minutes delay that is necessitated in the cleaning of the wagons, sieves and other parts where weed seeds are likely to collect.

CLEAN HAY AND MANURE.—Hay meadows or fields of alfalfa infested with Canada thistle or Russian knapweed are likely to be sources of mature seeds when the hay is made. If much Canada thistle is in the hay, it is unfit for feeding and the seeds go wherever the hay is taken. The stiff stalks and rough leaves of the Russian knapweed together with its seed heads make it a useless and dangerous impurity in hay. The hay is eventually returned to the soil and with it goes the seed of these pests.

If manure is known to contain seeds of the Canada thistle or Russian knapweed, it is necessary to leave it piled for a season so that decomposition will kill many of the weed seeds, and decrease the danger of infestation when the manure is applied to the land.

PREVENTION OF SEED FORMATION.—Once a place becomes infested with the Canada thistle or Russian knapweed, it is possible to check their spread by prevention of the formation of seed. This can be effectively done by cutting the stalks two or three times a year. If it is impracticable to cut them, spray poisons can be used when directions given on the container are followed carefully, and when proper precautions are taken to keep poisonous materials from injuring livestock.

Roadside weeds are often considered to be the business of the state, county or township, and not the concern of the person whose land lies along the road. When these weeds are noxious and endanger farm land, it is to the interest of all to prevent the formation of seed. In case the Canada thistle or Russian knapweed produces viable seeds along roadways or irrigation ditches the farmers must cut the plants down in self protection. The damage done in pastures or in waste places may not justify the expenditure necessary for eradication of these pests, but if they are a source of new infestations, nothing should be left undone to prevent the formation and dissemination of seed.

CONTROL MEASURES

Practices which result in prevention of new infestations, also tend to hold down the existing patches of perennial weeds.

CUTTING TO PREVENT SEED FORMATION.—The cutting of the stems to prevent the maturation of seed also tends to hinder the

development of the plant, as well as to prevent new infestations. When reseeding is stopped, control of existing patches is much easier than when the plant is continuously renewed by seedlings.

BURNING DRIED PLANTS AFTER CUTTING.—Many times there are mature seeds on plants when they are cut, or the seeds mature after cutting. As soon as they will burn, it is well to destroy the dried plants by fire before the seeds are shattered out and fall to the ground. Fire does not kill all the seeds unless the heads are completely burned, but a good heating injures them so that the danger of reinfestation from seeds is decreased.

SPRAYS AS A SUBSTITUTE FOR CUTTING.—Many places where the Canada thistle or knapweeds are growing cannot be cut over because of the nature of the ground. The development of tops is often just as good, and the production of seed is just as plentiful there as on cultivated soil or on places that can be mowed. Spray poisons which kill the tops fill a distinct need in such places, when temporary elimination of the tops is desired.

Many patent sprays are on the market for which great herbicidal powers are claimed. They have been found to be useful in other places and may prove to be useful in Colorado, although experiments to date are not conclusive. Most of them, however, are useful for killing the tops of perennial weeds. Sometimes with sufficiently frequent applications of these poisons, and with especially favorable conditions, an eradication of a perennial weed is possible.

SEPARATE CULTIVATION OF INFESTATIONS.—If the area infested with the thistle or knapweed is small, rigorous eradication measures are better than contentment with merely keeping the patch from spreading too rapidly, or being spread by careless cultural methods. When the infestation has reached a considerable size, the safest means of control is a practice that amounts to a quarantine. All machinery used to cultivate or work in land infested with perennial weeds should be cleaned thoroly before it is used elsewhere. It is essential that infestations receive separate treatment. Plowing, harrowing, floating or cultivation continuously from infested to weed-free soil should never be permitted. Sometimes the nature of the crop raised upon infested land neither lends itself to clean cultivation during any or all of the season, nor does it sufficiently shade the ground to smother out perennial weeds. This is especially true of the small grains and of corn. Infestations of any size in corn require much attention and hand labor.

In many cases, therefore, it seems more profitable to employ summer fallow for a season or two in order to get the upper hand

of the Canada thistle and Russian knapweed. One season of fallow will not kill these pests, but it will weaken them enough to make it possible to grow a paying crop upon the land the succeeding years. A single year of fallow is valuable in other ways, because it eliminates many of the annual weeds whose seeds have accumulated in the soil. They are caused to germinate and are destroyed by the stirring of the soil.

CROP ROTATION.—The presence of weeds of any kind upon a farm depends to a great extent upon the management of the land. Probably the largest factor in management of the land is the succession of crops. Soil infested with the Canada thistle or Russian knapweed can be freed from them by use of the proper methods of starvation with which may be combined a wise rotation of crops. If fallow cannot be practiced until the perennial pest is dead, the use of a crop-rotation system is essential, because the succession of crops has different effect upon perennial weeds and tends to keep them from becoming too vigorous.

In each locality and under each type of farming, there is a group of crops which can be used to keep the pest in its weakened state until a new direct attack can be made upon the reserve regions of the plant. No one system of crop rotation can be recommended because of the varying conditions in Colorado. In irrigated regions the use of cultivated crops alternated with smother crops is to be preferred to a rotation system that includes small grains, for in small grains the thistle or knapweed can recover in one year from the damage done in several years of clean cultivation, fallow, pasture or smother crops. If grains must be grown on land where perennial weeds are found, the land should be fallowed until late fall, and the crop sowed as late in the spring as is consistent with proper harvest. This is to destroy all the fall growth and to cut off shoots that have been pushing their way up thru the frozen ground during the winter.

Destruction of the early spring shoots gives spring grain a more nearly even start with these weeds and the rapid growth in May and June easily keeps up with their increase in size during these months. Seed production should be controlled in the grain fields by either cutting down the flowering stalks or by pulling them out by hand.

SMOTHER CROPS.—All of the cultivation methods for controlling the perennial weeds involve the expenditure of much labor. When this can be replaced even in part by equally effective methods which make use of the ability of some plants to shade and crowd out others, the time and effort necessary for cultivation of perennial weeds can be diverted to more immediately productive operations.

PASTURE.—It has already been developed that there is little permanent damage done to the Canada thistle or knapweed by pasturing. A good heavy sod checks spreading; the leaves of the very young plants are eaten freely by sheep and goats early in the spring when other forage is scarce, but little damage is done by animals. Trampling breaks the stems but unless they are completely broken off, new shoots do not form upon the roots. Furthermore, it is always necessary to cut the stems at the time of flowering to prevent the formation of seed. Of all the control measures recommended, this is the least effective for Canada thistle and Russian knapweed, but it is one of the best for the common wild morning-glory and other bindweeds.

ERADICATION MEASURES

GENERAL PRINCIPLES AND METHODS.—Any attempt to eradicate a perennial weed must be in accordance with the principles upon which effective treatments are based. Almost all operations which result in the death of perennial weed pests either starve the roots by using up the stored food, kill the tops and underground portions outright, or destroy the roots so that the tops also die. The discussion of the principles of eradication is followed by specific information and recommendations for eradication of both small and large areas.

STARVATION OF THE ROOTS.—Starvation of the roots results when the tops are not permitted to develop normally and to expose a large leaf surface for the manufacture of food. When for any reason the food-making organs fail, the new shoots draw upon the stored material in the reserve region of the roots. Energy is consumed in the growth of the shoot at the same time that the root is furnishing structural material for the new stalk. If the new parts reach the surface and develop normally, the food used in the regeneration is quickly replaced. On the other hand, if, instead of natural development, there is a continuous destruction of new shoots as fast as they reach the surface of the soil, there is a constant drain upon the reserve supply. This supply may be, and frequently is an exceedingly large proportion of the root, but it is not unlimited. If the reserve is used continuously without a chance being given for replacement, the time is certain to come when there is no more food in the roots to supply material or energy for the formation and growth of stems from the buds on the roots of perennial weeds. When the whole plant has been exhausted, the starvation process has been completed, and the infestation has been exterminated. This is a slow process for many plants, and a tedious one for the person who has to keep the tops from growing, even for a short time in sunlight and air. This means, however, has been found

by long and wide experience to be based upon the most practical, economical and even profitable principle when the proper eradication measures are used.

Operations which result in the starvation of the roots can be classed under clean cultivation or fallow, and "smothering." The smothering may be practiced either by the use of a plant which grows more vigorously than the weed pest to be eradicated, or by the use of dead material for shutting off light and air from the plant. The mechanical means usually consist of straw, manure or stack bottoms, or it may be heavy paper or sheet metal which stop the light as effectively as a thick layer of straw and offer more resistance to upward growth of stems and shoots than does loose material piled upon a patch of Canada thistle or Russian knapweed.

CLEAN CULTIVATION AND FALLOW.—This method has already been discussed under "control methods" where the principle of partial starvation is a control measure. If eradication is the aim, it is necessary that cultivation be clean and that the fallow be one that keeps down all growth. Clean cultivation in this sense means nothing less than cultivation which keeps any plant, other than the crop plant, from putting forth green leaves. If no crop is being raised upon the land and the condition is that of fallow, there must be enough disturbing of the surface of the soil to destroy all the shoots that come up from the perennial storehouse of food and energy. This probably will mean several times as many cultivations as are necessary for the extermination of annual weeds. The cultivation should be deep enough to cut off the new shoots at their base, but not deep enough to reach the horizontal roots. The cultivations must be repeated as often as it is found that shoots are about to push thru into the sunlight. This may mean as many as 20 cultivations a year for 2 years. From the nature of the Canada thistle and Russian knapweed, 2 years of cultivation should be enough to use up all the reserve of food and to practically eliminate the pests. For other perennial weeds whose roots live indefinitely, 2 years of clean cultivation or fallow may not exhaust the reserve supply of food.

SPRAYS AS A SUBSTITUTE FOR CULTIVATION OR FALLOW.—The most constant demand from the people who are troubled with perennial weeds is for a spray which will kill the pests with one application. As yet a spray has not been found that will work this way for perennial weeds under the conditions of Colorado. This does not mean that sprays do not injure weeds when they are applied to the aerial parts. It does mean, however, that with many of the sprays, perennial weeds suffer no more from a spraying than they

do from a single cultivation. If cultivation is impossible in locations where eradication is necessary, the roots can be starved by repeated applications of poisonous sprays. One must not become discouraged any sooner, nor be any less punctual in the application of sprays, than he is with cultivation practices for starvation. The effects of the spray materials are as variable as the costs, altho the effects are not necessarily in proportion to the cost of the material used. For the control of perennial weeds, most sprays are to be considered as an accessory to the less expensive cultivation methods.

SMOTHERING.—Smothering is usually thought of as elimination of air with eventual loss of life by suffocation. As it is used in this bulletin, the word "smothering" has something of this idea, but more of the idea of crowding a plant out of its room for growth, and the shutting off of light from the leaves. No plants keep air away from others to such an extent that the "smothered" plants cannot live; they effectively choke the plants by shading. This is the true conception that should be held of the "smother crop," and there should be a distinction made between the effect of choking out by shading a plant, and the smothering of one that is kept under the surface and has its air supply cut off at least in part and its light entirely absorbed by material that has been placed upon the infestation.

SMOTHER CROPS.—The nature and kind of smother crops that assist in the eradication of the Canada thistle, Russian knapweed or any other kind of perennial weed is varied. If the smother crop is sufficiently dense, tall and persistent, an open soil surface that is perfectly shaded is helpful because the crowding at higher levels is close enough to keep the stems from pushing up to the life-giving sunlight. Smother crops should of course be of value for other purposes and should be easy to remove from the land once their intended purpose is accomplished.

Smother crops must have the capacity to make a quick, dense growth, and to hold their own against the invader which they have been planted to suppress.

There are two kinds of smother crops; perennial plants, and annuals that are planted each spring after the pest has been kept under the ground by cultivation for a part of the season. Either the perennials or the annuals are effective if conditions are favorable. The perennials must come up as early or earlier than the Canada thistle or the Russian knapweed, if they are to be effective as smother crops. They must make a more rapid and dense growth during the months of May, June and July, and they must retain their vigor until frost, if they are to compete successfully with these plants.

If the smother crop is to be cut during the summer, it must be able to recover more quickly than the perennial weed and to keep the new shoots of the pests in the shade. Alfalfa has been found in many states to be a successful crop for controlling these and many other perennial weeds. It has the advantage of rapid growth, dense stand and quick recovery after cutting. One disadvantage is its limited height, which is naturally exceeded by some growths of the Canada thistle, and by the normal growth of Russian knapweed. It is rather frequently winter killed also, and dies out from other causes more easily than do the weeds it is expected to control. Biennial sweet clover grows taller, makes as dense a soil cover, and can be left to grow a whole season without losing density or vigor because of seed production. In general where good stands of the white sweet clover can be obtained, it is superior as a smother crop to the other clovers, or to alfalfa. It should be reseeded the fall of the first season it has made growth, so that there will always be a heavy stand of young plants close to the soil. The reseeding from the old plants will automatically take place the fall of the second year.

Altho alfalfa, sweet clover or similar smother crops with rank top growth hold the Canada thistle and Russian knapweed well under control, the roots of the smother crops do not seriously conflict with those of the Canada thistle or plants with similar root systems. Both have long vertical roots, but neither of them can be considered to be sod-forming plants. Such plants as do form a firm sod, however, impede the progress of the horizontal roots of the thistle or knapweed, but do not as a rule grow tall enough to shade the stems. Many of the horizontal roots of these two plants grow too far below the surface of the soil to encounter the mat of grass roots. The shoots, however, have difficulty at times in penetrating sod, which is therefore to be considered as a useful means of slowing up the progress of these pests but not an effective one for permanently weakening them.

In places where the growing conditions for annual crops are reasonably certain, or where crops can be controlled by irrigation, the use of a smother crop for the growing season, accompanied by mechanical means of control for the rest of the year has proved successful. Quick-growing, early maturing plants such as millet, cane or sorghum, when sowed heavily, after a fallow during April and May, will set perennial weeds back as much as a summer of intensive cultivation and will yield a profitable crop at the same time. In many ways these summer smother crops are more dependable than the perennial smother crops, because the time for their growth, and the condition of the pest when they are growing can be

more nearly controlled. Cane, sorghum or millet is recommended in Kansas for this purpose.

Another kind of annual smother crop that has been used extensively in northern Iowa and southern Minnesota for both the control and eradication of the Canada thistle, is the sugar beet which requires almost constant cultivation of the soil until the tops practically cover the ground and allow little light to filter thru the leaves. The leaves usually stand up some distance above the crown of the beet, so that it is necessary for any plant that comes up from below to make a great growth in length before it reaches sunlight. This combination of cultivation and smothering has been found to be one of the most successful control measures for the Canada thistle in the North Central states. Beans which are raised in quantities on the drylands of Colorado, can be used in much the same way as beets for the controlling of perennial weeds where irrigation water is not available. Beans require much cultivation while they are young and cover the soil well when cultivation ceases. These two crops are among the most profitable that can be raised. The increase in yield due to the cultivation necessary for the control of the perennial weeds almost always pays for the labor of control.

SMOTHERING BY COVERING THE PLOTS WITH DEAD MATERIAL.—Many attempts to kill out perennial weeds have been made by piling straw upon the place where the weeds are growing. Some of these treatments have been successful, but most of them have failed for the two following reasons: In the first place straw settles a great deal after it has been handled. The much thinner layer of straw after several weeks of standing allows the shoots to come thru to sunlight and air. The edge of the pile of straw must be 8 to 10 feet beyond the plants farthest from the center of the infestation because normal spreading by roots is not stopped by smothering. Straw is therefore ineffective when it is used in insufficient quantities.

In the second place dry smothering agents of this kind have no injurious effect upon the shoots as they come thru it. The straw acts like a very light soil which has no other influence upon the shoot than to force it to grow farther to light. Wet straw, on the other hand, will begin to decompose, and will sometimes become so warm that ordinary plants cannot live in it. Real damage is then done to the pests covered with this kind of a smother material. The principle of smothering with straw is correct; it is a question mostly of the quantity that is used, and the condition when applied.

There is no essential difference in the use of manure, straw or stack bottoms for smothering out patches of the Canada thistle or Russian knapweed. Manure is usually moist and does not settle as much as straw. It is full of organisms that cause the manure to

heat and to injure tender sprouts from the roots. As a general rule when manure is applied so that the fully settled pile is 6 feet thick and the area covered from 16 to 20 feet greater in diameter than the infestation there is little question as to the result. To be sure that none of the shoots of the Canada thistle or Russian knapweed can penetrate the manure, it is necessary to have the pile at least 6 feet deep for 3 years. After that, if no shoots are found creeping out from around the edges of the pile the manure can be safely removed.

Stack bottoms have the same virtue as manure, in that they are often wet, and already in the process of decomposition. The essentials for the use of vegetable materials as smothering agents for killing perennial weeds are that they be deep, wet and in the process of decomposition. Under these conditions, heat is generated, and the air is at least partly excluded from the solid mass of smothering agent and from the soil below.

There have been reports of successful eradication of the Canada thistle by covering the patch with sheet metal, often corrugated iron from an old building, and leaving it upon the patch for several years. This makes a covering that is light-proof and resistant to plant growth.

Heavy paper, usually tar paper, is recommended as a covering material for small patches. It acts in the same way as sheet metal, but has the disadvantage of being fragile and easily broken by an animal's foot, or any hard object that might fall upon it, so that it is almost essential to fence in well an infestation that is covered with paper. The expense of this method and of these materials practically prohibits their use.

DIRECT KILLING.—The other principle upon which perennial weeds are eradicated is that of a direct kill with a limited number of operations such as spraying, digging or treatment with carbon disulfide. It is obvious that the tops and the roots must be eleminated at the same time.

In other states, one application of a spray poison has been known to completely kill Canada thistles and other perennial weeds. In general, this is an exceptional case, for several treatments even, are recommended by the manufacturers of commercial sprays. During the last 3 years, the writer has not succeeded in killing anything but the tops of perennial weeds when using a number of typical arsenical sprays.

Altho the removal of a whole plant of the Canada thistle or Russian knapweed involves much labor, a sure way to kill perennial weeds directly is to dig out the whole plant, and destroy the roots. It is usually necessary to remove the roots to a depth of 3 to 4 feet

below the surface, being careful that all of the roots are taken from the soil when dug, and that none get put back into the excavation, because a small section of a root can render the whole operation useless if it is allowed to grow unmolested. Digging is practicable only where seedlings or isolated plants from fragments of roots are starting a new infestation.

Soil poisons have been used for many years in the disinfection for insects, and at times roots of plants were killed by the disinfecting agent. The use of carbon disulfide for killing the roots of perennial weeds has become rather general in Idaho, and has been found to be successful in tests in California and Colorado. Its value has not been established for all locations in this state, altho hopeful results were obtained during the summer of 1927 and 1928. The best results have been obtained in rather dry soil. The holes were placed at 2-foot intervals in rows 21 inches apart. The alternate rows of holes were staggered to make equal-sided triangles. Two ounces of carbon disulfide were placed in each hole, and the openings closed with dirt which was well tamped to prevent loss of the gas by evaporation. The killing may take place in a few hours after application, or be delayed for some time, according to the condition of the soil, and the soil is free from all traces of the poison within a month after treatment. There seems to be no particular season that is best for the application, excepting in so far as the amount of moisture in the soil is governed by the season. Penetration is faster at a higher temperature and in a drier soil.

Other soil poisons have been found to be effective, but the difficulty of application, or the dangerous nature of the materials makes them less desirable and more expensive to use.

Soil poisons are not specific for any kind of plant or animal. They kill most of the life that is in the soil if they come in contact with it. Very large woody roots are an exception.

Large quantities of salt spread upon the soil will kill any plant. Its action, which is one of drying out of the roots as well as poisoning them, is rather slow, and the effects upon the soil are bad. Experience has shown that at least 2 pounds of salt per square foot must be applied to assure a kill. This means 87,120 pounds or practically 44 tons of salt per acre. Ice-cream salt is both the cheapest and the most effective. A bottom price for it in Colorado can be considered to be $10 per ton. At $440.00 per acre, the use of this material is prohibited by cost for anything but small patches. Furthermore, except where the salt can be washed out by flooding, permanent damage is done to the soil; in some cases the soil is rendered useless for cultivation for many years. This kind of treatment is not to be recommended except on places where other

means would be impractical, and where sterility of the soil is not important.

ERADICATION OF SMALL AREAS.—The size of the infestation modifies only the method of treatment, and not the principles of eradication. Practices which will eradicate a small area will be equally effective upon large ones. Those recommended for small areas are not necessarily the best for large areas because of economic reasons, but they are practical because of their effectiveness and the protection they afford to the weed-free land about the pests. Additional information on eradication measures for small areas is given below.

Patches less than 2 square yards in extent can be dug in a short time. An 18- or 20-inch spade will turn up practically all of the horizontal roots of the Canada thistle or Russian knapweed. If the infestation is old, a second layer should be removed. When only one layer is taken out, shoots are likely to reappear from the ends of the vertical roots after several weeks. It will be necessary to starve these roots by digging out the sprouts as they are found.

Special, machine-cultivation of small patches of perennial weeds is usually impractical. If the areas are of moderate size, hoeing, or hand driven cultivators will bring about the desired results.

Small infestations of the Canada thistle or Russian knapweed are likely to start up in the feedlots on a farmstead. The easiest and most certain eradication measure in such a place is the use of salt, which may be applied either as brine or in the form of ice-cream salt. If the latter is used, care must be taken that poultry cannot pick it up, for a few chunks of salt are fatal to fowls.

When small patches of a perennial weed in a field are to be eradicated to protect the whole field, carbon disulfide is a quick, effective and economical means of eradication. The cost of treatment may be $1.50 or more per square rod for material and labor, but under favorable soil conditions results are immediate and permanent.

Sprays can be used upon small areas as economically as upon large ones. Care must always be taken to follow exactly the directions printed upon the container and to keep all of the spray material, whether dilute or concentrated, from getting into the mouth or eyes. When any of it comes in contact with the skin it should be washed off with plenty of water as soon as possible. Generous applications of linseed oil to the hands will protect the skin, and make easier the removal of the poison with water.

Smother crops are as useful on a small area as on a large one but are generally not economical. Other and better means of eradi-

cation are available for isolated patches. If, however, there are numerous small infestations spread about over a field, so that it must be treated as a unit, smother crops are the most effective and economical means of eradication that can be employed in the extermination of the thistle or knapweed.

It is only for relatively small infestations that the use of dead material for smothering out the Canada thistle or Russian knapweed is practicable. In the first place, supplies of the smothering materials are usually limited and in the second place the labor of moving enough of it to cover even half an acre to a depth of 10 feet with straw or manure is too great to be profitable when compared with the labor of clean cultivation or fallow. Then too, all the smothering material must be removed after the roots have been starved. Use of sheet metal or paper to kill the pests is prohibited by the price for anything but the smallest patches. Except for very small patches, or those inconveniently located, mechanical means or competition with other plants is to be preferred to the attempt to smother out the thistle or knapweed by covering them up.

ERADICATION OF LARGE AREAS.—Altho the expense connected with the extermination of large areas is greater than that involved in the eradication of small ones, the cost per unit can be much less because of the extensiveness of the operations.

Indirect methods of killing large areas of any perennial weed have been found to be the most practical and economical means in many places, especially those where smother crops cannot be depended upon to grow vigorously because of lack of water. *Clean fallow* during the growing season, like clean cultivation, requires more work than ordinary practices of farming because the stems of the thistle or other weed of this kind must be kept from forming green leaves even for a short time, or all the previous work is lost. Two years of clean fallow or cultivation will usually kill the roots of the Canada thistle, and probably the Russian knapweed, altho there have been no definite experiments completed on the latter weed in Colorado. This time limit cannot always be depended upon, and a third season should be allowed for cultivation, or a heavy smother crop should be planted. After this the patch should be watched closely for stray surviving plants which must be dug out completely whenever they are found.

The advantage of fallow for weed control and eradication is largely one of convenience. When fallow is not necessary for other reasons, the same labor on the land can be expended in clean cultivation of a crop which is as effective as fallow in the eradication of the Canada thistle, Russian knapweed and most other perennial

weeds. Like fallow this practice must be continuous thruout the growing season of the thistle or knapweed.

For large infestations there is no more convenient means of starvation of the roots than the use of a dense soil cover that can keep well ahead of the development of the Canada thistle or Russian knapweed. Recommendation of specific smother crops is difficult because of the difference in their behavior under varying conditions. On dryland, after two summers of clean fallow, a heavy stand of cane or millet should be easy to obtain, and it should complete the starvation of the roots of perennial weeds. Perennial crops which cannot be irrigated are likely to be ineffective for smothering out perennial weeds because they cannot produce a dense, rank growth season after season. On irrigated land, however, where growing conditions are largely under control the choice of smother crops can fall upon those that are most convenient and profitable.

Altho crop rotation is usually considered to be more of a control than an eradication measure, reports of killing perennial weeds by crop rotation are numerous. No generally useful recommendation can be made excepting that the systems always make use of a succession of cultivated and smother crops.

In any practice for the prevention, control, or eradication of perennials, the price of freedom from weed pests is ETERNAL VIGILANCE.