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INTRODUCTION

Weeds add enormously to the cost of crop production. They present to agriculture a tremendous problem which seems not to have received due attention, either in California or in any other state. Certainly, less effort and expense have been expended in combating weeds than in reducing the losses from insects and from fungus diseases. And yet weeds are said to cause more losses than do insects and fungi combined.

We are prone to take weeds for granted. Yet, some orchards and farms, large and small, have so effectively combated weeds, by carefully applying the best known methods of control, that now their cultivated fields and uncultivated areas are clean, their seed is clean, and the usual losses attributed to weeds are reduced to a minimum. The costs annually charged by most farmers to weed control can be largely eliminated.

Weed control requires community as well as individual effort, organized with a definite program and a definite object; not for one year, or for two years, but for a series of years. Any program outlined must be followed faithfully over a long period. The operations must be prompt and persistent. The initial costs may be great, but eventually the expense will become less and less.

Research on weeds is much needed—studies of life history, effects of tillage, and methods of control. Particularly is more study required concerning the use of herbicides, and the application of eradication methods as related to the physiology of the plant. The economics of the weed situation should be studied in more detail. Engineering problems include the development of various weeders, of harvester and thresher adjustments, of burners, of ditch cleaners, of chemical sprays and the apparatus to apply them. The solution of certain problems, now neglected, will mean better regulatory methods of weed control, which, in turn, will bring rich rewards to agriculture.

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This circular attempts to picture the weed problem in California, together with the most practical and promising methods now employed in weed control work. Obviously, some of the methods have not been sufficiently tried. It is far from time to lay down definite, arbitrary rules for the control of any one weed or group of weeds. The different species are so unlike in their characteristics and methods of life, the climatic and soil conditions under which they grow differ so greatly, and the effects of weeds on the various crops with their different cultural requirements also vary so much as to prevent the formulation of generally applicable methods. This circular emphasizes principles of weed control which have very general application. It attempts to answer the many questions brought before the College of Agriculture and the State Department of Agriculture.

LOSSES CAUSED BY WEEDS

There are four groups of agricultural pests: namely, (1) animal diseases, (2) plant diseases, (3) insects, rodents, and predatory animals, and (4) weeds. A recent report by the Agricultural Service Department Committee of the United States Chamber of Commerce pointed out that the annual losses from weeds considerably exceed the combined losses of the other three groups.

Few people, probably, ever realize what a burden weeds add to human existence. The production of almost all crops largely consists of a battle with weeds. The preparation of many products of the soil for human consumption involves the elimination of weeds or their effects. Weeds may cause illness or even death in men or animals. They militate against our full enjoyment of the out-doors; they are the bane of every home owner and amateur gardener. Few human activities, in fact, are not affected in some measure by weeds—pests which increase the cost of our food and clothes, hamper our movement, menace our health, and dampen many of our pleasures.

Weeds have been said to levy, in one way or another, an annual tax on agriculture and industry in the United States of about three billion dollars. No estimate has been made of the weed tax in California, but it may be safely assumed to be at least proportional to the country as a whole, or a minimum of sixty million dollars, the larger portion of which falls on agriculture. Indiana estimated in 1920 that its average annual loss through weeds was $210 per farm; Wisconsin's estimate in 1927 was about $244 per farm.

Weeds cause losses in many ways, the more important of which are as follows:

1. They offer serious competition to crops for plant food, moisture and light.
2. They add to the cost of crop production because of the large amount of labor necessary to keep them in check.
3. They increase the cost of preparing many crop products for consumption.
4. They impair the quality and destroy or reduce the value of many products of the soil.
5. They harbor insects and fungus pests destructive or injurious to economic plants.
6. They are sometimes poisonous and may endanger the health or life of men and animals.

Weeds Rob Crops of Plant Food, Water, and Light.—Probably the heaviest loss by weeds, especially in California, results from their competition with crops for plant food, moisture, and light. The crop-producing power of most of our agricultural soil is limited either by the moisture obtained frequently only at high cost, or the plant food available. When the crop must share this limited supply with weeds, the inevitable result is lower yields.

On most of our unirrigated land, water is the limiting factor in crop production, and poor yields or total crop failures often occur because the water supply has been exhausted before the crop matures. Weeds may contribute greatly to this exhaustion of the water supply. Grain fields infected with wild oats, mustard, radish, or other weeds obviously produce much lighter crops than do fields free from weeds. The reduced yield results partly, perhaps, from shading and from robbing of plant foods, but chiefly from the use of water by the weeds. One principal reason for cultivation is, in fact, the elimination of the undesirable plant growth which, except in the first few inches, is the principal reason for loss of water from the soil.

On irrigated land, competition may be mainly for plant food rather than water; but the effect is just as striking. For example, in an alfalfa field infected with foxtail or Bermuda grass, the alfalfa plants usually make but a slow, weak growth. When, however, the weeds are removed by cultivation or burning, the alfalfa is at once noticeably stimulated to greater growth and vigor.

The effect of patches of morning-glory, creeping mallow, and other perennials in depressing or preventing the growth of summer crops like corn, cotton, and beans is too well known to need discussion.

Weeds Add to the Cost of Labor and Equipment.—Another heavy tax incurred through weeds is the large amount of labor and equip-

ment necessary to keep weeds in check on those areas where they would seriously interfere with crop production. The main reasons for cultivating annual crops are the preparation of the land for planting, and the keeping down of weed growth. For vineyards and orchards the principal, if not the sole, reason for cultivation is weed control. The average cost of such tillage on cultivated lands has been estimated to equal about one-twelfth the value of the crop, or, for California, about $40,000,000 annually. These figures, however, do not include the very considerable expense for the eradication of weeds in ditches, roadways, etc., near the cultivated areas, or the public money expended, especially on campaigns against the more noxious weeds. In 1929, the various counties spent $73,000 in the war against such weeds as puncture vine, Johnson grass, and camel's thorn. The State Highway Commission likewise finances considerable eradication of weeds along highways, largely as a protection against fire.

Also chargeable against weeds is an enormous investment in equipment. Almost every farm possesses one or more implements used primarily for the destruction of weeds. In 1929 the various counties carrying on weed eradication campaigns had an investment in spraying equipment alone, used under the supervision of the County Agricultural Commissioner, amounting to $90,000.

Weeds Add to the Cost of Preparing Crop Products for Consumption.—After the crop is grown, weed contamination of the product may involve further expense in handling and processing. This is especially true of the seed crops, of rice, wheat, and other cereals. Millers must install costly equipment for the removal of weed seeds and other material of weedy origin before the products are fit for consumption.

Most of the seed crops grown in California are contaminated with weed seed, which must be removed before the seed can be used. In fact, one main reason for the relatively high price of seed to the farmer is that such seed, as grown, is usually foul with weeds, which the dealer must remove by expensive methods before the product can be marketed.

An excellent example of the extent to which weeds increase the handling costs may be found in our cereal crops. The average annual production of wheat, oats, barley, and rice in California is about 1,444,000 tons, with an average dockage of well over one per cent, consisting mostly of weed seed or material of weedy origin. In the harvesting and marketing of these crops, therefore, more than 11,000 tons of weed seeds and residue must be handled and transported.

Further, as already indicated, much of the cleaning cost to which most cereals must be subjected should be charged against weeds.

Weeds Impair the Quality of Farm Products.—Weed contamination of many crops reduces their quality and market value. Weedy alfalfa hay, for example, brings from one dollar to two and one-half dollars less a ton. A large portion of the first cutting and a part of the second are liable to be weedy, so that at least one-fifth of the crop may safely be assumed to contain objectionable quantities of weeds. With an average reduction in value of $1.50 a ton, the annual loss to the alfalfa industry in California is approximately $1,200,000. Some weeds are more objectionable than others. For example, hay infected with puncture vine may be practically worthless in some districts; in fact, many counties in California prohibit its importation.

The market value of wheat may be greatly reduced by the presence of certain weed seeds. Even a few seeds of sour clover, for example, will render a sack of wheat unfit for milling.

Weeds Harbor Insect and Fungus Pests.—Weeds serve as hosts for many fungus and bacterial diseases and for insect pests which prey on crop plants. Thus they aid in the propagation of such crop enemies, which they render more destructive and more difficult to control. The bacterial organism causing bean blight lives on some of the wild legumes, while the organism causing black leg of cabbage thrives also on wild mustard. Certain wild mustards may serve as a host for the fungus which causes club-root in cabbage. Many insect enemies of crop plants may be carried over on weeds during periods when crops are not available. The beet leafhopper lives a part of the year on Russian thistle, saltbush, and other weeds. The pod borer, so destructive to baby lima beans, thrives also on the lupine. Nightshade harbors the pepper weevil. J. C. Elmore, of the U. S. Bureau of Entomology, states that in the pepper-growing districts of southern California, approximately 85 per cent of the first infestations in the spring originate from one species of nightshade (*Solanum douglasii*), which is a host to the pepper weevil, especially in winter. The eradication of this weed from areas devoted to pepper growing is strongly advised. Nematodes and grasshoppers, so destructive of many crop plants, live and multiply on many weeds. Numerous other examples might be cited, but those given indicate the extent to which weeds aid in the propagation of crop pests. If, in fact, weeds and other uneconomic plants could be eliminated, the control of many of our worst crop pests would be greatly simplified.

Weeds May Injure Livestock and Human Beings.—Many domestic animals are lost annually from weed poisoning. The most important

poisonous weeds, such as larkspur, water hemlock, whorled milkweed and death camas, occur extensively on some ranges, under conditions difficult to control. Some also occur on cultivated lands and in pastures seeded to cultivated plants, and under such conditions many animals are lost annually through their owners' failure to recognize and eradicate poisonous plants. Certain species of lupine are poisonous when in seed, the annual losses of sheep from this plant being considerable.

The health of human beings may also be affected by weeds. Deaths occasionally occur from the eating of seeds, berries, or tubers of poisonous plants. Poison ivy, poison oak and the like annually cause much suffering and distress. Many victims of hay fever can trace their affliction to the pollen of weedy plants.

WEED CHARACTERISTICS

Of the many thousands of different kinds of plants in the world, fortunately but a relatively small number are weeds. Most of our native plants do not have the characteristics of weeds; they do not spread from the adjacent hills and valleys to our cultivated areas and establish themselves as pernicious pests. But the world contains some plants with a combination of characters such that they become pests: they tend to grow where not wanted; they resist man's efforts to combat and subdue them; they may resist frost, high temperature, and drought; they may be able to grow under a variety of soil and climatic conditions; they may produce enormous numbers of seeds which may live for many years in the soil; and they usually multiply and spread very rapidly. Of course, any one plant does not necessarily have all the characters which, from our standpoint, are undesirable, but it may have a sufficient number to be a pest. Any plant which seeds prolifically, or reproduces vegetatively from underground parts, or is poisonous to livestock or human beings, or causes mechanical injury, may become a *noxious weed*. Furthermore, a plant which is a weed in one locality may not be a weed in another section with different soil and climatic conditions; for example, Johnson grass is a noxious weed only where the winters are mild. Any newcomer in our cultivated areas should be viewed with suspicion for although it may not have been a serious weed in the region whence it came, it may, under the peculiar combination of conditions here, prove to be serious.

Many weeds produce an enormous number of seeds; this truth is shown in the accompanying table:

Species	Approximate Number of Seeds per Plant	Species	Approximate Number of Seeds per Plant
Tumbleweed	6,000,000	Crab grass	204,000
Tumbling mustard	1,500,000	Russian thistle	200,000
Purslane	1,250,000	Black mustard	143,000
Water grass	980,000	Green foxtail	142,000
Lamb's quarters	608,000	Buckthorn	118,000

The seeds of many weeds retain their vitality for many years, especially when buried in the soil. For example, the seeds of shepherd's purse, mustard, purslane, pigeon grass, pigweed, mayweed, dock, and chickweed are known to live more than 30 years buried in the soil; prickly pigweed and morning-glory, 25 to 30 years; mallow, 5 to 10 years; ragweed, corn cockle, cheat, wild oats, and plantain, 1 to 5 years. Plowing may turn weed seeds under, placing them at depths where there is insufficient oxygen to enable them to germinate; there they remain for many years, until finally a later plowing brings them again to the surface, where they germinate. Thus, a field which has for years been relatively free may suddenly develop a crop of weeds. The seeds of wild oats, tall pigweed, cockleburs, and others seldom germinate the year they are shed, but apparently require a period of rest in the soil.

INTRODUCTION AND SPREAD OF WEEDS

In the farming sections of California almost every year sees the introduction of new weeds, which, as far as any particular locality is concerned, may come from neighboring farms, from other areas in the state, from other states, or even from foreign countries. Time and time again a certain weed has been introduced into a locality, the infestation at first being confined, possibly, to a few square rods or represented by only a few individual plants; and because of ignorance, indifference, neglect, or improper methods of control, the small infestation forms the nucleus for a wider one which may spread throughout a whole country. For example, camel's thorn, an extremely pernicious weed, was first represented by a few isolated plants in one of our southern counties, where the seeds had probably been introduced from southwestern Asia in Turkestan alfalfa seeds. Camel's thorn is now found in six California counties, involving approximately 500 acres. If an infestation involves a small patch of a very noxious weed, perhaps a new introduction, strenuous methods and considerable expense are justified in order to prevent that weed from spreading and from gaining a foothold in the community. An expense

that might be considered inordinate if applied over a large territory, becomes in such an emergency a highly practical measure. In this particular the following points cannot be too strongly emphasized:

1. The necessity in every county of constant vigilance, not only of county commissioners and farm advisors, but also of growers themselves, in order to detect any new weed introductions or newly infested areas.

2. Prompt and proper measures to eradicate completely the newly found pest, perhaps through the cooperation of several parties concerned.

3. Marking of areas and inspection several times a year for several years to insure complete eradication.

Impure Commercial Seeds.—Probably the most common and effective means of introducing weeds is by the *sale* and *distribution* of *impure commercial seeds.*

The Seed Laboratory, Bureau of Field Crops, California Department of Agriculture, has prepared from its own tests, data giving the percentages of samples of each of the five major farm crops of California which show the presence of noxious weed seeds over a five-year period. Ordinarily samples received for testing by the Seed Laboratory represent lots of seed cleaned and ready for sale, so that the figures below may not correctly represent the cleanliness of California farm lands. With this in mind, it will be noted that weed seeds in seed cleaned for market are too prevalent and therefore indicate serious infestation of agricultural lands.

The data on the presence of noxious weed seeds in Sudan grass are especially interesting in manifesting the increase of Johnson grass infestation. During the fall of 1927 and the spring of 1928, many assignments of Sudan grass seed grown in Texas and Oklahoma were shipped into California for the seeding season of 1928. The rapid rise in percentage of Johnson grass seed begins with the receipt of samples of this Texas and Oklahoma grown Sudan grass seed in the fall of 1927 and continues through 1928. The high percentage for 1929 is believed to result from the seed crops harvested in fields sown to the Sudan grass infested with Johnson grass planted in the spring of 1928. Samples of Sudan grass seed received for test during 1929 showing the presence of Johnson grass seed also carry typical California weed seeds, indicating that the crops were grown in California and not elsewhere. This appears to prove that the Johnson grass infestation results from sowing unclean Sudan grass seed for the 1929 harvest.

The principal noxious weed seeds found in alfalfa seed are as follows: barnyard or water grass, large-seeded alfalfa dodder, Russian

thistle, field dodder, and creeping mallow. During the years 1925 to 1929, from 23 to 36 per cent of all alfalfa samples contained barnyard grass; 12 to 22 per cent contained large-seeded alfalfa dodder; 9 to 15 per cent Russian thistle; 8 to 15 per cent, field dodder; and 7 to 12 per cent, creeping mallow. Other noxious weeds found in alfalfa samples are yellow star thistle, tocalote, small-seeded alfalfa dodder, Johnson grass, morning-glory, bull thistle, Russian knapweed, and hoary cress.

The principal noxious weed seeds found in barley seed are star thistle, morning-glory, blessed thistle, barnyard grass, and Johnson grass. From 7 to 14 per cent of all barley seed samples submitted to the Laboratory during the period from 1925 to 1929 contained star thistle; 5 to 15 per cent, morning-glory; 0.5 to 3.5 per cent, blessed thistle; 0.5 to 1.5 per cent, barnyard grass; and 0.5 to 3 per cent, Johnson grass.

In oats seed the chief noxious weed seeds are star thistle, Johnson grass, blessed thistle, and morning-glory.

In wheat seed the principal noxious weed seeds are morning-glory, star thistle, barnyard grass, and blessed thistle.

In Sudan grass seed, the principal noxious weed seeds are barnyard grass, which during 1929 was found in 43 per cent of all Sudan samples; morning-glory in 26.5 per cent of the samples during 1927; Russian thistle, in as high as 39.5 per cent of the samples during 1928; Johnson grass in 22 per cent of the samples in 1928; and yellow star thistle in 12.5 per cent of the samples in 1925.

The foregoing paragraphs give the impurities in samples of seed submitted to the California State Seed Laboratory; however, much of the seed actually planted is raised by the owner or secured from a neighbor, and consequently never tested by a laboratory. Drill surveys made in a number of states reveal what is actually being planted through the drills. One example, from New York state, shows that 35 per cent of the drill samples contained quack grass seed; 45 per cent contained seeds of cockle; one sample contained 19 kinds of weed seeds; and only 10 per cent of the samples showed that they had been properly cleaned for seeding purposes. Similar drill surveys in other states show that the individual planter is not giving enough attention to clean seed, and that by means of the drill he is scattering weeds on his land.

The origin of many of our weeds has been definitely traced to plantings of alfalfa and other crops which were imported to this state several years ago; these importations of seed carrying noxious weed

seeds occurred, however, before the present seed law. Federal legislation appears to be inadequate. One should note in this connection, that the present California seed law only partially protects the farmer. For example, such seeds as clover and alfalfa can be sold with 89 weed seeds per pound—a number sufficient to start an infestation—without this fact showing on the label.

Weed Seeds in Screenings, Baled Hay, Packing About Trees, Feed Stuffs.—The introduction of weeds into new localities is strikingly often traceable to operations connected with shipments of agricultural plant or animal produce. Seeds are conveyed in screenings, in baled hay, in the packing about trees, and in feed stuffs. As these materials are transported from place to place by railway cars or trucks, portions may jostle out and scatter seeds along the way. Weed seeds leak out of railway cars or trucks transporting grain or other seed in bulk. Some weed seeds which may occur in screenings, baled hay, or other feed stuffs will pass through the digestive tracts of animals unharmed and consequently be spread on the field in manure. If hay containing puncture vine is fed, the seeds will pass through the animal and retain their vitality. One dairyman grazed his animals in a pasture infested with camel's thorn and later moved the stock to the foothills. The path over which the animals were driven was marked by scattered infestations of seedling camel's thorn. Stock en route are often fed upon screenings or bedded with straw containing weed seeds. The manure, in instances carrying viable seeds, may be thrown from the cars or left at loading and unloading corrals. Bran, shorts, middlings, and chop-feed should be free from viable seeds of any of the noxious weeds.

Weed Seeds Conveyed in Dirt, Sand, and Gravel.—Seeds are conveyed in dirt and sand which are transported from place to place and employed in construction work, such as embankments, fills, and grades. In one instance gravel from a badly infested pit was the source of puncture vine on the shoulders of highways which had been finished with it.

Weed Seeds Conveyed by Animals and Vehicles.—Seeds are distributed by means of mud and dirt on the feet of animals, the wheels of vehicles, or the rubber casings of automobiles. Puncture vine is an example of a weed carried thus.

Weed Seeds Carried by Harvesting Machinery.—All kinds of harvesting machinery may carry weeds from farm to farm. This is particularly true of the combined harvester, a machine undoubtedly responsible for new weed infestations and also for the spread of weeds throughout a field. Some weeds are dragged by plows, cultivators, and

harrows from one area to another. This is true of vine-like plants and of those whose underground stems may be cut up into fragments by cultivating implements.

Weeds Have Splendid Natural Means of Seed Dispersal.—Some weeds are adapted for dispersal by wind, some by water, and some by animals. The seeds of such weeds as the thistles, milkweeds, dandelions, sow thistles, and wild lettuce have feather-like or cottony attachments which enable them to be carried far by wind. A great number of weed seeds will float on water, which, in the irrigated sections, is known to be one of the most important means of spreading seeds. One of the writers, working in Colorado, found in 156 weed seed catches from three different irrigation ditches a total of 81 different species of weed seeds, those most frequently met with being prostrate pigweed, tall pigweed, sedge, lamb's quarters, tall marsh elder, doorweed, black bindweed, curled dock, and dandelion. The number of seeds passing a given point on a 12-foot ditch during a period of 24 hours may reach several millions. Early irrigation waters were found to be most heavily loaded with weed seeds, and many weed seeds were observed to rest during the non-irrigating season in the mud of the ditch. Ditch banks, apparently, are more to be feared than roadsides as effective sources of weed infestation.

A number of weed seeds, like those of sand bur, puncture vine, cocklebur, beggarticks, etc., have barbs or hooked prickles by which they attach themselves to the hair or wool of animals, or to the clothing of man, and are carried thus from place to place.

PRINCIPLES OF WEED CONTROL

Before formulating a method of control for a weed, one should certainly know its habits of growth and reproduction. In fact, the first question asked is usually: Is the weed an annual, a biennial, or a perennial?

Annuals.—Annual weeds are those which live but one year; they produce seed but once and then die down entirely, root and all. An annual has no parts underground by means of which it is capable of spreading; it propagates itself by seeds alone. Obviously, all methods of controlling such weeds have one principal object—*the prevention of seeding.* This end may be attained in a variety of ways: mowing, cultivating, burning, spraying. If seed production is consistently prevented over a series of years, and if the introduction of weed seeds from neighboring areas is largely eliminated, the annual weed population will gradually decrease. Of course, weed seeds of many

annuals may live a number of years in the soil, and the working of the soil only brings them to the surface, where conditions for their growth are favorable. The germination of such seeds should, in fact, be encouraged before the crop is in or is well along, in order to insure an opportunity to kill the young plants before they are of such size as to injure the crop and to defy easy, inexpensive destruction. Annuals in the early stage are very easily and cheaply destroyed by cultivation and by chemical sprays. Remember that, with annuals, once the top has been destroyed the root has no power of rejuvenating the plant.

One must distinguish between *summer annuals* and *winter annuals*. In the case of *summer annuals*, the seeds germinate in the spring and the plants grow to maturity during the same season, develop a crop of seeds, and die before the end of the colder part of the year. In *winter annuals*, the seeds germinate in the fall or early winter, or when soil moisture conditions are favorable; and the young plants live throughout the winter in a vegetative condition, often forming a rosette-like growth. The next spring they resume growth, flower soon, and shed their seeds.

Winter annuals are effectively destroyed by shallow cultivation soon after they germinate in the fall, or they may be killed by this means at any subsequent time. But, the older they get, the more difficult and expensive is their destruction; and postponement also increases the chances of some plants going to seed. The great value of growing clean-cultivated crops, from the weed-control standpoint, is that the care normally given them destroys weeds and prevents seeding.

Mowing annual weeds will prevent seeding; but some annuals, such as wild lettuce and radish, will send up new shoots from buds in the axils of the lowermost leaves and may, if seasonal conditions permit, produce another crop of flowers and seed. Procrastination in the destruction of weeds always means increased cost of control. A trite saying, but one apparently often overlooked, is that *all plants are killed more readily and cheaply when young.*

Common examples of annuals in California are as follows: barnyard grass, chess or cheat, wild oats, pigweeds, lamb's quarters, Russian thistle, tumble weed, mustards, puncture vine, turkey mullein, dodder, spiny sow thistle, star thistle, sunflower, milk thistle, cocklebur, crab grass, and shepherd's purse.

Biennials.—A biennial weed is one which lives two years, producing seed at the end of the second year. It lives through the first winter usually in a low rosette form, producing a crop of the seed the second summer, and then dies, root and all. The methods of control given for

annuals apply to biennials as well. Some common biennial weeds are mullein, wild parsnip, wild radish, cheese weed, and burdock.

Perennials.—The most troublesome weeds are perennials, for their control requires special methods and systematic, painstaking endeavor. Plants in this group, as contrasted with annuals and biennials, live three years or more and spread not only by seed but also by underground roots or stems.

Perennials may be placed in three classes, based upon their methods of reproduction:

The simple perennials have either a large taproot, like the dandelion, or a fibrous root system, like certain bunch grasses; in either case there is a well-developed perennial crown. Under natural conditions these perennials propagate only by means of seed; but if the roots of such plants as the dandelion, or the crowns of the bunch grasses, are broken into pieces, each piece is capable of rejuvenating the plant.

The creeping perennials are the worst type to control because its representatives reproduce by creeping underground stems (rootstocks or rhizomes) as well as by seed. Some of our most common members of this group are Johnson grass, morning-glory, Canada thistle, and Russian knapweed. Because these roots or rootstocks put out new shoots at different intervals, such plants are very difficult to control. Perennials of this class not only spread great distances in the soil horizontally but go to great depths, depending on the water level and soil conditions. The morning-glory, for example, may extend its roots to a depth of 18 feet or more.

The type known as bulbous perennials reproduces by means of bulbs or bulblets, and by seeds. Examples are the wild onion or field garlic, and nut-grass.

WAYS OF DESTROYING OR HOLDING PERENNIALS IN CHECK

The two chief ways in which perennials are destroyed or held in check are by prevention of seeding, and destruction of the top growth or food-manufacturing tissue. This latter may be accomplished by mechanical means, such as the hoe, scythe, mower, cultivator; and by cutting off light, thus preventing the food-manufacturing process from going on. This in turn may be accomplished by the use of smother crops, mulches of straw, manure, etc., and by the use of tar paper or other opaque material. Destruction of top growth may also be accomplished by chemical means, employing sprays, such as oils, which merely destroy top growth but may not penetrate the roots or rootstocks.

Perennials may also be held in check by destroying the structures beneath ground which store food. This involves a chemical treatment which will penetrate these subterranean structures and kill them.

Prevention of Seeding.—The first and most important step in the control of a perennial weed, in fact of any weed, is, of course, the planting of clean seed. This truism should scarcely require even mention. A second point, which likewise should need no emphasis, is that perennials should not be permitted to mature their seed, even though they spread in other ways.

Destruction of Food-Manufacturing Tissue.—As stated above, a very striking character of perennial weeds is the possession of underground structures which store food and also serve as propagative organs. These subterranean structures may be either roots or stems, or both. In the dandelion, for example, food is stored in the root, which may also propagate the plant; in Johnson grass the underground stems (rootstocks) are the food-storage and propagative organs; and in morning-glory, both underground stems and roots act as storage and propagative organs. The important and distinctive feature of a perennial weed is the occurrence of underground structures which have a reserve food supply and can send forth from these structures new shoots. In perennials, as in all other plants, the *leaves are the principal food-manufacturing organs.* Underground structures, devoid of a green coloring matter and shut off from the light, are incapable of manufacturing food. The reserves of starch, sugar, or other kinds of foods which they may possess are manufactured in the leaves and conducted down the stems to the storage organs. These storage roots or underground stems increase in size as they grow older, and their supply or reserve becomes correspondingly larger.

If the top growth of a perennial is destroyed, the plant, as is well known, shortly sends up new shoots from the structures underground. This new shoot growth was assuredly made at the expense of stored food, and the amount of reserve food in the underground organs was therefore certainly decreased to an extent depending upon the amount of shoot growth produced. If these new shoots are destroyed, a second group of shoots will again be sent forth, and reserve food will again be called upon to produce them. If top growth, that is, food-manufacturing tissue, is repeatedly destroyed before it has an opportunity to make food, and if in consequence of this destruction new shoots are repeatedly produced, the result must be an exhaustion of the food-storage organs in the ground. Now, the question is frequently asked, "How many times must one destroy the top growth of a perennial weed in order to starve or exhaust the storage organs underground?" In the

first place, the number of times required will depend upon the amount of food stored in these subterranean organs, which amount in turn depends upon their age and the area of their food-making surface. In the second place, the number will depend upon the thoroughness and promptness with which the top growth is destroyed. Obviously, a young plant with little reserve in its underground parts is more readily killed by destruction of the top growth than is an old plant replete with food. No perennial weed, it is safe to say, can ultimately escape being starved out by persistent and frequent destruction of the top growth. More practical methods may, however, be found; and of these we shall speak later.

Clean Cultivation.—As mentioned above, perennial weeds have the ability to store in structures underground the food manufactured by the green leaves of the plant. Seeding may be prevented and top growth kept down by clean cultivation, which, if properly done, prevents all of the leaves or food-manufacturing parts of the plant from appearing above the ground. By this means the storage system will eventually be starved out. Growers must realize, however, that some weeds can in one season store enough food to last them several years. Consequently, one summer of conscientious clean cultivation may be insufficient to exhaust the plants, and the grower may then be disappointed when new growth appears the following spring. The only way to insure results from clean cultivation is by persistence in keeping down all top growth, which may require several cultivations during one or more seasons. Many tools have been especially designed for this particular method of weed control: special knives can be attached to cultivators, which will cover a given area in a short time, thus cutting down labor and other costs.

Clean cultivation, though it aims primarily at starvation of roots or underground stems of perennials, also continually keeps the soil stirred and brings seeds formerly produced by weeds to the soil surface where, under favorable conditions, they germinate, the seedlings being killed by subsequent cultivations. Thus clean cultivation serves to bring about a decrease in the number of weed seeds in the soil. Clean-cultivated crops always form a part of any successful crop rotation and, when alternated with grain and alfalfa, have proved very successful. If clean cultivation of a row crop is carried on for a year or two, perennials are very much weakened, if not killed out. If the clean-cultivated crop is followed by a smother crop, competition may become so great that the weaker weeds are unable to grow and to replenish themselves with stored food.

In dry-land grain areas where a crop rotation may not be so easily established, inasmuch as row crops without irrigation may not be profitable, summer fallowing greatly disturbs the root system of weeds and will very often thin out, if not eradicate them. In summer fallowing, systematic plans must be formulated whereby cultivation can be carried on at such intervals during the summer as to keep down all plant growth. The entire summer's conscientious, persistent work may be lost if weeds are subsequently allowed to produce much vegetative growth. So, before attempting clean cultivation methods, be sure that nothing will interfere with the program.

Crop Rotation.—In any serious program of weed control, crop rotation plays a leading part. Among the many well-established reasons for such procedure control of weeds is one of the most important. On those farms where weeds are of little consideration, either in increasing labor costs or in decreasing crop yields, a definite plan of crop rotation is systematically adherred to. Planting land to the same crop for a series of years in succession encourages weed growth, and a lack of proper rotation is a chief cause of weedy fields.

Three main classes of field crops include: (1) Grasses and legumes used as forage; (2) grain crops, such as wheat, oats, barley, rye, millet, and certain sorghums; and (3) cultivated crops, such as potatoes, beets, beans, peas, corn, and sometimes sorghums. In planning a system of rotation, give consideration to each of these classes.

Smothering.—Top growth may be more or less successfully prevented by smothering, either with a smother crop or with non-living material. Smother crops are effective chiefly as a result of excluding light. Those usually grown include millet, Sudan grass, sweet clover, alfalfa, rape, rye, and sorghums, which, when grown for this purpose, must be heavily seeded, under very favorable soil conditions so that a quick, thick stand is secured. Alfalfa is probably our most practical smother crop. Not only does it grow thickly, but the frequent cutting and the quick recovery after cutting serve to keep down the top growth of weeds. It is to be recommended in the campaign against most perennials, and a splendid stand of it will effectively crowd out morning-glory.

Small patches of perennial weeds are successfully smothered in two to four feet of straw or manure, or with heavy tar paper. These non-living materials exclude light and air. Some workers advise, when using straw or manure, that the material be wet down and tramped, so as to exclude the air more effectively. If growth makes its appearance above the mass, pile on more material. When tar paper is

employed, the strips should be lapped several inches, and the edges and seams weighted down with soil. In Colorado, where tar paper has been used with some success in controlling whitetop, paper was nailed to small strips of wood, by which methods shoots were kept from growing into the light. A plant like morning-glory, which has running stems, is difficult to keep within the bounds of the paper; consequently, morning-glory is one perennial which has not been successfully held in control by this method.

Note that tar paper and other non-living smothering material can be used practically, only where the area of infestation is small and involves a most noxious weed.

CHEMICAL WEED CONTROL

California has unique weed problems. With its great highway system, its large acreages of farm and orchard land under control of one man or organization, its tremendous areas in ditch banks and levees, practical weed control becomes a somewhat different problem from that facing a community made up of small land owners. California, accordingly, must develop methods of weed control and eradication which can be applied in a practical way on large areas. In this connection, it seems probable that chemicals, the various toxic salts, acids, and oils, will find wider and wider application in California. In another ten years they may be employed on a scale undreamed of at the present time, particularly in the case of roadsides, ditch banks, levees, and other uncropped areas; but also, in a modified fashion for land in crops, and for small patches of highly pernicious weeds.

The employment of chemicals in weed control has the added advantage of ultilizing a number of by-products of the industries, including some almost waste materials which thus find their greatest economic use as an herbicide. The cost of herbicides, as well as the cost of their application, will be a constant problem. By necessity, herbicides must be not only effective but cheap if they are to find wide application. The agricultural interests and the industries which have such products for disposal must cooperate to the fullest extent so that herbicides may be sold at the very lowest price which will permit a reasonable profit to the manufacturer. The expense will decrease as the volume of business increases. As the difference between the cost of small quantities and carload lots is usually very great, farmer groups will be able, through cooperation, to secure large quantities of herbicides at very much reduced prices.

Kinds of Herbicides.—Herbicides may be classified according to the effects which they produce:

1. Herbicides which are applied to the tops and which do not affect the roots or rootstocks of perennials. These are employed to kill annuals and to prevent the seeding of biennials and perennials. At present the oils are the most extensively used chemicals belonging to this group; for their use we have practical and effective equipment. Sulphuric acid is another chemical in this class which is finding increased usefulness, but difficulties are being experienced in developing equipment to apply it.

2. Herbicides which are applied to the tops and which not only kill top growth but are carried down various depths to destroy the roots or rootstocks. Depth of penetration into the structures underground varies with a number of factors, not well understood, among which are the following: nature of the chemical, strength of the chemical, species of plant, stage of growth of plant, soil, humidity, and other environmental conditions. This type of herbicide is greatly in demand for the destruction of perennials. The ideal perennial herbicide, one which will, under ordinary conditions, kill such plants as morning-glory, Johnson grass, hoary cress, Bermuda grass, and camel's thorn, should be cheap, easy, and safe to apply, and should not only destroy top growth but be carried down to the extremities of the roots and rootstocks and bring about their death. Certain chemicals now in use answer these specifications in part, but this class of herbicides, and their behavior under varied plant, soil, and other environmental conditions, should be more thoroughly investigated. The principal chemicals of this group that have shown a varying degree of practicability are the chlorates and the arsenicals.

3. Herbicides which are applied to the soil and are directly absorbed by the roots. The chief chemical in this class is carbon disulfide. This, though an extremely toxic chemical, is usually so expensive to purchase and apply that its use is confined to small areas infested with some highly pernicious weed.

4. Herbicides which act as soil sterilizers. Chief of these is sodium arsenite. These destroy seedlings and the shoots arising from underground structures; they may in instances kill seeds in the surface layers of soil.

5. Herbicides which destroy weed seeds without sterilizing the soil. Oils employed in the control of puncture vine are an example. Others are dilute solutions of sulfuric acid, and a number of other chemicals.

THE OILS

These products of the petroleum industry have been extensively used in California, chiefly in the control of annual weeds, including grasses; for destroying the viability of seeds; for destroying the vegetation of fence rows, fire breaks, roadsides, and ditches; and also to destroy biennials and non-creeping perennials. For weed control of this sort, the oils are the most economical and practical herbicides. They have been widely utilized in puncture vine control. The State Highway Commission has also, through its Maintenance Division, employed the oils along hundreds of miles of highway, spraying a guard strip approximately nine feet wide on each side, between the fence and the shoulder of the highway, chiefly to prevent the spread of fire from the highway to adjacent grain fields. The Division of Highways has expended for this work approximately $80,000 on 1000 miles of the state highways. Oil was applied at the rate of 1/10 gallon per square yard of surface. The cost of the material plus labor was between 5 and 6 cents per gallon. This procedure of the Highway Commission has attracted much attention and stimulated the use of oil as a herbicide by farmers and others throughout the state. The oils have often been used at the time of burning the dead vegetation following spraying. Oil which penetrates the seed coat almost invariably kills the seeds. The oils have also been used where cultivation is not feasible, as for irrigation canals, levees, fence rows, areas around outbuildings, in driveways, and in other places difficult to reach by cultivation. Petroleum companies are experimenting with various grades of their oils, and may develop something more satisfactory than at present; but thus far the two most widely used products are Diesel oil and stovetop oil. If these oils are used without emulsifying, one is probably as efficient as the other for destroying vegetative growth; but, if an emulsion is desired, only Diesel oil, in the commercial state, will give a satisfactory emulsion. If Diesel oil is to be emulsified, a grade should be used which is between 24° and 35° Baume, and contains not less than 2 per cent nor more than 5 per cent asphaltum. This grade, mixed with an equal amount of water, will, when agitated, form a very satisfactory emulsion, which, under most conditions, has proved as efficient as when applied straight. Of the oils tested for puncture vine control, the most promising products are those least highly refined, such as crude oil, waste cylinder oil, slop distillate, and Diesel oil. Stovetop oil and certain special fuel oils and distillates failed to give a satisfactory kill.

Remember that the oils are, for the most part, top-killers and, when applied as a spray to the top growth, do not ordinarily penetrate tissue underground. In the case of certain perennials, however, such as Johnson grass, oil may slightly penetrate roots or rootstocks sufficiently to thin somewhat an infested area. With hoary cress, the effect of an oil spray has been traced to a depth of 8 or 10 inches below the surface. Generally, however, the oils are most efficient in controlling annual weeds and preventing biennials and perennials from seeding. However, they are effective on some of the simple perennials, and fairly valuable even on shallow-rooted creeping perennials, such as Bermuda grass and Johnson grass. Roots within direct reach of the oil will be killed to the extent of its penetration.

The rate of killing of plants sprayed with oil depends largely upon the temperature and type of plant. On very hot days the effects of the oil may be seen within a few hours, and within 12 to 24 hours the plants may be completely shriveled and dead; but cold weather retards the rate of killing.

For satisfactory results, complete coverage of the plant is essential. This may not be possible if the vegetation is too heavy and thick. Oils are most efficient when the vegetation is small for then complete coverage is more easily brought about, and the cost per unit area is much less. The attempt to cover tall and thick vegetation thoroughly with oil usually involves waste of material. Labor, furthermore, is sometimes careless in the handling of the spray nozzle and, consequently, causes criticism of the use of oil because the coverage is incomplete.

Waste crankcase oil, if used, should be diluted with distillate or Diesel oil to a proper consistency for spraying. Crude oil also may be diluted as above and used satisfactorily for "spot" work and with small equipment.

Among the many different factors which affect the cost of applying oil may be mentioned (a) species of weeds, (b) density of growth, (c) type and efficiency of spray equipment, and (d) efficiency of the operator. A good example is the cost of spraying with oil an average growth of weeds in San Joaquin County. These data were kindly furnished by the San Joaquin County Agricultural Commissioner. A power spray equipment with two men (driver and operator) can cover about 10 acres in 8 hours, using 3000 gallons of oil. At 3¾ cents per gallon, the material for an acre will cost $11.25. The labor of two men per day costs $10.00, or $1.00 per acre. The total expense per acre, excluding depreciation on equipment, is about $12.25.

THE CHLORATES

The chlorates are white crystalline substances, the two principal herbicides being sodium chlorate and "Atlacide" (calcium chlorate). Sodium chlorate usually comes in the pure crystalline form. "Atlacide" is a commercial herbicide, which is chiefly sodium chlorate with an addition of calcium chloride which, because of its deliquescence, lessens the fire hazard.

The chlorates are non-poisonous to animals. They have been employed rather extensively in a number of states, and in certain instances very successfully; but in some particulars their use is still in the experimental stage. Unpublished results of several workers appear to show that the chlorates are most effective when the solution has an acid reaction. If this be true, chlorate solutions should not be made with alkaline water, unless it is rendered acid by adding a small amount of acid. Much more must be learned about the amount to use, the time of application, the relation of time of application to environmental conditions, the method of application, etc. Evidently, however, the chlorates are among the most promising chemicals yet employed to control perennial weeds when applied as a spray to the tops of the plant. They will also effectively kill annuals; but thus far, in most instances, there are other herbicides for annuals more economical than the chlorates and just as effective. As regards perennials, remember that a desirable herbicide is one which, when applied to the tops of the plants will be absorbed and be carried to or result in the death of a large percentage of roots and rootstocks.

The following and similar perennials have been fairly successfully controlled by chlorates: Canada thistle, Johnson grass, wild morning-glory, Russian knapweed, poison ivy. Thus far, indifferent or varying results have followed the use of chlorates on tules, Bermuda grass, cat-tails, willows, and hoary cress, probably because the proper method or proper time of application has not been ascertained.

Time to Apply Chlorates.—The chlorates are evidently most effective if applied on mature plants or plants approaching maturity. They should accordingly, be applied when the plants are in full bloom, or just after this stage. In the case of perennials a maximum of top growth seems advisable if a large proportion of the underground parts of the plants is to be killed. Late summer and autumn applications seem more effective than spring or early summer. A perennial which develops its seed in the summer may, perhaps, be prevented from seeding more economically by means of cultivation,

mowing, oil sprays, or some other method less expensive than the use of chlorates, the chlorate treatment being thus postponed until fall, when the plants are attaining dormancy. In other words, chlorates apparently bring about a better root kill if applied when the plants are going into a dormant condition.

Amount of Solution Required.—The usual solution employed is that made by dissolving 1 to 2½ pounds of the chlorate in 1 gallon of water. The amount required depends upon the density and kind of vegetation. If the growth is heavy and rank the dilution can be less than when the growth is moderate or slight; but the number of gallons of solution must be increased. In the case of "Atlacide," for example, for a rank and heavy growth of morning-glory in full bloom there is a recommendation that there be applied 2 gallons to the square rod of a solution which contains 1½ pounds per gallon; but with less dense stand or growth, 1 to 1½ gallons to the square rod of solution containing 2½ pounds to the gallon. Often 1 to 2 gallons of solution may be expected to cover a square rod, if applied conservatively with a hand sprayer. But, if a large area rather completely covered with vegetation is to be sprayed with power equipment, it will usually require at least 300 gallons per acre to secure satisfactory coverage. The type of vegetation being sprayed may be such that a greater amount, even as much as 1000 gallons per acre, will be required. In any event the important consideration is to secure complete coverage of the vegetation and apply an adequate amount of the material per unit area. Remember, also, that power equipment varies in its efficiency.

Effectiveness of Chlorates as Influenced by External Conditions.—The effectiveness of the chlorates is lessened if the treated areas are disturbed in any way before the following spring. That is, the treated plants, even though dry and with tops dead, should not be burned off, or moved, or cultivated until the spring following their application.

The Ohio Agricultural Experiment Station states that sodium chlorate applied to quack grass and Canada thistle is most effective if applied on cloudy days and when the air is humid; also, that the effectiveness appears to be greater when the soil is somewhat moist. The Kansas Agricultural Experiment Station also states that chlorates are best applied when the air is moist, as in the late afternoon on damp days. They further point out that rain a short time after spraying has little retarding action. The Idaho Agricultural Experiment Station states that for the eradication of most perennials more chlorate is necessary on irrigated areas than on unirrigated areas, and that where high water tables prevail more chlorates are required than

where the water table is low. Experiments in Colorado, using equal amounts of chlorates on irrigated and non-irrigated plots, show better results on the latter.

At the present time experimenters are closely observing many field plots in different parts of California with a view to determining the influence of various factors upon the effectiveness of the chlorates.

Effect of Chlorates on the Soil and Subsequent Crops.—Some variation appears in the effect of chlorates upon the soil and subsequent crops. This variation might well be expected, for the soils to which the chlorates have been applied undoubtedly differ, and the treatments these soils received before and after the chemical application were by no means the same.

In Kansas it has been found in field bindweed plots sprayed with sodium chlorate August 19, September 2, and September 16, where the soil was sampled to a depth of 7 inches in May of the following year, that bacterial action had not been seriously interfered with, and that these plots sown to wheat in September bore a normal crop. Åslander, in New York, also found that autumn applications of sodium chlorate did not influence the ammonification and nitrification processes in the soil the following spring, and did not injure the oats then sown on the plots. In Idaho it was found that in irrigated sections, grain crops seeded the spring following chlorate treatments turn yellow, but are usually restored to normal by the first application of water. In Oklahoma areas sprayed twice with sodium chlorate in the summer and fall of 1928 showed considerable decrease in the yield of oats in 1929.

In California the writers have observed instances in which trees have developed disorders following the applications of chlorates to weeds in orchards. In these cases injury resulted from the chemical coming in direct contact, not with the foliage, but with the roots through the soil. Present knowledge advises caution in the application of chlorates to weeds in orchards.

At Davis, California, barley seeded in December on land sprayed with sodium chlorate in October and November failed completely. In the spring, after a winter rainfall of more than 12 inches, the seedlings of morning-glory and other weeds came up, soon turned yellow, and died. Two heavy irrigations were necessary before a satisfactory stand and a healthy growth of Sudan grass could be obtained.

Application of Chlorates, Dry.—It may be impracticable to provide spray equipment to treat a few small patches of weeds. In such cases,

chlorates may be applied dry. Spread the crystals broadcast with the hand, about one pound to the square rod. The chemical will not be effective until it goes into solution. Commercial "Atlacide" (calcium chlorate) is a finely-powered material and hence may be dusted. Special equipment, both of the knapsack and power types, has been devised for dusting of "Atlacide" (calcium chlorate).

In New York it was found that about 175 pounds of sodium chlorate per acre, applied dry on the ground late in the fall, was effective in killing the roots of Canada thistle. The fall application was more effective than the spring.

Precautions in the Use of Chlorates.—The chlorates are a *fire hazard.* In a number of instances individuals have been seriously burned in the use of a chlorate. The chlorates are strong oxidizing agents; that is, in contact with organic matter of any sort they readily give up oxygen to it, thus rendering it highly combustible. Thus, clothing, chaff, straw, sacks, wood, etc., covered with chlorate will readily ignite when dry. For example, parts of clothing worn while spraying with a chlorate may become wet with the chemical; then the clothing and chlorate become dry and, in this condition, *become highly inflammable.* Ashes from smoking tobacco, a match thoughtlessly lighted, or a spark from an exhaust pipe of spray equipment may set a fire.

Men should preferably not work alone in using chlorates. If two or more are working together, assistance is at hand in case of fire. A bucket of water may extinguish the blaze and prevent what otherwise might be a serious accident. Spray equipment sometimes carries a fire extinguisher.

In handling chlorates, as during loading or unloading, or in the preparation of the spray solution, any crystals or solution accidentally spilled on floors, trucks, or machinery, should be thoroughly washed off with a hose or otherwise drenched with water.

Chlorates are particularly combustible in contact with sulfur. Consequently, great caution should be taken not to store sulfur, or sulfur-containing spray materials, near chlorates. Moreover, a spray machine once employed in applying sulfur spray should be thoroughly washed inside and outside before it is used in applying chlorates.

Accidents are more likely to occur after spraying operations are completed, and the clothing is allowed to dry on the body. This danger can be eliminated by having two pairs of overalls. At noon one pair can be rinsed out in clean water to remove all chlorate, and the dry

pair put on for the afternoon; this pair should, in turn, be washed in the evening. Operators of chlorate sprays sometimes wear rubber boots. The material should not be allowed to dry on these, and they should be washed thoroughly every evening.

Keep spray equipment well painted so that the solution does not saturate the wood. Metal rather than wooden containers are better for chlorate solutions. Wooden containers, if employed, should be washed out thoroughly after use and even be allowed to stand for several days filled with water. A wooden barrel, for example, in which the chlorate solution has been made may, once emptied and dried out, become a highly combustible object.

As an extra precaution, mix solutions away from out-buildings, barns, straw stacks, etc.

Chlorates should be purchased preferably in metal containers. If shipped and stored in sacks, they should be kept in a dry place, for they absorb moisture from the atmosphere, and the chemical, coming into close contact with the fiber of the sack, presents when dry a fire hazard.

In emphasizing the precautions to be employed, one should remember that chlorate sprays are no more dangerous than gasoline and other chemicals used daily on the farm as insecticides and fungicides, and no more dangerous than dozens of chemical compounds handled constantly in the industries. If chlorates are effective herbicides, the care necessary in handling them should not be a serious drawback.

CARBON DISULFIDE

This is a highly explosive, volatile, clear liquid, employed with considerable success in the destruction of perennial weeds, such as morning-glory, Russian knapweed, poverty weed, Canada thistle, and Johnson grass. It has also rather effectively killed willows. It is applied by injecting into the soil, where it volatilizes and diffuses. As carbon disulfide is heavier than air, the direction of diffusion is more rapid downward than upward; however, the gas diffuses in all directions from the point of application. Being highly toxic, it usually kills the weeds within a short time, depending upon soil conditions. The effect may sometimes be seen within a few hours after application, and destruction of the weeds will be completed within 4 to 10 days. There seems to be a minimum concentration which will destroy plant tissue of any given species. In an experiment with Johnson grass, for example, the rootstocks within a radius of 8 or 10 inches from the point of application were killed for their entire length, whereas root-

stocks originating beyond this radius were unaffected. At the same time, the carbon dioxide diffused in 24 hours throughout a radius of 36 inches in the soil.

Carbon disulfide, on account of its cost and the expense of application, is applicable only to small areas heavily infested with a highly pernicious weed which threatens to spread to a much larger area of valuable land. Under such conditions of threatening infestation, an apparently high cost of eradication may be justified and wholly practicable. To treat a square rod of solidly infested land will cost from $1.50 to $1.75 which, assuming similar conditions, would make the cost per acre from $260 to $400. This cost would be prohibitive over a large acreage but, as stated, is often justified in a small area. Vigorously growing plants are apparently more susceptible to the gas than are those in a weakened dormant condition. Consequently, late applications in the fall, after growth has slowed down or ceased, are less effective than earlier applications.

An advantage of carbon disulfide is that the soil is free from the poison within a few weeks after its application and may be planted to a crop.

The depth and character of the root system will largely determine the depth and manner of application of carbon disulfide. The primary consideration is that the volatile gas must come in contact with the roots and rootstocks if they are to be destroyed. Consequently, if the root system is shallow, the chemical must be applied in the upper layers of the soil. For example, Johnson grass growing in a moist, light, sandy soil, with the greater part of its underground system a few inches below the soil surface, best results have followed from applications of the liquid immediately on the crown of the plant or in shallow depressions at proper intervals. Cover the treated areas with soil. If the larger part of the root system is at deeper levels, then the carbon disulfide must be placed correspondingly deeper.

At deeper levels holes are made in the soil and the carbon disulfide is poured into them. The holes may be made with a crowbar or with a sharpened steel stake driven into the ground. Great care should be taken in distributing the holes or treatments over the area infested. If, for example, an area of morning-glory is to be treated with carbon disulfide, the holes should be spaced evenly over the entire area, regardless of the density and distribution of the top growth. For we must remember that the soil is thoroughly penetrated in all directions by roots capable of sending up new shoots and extending beyond the limits indicated by the top growth. Therefore, lay off the area to be treated into rows about 20 inches apart and make holes, alternating in adjacent rows,

about 24 inches apart in the rows. The distance apart of the holes will vary with the type of soil. They should be closer together in a heavy soil and may be further apart in a light, sandy soil. Ordinarily four ounces of carbon disulfide to the hole is adequate. There are, however, exceptions to this rule. For camel's thorn, with its very heavy, deep rootstocks, four to five ounces are required to effect a kill. Immediately after treatment the hole should be plugged or tamped with earth.

Authorities disagree as to whether carbon disulfide is best applied on dry or on moist soil for both successful and unsuccessful results have followed under these two conditions. Presumably the amount of water in the soil determines the rate of diffusion of the chemical, which is probably the chief factor determining its effectiveness.

Attempts have been made to apply carbon disulfide by means of various types of machinery. A promising equipment is one which is attached to a sub-soiler.

ARSENICALS

The common so-called "arsenicals" used as weed-killers are sodium arsenite, arsenic trichloride, arsenic acid, and arsenious acid, all deadly poison to livestock and human beings.

Sodium arsenite, arsenic trichloride, and arsenic acid have been used extensively as sprays for perennial weeds. Sodium arsenite has been employed in large quantities by railroad companies in keeping down all classes of weeds along their right-of-ways. These three arsenic compounds, when applied as a spray to the tops of perennials, may penetrate the roots and rootstocks, to a distance depending upon certain conditions not well understood. According to general experience, these arsenicals are most effective when applied under humid atmospheric conditions, but moist soil conditions are not favorable for arsenical spraying.

Chemicals containing arsenic have been used more extensively in the control of morning-glory than of any other single weed. Their use in this particular is described in detail in the section discussing morning-glory.

Of the four arsenicals mentioned, sodium arsenite and arsenious acid ("white arsenic") are soil sterilents. They have been successfully used to keep walks, tennis courts, and other similar areas free of weeds.

Arsenic trichloride and arsenic acid are not such effective soil sterilents as the two compounds just mentioned. They are miscible

with oil, and in this form are repellent to livestock. For each unit of arsenic, arsenic acid is cheaper than arsenic trichloride.

Arsenic acid may be secured in the solid form (arsenic pentaoxide) or in a solution containing about 60 per cent arsenic pentaoxide. In 50-gallon steel drums the solution costs from 5 to 8 cents per gallon. A 1 per cent solution, very effective as a spray for annuals, will cost from 80 cents to $1.30 per 100 gallons of solution.

Arsenic trichloride as such is not marketed in quantities, but it is one of the chief constituents of the commercial herbicide known as "K.M.G."

Arsenious acid is sold commercially as powered "white arsenic", at a price ranging from 4 to 7 cents per pound. Not being readily soluble in water, it is unsuitable for use as a spray; but, as stated, it may be employed as a soil sterilent.

Sodium arsenite solution may be obtained either in powered form or in a solution equivalent to about 25 per cent arsenic trioxide.

OTHER HERBICIDES

The chemicals most economically used on a large scale include the three groups just discussed, namely, the oils, the chlorates, and the arsenicals. Many other chemicals have been tried, in instances with good results, and some have found application to special weeds or conditions.

Common salt has been used satisfactorily in the barberry eradication campaign; here it is applied dry at the base of the barberry plant. Individual plants of any sort are killed by common salt if enough of it is placed about them. If, however, salt is used in sufficient quantities to kill weeds, it destroys all other vegetation.

At the Arizona Agricultural Experiment Station it has been found that sulfuric acid, applied as a spray, is a practical chemical for the control of weeds. It kills more effectively when applied under pressure than when sprinkled on weeds; furthermore, it has no ill effects on the soil. Sulfuric acid has a further advantage in that, with the very low dilutions used, it is relatively cheap. Crude concentrated sulfuric acid may be obtained for from $17.50 to $20.00 per ton, depending upon the quantity purchased. The strengths of solution used in Arizona varied from 2 per cent to 10 per cent, depending upon the type of vegetation treated. Approximately 200 gallons of the spray will cover an acre.

The chief disadvantage of sulfuric acid is the difficulty in handling, which, however, may be partially overcome by protecting all

metal parts of spray apparatus with a covering of grease or heavy oil. One company now manufactures a compressed air type of power spray equipment which provides metal tanks containing a heavy acid-proof rubber bag, removable and washable. In an equipment of this sort, acid comes into contact only with easily replaced parts. The use of sulfuric acid as a spray in the control of weeds in grain fields is described further on.

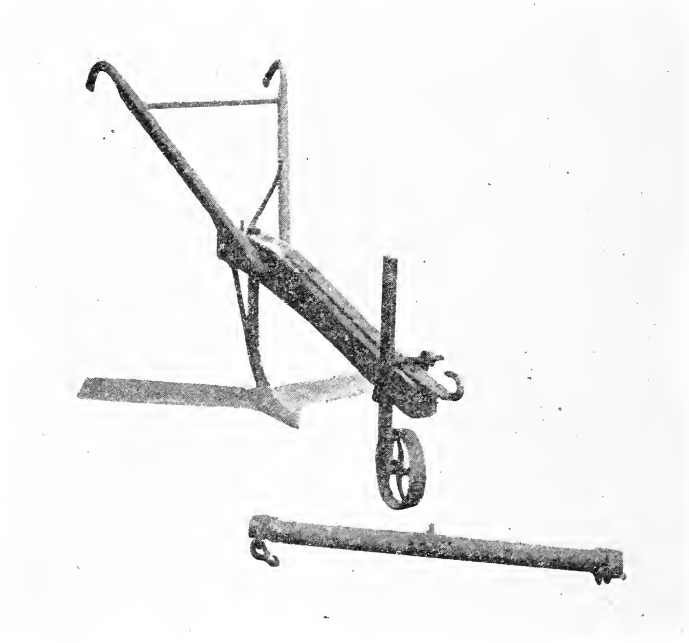

Fig. 1.—One-horse weed knife, made by blacksmith.
(From Exp. Sta. Cir. 256.)

Iron sulfate has been used extensively in the control of weeds, especially mustards, in grain fields, and also dandelions in lawns. A discussion of its use in these places is given elsewhere.

Carbolic acid (phenol) in the crude form is used to kill weeds in gravel courts, driveways, etc. One quart of the acid in one gallon of water will cover about one square rod.

EQUIPMENT FOR WEED CONTROL

Various types of cultivating implements have been devised for weed control, and also several different kinds of spray equipment. The majority of cultivating implements are, indeed, designed, at least in part, to destroy weed growth; but in addition to these, special imple-

ments have been constructed to fight certain pernicious weeds. In California the morning-glory has received special attention and figures 1, 2, and 3 show various types of 'weeders' designed to fight this and other perennials. In orchards and uncropped areas these implements may be used for clean cultivation.

In the last few years considerable interest has been shown in chemical methods of control. The writers believe that these methods will be used more and more. Along with the development of these methods have come demands for certain types of equipment suitable for the application of herbicides.

There are two general types of spray equipment, namely hand and power. Where the area of infestation is small, some type of hand sprayer may be employed more practicably than the hoe or other implement. There are two types of hand sprayers—the knapsack form and the barrel form. One of the most satisfactory knapsack sprayers is the compressed air type. Several strokes of the pump place enough pressure on the solution in the tank to spray several square yards with a fine mist spray. The ordinary types of knapsack sprayers usually hold from 2 to 5 gallons. The barrel type of sprayer, equipped with a hand pump, provides a greater capacity. This, too, is adapted to treatment of small infestations.

There are now in California over a hundred power sprayers designed for weed control work alone. By this is meant a type of spray equipment which is adapted to handle various chemicals, including oils, powerful oxidizing agents such as the chlorates, and alkalies and acids. The ordinary orchard spray rigs with their fiber, leather, and rubber packings, and with steel working parts are unsatisfactory for use with most herbicides. However, they may be adapted to weed work. Sprayers designed for weed control work alone are in use by the county agricultural commissioners, the State Highway Commission, irrigation districts, drainage districts, and a few large land owners. Some of these sprayers (figs. 4, 5, 6) are adapted for roadside work, others for ditches, and still others for general field and spot infestations. Their capacity varies from 250 gallons to 900 gallons. Their nozzle equipment may enable them to spray a strip as much as 15 feet wide. These spray equipments are almost always mounted on motor trucks, each consists of a supply tank, a pump, and a gasoline engine, with necessary hose, hose connections, and nozzles. One very satisfactory type of weed spray equipment utilizes the principle of atomization with compressed air instead of a pressure pump. (fig. 7). A spray of almost any degree of fineness can be obtained by proper regulation of the air and liquid lines.

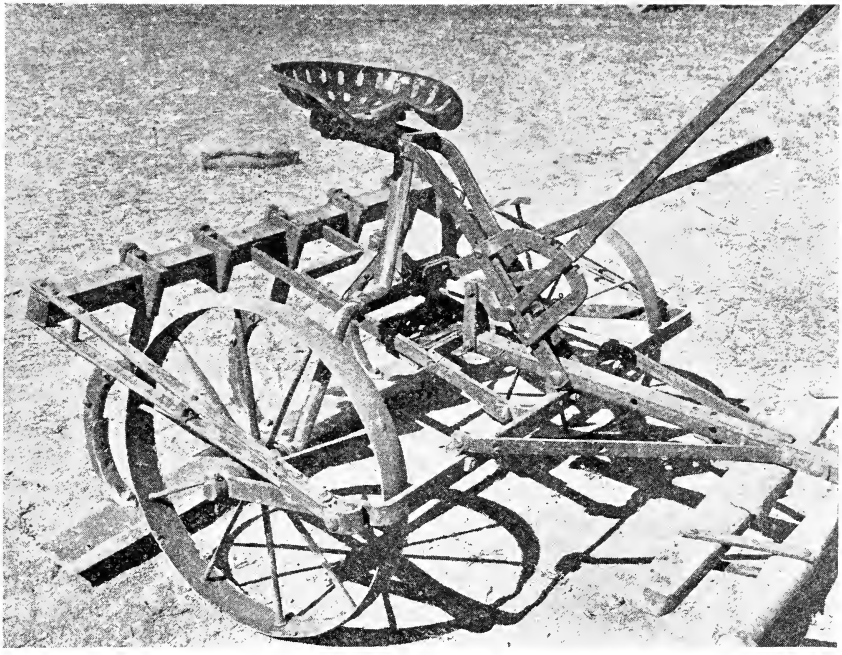

Fig. 2.—Two-horse weeder used for morning-glory control. The blade can be raised from the seat. (From Exp. Sta. Cir. 256.)

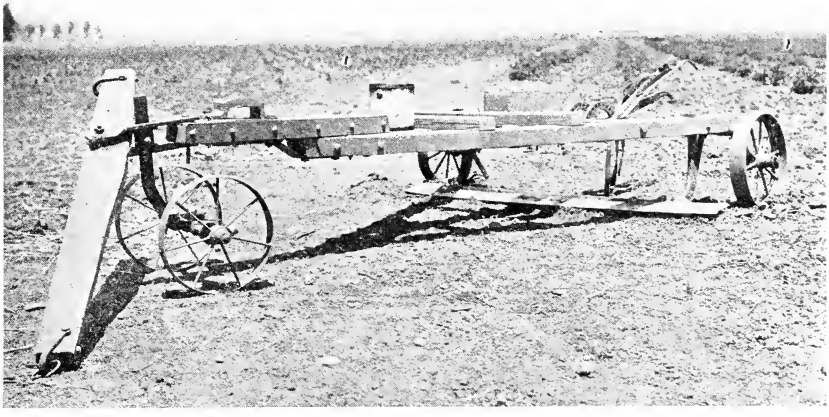

Fig. 3.—Three-horse weeder, used for morning-glory control. Made by blacksmith. (From Exp. Sta. Cir. 256.)

Fig. 4.—Power spray rig, showing two lines of hose with multiple nozzle.

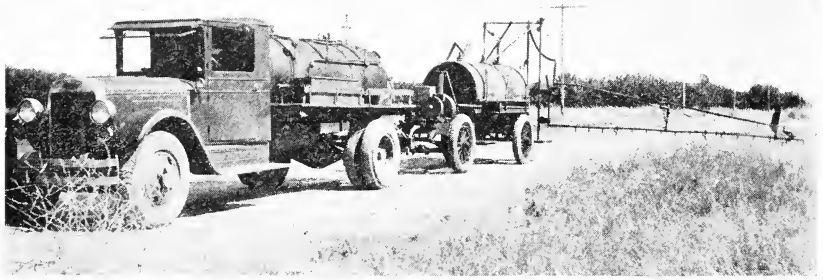

Fig. 5.—Power spray rig, built for roadside spraying. Will spray a strip 15 feet wide. Capacity, 900 gallons.

Fig. 6.—Power spray equipment adapted for spot work along roads. Two lines of hose.

The power equipment requires at least two operators, a driver and the spray operator. In the many instances where there are two hose lines, three men will be required.

For the successful and efficient operation of a spray equipment, the following points should be observed: (1) maintenance of pressure, and (2) clean nozzles, both of which will provide a fine mist spray insuring a complete coverage of the vegetation. One should, however, remember that a sufficient amount of the chemical must be deposited upon the plant. Failures very often result not only from neglecting to cover the vegetation completely, but also from diffusing an insufficient amount of the chemical.

Fig. 7.—Power rig equipped with two lines—one air, one liquid—which produces atomization, thus giving a very even and thin coverage. This machine shows lines attached to multiple nozzle.

In case the chemical used tends to corrode, brass or bronze fittings should be provided; and in all cases the life of equipment will be prolonged if tanks, hose lines, and all other parts are thoroughly rinsed with clean water after use.

WEEDS IN NON-CULTIVATED AREAS

Everywhere throughout the state, weeds grow in profusion on ditch banks, on levees, along fence rows, roadsides, and driveways, on vacant lots, in fact, in almost every out-of-the-way place. These weeds are the ever-present source of infestation which discourages the farmer in his efforts to keep his fields clean. Weeds of such places not

only furnish the seeds which infest the crops, but also harbor fungus and insect pests. Growers cannot be expected to gain the benefits of cultural methods looking towards weed control, or to carry on with enthusiasm any system unless a concerted effort is made to prevent the growth and seeding of weeds in the uncultivated areas surrounding their farms.

Weeds of all classes—annual, biennial and perennial—may be found in these non-cultivated areas; but, as a rule, annual weeds dominate. This fact should somewhat simplify the problem. The least we should do is to destroy the pests before they mature seed. All too frequently weeds along roadsides, or elsewhere, are mowed when they are in seed and the plants left on the ground to dry. Then entire plants or seeds blow in great numbers onto adjacent cultivated fields or orchards. Farmers often erroneously suppose that if the plants are mowed when in flower all danger of seed production is past. In many plants, however, flowers are formed over a period of several weeks and, although the plant may have the appearance of being in flower, still the plant may harbor mature seeds or seeds developed far enough to mature even though the plant is cut off near the ground line. Consequently, early destruction of these plants is advisable if seeding is to be prevented.

It should be stressed at this point that on all such non-cultivated areas as mentioned above, where it is possible to move a tractor or cultivating implements, clean cultivation with disks or plows, will usually prove to be the cheapest and most effective method of control. However, there are places difficult to reach with large equipment, and on such areas a very promising and relatively cheap method of weed control is one employing oils. The first application should be made when the growth is but a few inches high, for at that time a complete coverage of the vegetation can be made at the least cost. Moreover, the plants then are young and tender. Several applications may be needed during the season. The first year will naturally require more oil than subsequent years because the soil contains innumerable seeds which will germinate. If, however, after germination the seedlings and other growth not killed by the first spraying are sprayed again with oil, there is a rapid reduction in the weed population. In most sections of the state, where the dry summers permit very little growth, one or two sprayings with oil in a season will effectively keep down weeds on non-cultivated, unirrigated areas. The cost of application should be somewhat smaller each succeeding year for the vegetation to be covered constantly decreases.

Over a five-year period the cost of keeping ditch banks, levees, roadsides, and other non-cultivated areas free from weeds by repeated sprayings with oils will usually be less than under the methods now employed. The use of the mowing machine, the scythe, and the hoe is not at the present time preventing these weeds from going to seed. The oils, applied with power sprays, deserve serious trial generally over an extended period and under various conditions in the state.

We greatly need soil sterilents, that is, chemicals which, when applied to the soil, not only kill the vegetation but penetrate so deeply as to prevent, at least for several years, the germination of seed and destroy any growth which arises in or attempts to grow through this surface layer. An effective soil sterilent should be one which will not readily leach out. The oils have not proved desirable. At present sodium arsenite seems to be the most promising. Although it cannot be used on weeds where there is danger of poisoning livestock, it can be applied on areas freed from weeds or applied during the dormant season. The solution commonly recommended consists of 10 pounds of caustic soda and 20 pounds of white arsenic, dissolved in 5 gallons of water. Mix the caustic soda with the white arsenic in a wooden or earthenware receptacle. Add the water very slowly. The chemical reaction resulting from the addition of water will usually generate sufficient heat to bring all the arsenic into solution; but if this fails to occur, heat the mixture until the arsenic all disappears. This stock solution, diluted at the rate of 1½ gallons of solution to 100 gallons of water, will treat 100 square yards of surface. It has been found that one gallon or more of the arsenical solution applied to one square yard will make the area barren of all vegetation, except morning-glory, for fourteen months. The solution may be applied on small areas with a sprinkling can. On larger areas a power spray rig may be used to hasten the work.

Common salt has also been used as a soil sterilent, in some cases satisfactorily. From 20 to 30 tons per acre are required. The handling and distribution of this material makes it somewhat undesirable. Furthermore, salt will leach from the soil and if close to trees or growing crops may cause some injuries.

The prices of these chemicals fluctuate, making it impossible to give other than approximations. Oils range from 4 to 8 cents per gallon; sodium arsenite (50 per cent solution) about 50 cents per gallon, plus shipping rates; salt from 60 to 90 cents per hundred pounds.

WEEDS IN GRAIN FIELDS

The weeds which infest grain fields are extremely numerous and variable. The number, as well as the kind, varies with the district and the conditions of culture. They consist largely of winter annuals, although some perennials do occur.

Most of the grain in California is grown on unirrigated land; and the weeds, competing with the grain crop for moisture, plant food, and light, invariably reduce the yield. In addition, weeds increase the cost of harvesting, cleaning, and preparing for ultimate consumption.

Common Weeds Occuring in Grain Fields.—Some of the most commons weeds found in grain fields are wild oats, mustard, radish, common spikeweed, and buckthorn or fiddleneck. In addition, a number of thistles, such as the spiny sow thistle and the milk thistle, occur in some sections. In the Sacramento Valley the yellow star thistle and the Napa thistle or tocalote are particularly pernicious. The latter, however, is now quite general throughout the state. Some perennials, such as the morning-glory, also occur but they rarely cause much trouble except on land that is frequently fallowed.

Introduction and Spread of Weeds in Grain Fields.—Aside from the natural agencies of dissemination, there are two other very potent means of spreading the weeds of grain fields. One is the common practice of buying seed "over the back fence" or from a neighboring district, without taking the precaution to see that it is free from weeds, or to have the seed cleaned before sowing; the other is the custom harvester which moves from ranch to ranch, and from weedy fields to clean fields, without being cleaned.

Annual weeds, once started in a field, spread rapidly, especially on land that is cropped every year. Most of the winter annuals, such as wild oats, mustard, and radish, ripen their seed before or at the same time the grain crop ripens, so that their seed is shed or scattered with the combine in harvesting the grain. Others, like the star thistle and the Napa thistle, do not, as a rule, mature their seed until after the grain is harvested; such seeds on maturity drop to the ground and thus maintain the infestation.

Control of Weeds in Grain Fields.—The control of the annual weeds in grain fields is mainly a cultural problem. Some farmers keep their fields fairly free from weeds by delaying plowing until January or later, thus giving the weed seeds a chance to sprout, after which the young plants are plowed under. This practice, if followed con-

sistently, will normally keep the crop free from weeds; but late seeding in many of the grain growing sections usually results in low yields. Another practice commonly followed where the land is fallowed every second or third year is to delay plowing for the fallow until March, when all weeds and volunteer grain have started and can be destroyed readily by plowing. Furthermore, since little rain falls after the land is plowed, the subsequent growth of weeds is usually negligible. The practice, however, is not a good one, because it nullifies to a large extent the benefits which should accrue from the fallow, i.e., moisture conservation and the stimulation of nitrification.

The occasional fallowing of the land is ordinarily fairly effective in controlling or eradicating wild oats, the seeds of which remain viable for only two or three years; the other weeds, however, such as mustard, radish, and fiddleneck, the seeds of which may remain viable for many years, are less easily eradicated. Late winter or spring seeding, though undesirable, may be necessary as a part of the plan in weed eradication, where the infestation is heavy.

Probably the best procedure is to delay plowing or cultivation in the fall until most of the weed growth has started. Then, after plowing, a period of two or three weeks should elapse before the seed bed is prepared and the crop seeded. This delay will permit the germination of the weed seeds which have been turned up, and the seedlings can then be destroyed with surface tillage implements just before seeding. The practice of replowing the land just before seeding is not a good one, for a fresh supply of weed seed will be brought to the surface and will sprout with the grain. During the fallow year, a similar procedure should be followed, although the first plowing might be delayed until January or February in order to give the weeds a chance to get well started. After plowing, two or three cultivations during the spring months will destroy large numbers of the weeds and stimulate germination of the seed in the plowed layer. This practice, although more costly than that of delaying the plowing until spring, is more effective in destroying weeds.

Chemical Control of Weeds in Grain Fields.—In the eastern and middle western states, as well as in certain grain-growing sections of Europe, considerable success has attended the efforts to destroy mustard and other broad-leaved annuals in young grain by spraying with chemicals. The most widely used and effective spray employed in this country is iron sulfate (''copperas''). Solutions of this chemical varying in strength from 5 to 20 per cent have been used, their efficiency depending chiefly upon the relative humidity of the atmosphere. The spray was most successful if applied when the weeds

were small, with not more than four to six leaves, and when the atmospheric humidity was high. Injury to grains or other grasses was negligible.

In certain European countries, chiefly Scandinavian, sulfuric acid has been used very successfully in grain fields to destroy mustards and other broad-leaved weeds. The strengths recommended vary from 1.5 to 10 per cent, the difference in effectiveness depending chiefly on the age and condition of the crop, and the manner of application of the chemical. In general, sulfuric acid or other acids may be better suited to California conditions than iron sulfate, in that the best results are obtained in dry air. Chemical methods of weed control in California grain fields deserve extended trial.

Perennial Weeds in Grain Fields.—As already stated, morning-glory and other perennials which make their growth during the summer usually spread more rapidly on fallowed land than on land continually cropped. The reason is that during the fallow year the moisture conditions in the fallowed land are ideal for the luxuriant growth of the weed pests. On land fallowed every second or third year, such perennials, when once started, may soon come to occupy the whole field.

Perennials must be prevented from producing seed, for while some spread does occur because of the rootstocks, the greatest spread comes from dragging the mature vines, loaded with seed, over the field. When grain land becomes badly infested, the value of the land will perhaps not justify the attempt to eradicate such pests as morning-glory by present expensive methods. Where small areas occur, weeds can and should be eradicated to prevent further spread. As already stated, the morning-glory should be prevented from going to seed, then allowed to make a good vegetative growth in the fall, and sprayed heavily with a chlorate spray in October and November. The treatment should be repeated in succeeding years until the pest is eliminated. It will in all likelihood sterilize the soil for a short time; but if the area is not large and the weed is finally eradicated this temporary sacrifice is well justified.

WEEDS IN ALFALFA

As to their effects upon the alfalfa crop, weeds fall into three groups. (1) Weeds which appear in the new seeding of alfalfa and threaten to choke out or offer serious competition to the young plants. The weeds in this group consist mainly of the annual, herbaceous, broad-leaves plants such as pigweed, mustard, Russian thistle, and

bur clover. Such perennials as morning-glory and creeping mallow may also interfere with the growth of young alfalfa, especially that of late spring seeding. Alfalfa seeded in the fall or early spring ordinarily suffers but little. (2) Weeds which appear in the older fields and compete with the crop for plant food, moisture and light. These weeds may materially reduce the quality of the hay. Those of greatest concern to the grower are foxtail, Bermuda grass, brome grass, crab grass, and water grass. Johnson grass, too, may be troublesome in sections where it is prevalent. In some of the older fields, hoary cress and Russian knapweed may appear in dense patches, and are especially objectionable in the hay. A number of other weeds may occur in certain districts, but those mentioned are most prevalent. (3) Parasitic weeds, such as dodders, which prey on the alfalfa and reduce or completely destroy the plants. Of several species, the small-seeded dodder is most common in California.

Weeds Which Interfere with Establishment of Stand.—Controlling weeds which may interfere with the establishment of a new stand consists primarily in eliminating as many as possible before the alfalfa is seeded and in providing favorable conditions for the growth of the alfalfa. Preceding the alfalfa with a cultivated crop will eliminate many of the weeds. Sudan grass, if irrigated, is also an excellent crop to precede alfalfa, as it smothers most annuals before they have an opportunity to produce seed. A field known to be weedy should be plowed several weeks before the alfalfa is to be seeded and should be irrigated, if necessary, to provide favorable conditions for weed growth. Then, just before seeding, the seed bed should be prepared and the weed growth destroyed with as shallow tillage as possible. Shallow cultivation at this point is important in order to provide a good seed bed for the alfalfa, and also to prevent bringing a fresh supply of weed seeds to the surface. Handled in this way, a clean stand of alfalfa can usually be obtained from early spring seed, as by this time most of the winter annuals have started and are readily destroyed, and moisture and temperature conditions are, as a rule, favorable for the rapid growth of the alfalfa. The same procedure should be followed for fall seeding, although elimination of weeds is usually not so easy, because in the fall the time available for germination and destruction of the weeds is shorter, and the conditions of growth of alfalfa are less favorable.

If a heavy growth of weeds starts with the alfalfa, keep it clipped back and thus allow sunlight to reach the alfalfa plants. Weeds on a new field of alfalfa should, when clipped, always be cut high, three inches or more from the ground. The reason is that young alfalfa

plants grown in the shade are slender and spindling, with but few leaves; and if cut off close to the ground, with most of the leaves removed, many of the plants will die.

Weeds in an Old Stand of Alfalfa.—When a good stand of alfalfa has been obtained and the conditions for growth are favorable, weeds seldom cause much trouble for the first two or three years. After that period, however, the stand becomes thinner, and weeds begin to fill up the vacant spaces. The general belief that the weeds are the cause of the thinning of the stand is only in part correct. A dense, vigorous growth of alfalfa can normally hold its own against weeds, and only when space has been provided for the weeds do they come in and cause trouble. This may not be true of Bermuda grass, which appears to be actually able to crowd out the alfalfa. On the other hand, when soil and moisture conditions are good, some excellent crops of alfalfa are sometimes obtained from fields with a very dense undergrowth of Bermuda grass.

The winter annuals, when once started, spread rapidly and soon occupy all the vacant space, as they make their most rapid growth while the alfalfa is practically dormant. A bad infestation may greatly stunt the spring growth by robbing the crop of plant food and moisture, and may in addition render the first cutting of hay almost worthless.

Many alfalfa growers have attempted to reduce the winter annuals by cultivation, the only known practical way of keeping these weeds in check. This procedure has met with but little success in most cases, because the job has not been done at the proper time and done thoroughly. The spring-tooth harrow is the best implement for the purpose, and the cultivation should take place in late January or February after the weed growth is well started. The field must be gone over repeatedly until all of the weeds are dug out. Going over the field once, as is usual, will rarely get all of the weeds, and in many cases is wasted effort. The drastic cultivation necessary to destroy the weeds will, obviously, injure many of the alfalfa plants; but given favorable growth conditions most of them will recover and grow much more vigorously than with the weeds present. The only condition under which cultivation may not be advisable is where such diseases as bacterial wilt and crown wart are present, for the cultivation, by injuring the plants, will greatly facilitate the spread of these diseases. Recently, attempts have been made to control winter annuals with mechanical burners, with results that promise well if suitable equipment is developed. The method is, however, still in the experimental stage.

Most of the summer annuals, crab grass and water grass for instance, occur only where the soil is continually moist. They are troublesome, therefore, only in fields where unfavorable soil conditions necessitate two or three irrigations for cutting. Attempts to eradicate such weeds by cultivation have been unsuccessful, as heavy summer cultivation is likely to injure the alfalfa. The best remedy for such weeds is crop rotation, or correction of the unfavorable soil condition, to lessen the need of frequent irrigation.

Bermuda grass is the weed pest most troublesome to alfalfa in many sections of the state. From a small beginning, it spreads in ever-widening areas until in a few years it may occupy the whole field and greatly reduce the yield of alfalfa, which can compete with it successfully for plant food and moisture only under the best conditions. Bermuda grass cannot be removed economically from the alfalfa field. The only practical remedy is crop rotation. An alfalfa field really badly infested with Bermuda grass rarely repays cultivation. The best procedure is to plow it up and eradicate the pest as completely as possible before again seeding to alfalfa. After shallow plowing in August or September, all of the Bermuda plants being carefully cut off and the exposed roots left to dry and perish, the field should be left without further treatment until late fall or early winter, when it should be deeply plowed in preparation for future crops. Two or three years should elapse before again seeding to alfalfa, and the summer crop should be of a kind that permits cultivation and provides further opportunity to destroy such Bermuda as reappears.

Parasitic Weeds in Alfalfa.—The dodders are typical plant parasites. Starting from a seed, the yellow, leafless vines soon attach themselves to the alfalfa plant, after which their roots die and they grow entirely by extracting nourishment from the alfalfa. From a local infection, the parasite spreads rapidly by the elongation of the vines, usually appearing in rapidly spreading spots and, as a rule, greatly reducing the growth of the alfalfa plants or completely destroying the stand.

Of the various species of dodder, the small-seeded is the most prevalent in California, although others also occur. One species, prevalent on native vegetation, will also attack alfalfa; but apparently it does little damage.

Dodders are good examples of seed-borne weeds. The pernicious species are nearly always introduced into the fields with the alfalfa seed. For this reason dodder is emphasized as an impurity in alfalfa seed. The parasite, after appearing in fields, produces an abundance

of seed which may remain viable in the soil for many years. Several years of rotation are, therefore, usually necessary to eradicate a bad infestation; but a lighter case is remedied with ease, preferably by spraying the area with oil or kerosene and burning. This is better practice than mowing prior to treatment, for it involves less danger of spreading the dodder with the mower or scythe. In young stands the alfalfa plants may also be destroyed in this way, but in stands a year old or more the plants will not be injured. The spots should be carefully watched for a recurrence of the parasite. In generally infested fields the best procedure is to plow up the alfalfa and rotate with other crops for two or three years.

WEEDS IN ORCHARDS AND VINEYARDS

Weeds in orchards and vineyards may not be evidence of careless farming. They are not always an unmitigated evil. In fact, certain annual weeds are employed as a covercrop, and may even wisely be allowed to seed themselves. However, pernicious annuals such as Russian thistle and star thistle in the orchards or vineyards should not be allowed to come into seed, but should previously be plowed under or disked in. Such annuals employed as a covercrop in orchards may be relatively harmless to the orchard but dangerous to adjacent cultivated fields. Perennials, on the other hand, particularly morning-glory, hoary cress, Russian knapweed, Bermuda grass, and Johnson grass, should not be allowed to gain headway in an orchard or vineyard nor employed as covercrops; they provide a too dangerous source of infestation of adjacent fields and waste places.

The most important purpose of cultivation of orchard and vineyard soils is certainly to remove weed competition. This point has been well emphasized in a recent circular by Veihmeyer and Hendrickson.[4]

Different experiment stations have conducted numerous experiments to measure the yields on tilled and untilled plots. Areas in which weed growth has not been a contributing factor show no increase in yields which can be attributed to stirring the soil. In fact, the conclusion that cultivation is needed only to remove weed competition is almost unanimous.

As a result of these findings, many fruit growers have materially changed their method of soil management during the past several years and have allowed weeds to grow for long periods. Considerable

[4] Veihmeyer, F. J., and A. H. Hendrickson. Essentials of irrigation and cultivation of orchards. California Agr. Ext. Ser. Cir. 50:1–24. 1930.

saving has been made because much less frequent cultivations are given and tillage is shallower than formerly. It must, however, be pointed out that weeds in an orchard or vineyard may compete so seriously for water and soil nutrients as to make their removal imperative. In the eastern states, as well as in England, sod in an orchard has sometimes proved very injurious to the growth of trees, most likely through the reduction of nitrates, which should in such cases be added to the soil.

Weeds often harbor insect and fungus pests and may, in orchards and vineyards, be a source of infestation of neighboring crops; consequently clean cultivation, even though unnecessary to conserve moisture, may be needed to destroy the weed hosts of pests.

Evidently, therefore, as far as weeds are concerned, cultivation in orchards is advisable and perhaps necessary when weed growth becomes a serious competitor for soil moisture, when pernicious weeds threaten neighboring fields, and when the weeds harbor dangerous insect or fungus pests.

For the control of morning-glory and other perennials see the sections describing these specific topics. Note again that certain arsenicals, chlorates, and carbon disulfide, if used at all, must be applied with considerable precaution in orchards and vineyards.

WEEDS IN LAWNS AND GOLF GREENS

There is no easy royal road to the eradication or even the control of weeds in lawns and golf greens. In the first place, extreme care should be taken when establishing a lawn to have a well-prepared seed bed and the best and purest grade of lawn grass seed obtainable. A well-established lawn, properly watered, mowed and fertilized, will develop a solid turf which dandelions and other weeds cannot easily invade. However, even in the best cared-for lawns these pests may make their way. In a small lawn probably the most practical method of weed control is digging after heavy rains or irrigations, when the entire root of the dandelion and plantain can be pulled out with a suitable tool. Another method is to apply about one teaspoonful of gasoline or kerosene in the crown of each plant by means of an oil can. Even more effective are Diesel oil or carbon disulfide. If stronger herbicides, such as those containing sodium arsenite, are employed, a few drops in the crown of the plant will be effective. Recently ammonium sulfate has been employed with some success in killing plantain and dandelion in lawns. As much of the chemical is applied to the crown of each plant as can be held between the fingers and

thumb. One, who has employed this method, says: "Weeds so treated die quickly and completely. The grass surrounding the weed dies also. Shortly the growth of the grass bordering the circle is tremendously accelerated so that within a few weeks the whole bare spot is covered with a thrifty growth of grass." Usually herbicides applied as stated penetrate and destroy the entire root, unless it is exceptionally large. Remember that any portion of a dandelion root left alive in the soil will sprout. Herbicides applied in the crown of the plant may kill a small area of grass immediately surrounding the dandelion, but such an area is usually covered over with grass.

As a rule, the best procedure in treating an old lawn heavily infested with Bermuda grass, dandelions, and other weeds is to spade or plow it up, rake out the roots of weeds, fertilize well, and reestablish the lawn. A small infestation of Bermuda grass in a lawn, if detected soon enough before it has seeded, should be dug up to a depth of 12 to 18 inches, well beyond the limits of growth laterally, and the soil removed and replaced with new soil.

A practical spray material sometimes successfully used in killing dandelions in lawns is iron sulfate (also known as "copperas" and "green vitriol"). This spray has not, however, been thoroughly tested out under California conditions. The procedure described has brought the most satisfactory results in certain eastern and Rocky Mountain states. Prepare the spray solution by dissolving 1¼ pounds of iron sulfate in each gallon of water, and apply it in the form of a fine mist forcibly driven down into the crown of the plant. Some form of spray pump is preferable to a sprinkling can. For small lawns use a portable compressed-air sprayer or knapsack sprayer; for large lawns a type on wheels. Do not put the iron sulfate solution in galvanized iron, tin, or iron vessels. Use brass fittings throughout. When applied as a fine mist, a gallon of solution will cover from 370 to 380 square feet of yard surface.

Apply the spray on a calm day when there is little probability of rain within 12 to 24 hours. The results appear to be the same on a clear or a cloudy day. Several sprayings are necessary during the season. In New York "the best results were secured when the first application was made in early spring after the central blossom buds were formed, but before blossoming. The first application should be followed by two or three later ones at intervals of three to four weeks during the spring growing season, and one or two others in late summer or fall. The last application should be made late enough in the summer or fall to prevent the plants from recovering before the close of the growing season." In Colorado, "the most effective results

have generally been secured in late summer and with the application of not less than three sprayings." The number of applications and the most favorable times under the different climatic conditions of California have not been ascertained.

After spraying, the grass will be brown, but in a few days it will become green again. The spray material discolors the tips of the grass blades. It also kills lawn clover and other plants with broad leaves. A lawn suffering from lack of water will, apparently, be injured more by the spray than one well watered and growing vigorously.

The principle behind the spray method of killing dandelions is this: The dandelion root is perennial; it is filled with stored food; any portion of it is capable of sprouting a new plant, even if the crown is destroyed; repeated applications of the spray, with repeated killing of leaf growth, forces the plant to use up the reserve food in the roots, and thus finally exhaust them. Hence, the spray must be applied often enough to exhaust the root. Obviously, very young dandelions with small roots will be destroyed by fewer sprayings than old dandelions with large roots and a large food reserve.

Remember that iron sulfate solution, a strong corrosive, will leave rust stains on the walls of buildings, on cement walks and curbs, and on clothing.

Besides the dandelion—without doubt the most important lawn weed—lawns encounter such other pests as common chickweed, mouse-ear chickweed, plantains, crab grass, and sorrel (*Oxalis*). The common chickweed is a low-growing, rather succulent plant, favored by excessive watering. In most parts of California it may seed throughout the year. For scattered plants the most feasible method of control is digging. Some cases have been fairly satisfactorily controlled by spraying with iron sulfate, ammonium sulfate, or sodium nitrate. In each case use 2 pounds to the gallon of water. The mouse-ear chickweed, a low perennial herb, with sticky glandular stems, is as prevalent in shady lawns as is the common chickweed and may be treated equally well by the methods described above.

The plantains in lawns being, as a rule, well scattered yield to digging or, at least, to various herbicides applied to the crown as described in the paragraphs pertaining to the dandelion.

Crab grass is a difficult annual to control. It creeps close to the ground, rooting freely at the nodes, and produces in the autumn an abundance of seed. In a newly-established lawn, careful inspection may reveal a few crab-grass plants, which, if grubbed out and prevented from seeding, will cause no trouble. If allowed to spread,

the pest can hardly be eradicated except by reestablishing the lawns. It can be controlled by spraying with Diesel oil—a treatment from which the perennial lawn grasses recover, whereas the annual crab grass does not.

WEEDS IN DITCHES AND WATERWAYS

Weeds of ditch banks have been discussed under the heading "Weeds of Non-cultivated Areas." In addition to these, many weeds grow in water, either floating or rooted in the mud, and, by seriously interfering with the flow, cut down the carrying capacity of the ditch. Most of such weeds grow and spread very rapidly, each year's growth accumulating upon that of the preceding until finally dredging, or forking out, or spading is necessary. Keeping such ditches open by mechanical means is expensive.

The only floating weed of any significance in California is the water hyacinth, a most pernicious perennial which, fortunately, has gained a foothold only in a few localities. The most effective method thus far found to control it is spraying with sodium arsenite, which may be obtained commercially prepared according to directions given in an earlier paragraph.

Common weeds rooted in the bottom of ditches are cat-tails, tules (*Scirpus spp.*), and yellow water weed, which are all perennials. The control of such weeds by chemical sprays has been given but little trial. Some ditches under observation have been sprayed with oil, a method which deserves careful trial because it seems cheaper than that usually employed. These particular ditches were sprayed three times the first year, twice the second year, and once or twice the third year. The oil does not penetrate the roots and rootstocks, but it does destroy top growth. Persistent destruction of top growth weakens and may ultimately kill the underground parts of the plants. Plants growing in the water are apparently very difficult to eradicate by herbicides; but, even so, the use of such chemicals in keeping weeds under control may be cheaper than dredging, pulling, etc.

WEEDS IN RICE FIELDS

Because of the conditions under which rice is grown, the weeds which infest rice fields are in the main different from those occurring in other field crops. The most troublesome ones grow, like rice, in standing water. After the rice has been seeded, there is no practical means of combating the weeds; and as the rice requires a long growing season,

most of the weeds mature and drop their seeds before it is harvested. As a consequence, weeds in rice fields multiply very rapidly. Three years is, by common experience, about the maximum time in which a field can be cropped continuously to rice before becoming so weedy as to render the crop unprofitable.

The weeds most troublesome in the rice fields are varieties of water grass, red stem, scale grass or sprangle top, red rice, spikerush, cat-tail, the various umbrella plants or nut-sedges of which there are several species, tule or bulrush, and arrowhead.

Up to the present time, more war has been waged on water grasses than on most of the other species. Yet the water grasses, though most prevalent, are by no means the most serious. Such perennials as the nut-sedge, cat-tail, and spikerush, reproducing by underground parts as well as from seed, are much more difficult to eradicate when once established than is the water grass.

Water grass is of two types: common, and white. Common water grass fruits abundantly, matures, and sheds its seed before the rice crop is ripe. It spreads and infests the fields very rapidly. Fortunately, common water grass and also scale grass or sprangle top can be controlled successfully by *keeping the fields flooded from the time the seed bed is prepared until the rice crop is mature.* Submerged under 4 to 6 inches of water, the seed of common water grass will not germinate. When, however, rice is drilled or broadcast and irrigated lightly for two to four weeks to bring it up before it is permanently submerged, shallow submergence at 2 to 4 inches apparently does not control the water grass. The second type, the so-called "white water grass", matures somewhat later, at about the same time as the rice, so that when the crop is harvested most of the seed is removed from the field. Although, in consequence, it does not spread so rapidly as common water grass, it cannot be controlled by flooding. Its seeds will germinate and produce plants with any submergence which will permit the growth of rice.

None of the other important annuals can be controlled by flooding, so that at present the only known method of checking them is the periodic fallow, as now commonly practiced.

The perennials are a more difficult problem. The nut-sedge, for example, is spreading rapidly and, as it may be reproduced either by seed or vegetatively by the nut-like tubers, it constitutes a real problem. It thrives equally well on moderately moist and on wet soil. Because of its vegetative mode of reproduction it is extremely difficult to eradicate by the usual methods of cultivation.

Cat-tails, likewise, reproduce both vegetatively and by seed. In the field, the weed can be controlled by proper cultivation; but a fairly dense stand, once developed, is not easily destroyed by cultivation. Once cat-tail infests the land, heavy seeding with rice apparently does not control the weed; but a heavy stand of rice does prevent somewhat the entrance of cat-tail. Plowing in the spring and thorough drying of the roots will destroy many plants. In fact, spring plowing with good preparation of seed bed aids greatly in the control of many rice weeds. Disked stubble does not, as a rule, provide a satisfactory seed bed. Such roots as remain in the soil will, however, renew growth; and cultivation must usually be repeated two to three times during the season to be most effective. Most perennials can be controlled by cultivation repeated often enough to prevent an appreciable development of the above-ground organs. The number of cultivations necessary and the time required will vary with the species. Preliminary tests indicate the possibility of controlling cat-tails and some other perennial weed pests with chlorate sprays, but the conditions necessary have not yet been fully worked out.

Destruction of weeds in rice fields will not, however, solve the rice-weed problem; equally important is the prevention of their introduction from outside sources. Weed seeds are introduced into rice fields in three ways: with the rice seed, with the irrigation water, and by the wind and other agencies from plants growing on adjacent waste or unused land.

New weeds are, as a rule, introduced first into a district with the rice seed. Thus some of the sedges now spreading in the rice area were brought in with rice seed from the Orient. Red rice is, as a rule, also distributed with the rice seed. The use of clean seed is, therefore, important in preventing the introduction of potentially troublesome weeds.

Since most weed seeds float or are readily transported by flowing water, the seeds of weeds and grasses once allowed to mature on the ditch banks soon find their way to the land under irrigation. Unsuccessful attempts to filter off such seed from irrigation water by the use of screens have shown that the amount of weed seed thus transported is enormous.

Weeds allowed to grow on levees and waste land adjoining the fields constantly produce seed for re-infestation of the cultivated areas. Seed of the cat-tail, for example, is readily disseminated by birds, animals, or mechanical agencies. Any plan, therefore, for the control of weeds in rice fields must seek to prevent the introduction of weed seed from outside sources.

PUNCTURE VINE[5]

Puncture vine, which has been known in California since 1903, was introduced some years earlier. It appeared first along the railroads but spread rapidly through the state with the increase of automobile travel. Although automobile tires have been the principal means of dissemination, it is also carried by animals, by various crops and products, and by almost any object with which it comes in contact.

The damage done by puncture vine consists principally of mechanical injuries to persons and animals; increased operating costs in the production of crops; diminished value of land and of crop and livestock products; and limitation of markets for infested products. Authentic cases of direct injury to livestock from the feeding of infested hay are rare, but cows are said to fall off in milk production when first fed hay containing large quantities of puncture vine burs. A disease of sheep in South Africa is reported as caused by grazing on this weed. Contrary to a rather general belief, puncture vine injures very few tires except those light in construction or worn thin.

The longevity of puncture vine seed is not known. A plot on which no seed has matured for the past eight years has continued to sprout seed each season in undiminished numbers. When more than one seed is present in a bur, the uppermost usually germinates first; but under favorable moisture and temperature conditions, the others can be made to germinate the same season. Observations on a plot maintained under natural conditions for a period of four years showed that 90 per cent of the total number of plants for any season had sprouted by July 15; that the total number sprouted was greatest in those seasons when the May and June temperatures were highest, those being the only months of sufficiently high temperatures when favorable soil moisture conditions were present; that summer rains increased the rate of germination, whereas fall rains, after the mean temperature has dropped, had no apparent effect—nor did the total seasonal rainfall.

The relation between temperature and germination was further established by laboratory tests. Burs incubated at day temperatures of 95° F and night temperatures of 70° invariably showed a higher rate of germination than burs incubated at day temperatures of 86° and night temperatures of 70°.

[5] This account was prepared by Mr. Ethelbert Johnson, Deputy Agricultural Commissioner, Orange County.

The period from blossoming to maturity is very brief during the season of rapid growth. Burs picked less than 10 days from the time of blossoming failed to germinate, but a large percentage germinated when permitted to remain on the plant 10 days or more.

Puncture vine seed apparently requires a resting period after maturity before it will germinate with normal rapidity. When tested one or more seasons after maturity, more than 90 per cent of the total viable burs germinated within the first 3 days of incubation, and practically all germinated within 10 days. In tests made the same season as the burs matured, germination could be induced only with difficulty in the first 60 or 90 days, and was, in most cases, not completed for 200 days or more. If the plant is killed or the burs are picked before the natural ripening process is complete, germination is accelerated, apparently through an interruption of the physiological processes which are responsible for the resting period.

The approximate viability of puncture vine seed can be estimated by its appearance. If the burs are soaked over night in water and cut open, the number containing apparently sound seed checks fairly closely with a laboratory germination test of the same sample.

Since 1925 California has made a more or less concerted effort to control puncture vine, except in a few counties now considered too badly infested. The total amount expended by the counties since 1927 has averaged about $160,000 a year, not including expenditures by the State Highway Commission, the railroads, and individuals. Most of this sum has been expended for spraying with chemicals. Although orchard spraying equipment may be used satisfactorily for this purpose, special equipment adapted for weed spraying has also been developed.

The treatment of products infested with puncture vine to make them acceptable in districts where the pest is under control has presented a difficult problem, especially with reference to bulky materials. Alfalfa meal from infested hay, if milled by the ordinary process, is found to contain viable seed; but a process which passes the meal through a mesh not greater than 1/32 inch has been developed, in the finished product of which no viable seed can be found.

Composting of infested manure is suggested for the destruction of puncture vine seed. A process to destroy weed seeds in straw and other organic refuse without impairing the value of the material for fertilizer has been tested with success as to the material in the interior of the compost, the exterior not being sufficiently decomposed.

For the control of growing puncture vine, cultivation and cutting are satisfactory methods if used often enough to prevent seed forma-

tion. Heat, as from a weed torch or from live steam, may be used to destroy puncture vine, and is especially valuable after chemical treatments. Firing of dead plants without the aid of a weed torch or oil spray will not destroy the burs. Burning of green plants without previous treatment is considered too slow and expensive to be practical.

The chemicals now most valuable for the control of puncture vine are sulfuric acid, arsenic compounds, chlorates, and petroleum oils.

Sulfuric acid (2 per cent solution) makes a very cheap spray for puncture vine, but does not destroy the viability of the seeds. Arsenic compounds also effectively destroy the plants, but not the viability of the seed unless in high concentrations. Arsenic acid and arsenic trichloride, when used in dilute solutions as sprays, do not injure the soil. Sodium arsenite and arsenious acid are the cheapest known sprays suitable for soil sterilization.

Although chlorates have not been extensively used for puncture vine control, because of their comparative costliness, the few tests reported indicate that they will kill the plants of puncture vine and destroy the viability of a considerable proportion of the burs, at least in some stages. Tests on burs in various states of maturity have not been made. Chlorates, even in dilute solutions, appear to have an injurious effect on the soil and to inhibit germination of weed seeds remaining in it. This effect is probably not so permanent as with arsenical sterilizers, which are very much cheaper.

Petroleum oils have been used more extensively and more successfully on puncture vine than all other chemicals combined. The commercial product known as Diesel oil is more satisfactory for the purpose than other grades because of its low cost, its high proportion of unsaturates, and its ability to emulsify with water when the asphaltum content lies within the range of 2 to 5 per cent. Petroleum oils of various grades have the property of penetrating the burs of puncture vine and killing the seed as well as the plant. The oil possesses this property even when in emulsion with water under certain conditions. The effectiveness of oil in destroying seeds depends on the completeness of coverage in application.

Summarizing, the methods that have proved to be the most satisfactory and economical for the control of puncture vine can be stated as follows: (a) For tillable areas: shallow cultivation whenever plants appear and before burs form, supplemented by hand work, if necessary. The soil moisture should be maintained at the optimum during the summer months to encourage sprouting of seeds remaining in the soil. (b) For non-tillable areas: spraying with oil, preferably fol-

lowed by burning, if burs have formed; or with any cheap chemical weed killer, if no burs have formed. If sterilization is not objectionable, treat the soil with arsenious acid after removal of vegetation.

MORNING-GLORY

The common or wild morning-glory, without question the most serious and most pernicious weed in California today, infests every county of the state where agriculture is extensive. It invades our choicest land, and so far has defied all efforts to depose it. The presence of morning-glory may not be, therefore, an indication of poor farming.

Characteristics of Morning-glory.—Morning-glory is a perennial which renews its growth from year to year from its underground stems and roots, and through the spread of these subterranean structures rapidly widens its area of infestation. It ordinarily starts in a field from seed introduced in one way or another. Although the tender seedling can easily be destroyed in its early stages, it soon develops a large root in which it stores a reserve of food material, so that the plant is able to regenerate itself by development of adventitious buds from the root when the top is destroyed.

The root of the plant will, under favorable conditions, develop to enormous size and penetrate the soil to a distance of many feet, limited mainly by the depth of the soil. The main root underground throws out stems which send new shoots to the surface, so that the plants spread vegetatively in an ever-widening circle. Seed which is produced in abundance, rapidly increases the infestation and is, in fact, the most important means of dissemination. From a small area the pest can quickly be spread over a field by the tillage implements, which drag vines bearing mature seed. The underground stems, which are torn loose by the implements and carried for considerable distances may, if embedded in moist soil, also start a new infestation; but the spread in this way is small compared with the spread by seed.

The seed of the morning-glory probably retains its viability in the soil for many years, and although data on *Convolvulus arvensis* are not available, in trials with *Convolvulus sepium,* a closely related species, in which seed was buried at depths of 8, 22, and 42 inches, the seed showed a germination of 27, 41, 43 per cents respectively after 20 years. Where morning-glory has become established, therefore, one must not only destroy the established plants but also remain vigilant to prevent the recurrence of the pest from seed which has lain dormant in the soil.

Control of Morning-glory.—Although the control of morning-glory has received attention for many years, no very satisfactory or economical method has yet been devised. Experiments show that the pest can be kept in check and even almost completely exterminated, but only with a considerable expenditure of time, labor and money; nor is it likely that any easy or cheap method will be found.

Morning-glory has been attacked by three methods: (1) cultivation, (2) smothering, either with a smother crop or with non-living material, and (3) chemical herbicides. All three methods are useful, and often a combination of two or three of these methods may be found most feasible. Some attempts have also been made to control morning-glory by pasturing and by flooding, with varying degrees of success; but such methods are, at best, applicable only to special conditions.

Control by Cultivation.—The numerous attempts to eradicate morning-glory by cultivation have met with some success and many failures. Poor results can be attributed to brief or careless treatment. One principle to be scrupulously followed in eradicating perennials by cultivation is that the development of the green leaves must be prevented. A second rule is to continue cultivation until the reserve food material is used up in new growth, or until underground parts are starved to death. Poor results are, undoubtedly, usually attributable to failure to prevent leaves from developing, for only a small leaf development will soon manufacture and store in the root sufficient food material to undo the effect of several cultivations. The best procedure in attempting to eradicate morning-glory by cultivation is to cultivate at definite intervals, often enough so that no new shoots reach the light; and the work must be done religiously, like any other chore such as milking the cows. Come what may, every Monday morning the morning-glory patch must be cultivated, for in that way alone lies success. Just how often the field must be weed-cut will depend on the depth of cultivation, the season, the amount of reserve food in the roots, and perhaps certain local conditions. With the ordinary depth of cultivation of four to six inches, the intervals cannot be more than one week; and during the heat of the summer, when growth is most rapid, cultivations must be more frequent. Observations at Davis, California, have shown that during July and August shoots from plants cut off at a depth of 16 inches will reach the surface in 10 to 12 days. Cultivation must begin in the spring as soon as growth starts and continue until it has definitely stopped in the late fall or early winter. On shallow soils or soils with a high water table, where all the root development is near the surface, less time is required to eradicate morning-glory than on soils which permit deep root pene-

tration. Under the former condition, some farmers have reported eradication of the pest in a single season. On the other hand, at Davis, California, on deep, friable loam soil, plants were still thriving and producing vigorous shoots after three years of clean cultivation. As it is on the latter types of soil that morning-glory grows most luxuriantly, eradication by cultivating is, at best, obviously a long-time procedure.

The implement most suitable for cultivating morning-glory is the straight blade weeder, kept sharp and in good cutting condition. The field should be plowed rather deeply, in the early spring, and the soil worked down thoroughly. If a deep layer of loose soil is thus provided at the start, the weed cutter can be run at the necessary depth more easily than if the plowing had not been done. When weed cutting the field, the weeder must be lapped at least 18 inches to 2 feet to insure the cutting of all the shoots. Care and eternal vigilance are the price of success in any attempt to control morning-glory by cultivation.

Control by Smothering.—Where non-living material, such as tar paper and straw manure, has been used to control morning-glory, the efforts have mostly met with failure. Tar paper, if properly lapped, has proved effective for small areas; but one must watch the treatment carefully and see that the vines do not grow out between the layers of paper. The principle involved in smothering the plant with paper and other materials is the same as in the control by cultivation, namely, the prevention of the formation of green leaves, thus forcing the plant to use up its reserve material in developing new shoots. Efforts to smother morning-glory with organic materials, such as straw and manure, have uniformly failed.

Of the smother crops, a good vigorous stand of alfalfa, kept well watered, is best and will greatly reduce, though not entirely eradicate, the growth of morning-glory. Experience shows that if the field is kept in alfalfa four or five years, morning-glory will be so reduced in vigor that other crops can be grown for a couple of years at least before the weed increases so greatly as to render cultivated crops prohibitive. The use of alfalfa, followed by cultivation or by some of the chemical treatments, will in the long run probably prove most effective.

Control with Chemicals.—The attempts to eradicate morning-glory with chemical herbicides have been met with varying degrees of success because of a lack of knowledge as to the method of absorption of the chemical by the plant, and of the physiological and environmental conditions most favorable to absorption. Even yet, knowledge on some of these points is extremely meager; but certain conditions of growth and environment are now known to be necessary for success.

The chemicals most widely used and most likely to prove successful in the control of morning-glory are carbon disulfide, arsenicals, and chlorates. The principal arsenical on the market used in morning-glory control is sold under the trade name of "K.M.G." The nature and methods of application of these herbicides are given in sections under these headings.

As regards sodium arsenite, one should note that while this material effectively destroys vegetation, it is only partially successful in the destruction of perennials, such as morning-glory. Some years ago extensive experiments with solutions of sodium arsenite for the eradication of morning-glory gave fair results near the coast, where the humidity is relatively high; but there was failure to secure satisfactory results in the interior valleys where the humidity is low. Since that time considerable work has been done with solutions both of sodium arsenite and of arsenic acid. Arsenious acid seems to be absorbed more rapidly by morning-glory than is sodium arsenite. Recent investigations have also thrown more light on the conditions necessary for good results with solutions of arsenic and explain in part the early failure to secure satisfactory results away from the coast.

In order to eradicate morning-glory with arsenic sprays, at least three conditions are necessary: (1) the plants must have a good vegetative growth and be fairly mature, having reached at least the blooming stage; (2) the soil must be dry to a depth of several feet; and (3) the rate of evaporation must be low.

As the plant approaches maturity, a negative pressure develops within its tissue which greatly aids the transportation of the arsenic solution into the roots of the plant. Young, succulent plants which have not developed this negative pressure will, if sprayed, be killed to only a few inches below the surface of the ground. A mature plant, on the other hand, with soil conditions favorable, may be killed to a depth of four or five feet or more. A dry soil from which the plant can absorb moisture but slowly is a necessary aid in maintaining the negative pressure in the plant, thus hastening absorption.

A low rate of evaporation is desirable so that the solution may remain in the leaves and stems of the plant for a longer period and provide greater opportunity for the absorption of sufficient arsenic to kill the plants to a considerable depth. Apparently once the arsenic has dried on the tissue surfaces, it is rendered impotent and cannot be absorbed further by the plant. In applying arsenic sprays with ordinary types of sprayers one must use an outfit capable of developing a pressure of at least 100 pounds, so that the spray will be applied in a fine mist. Less pressure, however, is necessary with the com-

pressed air type of sprayer. All leaves and stems must, furthermore, be thoroughly moistened with the spray.

In experiments on morning-glory with arsenic sprays, for the most part with a commercial acid preparation, the best results have been obtained by applying the spray in the fall, October or November. The reason probably is that this season of the year offers a better combination of the necessary physiological and environmental conditions than any other. Although some fair results have been obtained, a single application has never given complete eradication. In fact, complete eradication probably cannot be effected with a single application of any spray except one which will sterilize the soil for a considerable period. Invariably some plants will be killed only to a comparatively shallow depth, and will develop new shoots that will eventually reach the surface. Again, on most of the land infested with morning-glory, the soil is loaded with seed, which will quickly renew the stand if special effort is not made to destroy the seedlings as soon as they appear—an impossible procedure unless the land is kept idle. Just how many applications of spray will be necessary to eradicate a patch of morning-glory completely has not been determined. Certainly, however, several applications will be required, over a period of years.

The physiological and environmental conditions necessary for success with chlorates are apparently the same as for arsenic. Work done thus far with morning-glory has produced satisfactory results only when spray was applied in October or November to plants of good vegetative development, in bloom, and on comparatively dry soil. Spraying during the spring or summer, or on young and succulent growth, or on moist soil, has simply destroyed the tops without permanent injury to the plants. To secure a good kill, 450 to 500 pounds of sodium chlorate or its equivalent must be applied per acre. Smaller amounts have given unsatisfactory results. As with arsenic, one application has failed to give complete eradication. How often the treatments must be repeated has not been determined. On the other hand, the effect of the chlorate, less transitory than is that of the arsenic, will last over a considerable period of time—partly, no doubt, because the chlorate may be absorbed through the roots as well as through the leaves, with injurious results to the plants. Applications of the salt in sufficient quantities to give a good kill will render the soil sterile for some time. Carbon disulfide properly applied will effect complete eradication, but the cost is usually prohibitive.

In conclusion: although the use of herbicides offers a most promising means of eradicating morning-glory, good results cannot be obtained

without due attention to the stage of growth, the conditions of the plants, and the environmental conditions at the time the spray is applied. No chemical is likely to be found, a single application of which will eradicate morning-glory completely and at the same time be practical. Chemicals now available are, it is true, too expensive for general use on large areas. More information is necessary as to the best conditions for the application of herbicides. At present the result of any one application cannot be predicted and until this uncertainty is removed the farmers cannot be expected to spend large sums of money for spray material, which may be largely wasted.

JOHNSON GRASS

(The reader should consult the section on the principles of weed control in connection with the discussion on Johnson grass.)

Johnson grass, first introduced as a forage plant, has become one of our worst weed pests. It is a prolific seeder, and a single plant, by producing numerous underground stems which in turn develop many new shoots, can soon make a large infestation.

The first step toward control is to prevent its spread by seed. To do this, cultivation on areas that can be so treated, mowing, hand cutting, or oil may be employed. Cultivation, if practised, should not extend beyond infested areas, for portions of the roots may be carried to non-infested parts and thus spread the pest rather than control it. On rather inaccessible areas, such as fence rows and ditch banks, the use of stove top or Diesel oil is probably cheaper, as the area can be covered in less time and with much better results than with any time of cutting. In a few cases, where Johnson grass was sprayed with oil during hot summer days, the oil has penetrated the underground stems as deep as eight inches and has thinned heavy infestations more than 50 per cent. The number of applications of oil depends greatly upon the growing conditions of the plant. Where, for example, plenty of moisture and good soil are available, Johnson grass is more difficult to kill than under dry and unfavorable soil conditions.

Many different herbicides have been tried in an attempt to eradicate Johnson grass. To date, the chlorates appear to be the most promising. "Atlacide" (calcium chlorate) has possibly been used more widely in this state than has sodium chlorate. One pound of chlorate to 1 gallon of water should be thoroughly applied as a fine spray to plants in full bloom or in the soft seed stage. Remember that plants treated with chlorates should not be mowed or burned, but should be allowed to stand in the dry condition until the following spring, when they

may be burned. On small areas Johnson grass is very effectively treated with carbon disulfide.

Johnson grass and Sudan grass are often confused, and frequently Sudan grass is infested with Johnson grass. In fact, the State Seed Laboratory finds that practically every sample of Sudan grass examined contains Johnson grass seed as an impurity. Johnson grass is readily distinguished from Sudan grass by the presence of rootstocks, which, in turn, differ from roots in having joints.

Camel's Thorn

(The reader should consult the section on the principles of weed control in connection with this discussion.)

Camel's thorn, a comparatively new weed pest in California, is thus far confined to certain limited areas in Imperial, Riverside, Kern, Kings, Merced and Fresno counties. Certain characteristics make it a most pernicious weed, and a very strenuous effort should be made to prevent its spread and to bring about complete eradication in these limited areas. The plant is browsed by animals and the seed has been spread to great distances by the movement of animals from one locality to another.

The thorny, semi-woody plant produces an enormous number of seeds. In addition, the roots may go to a depth of 10 or 12 feet and spread laterally as far as 25 feet to 40 feet; such laterals may send up new shoots.

Wholly satisfactory and practical control methods have not been found. The most satisfactory of those employed have been cultivation, carbon disulfide, and smothering by flooding. Experimental plots on which other herbicides are being used are now under observation.

Russian Knapweed

(The reader should consult the section on the principles of weed control in connection with this discussion.)

Russian knapweed was introduced into California about 1912 in impure sugar beet seed or Turkestan alfalfa seed. Since that time it has spread throughout the state by natural as well as artificial means. It is a pernicious perennial, very similar in its weed habits to morning-glory, Johnson grass, and hoary cress. Once established, it spreads very rapidly, especially on cultivated areas where portions of the underground parts are carried by cultivating tools. The spread by seed is not so rapid as in many other weeds because the seeds are

borne in a cup-shaped head which does not open readily at maturity; ready dispersal by wind is thus prevented.

Russian knapweed is one pest that deserves the serious attention of Californians, for wherever it spreads it works great crop injury. The methods of control mentioned under perennials apply here. Carbon disulfide is completely effective in its control. The chlorates have also given good results. Russian knapweed is, in addition, more susceptible to arsenicals than is the morning-glory.

HOARY CRESS

(The reader should consult the section on the principles of weed control in connection with this discussion.)

This weed, which made its appearance in California about 1907 in the Pajaro Valley, appears to have come originally from seed occurring as an impurity in alfalfa and lawn grass seed.

Hoary cress is a perennial which makes its first appearance early in the spring, often maturing by the last of May. Its underground stems are even more persistent than those of morning-glory. It appears to grow best in the coastal regions or where there is considerable moisture. Although found in the drier sections of the state, it does not grow there so vigorously, possibly because of its inability to withstand drought.

Thus far, carbon disulfide is the only chemical that has proved at all satisfactory, although it has sometimes failed. One very dry area on which hoary cress was found was treated successfully with "Atlacide" (calcium chlorate). Many other areas throughout the state which have been treated with the chlorates are yet in the experimental stage.

WILLOWS

The banks of ditches, levees, and drainage canals often become overgrown with willows. Gradually encroachment of the plants upon a waterway will greatly reduce its carrying capacity. Much money is spent in an effort to control willows, especially by hand cutting which, however, usually results in a thicker stand the following year and must necessarily be repeated annually.

Chemicals have been tried to some extent. Common salt is effective when applied in sufficient quantities. It requires approximately 10 pounds to an average-sized clump of willows. Usually the willows are so thick that a solid ground cover of the salt is necessary—about 250 pounds to each square rod, or 18 to 24 tons to the acre. In the

few instances where the chlorates have been tried as a foliage spray, a root penetration on some of the plants was distinctly noticeable, and in some cases complete eradication has been obtained. The observations were made on plants treated with one pound of chlorate to a gallon of water. The results of a follow-up of applications have not been seen.

On small areas, carbon disulfide is very effective. One to two cups injected around the roots of individual clumps will kill the root system.

BERMUDA GRASS

Bermuda grass, widely used as a pasture and lawn grass in the south, has now spread from these areas and rather generally infested the central and southern parts of California. Its ability to withstand heat and dry summer conditions makes it one of our worst weed pests.

Many chemicals have been unsuccessfully used in an attempt to control and eradicate this weed. Occasional treatments have been sometimes encouraging, but more often a failure. Heavy applications of chlorates made in late summer have proved promising. Wherever Bermuda grass infests ditch banks, roadsides, or non-cultivated soil, sterilization of the soil as described in a preceding section is the best method to follow. Crop rotation and clean cultivation have sometimes proved fairly successful. As this grass cannot withstand dense shading, a rotation system which includes a crop such as Sudan grass or cowpeas, or an inter-tilled crop, followed by grain, and then a heavy seeding of alfalfa is recommended.

REGULATORY PHASES OF WEED CONTROL[6]

In spite of a general recognition that a particular agricultural pest needs control or eradicative attention, there are those, fortunately only a few, who are negligent of their responsibility to others and do not take the advisable steps either toward suppressing the particular pest or preventing it from spreading; hence, there comes a demand for laws and regulations to compel the negligent to cooperate with his neighbor or with the community. It would be better not to need laws for weed control but unfortunately we seem unable to do without them.

Whenever they become a necessity, they should be responsive to three phases of need: (1) To prevent introduction of any new and serious noxious weed pests; (2) To give authority to responsible official

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agencies to eradicate any new or limited infestations of noxious weeds; (3) to provide authority for the abatement of any noxious weeds against which there is continual or active warfare and against which recalcitrants do not take the necessary steps to cooperate.

We find that the legal expedients available, in the main, are within the above three categories with as many variations as there are states and counties. Certainly, a primary phase of suppression should be to prevent entrance into a country, state, or even county. This means that there should be federal recognition of this need even before the states. So far, dodder seems to be the only weed pest which has claimed the distinction of federal recognition. If noxious weeds are to be ignored in seed shipments from other nations, and if the apparent policy of allowing a tolerable amount of weed seeds in such importations is not modified, American agriculture is faced with a continuous hazard and we will have more camel's thorn and Russian knapweed cases to cope with. Another very important means of acquiring undesirable plant immigrants is through new plant introductions. A plant or shrub seemingly of real value for ornamental or even forage purposes may develop noxious tendencies in a new environment and under the different climatic conditions prevailing in the place to which it may otherwise seem well adapted.

However, our immediate concern is: What has California accumulated in the way of regulatory measures affecting noxious weeds? To go back in history, we find that a new country must look to outside sources for seeds and planting stock. Of course, weeds are bound to be stowaways and unless detailed inspection is provided they will land. A country with wide divergences in climate and soil offers a fertile field for establishment. When large land holdings were the order, weeds were taken as undoubted evils but generally as necessary evils. Should one patch of ground become abnormally weedy, it was not difficult to transfer operations to another patch not so involved.

The first law passed by the legislature affecting weed control appears to have come in 1903 and was specifically directed to the eradication of Johnson grass. Since then and up to the present time, more specific authorities have been added.

It is obvious that every weed could not be considered noxious because some of them were reasonably desirable as covercrops. If we ignore the rôle which such covercrop weeds might play as harborages for injurious insect pests and plant diseases detrimental to commercial plantings, we might say they were of benefit. Hence, one of the original and practical necessities was to give us a good definition of a *noxious weed*. It apparently took years of study to determine this

and the 1929 legislature gave us the authority (Subsection *c* of Sec. 2322*e*, pol. Code) to consider any plant by its nature determined to be detrimental to agriculture, including the seeds of such plant, as "noxious". Probably it must be determined ultimately by the court whether or not a weed aspires to the category—"noxious". However, those generally concerned with the problem of weed control or eradication understand what this term really means.

There are actually available now on the statute books of the State of California the following authorities and provisions relative to weed control which appear to be operative:

To Prevent the Introduction and Spread of Noxious Weeds—

(a) Section 2323 of the Political Code gives authority to hold, after written notice, any commodity found to be actually infested with noxious weed seed on the ground or at the place encountered until it is cleaned of the weed to the satisfaction of the county agricultural commissioner. (Similar authority is found in subsection 2 of 2319*c* and subsection 8 of 2322*a* of the Pol. Code.)

(b) This same section (2323) provides that if a shipment originating in any locality of the state or in another state or foreign country is found, upon inspection, to be infested with seeds of noxious weeds not of common occurrence at destination, it may be rejected and returned to point of shipment within 48 hours upon notice, provided that if the seeds of the noxious weeds can be destroyed by a treatment such as to make the shipment safe, same may be delivered.

(c) The authority granted the director of agriculture to prescribe rules and regulations to prevent the introduction of noxious weeds is similar under his quarantine authority as applicable against injurious insect or animal pests or plant diseases. (Sec. 2319*b*, Pol. Code.)

(d) The Weed Free Area Act (Sec. 3) can provide against the transportation of the seeds of any specific weeds, for which a weed-free area has been declared, into the area proclaimed.

(e) The County Agricultural Commissioners Act, in Section 2322*h* of the Political Code, provides for the rejection of shipments infested with noxious weeds after the same fashion as shipments of nursery stock or other plant products or commodities susceptible to infestation or infection, as holds true in the case of insect pests and plant diseases.

Eradication of Limited Infestations—

(a) In Section 2322*a* of the Political Code it appears as a function of the county agricultural commissioner to make inspections of areas where infestations of noxious weeds might exist and to provide for the abatement of same, the practice generally being, in the case of weeds of very limited occurrence, to utilize eradication procedure.

(b) The Weed Free Area Act provides (Sec. 4) that it shall be unlawful to permit any weed named in a proclamation establishing a weed-free area to continue to propagate itself or go to seed in such area. This is helpful in areas where weeds named are of very limited distribution or are new to the area proclaimed.

(c) There is an authority (Sec. 2319*a* Pol. Code) for the State Department of Agriculture to enter into cooperative agreements with boards of supervisors and other official state and federal agencies for the purpose of controlling or eradicating noxious weeds dangerous to the agricultural industry of California.

(e) An area of limited infestation of a particularly serious and injurious weed pest can, if necessary, be circumscribed by quarantine lines (Subsection 1, Section 2319*c* Pol. Code) for extermination or prevention of spread purposes.

General Abatement Procedure Against Noxious Weeds—

(a) In the County Agricultural Commissioners Act (Sec. 2322*a* Pol. Code), wherein abatement notice is served upon an owner, the particular noxious weed being specified in the notice, and if action is not taken by the property owner within the time specified, the county agricultural commissioner has authority to proceed, the costs of such abatement becoming a lien upon the property. This, of course, should be used only in the case of areas where the community in general has provided for a continuous or active campaign against noxious weed species and where there are negligent property owners or recalcitrants who must be compelled to clean up; and

(b) The 1929 legislature gave authority, under Chapter 457, to authorize counties to declare noxious or dangerous weeds growing upon streets or sidewalks or even upon private property to be a public nuisance. It becomes necessary in this case for the governing board of the county to refer to the area infested, describing the property and authorizing the county agricultural commissioner or the county board of forestry or such other officer, board or commission as designated by the board of supervisors in the resolution to post notice, and in the event that no action is taken by the property owner, abatement may be proceeded with by the officer designated and the costs included on the bill for taxes and collectable at the same time and in the same manner as ordinary county taxes collected; also

(c) Under Subsection 6 of Section 4041 of the Political Code, pertaining to the general permanent powers of boards of supervisors, authority is given to provide for the destruction of noxious weeds along with other pests, generally speaking, this authority being diverted to channels of passing a county ordinance relative to any specific noxious weed under consideration; and

(d) In general law provisions generally applicable against public nuisances.

The 1931 legislature assisted the program of weed control on ditches and canal banks through additions to the statutes in two measures:

1. Under the Irrigation District Improvement Act by authorizing the organization of improvement associations for weed control purposes, and

2. By adding specific authority in the County Agricultural Commissioners Act for the service of abatement notices upon users of water from a ditch or canal not under the jurisdiction of an irrigation district, but which is used for distributing water on lands under several different ownerships: in other words the abatement provisions of the County Agricultural Commissioners Act are made applicable to community and certain types of private ditches.

There are still a few important needs in connection with regulatory measures affecting weed control: namely, improved federal regulations to prevent the introduction of noxious weed seeds in plant shipments and in imported commercial seed from foreign countries;

an improvement in seed inspection laws, both federal and state, tending toward the elimination of a permissible tolerance, recalling that one viable noxious weed seed alone is capable of starting an infestation; and, further, that for the guidance of enforcement officers basic research be inaugurated or intensified by agencies such as the U. S. Department of Agriculture, cooperating with State Experiment Stations, in some centralized manner in order that enforcement officials can devote a full share of their time to control work and not be burdened with the diverting need to engage in investigational work.

Perhaps, above all, the dissemination of sound information to aid and encourage the growing recognition of the importance and magnitude of the weed problem and its control is vital to the proper application of regulatory measures.

In the main, the above covers the authorities and provisions available for the enforcement or compulsion of weed control measures and for the prevention of introduction and spread. *However, under no circumstances can these be fully and effectively administered unless public sentiment is in thorough accord with their application and enforcement.*

SENDING WEEDS FOR IDENTIFICATION

As this circular does not deal with weed identification, the individual might well, in many instances, send in weed specimens for identification. One should usually know the specific weed in order to plan the best program for its control. Very often weeds sent in by growers for identification are so fragmentary or incomplete, or so poorly packed, that they cannot be identified with certainty. The leaves, flowers and fruits, and a portion of the underground system should always, if possible, be included in a specimen. In certain families of plants, such as the mustards and umbellifers, the mature fruits are frequently necessary in order to make an identification. In other families, such as grasses, the underground structures may be necessary. In any event, include flowers as well as leaves, for of all plant structures the flowers are the most useful in making an identification. Included with the specimen may well be a brief description of its habit of growth, including height, etc., and also the conditions under which it grows.

Specimens should be wrapped in moist paper, moist cotton or cloth, or moist moss, and these enclosed in a box or heavy paper wrapping. Or they may be pressed between several thicknesses of newspaper, or between folds of blotter paper or soft corrugated

cardboard, and mailed in a thoroughly dry condition. Material not pressed before shipping, or not kept moist during shipping, and simply placed in an envelope or packed in a box dry, usually reaches its destination in such poor condition as to defy identification.

Send specimens for identification to any of the following: County Agricultural Commissioner; County Farm Advisor; State Department of Agriculture, Bureau of Pest Control, Sacramento; Division of Botany, University Farm, Davis; or Department of Botany, University of California, Berkeley.

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