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PREFACE

Intensive weed-control research directed toward solving practical problems is a very recent development. The first coordinated and cooperative investigations in America began in 1935, with the formation of a weed project in the Bureau of Plant Industry, U. S. Department of Agriculture.

Weed research was greatly stimulated in 1944 with the first use of 2,4-D for the selective killing of weeds. Since that time much progress has been made, new interest has developed, and many capable scientists have focused their talents and energies on the weed problem. Rapid progress has been made recently, and many more developments are portended for the years that lie ahead.

Although the science of weed control is young, it is growing with a vigor not to be surpassed by other plant sciences. Accumulated facts from weed research have made this book possible. To appreciate the subject matter fully a good understanding of agronomy, botany, chemistry, and plant physiology is desirable.

Though the authors have written primarily for classroom instruction, they sincerely believe that this book will prove useful to research specialists, industrial chemists interested in herbicides, farmers, farm leaders, herbicide sales representatives, and agricultural extension and vocational agriculture teachers.

Accurate identification of weeds is even more difficult than that of crop and horticultural plants. Nevertheless, the writers have made every effort to assure positive identification of the weeds discussed in the text. Whenever there is any doubt about the common name of a weed, its first appearance in the text is followed by the botanical name. The botanical name is also given in the index, and in the appendix for those weeds tabulated for their susceptibility to treatment with 2,4-D. In making these identifications, to supplement the original published sources, the writers have accepted the following authorities: M. L. Fernald, *Gray's Manual of Botany,* eighth edition, American Book Company, New York, 1950; W. C. Muenscher, *Weeds,* The Macmillan Company, New York, 1946; L. H. Bailey, *Manual of Cultivated Plants,*

The Macmillan Company, New York, 1949; and Native Woody Plants of the United States, *U. S. Dept. Agr. Mis. Pub.* 303, 1938.

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CHAPTER

1

INTRODUCTION

The character of weeds, their identification, dissemination, habits, and methods of eradication are factors that have received much attention during the last decade or more. The various phases of the study of weeds have in this time been approached with much more scientific accuracy than in all the preceding years. A renewed scientific approach to the problem through applied chemistry and plant physiology has brought very satisfactory results but has by no means eliminated financial loss and much misdirected and useless endeavor. The main causes for poor results in weed control and eradication are carelessness and lack of knowledge. The problem, like any other study, should be approached with a complete understanding of all its aspects, especially the weeds, crops, cultural techniques, chemicals, and weed-seed habits and responses.

Weeds Defined

Just what is a weed? It is difficult to define such a plant, for what is a pest in one part of the country may be desirable in another. Furthermore, weeds vary in the amount of their harmfulness. They are therefore defined in a number of ways, any one of which may be appropriate, depending on circumstances. Thus we find such definitions as: "a weed is any injurious, troublesome, or unsightly plant that is at the same time useless or comparatively so." Also, "a weed is a plant that is out of place"; and "a plant growing where it is desired that something else should grow"; and "a plant that has no economic value"; and "a plant whose potentialities for harm are greater than its potentialities for good." In a general way, these quotations suggest not the noxious quality of weeds but rather their undesirability.

Without a proper definition of a weed or weeds, the difficulties of writing and enforcing of seed and weed laws, seed certification, interstate shipment of feed and seed, and associated problems become evident. What may be a serious weed in one state may be considered of no consequence in another.

History and Development of Control Practices

Certain weed-control practices have been with us since the beginning of agriculture. Early attempts at crop production must have been associated with weeding, first perhaps by pulling and later by hoeing and cultivating. Good seedbed preparation together with cultivation and other tillage methods are still the standard and most reliable procedures to use for weed control in most crops, and they will probably never be completely replaced by chemical techniques.

Cultural control. Scientific studies on weeds began at a late date. Perhaps the first basic investigation was the now classical buried-seed experiment started by Dr. Beal in 1879. The final results from this work as reported by Darlington (1941) and Toole and Brown (1946) showed a range in viability among various weed seeds from a few months and years to as long as half a century.

Studies by Atwood (1914), Chepil (1936), Crocker (1906), Brenchley and Warrington (1933), and others have shown that periods of dormancy are inherent in certain weed seeds; in others they depend upon the environment. Soil treatments that modify the oxygen content, moisture, or temperature will influence seed germination.

Vegetative reproduction in weeds is better understood as a result of the studies by Arny (1927), Pammel and King (1909), Pavlychenko, Kirk, and Kossar (1940), and Prentiss (1889). These investigators showed that seedlings of perennial weed species are as easily destroyed as the seedlings of annuals. Further, depending on the perennial, deep plowing and frequent mowing and cultivating are often effective as control practices.

The value of crop rotations and smother or competing crops as a means of weed control was pointed out as early as 1912 by Cates and Cox. Since then Blackman and Templeman (1938), Godel (1935), Kiesselbach, Anderson, and Lyness (1935), and

Pavlychenko and Harrington (1934) have pointed to well-planned rotations and competing crops as means of controlling weeds.

Organic reserves in the underground organs of perennial plants are important to their persistence; this has been demonstrated by the researches of Arny (1932), Barr (1940), Timmons (1941), and Welton, Morris, and Hartzler (1929). Depletion of such reserves by cultivating, fallowing, mowing, and grazing leads to a reduction of infestation by tenacious perennials.

FIG. 1. Weed control is an integral part of good farming (*J. I. Case Co.*).

Placing weeds and weed seeds in the silo in the process of making silage has been shown by Tildesley (1936) to be a successful method of destroying the seeds. Harmon and Keim (1934) found that weed seeds passed through most farm animals without being digested. Atkeson, Hulbert, and Warren (1934) and Stoker, Tingey, and Evans (1934) demonstrated that weed seeds in animal manures could be destroyed by composting. Additional methods of weed-seed destruction include the application of heat and chemicals for soil fumigation and sterilization.

The development of mechanical equipment has been a gradual evolution over many years. Probably the plow and the disk and

spring-tooth harrows were developed for other purposes, but they are certainly valuable implements for weed control. Such equipment as the hoe, rotary hoe, spike-tooth harrow, and cultivators with various types of shovels has been specifically designed for purposes of weed control and destruction.

Chemical control. The chemical attack on weeds was slower and less certain than that on diseases and insects. Solutions of copper salts were used about 1897 to kill certain weeds in grain crops. Many chemicals such as iron sulfate, sodium chlorate, sulfuric acid, sodium arsenite, and others were tried in the years immediately following. But the high costs per acre for materials, the explosion and fire hazards in some cases and equipment corrosion in others, together with only moderate success in killing weeds, left the science of chemical weed control in disrepute.

Nevertheless, when Bolley in North Dakota completed 12 years of research using sodium chloride (common table salt), iron and copper sulfate, and sodium arsenite, he was greatly impressed with the potentialities of this field. In 1908 he wrote as follows: "When the farming public has accepted this method of attacking weeds as a regular farm operation, the gain to the country at large will be greater in monetary consideration than that which has been afforded by any other single piece of investigation applied to field work in agriculture."

Soil-sterilization studies were first reported in 1899. In a short time sodium arsenite became the most widely used chemical for soil sterilization, the railroads being the largest consumers. Later the chlorates, borax, and carbon disulfide were proved valuable.

Sinox. About 1938 chemical weeding received a much-needed new impetus. French workers released a chemical called Sinox that killed many broad-leaved plants on contact without injuring the grasses. The active ingredient is 4,6-dinitro-*o*-cresol, sodium salt, and the cost per acre was reasonable enough so that Sinox was soon used for weed control in winter and spring grains, flax, field peas, alfalfa, and some vegetable crops. The discovery of Sinox rekindled an interest in chemical weeding, and the search for selective killers was intensified. Down from the shelf came ammonium sulfamate, a chemical discovered 60 years earlier. It proved capable of destroying chokecherry (*Prunus virginiana*), poison ivy (*Rhus radicans*) and poison sumac (*R. vernix*). Dilute sulfuric acid was sprayed on onions, and for calcium cyanamide

were found new uses weeding onions, asparagus, and tobacco seedbeds. Even sodium chloride was discovered to have selective properties for weeding young beets. Soon oil was found suitable for weeding carrots and other vegetable crops.

2,4-D. Even as these experiments were going on, a new attack was being developed. Organic chemists working with plant physiologists were studying plant hormones or "growth regu-

FIG. 2. Scientists studying the selective killing of giant ragweed (horseweed) in corn in Henderson County, Ky., 1946. This was one of the first large-scale tests made with 2,4-D in the United States (*Sherwin-Williams Co.*).

lators." In 1939 they succeeded in getting apples and pears to hang onto the trees until fully ripe by using 1-naphthaleneacetic acid and several other materials. Indoleacetic acid was used to encourage rooting of backward cuttings and acetylene for speeding the ripening and coloring of fruits. In 1944, 2,4-dichlorophenoxyacetic acid (2,4-D) came into prominence for its plant-killing properties. Wartime investigations showed its usefulness for the possibility of destroying enemy crops. The results soon proved that 2,4-D was a selective plant killer of wide applicability.

Early tests proved 2,4-D capable of destroying most broad-leaved weeds that infest lawns, such as dandelions (*Taraxacum*

spp.), narrow-leaved (buckhorn) plantain (*Plantago lanceolata*), and others, without injuring the grasses. Farm tests conducted in 1946 and 1947 showed that 2,4-D was useful for the selective elimination of many broad-leaved weeds from corn, small grains, flax, and grass hay and pasture crops.

The principle of pre-emergence weed control was first applied in the United States at the New Jersey Agricultural Experiment Station in 1946 when workers there were able to grow a crop of corn to maturity without cultivation. This astonishing feat was accomplished by spraying the surface of the soil with 2,4-D at the rate of 1½ pounds per acre shortly after planting.

With the development of 2,4-D came low-gallonage spraying. Formerly from 100 to 300 or more gallons of solution were considered necessary per acre. Now rates as low as 5 and 10 gallons have proved effective and are economical to apply. Precision spraying equipment, including pumps, booms, and nozzles, has been developed for both ground and air applications.

Since the advent of 2,4-D a great many new chemicals for specific weeds and crops have been developed. A few of these are salts of trichloroacetic acid, potassium cyanate, phenylmercury acetate, 2,4,5-trichlorophenoxyacetic acid, certain oils, sodium pentachlorophenate and isopropyl-phenylcarbamate. Many more are on the way from research laboratories and testing stations.

There is great emphasis on chemical weeding in modern agriculture as a means of realizing larger profits. Wherever possible hand labor is being replaced by mechanized techniques. Where economical mechanical methods can be used to destroy weeds, these methods are being increasingly employed, and with good justification. In all this it is necessary to bear in mind that there is still no substitute for good seedbed preparation and cultural practices together with a wise choice of crops. Combining the best mechanical and cropping techniques with chemical methods of weed control will be to the ultimate advantage of America's producers of food and feed.

The Influence of Ecology

Certain weeds are often associated with one or more specific crops. This is due to the kind of favorable germination condi-

tions provided for the weed seeds and because of the competition offered the weeds for light, moisture, and plant nutrients. Although a good seedbed is necessary for seeding down to crops, unfortunately it also provides favorable conditions for weed seeds to germinate. Perennial weeds are more commonly associated with hay and pasture fields and annual weeds with garden and cultivated crops. This is because annual weeds are soon destroyed in hay and pasture fields by mowing and grazing, and the heavy sod growth prevents new annual weeds from getting started.

The competition factor. Crop weeds are controlled by decreasing their competitive power or by increasing that of the crop. On land that is fairly free of weeds this is no real problem, but in dealing with heavily infested areas some ecological principles should be kept in mind.

It is always best to sow the crop at the season of the year that is most favorable to its germination and growth. Thus cool-season perennial grasses are often sown in early fall, oats as early as possible in the spring, and soybeans and sudan grass when the soil has warmed up. Under such favorable conditions the crop seed germinates quickly, and the rapid growth of the crop may shade or smother annual weed seedlings.

On weedy fields increased seeding rates are often useful. The production of a dense, heavy stand produces very strong competition against emerging weed seedlings, often smothering and destroying them. Another principle is uniform spacing of seeds so that all available space is occupied by crop plants with no room for the weeds. This is most applicable to drilled or broadcast seedings of grain, forage, and pasture crops.

For some crops cultivating after seeding but before emergence is a sound practice for checking weed competition. Potatoes, for example, are planted deeper than most crops, and after they have sprouted but before the sprouts emerge the field may be blind-cultivated or weeded. This destroys all newly germinated weed seeds and seedlings. Within a few days the crop emerges and may grow for from 1 to several weeks before additional weed seedlings appear. By this time the crop is well enough developed so that it offers competition to the weeds or makes it easy to control them with regular cultivation.

The choice of fast, tall-growing crops (sometimes called competitive or smother crops) is a satisfactory method of controlling weeds. The very vigor of crops such as sudan grass, sorghum, sweet clover, and alfalfa results in shading out most weeds, destroying the seedlings, and weakening even perennial plants.

Association with crops. In corn and other cultivated crops such weeds as pigweed (*Amaranthus* spp.), chickweed (*Stellaria*

FIG. 3. Sweet clover will act as a smother crop and will improve the soil at the same time.

media), lambs-quarters (*Chenopodium album*), purslane (*Portulaca* spp.), crabgrass (*Digitaria* spp.), annual morning-glory (*Ipomoea* spp.) and ragweed (*Ambrosia* spp.) are particularly common. In some grain fields corn-cockle (*Agrostemma githago*), wild garlic (*Allium vineale*), wild mustard (*Brassica kaber* or *arvensis*), shepherds-purse (*Capsella bursa-pastoris*), Canada thistle (*Cirsium arvense*), wild oats (*Avena fatua*), and the weedy bromegrasses are frequently found.

Weeds of pastures include bracken (*Pteridium* spp.), broomsedge (*Andropogon virginicus*), chicory (*Cichorium intybus*), ironweed, bull thistle (*Cirsium lanceolatum*), Canada thistle, plantain (*Plantago* spp.), coralberry, yarrow (*Achillea millefolium*), dande-

lion, and many others. Hayfields may include wild carrot (*Daucus carota*), fleabane (*Erigeron* spp.), quackgrass (*Agropyron repens*), winter-cress (*Barbarea vulgaris*), ox-eye daisy (*Chrysanthemum leucanthemum*), yellow (curly) dock (*Rumex crispus*), Canada thistle, and horse nettle (*Solanum carolinense*). On the western ranges weeds such as sage, phlox, prickly pear (*Opuntia* spp.), goldenrods (*Solidago* spp.), buckbrush (*Symphoricarpos occidentalis*), field bindweed (*Convolvulus arvensis*) and others are numerous.

In lawns dandelion, narrow- and broad-leaved (*P. major*) plantain, ground ivy (*Glechoma hederacea*), wild garlic, crabgrass, chickweed, and speedwell (*Veronica* spp.) are among a few that are most frequently found.

Soil and climate. Besides these crop associations, weeds are responsive to soil and climatic conditions. Thus sedges (Cyperaceae), bulrushes, horsetail (*Equisetum* spp.) and skunk cabbage are found in wet, poorly drained sites. On dry, sandy soils such weeds as mullein (*Verbascum thapsus*), broom-sedge, hawkweed (*Hieracium* spp.) and crabgrass are found.

Some weeds' responses to temperature are very evident. Canada thistle and quackgrass are not found in the southern states, nor is Bermuda grass (*Cynodon dactylon*) or Johnson grass (*Sorghum halepense*) found in the North. Wild onion (*Allium canadense*) and wild garlic do not occur in the far North or the extreme South but are restricted to central latitudes.

Weeds peculiar to the dry prairie regions include sagebrush (*Artemisia tridentata*), prickly pear, loco weeds, and others.

Annual Cost of Weeds

Farm losses from weeds are much higher than is generally recognized. The Chamber of Commerce of the United States estimated in 1930 [1,*] that the average farmer in the United States lost at least $450 per year because of weed costs. Nationally this amounts to about $3,000,000,000. More recent figures have raised this loss to about $5,000,000,000 a year. This is many times the cost of all animal diseases and more than that due to the combined destruction by insects and plant diseases.

* Superior numbers apply to references at ends of chapters.

Because weeds are so common and so widespread, their significance in terms of crop losses and control costs has not been fully appreciated. Methods of measuring such losses have not been developed easily, and their prevalence has made it natural to take them for granted without giving full thought to the damage and expense involved. Weeds are common on all our 350 million acres of cropland and billion acres of range and pasture. Some land has been so badly overrun that it has had to be abandoned. Reduction in yield and loss of farm, orchard, and garden crops and produce is considered to be about 10 per cent attributable to weed competition and damage.

Reduction in yields. Undoubtedly the crop loss through yield reductions is the greatest single item in the nation's weed bill. Crop growth may be retarded by competition with associated weeds for the essential growth factors of light, moisture, and plant nutrients. The taller or more numerous the weeds in relation to the crop, the stronger is the competition.

Light. The shading of crop plants by weeds results in stunted, often unhealthy, plants. If shading is severe enough the plants may be a yellow-green instead of dark green. This means that the food-making ability of the leaves and other green parts is reduced, and a slow, nonvigorous growth results. Under heavy shade many crop plants never mature. Eventually their strength is dissipated and they are destroyed.

Moisture. Large quantities of water are required to produce as little as a pound of dry matter. Studies have shown that this water requirement may range from 250 to 1000 pounds.

Often a limiting factor in crop production is the available moisture. Since it takes as much water to produce a pound of dry matter from weeds as from crops this source of competition becomes very significant. Elimination of weed growth makes more water available for the growing crops, which will benefit accordingly.

Nutrients. Weeds are vigorous growers, and they demand large amounts of plant nutrients. In fact it is a common observation that weeds grow best on the most fertile soils.

Obviously, since plant-nutrient content of the soil is frequently a limiting factor in crop growth, removal of the competition for

such nutrients will make more of them available to the growing crop.

Other losses. There are many other ways in which weeds cause losses and expense, especially to the farmer, but sometimes to those who process farm products. A number of these costs and losses follows:

1. *Cost of Cultivating.* About 40,000,000 acres are annually planted to cultivated crops such as corn, cotton, peanuts, tobacco,

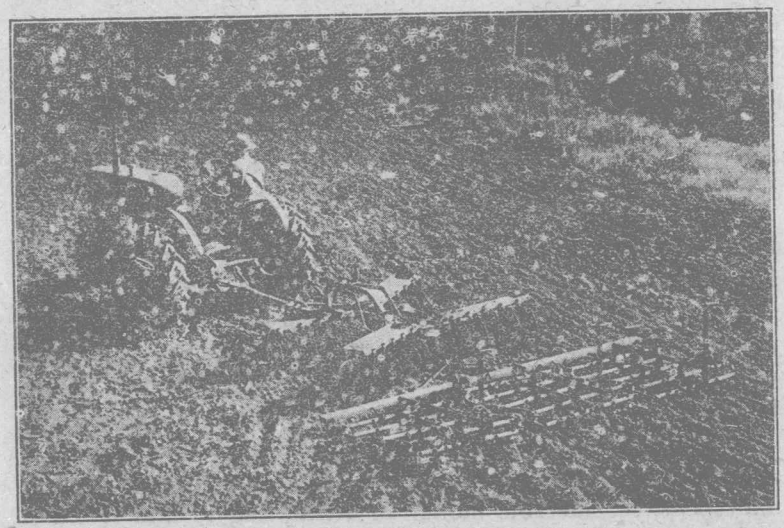

FIG. 4. The disk and spike-tooth harrows are effective implements for destroying weeds and preparing a good seedbed (*Allis-Chalmers Mfg. Co.*).

soybeans, vegetables, and fruits. Gasoline, oil, tractors, cultivators, hoes, sprayers, and other equipment are used to weed row crops. There is also the labor cost of running the equipment and often of hand weeding.

2. *Lowered Quality of Crop Products.* Wheat that is contaminated with garlic produces undesirable odors and flavors in flour, and the grower who sells such wheat to the mill is penalized accordingly.

3. *Lowered Quality of Animal Products.* Weed fragments, burs, and awns imbedded in wool and hides reduce the prices paid for these products. Odors in milk, due to garlic, onion,