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War on Weeds

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MORE WORK ON HERBICIDES and more in the way of scientific and practical achievement with herbicides has taken place in the past decade than at any time in history. No doubt the urgent need for increased food production, coupled with the drastic shortage of farm labor, stimulated interest in weed control.

Significance of Herbicides

A weed (*18*) may be defined as an undesirable plant or "a plant out of place." Weeds compete for a place in the sun by occupying space. They also compete for soil nutrients and thereby reduce not only the yield but also the quality of farm crops. Both woody and herbaceous plants may be weeds, and they can cause losses in many and devious ways. Most virus diseases of plants are spread by insects and in every known case weeds serve as hosts for the insect vector and may also harbor the virus pathogen. Many fungus and bacterial diseases of plants overwinter on, or are harbored by, weeds (e.g. downy mildew of lettuce winters on wild sunflower and thistles). Economic insects are frequently harbored on weeds, where the weed fits into the insect's life cycle (cotton aphid, potato flea beetle, red spider). The winter phases of the life cycles of the leaf hopper insects, which carry curly-top virus to sugar beets and yellow blight to tomatoes in California, are spent mainly on thistles. Weed control will become more and more important as more is known about the disease and insect pests of farm crops.

Weeds function as an unseen tax on the crop harvest. For example, it is estimated that losses from weeds in California total about $60,000,000 annually. According to Taylor (*25*), weeds rob farmers in the United States of $3,000,000,000 a year. From this, the economic importance of weed control cannot be questioned. The weeding operation, especially where vegetables like onions and carrots are concerned, can comprise 30 per cent of the cost of production. The hand labor involved in the first weeding of onions and carrots is always very tedious, requiring adequate, careful, and timely work costing about $30 an acre. Here an inexpensive, rapid method of killing weeds is needed.

Certain weeds are so efficient as competitors of the food and forage crops that they have thwarted the efforts of man to control them by any means. These weeds are called "noxious," and it is of interest to know that most of the noxious weeds (Canada thistle, sow thistle, Russian thistle, artichoke thistle, wild mustard, Russian knapweed, corn cockle (?), English plantain, wild oats, wild morning-glory, quack grass, etc.) are aliens or exotic. The water hyacinth which now clogs the fresh-water streams and lakes in subtropical America originally came from Japan.

Many weeds persist for long periods of time in the soil when buried in the plowing operation. Each cultivation usually starts off a new crop of weeds. While there are numerous species (annual, biennial, or perennial in habit), only a relatively few are of serious economic importance for any one crop. Annuals, in passing through their complete cycle back to seed in one season, are vulnerable to herbicides, especially when small. For the perennials the situation is different because the herbicide must be capable of reaching and killing the underground parts if it is to be successful.

The importance of weed control led several years ago to the organization of the Western Weed Control Conference, consisting of all weed-control officials in 11 Pacific slope states. Recently, a North Central States Weed Control Conference, composed of 13 states, was organized. Its research committee has suggested a uniform plan of experimentation on 2,4-dichlorophenoxyacetic acid (2,4-D) for 1946 based on the 1945 program. Apparently the remarkable number of new herbicides developed during the past decade (sulfuric acid, Sinox, ammonium sulfamate, sodium pentachlorophenate, oils, 2,4-D, 2,4,5-T, Sizzweeder, mechanical shredder, 2,4-dinitro-6-sec-butyl phenol, etc.) has stimulated an organized attack on weeds that will bear watching.

For convenience, herbicides can be divided into several groups: (1) soil sterilants, illustrated by sodium arsenite, ammonium thiocyanate, borax or borate ores, carbon bisulphide, chloropicrin, and sodium chloride; (2) nonselective contact sprays, such as the numerous nonselective oil, acid, and salt derivatives which kill all vegetation down to earth; (3) selective sprays, illustrated by sulfuric acid, oils, and Sinox, which wilt down most broadleaf weeds, but leave grains, flax, and grasses virtually unaffected; (4) translocated poisons, illustrated by arsenic trioxide, arsenic trichloride, sodium chlorate, ammonium sulfamate; (5) flame thrower, illustrated by the Sizzweeder, a machine designed especially for weeding row crops; (6) growth regulators or hormones, such as 2,4-D and 2,4,5-T—substances which in relatively minute quantities stimulate abnormal growth followed by death of plants; and (7) miscellaneous devices, including a machine for moving and crushing the water hyacinth, soil covers or barriers to suffocate weed growth, cover crops, etc.

History

The principle of selective weed killing with chemical sprays has been known for over a half century (*21*). A concentrated iron-sulfate solution was used against weeds in cereals for many years both in Europe and America and with some success. Bolley (*3*), in North Dakota, demonstrated that iron sulfate could be used to kill some weeds in cereals. Rabate (*20*) opened a new era by employing dilute sulfuric acid, but little came from his work until later.

Of the various materials, the soil sterilants were probably the earliest herbicides used by man. Many salts of acids, when applied to the soil in sufficient quantity, will kill all plant growth. The soil is thereby rendered unfit for growing plants until the chemical has been leached out by rains. For killing deep-rooted perennials, 250 pounds of table salt, 15 to 30 pounds of borax, and 3 to 4 pounds of sodium arsenite are required to treat one square rod of area. Many nonselective contact sprays contain sodium arsenite alone or in combination with sodium chlorate. This, however, is very poisonous to livestock, is expensive, and is a fire or explosion hazard. Aside from soil sterilants and nonselective contact sprays, most herbicides used today are new.

Sulfuric Acid

Ball and French (*1*) were the first to point out the possibility of using dilute sulfuric acid for killing weeds among young onions. Newhall, *et al.* (*19*) extended this work and demonstrated that, when properly applied, sulfuric acid functioned as an inexpensive, rapid method of killing weeds. One gallon of cheap ($.35) sulfuric acid added to 50 gallons of water made enough solution to spray one-half acre of onions. Weeding time and expense were cut to one-fourth by this method. Most weeds are killed, but certain ones, like grasses of upright growth or lamb's-quarters and purslane which have waxy bloom, are not easily wet by the acid and may not be killed.

Sinox

Sinox (sodium-dinitro-ortho-cresylate), a coal tar derivative in the form of yellow dye, was first used as a selective herbicide in France in 1933 and as a weed spray in the United States in 1938. It is also an insecticide and pollenicide. This herbicide has been used in extensive field trials in many places, including California (*27*), North Dakota (*10*), Montana (*15*) and Canada (*32*). Westgate and Raynor (*27*) obtained successful results in cereals and flax with spray rigs mounted on trucks and on airplanes. For airplane application the cost was about a dollar more than for ground rigs, averaging $3.65 an acre for controlling wild mustard and $4.65 for wild radish, fire weed, and yellow star thistle. The dosage of 1 gallon of Sinox to 120 gallons of water was applied at the rate of 80 to 100 gallons per acre on mustard when the weed was 3 to 7 inches high and had 3 to 7 leaves. Established transplanted onions were also sprayed with safety until they were approximately 10 inches high. Common dandelion, common plantain, and crab grass were successfully controlled in bluegrass lawns.

Sinox kills only the broad-leaved annual weeds, including ragweed, and has little effect on grasses. The young seedling weeds are most easily killed. Spraying with Sinox, Helgeson and Gebracht (*10*) increased the yields of flax by as much as 232 per cent. In their report on three seasons work, Litzenberger, *et al.* (*15*) obtained yield increases up to 264 per cent. They cautioned that flax and peas should never be sprayed before reaching 3 inches and never after bud formation. Small grains may be sprayed when taller, but treatment should be made before they reach jointing stage.

Schwendiman, *et al.* (*22*) studied the effects of Sinox on legume seedlings, weeds, and crop yields in Wisconsin and reported that Sinox killed 0 to 70 per cent of alfalfa and red clover up to 4 weeks of age, but that these plants developed a high resistance to this herbicide when 4 to 6 weeks of age.

Sinox, together with ammonium sulfate as an activator, has been used by Bonde and Schultz (*4*) and others for killing the tops and thereby controlling the late blight tuber rot of potatoes. Sinox spray also aids in harvesting and improving the quality of potatoes for early market, and enables growers to harvest the crop before the onset of freezing weather.

Ammonium Sulfamate

Ammonium sulfamate is technically a contact and translocation herbicide. For about 60 years it was known as a laboratory curiosity in chemistry. Originally it was sometimes used for fireproofing wood. Recently Du Pont chemists found an economical way to produce this in large quantities. In 1941 (*11*) it was found to be a more suitable herbicide than sodium chlorate for eradicating chokecherry, the wild host of the yellow-red or "X" disease of peach. It is also excellent for poison ivy, but was not satisfactory for killing water hyacinth (*7*). For spraying, about three-fourths of a pound of this salt is dissolved in a gallon of water and applied at the rate of from 1 to 3 gallons per 100 square feet of weed growth area. Ammonium sulfamate is nonpoisonous to animals, free from fire hazard, and does not leave the soil sterile for more than a short time. In fact, it contains a high percentage of fixed nitrogen which enriches the soil. Aside from its use for such special weeds as chokecherry and poison ivy or small areas of noxious perennial weeds where its nonselective action is tolerated, the cost of "Ammate" is too high to allow it to be used generally on large areas.

Sodium Pentachlorophenate or "Santobrite"

Santobrite was recommended by Hirsch (*12*) at a concentration of 5 ppm for retarding growth of water hyacinth where its complete removal is not essential or in zones where other life is to be preserved, and of 80 ppm for complete elimination.

Oils

Oils have long been known to be toxic to plants. It has been only recently, however, that their value as selective weed killers has been recognized. In California and other far-western states oil sprays have been used for weeding carrots on a commercial scale since 1943 (*6*). Oils are applied full strength, undiluted, and have since been widely used in several central and eastern states, including New York (*23, 24*), Massachusetts (*13*), Michigan (*8*), Wisconsin (*26*), and others. Kerosene was reported by Loomis and Noecker (*16*) and Litzenberger and Post (*14*) as a selective spray for dandelions in lawns. According to Warren (*26*), all important annual weeds in Wisconsin carrot fields, with the exception of ragweed, are easily killed by oil spray. In perennial weeds, such as quack grass and Canada thistle, the tops are burned severely, but the roots are not killed. One oil spray of carrots costs about one-half that of hand weeding, or about $13 an acre.

Sweet, *et al.* (*23*) report that the plants tolerant to oil sprays are members of the Umbelliferae family —carrots, celeriac, taprooted parsley, and celery. Some tolerant weeds are ragweed, wild carrot, galensoga, and a few grasses.

Young (*29*) reported that oils are translocated in onions and potatoes, are located principally between parenchyma cells, and persist in the tissues several months. He suspected toxic substances in the oil as one cause of death and mentioned physical suffocation as another.

Sweet, *et al.* (*24*) consider that the general types of injury possible from petroleum products are "chronic" and "acute." Chronic injury is associated with heavy oils, such as lubricating and motor oil. It is slow in action and kills practically all plants including carrots, due to "suffocation" of the tissues. Acute injury is due to chemical composition of the oil and is correlated with toxic aromatic content. It often acts within an hour or two after it has been applied. Carrots are rather tolerant of aromatic compounds, whereas most other vegetables and weeds are not. It is on this basis that oils can be used as selective weed killers. To avoid chronic injury only light-weight oils are used. The best are: (1) dry-cleaning fluids sold as Stoddard Solvent and (2) kerosenes that have 12 to 15 per cent aromatics. The important thing in application is thorough, uniform coverage of weeds when the carrots have 2 to 4 "true" or "fern" leaves and preferably before the weeds are over 3 inches tall. Due to oil absorption and slow dissipation, only one spray can be used for bunching carrots, as a month must elapse before harvest to get rid of the oil absorbed.

2,4-Dichlorophenoxyacetic Acid

The outstanding sensation concerning weed killers in 1944 was the public announcement of growth-regulating substances or plant hormones as herbicides. Work of a preliminary nature, started in July and published in August 1944 (*9*), demonstrated that 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) were selective herbicides. Credit for the original discovery of the chemical itself goes to Zimmerman and Hitchcock (*30*), and for methods of handling it in work on plants, to Mitchell and Hamner (*17*).

Because plant hormones operate on the principle of growth regulation rather than caustic action or poisoning, this discovery marks a new departure in the history of herbicides and promises in the future to prove particularly rewarding in special cases. The first tests (*9*) demonstrated that 1,000 ppm and 500 ppm of 2,4-D were effective in killing perennial bindweed (*Convolvulus arvensis* L.) on nursery fruit trees. Similar concentrations of 2,4,5-T also seemed to possess almost equally effective herbicidal properties against this weed. When it is remembered that black bindweed is considered the number one weed enemy of crops (herbaceous and woody) and that the quantity of material is measured in parts per million rather than in pounds or gallons, the sensation created by the discovery of 2,4-D can be readily understood.

The first results (*33*) were so remarkable that tests by a multitude of public and private agencies were conducted throughout the Nation (*34*), and in England (*2*) in 1945. This new departure is not the whole story of recent developments of scientific and practical interest on herbicides but only the beginning.

The most interesting characteristic of plant hormones is the small dosages needed to be effective. At 10 ppm, more or less, hormones in general produce beneficial effects. When increased to between 100 and 1,000 ppm, the 2,4-D hormone stimulates abnormal growth. The usual application is one-fourth to one-half ounce per square rod. Therefore, one pound incorporated into a spray would cover from 32 to 64 square rods compared with one-third to one-fourth square rods for such chemicals as sodium arsenite, sodium chlorate, and ammonium sulfamate. Although usually applied in water sprays, hormones may also be incorporated into dusts and aerosols.

Under favorable conditions 2,4-D applied to foliage migrates and causes death of entire deep root systems. Other important characteristics of 2,4-D are that it is noncorrosive, nonirritating to skin, and nonexplosive. Feeding trials with animals have been conducted without adverse effect. Some investigators have consumed the chemical and suffered no ill effects. The action of 2,4-D is highly selective. It attacks most broadleaf plants, but there are exceptions. Tomatoes are killed by 100 ppm, whereas Kentucky bluegrass has withstood 10,000 ppm. While disadvantageous in some respects, this property may be a great advantage in others. The fact that it is used in such dilute concentrations makes it relatively inexpensive, and it should not cost over $5 to spray one acre.

The work on 2,4-D is so new that only a few general principles will be stated at this time: (1) It is most effective on young plants in periods of rapid growth; (2) it acts slowly, requiring a month to produce killing action; (3) it appears to be most effective when applied to plants growing in moist soil; (4) eradicative action seems to proceed more rapidly in sun than in shade; (5) it should not be applied within 4 hours of a rain. For details see Willard (*34*).

People with weed control problems in 1946 in farm crops, nurseries, gardens, lawns, or waterways will be greeted with an array of over 30 preparations of 2,4-D (in acid, salt, or ester form) on the market. These materials are put up as powders, liquids, pastes, and tablets. One chemical concern prepared a dust form in 1945. Aerosol carriers are also a possibility in 1946. The preparations may contain all the way from about 10 to 100 per cent of active ingredient. It is still too early to make general recommendations on the use of 2,4-D. However, in the special case of the water hyacinth there is very little choice about using a hormone herbicide, since poisonous chemicals are ruled out.

Sizz-weeder

The Sizz-weeder, or Flame Cultivator, was first tried out on cotton in Mississippi (*31*) and on some other crops in New Jersey in 1944. In 1945 it was tested for killing weeds in corn and other row crops in New York (*28*). This machine is designed to produce a hot-air-blast flame to cause dehydration and destruction of weeds and grasses while leaving the desired crop unharmed. The burners are adjustable in three planes, and the principle of flame weeding is the application of heat at any time when the crop plant to be cultivated has more fiber content (heat resistance) than the weed growths possess. This method, like that of applying herbicides in sprays, has advantages, since it eliminates cultivation which continually brings weed seeds to the soil surface for germination.

Experiments to date indicate that (1) weeds 3 or 4 inches in height can be successfully killed in row corn 6 inches high or higher without seriously damaging the corn; (2) many large weeds, although not killed, are arrested in growth; (3) results on soybeans, peas, beans, cabbage, and spinach were discouraging; (4) two burnings spaced at least a few hours apart are even more effective than four burnings in immediate succession. Some difficulties were experienced, but these should be corrected with time.

Mechanical Weeder

Gowandloch (*7*) reported on the use of a mechanical weeder for combating the water hyacinth in Louisiana. An earlier device consisted of a conveyor to deposit the water hyacinth on stream banks to perish. This craft is equipped with crushing machinery so that the hyacinth plants are incapable of reproduction when returned to the water.

Crafts (*5*) has recently announced another new herbicide, 2,4-dinitro-6-sec-butyl phenol, which possesses some advantages over chemicals like sodium arsenite and sodium chlorate.

The Future

It is not necessary to point out the possibilities of scientific development of herbicides in the future. Of all the work to be done along the weed-control front, there is no doubt that in the future hormones like 2,4-D will receive adequate attention, although much will continue to be done all along the line of attack on weeds employing chemicals and machines as herbicides.

(*See page 492 for references.*)

H_1 is true. Now α is by definition the probability of accepting H_2 when H_1 is true; and $1-\beta$ is, by definition of β, the probability of accepting H_2 when H_2 is true. Thus, A must be so set that $1-\beta \geqq A\alpha$. From this the approximation follows that $A \doteq \frac{1-\beta}{\alpha}$. (An exact analysis of the discontinuities would permit a slightly smaller a; the use of a somewhat too large a has the effect of reducing the risks of error slightly below α and β.) By a similar line of reasoning, $B \doteq \frac{\beta}{1-\alpha}$, so that $a \doteq \log\frac{1-\beta}{\alpha}$ and $b \doteq \log\frac{\beta}{1-\alpha}$.

Tables are provided for obtaining values of a and b for selected values of α and β ranging from .001 to .40 Tables are also provided for finding the values of s, h_1, and h_2; these values can also be found by using the nomographs devised for that purpose. They are determined by the values of α, β, p_1 and p_2, which are fixed for the problem in hand. The acceptable quality limit is p_1; the unacceptable quality limit is p_2; α is the maximum risk or probability of rejecting lots of quality p_1 or better; and β is the maximum risk or probability of accepting lots of quality p_2 or worse.

Three other tools of analysis are supplied in the procedure: the operating characteristic (OC) curve, the average outgoing quality (AOQ) curve, and the average sample number (ASN) curve. The OC curve shows the relationship between the probability of accepting a lot and the true quality (fraction defective) of the lot. For most sampling plans it is unnecessary to construct these curves; but it is important to compute the average sample number for $p = p_1$ and $p = p_2$. Thus, in one of the problems illustrated the authors found $\bar{n}_{p_1} = 63$ and $\bar{n}_{p_2} = 61$. It could be assumed from these values that on the average the decision to accept or reject would be reached by the time 61–63 observations had been made. In the problem illustrated the decision was reached at the fifty-third observation. Being able to tell in advance approximately how large a sequential number of observations will be required to reach a decision is certainly an important advantage of the method.

Criticism is rampant on the question of acceptance sampling, but for the most part it deals with the validity of the tests, the relationship of the test to expected performance, the randomness of the samples, etc. However fine a method of analysis may be, it will remain impractical unless the data analyzed are suitable and in conformance with the assumptions involved in the method. Nevertheless, that criticism cannot detract from the importance of the contribution made by those who have developed the method of sequential analysis. The method is neatly and ingeniously contrived, and it is surprisingly simple in application as far as the primary requirements of any particular problem are concerned.

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(*Continued from p. 468.*)

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