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Chemical Weed Control In Field Crops

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Chemical Weed Control in Field Crops[1]

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A PERIOD of less than a decade has seen a revolution in farm weed control. The announcement of 2,4-D as a weed killer in the summer of 1944 has led to a tremendous industry, millions of acres treated, millions of pounds of herbicides sold each year, amazing resultant savings in human labor, and the ability to do things not before possible.

Even so, chemical weed control will never entirely replace cultural methods. No herbicides so far available for use in crops will kill all weeds, leaving just the crop plants. If we use chemicals without cultivation to remove the remaining weeds, it will be only a short time before we have fields which are as weedy as before, but the weeds present will be different, of kinds harder to kill. Furthermore, even when weed control is achieved, many soils will give higher yields of crops when cultivated.

The herbicide field is developing with almost explosive rapidity. Every year sees many new chemicals tried, and usually one or two accepted as worthy of recommendation for general use. The few workers in the field cannot obtain answers about these new materials as fast as they are introduced, so that even the specialist is often at a loss.

The individual farmer should try to obtain the best possible information about his particular problem, either weed or crop. Since he cannot take time to become a general expert, he should go slow, and take up new things only after they are well worked out, or when he is in a jam, with much to gain and little to lose.

Our Chemical Tools

At present, 2,4-D is still the most important chemical being used to control weeds, but many others are being used. Chemical weed control is rapidly becoming more and more specialized. We do not have a chemical for every weed, but we tend to greatly increase the number of chemicals used, and to use each for very specific plants or purposes. This specificity of chemicals to plants and situations means that chemical weed control is more and more a specialist's job.

Our new tools are immensely effective, and therefor likely to cause injury if wrongly or carelessly used. Moreover, the line between crop injury and no injury is fine. So many things, like weather, soil, variety of crop, or rate or method of application, can shift the balance, that it seems likely that the hazard of possible crop injury in using these materials will be present for a long time —perhaps always. We must, of course, guard as much as possible against conditions which result in injury, but it is unlikely that all hazard can be avoided. Certainly it cannot be avoided now.

2,4-D. This herbicide (2,4-dichlorophenoxyacetic acid) is in many ways an ideal weed killer. It is effective in small doses on many weeds, highly selective, non-toxic to man or livestock, non-corrosive to equipment, inexpensive, and easy to apply.

Also 2,4-D will not accumulate in the soil or affect it unfavorably, in this climate. The heaviest doses are decomposed in the soil in 15 to 60 days. In dry soils and climates it may last all season or longer, but not here. It has no unfavorable effect on soil bacteria or other microorganisms. Farm animals, insects, and men are unaffected by 2,4-D except in doses far above those received in any herbicidal use.

[1] This bulletin summarizes the practical recommendations from Project R. M. 20, Subproject 1, of the Ohio Agricultural Experiment Station, Chemical Weed Control in Field Crops. Since 1946, the following research assistants and graduate students have contributed to this work: Richard J. Aldrich, R. L. Bernard, Evert O. Burt, E. B. Eskew, Gideon D. Hill, Richard D. Ilnicki, William F. Meggitt, Homer B. Neville, Clarence B. Owens, R. A. Peters, Warren C. Shaw, and W. W. White.

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Hazards and Precautions: Never forget, when using 2,4-D, that you are using an extremely potent material. Damage to sensitive crops from careless application of 2,4-D has led to the restriction or prohibition of its use in some states. Use no more than necessary, and use every precaution to prevent drift and misapplication. Esters are definitely more likely to cause injury to adjacent sensitive plants than other forms of 2,4-D.

In applying 2,4-D, use low pressures, which result in coarser sprays than high pressures, and nozzles designed to produce droplets, not mists. Do not apply on windy days. Keep spray as close to the ground as possible. Do not apply on large areas within several hundred feet of sensitive crops, such as tomatoes, tobacco, cotton, most garden vegetables, flowers, and ornamentals.

How does 2,4-D kill plants? When absorbed by plants 2,4-D has widely varying effects. With sufficient doses, some plants are killed outright almost at once after application. In other plants, any tissue that is growing at the time will be stimulated to abnormal growth of many kinds. It often stimulates respiration, and so causes exhaustion of reserve food materials in stems, roots, or elsewhere. Essentially, it disorganizes the biochemical processes inside the cells of the plants so that they do not proceed, or proceed abnormally, but each kind of cell in each plant responds in its own almost unique way.

Kinds of 2,4-D available. 2,4-D itself is an organic acid, which is not soluble in water or oil, and so cannot be used generally for weed-killing. It must be compounded for use. These compounds contain different proportions of 2,4-D acid. Since it is the 2,4-D in the compound which kills the weeds, all rates of application are stated in terms of the amount of 2,4-D acid present in the compound, that is, as the "acid equivalent". Rates of using 2,4-D always refer to the acid equivalent. Liquid formulations of 2,4-D state on the label the number of pounds of 2,4-D acid equivalent present in one gallon of solution, so that making up solutions is fairly simple.

There are three general forms of 2,4-D on the market: (1) Dry powders, which are usually the sodium salt of 2,4-D. These have nearly disappeared from the market. They are the least active form of 2,4-D. (2) Liquids, which mix with water in any proportion, making clear solutions. These are water solutions of organic salts of 2,4-D, commonly referred to as amine salts or "amine" forms of 2,4-D. (3) Liquids which make milky mixtures (emulsions) with water. These contain esters of 2,4-D dissolved in miscible oil.

Because they are in oil solutions, which stick to the plant and permit the 2,4-D to penetrate, the ester forms are more effective under dry conditions, on hard-to-kill plants, and under unfavorable conditions generally. Rain, even immediately after application, does not materially affect ester formulations. They are more active than the others, hence more effective on weeds and more hazardous to crops, per unit of 2,4-D acid, than others. Smaller doses of 2,4-D acid in ester forms should be used than of other forms. In the discussions that follow, whenever a range of rates is recommended, (except for pre-emergence treatments) the esters should be applied at the lower rates in the range and the amines at the higher rates.

The esters are also somewhat more volatile than the other compounds of 2,4-D and it is possible to have damage to adjacent susceptible plants from vapors from sprayed areas. However, although this hazard is real, much of what has been attributed to vapor damage is actually drift. At the same pressure and concentration, sprays containing the esters will form smaller droplets, and hence will drift farther and more readily than sprays of other formulations. Drift is a hazard, however, with any formulation of 2,4-D.

The esters first used were the alkyl esters (methyl, ethyl, butyl, isopropyl and amyl esters). Recently much more complex long chain esters have been introduced as "low volatile" esters. These actually are less volatile than the other esters, but the most important reason for using the long chain or "low volatile" esters is their still greater activity. They are the most active compounds of 2,4-D so far produced, and are particularly valuable against plants which are otherwise hard to kill.

Compounds similar to 2,4-D. Not only can 2,4-D be prepared in a vast number of compounds, some of which have just been described, but there are many other compounds similar to 2,4-D, with similar, but importantly different, properties. One of these is 2,4,5-trichlorophenoxyacetic acid or 2,4,5-T. To the chemist, it differs from 2,4-D only in having three chlorine atoms in its molecule instead of two; hence trichloro–, instead of dichloro–, phenoxyacetic acid. This compound is herbicidal, but on different plants and to a different extent from 2,4-D. It is especially effective on many woody plants; also on horse nettle and wild cucumber. On the other hand it is less effective than 2,4-D on Canada thistle and Indian currant or buck-brush, and has about the same effect on many others.

In England, the most widely used "hormone" herbicide is 2-methyl-4-chlorophenoxyacetic acid, or MCP. This material is less toxic to flax, specifically, and to many weeds and crops generally than 2,4-D. It is more toxic to buttercups. It has been reported more toxic to Canada thistle, but our tests do not bear this out. MCP is not so quickly decomposed in the soil as 2,4-D. The place, if any, for MCP in Ohio is not yet clear. It is being recommended for small grain in which clover is sown, but it is sufficiently toxic to clover and alfalfa so that, as with 2,4-D, the canopy of small grain and weeds is needed to keep the spray off the legumes. Since MCP is generally less toxic than 2,4-D, it would seem that in most instances lower rates of 2,4-D could be used instead of the more expensive MCP.

There are thousands of others, but they are not now being extensively offered or recommended for control of field weeds. In general 2,4,5-T and MCP are formulated in the same compounds as 2,4-D and recommendations of rates are made in terms of the acid equivalent.

Trichloroacetic acid (TCA) has been described for over a hundred years, but has been used as an herbicide only since 1947. The most common compound of TCA is sodium trichloroacetate or STCA. Our rate recommendations are being made in terms of pounds of the commercial salt as sold. TCA is an excellent grass killer, and affects many broad-leaved plants as well. It may kill by direct contact, or through the soil, but its action through the soil is much the most important. It has been more efficient to plow or otherwise work the soil over grass weeds, before applying TCA, rather than applying it to the tops. TCA is caustic to the skin and corrosive to metal equipment. It takes up water readily and cannot well be applied dry. TCA disappears from the soil more rapidly than sodium chlorate. The sterility from large doses of TCA can be expected to last about 60 days (longer for some effects on sensitive plants) in the humid climate of Ohio and up to a year and more west of the Missouri river.

Sodium chlorate, introduced as an herbicide in the United States in 1926, was the first chemical which was effective at sufficiently low doses and was sufficiently low in price to be seriously considered as a general weed killer. In sufficient concentrations it will kill any plant life. The killing dose varies enough so that it can be used selectively in some situations, but in general it is usable only when temporary soil sterility, 6 months to 3 years, is not objectionable. Under these circumstances, there is still no better weed killer. It is readily applied dry. It is not caustic to the hands, and is essentially non-poisonous. It is valuable for use on Canada thistle, quackgrass, poison ivy and common chickweed.

Sodium chlorate is a definite fire hazard. Sodium chlorate itself will not burn, but if mixed with organic matter or sulphur the mixture becomes explosively inflammable and can readily be ignited by friction or a blow. Consequently, every possible precaution must be used to prevent the spilling of chlorate or its solution on floors or truck beds. Remove clothing wet with chlorate spray at once, and wash thoroughly. Use rubber boots instead of leather shoes. Many fires, personal injuries, and some deaths are due to the careless use of chlorate. Don't add to the number!

Ammonium sulfamate is sold under the trade name of Ammate. Ammonium sulfamate absorbs water from the air rapidly and can only be applied in solution. It is a general weed killer, acting both on the tops and through the roots. For most farm uses it is inferior to

chlorate, but it is valuable in brush and stump control and for poison ivy. Rates of application recommended are of the commercial salt.

Dinitro compounds. Several "dinitro" compounds have been used as herbicides. Dinitro-ortho-*sec*-butyl phenol (DNBP) has been used most extensively of late. The phenol is used as a contact herbicide —that is, it kills plants by contact. It is not translocated to the roots, and so is of no value for perennials which can sprout from underground parts. It is sold as an oil solution which can be applied in oil or as an emulsion in water. The oil solution is considerably used to kill crops at maturity and weeds in crops at maturity to permit combining.

The alkanolamine salts of DNBP are similar in their effects, but are water soluble and hence more easily applied. They are sold under the trade names of Premerge and Sinox PE. Our recommendations are on the basis of the active ingredient (phenol). This is stated on the labels for this material—usually 3 pounds per gallon of concentrate.

Pentachlorophenol (PCP) and its sodium salt (SPCP) have been used as pre-emergence herbicides and contact herbicides. They have been too erratic in action for general recommendation for pre-emergence, despite some almost perfect results. PCP is being widely used to kill crops and weeds in crops at maturity to permit earlier combining.

3-(Parachlorophenyl)-1,1-dimethylurea (CMU) was introduced to weed control experimenters in 1951. It gives promise of being an outstanding soil sterilant to prevent all plant growth on drives, tennis courts, rights-of-way, etc. It is also being tried in very low doses as a pre-emergence herbicide in corn, soybeans and other crops. It must be further evaluated before recommendation.

Maleic hydrazide (MH) is a new chemical of many extraordinary properties. As an herbicide it is now recommended for trial on quackgrass. It is available dry and as an amine salt solution containing 3 pounds per gallon.

There are many other chemicals which are valuable in limited areas, especially for horticultural crops, or which have given promising results for a year and may be recommended after more tests.

Using Selective Herbicides In Crops—Corn

Corn is by long odds the most important crop selectively treated with herbicides in Ohio. A considerable number of herbicides can be used in corn fields, but 2,4-D is almost the only one now recommended. Corn can be treated with 2,4-D after planting but before it emerges (pre-emergence), or after it is up (post-emergence).

Pre-emergence treatments have not been widely used in Ohio, but will solve many problems if properly used. Annual grasses are often controlled by pre-emergence sprays, and this is the only way that annual grasses can be affected by 2,4-D. Many broad-leaved weeds are likewise controlled. Smartweed often is not controlled, and usually no perennials are controlled.

Pre-emergence application should be made 3 to 5 days after planting the corn, if possible. Applying at this time is more effective on the weeds and less hazardous to the corn than treating on the date of planting, though the latter may give satisfactory results. Pre-emergence rates may be used until after emergence, but should not be used after any leaves unfold.

The pre-emergence rate is 1 to 2 pounds per acre. Less than 1 pound is too ineffective to use; over 2 pounds is not necessary and less safe. One pound will not give the best weed control, but is cheaper, involves less hazard, and so may be more practical. One and one-half pounds is a good average rate. Dark (high organic matter) soils may require two. The ester forms are much less likely to injure corn pre-emergence than the amines, because they are not carried through the soil by water to the extent that the amines are.

Advantages and limitations of pre-emergence 2,4-D. 1. When conditions are favorable, only one cultivation, at or just before the usual time of "laying by", may be needed, and both grass and broad-leaved weeds may be kept out of the corn rows.

2. If considerable rain follows too early application, injury to corn may result. This is particularly likely to happen on sands and similar readily per-

meable soils. Pre-emergence applications are not safe on such soils.

3. If applied on dry soil and no rain follows until after weeds are established, pre-emergence applications will be ineffective.

4. Rough cloddy seedbeds may result in more or less ineffective control.

5. Leave a treated field undisturbed for two weeks or more after treatment, unless dry weather makes the treatment ineffective.

Dinitro compounds can also be used pre-emergence in corn, but since they cost considerably more per acre and are much more difficult to handle than 2,4-D, it does not now seem desirable to recommend them for field corn. CMU and other pre-emergence herbicides are also under test.

Post-emergence spraying is the common and generally recommended practice. Both esters and amine salts may be used, the former at ¼ pound and the amine salts at ½ pound per acre. More of either, up to ¾ or even 1 pound per acre, may be required for resistant weeds, with definite chance of injury to the corn.

Post-emergence spraying is cheaper than pre-emergence and controls many common broad-leaved annuals, also some perennials if they are up in time to be treated. It will not control foxtail, crabgrass, or other annual grasses.

When to spray. For some years we have been trying to discover specific stages at which corn is particularly sensitive or tolerant to 2,4-D sprays. The results, though not conclusive, lead us to believe that except for tasseling and silking stages, when one cannot spray overall with ordinary equipment, there is no specific stage when corn is especially resistant or especially likely to be injured. There is always some possibility of injury to the corn. Rapidly growing corn at any stage is definitely more readily injured than that which is, for any reason, growing slowly.

With sufficient moisture, high temperatures produce very susceptible plants. The work of Alban and Forshey of the Department of Horticulture in 1952 showed severe injury from ½ pound per acre of an amine formulation applied to corn that had been grown at a constant temperature of 80° F., and no visible damage from 2 pounds applied to the same (sweet) corn grown at an average temperature of 61° F. The temperature of the growing period, **not** the temperature at time of application, was the determining factor.

Types of damage to corn. 1. Onion leaf is a condition in which the leaves remain tightly rolled, with the leaf edges often grown together. Where this prevents emergence of the tassel, as it often does, it causes serious damage.

2. Abnormal brace roots of various kinds are very common, but have never been shown to result in lower yields.

3. Shorter, slower growth is a common result of overdoses of 2,4-D.

4. Brittleness at the joints is very common in rapidly growing corn. Bending of stalks often goes with this, and, in tall corn, stalks may break of their own weight. Corn of any height may be broken when blown by storms or struck in cultivating. This brittlenesss may last for 10 days or more but if breaking does not follow, the yield is not greatly reduced. Brittleness becomes more serious as the corn becomes older, because there is more weight in the stalk to cause breakage.

To reduce damage, avoid spraying after a **period** of hot, moist, favorable growing weather. Always use dropped nozzles on extension pipes as soon as the corn is tall enough so the spray can be put under the top leaves. However, the tops of the weeds must be sprayed. Spray preferably when corn is 3 to 12 inches high. Spray the weeds when they are small. Don't wait to see if weeds will take the corn before spraying.

Hybrid seed production. There are definite differences between hybrids in 2,4-D tolerance but all double crosses recommended for Ohio will endure the recommended rates and treatments. Some single crosses and especially some inbred lines are much more susceptible to 2,4-D than double-crosses. Single- and double-cross seed fields should be sprayed only in emergencies and after experience has shown treatment to be safe for the particular crosses or inbreds being used.

"Lay-by" spray. On rich soil, river bottoms especially, corn can be free of weeds at the last cultivation and still have weeds as tall as the corn at harvest.

Chemical Weed Control Re

Crop or weed	Herbicide	Amount per acre Lb.	Water per acre Gal.
Canada thistle	2,4-D (**not** 2,4,5-T)	½ amine	5 to 10 or more
	Sodium chlorate	500 (3 lb. per sq. rod)	Apply dry
Corn pre-emergence	2,4-D esters best	1 to 2 esters	5 to 10 or more
Corn 3 to 12 inches high	2,4-D amine salts or esters	¼ to ½ esters at lower rate	5 to 10 or more
Corn 12 to 24 inches high	2,4-D (as above)	¼ to ½ (as above)	5 to 10 or more
Corn after final cultivation	2,4-D esters or amine salts	1 to 1½ (as above)	5 to 10 or more
Oats, no legume sown	2,4-D amine	¼ to ½	5 to 10 or more
Oats, legume sown	2,4-D amine	¼	5 to 10 **not** more
Quackgrass	TCA	40 to 50	40 to 50
	Sodium chlorate	300 to 500	apply dry
	MH	8 to 12	10
Soybeans	Alkanol amine salts of DNBP	6 to 7½	40
Sugar beets	TCA	5 to 8	10 to 40
Wheat, no legume sown	2,4-D ester or amine	¼ to ½ (more if needed for resistant weeds)	5 to 10
Wheat, legume sown	2,4-D amine	¼	5 to 10 **not** more
Woody plants, foliage spray	2,4-D + 2,4,5-T or 2,4,5-T only	Use 4 lb. acid per hundred gallons water ar apply to thorough wetting.	
	Ammonium sulfamate	Use 75 to 100 lb. in 100 gallons to wet well.	
Woody plants, basal treatment, winter or summer	2,4-D + 2,4,5-T or 2,4,5-T	Use 8 to 16 lb. per hundred gallons of **fuel or kerosene (not water)**	ies
Woody plants, stumps	2,4-D + 2,4,5-T or 2,4,5-T	Same solution as for basal treatment.	
	Ammonium	Dry salt or strong water solution applied	

Recommendations for 1953

ıter acre al.	Remarks
ɔ 10 nore	Apply twice a year for 3 years, more or less, until eradicated. First treatment at bud or very early bloom.
y dry	Apply evenly, May or September. Will sterilize soil 6 months to 3 years. Small patches only.
ɔ 10 nore	Apply just before emergence or on day of emergence. At planting some hazard if much rain at once after treating. Don't use on sandy soils. May be ineffective if dry weather follows application on dry soil.
ɔ 10 nore	Apply over-all when weeds are up, but small. Damage always possible if cultivation or windstorms follow application—hazard greater as corn gets larger and following high temperatures.
ɔ 10 nore	Use drop nozzles, putting spray on top of weeds and off corn so far as possible.
ɔ 10 nore	This "lay-by" spray will keep most annual weeds from establishing for 3 weeks. Worth while on bottom lands. Do not use following period of maximum temperatures over 85° to 90°. Apply to soil and stalk bases only.
ɔ 10 nore	Apply from 4 to 5 leaf stage until oats start to joint. Do not use unless weeds justify it. Many varieties of oats are rather easily injured.
ɔ 10 more	Use low pressure, and apply before oats joint, but after oats and weeds have established good canopy over legumes. Will always result in some loss of stand.
;o 50	Apply at once, after plowing, Aug.-Sept. best, April-May next.
y dry	Apply April-May, or Sept.-Oct. Retreatments may be needed.
.0	Apply March-April, plow 4 to 10 days later. Experimental; looks good. Use for quack where plowing for corn. Corn not injured.
!0	Apply on date of planting or, preferably, up to 1 day before emergence. Smooth the soil over the seed first. In wide rows, treat over-the-row only to to cut costs.
;o 40	Apply pre-emergence only. Will control annual grasses, other than wild oats, also smart weed.
o 10	Apply just before jointing for annual weeds. Any time March to jointing for perennials, as indicated.
o 10 more	Apply just before jointing, to get best possible canopy of wheat and weeds. Low pressures only. More or less injury certain—least with red and ladino clovers. Don't use unless essential.
ater and	Use low volatile ester formulations. For plants over 4 feet tall, cut and spray stumps and/or regrowth next year. Use 2,4,5-T for osage orange hedge.
; well.	Safer (less hazard to adjacent crops) than 2,4-D-2,4,5-T, but more expensive.
of diesel	Apply to heavy runoff to base of plant (junction of root and trunk) only. Must be excess to run down on to roots. More effective on many species than top sprays.
t.	Apply at once after cutting when possible. Fair results obtainable later. Apply to root crown, as for basal treatment, also surface of stump.
pplied to	Early treatment more necessary than for 2,4-D-2,4,5-T.

A spray at pre-emergence rates, 1 to 1½ pounds per acre, can be applied on the soil and stalk bases only, after the final cultivation. This will largely prevent the emergence of weeds for 2 to 3 weeks and so largely prevent this overgrowth of weeds at harvest. Except to meet special problems, this treatment will not be worth while on most upland soils. This application when corn is growing rapidly during or following a period of hot weather may result in much bending and twisting at the base of the stalks.

Herbicides in Small Grains

The standard rate for spraying small grains with 2,4-D is ¼ to ½ pound per acre, esters at the lower rates. Higher rates are often needed for resistant weeds, with greater chance of injury. The most favorable stage for treating all small grains is a stage commonly referred to as "fully tillered". This is just before, or at the very beginning of, the "jointing" stage, in which the stalks bearing the heads start rapid growth in height. The "jointing" stage ends with the appearance of the head. The head is wrapped in the top leaf blade for a day or two, the "boot" stage. This is followed by the "fully headed" stage. In all small grains, but especially wheat, spraying in the boot or fully headed stages results in serious injury to the crop. Usually, spraying at the late jointing stage results in injury. Oats is more susceptible to injury than wheat or barley.

Wheat should not usually be sprayed in the fall, since severe damage can follow even ¼ to ½ pound rates if applied when the heads are starting to form in the young shoots. The damage appears at heading time the next year. If winter annual weeds, such as winter cress, are sufficiently serious to justify taking some loss, treat at ½ lb. per acre about a month after planting, at the 3- to 4-leaf stage.

In the spring much higher rates can be used, with less likelihood of reduced yields, until the late joint and "boot" stages. At these stages, and on through the bloom stage, wheat is readily injured by even standard doses of 2,4-D. In and after the milk stage, rates up to one pound per acre will not usually result in loss.

Oats should be sprayed at the fully tillered stage, or after the milk stage. Barley, unimportant in Ohio, can be sprayed at the same stages as wheat (winter barley) or oats (spring barley).

Small grain undersown to legumes. The legumes in a small grain seeding are always likely to be injured by 2,4-D, even at standard rates. Red clover, ladino, and lespedeza will be injured less than alfalfa, birdsfoot trefoil, and sweetclover. In spraying such seedings, the legumes are best protected by the canopy of weeds and small grain, and undersown grain should not be sprayed until such a canopy is established. Do not spray unless the weeds are serious enough to justify some loss in legume stand. Use low pressures and low volumes. In one test by the Station, alfalfa-clover hay was harvested from plots where oats had been treated the year before (with an ester formulation, which we would not recommend). Although the stands had been reduced, as noted in the seeding year, the hay yields were not reduced at the recommended stage and rates.

Several states are recommending MCP over 2,4-D for small grains undersown to legumes. There is little doubt that MCP is less toxic than 2,4-D to several crops and weeds, including several legumes, but it is sufficiently toxic so that the most important protection to the legume seedlings, from MCP as from 2,4-D, is the canopy of weeds and grain over them. It seems probable that lower rates of the lower-priced 2,4-D will do as little harm to legume seedlings as standard rates of MCP. MCP may be used at ¼ to ½ pound per acre as recommended for 2,4-D.

Effects of 2,4-D on quality and germination. Extensive milling and baking tests showed that standard rates of applying 2,4-D did not affect milling quality of the wheat or baking quality of the flour. Heavy rates (4 pounds per acre) did affect milling and baking quality at the susceptible stages. Germination of harvested grain has not been affected by any but very heavy rates at susceptible stages in wheat. Unfavorable effects on germination were more general in oats, but did not extend to recommended rates and stages of application.

Soybeans Easily Damaged

Because of the importance of the weed problem in soybeans, extensive studies on chemical control of weeds in soybeans have been conducted. The results are promising, but as yet only partially successful. So far, no herbicide has been found which can be applied to beans post-emergence, and take out any important soybean weeds. The Ohio Station applied from ⅛ ounce to 8 ounces of 2,4-D per acre to soybeans at three stages of growth from two true leaves to first flowers. All rates caused damage, and significant losses in yield were recorded at one-fourth and one-half pound, the latter rate reducing yields by nearly two-thirds. There are no important weeds in the Corn Belt which are more sensitive to 2,4-D than soybeans. 2,4-dichlorophenoxyethylsulfate (sold commercially as CRAG Herbicide 1) applied post-emergence did not injure beans or weeds. It is effective only on seedlings which germinate after it is applied.

Pre-emergence chemicals on soybeans are subject to all of the problems already discussed in connection with pre-emergence on corn. Under just the right conditions 2,4-D pre-emergence on soybeans at the same rates as corn gives results so completely ideal that one feels like announcing that it has solved all weed control problems in soybeans. However, if there is any considerable amount of rain after the 2,4-D is applied and before the beans come up, beans will be severely injured or entirely killed. We do not recommend taking that chance. If you wish to do so, three items will reduce the chance:

1. Level the furrows made by the corn planter or grain drill before applying.
2. Use an isopropyl or butyl ester formulation, not an amine formulation.
3. Apply before the beans have cracked the soil, but as long after planting as possible. Since beans in warm weather come up in four or five days, there is not much latitude here.

The most generally successful pre-emergence herbicide in five years' work with herbicides on soybeans has been the alkanol amine salt of dinitro-ortho-secondarybutyl phenol (DNBP) sold commercially under the trademarks Premerge and Sinox PE. The rate should be from 5 to 10 pounds active ingredient (phenol) per acre, with 7 pounds a good average recommendation. It is best applied just before emergence of the beans, but has been successfully used immediately after planting. Some loss of stand of the beans practically always results, but in five years' experiments the yield per acre in the fall has not been significantly reduced. Averaging wet years, dry years, and ordinary years, DNBP, although by no means perfect, has been the most uniformly satisfactory herbicide we have tried. The 7 pound rate is for beans drilled solid. On rowed beans, the amount of material used can be reduced by spraying a strip over each row. DNBP will be safer and more effective if the soil over the beans is smooth and firm, not in ridges as the drill leaves it. Use a roller, smoothing harrow or solid wheel corn planter.

Several other materials have given good results on soybeans at times. Pentachlorophenol (PCP) in oil has been one of these; but despite some very excellent results, the general results have been so erratic both in damage to beans and in weed control, that we do not recommend it for general farm use.

Three new materials, N-1 naphthyl phthalamic acid (NP), CMU, and isopropyl-N-(3-chlorophenyl) carbamate (CIPC), have given promising results, but cannot be recommended until further trial.

TCA Best on Sugar Beets

Tremendous progress has been made in the last 10 years in mechanizing the culture of sugar beets. Since hand weeding at the time of blocking and thinning is one of the most serious problems in beet culture, much study has been given to pre-emergence herbicides on beets.

Although many partial successes have been recorded, the only herbicide which can be recommended today is TCA. Where the weed problem is smartweeds or annual grasses such as pigeongrass, foxtail, or crabgrass, the pre-emergence use of 5 to 8 pounds per acre of sodium TCA, the commercial salt, will often control these weeds without injury to the beets. Lambsquarters, pigweed and other weeds

closely related to beets are not controlled, nor are wild oats. The TCA can be applied in any convenient amount of water per acre, from 10 to 40 gallons. The larger amounts permit more accurate application.

Pastures and Lawns

In many pastures, weeds are merely indicators of poor soil and poor management. Herbicides cannot substitute for fertilizer. Build up the soil! Otherwise the use of herbicides will merely result in bare soil.

One of the most important possibilities of weed spraying in pastures is the eradication of patches of Canada thistle by repeated spraying with 2,4-D. See the paragraph on Canada thistles, below.

Any 2,4-D treatment that will kill weeds in pastures will also kill or severely injury any alfalfa, red clover, alsike clover, or sweetclover that may be present. White clover (including Ladino) is fairly tolerant to light applications of 2,4-D but repeated applications will kill it.

Dandelions and plantains in lawns or pastures can be eliminated by ½ to 1 pound 2,4-D per acre in the spring, or in the fall after rains have started vigorous new growth of the dandelions. Fall is the preferable time for killing dandelions on a lawn, so that the spaces left by the dandelions can be filled by bluegrass before crabgrass time. Killing dandelions in May often merely makes room for crabgrass in June. Because sensitive plants are usually growing around a lawn, amine salts in dilute coarse spray, to avoid drift, are perhaps most satisfactory for lawns. One tablespoon of a standard 4-pound per gallon amine solution per gallon of water, applied at low pressure, sufficient to wet the plants, is a good lawn solution—or follow directions on the packages, if you buy a "lawn" weedkiller.

Controlling Special Weeds*

Canada thistle. Sodium chlorate at 3 pounds per square rod is the only "one shot" treatment for Canada thistle so far available. For two or three square rod patches, this may be the best recommendation. Retreatments should be expected. TCA is almost harmless to Canada thistle.

No single dose of 2.4-D (we have tried up to 20 pounds per acre) has killed thistles at one treatment. 2,4,5-T is definitely less effective on thistles than 2,4-D, and MCP was no more effective than 2,4-D in corresponding formulations.

In studies of repeated treatments, ½ pound per acre has been more effective than any heavier rate, apparently because heavier doses kill the tops so rapidly that there is little opportunity for the 2,4-D to be translocated to the roots and kill them. One-fourth pound per acre was definitely too little and ineffective.

The best treatment for Canada thistle, then, to date, is to treat twice a year (three times the first year may be better, but we have not shown it) with 2,4-D at ½ pound per acre of an amine salt formulation for 3 years, perhaps more. Only a few stragglers will be left after 2 years. The first treatment each year should be made at bud to early bloom (the drier the season, the earlier) and the second after growth is well started in August or September.

It is not profitable to spray thistles in the spring before plowing for corn. The plowing does them as much harm and must be done, anyhow.

Bindweeds. Both field bindweed (sometimes called morning glory) and hedge bindweed ("pea vine") are readily killed by 2,4-D, both tops and roots, under most Ohio conditions. This is not true further west, so we need not be surprised at some failures here. The hedge bindweed is the more readily killed, but one application of ½ pound to 1 pound per acre has frequently killed 90 to 95 percent of both of them. Application may be made any time when there is a vigorous growth. Where patches are present in corn in August after the corn is laid by, it is possible to practically eliminate these by treatment with hand sprayers. It is also possible where patches of either bindweed are present in small grains, to go in when the grain is in the milk and spray just these patches with a hand sprayer. This will save much trouble in combining, and the patches may be almost eliminated.

* Circulars giving more complete discussions of each of these weeds are available on request.

Wild garlic or wild onion. The tops of this pest of wheat fields and pastures can be killed and the formation of aerial bulblets prevented by the use of ester formulations of 2,4-D. The application should be made early—before March 15, if possible, in southern Ohio, and before April 1 anywhere in Ohio. The best rate is 2 to 3 pounds per acre. Neither rate will injure bluegrass, nor has even 4 pounds injured winter wheat seriously at Columbus when applied before April 1. It will not be possible to sow legumes in wheat sprayed at these rates. The underground parts of garlic are not usually killed, so that repeated treatments will be needed for eradication, if, indeed, eradication is possible with 2,4-D.

Johnsongrass. Both TCA and sodium chlorate are effective on Johnsongrass, but cultural methods are much more important than any herbicide in combating this weed.

Poison ivy. (See "Woody plants," following.)

Quackgrass. Cultural methods should also be depended on to control any large infestations of quackgrass. Sodium chlorate is effective at rates of 2 pounds per square rod (300 pounds per acre) and up, either in September-October or April-May, with retreatments following, but it sterilizes the soil too long to be desirable.

TCA is perhaps the most satisfactory chemical available today. It is most economically used in August or September, applying 50 pounds per acre of the commercial 90% sodium TCA per acre immediately after shallow plowing and disking down. The field should go to corn the next year, in order to keep the quack areas cultivated. Corn will not be injured by the fall treatments.

A spring treatment which is still experimental but very promising is to use maleic hydrazide (MH) at 8 to 12 pounds per acre on the spots of quackgrass in fields that are to go to corn, as soon as the grass is well started (late March or April). From 4 to 10 days (**this exact period is important**) after treatment, plow the field. Several experimenters, including the Ohio Station, obtained over 90% control by this method in 1952. It should not be expected to eradicate the grass. The corn following will not be injured.

Killing Woody Plants—Trees and Brush

In Ohio, trees, shrubs, stumps, and sprouts are an important part of the unwanted plant growth with which the farmer must contend. Great advances have been made recently in the chemical control of brush and woody plants. Many points remain to be worked out, but great savings in labor are possible today. 2,4,5-T is much more effective on many woody plants than 2,4-D. However, there are some plants on which 2,4-D is the more effective and 2,4-D is very much less expensive. Consequently, there are on the market a considerable number of "brushkillers", which are mixtures of esters of 2,4-D and 2,4,5-T, either half and half, or 60 or more percent of 2,4-D and 40 or less percent 2,4,5-T. For mixed brush, where one does not know the species involved, or where many species are present, these "brushkillers", especially the 50-50 mixtures, are quite satisfactory. For use on sprouts from osage orange "hedge", straight 2,4,5-T will probably be the most economical material. The long-chain "low-volatile" ester formulations are recommended for use on woody plants. Ammonium sulfamate, is also useful for poison ivy, especially, and for woody plants generally. It is more expensive than 2,4-D or 2,4,5-T, but there is no hazard of drift or vapors injuring nearby sensitive plants.

Foliage sprays. These materials can be used in several ways. If the growth is not over 4 or 5 feet tall, the standard method is to spray after the foliage is well developed, with a drenching spray containing 4 pounds acid per 100 gallons of water. Since the better grades of these materials are made up at 4 pounds, acid equivalent, per gallon of concentrate, this means 1 gallon of this concentrate to 100 gallons of water. However there are concentrates on the market which contain down to only 1 pound acid per gallon, **so read the labels,** and make up solutions accordingly. Ammate should be used at ¾ to 1 pound per gallon. Special attention should be given to covering the plants thoroughly, and sufficient pressure to penetrate the cover should be used. Care must be taken, always, that the

material does not drift to adjacent sensitive plants.

If the brush is more than 4 or 5 feet tall, cut close to the ground, and spray the stumps and stubs with a solution of 8 to 16 pounds acid in 100 parts of kerosene or fuel oil. The edges and ground line of the stumps should be well wetted with this mixture as described below for basal treatment. This will kill most stumps and prevent most sprouting. Any sprouts that develop from these stumps should be sprayed with a foliage spray made up as described in the preceding paragraph. For an area of many small stumps or stubs, it may be more economical to treat the sprouts without first treating the stumps.

Ammate can be used either by distributing the dry crystals at the edge of the stump or by applying a concentrated water solution (4 pounds of Ammate to 1 gallon of water) to the top of stump, again paying particular attention to the junction of the wood and bark.

Basal applications. Perhaps the most effective method of using brushkiller or 2,4,5-T is to use a solution of 8 to 16 pounds acid per 100 gallons of either brushkiller or 2,4,5-T in diesel fuel or kerosene to spray just the bases and ground line of standing trees and brush at any time in the winter or early spring, when there are no leaves to interfere. The spray should be liberally applied so that the ground line is well wetted. An excess of solution at the base to run down into the root crown is essential to success. This has been successful on more species than any other method of application. It has the great advantage of getting the work done at a less busy time of year and of avoiding much (definitely not all) of the hazard from drift.

Simpler equipment can be used, since there is no need for high pressure in putting on this spray. An ordinary 3-gallon hand sprayer will do an excellent job. Brush treated in this manner will often leaf out the next spring and then die during the summer. Basal applications are probably equally effective in the summer. The labor and material cost of this method is high, but it is simple and effective. Ammate is not useful in basal applications.

Problems in Applying Herbicides

Herbicides are usually applied in water or oil solutions or emulsions. Any equipment which will distribute the spray mixture uniformly on the plants or area to be treated is satisfactory. In making pre-emergence applications, complete uniform coverage is essential. In applying translocated sprays, such as 2,4-D, if the spray does not run off the plants, the amount of water in which the spray is applied will not affect the results except as it affects uniformity of application. Contact herbicides must be applied to cover the entire plant.

For weed control in field crops with 2,4-D there is no need for high pressures or large amounts of water. Good results have been obtained with equipment operating at 30-40 pounds pressure and applying 5 gallons per acre where the equipment traveled at the rate of 4 miles per hour. There is some evidence that 10 gallons per acre give enough better distribution than 5 gallons to justify using that amount. Where dense foliage must be penetrated, as in roadside spraying, higher pressures with more dilute solutions may be justified.

Low gallonage spraying. There are at least three important variables in applying 2,4-D with a low-gallonage sprayer—the size of the nozzle opening, the pressure in the tank, and the speed of travel. It is desirable to use nozzles with interchangeable tips so that the rate of delivery can be changed from 5 gallons per acre to 10, 20, or 40 gallons per acre without changing the pressure or rate of travel of the equipment. This enables the operator to apply the necessary amount of water to obtain uniform coverage, depending on the density of foliage or the necessity of complete cover-

Calibrate equipment accurately. Put water in your sprayer, set the speed of travel at a standard rate (3 to 4 miles per hour) keep pressure constant, and spray a measured area of an acre or more. Measure the amount of water sprayed out and calculate the amount of water applied per acre. Make up solutions with the recommended amount of 2,4-D per acre in the amount of water delivered per acre by your sprayer.

How can one tell how much of a commercial product to use? The amount of 2,4-D acid in commercial formulations varies from 9.6 to 83 percent. Obviously it is not possible to give directions for using each of the hundreds of products on the market. Recently manufacturers have put out materials containing an even number of pounds of active material per gallon of concentrate.

Table 1 gives data on typical liquid formulations, and data from it will fit many products on the market. **Read the label,** and see if the product you have is different from these. In general, it is satisfactory to follow manufacturers' directions for their products. After all, they have a high stake in your obtaining good results.

For example, to apply ½ pound per acre of 2,4-D in the amine salt formulation represented by the top line of the table, one would put (2x½) = 1 pint of the material into the amount of water for one acre; to apply ¼ pound per acre of 2,4-D in the butyl ester formulation, apply (3x¼) = ¾ pint of the formulation per acre.

Cleaning spray equipment. If sensitive crops are to be sprayed with other materials using sprayers previously used for 2,4-D, this equipment should be carefully cleaned. (Wooden tanks can hardly be freed of 2,4-D.) After applying an amine formulation, rinse thoroughly, allow a 1 percent solution of household ammonia (2 teaspoonsful per quart of water) to stand in the spray tank, booms, and hoses for 12 to 24 hours, then rinse thoroughly again. A 1 percent suspension of activated charcoal will clean the sprayer in about 2 minutes. Rinse thoroughly. The effectiveness of either method should be tested when possible—spray young tomato or bean plants from the cleaned sprayer—if no effect in one or two days, the equipment is safe.

Because they are in an oil base, ester formulations are much more difficult to remove than amine salts. Rinse the sprayer twice with gasoline or kerosene when esters have been used; then clean with ammonia or activated charcoal as described above, or use trisodium phosphate (TSP) at 2/3 ounce per gallon of water.

Table 1. Data on typical commercial formulations of 2,4-D

Type of compound	2,4-D acid	Wt./gal.	2,4-D acid/gal.	2,4-D acid/pint	Pints per acre to give 1 lb. 2,4-D acid
	Pct.	Lb.	Lb.	Lb.	Pints
Amine salt	40	10.0	4.00	0.50	2
Butyl ester	32	8.3	2.64	0.35	3
Isopropyl ester	37	8.9	3.29	0.41	2½

Table 2. Effect of 2,4-D on Crops

Selective control of weeds with 2,4-D is not possible in the crops in Column a. With proper dosages and precautions (specific for each crop) susceptible weeds may be killed in the crops in Columns b and c. The crops in Column c are more tolerant than those in Column b.

a. 2,4-D will kill	b. 2,4-D can injure	c. 2,4-D will not usually injure
Alfalfa	Barley	Bromegrass
Alsike clover	Bentgrass	Fescue grasses
Cotton	Corn	Kentucky bluegrass
Cowpea	Lespedeza	Orchard grass
Crimson clover	Flax	Reed canarygrass
Field pea	Oats	Timothy
Red clover	Redtop	
Soybean	Rye	
Sugar beet	Sorghums	
Sweetclovers	Wheat	
Vetches	White clover (includes Ladino)	

Table 3. Seedlings or young growth of the following weeds will usually be killed or controlled by 2,4-D at the ¼ to ½ pound per acre rate recommended for corn and small grain fields.

Annuals	Perennials and Biennials
Black medic or yellow trefoil	Artichoke
Butterprint, Indian mallow or velvetleaf	Bindweed, field* (often called morning glory)
Carpetweed	Bindweed, hedge^
Cocklebur	Buckhorn
Fanweed, Frenchweed, or stinkweed	Bull thistle
Fleabane, daisy	Burdock
Flower-of-the-hour	Canada thistle*
Galinsoga	Chicory
Hemp	Cinquefoils, five-fingers
Lamb's quarters	Dandelion
Morning glory (annual)	Heal-all
Mustard, tumbling	Nettle, stinging
Mustard, wild, or charlock	Plantain, common
Peppergrass	Sunflowers, perennial
Pigweed, rough	Wild sweet potato, man-of-the-earth
Pigweed, prostrate	
Radish, wild	
Ragweed, common	
Ragweed, giant	
Sunflower	
Tumbling amaranth	^See discussion

Table 4. Weeds that will not usually be killed or controlled by 2,4-D at the ¼ to ½ pound per acre rate.

A star (*) indicates weeds that can usually be killed or controlled by 2 to 3 pounds of 2,4-D acid per acre.

Annuals	Perennials and biennials	
Bitter wintercress	Aster, fall—*Aster* sp.	Milkweed, common
Black nightshade	Blackberries	Milkweed, climbing
^Bedstraw	Bladder campion	*Mouse-ear chickweed
*Buckwheat, wild	Bermudagrass	*Mullein, common
Catchflys	Bouncing Bet	Night-blooming catchfly
*Chickweed, common	Butter and eggs	Nimblewill
Corn cockle	*Buttercups	Ox-eye daisy
*Dodders	*Carrot, wild	*Pokeweed
*Fleabane, Canada (marestail)	Cattails	Quackgrass
Grasses, all	*Catnip	^Sorrel, red or sheep
*Henbit or dead-nettle	*Docks	Spurges
*Jimsonweed	*Dogbane (Indian hemp)	Swamp or perennial smartweed
*Knotweed, doorweed	Foxglove beardtongue	*Teasel
*Lettuce, prickly	*Goatsbeard	Violets
*Mallow, roundleaved	*Goldenrods	*Water hemlock
*Mayweed or dog-fennel	Ground cherry	White cockle
*Purslane	*Ground ivy	*Wild garlic
*Shepherd's purse	Horse nettle	*Wild onion
*Smartweed	*Horsetail	*Wild parsnip
*Speedwells	Ironweed	*Yarrow
*Wild cucumber	Johnsongrass	
Wood sorrel		