THE CONTROL OF JOHNSONGRASS (SORGHUM HALEPENSE L. PERS.)
BY HERBICIDES AND CULTURAL PRACTICES

DISSERTATION

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EVERT OAKLEY BURT, B.S., M.S.

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Approved by:

[Signature]

Adviser
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THE CONTROL OF JOHNSONGRASS (Sorghum halepense L. Pers.)
BY HERBICIDES AND CULTURAL PRACTICES

INTRODUCTION

Johnsongrass is one of the worst pests with which farmers have to contend wherever it becomes established. Although this plant can be controlled and even eradicated, the increasing number of acres being abandoned to it annually is evidence of the inadequacy of the control measures. It is legally classed in Ohio and many other states as a primary noxious weed. The principal characteristics which have caused it to be so rated include its extensive system of underground rootstocks with large food reserves, and the large amount of seed that is produced, some of which may remain viable in the soil for a number of years.

As a result of the decline in population of broadleaf species by the use of 2,4-dichlorophenoxyacetic acid (2,4-D), grasses are able to establish more readily and may offer a more serious problem than broadleaf species. Perennial grasses, especially those with a rhizomatous habit, are among the most difficult weeds which farmers must fight. This is true because of the ease with which the plants are spread by seeds and rhizomes, because of their high resistance to cultural practices, and because of the ineffectiveness of 2,4-D and related compounds in controlling them.

Since Johnsongrass spreads rapidly and is difficult to eradicate after it is once established, it is a serious weed pest not only in
the sugarcane and cotton producing sections of the south, but also in
the rich river bottom lands to the north where corn is a high value
crop. A survey of three counties in southern Ohio in 1937 (Willard,
1953b) showed 1,000 acres abandoned to Johnsongrass, with 4,000
additional acres seriously infested. The situation has become
steadily worse since, until many persons have despaired of continuing
crop production in the river bottoms. Although the actual acreage
involved in Ohio is not large, Johnsongrass infests much of the most
fertile land of the Ohio River Basin.

During recent years tremendous advances have been made in the
field of chemical weed control. Unprecedented interest in new herbi­
cides has been created by the spectacular successes achieved through
the use of 2,4-D. Aside from the control of grasses at time of germina­
tion by pre-emergence treatments, 2,4-D has had little or no effect on
established grasses. Chemicals that are effective in controlling
established grasses are required in relatively large amounts and it
is therefore expensive to treat large areas.

Cultural methods have given successful control and even eradication
of Johnsongrass. However, the necessity of taking the land out of
production and the expense incurred by following cultural practices
have limited their use.

The need for better methods of controlling established stands of
Johnsongrass has been apparent for many years, in spite of the fact that
much work has already been done on this problem.
Johnsongrass

Distribution. According to Vinall and Crosby (1929) Johnsongrass is a native of the Mediterranean coast countries of Europe, Africa, and Asia. It was introduced into the United States from Turkey about 1830. Governor Means, of South Carolina, sent a planter to Turkey to teach cotton culture, and on his return the planter brought seeds of this grass with him. About 1840, Colonel William Johnson, of Selma, Alabama, carried seeds of this grass from South Carolina to the rich bottom lands of the Alabama River. It thrived wonderfully in this new locality and because of Colonel Johnson's utilization of and enthusiasm for this grass, it became known as Johnsongrass. Since that time, Johnsongrass has been intentionally cultivated and unintentionally disseminated in many areas of the United States.

Johnsongrass has become a nuisance in the alluvial river bottoms and rich black prairie lands of the Gulf States and as far north as the Ohio Valley and southwestern Kansas (Wheeler, 1950, p. 655). It is also classed as a pernicious weed in the irrigated lands of New Mexico, Arizona, and California, where it grows luxuriantly along the irrigation canals. It extends along the Pacific Coast in the river valleys as far north as Oregon and Washington (Martin and Leonard, 1949, p. 424). A recent distribution map by Hitchcock (1951) shows that the plant may be found in all but about a dozen northern states.

Pammel and King (1919) reported that Johnsongrass survived the severe winter of 1916-1917 which was cold enough to damage alfalfa
and winter wheat. Willard (1925) reported the establishment of a
Johnsongrass stand at Columbus, Ohio, which survived for 8 years.
Talbot (1940) and Paulling (1945) pointed out that the germination
of the seeds may be delayed several years.

There is no accurate record of the date of the first infestation
in Ohio. The first recorded reference to Johnsongrass in Ohio was in
a survey by Keeler et al. (1932) in which they reported a stand of
Johnsongrass which was present in 1918 on the Robert Free farm in
Highland County. They stated that this was apparently the upstream
source of infestation on Paint Creek.

Johnsongrass is now well established in many lowland areas of
southern Ohio, but there are few seriously infested areas north of
U. S. Highway 40. This is probably because Johnsongrass is susceptible
to injury by severe freezing. There are few infestations of the grass
on uplands, but the plant is widely established in bottomlands due to
the deposition of seeds by flood waters in the fertile alluvial soils.

Soil Adaptation. Johnsongrass is best adapted to heavy clay
soils of relatively high fertility and water-holding capacity (Bennett,
1940). However, it also grows well on fine sandy loams. Good yields
can be obtained on any soil that will produce good yields of cotton
or corn, but it will not grow well on poor or depleted soils.

Description of the Plant. Johnsongrass, Sorghum halepense (L.)
Pers., is a monocotyledon belonging to the Gramineae, or grass family.
It is an erect perennial that propagates by seeds and rootstocks. The
leaves are 12 to 18 inches long, 1/4 to 3/4 inch wide, smooth, with
the mid-veins thickened and white. The plant is highly cross-fertile.
The inflorescence is a loose purplish panicle that is large and open when in bloom (Figure 4). The seeds shatter readily when ripe. A single seed may produce from 1 to more than 100 culms or stems per plant, depending upon fertility, moisture, and space, as well as inherent differences (Bennett, 1940). The spikelets are sessile, plump, and pubescent. The awns are 1 to 1.5 cm, long and deciduous. Some seeds of Johnsongrass have short stems because of failure to separate at the articulation of the rachis and spikelet. In such cases, the distinct suture at the articulation in Johnsongrass seed distinguishes it from that of Sudangrass, *Sorghum vulgare* (Hillman, 1916).

In addition to the fibrous roots customarily associated with grasses, Johnsongrass produces numerous underground stems, rootstocks, or rhizomes, which send up shoots from axillary buds at the nodes, or joints, thus producing new plants. The rhizomes are usually large, 1/4 to 1 inch in diameter, fleshy in appearance, and have pronounced scale leaves at the nodes (Figure 2). Johnsongrass resembles and is closely related botanically to Sudangrass, the chief difference between the two grasses being the presence of rootstocks on the former. These rootstocks on Johnsongrass are most abundant at a depth of 6 to 8 inches (Russ and Zahnley, 1951), but in cultivated fields they are often found 18 to 24 inches beneath the surface of the soil (Wheeler, 1950, p. 656). The stems are smooth, pithy, and stout. They vary in height from 3 to more than 10 feet, according to the fertility of the soil and the abundance of soil moisture. In thick stands the stem is ordinarily not more than 1/8 to 3/16 inch in diameter, but on spaced vigorous
plants the diameter is somewhat greater (Wheeler, 1950, p. 656).

Johnsongrass produces from 500 to 600 pounds of seeds per acre annually (Pollock, 1927). The seeds are markedly dormant when first mature, and require a number of months for complete after-ripening and then do not germinate completely except with the use of alternating temperatures in a warm temperature range (Harrington, 1918). Seeds of its close taxonomic relative, Sudangrass, germinate freely under a wide range of temperature conditions, either constant or alternating, and without any appreciable period of after-ripening.

The inner integument and the various layers of the pericarp of Johnsongrass seeds contain tannin compounds which decrease their permeability. These layers and the need for after-ripening explain the excellent results from winter and fall seeding of Johnsongrass (Harrington and Crocker, 1923).

Growth Characteristics. For convenience of description, Cates and Spillman (1907) classified rhizomes as primary, secondary, or tertiary. Primary rhizomes are those which are alive at the beginning of the growing season but decay after the season is over. Secondary rhizomes arise from the primaries, grow to the surface and there form new plants. As a rule they are no larger in diameter than the primary rhizomes from which they develop, and their length is determined by the depth to which the primary rhizomes are buried. Tertiary rhizomes are those that develop from the base of the crown about flowering time. Under optimum conditions these rhizomes may extend to as much as 4 feet in depth and commonly from 15 to 30 inches. When the soil is compact or the stand is mowed or grazed the tertiary rootstocks are found just
below the surface of the soil, cropping out at intervals and forming new plants.

Much of the top-growth which occurs in the spring is at the expense of the rhizomes. After the tops have become established, the new rhizome growth begins. The development of rhizomes is correlated with top-growth (Sturkie, 1930, 1937; Talbot, 1940; Hughes et al., 1952, p. 365).

Sturkie (1930) and Talbot (1940) observed that rhizomes usually begin to appear at the time of seed formation on seedling plants. More recently, Russ and Zahnley (1951) and Oyer et al., (1951) have reported that Johnsongrass seedlings develop rhizomes prior to blooming, in fact, in less than 2 months after germination. Pollock (1927) stated that new rootstocks begin to form when the plants reach a height of 10 to 15 inches. Sturkie (1930) found that some rhizomes formed late in the season even if heads were not allowed to appear, the most rapid growth of rhizomes occurred as the seeds matured. He postulated a transfer of food from the tops to the rhizomes as the plants reached maturity, resulting in a decrease in weight of the tops and an increase in weight of the rhizomes. The tendency of the rhizomes to grow most actively in the latter part of the summer explains the difficulty in controlling Johnsongrass in intertilled crops such as corn.

The seasonal trend in the food reserves has been followed by taking rhizome samples from potted plans periodically over a period of a year. Rapp (1947) found that sucrose is the predominant carbohydrate in the rhizomes, except when new top-growth is being formed. During the period of initial growth, the total carbohydrates of the rhizomes
decrease as the tops are forming. Reducing sugars predominate in the rhizomes up to the time of seed formation. After this stage the total carbohydrates increase, with the increase being primarily in the sucrose component. Rapp determined that the sucrose increased from a low of 30 milligrams per gram of oven-dry tissue, 51 days after growth started, to a high of 310 milligrams per gram at 365 days. All components increased in the tops during the first 120 days, after which date the weight decreased. The latter decrease was attributed to the translocation of glucose to the rhizomes where it was stored as sucrose.

**Economic Value.** In spite of all the objections to Johnsongrass, it must be said in its defense that it has supplied a substantial part of the hay for livestock feed in the South (Wheeler, 1950, p. 655), that it gives good yields of hay when properly managed, and that such hay, when cut at the right time and well cured, is equal or superior to timothy and most other grass hays (Grimes and Taylor, 1930, 1935; Leveck, 1939). Martin and Leonard (1949, p. 424) rate it as the most important perennial hay grass of the southeastern United States. Vinall and Crosby (1929) stated that the principal grass of the Alabama Black Belt was Johnsongrass. According to Pollock (1927), more hay is produced from Johnsongrass than from any other perennial hay plant in Texas. However, Johnsongrass hay is rather coarse and contains so many stems that it is difficult to cure for hay.

Where it already occupies the land, Johnsongrass may be utilized profitably as a hay crop with good management practices, but it does not make a good permanent pasture. Pasturing Johnsongrass weakens it considerably and causes the rootstocks to be produced near the
surface, thus making it easier to destroy the grass. Consequently, it is used to a lesser extent for pasture than for hay. It does not stool to a great extent, and the basal foliage is scant. It has about the same carrying capacity as Bermudagrass and will generally support one or two mature animals per acre, depending on the fertility and rainfall (Pollock, 1927). Akers and Westover (1934) found that Johnsongrass-sweetclover pastures produced more beef per acre than other mixtures used at the West Point Branch of the Mississippi Agricultural Experiment Station. Close grazing of Johnsongrass-sweetclover pastures, however, necessitated the reseeding of these plants every other year. Vinall and Crosby (1929) credited exposed rootstocks for carrying hogs and cattle during the winter. This grass is also used to reduce soil erosion. The network of rhizomes and roots of Johnsongrass makes it ideal for this purpose (Briggs, 1944).

In general, however, the rhizomatous habit of growth makes this an undesirable species. In recognition of this fact, breeding work was initiated and a perennial forage strain free of rootstocks was announced in the October, 1951 issue of What's New In Crops and Soils.

Johnsongrass as a Weed. Although Johnsongrass has considerable agronomic value and was therefore cultivated quite extensively in some areas after its introduction into the United States, it soon became apparent that the grass, once established, would be difficult to eradicate. Ordinary tillage may serve to do little more than to invigorate the grass. Consequently, Johnsongrass is a major problem in fertile areas planted to intertilled crops.
Johnsongrass is enemy number one in cultivated fields of both sugarcane and cotton (Cobb, 1950). It has been harder fought by more different methods than any other grass. Over 100,000 acres of land in the sugarcane belt alone are so badly infested with Johnsongrass that cane cannot be produced economically. These lands are the best cane lands in the area. Johnsongrass grows best where cane grows best. According to Overpeck (1925), Johnsongrass is one of the worst pests with which farmers of New Mexico have to contend. It is listed by Robbins et al. (1952, pp. 361 and 371) as one of the principal weeds to infest cotton in the southern states and as one of the most serious weeds in established alfalfa in California.

Ball (1902) stated that the seeds of Johnsongrass are commonly disseminated by floods, birds, cattle, and the sale of unclean agricultural seed. The seeds and rhizomes may also be spread by farm machinery and by the transportation of forage and grain. Ball noted that the seeds passed unharmed through the digestive tract of animals, thus readily disseminating the pest.

Cultural Control of Johnsongrass. Johnsongrass has been effectively controlled by cultural means for many years. Talbot (1928) and Willard and Beard (1933) set forth the necessary objectives. They are (1) to weaken and kill existing rootstocks and to prevent the formation of new ones, (2) to kill seedlings from seeds already in the soil, and (3) to prevent the ripening and scattering of more seeds. Complete eradication of Johnsongrass is not feasible on areas which are frequently flooded, since reinfestation may occur from seeds and rhizomes washed in by floods (Talbot, 1928; Paulling, 1945; Willard, 1953).
Successful methods of eradicating Johnsongrass on land not subject to overflow have been known and recommended in Ohio since 1933 (Willard, 1953).

The first step in any cultural control program is that of mowing frequently or grazing intensively over the infested area. The general vigor will be reduced, as demonstrated by Sturkie (1937), and the rhizomes will be concentrated near the surface. Furthermore, this procedure prevents the production of seeds.

When Johnsongrass is deliberately grown as a forage crop, it is difficult to maintain a vigorous stand. Any cutting treatment before maturity will reduce the production of rootstocks and hay (Sturkie, 1930, 1937; Talbot, 1940; Hughes et al., 1951, p. 365). The more frequent the cuttings the greater is this reduction. Sturkie found that cutting late in the season reduced top-growth the following year as much as cutting throughout the season, even though the weight of rhizomes in the soil was not reduced as much by the former treatment. This indicated that the food reserves had been reduced by late cutting more than the rhizome weight indicated. Cutting the foliage only in the first half of the season allowed 40 percent more rhizome development than continuous cutting. This investigator also found that the maximum yield of Johnsongrass hay was produced when the plants were cut when seeds were in the late milk stage. Cutting only until mid-summer produced as much hay as did continuous cutting. Cutting only every other year resulted in almost twice the total yield in the year of harvest compared with cutting once each year.

Results by Oyer et al. (1952) indicated that repeated clippings at biweekly intervals were as effective in controlling Johnsongrass as
were cultivations at similar time intervals. They also noted that an initial clipping of Johnsongrass top-growth reduced the carbohydrate content of the rhizome tissue greatly, but additional clippings had little effect on the composition of the viable rhizome tissue.

Where facilities for caring for livestock are available, pasturing offers one of the most economical means of controlling Johnsongrass. However, the problem of maintaining fences, suitable water, and an adequate number of livestock limits the usefulness of this method. Pasturing must be sufficiently heavy throughout the summer to control top-growth. If there is not sufficient livestock on the farm to accomplish this, mowing should supplement the grazing. The plants should not be permitted to grow more than a foot high and certainly no plants should be allowed to produce seeds (Paulling, 1945).

One of the most satisfactory methods of control is obtained from an all-season fallow. Hagood (1951) stated that 7 to 9 plowings in the spring and summer have proved to be more effective and considerably cheaper than the use of chemicals on land to be planted to sugarcane. He (1950b) obtained 99 percent control of the rhizomes by plowing 6 times at 2-week intervals while only 73 percent control was obtained by mowing at 2-week intervals. Stamper and Chilton (1950) reported that fallow plowing or continuous plowing the year sugarcane is not grown is the best method of control for established Johnsongrass. The 6 to 11 plowings required cost from 12 to 16 dollars per acre. While effective in reducing the vigor of the rootstocks and even in destroying them, a single season of fallow plowing, does not destroy the dormant seeds. The plants from seed are only slightly less serious in corn
than those from rhizomes (Willard, 1953). More than one season of fallow seems to be necessary unless the production of seeds is prevented by mowing or grazing previous to fallow, or unless seedlings are controlled by flaming, roguing, or chemicals. Headley and Hastings (1908) emphasized the necessity of thorough and frequent cultivations. Instead of injuring Johnsongrass, improper or infrequent cultivations make it thrive.

Many authorities have suggested plowing in the late fall or summer after 1 or 2 years of such mowing or grazing. (Gates and Spillman, 1907; Roberts, 1920; Pollock, 1927; Talbot, 1928; Paulling, 1945; Cobb, 1950; and Willard and Beard, 1950). The plowing results in the exposure of rhizomes to freezing during the winter. If soil erosion is of concern, winter barley can be planted in September (Willard, 1953), and can be harvested the next season before the Johnsongrass is advanced enough to interfere with the harvesting. Frequently it is necessary to repeat this procedure a second year. This will kill all but occasional plants of Johnsongrass, which can be cleaned up chemically, with little loss of crop if the land is utilized as pasture or hay the first year. Willard (1953) states that heavy pasturing or frequent mowing for 1 year until frost, followed by plowing and leaving the land rough and unworked over the winter, will reduce Johnsongrass sufficiently under some conditions to permit growth of a corn crop the next year.

The value of alfalfa in weakening Johnsongrass has been mentioned by Talbot (1940), Paulling (1945), and Willard (1953).

Willard (1953) reported that late spring preparation of corn
land may be effective in reducing the competition of Johnsongrass with the corn crop. This procedure accomplishes two things. Firstly, the last plowing destroys the first vigorous sprouts, and leaves the rootstocks somewhat depleted and slower to recover; secondly, one crop of seedlings in the surface soil is destroyed by the afterworking.

Overpeck (1925) stated that Johnsongrass can be controlled in cotton fields by flocks of geese, since the geese prefer the grass to cotton and eat the top-growth of Johnsongrass, leaving the cotton plants unmolested.

While cultural practices for control of Johnsongrass have been used extensively, several herbicides have been used with varying degrees of success. Some of the properties as well as some of the effects of the most promising herbicides for the control of Johnsongrass will be discussed.
Sodium Chlorate

Properties. Sodium chlorate (NaClO₃) is a white crystalline salt that resembles common table salt, sodium chloride (NaCl), in appearance. It may form large crystals resembling rock salt, but it is usually ground to about the consistency of table salt for herbicidal use. It is formed hydrolytically by combining sea salt (NaCl) and oxygen in aqueous solution (Robbins et al., 1942, p. 254). It is very soluble in water: 75 grams will dissolve in 100 cc. of water at 0°C.

It is a strong oxidizing agent, and, besides having many uses in industrial chemistry, it has been employed in the manufacture of matches and fireworks. Sodium chlorate has some features which are objectionable. It is corrosive to metal spray equipment. Sodium chlorate itself will not burn but when added to any readily oxidizable material, forms an easily ignited, highly combustible mixture that is dangerous to handle. Since it has a salty taste, "salt hungry" animals may eat sufficient quantities to be poisoned.

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 inexpensive to be seriously considered as a general weed-killer (Willard, 1953). In adequate concentration it will kill any plant life. Plants vary enough in their susceptibility so that it can be used selectively in some instances, but in general it is usable only when temporary soil sterility for a period of 6 months to 3 years is not objectionable. It is toxic to plant
tissue as a contact spray. It will kill plants upon being absorbed by the roots, and under certain conditions it is translocated. Dormant seeds in the soil usually survive the rates commonly used. Sodium chlorate dissolved in the soil water readily penetrates and kills the roots and rhizomes either of actively growing or of dormant plants (Loomis et al., 1933). It is believed that actively growing roots absorb the chlorate ions most rapidly. Once the chlorate has been leached into the root zone a decrease in soil moisture increases its killing action. This is probably due to the resultant increased concentration of the chlorate in the soil solution (Crafts, 1953).

Persistence in the Soil. Sodium chlorate is principally removed from the soil by leaching (Seely et al., 1948; Bowser and Newton, 1933; Crafts, 1952; and Robbins et al., 1942, p. 278). The distribution of chlorate in soils is largely determined by the amount of water that passes into and through the soil after the chemical is applied. Consequently the effects of precipitation, soil texture and structure, organic matter content, and temperature (frozen soils) are very important. In areas of low annual precipitation chlorate may remain toxic for 5 years or even longer, whereas in the more humid area of southeastern United States toxicity may disappear in 18 months on heavy soils and in 6 to 10 months on sandy soils. In addition to the removal of chlorates from the soil by leaching, soil microorganisms are able to reduce their phytotoxic effects by decomposing them to chlorides (Seely et al., 1948; Schwendiman, 1941). Schwendiman found chlorate decomposition was greatest at high moisture levels and high soil temperatures.
When soil sterility from sodium chlorate is undesirable it may be partially corrected (1) by adding large amounts of easily decomposed organic materials such as alfalfa, sweetclover, or manure, (2) by heavy leaching with water, (3) by adding 600 to 700 pounds of gypsum per acre on soils not high in lime, or (4) by adding about 40 pounds of nitrogen per acre in the form of a nitrate fertilizer (Seely et al., 1948).

The basic cause of chlorate toxicity to plant tissue is unknown. The chemical disrupts the metabolic processes to such an extent that they no longer function properly (Ahlgren et al., 1951, p. 96). Sodium chlorate causes a depletion of food reserves (Latshaw and Zahnley, 1927; Crafts, 1935; and Bakke et al., 1939), a temporary increase in rate of respiration, and a decrease in catalase activity (Neeler, 1931). Plants increase in susceptibility to frost injury after treatment with chlorates (Latshaw and Zahnley, 1927). This can probably be attributed mainly to the depleted food reserves.

The Use of Sodium Chlorate on Johnsongrass. Since its introduction as an herbicide in 1926, sodium chlorate has been the most widely used chemical for the control of Johnsongrass. Prior to that time other chemicals had been used to a limited extent. Ball (1902) mentioned the use of sodium chloride, calcium chloride, arsenic, and kerosene. Overpeck (1925) listed sulfuric acid, kerosene, gasoline, and brine solutions as being toxic, but all of these materials proved to be too expensive. Even with chlorate, its cost usually limits its use to the smaller infestations. Moreover, the chemical can be expected to prevent crop production for 6 months or longer. Another important drawback in the
use of sodium chlorate is the ease with which it will oxidize organic matter, making it a fire hazard. Atlacide, a commercial mixture of sodium chlorate and sodium carbonate with a 60 percent chlorate content, reduces but does not eliminate the possibility of combustion. The mixture is phytotoxic in proportion to its chlorate content.

Recommendations for the use of sodium chlorate vary considerably, but a rate of 300 pounds or more per acre is usually suggested. Stamper and Chilton (1950) recommended as high as 600 pounds per acre for a good kill of rhizomes, but found that 450 pounds per acre was equally as effective in many cases. Harper (1930) and Willard and Beard (1950) recommended 500 pounds per acre as a practical rate of application. Willard (1953b) suggested that 100 pounds per acre may be used if Johnsongrass is weakened by heavy pasturing, repeated mowing, plowing, or cultivation prior to application.

**Time of Application of Chlorate.** Complete agreement has not been reached as to the best time of the year to apply chlorate. Paulling (1945) recommended September or October as the best time to apply chlorate since it will be leached into the soil by fall rains. Harper (1930) found October and mid-winter applications to be ineffective. Stamper and Chilton (1950) reported that best results were obtained when the Johnsongrass was headed at the time applications were made. Harper obtained 95 percent kill from 100 pounds per acre, applied on 12 to 18-inch regrowth after mowing on July 28. Applications made on 24-inch top growth on May 15, at the same rate, gave an initial top kill, but there was considerable recovery by fall. Seedlings appeared the year after treatment, indicating that many Johnsongrass seeds
remained dormant but viable during the time the chlorate was in the soil. Harper found that under summer temperatures and high moisture levels, the chlorate decomposed within 7 days. A residual toxic effect was noted which was traced to decreased nitrification in the soil.

Porter and Talley (1950) obtained better results from early spring applications when the rhizomes were still dormant than from applications made when growth had started. Rowley (1931) had equally effective results from April, June, October, or December applications of 10 percent sodium chlorate. He found no advantage in applications made on green tops as compared with applications made on dried tops.
Trichloroacetates

According to Hummer (1950) trichloroacetic acid (TCA) has been known for more than 100 years, but only in 1947 was it sufficiently investigated for herbicidal properties to establish its potential value in this field. During this short period it has become established as a valuable herbicide for the control of many grasses. The ammonium salt was the first to be used, with several other formulations soon following. At present the sodium salt is the most widely used. Unless otherwise stated, the use of TCA will refer to the sodium salt.

Properties. Trichloroacetic acid when in aqueous solution is nearly as strong as hydrochloric acid and has an extremely high solubility, both in polar and non-polar compounds. Hummer (1950) stated that trichloroacetic acid has a solubility of 92.3 percent by weight in water, 60 percent by weight in xylene, and is very soluble in both ether and alcohol. In the presence of alkaline agents in aqueous solution, trichloroacetic acid breaks down to yield chloroform and carbon dioxide or, in case of the sodium salt, chloroform and sodium carbonate. In the presence of pyridine in an alkaline solution, a magenta color develops in the pyridine layer. Hummer (1950) reported that this reaction can be used for a quantitative determination of trichloroacetic acid, accurate to 1 microgram. The test is not specific for trichloroacetic acid since it depends upon the presence of trimethyl groups.

Trichloroacetic acid has known protein precipitating properties, and, therefore, has been used as a fixative and for the treatment of
warts and other skin conditions. It has been reported to have an effect on certain enzyme systems. Bernhard and Rosenbloom (1949) reported an increase of organic phosphorus content when an adenosine triphosphate solution is allowed to remain for some time in a 5 percent solution of TCA.

The trichloroacetates are highly toxic to the protoplasm of plant cells. When applied to the tops of perennial weeds to kill underground reproductive parts, they may kill the phloem tissue, and this effect results in much slower rates of translocation (Ahlgren et al., 1951, p. 97). If applied to the soil and absorbed by the roots the trichloroacetates are rapidly carried to all parts of the plant through the xylem, since the xylem is principally "dead" conducting tissue.

**Effect of TCA Formulations.** Barrons (1948), working with quackgrass and bluegrass, found that the pure acid and the sodium and ammonium salts of TCA were equally effective. In making applications on dormant Johnsongrass no differences in effectiveness of calcium or sodium salts were found by McCall and Zahnley (1950). Burt and Willard (1952), working with alfalfa, found the calcium and sodium salts equally as effective, while Barrons and Hummer (1951) confirmed these findings, using quackgrass and wheat as test plants. Stamper et al., (1951) and Stiver et al., (1949) found no large difference between sodium TCA and ammonium TCA. In contrast, Stamper, et al., noted that the isopropyl ester of TCA was only half as effective as either of the salts. In a limited comparison of sodium TCA, calcium TCA, and TCA acid in oil on quackgrass, Peters (1952, p. 136) noted no difference in effectiveness.
between the two salts, though TCA acid in oil was somewhat more effective than either salt. Raleigh (1951) found calcium TCA to be more phytotoxic than sodium TCA.

**Mode of TCA Entry into the Plant.** TCA enters the plant primarily through underground parts. Applications made directly to the soil have generally yielded better results than foliage applications (Dow Chemical Company, 1949). Tests by Barrons and Hummer (1951) involving foliage treatment with no application to the soil showed that foliage is at most a relatively unimportant avenue of entry as far as the systemic effect is concerned. They suggested that top-growth of treated grasses, as well as other species present, may actually reduce the effective rate of TCA through absorption and tie-up of the TCA in the foliage. Stahler (1950) also indicated that TCA was most effective when applied so as to come into contact with the underground parts. In experiments involving application to plowed quackgrass sod, better kill was obtained than when the foliage was sprayed (Dow Chemical Company, 1949; Barrons and Watson, 1949), thus indicating further that the important avenue of entry is the roots rather than the tops. Plowing just prior to the application of TCA has now been established as a very efficient method of using this chemical for control of quackgrass (Carder, 1950; Friesen, 1950; Watson, 1950a; Willard, 1953a; Lee, 1951) and Johnsongrass (Willard and Peters, 1951).

**Translocation of TCA in Plants.** Three groups of workers have verified independently the systemic movement of TCA in plants. Barrons and Hummer (1951) maintained that although absorption by underground parts was the primary site of entry of TCA, the chemical might be moved
from tops to underground parts along a water tension gradient when
soil moisture was low and water was absorbed from the atmosphere by
the leaves. They listed tolerant and susceptible species and stated
that analysis of the soil solution and plant extracts showed TCA is
apparently absorbed at the same rate by both, resulting in a lowered
TCA content of the soil. A higher concentration of the chemical was
found in the sap of tolerant species than in that of susceptible species.
It was suggested that species susceptible to TCA utilize it in their
metabolic processes, while tolerant species do not; thus the TCA
accumulates. Peters and Willard (1951) observe that rhizome buds
of Johnsongrass developed abnormally after TCA was applied to the
soil. Elongation of the internodes was restricted and a disorganized
mass of meristematic cells was found at the apex. The same malforma-
tions were observed when the chemical was applied to the foliage,
indicating that the TCA was translocated from the tops to the rhizomes.
Hagood (1950a) dipped the tops of Johnsongrass plants in solutions of
several herbicides and then removed the tops at intervals of one, two,
and three weeks after treatment. Counts of new shoots that developed
from the rhizomes were made three months later, and the results
indicated that TCA, sodium chlorate, maleic hydrazide, and 2,4-D were
all translocated from the tops to the rhizomes of the plants.

There is evidence of some translocation through the foliage in
the case of vigorously growing Johnsongrass (McCall and Zahnley, 1952a;
Dow Chemical Company, 1950; and Hagood, 1951). Willard and Peters
(1951) found no evidence that translocation of TCA from the tops to the
roots or rhizomes was of any field importance.
Movement and Persistence of TCA in Soils. Arakeri and Dunham (1950), Loustalot and Ferrer (1950), Barrons and Hummer (1951), and Peters (1952, p. 136) all found that TCA gradually disappeared from the soil. In the latter three reports leaching was considered an important factor. Loustalot noted that in the absence of rain the chemical did not move downward in the soil more than 2 inches. With 1 inch of rain sodium TCA was moved to a depth of 8 inches in a silty clay loam soil. Enough TCA remained in the top 2 inches of soil, however, to inhibit the growth of corn seedlings. The interaction of rainfall and TCA movement has been emphasized by Barrons and Watson (1949b), McCall and Zahnley (1949b), Watson (1950b), Stahler (1950), and Peters (1952, pp. 128-131). Best results have been obtained when there was sufficient moisture to leach the herbicide down to the zone of greatest rhizome and root concentration and when heavy rains did not occur soon afterward. Light rains following treatment are beneficial, when heavy rains are likely to cause leaching and dilution in the root zone. In light, sandy soil a prolonged heavy rain can almost completely leach out the chemical, nullifying the herbicidal action. Applications should be avoided when heavy rains are anticipated, particularly if the soil is already saturated with water (Dow Chemical Company, 1949).

TCA was found to disappear fairly rapidly when no leaching occurred. Loustalot reported a more rapid detoxification in moist soils than in air-dry soils and at relatively high temperatures than in cool soils. Both Loustalot and Barrons found considerable variation in the detoxification period between soil types and between soils high and low in
organic matter. In contrast, Arakeri found no difference between soil types or between sterilized and non-sterilized peat. Barrons (1949) suggested that microorganism may be the cause of detoxification in the absence of leaching. In general, better results have been obtained on light than on heavy soil with the same amount of material.

In a study in Texas (Rea et al., 1952) the duration of the effect of 300 pounds per acre of TCA was not materially longer than that of 50 pounds per acre. On the other hand, Loustalot and Ferrer (1950), Peters (1952, p. 110), and Rea (1953) noted that toxicity persisted longer with higher rates of application.

McCall et al., (1950) applied TCA at rates of 50, 100, and 200 pounds per acre in November and observed that the soil was toxic to sweetclover and soybeans planted the following June, but corn and sorghum survived. In Ohio, Peters (1952, p. 136) found the residual soil toxicity from TCA applications to vary from 6 to 12 weeks depending principally upon the amount of rainfall. Rea (1953) stated that the residual effect of TCA in the soil is usually lost in 12 to 16 weeks when applied at rates of 50 pounds per acre.

Time of Application of TCA. TCA applications at almost all stages of growth have been tried by various workers. Since the phytotoxicity of TCA is dependent upon the internal processes of the plant and particularly upon the soil and climatic conditions, complete agreement on the results from the use of TCA would hardly be anticipated. There has been considerable variation in the degree of control obtained even in a given geographic area. Such factors as thickness of stand, temperature, rainfall, soil moisture before and after treatment, soil type,
and stage of growth of plants at time of treatment are not always recorded and may account for the erratic results which are reported. Porter and Talley (1949) and Bratte (1950) obtained better results from early spring applications than from summer applications on foliage. Bratte obtained the same degree of control with 100 pounds of TCA in July on Johnsongrass 15 to 16 inches high as with 50 pounds in March. Peters and Willard (1951a) had better results from applications made in March than in October. No growth from rhizomes occurred following the 20-, 40-, and 80-pound applications in March while only a few culms emerged at the 10-pound rate. In another study they (1951b) found May applications superior to those made in August. McCall and Zahnley (1950) obtained 95 to 100 percent control with 40-pound rates applied in April. Stamper and Chilton (1951) reported a 97 percent control of Johnsongrass in sugarcane in Louisiana from dormant applications in the spring with 10 pounds per acre on 24 inches of sugarcane drill. A control of 92 percent was observed from a similar treatment on stubble cane.

Elder (1949) applied 50, 100, and 150 pounds sodium TCA per acre at monthly intervals during the growing season from May through October. He reported 60 to 75 percent control from applications made in May and early June, 90 to 99 percent control when applied in July and August, and unsatisfactory control from September applications.

Reports by Texas workers (Hamilton and Rea, 1950a, 1950b) indicate that treatments made in mid-October were more effective than those made earlier in the season. Results of 2 years of testing in Arizona and in California (Dow Chemical Company, 1950) indicate that
the most effective time to treat Johnsongrass with sodium TCA is from the first of October to the time of frost. Spring and summer applications have resulted in control up to 6 weeks, but normal regrowth appeared following this temporary control. Applications made 1 year in August prior to a rain resulted in successful control but consistent results have been obtained only from fall treatments.

Several experiments have been reported in which TCA was applied to infested soil during the winter. Elder and Gassaway (1951) in Oklahoma applied 100 pounds of the chemical per acre to dormant plants in November and March. Complete kill of the rhizomes was obtained with the November treatment, but there was some regrowth on plots treated in March. November treatments gave equally as effective results in Kansas trials (McCall et al., 1950). Sodium or calcium salts of TCA applied at rates of 50 pounds per acre gave 95 to 100 percent control of top-growth. However, in Ohio, Peters (1952) found August and March applications considerably more effective than October and November applications.

Elder (1949) reported the best control with TCA when applied on Johnsongrass 12 to 18 inches high. Fleetwood (1950) also obtained best control on grass 18 to 24 inches high. On the other hand, McCall and Zahnley (1949) noted that applications made just before or during bloom were most successful. McKibben and Fuelleman (1950) treated Johnsongrass in Illinois with 80 and 160 pounds of TCA per acre, in June when the plants were 4 to 6 feet tall, and no regrowth was observed for 16 months after treatment.

The extreme variability in results from treating plants at
different stages of growth is probably due to the fact that the effectiveness of TCA is dependent more on the amount of rainfall than on the stage of growth. McCall and Zahnley (1949) considered soil moisture conditions to be of greater importance than stage of growth of plants. Watson (1950b), Peters (1952, p. 125), Barrons and Watson (1949a, 1949b), and others have noted a direct correlation between rainfall and effectiveness of TCA.

**Cultural Practices Combined with TCA Applications.** Many workers have reported that cultural practices have an effect on the degree of Johnsongrass control. Spraying the soil after plowing and diskimg has generally given better results than spraying untilled grass, particularly when low rates are used (Dow Chemical Company, 1949; Barrons and Watson, 1949b; Barrons and Hummer, 1951; and Peters, 1952, p. 58). Peters suggested two possible reasons for the increased control. Plowing breaks the rhizomes into sections, exposing non-cutinized surfaces which more readily absorb the chemical. Secondly, the effective concentration of the TCA may have been reduced by some immobilization within the leaf tissue. Barrons and Hummer (1951) showed such immobilization in some TCA resistant plants to preclude toxic action from the TCA. Translocation of TCA or a derivative of it has been demonstrated, but the value of the foliage in translocation must be weighed against possible immobilization of TCA by the same tissue. TCA absorption may be more rapid into this exposed tissue.

Some authorities found that clipping Johnsongrass just prior to spraying decreased the effectiveness of TCA (Ehler and Stephens, 1949;
McCall and Zahnley, 1949a; and Fleetwood, 1950). In contrast, Oyer et al. (1952), obtained better control with applications made on stubble than with those made on foliage.

TCA for the Control of Seedlings. Many plants appear more tolerant of TCA when well established than in the seedling stage (Barrons, 1951). This may be because of considerable root development below the toxic layer of soil, or it may result from the development of greater physiological tolerance with age. Despite the fact that seedlings are more easily killed than are established plants, control of Johnsongrass seedlings has been a major problem because the seeds will remain dormant during the period in which TCA and other herbicides are in the soil.

Sugarcane which had been shaved and off-barred on March 15 was sprayed March 30 as grass seedlings were emerging. 6 weeks following treatment, 100 percent control of Johnsongrass seedlings was noted with 10-, 20-, and 30-pound rates of sodium TCA (Stamper et al., 1950). Chilton and Stamper reported alternate methods for controlling seedlings. They obtained the best seedling control with 10 pounds of TCA per acre on the plant cane and 3.5 pounds in the stubble crop. Roguing was done in the fall and spring to cope with plants which escaped treatment. The control obtained, based upon stools of Johnsongrass per foot of drill, was 97.6 percent. The use of 2,4-D on successive dates at rates of 2 pounds per acre combined with flaming and roguing, gave 92.3 percent control. The recommended practice (Hardcastle and Stamper, 1953) in Louisiana for controlling Johnsongrass seedlings is a spring application of 4 pounds of 90 percent TCA per acre on
a 2½- to 30-inch drill at shave and off-bar and a second application at the time of fertilization at the same rate. This practice has continued to give the best results in weed control, yield of cane, and sugar production.

**TCA for the Control of Rhizomes.** During early trials with the use of TCA on Johnsongrass, relatively high rates were used. McCall and Zahnley (1949), Barrons (1949), and Elder (1949) all reported good control of Johnsongrass top-growth by using rates of 50 pounds or more per acre. Lower rates were later tried and found to be effective. McCall and Zahnley (1950), Peters (1952, p. 73), and Hamilton and Rea (1950a) obtained 95 percent control of plants developing from rhizomes by applying TCA at the rate of 40 pounds per acre. A study in Louisiana (Hagood, 1950b), is reported in which rhizomes were collected and weighed after treatments of TCA were applied in a band over the drill row of infested sugarcane stubble. Rates of 20, 27, and 36 pounds of chemical per acre sprayed on a band 2½ inches wide caused reductions of 91, 95, and 98 percent, respectively, in the weight of rhizomes on the treated plots compared with the controls. Sodium chlorate at 36, 55, and 73 pounds per acre applied in the same manner resulted in a decrease in rhizome weight of 80 to 84 percent.
Sodium 2,2-dichloropropionate

Properties. Sodium 2,2-dichloropropionate (Dalapon) is a white to tan-white, free-flowing powder which is readily soluble in water. It has a melting point of 193 to 197° C. and a solubility of 50 grams per 100 grams of water at 5° C. In aqueous solutions sodium 2,2-dichloropropionate is hydrolyzed into pyruvic acid, hydrochloric acid, and sodium chloride. At 25° C. little conversion takes place, whereas at 50° C. conversion is much more rapid (Dow Chemical Company, 1953). Laboratory investigations (Southwick, 1954) have established that Dalapon is actively absorbed and translocated by living grass foliage. It is also absorbed by roots following soil application. The physiological response of plants to Dalapon is similar in many respects to the response to TCA. With the latter, however, there is little foliar transport to growing points. At high concentrations of Dalapon, as with TCA, plants may show an immediate "burn" of foliage. This burning effect appears to be physiologically distinct from the systemic growth regulator effect and may reduce systemic activity.

Dalapon for the Control of Johnsongrass. Dalapon at the rate of 20 to 25 pounds acid equivalent per acre applied to Johnsongrass resulted in 90 to 100 percent kill of top-growth (Fletchall, 1953; Freeman, 1953; and Rahn, 1953). Dalapon at rates of 50 and 100 pounds per acre killed the tops of Johnsongrass soon after application; however, many live rhizomes were present and some regrowth appeared 5 months later (Dreessen and Elder, 1953). Dalapon at the rate of 40 pounds per acre when Johnsongrass was at the flowering stage resulted in very
little viable seed being produced (Fletchall, 1953).
3-(p-Chlorophenyl)-1,1-dimethylurea

Properties: 3-(p-Chlorophenyl)-1,1-dimethylurea (CMU) is a relatively new chemical which has outstanding weed-killing properties. It is a white crystalline compound which melts at 171° C. It is an essentially neutral, stable substance, and only slightly or moderately soluble in water and most organic solvents. Its solubility in water is approximately 230 ppm at 25° C. It is neither corrosive nor flammable. CMU has been formulated into a wettable powder which contains 80 percent by weight of the active ingredient (Cowart, 1952; Wolf, 1951).

The amount of CMU required to give complete control of all vegetation varies with rainfall, soil type, soil moisture, pH, and the species of plant. Under dry conditions herbicidal action of CMU may be very slow. In one instance (Cowart, 1952) an application of CMU to Johnsongrass was followed by a period of 3 months of drought. After a rain, however, the plants soon died.

Laboratory and greenhouse studies (Cowart, 1952) indicate that CMU is translocated downward at least in some species. CMU is readily absorbed by the roots and is apparently translocated upward also (Buch& and Todd, 1951).

CMU for the Control of Johnsongrass. Elder and Gassaway (1951) found that 80 pounds, active ingredient, per acre of CMU applied in March prevented all Johnsongrass plants produced by rhizomes and seedlings from developing during the growing season. The 20-pound rate was not sufficient for effective control and the 40-pound rate
gave only 75 percent control of plants growing from rhizomes. Gassaway and Rea (1952) obtained complete control from applications made in May with 80 pounds per acre but Johnsongrass survived the 100-pound rate. Peters and Willard (1951c) applied CMU at rates of 12.5, 25, 50, and 100 pounds per acre in May on an established stand of Johnsongrass as the plants were emerging. Control obtained two months later was 0, 50, 90, and 100 percent, respectively. Rea et al. (1952) obtained complete control of Johnsongrass, with no reinfestation during the growing season, from applications of 12 pounds or more per acre made in May. Lee (1952) applied CMU at rates of 20, 40, 60, 80, and 100 pounds per acre to Johnsongrass in June and noted complete control of top-growth throughout the remainder of the season from all concentrations. Excavations made in October indicated that all rates destroyed the rootstocks.

CMU at rates of 1/2, 1, 2, and 3 pounds per acre applied in June pre-emergence to castor beans gave excellent control of Johnsongrass seedlings at all rates (Tocquigny and Livingston, 1953).
Maleic Hydrazide

Properties. Maleic hydrazide (MH) is a white crystalline solid, 0.4 percent soluble in water at room temperature, and slightly acid in reaction. It has been prepared in various formulations, among which is the liquid formulation of the diethanolamine salt which is water soluble and contains 30 percent maleic hydrazide by weight (Schoene and Hoffman, 1949).

An accurate analytical procedure based on hydrolysis and colorimetric determination of distilled hydrazine sensitive to a fraction of a part per million may be used for determining MH concentrations in various parts of treated plants (Zukel, 1951).

Absorption and translocation of MH. Maleic hydrazide is absorbed very slowly by plants and has only a short residual effect in soils (Hoffman and Sylwester, 1950). Zukel (1950) found that 1/3 of the chemical, as measured by plant response, was absorbed by the plant 18 hours after spraying. Linder (1951) reported that aqueous solutions of maleic hydrazide were readily absorbed by leaves and roots of the oat plant. Translocation occurred in an upward and downward direction when it was applied to the leaves. Hagood (1951) found evidence of translocation of MH in Johnsongrass in experiments in which only the tops were dipped in solutions of the chemical.

Phytotoxic effects of maleic hydrazide. MH differs from the so-called "growth regulators" such as 2,4-D, indole-3-acetic acid, and naphthaleneacetic acid in that it does not cause epinasty of leaves or cell proliferation and elongation. However, according to Hoffman
and Sylwester (1950), there are three effects which it does have in common with chemicals that have been commonly regarded as growth regulators. It produces a formative effect on leaves and causes seedless fruit set on tomatoes. It also retards the sprouting of buds on tubers, corms, and branches.

Maleic hydrazide applied as a pre-harvest foliage spray inhibits sprouting and decreases storage breakdown of onions, carrots, beets, sugar beets, rutabagas, turnips (Paterson, 1952; Wittwer and Paterson, 1951), potatoes (Kennedy and Smith, 1951; Paterson, 1952; Paterson et al., 1952; Wittwer and Paterson, 1951; Marshall and Smith, 1951), apples (Smock et al., 1951). Paterson (1952) observed that foliar treatments with low concentrations of MH stimulates sprouting of potato tubers, and these when planted produce increased yield of the subsequent crop.

Maleic Hydrazide as an Herbicide. Field results with MH have been quite varied, possibly due in part to leaching of MH from the plant surface by heavy dews or rains before absorption occurs, or due to the omission of wetting agent in the spray with the diethanolamine formulation.

Maleic hydrazide is an effective herbicide when used at relatively high dosages. Such dosages followed by the use of phytotoxic oil did not improve the herbicidal effect against Johnson grass or Bermuda grass (Arle, 1952).

Maleic hydrazide at low dosages may temporarily inhibit plant growth. Degree of inhibition may vary among plant species and within the same species depending upon the dosage used and the age of plants.
at time of treatment. Young plants and plants treated at the start of the growing season are most susceptible. Plants treated later in the growing season may show little or no effect (Crafts et al., 1950; Naylor and Davis, 1950; Zukel, 1950; and Greulach, 1951).

Application of MH at the start of the growing season when green vegetation appears, followed in 2 weeks either by cultivation (Newall, 1951), or by the use of an herbicidal oil (Hoffman and Sylvester, 1950) might be useful in reducing the heavy dosage per acre required to control Johnsongrass. Zick and Buchholtz (1952) found that spring treatment of quackgrass followed by plowing 13 days later reduced the quantity of MH required for herbicidal effects. Early spring treatment followed by plowing in four days likewise gave control of quackgrass, whereas similar procedures in May followed by plowing 8 days later were less effective (Hill et al., 1952). Willard (1953a) recommended an MH spray of 8 to 12 pounds per acre followed in 4 to 10 days by plowing for the control of quackgrass.

Pre-emergence use of MH has not generally been successful (Slife et al., 1950; Stamper et al., 1951; Shaw et al., 1952; 1953; Hansen and Freeman, 1952). MH shows little selectivity in post-emergence application (Arle and Cords, 1952; Friesen, 1952) with the exception in the weeding of peas (L'Arrivee and Andersen, 1952) and the control of Johnsongrass in cotton (Crafts, 1953). MH likewise has little residual effect in the soil (Friesen, 1950; Kernard et al., 1951; Zick and Buchholtz, 1952; Brown, 1952; Shaw et al., 1952).

Oyer (1950) noted that clipped Johnsongrass showed no response
from applications of 8 to 30 pounds per acre. However, two weeks later when grass showed regrowth, applications killed top-growth at 30 pounds per acre and inhibited top-growth at 8 and 12 pounds with incomplete kill at each rate.
2,4-Dichlorophenoxyacetic acid

Properties. Since the properties and mode of action of 2,4-dichlorophenoxyacetic acid (2,4-D) have been recently reviewed in a number of articles (Norman et al., 1950; Mitchell, 1951; and Blackman et al., 1951) and two books (Ahlgren et al., 1951; and Robbins et al., 1952), it does not seem necessary to review this subject here.

2,4-D for the Control of Johnsongrass. Many workers have found 2,4-D to be effective in controlling Johnsongrass seedlings. Here again the reported results are quite erratic probably because of extreme variability in experimental conditions.

Only one reference was found in the literature in which 2,4-D gave control of rhizomes. Klingman (1949) in North Carolina reported a complete kill of all rhizomes and roots and the prevention of all top-growth when soil was treated with 20 pounds of 2,4-D per acre prior to emergence of the Johnsongrass plants. Tops of plants receiving the same treatment when 6 inches high continued to grow, but all rhizomes were killed. McCall and Zahnley (1950) reported that 40 pounds of 2,4-D per acre was effective in controlling seedlings but gave no control of established plants when the chemical was applied one or two weeks before the dormant rhizomes sprouted.

Stamper and Chilton (1950) recommended that 2 pounds of 2,4-D per acre be applied to sugarcane as an over-the-row spray for the prevention of growth of Johnsongrass seedlings. Chilton and Stamper (1951) and Stamper and Chilton (1952) stated that 2,4-D at 2 pounds per acre did not give sufficient control of Johnsongrass seedlings in sugarcane on
land that was fallow plowed before planting to destroy Johnsongrass rhizomes. The use of 2,4-D on successive dates (Chilton and Stamper, 1951) at rates of 2 pounds per acre, combined with flaming and roguing, gave 92.3 percent control, based upon stools of Johnsongrass per foot of drill.

Best and Gibbons (1951) described methods used on a large scale in Louisiana sugarcane plantations. A season of fallow largely controlled established Johnsongrass, but seedlings severely reduced the sugar yields in the stubble crop the following year. A 2,4-D pre-emergence spray was found to kill a large percentage of the Johnsongrass seedlings which grew in the plant cane. The yield of sugarcane for the combined plant cane and first stubble crop was increased from 36 tons per acre in 1948-1949, when conventional weeding was done, to 45 tons per acre in 1949-1950, when 2,4-D was used. The labor cost per acre dropped from $29.88 in 1948 to $12.66 in 1949.
Summary

Much work has been conducted on the control of Johnsongrass by cultural and chemical methods. Cultural methods, although effective, are expensive, time consuming, and necessitate taking the land out of production for one or more years. On the other hand, cultural practices are less dependent upon weather conditions than is the use of chemicals. Cultural practices are also effective in controlling other weeds, some of which present nearly as serious a problem as Johnsongrass.

Such practices as frequent mowing, close grazing, or fallow cultivation for one or more season with the purpose of weakening the plants by depleting the food reserves, followed by the use of chemicals to kill the few remaining plants, have been recommended most consistently.

Chemicals have been used successfully for the control and eradication of Johnsongrass on small areas, but expense, uncertainty of results, application problems, and extended periods of soil sterility have limited their use on a large scale.

The degree of success from the use of chemicals has varied considerably depending chiefly upon stage of growth of the plants, soil texture, soil organic matter, and particularly upon soil moisture conditions.
METHODS, RESULTS, AND DISCUSSION

General Methods and Materials

The nature of the studies necessitated widely different procedures in conducting the experiments. Consequently, the experiments are described and discussed individually. Certain methods that were fairly uniform in the various experiments are described here.

Location and Design of Experiments. The field studies were conducted in Ross County, Ohio on the flood plain of the Scioto River or on one of its tributaries. The sites used are typical of the areas in southern Ohio infested with Johnsongrass. One experiment studying the persistence and depth of penetration of CMU in soil was conducted on The Ohio State University Farm at Columbus, Ohio. One phase of this study was conducted in the University greenhouse.

The design of each experiment was a randomized block with three or four replications as noted later.

Spraying Equipment and Method of Chemical Application. All applications were made as sprays, using either a hand operated sprayer or a "bicycle" sprayer of the type described by Shaw (1950). The hand operated sprayer was a Hudson Industro No. 710S, 3 gallon, stainless steel knapsack sprayer with a pressure gauge mounted on the tank. The original spray equipment was replaced by a boom constructed from galvanized 1/4-inch pipe. The boom contained 4 Spraying Systems Company Teejet nozzles, No. 6504, spaced 20 inches apart and gave an overall spray pattern 80 inches wide. By maintaining a pressure of
40 pounds per square inch and a walking speed of 3 miles per hour, and by holding the boom 20 to 22 inches above the surface to be sprayed, the spray solution was delivered at the rate of 40 gallons per acre. It was not possible to maintain the pressure at exactly 40 pounds, but a mean pressure of 40 was obtained by starting on a plot at 42 pounds and allowing a drop to 38 pounds before the pressure was renewed.

The "bicycle" sprayer was calibrated to deliver 40 gallons of solution per acre when using Spraying Systems Company Teejet nozzles, No. 6506, with 26 pounds pressure per square inch and when traveling at the rate of 4 miles per hour.

Reference made to rate of application refers to pounds of the acid equivalent per acre unless otherwise noted.

Methods of Obtaining Data. All plots were observed throughout the growing season and notes were taken as changes occurred. In some cases the effectiveness of the treatments was evaluated by giving the plants in the plot an injury rating according to a numerical scale of 0 to 10 as follows: 0, no visible effect; 1, 2, 3, slight injury, plants usually recover with little or no reduction in vigor; 4, 5, 6, increasingly serious injury but plants usually recover; 7, 8, 9, severe injury, plants usually do not recover; 10, all plants killed.

For corn yield measurements, the ears from 2 corn rows 1 rod in length in 1952 and 2 rods in length in 1953 were husked and weighed. Two rows of grain from each of 10 randomly chosen ears were shelled for a moisture sample. The percentage of moisture in the grain at harvest was determined on a Tag-Heppenstall moisture meter and yields
were converted to 15.5 percent moisture.

Source of Chemicals. The Dow Chemical Company of Midland, Michigan, supplied the sodium TCA, Dalapon, and the 2,4-D. The sodium TCA was formulated as 90 percent sodium trichloroacetate with a 79.3 acid equivalent. Dalapon was formulated as the sodium salt of dichloroponic acid, equivalent to 64-68 percent dichloropropionic acid. The 2,4-D was formulated as the polypropylene glycol butyl ether ester.

The 3-(p-chlorophenyl)-1,1-dimethyl urea (CMU) 80 percent active ingredient, was supplied by the E. I. duPont de Nemours and Company, Wilmington, Delaware.

The maleic hydrazide, formulated as the diethanolamine salt, containing 30 percent 1,2-dihydropyridazine-3,6-dione, by weight, was furnished by the United States Rubber Company, Naugatuck Chemical Division, Naugatuck, Connecticut.
Certain cultural practices have been known for years to have a marked retarding effect on the development of Johnsongrass. Recently, it has been shown that combined chemical and cultural practices have been effective in controlling Johnsongrass (Peters, 1952, p. 62).

Since it is possible to produce satisfactory yields even when corn is grown almost continuously in fertile river bottoms and since at present there is no herbicide that will selectively kill Johnsongrass without injury to corn, it was thought desirable to test certain practices that may be employed in the fall after corn harvest to control Johnsongrass. A series of 3 experiments were initiated in the fall of 1951 and 1 experiment in the summer and fall of 1952 to study the possibilities of certain cultural practices and chemicals when used alone and in combination as a means of controlling Johnsongrass.

Methods: 1951. The three experiments were located on a fertile Genesee silt loam soil in the flood plain of the Scioto River near Chillicothe, Ohio, on the O. D. Grimes farm. Corn was grown in the area in 1950 and was heavily damaged by Johnsongrass. The infestation of Johnsongrass the following year was uniformly severe. The 1951 corn crop was severely damaged and yielded about 27 bushels per acre.

In the first experiment, corn was picked in early September, 1951, and Johnsongrass and corn stalks were mowed immediately. The residue was burned a week later. The experiment was set up as a
split-plot design replicated 3 times. The main plots, 14 by 40 feet, consisted of chemical treatments randomized within replications. Plowed and unplowed strips, which extended across all of the replications, divided each of the main plots into two 7 by 40 foot sub-plots. The plowed strips were plowed and disked once on September 12, 1951. The following diagram illustrates the field layout.

**Figure 1. One replication of the field layout.**

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<td>Ck.</td>
<td>Chlorate 100</td>
<td>2,4-D</td>
<td>400</td>
<td>Polybor-Chlorate Ck.</td>
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</tr>
<tr>
<td></td>
<td>Chlorate 150</td>
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<tr>
<td>TCA</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>lO</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2,4-D</td>
<td></td>
<td></td>
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<tr>
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<td></td>
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<td>Ck.</td>
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<tr>
<td>Ck.</td>
<td>Chlorate 50</td>
<td>2,4-D</td>
<td>20</td>
<td>TCA</td>
<td></td>
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<tr>
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<tr>
<td>Ck.</td>
<td>Polybor-Chlorate 100</td>
<td>2,4-D</td>
<td>20</td>
<td>TCA</td>
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<tr>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

*Plowed September
**Not plowed until the next spring
The following treatments were applied: (rates of TCA and 2,4-D are based upon acid equivalent, rates of sodium chlorate are commercial material)

(1) No herbicide - every third plot.
(2) Cultivated with disk harrow October 1 and again October 21 to keep down top-growth until frost.
(3) TCA at 20 pounds per acre on September 14.
(4) TCA at 40 pounds per acre on September 14.
(5) TCA at 40 pounds per acre on October 23.
(6) Sodium chlorate at 100 pounds per acre on September 14.
(7) Sodium chlorate at 100 pounds per acre on September 14, and corn treated pre-emergence on May 17, 1952 with 2,4-D at 2 pounds per acre.
(8) Sodium chlorate at 100 pounds per acre on October 23.

A second experiment, with the same experimental design, was started adjacent to the one above. Whole plots, however, were 28 by 21 feet; sub-plots 14 by 21 feet. The plowed strips were plowed and disked once on October 23. Corn was picked and the area was mowed on October 15, 1951. Residue was removed and sub-plots were plowed and disked on October 22. Herbicides, except for 2,4-D, were applied October 23, 1951. 2,4-D was applied pre-emergence to corn on May 17, 1952. The treatments were as follows: (rates of polybor-chlorate are commercial material)

(1) No herbicide.
(2) TCA at 20 pounds per acre.
(3) TCA at 40 pounds per acre.
(4) TCA at 60 pounds per acre.
(5) TCA at 40 pounds per acre and 2,4-D at 2 pounds per acre pre-emergence to corn.
(6) TCA at 40 pounds per acre and 2,4-D at 4 pounds per acre pre-emergence to corn.
(7) Sodium chlorate at 50 pounds per acre.
(8) Sodium chlorate at 100 pounds per acre.
(9) Sodium chlorate at 150 pounds per acre.
(10) Sodium chlorate at 100 pounds per acre and 2,4-D at 2 pounds per acre pre-emergence to corn.
(11) Sodium chlorate at 100 pounds per acre and 2,4-D at 4 pounds per acre pre-emergence to corn.
(12) Polybor-chlorate at 100 pounds per acre.
(13) Polybor-chlorate at 200 pounds per acre.
(14) Polybor-chlorate at 400 pounds per acre.

A third experiment was started later in the fall. Corn was picked and the area mowed November 15, 1951. Residue was removed and herbicides were applied November 20. The design was the same as in first experiment except that the sub-plots were 11/4 feet wide and the main plots were 28 feet wide. The plowed strips were plowed and disked once on November 20. Chemical treatments included TCA at 20 and 40 pounds, acid equivalent, per acre and sodium chlorate and polybor-chlorate each at 100 pounds of commercial material per acre. Every third plot received no herbicide.

The following spring (May 14, 1952), the entire field was plowed, disked, and drilled to US13 corn. Corn was cultivated in the usual
way on June 2, June 14, and July 2. 2,4-D was applied at the rate of 1/4 pound per acre on June 16 on the entire field for the purpose of controlling broadleaf weeds.

In order to further study the effectiveness of certain cultural practices when used alone and in combination with herbicides, an experiment was started in July, 1952 on the farm operated by Robert L. Harness, Jr., 9 miles southeast of Chillicothe, Ohio.

Methods: 1952. Corn had been grown in the field in 1950. During 1951 and 1952 the field was in Johnsongrass pasture. Since the field was not pastured closely in 1951 a considerable amount of seed was produced. During the 1952 season the Johnsongrass was pastured to the extent that virtually no seeds were produced. It was not, however, grazed as closely as it should have been to deplete the food reserves. About 1 to 2 feet of top-growth was present during most of the summer.

This was a combined research-demonstration project in which one of 3 replications were used for demonstration purposes. The experiment was set up as a split-split-plot design. Main plots, 1333 1/3 feet by 50 feet, consisted of strips which extended throughout the replications that were plowed on different dates; sub-plots, 160 feet by 200 feet, consisted of dates of applying chemicals; sub-sub-plots, 26 2/3 feet by 50 feet, consisted of chemical treatments that were randomized within replications. Four strips were plowed respectively on July 30, August 20, September 10, 1952, and on March 21, 1953. Herbicides were applied on September 15 and on October 15, 1952. TCA was applied at rates of 20 and 40 pounds, acid equivalent, per acre and sodium chlorate was applied at rates of 100 and 200 pounds of commercial material per acre.
in combination with 4 dates of plowing.

The strip that was plowed July 30 was cultivated once with a disk harrow on August 25 to kill top-growth. Prior to disking the plants were about 8 to 10 inches high. Regrowth was about the same height by the time of the first frost. Thus on the strip plowed in July a single disking was sufficient to prevent regrowth from obtaining a height of more than 12 inches. The previous year, one disking after the first of September was necessary in order to prevent excessive top-growth. Two main reasons may be postulated for the difference in results obtained. (1) Fewer diskings were required in 1952 since Johnson grass plants were weakened considerably by the two years of pasturing. On the other hand, more diskings were required in 1951 since the experimental area had been in corn the previous year. (2) It was much drier in July and August of 1952 than in 1951, hence fewer diskings were necessary in 1952. Willard (1953) recommends fallow cultivation every two weeks until about September 15.

In the spring of 1953 the experimental area, along with the remainder of the field, was prepared in the usual way and US13 corn was drilled at the rate of 1 kernel every 10 inches on May 19, 1953. Corn was cultivated during the weeks of June 8, June 15, and June 29.

Results: General Phytotoxic effects of TCA on Johnson grass. TCA applied to grasses results in a direct contact effect or an internal systemic effect primarily evident as a modification of growing tissues. The two types of effects appear to be physiologically distinct, but both will ordinarily occur in the same plant.

The contact injury was evidenced by a localized firing of the
Foliage. If the TCA concentration was great enough, the top-growth gradually became brown and finally died. If the systemic effects was not too pronounced the plants recovered from the underground parts. The stage of growth as well as the concentration of TCA were factors in the rate and degree of top-kill.

The systemic effects of TCA were primarily evident in those regions of the stem or leaf where rapid cell elongation was occurring. Depending principally upon the concentration of TCA used, the effect was inhibitory in some cases, lethal in others. The plants were severely stunted because of reduced elongation of the internodes. In many cases inhibitory effects led to death after a lapse of time. The leaves on newly formed shoots failed to expand normally and remained tightly rolled for a few weeks. If the concentration was not excessive the younger leaves continued to develop within the boot. This growth produced mechanical constrictions because of the failure of the older leaf blades to unroll. As growth continued within the boot, pressures were developed which resulted in extreme curvatures of the stem, and in some cases the enclosed tissues broke out directly through the side of the sheath. Malformations of this type are shown in Figure 5.

Frequently there was increased tillering from the crown of Johnsongrass. Other species in which increased tillering was noted include timothy (Phleum pratense), oats (Avena sativa), and smooth bromegrass (Bromus inermis). Usually the tillers did not grow more than a few inches. The numerous malformed tillers remained static for several weeks with recovery occurring in some cases, death in others.
In plants showing TCA toxicity symptoms, blooming was delayed 10 to 14 days. Many of the inflorescences did not emerge even though they matured within the boot. Of the heads that did emerge the rachises and spikelets were twisted and distorted. Those heads which remained within the boot usually decayed in place.

TCA had a marked retarding effect on the development of rhizome buds as well as on buds of aerial stems. The first effects were evident in the terminal buds. The tips of the rhizomes soon ceased to elongate and frequently disintegrated. Later the lateral buds began to elongate. Their growth was usually quite limited in extent and these, too, would frequently die. The short, thickened stems with greatly shortened internodes (Figure 8) were designated as "stubs" by Peters (1952, p. 35).

TCA had a greater retarding effect upon growth of stem tissue than upon root tissue. This fact was revealed by the apparently normal growth of roots from rhizomes which produced nothing but abnormal stem tissue. As is shown in Figure 8, quite frequently roots continued to grow from the nodes of stubs which were inactive.

**Phytotoxic effects of TCA on Corn.** The primary root and seminal roots of corn in TCA treated soil developed normally. Secondary root development was greatly retarded. The mesocotyl appeared to elongate normally and the coleoptile emerged through the soil normally. However, the coleoptile usually continued to elongate and had a tendency to become enlarged and thickened. The first 2 or 3 leaves would usually break through the coleoptile but were fused and failed to unroll. The younger leaves continued to develop within the tightly rolled older
leaf blades, resulting in enlargement of the growing point and severe bending of the seedling. These symptoms may be noted in Figure 10. In some cases the first leaves could not break through the coleoptile and were forced to push through the side. Some leaves were fused to the coleoptile, resulting in severe bending and eventually breaking of the leaves as they elongated. In a few cases the first leaves would break loose from the coleoptile and develop normally. In most cases, however, the plants eventually would die.

The most evident symptoms of TCA toxicity in corn were reduction in height and failure of the leaf blade to expand normally. These plants had short, usually bent stems with thickened, leathery leaves. Compaction and contortion of the developing tissues within the tightly rolled leaves resulted in twisted and often torn leaf blades. In a few of the plants tassel development occurred within the tightly rolled terminal leaf blades, but the tassels later decayed in place.
Figure 2. April 20, 1953. Dormant Johnsongrass rhizome. CM scale.
Figure 3. May 12, 1953. Spring growth from axillary buds of a Johnson grass rhizome. CM scale.
Figure 4. Normal Johnson grass inflorescence.

Figure 5. Johnson grass inflorescences confined within the sheath following treatment with TCA.
Figure 6. Johnsongrass inflorescence affected by TCA.
Figure 7. Normal Johnson grass rhizomes.

Figure 8. Abnormal lateral growth from nodes of Johnson grass rhizomes treated with TCA.
Figure 9. June 20, 1953. Corn and Johnsongrass following applications of sodium chlorate at 100 lb/A on May 15.

Figure 10. June 20, 1953. Corn following applications of sodium chlorate at 20 lb/A on May 15.
Results: 1951-1952. The effectiveness of the various treatments was estimated by evaluating the regrowth of the grass in June, 1952, assuming that growth of the plants from rhizomes the year following treatment was proportional to the number of rhizomes which survived the treatment. The data are given in Table 1 as per cent kill of Johnsongrass rhizomes in the treated plots compared to the unplowed plots that received no herbicide.

The growth of seedlings the following spring was not inhibited by any of the fall treatments, with the exception of plots receiving polybor-chlorate. This indicated that, except for polybor-chlorate, the herbicides were not present in the soil in sufficient quantities to be toxic to weed seedlings.

Corn planted the following spring was not visibly damaged by any of the treatments except in those plots receiving polybor-chlorate. Polybor-chlorate was evidently present in toxic quantities the following spring since the stand of corn was reduced by about 30, 65, and 90 percent in plots treated at rates of 100, 200, and 400 pounds, respectively. The corn that did survive was severely stunted throughout the growing season. Six weeks after planting, the corn in these plots was less than one-half as high as that in the other plots. During the early stages of growth, leaves of the corn were light-yellow in color, later the color changed to a light-green, and by time of tasseling the leaves were dark-green. Johnsongrass was not damaged as severely as corn. During the early stages of growth, Johnsongrass was light-green in color; by the time of flower initiation, it was a very dark-green. Johnsongrass was not retarded in growth
except in the very early stages. By July 15 Johnsongrass was more
glorious in plots treated with polybor-chlorate than in any of the
other plots, presumably because of the reduced competition from corn
and other weeds. Later in the season the stand was even more dense
and the plants were more vigorous. Although flowering was delayed
about 10 days, Johnsongrass produced seeds that germinated and grew
normally when planted the following spring.

It may be noted that plowing in the fall with no further treat-
ment reduced the stand of Johnsongrass plants from rhizomes the next
spring by about 10 to 23 per cent. Furthermore, plowing prior to
treatment increased the effectiveness of all herbicides.

Disking on October 1 and again October 21 did not significantly
reduce the number of Johnsongrass plants the following spring.

All herbicides were more effective when applied in September than
in October. Herbicides applied in October were, in turn, more effective
than those applied in November. Presumably this was due to the fact
that more active growth was occurring at the earlier date.

TCA at the rate of 60 pounds per acre gave the best control.
Chlorate at 150 pounds was almost as effective. In general, TCA at
rates of 20, 40, and 60 pounds gave results similar to 50, 100, and
150 pounds of chlorate. Polybor-chlorate very definitely gave poor
control of Johnsongrass.

2,4-D applied pre-emergence to corn at rates of 2 and 4 pounds
per acre gave 65 and 85 per cent control of Johnsongrass seedlings,
respectively, with no apparent damage to corn.

The corn in plots treated with herbicides October 22, 1951 was
harvested September 22, 1952. The yield data are given in Table 2. As indicated by the yields, the herbicides were much more effective when the land was plowed prior to application of the herbicides. Plowing alone in the fall was effective in exposing some of the rhizomes so that they were more subject to drying and/or freezing, which resulted in increased yields of corn compared with plots not plowed in the fall. With the exception of polybor-chlorate, all herbicides resulted in a higher yield of corn.

As measured by yield of corn, the descending order of effectiveness of the herbicides applied to land plowed prior to treatment are as follows: TCA 60 pounds, TCA 40 pounds plus 2,4-D 4 pounds, chlorate 150 pounds, TCA 40 pounds plus 2,4-D 2 pounds, TCA 40 pounds, chlorate 100 pounds plus 2,4-D 4 pounds, chlorate 100 pounds, chlorate 100 pounds plus 2,4-D 2 pounds, TCA 20 pounds, and no herbicide. Polybor-chlorate at rates of 100, 200, and 400 pounds per acre damaged the corn severely.
Table 1. Estimated percent kill of Johnson grass from herbicides applied in the fall of 1951 and from cultural practices as indicated by top-growth on June 11, 1952.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rate/A</th>
<th>Kill, plowed (or disked)</th>
<th>Kill, not plowed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Replication</td>
<td>I</td>
</tr>
</tbody>
</table>

Plowed September 12, herbicides applied September 14 except as noted.

1. No herbicide
   - 20 20 30 23 8 0 0 0 0 7
2. Disked twice***
   - 30 40 30 33 6 0 0 0 0 7
3. TCA
   - 20 55 60 55 57 4 30 40 50 40 5
4. TCA
   - 40 90 60 90 80 1 60 70 60 63 1
5. TCA
   - 40** 80 70 60 70 2 50 70 40 53 2
6. Chlorate
   - 100 60 50 40 50 5 30 40 60 43 4
7. Chlorate
   - 100
8. Chlorate
   - 100** 30 40 50 40 6 45 30 35 37 6

Plowed October 22, herbicides applied October 23.

1. No herbicide
   - 10 0 20 10 11 0 0 0 0 12
2. TCA
   - 20 30 40 35 35 9 5 10 15 10 9
3. TCA
   - 40 60 75 75 70 3 10 20 30 20 5
4. TCA
   - 60 80 85 90 85 1 30 40 35 35 1
5. TCA
   - 40
6. TCA
   - 40
7. Chlorate
   - 20 25 25 20 23 10 15 15 0 10 9
8. Chlorate
   - 100 60 50 70 60 7 20 20 30 23 4
9. Chlorate
   - 150 70 90 80 80 2 30 30 40 33 2
10. Chlorate
    - 100
11. Chlorate
    - 100
12. Polybor-chlorate
    - 100 0 5 10 5 12 0 0 0 0 12
13. Polybor-chlorate
    - 200 10 0 0 3 14 0 0 0 0 12
14. Polybor-chlorate
    - 400 5 5 5 5 12 10 0 20 10 9

Plowed and herbicides applied November 20.

1. No herbicide
   - 5 20 20 15 5 0 0 0 0 4
2. TCA
   - 20 25 25 20 23 3 20 20 10 17 3
3. TCA
   - 40 50 65 45 52 1 30 30 20 27 1
4. Chlorate
   - 100 60 30 40 43 2 25 30 25 27 1
5. Polybor-chlorate
   - 100 30 20 20 23 3 0 0 0 0 4

* 2,4-D applied pre-emergence to corn (seedling control by 2,4-D at 2 and 4 lb. rates was 65 and 85 percent respectively).
** Applied October 23.
*** Disked October 1 and again October 21.
Table 2. Yield of corn as affected by plowing and by herbicides applied October 23, 1952.

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Rate/A</th>
<th>Replication</th>
<th>Plowed</th>
<th>Replication</th>
<th>Not plowed</th>
</tr>
</thead>
<tbody>
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<td>Lb.</td>
<td>I</td>
<td>II</td>
<td>III</td>
<td>Av.</td>
</tr>
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<td>33 37 37</td>
<td>30 24 28</td>
<td>49 39 30</td>
<td>18 39 31</td>
</tr>
<tr>
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<td>61</td>
<td>57</td>
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<td>62</td>
</tr>
<tr>
<td>3. TCA</td>
<td>40</td>
<td>89</td>
<td>65</td>
<td>78</td>
<td>77</td>
</tr>
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<td>4. TCA</td>
<td>60</td>
<td>93</td>
<td>87</td>
<td>91</td>
<td>90</td>
</tr>
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<td>5. TCA</td>
<td>40</td>
<td>75</td>
<td>88</td>
<td>85</td>
<td>83</td>
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<tr>
<td>+ 2,4-D*</td>
<td>4</td>
<td>89</td>
<td>90</td>
<td>86</td>
<td>88</td>
</tr>
<tr>
<td>6. TCA</td>
<td>40</td>
<td>75</td>
<td>88</td>
<td>85</td>
<td>83</td>
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<tr>
<td>+ 2,4-D*</td>
<td>4</td>
<td>89</td>
<td>90</td>
<td>86</td>
<td>88</td>
</tr>
<tr>
<td>7. Chlorate</td>
<td>50</td>
<td>64</td>
<td>70</td>
<td>91</td>
<td>75</td>
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<td>9. Chlorate</td>
<td>150</td>
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<td>84</td>
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<td>14</td>
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<td>+ 2,4-D*</td>
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<td>77</td>
<td>67</td>
<td>84</td>
<td>76</td>
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<td>11</td>
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<td>20</td>
</tr>
<tr>
<td>13. Polybor-</td>
<td>200</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>14. Polybor-</td>
<td>400</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>3</td>
</tr>
</tbody>
</table>

*2,4-D applied pre-emergence to corn.

L.S.D. Herbicide | 8.6 | 11.5
L.S.D. Plowing    | 2.9 | 4.0
L.S.D. Replication| 3.6 | 4.8
Results: 1952-1953. Corn planted in 1953 was not visibly damaged by any of the treatments during the early stages of growth. At the time of silk emergence, the lower leaves began to turn brown in plots treated with sodium chlorate. By the time the corn was in the soft dough stage, the lower 1/3 of the leaves were brown in these plots, while all of the corn leaves were still green in the check plots and in plots treated with TCA. The ears of corn were conspicuously smaller and the soil was subject to puddling in chlorate treated plots compared with the other plots. Moisture determinations made at the time of harvest showed that corn in the chlorate treated plots was lower in moisture compared with the other treatments. Corn in plots treated with 200 pounds per acre of chlorate contained an average of 25.0 percent moisture; in plots treated with 100 pounds per acre of chlorate corn contained 28.7 percent moisture, while the corn in the remainder of the plots contained 30.4 percent moisture. There was no significant difference in the moisture content of the corn in TCA treated plots and in those receiving no chemical.

None of the treatments reduced the number of Johnsongrass seedlings.

An estimate of the percent control of Johnsongrass top-growth from rhizomes was made June 20, 1953. As indicated by the data in Table 3, the July plowing and, to a lesser extent, the August plowing, had a marked retarding effect on the development of Johnsongrass the following summer. Plowing July 30, with no further treatment except one disking on August 25, resulted in 84 percent control of Johnsongrass from rhizomes. Plowing 3 weeks later (August 20) while reducing the stand of Johnsongrass by 50 percent, was definitely less effective. Plowing
September 10 was slightly less effective than plowing the following spring (March 21). Plowing March 21 resulted in 12 percent control compared to the September 10 plowing.

In spite of the fact that plowing in July is a difficult operation, since the soil is frequently dry at this time, plowing followed by cultivation, to prevent excessive top-growth, offers one of the most economical and surest ways of controlling Johnsongrass in large areas.

In areas where it is desirable to reduce the stand of Johnsongrass to a minimum or where an attempt is made for eradication, a combination of chemical and cultural practices may be desirable. As is indicated by the data in Table 3, Johnsongrass top-growth, except for seedlings, was almost completely controlled (99 percent) in plots that were plowed July 30, disked once August 25, and received 200 pounds per acre of sodium chlorate the middle of September. The 200 pound rate of chlorate applied September 15 gave good control (83 to 90 percent) even in the plots that were plowed September 10 or the following March 21. Sodium chlorate at the rate of 100 pounds per acre gave about the same control (98 percent) as the 200-pound rate, when applied September 15 to land that had been plowed on July 30. The 100-pound rate, however, was considerably less effective (37 percent control) when applied September 15 to plots that were plowed 5 days previous or that were not plowed until the following March (77 percent control).

TCA applied at the rate of 40 pounds per acre to land that was plowed July 30 gave similar results (97 percent control) as the 100- or 200-pound rates of chlorate applied the middle of September. The 20-pound rate of TCA was almost as effective (93 percent control).
Figure 11. June 20, 1953. Land plowed July 30, 1952, disked one month later. 84 percent reduction in stand of Johnsongrass.

Figure 12. June 20, 1953. Land plowed September 10, 1952. No reduction in stand of Johnsongrass.
Figure 13. June 20, 1953. 200 lb/A of sodium chlorate applied September 15, 1952 reduced Johnson–grass stand 83 percent. Land plowed March 21, 1953.

Figure 14. June 20, 1953. 20 lb/A of TCA applied September 15, 1952 reduced Johnsongrass stand 18 percent. Land plowed March 21, 1953.
With both rates of TCA, as with the 100-pound rate of sodium chlorate, the percent control decreased considerably when the land was plowed later in the summer (August 20 or September 10) or the following spring (March 21). The 200-pound rate of chlorate gave good control regardless of when the land was plowed.

Corn in the plots was harvested September 29. As indicated by the yield data in Table 4, there is a positive correlation between yield and degree of Johnsongrass control in plots treated with TCA. Soil moisture was low at the time ears were forming and the lack of moisture in plots containing considerable Johnsongrass resulted in low yield of corn. In spite of the fact that good control of Johnsongrass was obtained, the yield of corn was low in plots treated with sodium chlorate due to the toxic effects of the residual chlorate. The yield of corn in these plots was reduced in direct proportion to the amount of chlorate applied.

From the data in Table 3, it may be noted that both TCA and sodium chlorate were more effective in controlling Johnsongrass top-growth when applied in September than when applied in October. These results are consistent with those of the previous year. It appears, therefore, that both cultural practices and chemicals are more effective when applied at a time when Johnsongrass is growing rapidly.

In this experiment sodium chlorate gave much better control of Johnsongrass than TCA at the rates used. In the experiments of the previous year, TCA was more effective than chlorate. The reason for the variability in results may be attributed to differences in rainfall. The season was very dry the year that sodium chlorate was more
effective. The rainfall from September through December was 6.8 inches the year chlorate gave better results. Rainfall for the same interval the year TCA gave better results was 14.6 inches (U.S. Weather Bureau). Thus it appears that sodium chlorate is relatively more effective when the soil moisture is low and TCA is relatively more effective when soil moisture is more abundant. Peters (1952, pp. 125-131) and others have shown that the effectiveness of TCA is greatly dependent upon the amount and distribution of rainfall.

It should also be noted that much better control was obtained in 1953 than in 1952. The 1953 results were obtained on land that had been pastured for two years previous to treatment. The 1952 results were obtained on land that had been in corn the previous year and the Johnson grass was able to store more food in the rhizomes.

While none of the treatments reduced the seedling population in 1953, there were fewer seedlings present compared with plots similarly treated the previous year. This difference in results may also be explained by the difference in the use of the two fields prior to treatment.
Table 3. Estimated percent kill of Johnsongrass top-growth from rhizomes on June 20, 1953 as affected by cultural practices and herbicides applied in the fall of 1952.

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Rate/A</th>
<th>July 30, 1952</th>
<th>August 20, 1952</th>
<th>September 10, 1952</th>
<th>March 21, 1953</th>
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<tbody>
<tr>
<td></td>
<td>Replication</td>
<td>Percent kill of top-growth</td>
<td>Replication</td>
<td>Replication</td>
<td>Replication</td>
</tr>
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<td>II</td>
<td>III</td>
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<tr>
<td>Check</td>
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<td>92</td>
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<tr>
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Herbicides applied September 15, 1952

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Herbicides applied October 15, 1952

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<tr>
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Table I. Yield of corn as affected by cultural practices and herbicides applied the previous year.

<table>
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<tr>
<th>Herbicide</th>
<th>Rate/A</th>
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<th>August 20, 1952</th>
<th>September 10, 1952</th>
<th>March 21, 1953</th>
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</thead>
<tbody>
<tr>
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<tr>
<td>Mean</td>
<td></td>
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Yield in bushels per acre at 15.5 percent moisture

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<th>August 20, 1952</th>
<th>September 10, 1952</th>
<th>March 21, 1953</th>
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<tr>
<td>TCA</td>
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Herbicides applied September 15, 1952

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<th>August 20, 1952</th>
<th>September 10, 1952</th>
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</thead>
<tbody>
<tr>
<td>TCA</td>
<td>20</td>
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<tr>
<td>Chlorate</td>
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<td>67</td>
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<td>Mean</td>
<td>70</td>
<td>48</td>
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Herbicides applied October 15, 1952

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<th>Herbicide</th>
<th>Rate/A</th>
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<th>August 20, 1952</th>
<th>September 10, 1952</th>
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<tr>
<td>TCA</td>
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<td>83</td>
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<tr>
<td>TCA</td>
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</tr>
<tr>
<td>Mean</td>
<td>70</td>
<td>48</td>
<td>33</td>
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</table>
Applications of Herbicides in the Early Spring for
the Control of Johnsongrass

Since it is frequently desirable to grow corn continuously on much of the Johnsongrass-infested soil of the Ohio River Valley and since it is difficult to harvest corn sufficiently early in the fall for chemical and cultural practices to be effective, the use of herbicides in the early spring seems desirable. The residual toxicity of TCA for corn has generally disappeared within 60 days in these soils (Willard, 1953). Peters (1952, p. 73) obtained 90 percent control in 1950 with TCA applied at the rate of 40 pounds per acre in March. He obtained good control in 1951 with TCA at the rate of 10 pounds per acre in March.

Methods: 1952. Tests were conducted in 1952 and in 1953. A Genesee silty clay loam soil along Paint Creek, a tributary of the Scioto River, 1 mile south of Chillicothe, Ohio on the Isaac Cook farm, was used for the tests in 1952. The field was in corn in 1950 and in Johnsongrass meadow in 1951. Only one cutting of the Johnsongrass was removed in 1951. Following this cutting, a copious amount of regrowth occurred which produced an abundance of seed.

Sodium TCA and sodium chlorate were applied to unplowed sod on March 18, 1952. Triplicated plots, 14 by 42 feet, were used for each planting date. TCA was applied at rates of 0, 10, 20, and 40 pounds, acid equivalent, per acre. Sodium chlorate was applied at the rate of 100 pounds of commercial material per acre. The experimental area was plowed April 30. Ohio W10 corn was drilled in 1/2 of the area on May
15, fifty-eight days after treatment, and in the other 1/2 on June 3, seventy-seven days after treatment.

Methods: 1953. Instead of planting corn on 2 different dates subsequent to treatment in order to determine the length of time herbicides remain phytotoxic in the soil, as was done in the previous year, herbicides were applied on different dates and the corn was planted in the entire area at one time.

TCA at rates of 0, 10, 20, and 40 pounds per acre was applied on 3 dates; March 7, March 21, and April 4. A randomized block design with 4 replications was used for each date of treatment. Three of the replications for each date of treatment were plowed in mid-August of 1952, the remaining replication was plowed after TCA was applied. A single plot was treated with sodium chlorate at the rate of 100 pounds per acre on March 7. Each plot was 13 1/3 feet by 50 feet.

US13 corn was drilled in the area on May 25, 1952. It may be recalled that corn was planted May 19 in the adjacent area in which the chemical and cultural treatments were used in the summer and fall of 1952. Three-fourths of an inch of rain fell during the evening of May 19 and a light shower occurred 2 days later. Due to excessive soil moisture the remainder of the field could not be planted until May 25. The soil had not been disturbed since May 17. An abundance of Johnsongrass plants from rhizomes as well as seedlings emerged following the rain on May 19. These plants were destroyed by diskng while preparing for the May 25 planting.

Results: 1952. The field was not under our control and the corn was not cultivated. The effects of the herbicides, however, were more
accurately evaluated than if the corn had been cultivated. On the other hand, it was not feasible to take yields since all plots were infested with Johnsongrass seedlings by late summer and the corn was severely stunted. With normal cultivation these seedlings would not have been such a serious problem.

Corn planted 77 days after application of herbicides was not damaged by any of the TCA treatments. Corn in plots treated with the 100-pound rate of sodium chlorate showed symptoms of toxicity, but the stand was not significantly reduced. Corn planted 58 days after treatment was damaged by the 40-pound rate of TCA and the 100-pound rate of chlorate. These treatments reduced the stand by 9 and 23 percent, respectively. About 20 percent of the corn plants in plots treated with the 40-pound rate of TCA exhibited toxicity symptoms. All of the corn plants in plots treated with sodium chlorate were restricted in top-growth and showed other symptoms of chlorate toxicity.

An estimate of reduction of Johnsongrass top-growth from rhizomes was made June 21, by counting stands in 4 randomly selected square yard samples in each plot. The data are given as percent reduction in stand of plants from rhizomes compared with those in the untreated plots (Table 5). The 10-pound rate of TCA gave essentially the same degree of control as the 100-pound rate of sodium chlorate.

Somewhat better control was evident in plots in which corn was planted at the later date. This may be attributed to the destruction of the young Johnsongrass plants that were present when the land was prepared for the late planting of corn. Both Johnsongrass and corn
Table 5. Stand reduction of Johnsongrass from rhizomes as percent of check plots, June 21, herbicides applied March 18, 1952.

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Rate/A</th>
<th>Corn planted May 15 Replication</th>
<th>Corn planted June 3 Replication</th>
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</thead>
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<tr>
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<td>I     II   III   Av.</td>
<td>I     II   III   Av.</td>
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<td>TCA</td>
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<td>43    50    57    50</td>
<td>55    54    65    58</td>
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<tr>
<td>TCA</td>
<td>20</td>
<td>74    80    87    80</td>
<td>93    79    85    86</td>
</tr>
<tr>
<td>TCA</td>
<td>40</td>
<td>96    99    99    98</td>
<td>100   98    100   99</td>
</tr>
<tr>
<td>Chlorate</td>
<td>100</td>
<td>44    40    56    47</td>
<td>68    52    70    63</td>
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<tr>
<td>Mean</td>
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<td>69</td>
<td>77</td>
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</tbody>
</table>

were damaged to a greater extent by TCA and chlorate on the lighter colored, low organic matter soils.

Johnsongrass seedlings appeared in the check plots before the corn was planted. Seedlings became established in plots treated at the rate of 10, 20, and 40 pounds per acre of TCA and 100 pounds of chlorate about 45, 55, 70, and 100 days from date of treatment, respectively. The appearance of seedlings in a plot was considered to indicate that the phytotoxicity of the chemical had been reduced in the soil. The time required for the residual toxicity to drop to a level permitting Johnsongrass seeds to grow corresponded roughly with the time required for corn to grow. By late summer all plots were completely infested with seedlings.

In order to further study the effects of herbicides when applied in the early spring, similar tests were conducted in 1953 on the farm
operated by Robert L. Harness, Jr. The experimental area was in the same field and adjacent to the area used for the combined chemical and cultural treatments.

Results: 1953. On the area planted May 25, Johnsongrass emerged on or about June 3; most of these plants were destroyed by the first cultivation on June 8. On the area planted May 19, Johnsongrass emerged about May 29. By the time of the first cultivation on June 11, most of these plants were as high as the corn and could not be covered with soil in the row without covering the corn also.

Johnsongrass emerged a few days after the emergence of the corn. For a period of about 6 or 7 days the corn was higher than the Johnsongrass. The May 25 planting was cultivated during this period and much of the Johnsongrass in the row was covered with soil. Since the early planting of corn was cultivated last, very little of the Johnsongrass in the row could be destroyed without covering the corn.

The lack of a uniform stand of Johnsongrass prevented an evaluation of the chemical treatments. The sparse stand of Johnsongrass may be attributed to at least 3 factors which may be additive in their effects. (1) the field had been in pasture for 2 years prior to treatment, (2) the top-growth of Johnsongrass was destroyed by disking on May 17, the regrowth was again destroyed May 25, and (3) the corn was cultivated at a time when it was somewhat higher than the Johnsongrass.

The late preparation of the land, permitting an extra working of the soil prior to planting corn, was more effective in 1953 than in 1952. The difference may be attributed to the fact that the land on which the 1953 results were obtained was in pasture for 2 years previous
to treatment, while the land on which the 1952 results were obtained was in meadow the preceding year.

Corn was not visibly damaged by any rate of TCA applied on any of 3 dates. Under the conditions of this experiment, TCA when applied at rates up to 40 pounds per acre was not present in toxic quantities for corn 51 days after application.

In the single plot that was treated with sodium chlorate at the rate of 100 pounds per acre on March 7, corn was severely stunted and showed other symptoms of chlorate toxicity. Thus chlorate remained phytotoxic for a period of more than 79 days after application. The stand of corn was reduced about 25 percent. At the time of maturity the corn was about 1/3 shorter, the ears were smaller, and the corn matured about 2 weeks sooner than that in the untreated plots.
Control of Johnsongrass in Established Alfalfa

Johnsongrass in alfalfa is not a serious problem since it is cut in the early stages of growth. However, if Johnsongrass could be controlled in alfalfa it would be possible to produce one or more corn crops without the usual reduction of yield. Dalapon and TCA have been used to take grasses out of legumes. It was thought desirable to further test the practicability of using these herbicides to selectively take Johnsongrass out of alfalfa.

Methods: 1952. A three-year old stand of alfalfa on a Genesee sandy loam soil on the Roy Cooper farm near Chillicothe, Ohio was used for the experiments in 1952. Three cuttings of hay had been removed the year previous to experimentation.

A randomized block design was used with plots 13 by 30 feet replicated 3 times. TCA was applied at rates of 0, 10, 20, and 40 pounds, acid equivalent, per acre. Applications were made to separate blocks on July 17, 1952, one day after the second cutting was removed, and on August 27, one day after the third cutting was removed.

Methods: 1953. Similar tests were conducted in 1953 at two locations about 10 miles apart. A second bottom, Genesee silt loam soil on the Robert L. Harness, Jr., farm was used as one site. The field had been in corn in 1951 and in wheat in 1952.

The second site was a first bottom, Philo silt loam soil on the Mrs. H. H. Burt farm along Salt Creek, a tributary of the Scioto River. The field had been in corn in 1951 and in oats and alfalfa in 1952.
Alfalfa—Johnsongrass stubble was treated on two dates, immediately after the first and second cuttings. Triplicated plots, 14 by 40 feet, were used on each date at each location. In addition to TCA, a new herbicide, sodium 2,2-dichloropropionate (Dalapon), was included in the tests in 1953. TCA was used at rates of 0, 10, 20, and 40 pounds per acre, and Dalapon at rates of 0, 2, 5, 10, 20, and 40 pounds per acre at each location following the removal of the first cutting of alfalfa—Johnsongrass. On the R. L. Harness, Jr. farm, TCA and Dalapon were applied June 4, the same day the first cutting of alfalfa—Johnsongrass was removed, and on July 17, the day following the second cutting. On the farm of Mrs. H. H. Burt, TCA and Dalapon were applied June 6, the day following the removal of the first cutting, and on August 17, four days after the removal of the second cutting. Data from both locations indicated that Dalapon was considerably more phytotoxic than TCA at the same rates; consequently, the 40-pound rate of Dalapon was omitted from the treatments that were applied after the removal of the second cuttings.

Results of July, 1952 Treatments: Except for Johnsongrass, the treated plots remained weed-free until about September 1 when carpet weed (Mollugo verticillata) appeared in plots treated at the 10- and 20-pound rates. Among the more common annual weeds that were controlled by TCA were crabgrass (Digitaria sanguinalis), broadleaf plantain (Plantago major), dandelion (Taraxacum officinale), and green foxtail (Setaria viridis).

On August 7, twenty-one days after treatment, alfalfa in plots treated at the 10-pound rate was about 3 inches higher than that in
the untreated plots and showed little or no damage from TCA. Top-growth of alfalfa was somewhat restricted at the 20- and 60-pound rates. At the highest rate the leaflets failed to expand normally, remained curled or completely folded. About 25 percent fewer shoots were produced from crows in plots treated at the highest rate.

Yields from the July-treated plots were obtained from samples cut on August 25, 1952 from an area 3 by 24 feet in each plots. The component yields of alfalfa and Johnsongrass were based upon hand separations of the green material from which the dry matter was computed, estimating the dry matter at 25 percent moisture. The dry matter yields are given in Table 6. The data indicate that TCA had a marked effect on both alfalfa and Johnsongrass, with the effect on the latter being more marked than the former. A consistent decrease in yield of forage with an increase in rate of chemical is indicated by the data.

Results of August, 1952 treatments: Applications made August 27 were less effective than those made July 17. Symptoms of TCA toxicity in both alfalfa and Johnsongrass were less pronounced following the August treatments. Soil moisture was much lower in August than in July. According to data of the U.S. Weather Bureau, Chillicothe received 6.16, 2.84, and 1.87 inches of rainfall, respectively, during the months of July, August, and September, 1952. The rainfall for the period of 1 week prior to each date of treatment to 3 weeks following treatment was calculated from the daily rainfall records. The rainfall for this period was 5.94 inches prior to and following the July 17 treatments, while 1.51 inches fell during the same interval.

<table>
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<tr>
<th>TCA per acre as acid equiv.</th>
<th>Yield of hay per acre (lb.)</th>
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<tr>
<td>0</td>
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<td>20</td>
<td>730</td>
<td>680</td>
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<tr>
<td>40</td>
<td>1410</td>
<td>450</td>
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</tbody>
</table>

L.S.D. 0.05 121 43
L.S.D. 0.01 183 65

* Significant at 0.05
** Significant at 0.01
when the August 27 treatments were made. Lack of soil moisture, therefore,
was probably the chief reason for the poorer results from the August

Yields were not taken, but the percent reduction of Johnsongrass
stand, compared to nearest check plot, was estimated 24 days after
treatment. The 10-, 20-, and 40-pound rates gave an average top-kill
from the 3 replications of 37, 61, and 78 percent, respectively.
Alfalfa showed little or no damage at the 10- and 20-pound rates and
was somewhat restricted in top-growth at the 40-pound rate. None of
the treatments reduced the number of new shoots from crowns.

Results: 1953. As was noted the previous year, alfalfa recovered
more quickly in plots in which the Johnsongrass had been controlled
than in plots receiving no herbicide. The difference in rate of
recovery was probably due to less competition, especially for moisture,
compared to the untreated plots. The drier the soil at time of
cutting, the greater was the difference in rate of recovery. Observa-
tions which were made the latter part of August found alfalfa to be
from 50 to 100 percent higher during the early stages of growth.

The difference between the yield of alfalfa in the untreated
plots and plots receiving the 10-pound rate of TCA was not statistically
significant. However, the yield of alfalfa was decreased in plots
receiving the 20- and 40-pound rates. The yield of Johnsongrass was
highly significantly reduced by the 10-, 20-, and 40-pound rates, as
compared to the check plots. It is apparent that the 20-pound rate
gave good control of Johnsongrass without reducing the yield of
alfalfa to a very great extent.
Both TCA and Dalapon were effective in decreasing recovery of Johnsongrass from rhizomes (Figures 15-22). These herbicides were also effective in controlling seedlings as long as toxic quantities were present in the soil. The length of time TCA and Dalapon remained in toxic concentrations in the soil following application varied somewhat. At equal rates of application Dalapon persisted a few days longer than TCA. The length of the period these herbicides remained in phytotoxic concentrations varied, depending chiefly upon the rate of application, amount of rainfall, and characteristics of the soil. TCA at the rate of 10, 20, and 40 pounds per acre was generally reduced to a level whereby Johnsongrass seedlings could become established within 25, 35, and 45 days, respectively. The length of the residual period was less when rainfall was abundant following applications or when applications were made on coarse textured soils.

Better results were obtained when applications were made following the removal of the second cutting than when applications were made later in the season. Here again there was a positive correlation between degree of Johnsongrass control and amount of rainfall. The rainfall for the period of 4 weeks following the June applications was 4.23 inches. The rainfall for the same period following the July applications was 1.68 inches.

Even though a consistent decrease in yield of forage was generally obtained with an increase in rate of herbicide, with certain dosage ranges, both TCA and Dalapon increased the percentage of alfalfa without decreasing the yield of alfalfa.

Yields were taken from all plots except those treated August 17.
Figure 15. July 25, 1953. Johnsongrass-alfalfa mixture. 53 percent alfalfa. First cutting made June 3, 1953.

Figure 16. July 25, 1953. 2 1/2 lb/A of Dalapon applied June 6, 1953 to mixture shown in Figure 15. 79 percent alfalfa.
Figure 17. July 25, 1953. 5 lb/A of Dalapon applied June 6 to mixture shown in Figure 15. 92 percent alfalfa.

Figure 18. July 25, 1953. 10 lb/A of Dalapon applied June 6 to mixture shown in Figure 15. 99 percent alfalfa in mixture.
Figure 19. July 25, 1953. 10 lb/A of TCA applied June 6 to mixture shown in Figure 15. 98 percent alfalfa.

Figure 21. August 17, 1953. 10 lb/A of Dalapon applied June 3 to mixture shown in Figure 20. 61 percent alfalfa.
Figure 22. August 17, 1953. Left, 20 lb/A of Dalapon; right, 20 lb/A of TCA applied June 3 to mixture in Figure 20. 93 and 68 percent alfalfa, respectively.
The limited amount of Johnsongrass top-growth prevented an evaluation of the herbicides applied on this date. Rainfall during August and September totaled only 2.47 inches.

Yield data from plots treated June 3, June 6, and July 17 were obtained by cutting an area 3 by 36 feet on each plot. The component yields of alfalfa and Johnsongrass were obtained in the same manner as in 1952. The data are given in Table 7.

Of the treatments used, only the 20- and 40-pound rates of both Dalapon and TCA significantly reduced the yield alfalfa in the first crop following treatment. Only the 40-pound rate of Dalapon significantly reduced the yield of alfalfa in the second crop following treatment. The 20-pound rate of TCA reduced the yield of alfalfa only when applications were made July 17 when the rainfall was low following treatment.

The yield of Johnsongrass was reduced at the .01 level of significance by all treatments with the exception of the second crop in plots treated at the rate of $2\frac{1}{2}$ and 5 pounds of Dalapon and the 10-pound rate of TCA. Johnsongrass in these plots consisted of seedlings as well as established plants.

In general, Dalapon was about 2 times as effective as TCA at equal rates. The 10-pound rate of Dalapon (Figure 21) and the 20-pound rate of TCA (Figure 22) gave excellent control of Johnsongrass with little or no damage to alfalfa. Later in the season, after the phytotoxic effects of TCA and Dalapon had disappeared, seedlings became established. Consequently, it is necessary to retreat if Johnsongrass seeds are in the soil.
Table 7. Yields of alfalfa-Johnsongrass mixtures following applications of TCA and Dalapon, 1953.

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Rate/Rate/Acid equiv.</th>
<th>Alfalfa Yield hay per acre (Replication)</th>
<th>Johnsongrass Yield hay per acre (Replication)</th>
<th>Total</th>
<th>Alfalfa in mixture Pct.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Replication I II III Av.</td>
<td>Replication I II III Av.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>2210 2100 1860 1970</td>
<td>1360 1540 1210</td>
<td>1320</td>
<td>3290</td>
<td>60</td>
</tr>
<tr>
<td>None</td>
<td>1740 1910 2000</td>
<td>1180 1170 1460</td>
<td>1320</td>
<td>2540</td>
<td>76</td>
</tr>
<tr>
<td>Dalapon</td>
<td>1890 1900 1970 1930</td>
<td>1140 740 660</td>
<td>610**</td>
<td>2370</td>
<td>82</td>
</tr>
<tr>
<td>Dalapon</td>
<td>2020 1740</td>
<td>360 350 560</td>
<td>140**</td>
<td>2030</td>
<td>92</td>
</tr>
<tr>
<td>Dalapon</td>
<td>2100 1870 1610 1860</td>
<td>190 200 110</td>
<td>170**</td>
<td>1120</td>
<td>100</td>
</tr>
<tr>
<td>Dalapon</td>
<td>1010 1110 1240 1120**</td>
<td>0 0 0</td>
<td>0**</td>
<td>700</td>
<td>100</td>
</tr>
<tr>
<td>Dalapon</td>
<td>820 700 570 700**</td>
<td>0 0 0</td>
<td>0**</td>
<td>2280</td>
<td>82</td>
</tr>
<tr>
<td>Dalapon</td>
<td>1710 1580 2310 1870</td>
<td>1000 390 440</td>
<td>410**</td>
<td>1970</td>
<td>96</td>
</tr>
<tr>
<td>Dalapon</td>
<td>20 1870 1920 1900</td>
<td>40 30 20**</td>
<td>1970</td>
<td>100</td>
<td></td>
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<tr>
<td>Dalapon</td>
<td>1290 1310 920 1170**</td>
<td>0 0 0</td>
<td>0**</td>
<td>1170</td>
<td>100</td>
</tr>
<tr>
<td>TCA</td>
<td>1710 1580 2310 1870</td>
<td>1000 390 440</td>
<td>410**</td>
<td>2280</td>
<td>82</td>
</tr>
<tr>
<td>TCA</td>
<td>20 1870 1920 1900</td>
<td>40 30 20**</td>
<td>1970</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>TCA</td>
<td>1290 1310 920 1170**</td>
<td>0 0 0</td>
<td>0**</td>
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<td>213</td>
<td></td>
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<tr>
<td>L.S.D.</td>
<td>0.01 475</td>
<td>213</td>
<td></td>
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</table>

Treated June 3, harvested August 17.

| None      | 1700 1980 1520 1740 | 1650 1810 2150 | 1950 | 3690 | 47 |
| None      | 1610 1650 2010 1740 | 1680 1680 2550 | 1950 | 3600 | 47 |
| Dalapon   | 1510 1740 1820 1690 | 1790 1860 2090 | 1910 | 3600 | 47 |
| Dalapon   | 1920 1690 1990 1870 | 1990 1780 1740 1840 | 3710 | 50 |
| Dalapon   | 1890 2010 1780 1870 | 1210 1360 990 | 1990 | 3600 | 50 |
| Dalapon   | 1840 1750 1690 1760 | 110 80 210 | 130** | 1900 | 93 |
| Dalapon   | 1280 1480 1360 1370* | 70 50 130 | 80** | 140 | 94 |
| TCA       | 1800 1970 1700 1820 | 1520 1840 1760 | 1711 | 3530 | 52 |
| TCA       | 20 1890 2020 1870 1930 | 940 800 1010 | 920** | 2850 | 68 |
| TCA       | 1760 1520 2000 1760 | 200 50 190 | 150** | 1910 | 92 |
| L.S.D.    | 0.05 287 | 329 | 1450 |
| L.S.D.    | 0.01 393 | 1450 |

* Significant at 0.05
** Significant at 0.01
Table 7. Continued. Yields of alfalfa-Johnsongrass mixtures following applications of TCA and Dalapon, 1953.

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Rate/A, acid equiv.</th>
<th>Alfalfa Replication</th>
<th>Johnsongrass Replication</th>
<th>Total Alfalfa in mixture</th>
<th>Pct.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lb.</td>
<td>Lb.</td>
<td>Lb.</td>
<td>Lb.</td>
<td></td>
</tr>
<tr>
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<td>2240</td>
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<td></td>
<td>1810</td>
<td>1920</td>
<td>1760</td>
<td>1800</td>
</tr>
<tr>
<td>Dalapon</td>
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<td>1860</td>
<td>1770</td>
<td>1690</td>
<td>1780</td>
</tr>
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<td></td>
<td>360</td>
<td>1420</td>
<td>610</td>
<td>1600</td>
</tr>
<tr>
<td>Dalapon</td>
<td>5</td>
<td>2210</td>
<td>1710</td>
<td>1810</td>
<td>1920</td>
</tr>
<tr>
<td></td>
<td></td>
<td>220</td>
<td>210</td>
<td>80</td>
<td>1700</td>
</tr>
<tr>
<td>Dalapon</td>
<td>10</td>
<td>2100</td>
<td>1860</td>
<td>1910</td>
<td>1960</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>30</td>
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<td></td>
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<td>0</td>
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L.S.D. 0.05 296 187 257 0.01

Treated June 6, harvested July 13.

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Rate/A, acid equiv.</th>
<th>Alfalfa Replication</th>
<th>Johnsongrass Replication</th>
<th>Total Alfalfa in mixture</th>
<th>Pct.</th>
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<tr>
<td></td>
<td>Lb.</td>
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<td>Lb.</td>
<td>Lb.</td>
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<tr>
<td>None</td>
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<td>1850</td>
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<td></td>
<td>1850</td>
<td>1860</td>
<td>2150</td>
<td>1950</td>
</tr>
<tr>
<td>Dalapon</td>
<td>21/2</td>
<td>1810</td>
<td>1790</td>
<td>1870</td>
<td>1820</td>
</tr>
<tr>
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<td></td>
<td>110</td>
<td>1860</td>
<td>1620</td>
<td>1530</td>
</tr>
<tr>
<td>Dalapon</td>
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<td></td>
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<td>1300</td>
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<td>0</td>
<td>20</td>
<td>10</td>
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<td>1800</td>
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<td>80</td>
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</tr>
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</table>

L.S.D. 0.05 394 247 341 0.01

Treated July 17, harvested August 17.

*Significant at 0.05
**Significant at 0.01
Late Spring Flowing and 2,4-D for the Control of Johnsongrass

Willard (1953) reported late planting of corn, giving time for an extra working of Johnsongrass land before planting, resulted in giving Johnsongrass a setback which permitted the production of a late crop of corn. If the land is plowed and worked down about May 20 and worked again about 10 days later, it is possible to destroy the seedlings that have emerged and the top-growth from rhizomes by the afterworking.

Methods: The experimental area was located on the Isaac Cook farm. A description of the soil and the past use of the land may be found on page 73 of this manuscript.

A split-plot design was used. Main plots, 14 by 360 feet, consisted of cultural treatments; sub-plots, 14 by 40 feet, consisted of 2,4-D treatments applied pre-emergence to corn. Three strips, each 14 by 360 feet, were plowed on different dates. Strip A was plowed May 8 and corn was planted May 10. Strip B was plowed May 8, plowed again June 1, and corn was planted June 3. Strip C was plowed June 1 and planted to corn June 3. Propylene glycol butyl ether ester of 2,4-D was applied pre-emergence to corn at rate of 0, 2, and 4 pounds per acre on May 13 to plots in strip A and on June 6 to plots in strips B and C. The sub-plots were replicated three times.

Results: Plants from rhizomes. In order to estimate the effects of the different dates of plowing, counts were made of culms from rhizomes only in those plots treated at the rate of 4 pounds of 2,4-D per acre. Counts were more easily made in these plots because of the fewer number of seedlings present. The few seedlings that survived the 2,4-D treatment were readily distinguished from the rhizomatous
plants at the early stages of growth. Low rates of 2,4-D have little or no direct effects on plants developing from rhizomes. Stand counts of culms in four randomly selected square yard samples from each of the 3 plots in each plowed strip were made 21 days after corn was planted in the strip. Strips A, B, and C had an average of 13, 7.3, and 10 culms per square yard, respectively. Flowing early and plowing again late (strip B) resulted in about 44 percent fewer plants from rhizomes than in the strip plowed once early (strip A). Flowing early and plowing again late (strip B) was about 27 percent more effective than a single plowing late in the spring (strip C).

Seedlings. Numerous Johnsongrass seedlings emerged a few days after corn emerged in strip A. Soil in strip B was not worked down after plowing and the seedlings did not emerge until 10 to 14 days after those in strip A, nor were they as numerous as in strip A.

Twenty-one days after corn was planted, counts were made of the number of seedlings in 4 randomly selected square yard samples in each plot. From the data in Table 8, it may be noted that corn planted early (strip A) had a slightly greater infestation of seedlings than corn planted later (strips B and C). There appeared to be no advantage in plowing early and plowing again later (strip B) over a single late plowing (strip C). Had the ground been worked by diskimg following the early plowing, the seedlings would have probably appeared sooner and therefore more of them would have been destroyed by the second diskimg.

From the data in Table 8, it may also be noted that 2,4-D was effective in reducing the number of seedlings. On plots receiving
Table 8. Johnsongrass seedlings per square yard 21 days after each date of planting corn as affected by 2,4-D and cultural practices.

<table>
<thead>
<tr>
<th>2,4-D acid equiv., per A.</th>
<th>Strip A, plowed May 8</th>
<th>Strip B, plowed May 8 and June 1</th>
<th>Strip C, plowed June 1</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Replication</td>
<td>Av.</td>
<td>Replication</td>
</tr>
<tr>
<td>0</td>
<td>I  II  III</td>
<td>16.3</td>
<td>I  II  III</td>
</tr>
<tr>
<td>2</td>
<td>I  II  III</td>
<td>6.7</td>
<td>I  II  III</td>
</tr>
<tr>
<td>4</td>
<td>I  II  III</td>
<td>3.3</td>
<td>I  II  III</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>8.8</td>
<td></td>
</tr>
</tbody>
</table>
0, 2, and 4 pounds per acre of 2,4-D there was an average of 13, 5, and 2 seedlings per square yard, respectively. Hence, the 2-pound rate of 2,4-D gave about 63 percent control, and the 4-pound rate gave about 81 percent control of seedlings.
Use of Herbicides Pre-emergence to Corn for the Control of Johnsongrass Seedlings

In an attempt to control Johnsongrass seedlings an experiment was initiated in the spring of 1953 in which various herbicides were applied pre-emergence to corn. The experimental area was located on the farm operated by Robert L. Harness, Jr., adjacent to the area treated in March and April of 1953 with TCA.

Methods: Triplicated plots, 13 1/3 feet by 50 feet were treated May 29, four days after corn was planted in the area. The following herbicides were used: propylene glycol butyl ether ester of 2,4-D at rates of 2 and 4 pounds per acre, butoxy ethanol ester of 2,4-dimethyl, 4-chlorophenoxyacetic acid (MCP) at 2 and 4 pounds, alkanol amine salt of dinitro ortho secondary butyl phenol (Premerge) at 7 1/2 pounds, sodium salt of N-1 Naphthyl phthalamic acid (Alanap), TCA at 4 and 8 pounds, and CMU at 2 and 4 pounds per acre.

Results: As discussed on page 77, the stand of Johnsongrass was sparse, rendering it impossible to evaluate the effects of the herbicides on Johnsongrass. The effects of the herbicides on corn may be worthy of consideration. Of the treatments used, only the 8-pound rate of TCA and the 4-pound rate of CMU damaged the corn. With the former treatment about 15 percent of the plants were slightly stunted. About 6 weeks from planting most of these plants recovered. The 4-pound rate of CMU reduced the stand of corn from 10 to 40 percent, with the greatest reduction on the lighter colored soils. Four weeks from date of planting, corn in these plots was only 1/4 to 1/2 as high
as that in the untreated plots. Most of the corn on the darker colored soils recovered, while that on the lighter colored soils remained shorter throughout the season.
Post-emergence Applications of Maleic Hydrazide on Johnsongrass

Many workers have reported that maleic hydrazide (MH) produces a temporary cessation of growth in plants. It seemed that a high degree of control of Johnsongrass might be achieved if plants were treated and then plowed under while still "anesthetized" by this chemical.

Experiments were conducted on the Isaac Cook farm in which MH was applied to young, established Johnsongrass plants. A description of the area will be found on page 73.

Methods: Triplicated plots, 13 by 42 feet, were treated with maleic hydrazide at rates of 0, 4, 8, and 12 pounds, active ingredient, per acre on May 11, 1952, when the Johnsongrass was 6 to 8 inches high. It was planned to plow a few days after treatment, but this was not possible. As a result the land was not plowed until 20 days after treatment.

Due to the fact that the land was not plowed at the desired time, an adjacent area was treated in a similar manner on May 31, when the Johnsongrass was 12 to 14 inches high.

The entire area was plowed, seedbed prepared, and Ohio W10 corn planted on June 3.

In order to evaluate the effects of plowing, an area was treated with MH but not plowed subsequent to treatment. Triplicated plots, 7 by 25 feet, were treated with MH at rates of 0, 4, 8, 12, and 24 pounds, active ingredient per acre on May 11. A single series of plots was treated at rates of 32 and 64 pounds per acre.

The plots contained a heavy infestation of Johnsongrass and scattered plants of curly dock (Rumex crispus), dandelion, hedge
bindweed (*Convolvulus sepium*), wild garlic (*Allium vinale*), lamb's quarter (*Chenopodium album*), wild carrot (*Daucus carota*), wild parsnip (*Pastinaca sativa*), yellow foxtail (*Setaria lutescens*), cheat (*Bromus secalinus*), Korean lespedeza (*Lespedeza stipulacea*), white clover (*Trifolium repens*), and red clover (*T. pratense*). Johnsongrass and most of the other weeds were about 10 inches high at time of treatment.

Results: General. Both mono- and dicotyledonous plants were affected when treated with TCA. The first symptom was a general inhibition of vegetative growth. In most species the terminal bud would subsequently die and the axillary buds would begin to elongate. The internodes were shortened and the plants were generally severely stunted. The green color of the leaves of most species was intensified and a reddish-purple anthocyanin-like pigmentation developed within one month after treatment. Flowering was delayed or even prevented, depending upon the species and amount of chemical applied. If the general inhibition of growth persisted long enough, the affected plants were killed. In none of the species examined were there evidences of root initiation, fasciation of stem or root tissues, twisting of petioles, or true epinasty of leaves such as is common when plants are treated with 2,4-D and other so-called "growth regulators". MH produced a response at different concentrations on different plants. However, there was not the wide concentration difference in response between grasses and broad leaf plants to MH that is commonly noted with 2,4-D and related compounds. Of the plants that were present, Johnsongrass was the least affected by applications of MH.
Results: Areas planted to corn. Corn was not visibly damaged by any of the treatments. There were few weeds present other than Johnsongrass. Since this was a coarse textured soil and rainfall was low, soil moisture was probably the chief factor limiting the growth of other weeds.

An estimate of stand reduction of Johnsongrass plants from rhizomes was made July 7, by making stand counts of 4 randomly selected square yard samples in each plot. The data are given in Table 9 as percent reduction of culms compared to check plots. The 4, 8, and 12 pound rates gave, respectively, 27, 23, and 33 percent stand reduction compared with the untreated plots. In the area plowed 20 days after treatment, none of the treatments reduced the stand of Johnsongrass to a satisfactory level.

When the land was plowed 3 days after applications of MH, results were much more satisfactory. The 12-pound rate gave 83 percent control. Johnsongrass seedlings were present in the corn. None of seedlings showed symptoms of MH injury.

Results: Areas not tilled. The first symptoms observed on most weeds were the inhibition of vegetative growth and subsequent death of the terminal bud. The green color of the leaves was intensified and a reddish-purple, anthocyanin-like pigmentation developed within a month after treatment. Prior to or following death of the terminal bud, lateral buds began to elongate. Growth of the lateral buds, in most cases, was quite limited.

The usual sequence of symptoms produced in treated plants was:
(a) loss of apical dominance; (b) expansion of leaves already formed,
often to a size greater than the controls; (c) production of a darker green than the controls; (d) increase in production of anthocyanin pigmentation, and some chlorosis. Subsequent behavior depended to a large extent upon the amount of MH applied, the age of the plant, and the species.

Very few of these weeds increased in height except in plots treated at the 4-pound rate. Annual grasses were abundant later in the season in plots treated at the 12- and 24-pound rates.

Johnsongrass apparently was not affected to the same degree as the other weeds. Inhibition of vegetative growth as well as the reddish-purple pigmentation, especially of the veins, was also noted in Johnsongrass. Johnsongrass appeared to recover to a limited extent about 2 months after treatment at the 4- and 8-pound rates and about 3 months after treatment at the 12- and 24-pound rates. About 85 percent of the Johnsongrass plants treated at the 2 higher rates did not form inflorescences. The inflorescences that developed were abnormal and formed within the tightly rolled terminal leaf blades about 6 weeks later than those on untreated plants. Most of these inflorescences later decayed in place. None of the plants that were established at time of spraying recovered in plots treated at the 32- and 64-pound rates.

The injury ratings of the Johnsongrass plants 2 weeks after spraying are given in Table 10. Very few seedlings were present in any of the plots. Since the soil was not disturbed and soil moisture was low, the seedlings apparently could not establish.

From the results of these tests certain conclusions may be drawn.
MH at 12 pounds per acre was effective in giving 83 percent control of top-growth when the land was plowed 3 days after treatment. Plowing 3 days after application of MH was much more effective than plowing 20 days after application. The latter treatment, in turn, was much more effective than not plowing following treatment. More than 24 pounds per acre was required to effectively control top-growth of established Johnsongrass when the land was not plowed after treatment.

Since other investigators have shown that corn and vegetable crops, such as beets, green beans, and potatoes can be grown without any apparent effects on areas treated with at least 16 pounds per acre of MH, it is possible that this herbicide can be used to bring areas infested with Johnsongrass and other perennial grasses into an economically productive state without subjecting these areas to intensive cultural practices or prolonged sterilization from the use of chemicals.
Table 9. Estimated inhibition of Johnson grass on July 7 from maleic hydrazide. Land plowed June 3.

<table>
<thead>
<tr>
<th>Maleic hydrazide active ingredient per acre.</th>
<th>Reduction in sprouting</th>
<th>Replication</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>Applied May 14</td>
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<tr>
<td>12</td>
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<td>89</td>
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</table>

Table 10. Injury rating of established Johnson grass on June 28, 1952 as affected by maleic hydrazide applied May 14, 1952.

(0 — no effect, 10 — complete top-kill)

<table>
<thead>
<tr>
<th>Maleic hydrazide active ingredient per acre.</th>
<th>Injury rating June 28, 1952</th>
<th>Replications</th>
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<td></td>
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<tr>
<td>64</td>
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CMU For Control of Johnsongrass and Studies
of the Persistence and Depth of Penetration
of CMU in Soils

Experiments were initiated in 1951 and 1952 with the two-fold purpose of (1) determining the feasibility of controlling established Johnsongrass by the use of 3-p-chlorophenyl-1,1-dimethylurea (CMU) and (2) determining the persistence and depth of penetration of CMU in different soils.

Methods: An established Johnsongrass sod was used for the studies in 1952 and 1953. The experimental area was on the J. S. Cook farm in the same field as the maleic hydrazide experiments. CMU was applied to an undisturbed Johnsongrass sod at rates of 0, 20, 40, 60, and 80 pounds, active ingredient, on March 29, 1952 to triplicated plots, 7 by 25 feet.

In 1951 an experiment was initiated with the purpose of determining the persistence of CMU in a silty clay loam soil and to determine the effects of CMU on Canada thistle (Circium arvense). This experiment was conducted on a fertile Westland silty clay loam soil on The Ohio State University Farm at Columbus, Ohio. CMU was applied on various dates during the summer of 1951. Soil samples were taken from some of these plots in 1952 and 1953 and bio-assays conducted in the greenhouse in order to determine the residual toxicity and the depth of penetration of CMU. Chemical analyses of the soil samples were made by E. I. DuPont de Nemours and Company under the supervision of Dr. Dale E. Wolf in 1952 and Dr. Gideon D. Hill, Jr. in 1953.
Triplicated plots, 6 by 25 feet, with a uniform growth of Canada thistle and a substantial amount of quackgrass (*Agropyron repens*) were treated with CMU at rates of 0, 16, 32, and 64 pounds, active ingredient, per acre when Canada thistle was at 4 stages of growth: rosette (April 20, 1951), bud stage (May 29), rosette after mowing (July 6), and when fall growth was 10 inches high (September 5).

Soil samples were taken in June, 1952 and in June, 1953 from some of these plots and bio-assays and chemical analyses conducted to determine the depth to which CMU had moved.

Soil samples were taken from plots treated April 20, 1951 at rates of 16 and 64 pounds per acre of active CMU and from plots treated September 5, 1951 at the same rates.

Each treatment in the field was replicated 3 times. Two soil samples were taken from each treated plot at depths of 0 to 4 inches, 4 to 8 inches, and 8 to 10 inches. The soil was air-dried and the 2 samples from each depth in each of the 3 replications were thoroughly mixed. Three 5-inch glazed pots were filled from each composite. The pots were placed in 8-inch galvanized metal pans containing water.

Six kernels of Ohio W64 corn, 6 Lincoln soybeans and 6 Marglobe tomato seeds were planted in each pot. All of the corn and soybeans germinated, but only a small percentage of the tomato seeds germinated. The tomato seedlings that were present were later removed. Corn and soybeans emerged 3 days after planting and were thinned to 3 plants per pot 3 days later.

With some exceptions the methods used in 1953 were similar to those used in 1952. In order to sample undisturbed soil in 1953,
samples were taken from plots treated May 29, 1951 at rates of 16 and 64 pounds per acre and July 6, 1951 at the same rates. Since CMU was present in the 8 to 12 inch layer in 1952, samples from a depth of 20 to 24 inches were included in the 1953 studies. Corn and soybeans were planted June 11, 1953 and emerged 3 days later.

Results: CMU on Johnsongrass. All rates of CMU gave complete top-kill of all vegetation except Johnsongrass. The rate of kill was slow and in direct proportion to the amount of chemical applied. Symptoms of CMU toxicity were first apparent about 2 weeks after treatment in plots treated at the 80-pound rate and about 5 weeks after treatment in plots treated at the 20-pound rate. These symptoms were first evident as a light-green color of the tips of the leaves. This discoloration progressed toward the petiole, and the entire leaf gradually became chlorotic. The margin of the leaves turned yellow and finally brown. The roots of plants treated with CMU were greatly restricted. While growth of the rhizomes was greatly retarded, the rhizomes were somewhat longer than those treated with TCA. Rainfall prior to and following treatment was below normal. No rain occurred during the week preceding treatment and only 2.29 inches fell during the month following treatment.

Broadleaf weeds were first to exhibit toxicity symptoms. Johnsongrass was the last species to be visibly affected. All broadleaf species were killed in all plots receiving CMU. Except for a few climbing milkweed (Ampelamus Albidus) plants that appeared about the middle of August in some plots of all treatments, the CMU treated plots remained free of all vegetation except Johnsongrass throughout
Johnsongrass seedlings did not establish in any plots receiving CMU. A few seedlings were present in the check plots.

Johnsongrass treated at the 20-pound rate of CMU appeared to recover from the toxic effects about 2 months after treatment. For the remainder of the growing season these plants were more vigorous and the leaves were of a darker green color than the untreated plants. As the data in Table 11 indicate, there were about 12 percent more plants per unit area than in the untreated plots. At time of heading these plants were 12 to 18 inches higher than those not treated. This greater growth may be attributed to less competition for essential minerals, soil moisture, and radiant energy since all vegetation except Johnsongrass was killed in these plots.

Johnsongrass in plots treated at higher rates did not recover to as great an extent. None of the plants recovered completely in plots treated at rates of 40, 60, and 80 pounds per acre. Approximately 25 percent of the plants treated at the 40-pound rate formed inflorescences. Most of the inflorescences were abnormal and exhibited typical CMU toxicity symptoms. Only a few plants treated at the 60-pound rate and none treated at the 80-pound rate formed inflorescences. Satisfactory top-kill of Johnsongrass was obtained only in plots treated at the 60- and 80-pound rates.

A single plot treated at the rate of 100 pounds per acre of CMU remained free of all vegetation throughout the growing season.

The structure of the soil was much better in the treated plots than in the checks. Improvement in structure was in direct relation
to the amount of CMU applied. This may be due to the direct effects of CMU on soil structure, or to the indirect effects through the death and subsequent decay of plant tissue.

The following results were noted in 1953. The phytotoxic effects of CMU decreased somewhat during the year. But as the data in Table 11 indicate, plots treated at the 60- and 80-pound rates still contained sufficient residual CMU to maintain plots 78 and 90 percent, respectively, free of Johnsongrass. Few of the plants that were present formed inflorescences, and these were abnormal. Plots treated at the 40-pound rate contained about the same amount of Johnsongrass as the untreated plots. Plots treated at the 20-pound rate contained about 10 percent more plants than the untreated plots. Johnsongrass seedlings were present in the untreated plots but were not present in any of the plots receiving CMU. A few climbing milkweed plants were present in some plots of all treatments. Johnsongrass and climbing milkweed were the only species that became established in plots treated with CMU.
Table 11. Estimated percent stand reduction of Johnsongrass from CMU applied March 29, 1952 as indicated by top-growth.

<table>
<thead>
<tr>
<th>CMU active ingredient</th>
<th>Reduction in stand</th>
<th>Replication</th>
<th></th>
<th></th>
<th></th>
<th>Av.</th>
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<td>-15*</td>
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<td>-12*</td>
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<td>-10*</td>
<td>-10*</td>
<td>-10*</td>
<td>-10*</td>
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<td>-3*</td>
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<td>85</td>
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</table>

*percent increase in stand of Johnsongrass.
The Effects of CMU on Canada Thistle and Other Weeds

Results: 1951. All rates gave complete control of all vegetation except thistle at each stage of growth. The 16-pound rate gave 85 to 90 percent top-kill regardless of date of treatment. The 32- and 64-pound rates resulted in 100 percent top-kill regardless of date of treatment.

The first symptoms of CMU toxicity in Canada thistle appeared 10 to 14 days after treatment as a light-green color at the tips of the leaves. This discoloration progressed slowly to the basal portion of the leaves. The buds remained green longer than any of the other vegetative parts. Later the leaves and buds turned yellow and finally brown.

In all plots treated at the first 2 stages of growth (April 20 and May 29) regrowth from thistle rhizomes appeared during the latter part of June and the first few days of July. The moisture content of the soil was very low preceding this period. Evidence from excavations indicated that the thistle sprouts grew up through the dry, toxic layer of soil. Stand counts were made July 6 of the number of thistles in 2 square yard samples in each plot treated April 20 and in those treated May 29. As the data in Table 12 indicate, somewhat more regrowth appeared in plots treated on the first date than in plots treated on the latter date. Much less regrowth appeared in plots treated at the 64-pound rate than in plots treated at lower rates.

Following 0.85 inches of rain on July 30 the thistle sprouts began to die. Within 10 to 14 days all of these plants were killed
to the soil surface.

During a second extremely dry period that occurred in August, thistle sprouts again appeared in plots treated at the first 2 stages of growth. This regrowth was killed to soil surface following 0.42 inches of rain on September 10.

Vegetation in plots treated July 6 and in those treated September 5 did not show CMU toxicity symptoms as quickly as vegetation in plots treated earlier. Since July and August were the driest months in the history of the Columbus Weather Bureau, the slowness of response of plants to CMU toxicity may be attributed to insufficient moisture to put the chemical in solution. No regrowth appeared in these plots during 1951.

Results: 1952. The 32- and 64-pound rates resulted in 84 and 96 percent top-kill of thistle, respectively. Thistle sprouts were abundant in all plots treated at the 16-pound rate. A few plants of curled dock, buckhorn plantain (Plantago lanceolata), and dandelion appeared in May in plots treated at the 16-pound rate. By July, large crabgrass, smartweed (Polygonum pensylvanicum), prickly lettuce (Lactuca scariola), and nutgrass (Cyperus esculentus) were also present in these plots. With the exception of Canada thistle, crabgrass was the first species to appear in abundance. It covered all but 1 replication of the plots treated at the 32-pound rate and a few plants appeared in plots treated at the 64-pound rate. There were more weeds in those plots treated in the spring than in those treated in the fall.

The presence of the above-named plants was indicative of a reduction of CMU in the upper few inches of soil. The absence of other
species in these plots was taken as evidence that the above-named species are more tolerant of CMU than are other common weeds.

The number of thistle plants per square yard at different times during the growing season is given in Table 12.
Figure 23. June 25, 1952. Untreated check - Canada thistle, quackgrass, and other weeds.

Figure 24. June 25, 1952. 16 lb/A of CMU applied May 29, 1951 to mixture shown in Figure 23. Vigorous, almost pure, stand of Canada thistle.
Figure 25. June 25, 1952. The effect of 32 pounds per acre of CMU applied May 29, 1951. No vegetation.

Figure 26. June 25, 1952. The effect of 64 pounds per acre of CMU applied May 29, 1951. No vegetation.
Table 12. Effects of CMU applied on different dates on the stand of Canada thistle. Counts are averages of two square yard samples per plot.

<table>
<thead>
<tr>
<th>Rate/A</th>
<th>CMU Active Ingredient</th>
<th>Treated 1-20-51 Replication I II III Av.</th>
<th>Treated 5-29-51 Replication I II III Av.</th>
<th>Treated 7-6-51 Replication I II III Av.</th>
<th>Treated 9-5-51 Replication</th>
<th>Mean</th>
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July 6, 1951

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<th>Treated 7-6-51 Replication I II III Av.</th>
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May 13, 1952

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June 26, 1952

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September 15, 1952

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<th>Treated 7-6-51 Replication I II III Av.</th>
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May 15, 1953
Results: 1953. Quackgrass became a serious competitor with thistle in the untreated plots. In plots treated at the 16-pound rate thistles were more vigorous and more abundant than in the untreated plots or plots treated at higher rates. Very little quackgrass was present in these plots. As the data in Table 12 indicate, only the 61/4-pound rate was effective in preventing regrowth of thistle for 2 years.

Sudan grass was seeded in the field the first week in June. The stand of Sudan grass was reduced about 15 and 90 percent respectively in plots treated at the 16- and 32-pound rates (Figures 27 and 28). No Sudan grass was present in plots treated at the 61/4-pound rate (Figure 29). Canada thistle was abundant in plots receiving no CMU and in those treated at the 16-pound rate. An almost pure stand of crabgrass was present in all plots treated at the 32-pound rate. No plants except some severely stunted thistle plants were present in plots treated at the 61/4-pound rate.
Figure 27. August 11, 1953. Left, untreated; right, 32 lb/A of CMU applied May 29, 1951. Practically no vegetation except quackgrass.

Figure 28. August 11, 1953. Left, 64 lb/A of CMU applied May 29, 1951; right, 16 lb/A (Sudangrass, Canada thistle, and crabgrass).
Figure 29. August 11, 1953. Left, 64 lb/A of CMU applied May 29, 1951; right, untreated.
Results: Bio-assays and chemical analyses of CMU treated soils.

The seed leaves of the soybeans were normal in all pots. The first symptoms of CMU toxicity in soybeans appeared as a light-green color of the first true leaves, followed by a retardation of growth. The first true leaves were almost fully expanded when the tips began to turn a greenish-yellow color. This discoloration progressed toward the petiole, and the entire leaf gradually became chlorotic with the margins dying first. The younger leaves turned a light-green color at about the same time the first true leaves turned brown.

From 2 to 6 days after soybeans showed symptoms of CMU damage the corn also turned a light-green color. Later the corn turned light-yellow and the leaves became flaccid as though the cells were plasmolyzed. Some of the leaves turned a dark-purple. About 1/8 to 1/2 inch from the stalk the leaves of corn bent sharply downward. Still later a short section of the stalk near the base became weak and the plants gradually became prostrate on the soil. The injury ratings 26 days after planting are given in Table 13.

The results of the bio-assay indicate that corn is more tolerant than soybeans to CMU. Furthermore, roots of both corn and soybeans were more sensitive than the aerial parts to CMU toxicity. The roots of some plants were shorter and fewer in number even though the tops appeared normal.

A close correlation existed between soil structure and amount of CMU present in the soil. Soil from plots treated at the 64-pound rate possessed a much better structure than the soil from plots treated at the 16-pound rate. Soil from the latter plots was better aggregated
than from plots receiving no herbicide. This same difference in soil structure was also noted in the plots in the field.

A chemical analysis of the soil was made in 1952 by E. I. DuPont de Nemours and Company under the supervision of Dr. Dale E. Wolf. The concentration of CMU in p.p.m. of air-dry soil was determined for each composite (each composite consisted of 2 samples at each depth from each of the 3 replications which had received the same treatment). The analytical results are given in Table 13.

These data, in general, are in close agreement with the results of the bio-assay. An examination of the results of either the chemical analysis or the bio-assay reveals the fact that CMU was very persistent in toxic amounts, especially in the surface (0-4 inch) layer. This layer contained almost twice the amount that was present in both the 4 to 8, and 8 to 12 inch layers. Toxicity decreased as depth of soil increased. Even though CMU is very persistent there is vertical movement of this herbicide as indicated by its presence at a depth of 8 to 12 inches in plots treated at the lowest rate - 16 pounds per acre.

The results of the chemical analyses showed no significant difference between the concentration of residual CMU in plots treated in the spring and those treated at comparable rates in the fall. However, the results of the bio-assay indicated a definitely greater residual toxicity in plots treated in the fall than in those treated in the spring. Observations of the vegetation in the field agree with the results of the bio-assay.
Table 13. Injury ratings of corn and soybeans grown on soil treated the previous year with CMU and chemical analyses of the soil.

(0 — no effect; 10 — all plants killed)*

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<th>CMU applied</th>
<th>Time</th>
<th>Rate/A active ingredient</th>
<th>Depth sampled</th>
<th>Rating 26 days after planting</th>
<th>Chemical Analyses</th>
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<td>Corn Replication</td>
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<td>Sept.</td>
<td>16</td>
<td>4-8</td>
<td>2 4 3 3</td>
<td>4 6 5 5</td>
<td>2.1</td>
</tr>
<tr>
<td>Sept.</td>
<td>16</td>
<td>8-12</td>
<td>0 1 1 0.7</td>
<td>2 2 2 2</td>
<td>1.1</td>
</tr>
<tr>
<td>April</td>
<td>64</td>
<td>0-4</td>
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<td>10 10 10 10</td>
<td>19.7</td>
</tr>
<tr>
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<td>64</td>
<td>4-8</td>
<td>8 9 9 8.7</td>
<td>10 10 10 10</td>
<td>6.6</td>
</tr>
<tr>
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<td>8-12</td>
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<tr>
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<td>8-12</td>
<td>10 10 10 10</td>
<td>10 10 10 10</td>
<td>6.4</td>
</tr>
</tbody>
</table>

*Plants receiving a rating of 7 or higher later died.
Results: 1953. The first symptoms of CMU toxicity in soybeans appeared 9 days after date of planting. At this time the first 2 unifoliate leaves were fully expanded. CMU toxicity symptoms first appeared in corn 8 days later when it was in the 3 to 4 leaf stage.

Injury ratings were made June 11, 1953, twenty-nine days after planting. The data in Table 14 indicate that 2 years after date of application, CMU at the rate of 64 pounds per acre was present in sufficient quantities to be lethal to soybeans. While corn was not killed, it did exhibit typical symptoms of CMU toxicity.

At the 16-pound rate soybeans showed symptoms of CMU toxicity, but corn was not visibly affected. None of the soybean plants were killed.

Vertical movement of this herbicide was shown by its presence at a depth of 20 to 24 inches. The data also indicate that CMU was distributed throughout the 0- to 24-inch layer of soil with no distinct zone of high concentration.

As noted the previous year, roots of both corn and soybeans were more affected by CMU than the aerial parts. Again, the soil structure was much better in plots treated with CMU than in the untreated plots.

(0 — no effect; 10 — all plants killed)*

<table>
<thead>
<tr>
<th>CMU applied</th>
<th>Rate/active ingredient</th>
<th>Depth sampled</th>
<th>Rating 29 days after planting</th>
<th>Chemical analyses</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Corn</td>
<td>Soybeans</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>Replication</td>
<td>Replication</td>
</tr>
<tr>
<td>Time</td>
<td>Lb.</td>
<td>In.</td>
<td>I   II  III  Av.</td>
<td>I   II  III  Av.</td>
</tr>
<tr>
<td>May 16</td>
<td>0-4</td>
<td>0</td>
<td>0   0   0   0</td>
<td>1   1   1   1.0</td>
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<tr>
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<td>8-12</td>
<td>0</td>
<td>0   0   0   0</td>
<td>1   0   1   0.7</td>
</tr>
<tr>
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<td>20-24</td>
<td>0</td>
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<td>0   0   2   0.7</td>
</tr>
<tr>
<td>July 16</td>
<td>0-4</td>
<td>0</td>
<td>0   0   0   0</td>
<td>0   1   3   1.3</td>
</tr>
<tr>
<td>July 16</td>
<td>4-8</td>
<td>0</td>
<td>0   0   0   0</td>
<td>1   0   0   0.3</td>
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<tr>
<td>July 16</td>
<td>8-12</td>
<td>0</td>
<td>0   0   0   0</td>
<td>0   0   0   0.0</td>
</tr>
<tr>
<td>July 16</td>
<td>20-24</td>
<td>0</td>
<td>0   0   0   0</td>
<td>0   1   1   0.7</td>
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<tr>
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<td>0   1   0.7</td>
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<tr>
<td>May 64</td>
<td>8-12</td>
<td>1</td>
<td>1   1   0.7</td>
<td>4   3   4   3.7</td>
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<tr>
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<td>1   1   1.0</td>
<td>9   10  9   9.3</td>
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<td>July 64</td>
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<td>2   1   1.3</td>
<td>5   5   9   6.3</td>
</tr>
<tr>
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<td>1</td>
<td>1   1   1.0</td>
<td>5   7   8   6.7</td>
</tr>
<tr>
<td>July 64</td>
<td>8-12</td>
<td>1</td>
<td>2   2   1.7</td>
<td>8   10  9   9.0</td>
</tr>
<tr>
<td>July 64</td>
<td>20-24</td>
<td>2</td>
<td>1   0   1.0</td>
<td>8   3   4   5.0</td>
</tr>
</tbody>
</table>

*Plants that were given a rating of 7 or higher later died.
Longevity of Johnsongrass Seed

No studies of the longevity of Johnsongrass seed in the soil were found in the literature. An experiment was initiated in 1951 in which freshly harvested seed from a natural infestation of Johnsongrass was placed in 5-inch porous clay pots with porous clay covers. Four hundred seeds were placed in each of 18 pots. These were buried at 3 different depths so that the seeds were 4 to 6 inches, 7 to 9 inches, and 16 to 19 inches below the surface of the soil. Pots were removed and germination tests were conducted in the fall of 1952 and 1953. The percent of Johnsongrass that germinated is given in Table 15. These data definitely indicate that Johnsongrass seeds that are plowed under may be a source of reinfestation for several years.

Table 15. Germination of Johnsongrass seed buried in the soil.

<table>
<thead>
<tr>
<th>Depth buried In.</th>
<th>Germination after 12 months Fct.</th>
<th>24 months Fct.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-6</td>
<td>24</td>
<td>26</td>
</tr>
<tr>
<td>7-9</td>
<td>60</td>
<td>27</td>
</tr>
<tr>
<td>16-19</td>
<td>81</td>
<td>49</td>
</tr>
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</table>
This study of the control of Johnson grass includes at least six lines of approach: (1) the use of summer fallow, (2) the use of summer fallow and herbicides, (3) the use of herbicides alone, (4) the use of selective herbicides to kill Johnson grass in established alfalfa, (5) the use of herbicides pre-emergence to corn to control Johnson grass seedlings, and (6) the use of maleic hydrazide (MH) on Johnson grass foliage followed by plowing. Although the use of Johnson grass and Johnson grass mixtures for hay or pasture was not studied extensively, it is common knowledge that if the grass is pastured closely or mowed frequently it will not produce seeds or rhizomes. The first step in a Johnson grass control program is to keep the production of seeds and rhizomes to a minimum by pasturing heavily and/or mowing frequently.

The greater effectiveness from the use of chemical and cultural practices in 1952-1953 compared to 1951-1952 may be attributed to the fact that the area used for the 1952-1953 studies had been pastured for one and one-half seasons prior to treatment. This pasturing resulted in restricting the top-growth and the plants did not have sufficient foliage to produce large quantities of reserve foods. These weakened plants were more easily killed than were those used for the 1951-1952 studies. The area used for the 1951-1952 studies had been in corn for the two years prior to treatment. These plants grew to a height of 10 to 12 feet and produced an abundance of seeds and an extensive system of large rootstocks. A high degree of control of these vigorous plants was not obtained by the use of chemical and
cultural practices.

Satisfactory control from the use of cultural practices was obtained when the plants were weakened by pasturing, followed by plowing July 30 and working the soil frequently enough thereafter to prevent top-growth from obtaining a height of more than 8 or 10 inches. This practice resulted in 84 percent control of top-growth from rhizomes. Plowing three weeks after the above date (i.e. August 20) resulted in only 50 percent control of top-growth. Plowing later in the season gave still less control.

When treatments were made during the summer or early fall, plowing the land prior to the application of herbicides consistently gave better results than when the land was not plowed. Plowing prior to treatment results in turning the roots and rhizomes up to or near the surface, bringing them in closer contact with the herbicides. Treatments made in the early spring gave good results even when applications were made to established Johnsongrass that had not been plowed. Rainfall was sufficient in the early spring to leach the herbicides down to the rhizomes.

A positive correlation between the effectiveness of the herbicides and the precipitation pattern following treatment was demonstrated. Such correlation offers a reasonable explanation for much of the variation between applications made on different dates. Applications made in the spring when rainfall was adequate consistently gave good results. Some applications made in the summer did not give good results because of the low precipitation following treatment. Optimum control of Johnsongrass by the use of herbicides was obtained when
sufficient rainfall occurred soon after application to leach the herbicides into contact with the rhizomes. Depending on such factors as amount of vegetation, soil type, and initial content of moisture in the soil, best results were obtained when from one to two inches of rain fell following applications. The rainfall factor would probably account for many of the apparent inconsistencies in results reported in the literature. This conclusion is also that of McCall and Zahnley (1949), Watson (1950), and Peters (1952, p. 130).

The residual toxicity of TCA for corn generally disappeared within 60 days; this suggests the possibility of growing a corn crop the same year TCA is applied, if it can be applied in March. Under optimum conditions this method gave as effective control of Johnson-grass as any other method. TCA at the rate of 40 pounds per acre gave 98 percent control of Johnson-grass with no damage to corn that was planted 77 days after treatment. Essentially the same degree of control of Johnson-grass was obtained with very minor damage to corn that was planted 58 days after treatment. The 20-pound rate gave 80 to 83 percent control with no damage to corn planted 58 days after treatment. The results of these tests and those of Peters (1952, pp. 76-88), indicate that a rate of about 30 pounds per acre applied in March is worthy of trial on a limited scale. The wet soils at this time of the year, the uncertainty of the length of time that TCA will remain phytotoxic in the soil, and the fact that corn planting is delayed are objections to this practice.

The effectiveness of the herbicides was dependent upon the stage of growth of Johnson-grass at time of application. If the herbicides
remained in the soil for some time, rhizome buds absorbed them but the phytotoxic effects were not visible until after growth had resumed. However, the best results were always obtained if the herbicides were present when active growth was occurring from the rhizomes. Applications made in September were more effective than those made in October, and these in turn were more effective than those made in November.

The necessity of taking the land out of production for one or more seasons has limited the use of many cultural practices as well as the use of some chemicals. Two herbicides, TCA and Dalapon, showed promise of being employed as selective herbicides in alfalfa-Johnsongrass sods. Under favorable conditions these herbicides controlled Johnsongrass without permanent damage to the alfalfa. One pound of Dalapon was equal to about two pounds of TCA in effectiveness. The 10-pound rate of Dalapon and the 20-pound rate of TCA gave the best results. Higher rates gave better control of Johnsongrass but sometimes damaged the alfalfa. Lower rates at times gave good results but were not satisfactory when rainfall following treatment was limited.

Since Johnsongrass seeds are not killed when in contact with most herbicides and since some seeds remain in a viable condition in the soil for a number of years, a satisfactory control program must include not only the prevention of seed formation but also the control of plants from seeds that remain dormant for a few years. The use of 2,4-D pre-emergence to corn resulted in good control of Johnsongrass seedlings as well as most other weed seedlings. The 2- and 4-pound
rates gave an average of 64 and 83 percent control of Johnsongrass seedlings, respectively, with no visible damage to corn. The yield of corn was increased due to less competition from the weed seedlings.

Of the herbicides used, maleic hydrazide and Dalapon are the only ones that are primarily absorbed by the foliage. Seventy-seven percent control of Johnsongrass was obtained when MH was applied at the 8-pound rate to the foliage of young Johnsongrass plants and the land was plowed 3 days later. When the land was not plowed or was plowed 21 days after treatment, the effectiveness of this herbicide was reduced considerably.

CMU was less effective in controlling Johnsongrass than most other weeds. At rates of 20 pounds per acre, other species of weeds were controlled but, due to less competition, Johnsongrass was even more vigorous than in the untreated plots. Eighty pounds or more per acre were necessary to give satisfactory control of Johnsongrass. At this rate CMU sterilized the soil for crop production for a period of at least two years.

Late planting of corn, giving time for extra working of the land before planting, gave Johnsongrass a setback which permitted producing a late crop of corn on the land.
The Seasonal Development of Johnsongrass

The development of Plants from Seedlings. Johnsongrass seedlings emerge about the third week in May. This is about the time corn is emerging in the area studied. Normal corn cultivation destroys many of the first seedlings. However, Johnsongrass seedlings become established in the corn hills and cannot be removed without damage to the corn. Because Johnsongrass makes its most rapid growth in mid-summer and because the seeds may germinate over a protracted period of time, many plants may become established after corn cultivation has terminated.

The initiation of rhizomes on seedling plants was noted when the plants were in the 7 to 8 leaf stage or about 50 days after emergence. At this time the plants are from 18 to 24 inches high. A moderate amount of rhizome development takes place when the plants are in the boot stage or about 63 days after emergence. At this stage small branches are developing from axillary buds on the oldest rhizomes. The rate of growth of the rhizomes increase greatly from the time the plants are in the boot stage until the seeds are in the hard dough stage or about 85 days after emergence; subsequently the rate of growth declines rapidly.

The initiation of rhizomes when plants were in the 7 to 8 leaf stage is in agreement with results obtained by Oyer (1952) and by Russ and Zahnley (1951). In contrast, Sturkie (1930) and Gates and Spillman (1907) did not observe rhizome formation until plants were headed or flowered.
Under the conditions studied, Johnsongrass matures in about 90 days from the time the seedlings appear. Seed production continues for some time, however, since tillers are later in blooming than are those on the first culm.

The seedling plant may produce numerous tillers and rhizomes due to the profuse growth of axillary buds on the newly formed aerial stems and rhizomes. This growth accounts for the branching pattern of the rhizome system and for the large number of tillers observed on a mature plant. In turn, each tiller may produce an inflorescence; thus the number of seeds produced from a single seedling is very great. By the time the seedling plants reach maturity they become indistinguishable in appearance from the rhizomatous plants. Early in the season, of course, the distinction between seedling and rhizomatous plants is obvious after an examination of the below-ground parts.

The Development of Plants from Rhizomes. The seasonal development of Johnsongrass plants propagated by rhizomes is similar to that of plants from seed. A picture of a dormant rhizome may be seen in Figure 2. Growth of rhizomes in the spring, after dormancy is broken, may originate from axillary or apical buds of the rhizomes which were produced the preceding year. An example of spring growth from axillary buds is shown in Figure 3. Upon reaching the surface of the soil, these rhizomes become aerial stems and produce crowns and tillers. The aerial stems from rhizomes emerge about the middle of May, a few days earlier than those from seed. Plants established from rhizomes grow more rapidly and produce rhizomes a week to 10 days earlier than plants arising from seeds. The more rapid development is particularly evident when the plants of the preceding year
are allowed to accumulate large amounts of reserve food.

As with seedlings, some rhizomatous shoots become established in corn hills, no matter how intensively the corn is cultivated. In fact, the rhizomes are broken into segments by tillage operations and each segment becomes a potential Johnsongrass plant.
A study was made in 1951, 1952, and 1953 of the use of certain cultural practices and herbicides when used alone and in combination for the control of Johnsongrass. The experiments were conducted on natural infestations of Johnsongrass near Chillicothe, Ohio.

The normal development of Johnsongrass was studied since the knowledge is essential in planning control measures.

Sodium trichloroacetate (TCA), sodium chlorate, and polyborochlorate were applied in the summer and fall in combination with different cultural practices. TCA and sodium chlorate were also applied in the early spring to Johnsongrass sod. Maleic hydrazide (MH) was applied to Johnsongrass at different stages of growth and the land was either plowed or left undisturbed. 3-(p-chlorophenyl)-1,1-dimethylurea (CMU) was applied to Johnsongrass sod.

Attempts were made to control Johnsongrass seedlings by plowing at different times in the spring in combination with the use of 2,4-D pre-emergence to corn. Other herbicides were also used with the objective of controlling seedlings.

TCA and sodium 2,2-dichloropropionate (Dalapon) were used as selective herbicides on alfalfa infested with Johnsongrass.

Studies concerning the persistence and depth of movement of CMU were made in the greenhouse using soil that had been treated in the field with different rates of CMU.

The principal results of these experiments follow:

1. Johnsongrass seeds buried in soil germinated 26 and 49 percent
after 2 years.

2. The effectiveness of both herbicides and cultural practices was related to the root reserves of Johnsongrass at time of treatment. Plants weakened by pasturing or mowing were more easily controlled.

3. When Johnsongrass had been weakened by pasturing, plowing in July followed by diskng to prevent more than 8 to 10 inches of top-growth resulted in reducing the stand of Johnsongrass the following year 84 percent. Plowing later in the summer or in the fall was progressively less effective.

4. Plowing prior to treatment consistently increased the effectiveness of TCA and sodium chlorate applied in the summer or fall.

5. The effectiveness of TCA and sodium chlorate was associated with the amount and distribution of rainfall following treatment. Optimum control was obtained when enough rainfall occurred to leach the herbicides into the upper 6 to 8 inches of the soil but not beyond this zone.

6. The effectiveness of the herbicides was found to be associated with the stage of growth of the Johnsongrass at time of treatment. Top-growth was most readily controlled when herbicides were applied prior to or soon after initiation of spring growth.

7. Minimal dosage for summer or fall applications was 40 pounds per acre of TCA or 100 pounds per acre of sodium chlorate. Higher rates were necessary if Johnsongrass was not weakened by pasturing or mowing or if the land was not plowed prior to treatment. Polyborochlorate was definitely ineffective at rates of 100 to 400 pounds
per acre and was seriously toxic to corn the year following treatment.

8. March applications of TCA at the rate of 20 pounds per acre gave very good control of Johnsongrass and permitted the production of a corn crop the same year if planted 60 days after treatment.

9. Maleic hydrazide applied to young Johnsongrass foliage followed by plowing in a few days, gave effective control. The 12-pound rate gave 83 percent control when the stand was plowed 3 days after treatment. No effective control was obtained when the stand was plowed 20 days after treatment, or not plowed at all.

10. 2,4-D applied pre-emergence to corn at rates of 2 and 4 pounds per acre gave 64 and 83 percent control, respectively, of Johnsongrass seedlings, with no visible damage to corn.

11. Preparing land for corn the first week in May and refitting the land a month later gave sufficient control of Johnsongrass from both rhizomes and seed to permit the production of a late crop of corn.

12. Selective control of Johnsongrass in alfalfa-Johnsongrass mixtures was obtained by applying Dalapon and TCA. Under favorable conditions Johnsongrass was controlled without permanent damage to alfalfa. Dalapon at the rate of 10 pounds per acre and TCA at the rate of 20 pounds per acre gave the most satisfactory results.

13. Eighty pounds per acre of CMU almost eradicated Johnsongrass. These plots were free of all vegetation except for a few stunted Johnsongrass plants 2 1/2 years after treatment.

14. CMU was present in soil at a depth of 20 to 24 inches
in quantities lethal to soybeans 2 years after treatment with 64 pounds per acre of CMU.

15. Soil structure was improved by CMU somewhat in proportion to the rates used.


Dow Chemical Company. 1950. "Control of Johnson grass with Sodium TCA." Down to Earth, 6, No. 2 (Fall, 1950) pp. 8-9.


Hagood, E.S. 1950b. "Control of Johnsongrass Rhizomes in Sugar Cane." S.W.C.C., Proc. 3 (Feb., 1950), pp. 31-34.


Table 16. Summary of mean squares and calculated F values for yield of corn as affected by cultural practices and herbicides applied 1951.

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of squares</th>
<th>D.f.</th>
<th>Mean square</th>
<th>Calculated F values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole plot</td>
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<td>50</td>
<td>850.61</td>
<td></td>
</tr>
<tr>
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<td>40748.32</td>
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<td>2546.77</td>
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<td>636.30</td>
<td></td>
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<tr>
<td>Whole plot</td>
<td>42530.32</td>
<td>50</td>
<td>850.61</td>
<td></td>
</tr>
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<td>1</td>
<td>8997.69</td>
<td>169.70**</td>
</tr>
<tr>
<td>Plowing x Herbicide</td>
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<td>16</td>
<td>680.60</td>
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<td>Plowing x Replication</td>
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<td>1.43</td>
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<tr>
<td>Error (b)</td>
<td>1696.65</td>
<td>32</td>
<td>53.02</td>
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* Significant at 0.05
** Significant at 0.01
Table 17. Summary of mean squares and calculated F values for yield of corn as affected by cultural practices and herbicides applied 1952.

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of squares</th>
<th>D.f.</th>
<th>Mean square</th>
<th>Calculated F values</th>
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<td>3650.80</td>
<td></td>
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<tr>
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<td>12581.68</td>
<td>109.67**</td>
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<tr>
<td>Replication</td>
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<td>862.72</td>
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<td>Error (a)</td>
<td>688.35</td>
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<td>Sub-plot</td>
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<td>1760.71</td>
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<td>11</td>
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<td>40.11</td>
<td>1.35</td>
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<td>Error (b)</td>
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<td>Herbicide</td>
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<td>5.76**</td>
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<td>5</td>
<td>96.74</td>
<td>1.80</td>
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<td>315.78</td>
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<td>Error (c)</td>
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</tbody>
</table>

* Significant at 0.05  
** Significant at 0.01
I, Evert Oakley Burt, was born near Chillicothe, Ohio, August 24, 1923. I received my secondary education in the public schools of Vinton County, Ohio. My undergraduate training was obtained at Ohio University, Athens, Ohio, from which I received the Degree of Bachelor of Science in 1944. In June, 1944 I entered the United States Army and was discharged in May, 1946. I re-entered Ohio University in September, 1946 and received the Degree of Master of Science in 1950. From July, 1947 to July, 1948 I was employed as a Veterans On-the-Farm Training Instructor at Allensville, Ohio. From July, 1948 to February, 1951 I was Farm Superintendent and Instructor in Agriculture at Ohio University. I entered The Ohio State University in March, 1951 and in July of the same year I was appointed as a Research Fellow at The Ohio Agricultural Experiment Station, Wooster, Ohio. In January, 1954 I was appointed Teaching Assistant at The Ohio State University. In April of the same year I accepted the position of Assistant Agronomist at the Florida Agricultural Experiment Station, Gainesville, Florida.