THE USE OF TRICHLOROACETATES AS HERBICIDES
FOR PERENNIAL GRASSES

DISSERTATION

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Robert Alexander Peters, B.S., M.S.
The Ohio State University
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Approved by:

C. J. Willard
Adviser
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INTRODUCTION

The introduction of 2,4-dichlorophenoxyacetic acid provided a valuable new tool for the control of weeds, an ever present agricultural problem. Despite its effectiveness as a herbicide, one class of weeds upon which 2,4-D has had little effect has remained, namely the perennial grasses. Grasses, both annual and perennial, have been controlled at the time of germination by pre-emergence treatment with 2,4-D compounds, but established perennial grasses have as a class shown high resistance to 2,4-D as well as to most of the other herbicides subsequently introduced.

Perennial grasses, especially those with a rhizomatous habit, are recognized as being among the most costly weeds with which farmers must contend because they have a high resistance to cultural methods.

Johnsongrass (Sorghum halapense) and quackgrass (Agropyron repens) are common examples of those perennial grasses perpetuating from rhizomes. Both of these weeds are on the list of Primary Noxious Weeds in Ohio as well as in several other states and present a critical weed problem in Ohio.

The trichloroacetates were chosen for study since, to date, they have been generally rated as being the most effective herbicides for
use against grasses.

In recognition of the fact the rhizomatous grasses are generally the most difficult to control, emphasis was placed upon two species, Johnsongrass and quackgrass. They represent fairly wide extremes in adaptation and growth habits and are two of the most serious weeds in Ohio. Any additional information on their control would be of direct economic value.
REVIEW OF THE LITERATURE

Trichloroacetates as Herbicides

General. Since 1947 the salts of trichloroacetic acid have been used as herbicides on an experimental and field basis. The ammonium salt was the first to be used, with several other formulations soon following. The 90 percent sodium salt with an acid equivalent of 79.3 had become the most widely used by 1949.

TCA is not a new chemical, having been known over a century, according to Hummer (1950). It has known protein precipitating properties and, consequently, it has been used as a fixative and for the treatment of warts and other skin conditions. It has also been reported to have an effect on certain enzyme systems. Bernhard and Rosenbloom (1949) reported an increase of inorganic phosphorus content when an ATP solution is allowed to remain for some time in a 5 percent TCA solution.

Trichloroacetic acid, a strong acid comparable to HCL and H2SO4, 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 solutions, TCA breaks down to yield chloroform and CO2 or NaC03 in the case of sodium salt. 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 TCA, accurate down to 1 microgram. The test is not specific for TCA since it depends upon the presence of trichloromethyl groups.

Fate of TCA after application. Several workers have reported on the course taken by TCA after being added to soil. Arakeri and Dunham (1950), Loustalot and Ferrer (1950) and Barrons and Hummer (1951) all found that TCA gradually disappeared from the soil. Leaching was said to be an important factor in the latter two reports. Loustalot found that 1 inch of rain moved sodium TCA to a depth of 8 inches in a silty clay loam. Enough TCA remained in the top 2 inches of soil, however, to inhibit corn seedlings. The interaction of rainfall and TCA movement in the soil has been emphasized by Stahler (1950). He indicated that TCA was most effective when there was sufficient moisture to leach the herbicide down to the zone of greatest rhizome and root concentration. TCA was also 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. Arakeri, in contrast, found no difference between soil types or between sterilized and non-sterilized peat. Barrons suggested that micro-organisms may be the cause of detoxification in the absence of leaching. Minarik (1951) has suggested that TCA, because of its simple
nature, is completely oxidized to CO₂ and H₂O with the release of chloride ions.

Little has been reported as to the fate of TCA absorbed by plants. Barrons and Hummer (1951), testing the TCA in plant extracts, using the pyridine test, found a greater concentration of TCA in pea sap than in corn sap. The latter, however, was the species most affected by the TCA as indicated by abnormal growth. It was suggested that species susceptible to TCA utilize it in their metabolic processes, while tolerant species do not; thus the TCA accumulates.

TCA in plant tissue. The action of TCA on plants has been divided into two phases by Barrons and Hummer (1951), namely a contact effect and a systemic effect. The two effects tend to be independent. The contact effect is evidenced by burning of foliage, while the systemic effect varies according to species, but restricted growth and malformed tissue formation is the usual pattern. It was possible to get a systemic effect in quackgrass without a contact effect when the TCA was quickly washed off the foliage into the soil. On the other hand, when TCA was applied only to the foliage, there was no systemic effect. It was concluded that the roots were the most important avenue of entry. Stahler (1950) also indicated that TCA was most effective when applied so as to come into contact with the underground parts.

Several workers have mentioned the effect of TCA upon the buds of grass rhizomes. Stahler (1950) and Barrons and Hummer (1951) have reported that TCA causes a profound dormancy which is followed by
death in some cases, by recovery in others.

Barrons and Hummer (1951) 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.

**Phytotoxic effects of TCA.** Toxic effects have been reported for both bacteria and many species of higher plants. Kratochvil (1950) found that rates of 10 to 150 pounds, acid equivalent, per acre had a depressing effect on the activity of soil microorganisms as measured by gas escape from incubated soil.

A classification of green plants affected by TCA does not consistently follow a botanical classification, but in general TCA is more toxic to grasses than to broadleafs. Barrons and Hummer (1951) have given a tolerance classification, including three categories, based upon greenhouse trials. The tolerant group includes carrots, celery, parsnips, tomatoes, peppers, eggplant, tobacco, beets, flax, peas, vetch and many species in the **Crucifer** family. The intermediate group includes several of the **Cucurbitaceae**, spinach, cotton, asparagus, potatoes, onions, sweet potatoes, strawberries, alfalfa, Ladino clover, peanuts, **Gladiolus** and oats. The susceptible group includes most of the **Gramineae**, beans, soybeans, lima beans, sweet clover, alsike clover, crimson clover, red clover, blue lupine and Korean lespedeza. Robinson and Dunham (1951) have rated several crops in order of tolerance, based upon field plantings for three
separate years, made in the spring following fall applications. The tolerance rating in descending order was flax, oats, corn, barley, wheat and soybeans. Red clover was found to be less tolerant than alfalfa. The relatively greater tolerance of some crop species to TCA has permitted its use as a pre- and post-emergence herbicide. TCA has effectively controlled such annual grasses as Setaria, Echinochloa and Panicum in sugar beets, flax and alfalfa. At least one broadleaf, Polygonum spp., has been successfully controlled in sugar beets.

The principal interest in TCA has centered around its toxic effects on quackgrass, Johnsongrass and Bermudagrass, all tenacious perennial grasses with a rhizomatous habit. McCall and Zahnley (1949) have also reported the control of the rhizomatous grasses, bluegrass, buffalo grass, Muhlenbergia and gramaggrass.

**Johnsongrass**

*Distribution and economic value.* Johnsongrass (*Sorghum halapense*) has been an agricultural plant since a very early date. Overpeck (1925) states that this grass was first cultivated in the Mediterranean area, the area of probable origin. It came into the United States at a relatively late date, having been introduced from Turkey into South Carolina in 1830. According to Pammel and King (1919), it was first extensively grown by Colonel Johnson of Alabama in 1840. Since that date it has spread into the general area bounded on the
East by the Atlantic Ocean, the Gulf of Mexico on the South and, according to Martin and Leonard (1949), the Colorado border to the West. It is localized west of central Texas in irrigated areas and in the river valleys along the coast as far north as Oregon and Washington. Martin and Leonard (1949) state that most of the spread of Johnsongrass has been by natural means, western Texas being about the only place where it has been deliberately seeded within the past 50 years. It is found well established locally in the flood plains of the major streams as far north as the Corn Belt. Pammel and King (1919) reported it in Fremont County, Iowa, in 1912. The 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 in Columbus, Ohio, which survived for eight years. Seldom thriving on soils of low fertility, it is most tenacious in the irrigated soils of the West, the Black Belt of Alabama and on alluvial river bottoms.

Johnsongrass was introduced into the United States because of its expected forage value and has proven to be of considerable agronomic value. Martin and Leonard (1949) rate it as the most important perennial hay grass of the southeastern United States. Vinall (1929) stated that the principal grass of the Alabama Black Belt was Johnsongrass. The hay yields 1 to 4 tons per acre and has a feeding value, when well handled, equal to that of timothy. In 1924 alone.
150,000 tons of hay were produced in Texas with a value of 2.5 million dollars (Pollock, 1927). Johnsongrass is used to a lesser extent for pasturage. Vinall (1929) has credited exposed root-stocks with the ability to carry hogs and cattle during the winter season.

Despite its agronomic value, Johnsongrass is more generally known as a weed than as a crop plant. The plant propagates both by rhizomes and by seeds. Talbot (1940) pointed out that the germination of the seeds may be delayed several years. Ordinary tillage may serve to do little more than invigorate the grass. Consequently, Johnsongrass is a major problem in fertile areas planted to intertilled crops. The general infestation of at least 100,000 acres of sugar cane in Louisiana is a prime example of the economic pressure of Johnsongrass. Half of this acreage is so infested with seed that permanent control has not been achieved.

Gibbens (1950) has indicated that it is a standard practice to fallow by plowing eight to ten times during the summer prior to planting sugar cane in August to September. Following two to three hoeings and routine tractor cultivation, the Johnsongrass is cut back with cane knives at lay-by time. Despite the use of such control measures, the Cinclaire Central Factory of Cinclaire, Louisiana, reported a 2.4 ton per acre loss of sugar cane during 1946, 1947 and 1948 and a loss of 5.3 tons per acre in 1947, 1948 and 1949. This company lost 51 thousand dollars from 2200 acres in sugar cane.
An additional 16 thousand dollars per year was spent on labor and fuel for the fallowing operation.

Willard and Beard (1950a) reported a survey made in southern Ohio in 1937 in which it was estimated that over 1000 acres of corn land had been abandoned because of Johnsongrass infestation, while over 18,000 acres had some infestation. Most of this land is river bottom land and is capable of continuous corn production.

Since it is recognized that Johnsongrass would be a desirable species if it did not have the rhizomatous habit, breeding work has been initiated. In Crops and Soils, October 1951, a perennial strain free of rootstocks was announced.

Growth characteristics of Johnsongrass. Talbot (1940) used the rhizome classification set forth by Cates and Spillman in 1907. Three categories were listed. The primary rhizomes are those which are alive at the beginning of the growing season but which decay after the growing season is over. The secondary rhizomes arise from the primaries, grow to the surface and there form new plants. The length of these secondary rhizomes is dictated by the depth to which the primary rootstocks are buried. The tertiary rootstocks are those the plant sends out from the base of the crown about flowering time. Under optimum conditions the tertiary 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 run along just below the surface, cropping out at
intervals to form new plants. Hagwood (1950) found in the sugar cane fields of Louisiana that 63 percent of the rhizomes were in the top 6 inches of soil while 13.7 percent were in the next 18 inches. The total weight of rhizomes in the 0 to 24 inch layer was slightly less than 20,000 pounds per acre.

The pronounced effects of cultural and cropping practices as determined by Cates and Spillman are cited by Talbot (1940). Johnsongrass reaches maximum vigor in cotton and corn fields. The favorable soil conditions resulting from cultivation permits extensive and vigorous development of the tertiary rootstocks after cultivation has ceased. In closely grazed soil, Cates and Spillman reported that little tertiary growth will occur. On meadow land the rhizomes become concentrated near the surface and are restricted in extent and vigor.

When Johnsongrass is deliberately grown as a forage crop, it has been difficult to maintain a vigorous stand. Sturkie (1937) found that if seedling Johnsongrass is cut each time the late milk stage is reached, the yield can be maintained but if cut prior to this stage, the yield is cut the following year. When seedling plants were cut three times during the season at the blooming stage, the yield of hay was 8,606 pounds per acre the following year while the yield of hay following two cuttings at the late milk stage was 11,709 pounds per acre on a dry weight basis. This was a reflection of the effect of the first year's cutting on the rhizome weight.
When the cutting was at the blooming stage, the rhizome dry weight was 1,942 pounds per acre while when cut at the late milk stage, the weight was 2,803. In another test Sturkie obtained as much hay from cutting only until mid-summer as he did by continuous cutting. If he cut only every other year, he obtained almost twice the total yield in the year of harvest.

The rhizome development is correlated with the top growth. The growth which occurs in the spring is mostly top growth at the expense of the rhizomes. After the tops have become established, the new rhizome growth begins. Talbot (1940) and Sturkie (1930) stated that rootstocks begin forming at the time of seed formation on seedling plants. Both Russ and Zahnley (1951) and Oyer et al. (1951) have more recently reported that Johnsongrass seedlings develop rhizomes prior to blooming, in fact, in less than two months after germination. Sturkie (1930) found that some rhizomes would form late in the season even if heads were not allowed to appear. Established plants which were not cut after the middle of the summer produced 37 percent more rhizomes than those which were cut twice as the booting stage was reached. In general it was found that the more frequently Johnsongrass is cut the less the top and rhizome growth. 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. Cutting seedling plants five times during the season reduced the rhizome dry
weight from 5,616 pounds per acre to 619, with the former weight being the weight produced by uncut plants at the end of the season. A similar trend existed for frequent cutting of the established plants. Cutting twice at the mature seed stage resulted in a rhizome weight of 3,818 pounds per acre as compared to 6,098 when cut at the end of the growing season. Cutting only during the latter half of the summer did not reduce the weight of the rootstocks as much as continuous cutting, but the top growth the following year was reduced as much. This implied that the food reserves had been depressed by late cutting more than the rhizome weight indicated.

The seasonal trend in the food reserves has been followed by taking rhizome samples from potted plants periodically over a period of a year. Rapp (1947) found that sucrose is the predominant carbohydrate in the rhizomes, except in the period when new top growth is being formed. During the period of initial growth, the total carbohydrates of the rhizomes decreases 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. In his determination, 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.

Cultural control of Johnsongrass. Cultural means of controlling Johnsongrass have been effectively used for years. Talbot (1940) set forth the necessary objectives. They are (1) to weaken and kill existing rootstocks, (2) to kill seedlings already in the soil and (3) to prevent the ripening and scattering of more seeds. It has been stressed by Paulling (1945) and Willard (1951) that complete eradication of Johnsongrass is not feasible on areas which are frequently flooded, since reinfestation may occur from seeds washed in by floods.

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 become concentrated near the surface. Paulling (1945) and Willard and Beard (1950a) have suggested plowing in the late fall or summer after one or two years of such mowing or grazing. The plowing results in the exposure of rhizomes during the winter to freezing. If soil erosion is of concern, winter barley can be planted in September. Barley is used since it can be harvested the next season before the Johnsongrass is advanced enough to interfere with the harvest. This process often must be repeated a second year.

The surest method of control is obtained from an all season fallow. Hagwood (1950) obtained 99 percent control of the rhizomes by
plowing six times at two week intervals while he obtained only 73 percent control when mowing at two week intervals. Stamper and Chilton (1950) reported that fallow plowing or continuous plowing the year sugar cane is not grown is the best method of control for established Johnsongrass. The six to eleven plowings required cost from 12 to 16 dollars per acre.

Talbot (1940) and Willard (1950) have mentioned the value of alfalfa in weakening Johnsongrass.

Willard (1951) reported that late spring preparation of corn land may be effective in reducing the competition of Johnsongrass with the corn crop.

**Early chemical control of Johnsongrass.** The use of chemicals in the control of Johnsongrass is not new. Overpeck (1925) listed sulfuric acid, kerosene, gasoline and brine solutions as being toxic, but all of these materials proved to be too expensive.

The most widely used chemical to date has been sodium chlorate. The recommendations for its use vary considerably, but a rate of 300 pounds per acre or more is usually suggested. Stamper and Chilton (1950) have recommended as high as 600 pounds per acre for a good kill of rhizomes, but they found that 450 pounds per acre worked in many cases. Harper (1930) and Willard and Beard (1950a) recommended 500 pounds per acre as a practical rate of application. 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. October and mid-winter applications were ineffective. Seedlings appeared the year after treatment, implying 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 a week's time. A residual toxic effect was noted, however, which was traced to decreased nitrification in the soil. Rowley (1931) obtained 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 to applications made on dried tops. 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. Of the ten chemicals tested, only sodium TCA gave comparable results. Oils and Sharples 3740 killed the tops, but recovery soon occurred. It was found that 436 to 654 pounds per acre of sodium chlorate were required to give the same results as 100 pounds of sodium TCA. One of the principal drawbacks 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 combus-
tion.

Use of trichloroacetates for control of Johnsongrass.

Direct application of TCA salts

While there has been considerable variation in the degree of
control obtained, the effectiveness of TCA was well established by
1949. Barrons (1949), McCall and Zahnley (1949) and Elder (1949)
all reported control of Johnsongrass by using relatively high rates,
exceeding 50 pounds, acid equivalent, per acre or more. The control
in all the cases cited was in terms of top growth. Lower rates were
later tried and found to be effective in some instances. Hamilton
and Rea (1950) obtained 95 percent control with 40 pounds, acid equi-
valent, per acre while McCall and Zahnley (1950) obtained from 95 to
100 percent control of Johnsongrass regrowth from 40 pound, acid equi-
valent, per acre using sodium or calcium TCA.

Time of application

Applications at almost all stages of growth have been tried by
various workers. McCall et al. (1950) reported 95 to 100 percent con-
trol of top growth in Kansas with 50 pounds, acid equivalent, per acre
of sodium or calcium TCA applied in November, 1949. McCall and Zahnley
(1950) obtained 95 to 100 percent control with 40 pound applications
on April 20, 1950. The rhizomes were completely dormant in November.
New growth was starting from the rhizomes when the April applica-
tions were made, but the shoots had not yet emerged. Stamper and
Chilton (1951) reported a 97 percent control of Johnsongrass in
sugar cane in Louisiana from dormant applications in the spring of
10 pounds per acre on 24 inches of sugar cane drill. A control of
91.6 percent was obtained from a similar treatment on stubble cane.

November applications were better than March applications in
an experiment reported by Elder and Gassaway (1951). 100 pounds
of TCA killed all Johnsongrass plants in August and November, 1950,
treatments, but did not in March, 1951. Corn planted in 1951, fol-
lowing the November applications, developed normally, but Johnson-
grass seedlings were a problem by June. Porter and Talley (1949)
and Brutto (1950) both obtained better results from early spring
dormant applications than from summer applications on foliage.

Brutto used 100 pounds in July on grass 15 to 16 inches high to get
the same degree of control obtained with 50 pounds in March.

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

Applications made just before or during bloom have been reported
as being most successful by McCall and Zahnley (1949). Fleetwood
(1950) reports the best control with TCA when applied on Johnsongrass
18 to 24 inches high while Elder (1949) reports the best control on grass 12 to 18 inches high. McKibben and Fuelleman (1950) on the other hand, obtained complete top growth control three months after application on Johnsongrass 5 to 6 feet tall.

The importance of rainfall conditions have been emphasized by McCall and Zahnley (1949) who considered soil moisture conditions to be of greater importance than stage of plant growth when soil treatments were made.

**Cultural practices combined with chemical applications**

Cultural practices have been reported to have an effect on the degree of Johnsongrass control obtained. McCall and Zahnley (1949) and Fleetwood (1950) found clipping just prior to spraying decreased the effectiveness of TCA. Oyer and Lee (1951), however, obtained better control in July with applications made on stubble than on foliage. McCall and Zahnley (1949) attribute the superiority of foliage applications to the translocation of TCA which occurs in this species. Translocation of TCA in Johnsongrass has also been reported by Hagwood (1951). He dipped potted plants so as to wet the foliage, only, and then cut the tops off at 1, 2 and 3 week intervals. He then noted the number of shoots which grew from the rhizomes. The number of shoots growing back after cutting at 1, 2 and 3 week intervals were 20, 10 and 3 when treated as compared with 206, 222 and 183, respectively, when not treated.
Seedling control

Johnsongrass seedling control has proven to be a major problem since seeds will remain dormant during the period TCA is in the soil. Best and Gibbons (1951) described methods used on a large scale in Louisiana sugar cane plantations. A season of fallowing 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 sugar cane for the combined plant cane and first stubble crop was increased from 35.75 tons per acre in 1948-1949, when conventional weeding was done, to 44.68 tons per acre in 1949-1950, when 2,4-D was used. The labor cost dropped from $29.88 in 1948 to $12.66 per acre.

Chilton and Stamper (1951) have reported alternate methods for controlling seedlings. The best seedling control was obtained with 10 pounds of TCA per acre on the plant cane and 3.5 pounds in the stubble crop. Rogueing was done in the fall and spring to cope with plants which escaped treatment. The control obtained, based upon stools per foot of drill of Johnsongrass, was 97.6 percent. The use of 2,4-D on successive dates at rates of 2 pounds, acid equivalent, per acre, combined with flaming and rogueing, gave 92.3 percent control.

McCall and Zahnley (1950) reported that 40 pounds per acre of
2,4-D as the dimethylamine salt gave no control of rhizomes but did prevent the establishment of seedlings.

**Effect of TCA formulation**

No difference in the effectiveness of calcium TCA or sodium TCA was found by McCall and Zahnley (1950) in making applications on dormant Johnsongrass. Stamper et al. (1951) and Stiver et al. (1949) found no large difference between sodium TCA or ammonium TCA. In contrast, Stamper et al. found that the isopropyl ester of TCA was only half as effective as either one of the salts.

**Quackgrass**

*Distribution and economic value.* Quackgrass (Agropyron repens) is one of the most widespread noxious weeds on the North American Continent. According to Fernald (1950), it is naturalized from Newfoundland in the North to North Carolina in the South with its westward limit varying with the latitude.

In contrast to Johnsongrass, it is a cool climate grass. Kephart (1923) has stated that the zone of greatest concentration of quackgrass in the United States corresponds with the timothy-red clover belt. Quackgrass, a native of Europe, is not known to have been deliberately introduced. The first authentic record of quackgrass in the United States, according to Kephart, is that of Rev. Jared Eliot of Connecticut who described it in 1751 as being a harmful
weed.

In a few places in the United States, quackgrass is utilized for forage. It has many of the desired characteristics of a hay grass and, if cut early, makes as good hay as does timothy. Quackgrass is seldom as abundant in pastures as in meadows, according to Kephart (1923), because of its tendency to become sod bound and unproductive. Its lack of vigor in pastures is attributed to the effects of continued close grazing. Quackgrass is of prime importance as a forage grass in the sandy soils of the states surrounding the Great Lakes because of its ability to grow under the poor conditions which prevail there. The rootstocks in newly plowed fields have also furnished forage, especially for hogs and sheep. In the latter part of the season, quackgrass rhizomes will often contain more feed value than the above ground parts.

Growth characteristics of quackgrass. Quackgrass is described by Kephart (1923) as being well adapted to a wide range of soils, all the way from sandy to clay soils. It grows as far north as the limits of cultivation and practically never winterkills. While hot, dry weather curtails its growth, it can survive considerable drought. Rootstocks begin to form on seedlings about the second or third month. A single quackgrass seedling may increase into a patch a foot in diameter within one season. Individual quackgrass rhizomes seldom live more than 15 months, but new rhizomes keep replacing the older ones. The time of most active rhizome formation is in spring and
fall. At the Arlington Experimental Farm, about 5,500 pounds of rhizomes per acre were found in April and November, while only 3,500 pounds were found in August. Arny (1915) found 2.4 tons green weight of rhizomes per acre on June 28 as compared to 8.3 tons on November 10. In a regularly plowed field most of the rhizomes will be found in the plow layer with only a few extending deeper. When the soil is undisturbed, the grass will become root-bound with the rhizomes massed in a thin layer just below the surface. This fact is of prime significance in cultural control plans.

Arny (1915) stated that quackgrass seed is a common means of spreading the grass. Seeds were found to be viable while still immature. Thirteen percent germination was obtained from seeds in the milk stage. Seeds were found to mature sooner on old sod than cultivated ground.

**Quackgrass as a weed.** Quackgrass is an injurious weed, primarily in annual crops requiring plowing prior to planting. Kephart (1923) stated that the yield of spring oats and wheat is often reduced 50 to 70 percent. Potatoes are severely affected by quackgrass, since the spreading habit of the potatoes makes cultivation in the latter part of the season difficult. In addition, growth of rhizomes into and through potatoes will reduce the market grade. Corn and sugar beets are usually not as severely damaged because they can be more thoroughly cultivated. Quackgrass is an indirect hazard to wheat,
since it is a host plant for the red rust. It also is a host for ergot and may harbor the Hessian fly over winter.

**Cultural control of quackgrass.** The seasonal variation in the organic reserves of quackgrass was found by Arny (1932) to be less than for Canada thistle and four other perennial plants studied. Under Minnesota conditions, there was a slight rise in April and May, a definite decline to June 20, a rise followed by a leveling off until late October and, finally, a decline followed by another rise. Arny (1915) found that the nitrogen percentage of the rhizomes was 0.74 on June 28 as compared to 1.16 on November 10. Dexter (1936) also gave evidence that the period of lowest reserves is at the time of bloom. He found that the grass was easier to eradicate if tillage was started just before blooming than at any other time.

Arny (1915) and Willard (1950b) have given cultural control measures for use on quackgrass. The infested area should be plowed soon after taking off a hay crop in the early bloom stage. The plowing should be no deeper than the deepest rhizomes. Disk about every 10 days, the remainder of the season, until the ground freezes. Replow the next spring and disk until corn planting time. Willard (1950b) suggested beginning with a shallow cultivation, using quackgrass points on a field cultivator. About every 10 days, until freezing, the area should be cultivated again, each time a little deeper and in a different direction in the field. The resulting
exposure of the rhizomes on the surface will kill many of them.
The next spring, plow early and work until corn planting time.
Another method gives an economic return the same year control is
started and is based upon the tendency of quackgrass to produce
its greatest growth during the cool part of the season. Plow
early, using a jointer and keep worked until planting time. In
the early summer, plant a quick maturing crop such as buckwheat,
soybeans, sunflowers, sudan grass or millet, all of which produce
a dense stand. After harvest, work the ground until freezing
weather. The process usually must be repeated for one to three
more years. Arny (1915) controlled quackgrass in a field planted
continuously to fodder corn by plowing in the fall and diskimg
every spring until corn planting time.

The importance of dry weather during the period of frequent
cultivation has been emphasized by Buchholtz in a published in-
terview. (Anonymous, 1951) In a Michigan test, seven cultivations
with a spring tooth harrow after August 1 gave good control of quack-
grass.

Dexter (1936) found that heavy fertilization of quackgrass with
nitrogen in early spring increased the degree of rhizome exhaustion
because of the greater amount of top growth. When fallowing was
started in June, the weakened rhizomes were less able to recover.
Use of TCA for quackgrass control.

Control from direct application

Many reports of complete control of quackgrass have been published, but most of these reports have been based upon the degree of recovery in the year of treatment or the year following. Pavlychenko (1951) has found that plots which had been treated with as high as 200 pounds of TCA per acre in 1949, recovered in 1951 after having been bare throughout 1950. Some of the buds which remained inactive in 1949 resumed growth in 1950. Buchholtz (1951) has reported that a rate of 20 pounds per acre which effectively killed the top growth of quackgrass for a season had little effect on the rhizome weight. 80 pounds of TCA in May caused a decline from 24 grams to 5.1 grams per square foot in October, but the weight increased to 8.6 grams by the following April with general reinfestation following. He concluded that eradication is not to be expected from a single direct TCA application and suggests supplemental cultural or chemical treatments.

Combined use of cultural practices and TCA

Several workers, MacDonald et al. (1950), Buchholtz (1950), Watson (1950a), Carder (1950) and Grigsby (1950) found that cultivation just prior to TCA applications greatly increased the control obtained with a given rate. Based upon rhizome weights, Buchholtz
found that only 9 percent of the original stand remained 6 months after treatment when the sod was disked or plowed prior to treatment as compared to 55 percent in the check. Watson found plowing to be superior to diskling. Carder found an advantage in pre-tillage for a fall application, but not for a spring application. There was in this case, however, ample rain in the fall, while there was little rain for 3 months after the spring applications.

Effect of time of application

Control has been obtained on a wide range of dates. Friesen and Harris (1951) made applications at 2 week intervals from June 29 to August 15. All gave top kill, but August 2 treatments were best. Barrons and Watson (1949) treated quackgrass and bluegrass periodically from April to November and found summer treatments to give the most consistent results. They concluded that moisture was an important factor with best results being obtained on moderately dry soil with scant to moderate rainfall in the month following treatment. Watson (1950b) noted a direct correlation between degree of control and rainfall. He obtained good control with 40 pounds of TCA applied on June 7 when an inch of rain fell within a week, while he obtained no control with 80 pounds applied on July 24 when no rain fell for 6 weeks afterward. In some cases the TCA may show delayed effectiveness when rain does occur to carry it deeper into the soil profile. However, the work of Loustalot
and Ferrer (1950) indicate that if some moisture is present, part of the TCA may be broken down.
GENERAL STATEMENT UPON EXPERIMENTAL PROCEDURE

Location of Experiments

The field experiments were carried on at two locations about 70 miles apart, Columbus and Waverly, Ohio. Two sites were chosen for several reasons. It was possible to find heavy, naturally occurring infestations of Johnsongrass near Waverly and of quackgrass at Columbus. By working at both locations it was possible to apply TCA upon two diverse soil types under two different precipitation patterns.

The area used at Waverly was on the farm of Louis Schauseil, while the areas used at Columbus were on The Ohio State University Farm. The Waverly site was on the flood plain of the Scioto River and was typical of the areas in southern Ohio infested with Johnsongrass. Flooding occurred several times during the winter of 1950-1951, most of them of short duration. A single application was also made on quackgrass at The Ohio Agricultural Experiment Station, Wooster. One application of TCA on Johnsongrass was made on June 16, 1950, on the farm of Earl Simmonds, Cleves, Ohio, in the southwestern corner of the state.

Method of Chemical Application

All applications were made as sprays, using a Hudson Industro sprayer No. 710S. This was a four gallon, stainless steel knapsack
sprayer with a pressure gauge mounted on the tank. A boom was constructed from galvanized, one-fourth inch pipe as a replacement for the discharge equipment originally provided with the sprayer. The boom was 60 inches wide with four Spraying Systems Company Tee-jet No. 6504 nozzles spaced 20 inches apart. The over-all spray pattern was 80 inches wide. Walking at a speed of three miles per hour at 40 pounds pressure per square inch, the spray solution was applied at the rate of 40 gallons per acre. It was not possible to maintain the pressure exactly at 40 pounds, but a mean pressure of 40 was obtained by starting on a plot with 42 pounds and allowing a drop to 38 before the pressure was renewed.

The largest source of error in the method employed was in maintaining a walking speed of three miles per hour. An increase from three to four miles per hour results in a 25 percent decrease in the rate of chemical being applied. However, since in all field applications each increment was doubled, the error involved in walking was not considered excessive.

Source of Chemicals Used

Several TCA formulations were used during the course of the experiments. The material used most frequently was 90 percent sodium trichloroacetate, sodium TCA, with a 79.3 percent acid equivalent. Eighty percent calcium trichloroacetate, calcium TCA, with a 71 percent
acid equivalent was also used. Both of the salts were provided by the Dow Chemical Company, Midland, Michigan.

TCA acid in an oil carrier, provided by the General Chemical Division, Allied Chemical and Dye Corporation, was also used. This material contained 5 pounds of TCA acid per gallon of oil.

The 3-<i>p</i>-chlorophenyl-<i>l</i>-<i>l</i>-dimethyl urea, CMU, used for comparison with TCA, was supplied by the E.I. du Pont de Nemours and Company, Wilmington, Delaware.
in those regions where rapid cell elongation of stem or leaf tissue was occurring. Depending upon the species of grass treated and the concentration of TCA applied, the effect was lethal in some instances, inhibitory in others. In many cases inhibitory effects led to death after a time lapse due to the continued static status of the plant. The inhibitory effect of the TCA was traced to reduced elongation of internodes. An example of inhibition of this kind was the reduction in height of otherwise normal plants following TCA application on quackgrass during the winter months. The height suppression data are given in Table 9.

More typically, the effects of TCA became evident as a limited expansion of leaves on newly formed shoots. Leaves on treated plants remained tightly rolled as in "onion rolling" of grasses treated with 2,4-D, but the rolling was more severe and lasted longer. Within the boot of the grass plants the younger leaves continued to develop. After reaching a certain point, however, mechanical constrictions occurred because of the failure of the older leaf blades to unfurl. This crowding of leaves within the boot of a Johnsongrass plant is shown in Figure 1. The result of the constriction of the growing tissues was a crumpling and tearing of the tightly rolled leaves. As growth continued within the boot, pressures were developed which caused extreme curvatures of the stem, and in some cases the enclosed tissues broke out directly through the side of the sheath. Aberrations of the type described above are shown in Figures 33, 34 and 35.
CONDUCT OF EXPERIMENTS

Phytotoxic Effects of Trichloroacetates Upon Grasses

TCA applied to grasses results in (a) a direct contact effect or (b) an internal effect primarily evident as a modification of growing tissues. In many cases both will occur in the same plant.

Contact injury was evidenced by a localized firing of the foliage. When the TCA concentration was great enough, the top growth gradually became brown and finally dies. The stage of growth as well as the species of grass sprayed were factors in the rate and degree of top kill. When sodium TCA was sprayed on Johnsongrass about 1 foot tall and in a very active stage of growth, the foliage was completely brown within three days. On the other hand, when TCA was applied to quackgrass in the early boot stage, the stems were not killed while the leaf blades were. When oats were sprayed with 40 pounds of sodium TCA, acid equivalent, per acre, there was only slight browning of the leaf tissue. The tops of wheat were readily killed by the same concentration.

Top kill due to the contact injury from TCA proved to be an unsatisfactory criterion of the kill of perennial grasses due to frequent recovery from underground parts.

A second mode of action was noted of the type called "systemic" by Barrons and Hummer (1951). When TCA entered metabolically into the tissues of the grass plant, its effects became primarily evident
Fig. 1—Confinement of leaves within the boot of Johnsongrass following treatment with sodium TCA. (enlarged 5X)
Blooming was found to be inhibited both from physical restrictions within the boot and from reduced internode elongation. Of the heads that did emerge, the rachises were often twisted and many of the spikelets distorted. Many of the heads did not emerge at all despite the fact that they matured within the boot. Those heads which remained within the boot usually decayed in place. In another instance formative effects appeared in corn which was planted a full month after the TCA had been applied to the soil.

The most destructive effect of TCA upon grasses was upon bud expansion. The effects were evident upon rhizome buds as well as upon those on aerial stems. When rhizomes were exposed to TCA, the first effects were evident in the terminal buds. The tips soon ceased to elongate and frequently disintegrated. Quackgrass rhizome tips readily abscissed at the first node back of the tip. Following or prior to the disruption of the terminal bud, the lateral buds on the rhizomes began to grow. The growth was usually quite limited in extent. The short, thickened stems with greatly shortened internodes which resulted were named stubs, a term which will be used throughout the dissertation. This type of structure is shown in Figure 2. Several stubs which have grown from a rhizome treated while dormant are shown.

In most cases the apices of the stubs soon became inactive and elongation ceased. Further elongation usually stopped by the time the stubs were an inch long on Johnsongrass or a quarter of an inch long.
Fig. 2—Abnormal lateral growth from nodes of a Johnsongrass rhizome treated with sodium TCA. (Enlarged \( \frac{1}{2} \times \) – rule is in cms.)
on quackgrass.

The terminal tissues frequently became a disorganized mass of proliferated cells as seen in Figure 3. The stubs remained inactive for weeks with disintegration gradually setting in. Occasionally new growth arose terminally or laterally from the stubs. Weak shoots formed or, more commonly, the new tissue disorganized and soon ceased to grow.

Development of the kind described above may occur either from applications of TCA made on actively growing Johnsongrass or upon dormant rhizomes.

Following an application of TCA on Johnsongrass or quackgrass rhizomes, several of the lateral buds usually start growing as described above. The renewed activity of these laterals can probably be attributed to the loss of apical dominance following the disruption of the terminal bud. Activation occurred similarly in untreated rhizomes when the terminal buds were removed. After treatment there was always a certain percentage of the buds which remained inactive, again paralleling the normal rhizomes. These buds remained quiescent following treatment only to develop several weeks later. The internodal tissue displayed little evidence of injury from the TCA applications. It remained intact for several months after treatment even in those cases where most of the buds on the rhizomes were inactivated through stub formation.

The buds on the aerial stems were affected by the TCA in a manner
Fig. 3—Malformed lateral growth from Johnsongrass rhizome showing cell proliferation and disrupted stem tip. (Enlarged 5X)
similar to those on rhizomes. Frequently, there was increased tillering from the crown of both annual and perennial grasses. Species in which increased tillering was noted included oats (*Avena sativa*), timothy (*Phleum pratense*), smooth bromegrass (*Bromus inermis*), tall oat grass (*Arrhenatherum elatius*), quackgrass (*Agropyron repens*) and Johnsongrass (*Sorghum halapense*). Usually the tillers did not develop beyond the stub stage. The numerous malformed tillers which formed remained static for several weeks with recovery occurring in some cases, death in others.

TCA had a greater inhibitory effect upon stem tissue than upon root tissue. This was shown by the abundant normal growth of roots from dormant rhizomes which produced nothing but abnormal stem tissue. As shown in Figure 2, quite frequently roots continue to grow from the nodes of stubs which are inactive.

The systemic nature of the growth modifying effects of TCA was indicated by several observations. Quackgrass height suppression occurred in the new spring growth following applications made on dormant rhizomes during the winter months. Corn showed formative effects after being planted a full month after the TCA had been applied to the soil. Growth aberrations continued to develop for several weeks after germination. In greenhouse tests it was found that the buds on rhizomes which were well rinsed after being exposed to a TCA solution failed to develop normally. This indicated that TCA was absorbed where it either caused damage to the embryonic tissue or was
Field Control of Johnsongrass

**Normal Johnsongrass development.** When Johnsongrass begins to grow in the spring, two populations are evident. One comes from seed, the other from the over-wintering rhizomes. By the end of the season it is difficult, if not impossible, to separate the two populations.

Since Johnsongrass is found in southern Ohio, primarily in the over-flow areas from Columbus south, it has been suggested that periodic floods were responsible for the spread of Johnsongrass. The transport of seed by flood waters is unquestionably a factor in extending Johnsongrass infestations. Perhaps more important, however, is the seed produced and dropped in place. It was noted at Waverly that the number of seedlings growing in plots in which flower production had been prevented was much less than where seed formation occurred.

Under the conditions studied, Johnsongrass matured in about 3 months from the time the seedlings appeared. Seed production continued for some time, however, since tillers were later in blooming than those on the first culm. Considerable seed was produced. In a typical Johnsongrass infestation, 10 or more Johnsongrass seeds per square inch could be counted on the soil surface.
Seedling development

When collected at the time the seeds were shattering, Johnsongrass seeds would not germinate, but germination was abundant the next spring. Only a certain percentage germinated, however, since some of the seeds were delayed in germinating. Seeds planted in the greenhouse germinated over a 4 month period.

The date on which the first Johnsongrass seedlings start to germinate generally coincides with the time corn is emerging in the area studied. Normal corn cultivation will destroy most of the first seedlings. However, Johnsongrass seedlings become established in the corn hills and cannot be removed without damage to the corn. The comparable form of corn and Johnsongrass is seen in Figure 4, showing Johnsongrass growing in a corn hill. Consequently, some Johnsongrass will invariably become established in a corn field despite the cultural methods employed. Seedling plants become virtually inseparable in appearance from the rhizomatous plants by the time the growing season is over. Early in the season, of course, the distinction between the below ground parts is obvious. Rhizomes start forming on the seedlings within 2 months from the time of germination. At this time the grass is less than 2 feet tall. A typical plant is seen in Figure 5, as photographed on June 20, 1951.
Fig. 4—Johnsongrass growing in corn hill showing similar developmental pattern.
Development of rhizomatous plants

Severe infestations of Johnsongrass on cropland are found primarily when over-wintering rhizomes are abundant. At Waverly, rhizomes over-wintered in an apparently normal way during the severe weather conditions of 1950-1951. A low of minus 28 degrees Fahrenheit, air temperature, was reached on February 3, 1951. The snow covering present during the 2 days of extreme temperatures, prevented any such extreme in soil temperatures. About the last week of April in 1951, when corn was being planted locally, the buds on the rhizomes became active.

The initial growth is vertical. This organ is rhizomatous in nature, having scale leaves at each node until the soil surface is reached. It corresponds to what Cates and Spillman termed secondary rhizomes. When the vertical rhizome reaches the soil surface, a typical culm with expanded leaves develops. There is little root formation until this stage is reached. Roots form primarily from the point of union between the vertical rhizome and the shoot. It is suggested that this zone be called the crown of the Johnsongrass. It is from this crown that most of the new rhizomes originate. This type of development is seen in Figure 6. Frequently, rhizomes will also start developing from nodes along the vertical axis, as seen in Figure 7. Infrequently, new rhizomes will grow directly from buds on the over-wintered rhizomes as also seen in Figure 6.
Fig. 5— Seedling Johnson grass plant about 6 weeks after germination showing development of rhizomes. Photo, June 20.

Fig. 6— Development of new Johnson grass rhizomes. Shows two new rhizomes arising from crown of plant and one (lower left) arising from previous year's rhizome. Photo, June 20.
In 1951, rhizome development was noted within 1 month of emergence. By June 16, when the shoots were about a foot tall, rhizomes 4 inches or more long had developed. By the first of August, rhizomes 2 feet or more in length were found. After mid-July, when the Johnsongrass was coming into bloom, rhizome formation became particularly active, but rhizomes had definitely formed prior to the time of blooming.

Course of development in corn fields

Plowing and cultivation, unless in fallowing, does little to control Johnsongrass. As rhizomes are broken into segments by the tillage operation, each segment becomes a potential Johnsongrass plant. Normal corn cultivation stops in mid-summer at a time when Johnsongrass rhizomes are beginning their most active development. As with seedlings, some rhizomatous shoots become established in corn hills, no matter how intensively the corn may be cultivated. These plants in the corn hills serve as centers from which rhizomes originate and extend between the corn rows where soil conditions are optimum. Supported by the undisturbed Johnsongrass tops in the corn hills, rhizomes develop vigorously, as evidenced by their size.

Course of development when undisturbed

On an area of about 30 acres adjoining the plots, Johnsongrass remained undisturbed in 1950. The growth was vigorous and very dense,
the average height exceeding 6 feet. In 1951, however, the vigor of the Johnsongrass was considerably reduced. The foliage was somewhat chlorotic, implying nitrogen deficiency, while the average height was no more than 4 feet. This tendency for undisturbed Johnsongrass to become "sodbound" was also evident in 1951 on the experimental area. On the check plots, the Johnsongrass seedlings were relatively chlorotic and restricted in growth, as compared to the seedlings which grew on the plots treated in 1950. It seems that a temporary nitrogen deficiency follows after a season in which Johnsongrass has grown undisturbed. The nitrogen becomes immobilized by the microorganisms which are active in the decomposition of the mass of rhizomes from the previous growing season.

The transient nature of rhizomes was quite apparent. Decay of rhizomes appeared to be associated more with the physiological status of a rhizome section than with its calendar age. Although the vertical rhizomes arise most commonly from rhizome tissue formed the season before, in some cases they can be traced to rhizomes formed two seasons previously, as seen in Figure 8.

It is not clear what determines the course of development of a particular rhizome. If it emerges either vertically or horizontally from the soil, the course of development changes and a typical shoot is formed.

In Figure 9 is seen a Johnsongrass plant which was growing with the rooting zone exposed on one side. The growth originating on that
Fig. 7—Development of new Johnsongrass rhizomes from node of vertical rhizome formed same year. Photo, June 20.

Fig. 8—Development of Johnsongrass plant from a rhizome (lower left) at least 2 years old. Photo, June 20.
side developed into normal shoots, while within the soil typical rhizomes were produced.

In the greenhouse it was noted several times that rhizomes which developed in pots, occasionally grew out the drainage holes at the bottom of the pot. A leafy shoot invariably formed when the rhizome tip extended from the hole. Thus the morphology of the growth arising from a particular bud is a function of the environment. If the growing point remains in the soil, rhizomatous tissue will be formed while if the growing point is in the light, green shoots will be formed.

The question arises as to what determines the course of a particular growing point? Certain conditions were noted under which new growth extended along the vertical axis rather than along the horizontal axis. When no green shoots were present, the rhizomes usually grew vertically. Thus when growth starts from dormant rhizomes in the spring, shoots are formed before horizontally extending rhizomes start to develop. In greenhouse tests it was found that the initial growth was vertical, no matter in what position a dormant rhizome section might be placed. Once green shoots were formed, newly initiated rhizomes would extend horizontally. Mowing Johnson-grass often results in the upward curvature of rhizome tips and the subsequent formation of new shoots. A hormonal mechanism is indicated by these observations. When top growth is absent, possibly a geotropic hormone is present and, as a result, only vertical growth
occurs. After green shoots form, however, some mechanism brings about a decrease in the geotropic hormone in the rhizomes and, consequently, the direction of new rhizome growth is at random.

**Combined chemical and cultural methods for Johnsongrass control.**

**Procedure**

Since certain cultural methods have been known for years to have a marked effect on Johnsongrass development, several cultural practices were used alone and in combination with sodium TCA during the growing season of 1950.

The experiment was on a Genesee soil in the flood plain of the Scioto River near Waverly, Ohio. Corn had been grown on the area in 1949 and had been heavily damaged by Johnsongrass. The infestation of Johnsongrass was uniformly severe. Abundant seed had been produced in 1949 as evidenced by the density of the seed on the surface of the soil.

A split-plot design was used with three replications with the sub-plots measuring 14 by 30 feet. Sodium TCA treatments were applied at monthly intervals; on May 13, June 14, July 15 and August 19, 1950. The different stages of growth were designated as stages A, B, C and D. Rates of 0, 20, 40, 80 and 160 pounds sodium TCA, acid equivalent, per acre were applied in combination with six cultural treatments. Treatment No. 1 consisted of plowing after chemical application. Plowing was always done within a week of the time
the chemical was applied. Cultural treatment No. 2 was plowing before the chemical was applied. Cultural treatment No. 3 consisted of fallowing throughout the season to keep down the Johnsongrass top growth. All fallowed strips were plowed on May 6, July 17 and August 30, and disked on September 30, 1950. Cultural treatment No. 4 consisted of mowing on June 24 and on August 19, 1950, when the top growth was 2 to 3 feet in height. Treatment No. 4 of stage C was mowed once more than the other stages since the entire stage was mowed prior to the chemical application on July 15, 1950. Cultural treatment No. 5 was no treatment at the first two stages. On the two later stages, the strips at stage C were mowed on July 12 and at stage D on August 19, 1950, since it was necessary to mow all plots to permit spray applications. Cultural treatment No. 6 consisted of the application of a nitrogen fertilizer before emergence of the Johnsongrass, followed by mowing after the top growth was well established. Ammonium nitrate was applied with a cyclone seeder on May 6 at the rate of 200 pounds of elemental nitrogen per acre. The plots were mowed on June 24 and August 12, 1950. The type of growth present on August 12, 1950, at the time all plots were being mowed, is seen in Figure 10. Following the July mowing, the vegetation was allowed to dry for a week and was then burned in place.

In the spring of 1951, while the rhizomes were still dormant, square yard samples of rhizomes were dug to a depth of 10 inches.
Fig. 9—Effect of environment on Johnsongrass development. Crown exposed on left with normal culms developing. Crown covered with soil on right with rhizome developing.

Fig. 10—Stage of growth of Johnsongrass at the time of mowing prior to the Aug. 19, 1950, treatment.
Because of limitations in time and labor, samples were dug only from selected plots. Only living rhizomes were weighed, fresh, after removing as much dirt as possible by hand. Two square yard samples per plot were taken in stage A and one square yard sample per plot in stage D. Samples were dug from three replication in each stage. It was considered that the most important comparisons were between plowing at the time of treatment, fallowing for the season and no cultural treatment. These treatments were compared in stages A and D, which represented the two extremes of development.

The experimental area was plowed and planted to corn on May 3, 1951, in the usual way. The development of corn and Johnsongrass was noted throughout the 1951 season. It proved most difficult to assess the recovery from rhizomes treated the previous year since a heavy growth of seedlings masked the development of shoots from the rhizomes. The field was not under our control and was not given the usual corn cultivation. As a consequence, seedlings developed very freely.

Control of top growth from sodium TCA applications

The stage of growth at which sodium TCA was applied was found to have a marked effect on the top control obtained. When the May 13 (stage A) applications were made, some of the Johnsongrass had emerged, while considerable had not. Many of the tops exposed to the
chemical were killed back. However, on June 14, there was considerable growth on some plots. Top growth was 20 percent of the check after the 160 pound rate and 70 percent after the 20 pound rate. On July 4, 1950, top growth was 10 percent of the check at the 160 and 80 pound rates, 25 percent or less at the 40 pound rate and 50 percent or more at the 20 pound rate. Most of the growth on the plots was abnormal. The leaves were restricted and the expanding portions of the plant were torn and twisted. This type of development is shown in Figure 11. Plots plowed prior to the application of 0, 20, 40 and 80 pounds per acre on May 13, 1950, are shown in Figures 12, 13 14 and 15, respectively, as seen on July 7.

Following sodium TCA applications on June 14, stage B, when the Johnsongrass was about 1.5 feet high, the tops were almost killed to the ground by July 7 in all plots except those which had received 200 pounds of nitrogen on May 6. There was some recovery by the end of the season, however, as indicated by Table 1.

The mowing of the 6 foot top growth from all plots in July and August precluded rating the top kill by the chemical applications. There was only a small amount of top recovery following treatment. The plots receiving 160 and 80 pounds remained essentially bare until frost. Following the July 15 applications, there was some slight recovery at 40 pounds per acre and no more than 25 percent recovery at 20 pounds per acre.
Fig. 11—Growth modifications following sodium TCA application on May 13, 1950. Photo, June 17, 1950.
Fig. 12—Johnsongrass plot plowed on May 13, 1950, but not treated with TCA. Photo, July 7, 1950.

Fig. 13—Control of Johnsongrass top growth with 20 lb., acid equiv., per acre of sodium TCA applied on May 13, 1950, after plowing. Photo, July 7, 1950.
Fig. 14—Control of Johnsongrass top growth with 40 lb., acid equiv., per acre of sodium TCA applied on May 13, 1950, after plowing. Photo, July 7, 1950.

Fig. 15—Control of Johnsongrass top growth with 80 lb., acid equiv., per acre of sodium TCA applied on May 13, 1950, after plowing. Photo, July 7, 1950.
It is evident the sodium TCA was effective as a contact herbicide and also in preventing regrowth from the rhizomes. The greater control obtained in June than in May may be attributed to the difference in stage of growth. Many shoots had not yet emerged in May at the time of treatment. By the time it was absorbed by the developing shoot the TCA concentration was diluted by the large soil volume. Enough remained, however, to result in the growth constrictions. Since these restrictions were severe enough to prevent development beyond a certain point, the stand of Johnsongrass decreased as the season progressed.

Top growth in a succulent stage of growth, as on June 14, was readily killed by the sodium TCA. There was no contact action in July and August, since the tops were removed, but it was shown in parallel experiments that contact action is considerably less when the Johnsongrass has elongated and the tissues, especially the stem tissues, have hardened.

Control of top growth from combined chemical and cultural treatment

At the time of the initial application on May 15, 1950, the various cultural treatments had had little chance to exert whatever influence they might have had. The effect of cultural treatments was most evident in the case of the June 14 treatments. At the end of the active growing season, each plot in replication I and II was visually rated, using a 0 to 10 rating system. A 0 rating indicated
no difference in stand density as compared to the check, while 10 indicated complete control of the Johnsongrass top growth. The ratings are given in Table 1.

Table 1. Rating of cultural and chemical treatments on stand of established Johnsongrass on October 7, 1950, following sodium TCA applications on June 14, 1950.

(0 = no effect, 10 = complete control)

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Based on the data in Table 1, certain conclusions can be made. The nitrogen application had the most obvious effect, particularly at the two lowest rates where the top kill was markedly reduced when nitrogen was applied. The slight control obtained with 80 pounds is shown in Figure 16. Control at the two higher rates was not consistent, but every indication was that the control was reduced when the grass had been fertilized.

Plowing Johnsongrass after TCA application markedly decreased the control obtained at the two lower rates. In contrast, plowing before the chemical was applied increased control at the low rates.
Fig. 16—Control of Johnsongrass top growth with 80 lb., acid equiv., per acre of sodium TCA applied on June 14, 1950, following an early application of 200 lb. of elemental N. Photo, July 7, 1950.

Fig. 17—Seedling reinfestation on plot treated with 160 lb., acid equiv., per acre of sodium TCA on May 13, 1950. Photo, Aug. 19, 1950.
It is evident that the interactions between cultural treatments and chemical rates were found principally when the lower rates are involved. If 80 or 160 pounds of sodium TCA were used, cultural treatments were not important.

The decreased control obtained when the Johnsongrass was sprayed before being plowed suggests that the effective concentration of the TCA was reduced by being physically moved below the zone of maximum rhizome concentration.

The increased control obtained by plowing the Johnsongrass under before the chemical was applied could be due to several factors. The effective concentration of the sodium TCA may have been reduced by some immobilization within the leaf tissue. Barrons and Hummer (1951) have shown 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.

Another possibility is that plowing breaks the rhizomes into sections, exposing non-cutinized surfaces. TCA absorption may be more rapid into this exposed tissue.

Control of seedlings by combined chemical and cultural treatments

In the younger stages the Johnsongrass seedlings were readily killed by all rates of sodium TCA applied. In May only a few seedlings
had emerged, while none were over 2 inches in height. Seedlings were about 12 inches, half the height of the rhizomatous plants, at the time of the June applications. By July the distinction between seedling and rhizomatous plants became obscure.

Because of the prolonged dormancy of some seeds, Johnsongrass seeds germinate over a protracted period. Freedom of the TCA treated plots from seedlings for several weeks after treatment showed that it killed the germinating seeds. The reappearance of seedlings in a plot was considered to indicate that the phytotoxicity of the chemical had been reduced in the soil. The time interval required for the residual toxicity to drop to a level permitting Johnsongrass seeds to grow corresponded roughly with time required for corn.

Seedlings became established 11 weeks after treatment following the May treatments. These seedlings are shown in Figure 17 as they appeared on August 19. These seedling plants were 4 to 5 feet tall and the seeds were in the hard dough stage. Rhizomes had developed up to 6 inches in length by that date.

Following the June application, the seedlings appeared somewhat sooner. By August 19, 9½ weeks after treatment, seedlings 4 to 6 inches high were found on the plots. On October 28, seeds on these plants were in the milk stage. Rhizomes 2 to 3 inches long were developing.

Following the July treatment on October 7, 15 weeks after treatment, seedlings were just beginning to appear. No seedlings appeared
following the August treatments.

An attempt was made to rate the seedling control at the end of the season on the various treated plots. A 0 to 10 rating system was used. A 0 rating indicated no difference in the stand density of the seedlings as compared to the check plots. A 10 rating indicated complete absence of seedlings. The ratings on October 7 are given in Table 2.

Table 2. Rating of cultural and chemical treatments on stand of Johnsongrass seedlings on October 7, 1950, following sodium TCA applications on June 14, 1950

<table>
<thead>
<tr>
<th>Sodium TCA acid equiv. per acre, lb.</th>
<th>Cultural treatment</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carbon tetrachloride</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Apply-</td>
<td>Plow-</td>
</tr>
<tr>
<td>I</td>
<td>II Av.</td>
<td>I II Av.</td>
</tr>
<tr>
<td>20</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>40</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>80</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>160</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Mean</td>
<td>7.9</td>
<td>6.6</td>
</tr>
</tbody>
</table>

It is apparent that seedlings were fewer on those plots which were plowed either before or after treatment. This is probably because considerable seed was buried by plowing. The plots mowed twice during the season also had few seedlings. These data must be questioned since it was particularly difficult to distinguish between seedling and rhizomatous plants following mowing of the plots. The
principal criterion for distinguishing between the two was the stage of flower development and mowing precluded this observation. Seedlings as well as rhizomatous plants were much more abundant on those plots which had been fertilized with nitrogen than elsewhere. However, the same criticism of the data applies as above, since the plots were mowed.

Effect of combined treatments in May and August upon rhizome weight

The weights of rhizomes in the spring of 1951 following the May and August, 1950, treatments are given in Tables 3 and 4. May treatment: A marked reduction in rhizome weight was obtained from May applications of sodium TCA. Each rate of application resulted in a highly significant decrease in weight, compared to the untreated plots. The 160 pound rate gave a significant decrease over the lowest rate of 20 pounds, but no significant decrease could be shown for the 160 over the 80 pound rate. Plowing before or after the application of the chemical increased the effectiveness of TCA only at the 160 pound rate. Plowing seemed to be of no benefit at the other rates, in fact, there were indications of decrease in effectiveness when the chemical was applied before plowing. Presumably, plowing carried much of the TCA below most rhizomes. August treatment: Mowing produced the most marked effect among the August treatments. The average weight of rhizomes in the unmowed plots
Table 3. Effect of TCA and cultural treatments upon the weight of Johnsongrass rhizomes. (Averages of 6 plots each treatment for May, 3 plots each treatment for August.)

<table>
<thead>
<tr>
<th>Cultural treatment number</th>
<th>Yield per acre of fresh rhizomes, after applying TCA at: (lb. acid equiv. per acre).</th>
<th>0</th>
<th>20</th>
<th>80</th>
<th>160</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sodium TCA applied on May 13, 1950*</td>
<td>lb.</td>
<td>lb.</td>
<td>lb.</td>
<td>lb.</td>
<td>lb.</td>
</tr>
<tr>
<td>1. Apply-plow</td>
<td>7,570 4,570 1,870 720 3,680</td>
<td>11,900</td>
<td>2,740</td>
<td>1,300</td>
<td>310</td>
<td>4,060</td>
</tr>
<tr>
<td>2. Plow-apply</td>
<td>1,900 2,740 1,300 310 4,060</td>
<td>8,840</td>
<td>2,140</td>
<td>1,630</td>
<td>1,900</td>
<td>3,630</td>
</tr>
<tr>
<td>5. None</td>
<td>9,400 3,150 1,600 980</td>
<td>**</td>
<td>**</td>
<td>980</td>
<td>980</td>
<td>980</td>
</tr>
<tr>
<td>Mean</td>
<td>9,400 3,150 1,600 980</td>
<td>**</td>
<td>**</td>
<td>980</td>
<td>980</td>
<td>980</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sodium TCA applied on August 19, 1950**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Apply-plow</td>
</tr>
<tr>
<td>2. Plow-apply</td>
</tr>
<tr>
<td>5. None</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>2,040 1,280 920 1,410</td>
</tr>
<tr>
<td>1,140 1,160 890 1,060</td>
</tr>
<tr>
<td>2,800 2,540 2,130 2,490</td>
</tr>
<tr>
<td>1,990 1,660 1,310</td>
</tr>
</tbody>
</table>

*Cultural treatments N.S.  *TCA treatment means L.S.D. 1 percent level - 2180 lb.  5 percent level - 1590 lb.

Table 4. Effect of TCA treatment combined with fallowing (treatment No. 3) upon the weight of Johnsongrass rhizomes. (Average of 3 plots per treatment)

<table>
<thead>
<tr>
<th>Time of application</th>
<th>Yield per acre of fresh rhizomes, after applying sodium TCA at: (lb. acid equiv. per acre)</th>
<th>0</th>
<th>20</th>
<th>80</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>May (Stage A)</td>
<td>1,250 430 810 830</td>
<td>840</td>
<td>280</td>
<td>10</td>
<td>380</td>
</tr>
<tr>
<td>August (Stage D)</td>
<td>1,040 360 410</td>
<td>**</td>
<td>**</td>
<td>410</td>
<td>410</td>
</tr>
</tbody>
</table>

*Treatment means N.S.**
was about 9500 pounds per acre, compared to 2000 pounds per acre in the mowed plots. This was a four-fold decrease from mowing alone.

The data from the various chemical and cultural treatments in August showed no statistically significant difference between them, but certain trends were apparent. Plowing caused a consistent decrease in rhizome weight, both in the plots which received TCA and in those which did not. This decrease was attributed to greater cold injury to the rhizomes in the plowed plots. In the spring of 1951, numerous dead rhizomes were found lying on the soil surface.

The plots treated with TCA in August had a somewhat lower rhizome weight than when treated in May, but the differences could not be clearly traced to TCA. There were no differences due to TCA on those plots which were not plowed, so the seemingly greater effectiveness of August applications compared to those in May can probably be attributed to effects of plowing at that time of year.

It must be concluded that, under the conditions prevailing during and following the August treatments, TCA had relatively little effect, compared to the cultural treatments, on rhizome weight.

The rainfall pattern following the TCA application may have been a factor. Since the TCA was applied on very dry soil and rain was scant for several weeks, considerable breakdown of the TCA may have occurred as reported by Loustalot and Ferrer (1950).

The physiological status of the Johnsongrass in August should also be considered as a factor in the lower TCA effectiveness. Since
TCA has more effect upon actively growing tissue than mature tissue, the toxicity would not be as marked when applied in August as when applied in May. In May several buds on any given rhizomes were actively growing. Application of TCA checked further growth from most of these buds, consequently, top growth and subsequent new rhizome formation were quite limited. When treatments were made in August, a large part of the new rhizome system was established, the weight of which was not greatly altered by the next spring. Inspection of the rhizomes in the spring of 1951 after growth resumed, showed that many of the buds had been affected by the TCA applications made the previous summer. A measurement of the percentage of recovery from the rhizomes treated in August would have given a better indication of treatment effect than the weight measurements. The heavy seedling growth in all the treated plots made any such measurement difficult.

The marked influence of a single mowing in August illustrates the influence of top growth upon rhizome development. The increase in weight of rhizomes during the latter part of the season can be attributed to both growth and accumulation of food reserves. Sturkie (1930) found a 50 percent greater weight of rhizomes when Johnson-grass plants were allowed to stand than when cut twice as the mature seed stage was reached. Rapp (1930) found that an increase in dry weight, following seed formation, occurred in the rhizomes as sugars were translocated from the tops into the rhizomes where it was stored.
as sucrose. Mowing in August greatly reduced the total photosynthetic area during the remainder of the growing season and thus the amount of sugar translocated to the rhizomes.

As indicated by the data in Table 4, the lowest weight of rhizomes was found in those plots which were partially fallowed throughout the season by plowing on May 6, July 17 and August 30, followed by diskng on September 30, 1950. While the plot to plot variation was large, there was a definite indication that TCA applications made in May were the most effective with the advantage over the August treatments being relatively greater for fallowing than for other cultural treatments. This could be traced to the effectiveness of fallowing in preventing establishment of seedlings in the May treated plots. The seedlings which grew after the May treatment no doubt contributed somewhat to the rhizome weight obtained the next spring. The 80 pound application combined with fallowing reduced the rhizome weight to a negligible level and was the only treatment which approached a complete kill of the Johnsongrass rhizomes.

**Direct application of sodium TCA for Johnsongrass control during the late fall and in the spring.**

**General**

Since action upon rhizomes is the most direct way of eradicating any rhizomatous plant, the feasibility of making applications during
the time of the year when little or no Johnsongrass top growth was present was studied.

**Procedure**

Applications were made on March 29, August 29 and October 28, 1950; and on March 31 and May 17, 1951. There was no top growth occurring on any date other than May 17. On the latter date, new growth had started from the rhizome buds, but only a few shoots had emerged. The plots treated in August were mowed in late summer, consequently there was little top growth present at the time of spraying. A randomized block design was used in each case, replicated three times with the individual plots measuring 7 by 30 feet except in the March, 1950, treatments. On the latter date, the plots were 1 square rod each with no replication. Sodium TCA was applied at rates of 0, 40, 120, 160 and 200 pounds, acid equivalent, per acre. Applications on all other dates included rates of 0, 10, 20, 40 and 80 pounds, acid equivalent, per acre.

**Results and discussion**

The March and May applications were effective in killing Johnsongrass rhizomes. The results are given in Tables 5, 6 and 7.

Any evaluation of the August 29 application was rendered impossible by the death of most of the rhizomes in the experimental area following prolonged flooding during the winter of 1950-1951.
Table 5.  

Effect of sodium TCA applications on Johnsongrass.

<table>
<thead>
<tr>
<th>Date</th>
<th>Stage of growth</th>
<th>TCA applied Acid equiv. per acre</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar. 29, 1950</td>
<td>Rhizomes buds completely dormant</td>
<td>40, 80, 120, 160</td>
<td>No more than 10 percent of the growth of check. Seedlings starting to grow. No top growth from rhizomes.</td>
</tr>
<tr>
<td>June 12, 1950</td>
<td>Seedlings 1 ft. high Rhizomatous plants 2 ft. high.</td>
<td>40</td>
<td>No top growth from rhizomes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>120</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>July 7, 1950</td>
<td>Plants 4-6 ft. tall with seeds in soft dough stage.</td>
<td>All</td>
<td>Seedlings growing in all plots.</td>
</tr>
</tbody>
</table>
Table 6. Effect of sodium TCA applications on Johnsongrass.

<table>
<thead>
<tr>
<th>Date</th>
<th>Stage of growth of check plots</th>
<th>TCA applied Acid equiv. per acre lb.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar. 31, 1951</td>
<td>Rhizome buds completely dormant.</td>
<td>10, 20, 40, 80</td>
</tr>
<tr>
<td>May 17, 1951</td>
<td>Shoots from rhizomes emerging. Seedlings 1-2 inches high.</td>
<td>All</td>
</tr>
<tr>
<td>June 16, 1951</td>
<td>Rhizomatous plants 1½ ft. tall. Seedlings 9 in. tall.</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20, 40, 80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>All</td>
</tr>
<tr>
<td>July 4, 1951</td>
<td>Shoots 3-4 ft. high and in late boot stage.</td>
<td>All</td>
</tr>
<tr>
<td>July 28, 1951</td>
<td>Seed in soft dough stage.</td>
<td>All</td>
</tr>
<tr>
<td>Aug. 25, 1951</td>
<td>Seed in hard dough stage and shattering.</td>
<td>All</td>
</tr>
<tr>
<td>Date</td>
<td>Stage of growth of check plots</td>
<td>TCA applied Acid equiv. per acre lb.</td>
</tr>
<tr>
<td>-----------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
<td>-------------------------------------</td>
</tr>
<tr>
<td>May 17, 1951</td>
<td>New growth from rhizomes emerging. Seedlings 1-2 in. high.</td>
<td>10, 20, 40, 80</td>
</tr>
<tr>
<td>June 16, 1951</td>
<td>Rhizomatous plants 1¾ ft. tall. seedlings 9 in. tall.</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40 and 80</td>
</tr>
<tr>
<td>June 26, 1951</td>
<td>Seedlings 1 ft. tall. Rhizomatous shoots 2½ ft. tall.</td>
<td>All</td>
</tr>
</tbody>
</table>
Table 7. (continued) Effect of sodium TCA applications on Johnsongrass.

<table>
<thead>
<tr>
<th>Date</th>
<th>Stage of growth of check plots</th>
<th>TCA applied Acid equiv. per acre</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>lb.</td>
<td><strong>Experiment III</strong></td>
</tr>
<tr>
<td>July 4, 1951</td>
<td>Plants 3-4 ft. high and in late boot stage.</td>
<td>10</td>
<td><strong>Av. no. of culms per 120 sq. ft. plot</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>20</td>
<td>173</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40</td>
<td>68</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80</td>
<td>14</td>
</tr>
<tr>
<td>July 28, 1951</td>
<td>Seed in soft dough stage.</td>
<td>20</td>
<td><strong>On the plants remaining, there was a marked increase over the check in the number of brace roots formed. There were also more rhizomes growing from the vertical axis than in the check. When the shoots had been initially killed, some top growth had occurred from stubs on latent buds.</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>40</td>
<td><strong>No top growth recovery. Some stubs produced lateral proliferations.</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>80</td>
<td><strong>No recovery.</strong></td>
</tr>
<tr>
<td></td>
<td>All</td>
<td><strong>Seedlings up to 1 ft. in height abundant on all plots.</strong></td>
<td></td>
</tr>
</tbody>
</table>
The October 29 application did not result in any obvious reduction in top growth of the Johnsongrass. Inspection of the rhizomes during May of 1951, however, indicated some effect from the TCA since a number of the buds had developed into malformed stubs. While the plots were not flooded for a period of several weeks, as were the August treated plots, they were subjected to intermittent floods which probably resulted in excessive leaching without reducing the viability of the rhizomes. Since TCA has been shown by Loustalot and Ferrer (1950) and others, to be readily leached, excessive flooding may cause too rapid movement of the TCA through the profile. Since floods are a rule rather than an exception in many areas heavily infested with Johnsongrass, floods should be considered before recommending fall or winter applications of TCA in flood plain areas.

Applications made in the latter part of both March 1950 and 1951 were particularly effective. In March, 1950, rates of 80, 120 and 160 pounds prevented any new growth from the rhizomes, and the 40 pound application gave commercial control, since the growth was only 10 percent of the check. The March, 1951, applications were even more effective in preventing top growth. There was growth only following the 10 pound application. Figures 18 and 19 show the plots in March, 1951, treated with 20 and 40 pounds, respectively.

In the case of both March applications, rhizome inspection disclosed that new growth started from most of the nodes of the rhizomes
Fig. 18—Right, control of Johnsongrass top growth from application of 20 lb., acid equiv. sodium TCA per acre on March 31, 1951. Left, untreated plot. Photo, June 16, 1951.

Fig. 19—Left, control of Johnsongrass top growth from application of 40 lb., acid equiv. sodium TCA per acre on March 31, 1951. Right, untreated plot. Photo, June 16, 1951.
in treated plots at the same time growth started in the untreated plots. The growth from the treated rhizomes, however, was limited and malformed. Few shoots were over an inch long.

There was no evidence of increased Johnsongrass control from the inclusion of Nonic 218 in the spray solution in March, 1951. There was some evidence of a longer residual effect. Corn planted 53 days after TCA application had a lower stand count following the 80 pound application when the wetting agent was included. A count of three corn hills per plot in three replications gave a mean of 6, 6, 6, 4 and 1 plant per three hills at rates of 0, 10, 20, 40 and 80 pounds of TCA, respectively, with Nonic 218 included. With no Nonic included the count was 7, 4, 7, 6 and 6 plants.

The application made on May 17, 1951, was also relatively effective in preventing top growth. As described in Table 7, growth had already started from the rhizomes at the time of treatment, but with very little emergence.

Of the plants which had emerged at the time of treatment, those which received the 80 and 40 pound rates were killed. Those receiving the 20 and 10 pound rates were seriously injured. Formative effects, including restricted leaf expansion and stub formation, occurred along the entire axis of the plant, both above and below ground. At the 20 pound rate there was also an obvious increase in the number of brace roots formed.

On July 28, 1951, there was no recovery at the 80 and 40 pound rates. There was a number of abnormal plants in the plots which
received 20 pounds but very little new growth from the rhizomes. At 10 pounds there was considerable recovery.

Seedlings which germinated after the TCA was gone from the soil revegetated all the plots treated in March and May to such an extent that the control obtained from the TCA applications was largely nullified by the end of the season.

Effect of sodium TCA upon an established alfalfa–Johnsongrass mixture.

Procedure

A three year old stand of alfalfa on a Genesee sandy loam near Waverly, Ohio, severely infested with Johnsongrass, was used for this experiment. Four cuttings of hay had been taken off the field each year. The usual number of cuttings had been removed prior to the first TCA application made in August, 1950.

TCA applications were made on August 28, October 7 and November 18 of 1950; and on March 30 and June 16 of 1951. The August application was made on the regrowth following the last cutting of the year when the alfalfa was about 3 to 6 inches tall. At the time of the October application the alfalfa was about 12 inches tall and the Johnsongrass about 16 inches tall. When the November application was made, the Johnsongrass tops had been killed by frost and the alfalfa was dormant. The alfalfa had about 1 inch of new growth when the March application was made. There was no evidence of the Johnsongrass above
ground. At the time of the June treatment the alfalfa had been cut once and had regrown to about 6 inches. The Johnsongrass was particularly evident at this time of treatment since it is usually more prominent in the second cutting of alfalfa than in any other. On July 4, the Johnsongrass comprised 50 percent of total dry weight of the mixture on the untreated plots.

The sodium TCA was applied at rates of 0, 10, 20, 40 and 80 pounds, acid equivalent, in 40 gallons of solution per acre. A randomized block design was used with plots 14 by 30 feet replicated three times. Separate blocks were used for each time of treatment.

**Results - General**

The August, March and June applications had the most effect. There was only a temporary effect from the October application. On October 28, 21 days following treatment, there was considerable retardation of growth of both the alfalfa and the Johnsongrass. The 10 pound rate had only a third as much new growth as the check. By May of 1951, however, none of the plots could be distinguished from the untreated plots. The November application had no visible effect. There was a high degree of Johnsongrass control obtained from the March applications, but there was also considerable reduction in the stand of alfalfa. The poor stand of alfalfa as seen on July 4 is shown in Figure 21.
Results of August treatment

The effect of the TCA applied on August 29 was very obvious by October 7. Complete control of Johnsongrass top growth was obtained with 40 and 80 pound rates, 90 to 95 percent at 25 pounds and 70 to 86 percent at 10 pounds. The alfalfa showed little effect at 10 pounds, was restricted in top growth but not in stand at 20 pounds, and was severely damaged at 40 and 80 pound rates. At the higher rates the top growth was killed back to the crown and the few new shoots which grew from the crowns developed abnormally. The leaflets of the new leaves failed to expand, remaining folded and frequently curled.

Yield data from the August treated plots were obtained from samples cut on July 4, from an area 3 by 20 feet on each plot. The dry matter yields are given in Table 8. The component yields were based upon hand separations of the green material from which the dry matter was computed, using an average dry matter percent of 25 for the alfalfa and 29 percent for the Johnsongrass.
Table 8. Yield of each component of an alfalfa-Johnsongrass mixture on July 4, 1951, following treatment with sodium TCA on August 28, 1950.

<table>
<thead>
<tr>
<th>TCA per A, lb., acid equiv.</th>
<th>Dry matter per acre, lb.</th>
<th>Percentage of alfalfa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alfalfa</td>
<td>Johnsongrass</td>
</tr>
<tr>
<td>0</td>
<td>450</td>
<td>1640</td>
</tr>
<tr>
<td>10</td>
<td>540</td>
<td>500</td>
</tr>
<tr>
<td>20</td>
<td>460</td>
<td>320</td>
</tr>
<tr>
<td>40</td>
<td>350</td>
<td>980</td>
</tr>
<tr>
<td>80</td>
<td>130</td>
<td>3000</td>
</tr>
</tbody>
</table>

Alfalfa Johnsongrass

L.S.D. = .05 90 lb. L.S.D. = .05 132 lb.
L.S.D. = .10 130 lb. L.S.D. = .10 192 lb.

The data indicate that the sodium TCA had a marked effect on both the alfalfa and the Johnsongrass, with the effect on Johnsongrass being more marked than on the alfalfa. There was a significant increase in alfalfa at the 10 pound rate, but no difference at the 20 pound rate, as compared with the check. At the 40 pound rate, however, there was a significant decrease. The 80 pound rate caused a highly significant decrease over all the other rates. The Johnsongrass was highly significantly reduced by 10, 20 and 40 pound rates, as compared to the check, but was increased at the 80 pound rate. The balance between the two components is graphically shown in Figure 20 as well as by the percentage of alfalfa to Johnsongrass given in Table 8. It is apparent that the 20 pound rate gave the highest degree of Johnsongrass control. Yet, at the same time, it
Fig. 20—Component yields of Alfalfa-Johnsongrass mixture on July 4, 1951, treated on August 28, 1950.

Sodium TCA, acid equiv., lb. per acre
did not change the yield of alfalfa. At the 80 pound rate, the Johnsongrass yield was greater and the alfalfa yield less than the check. The plots receiving 0, 10 and 80 pounds of TCA are shown in Figures 22, 23 and 24, respectively.

The explanation of the anomaly of more Johnsongrass at the high rate than at the low rate lies in the course of the Johnsongrass development following treatment. Virtually all the plants at the high rate were found to be seedlings, while there was a preponderance of rhizomatous plants at the other rates. Severe damage to the alfalfa at the high rate, as well as to the Johnsongrass, resulted in a bare plot by spring of 1951. Seedlings became established quite readily on these bare plots in the absence of competition.

Results from June application

The effect of the June application was fully evident by the time of cutting 18 days after treatment. The yields were based on samples cut on July 4, from strips 3 by 17 feet and the dry matter determined as described for the August treatment. The dry matter yields are given in Table 9.
Table 9. Yield of each component of an alfalfa-Johnsongrass mixture on July 4, 1951, following treatment with sodium TCA on June 16, 1951.

<table>
<thead>
<tr>
<th>TCA per A, lb., acid equiv.</th>
<th>Dry matter per acre, lb.</th>
<th>Percentage of alfalfa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alfalfa</td>
<td>Johnsongrass</td>
</tr>
<tr>
<td>0</td>
<td>1130</td>
<td>970</td>
</tr>
<tr>
<td>10</td>
<td>910</td>
<td>350</td>
</tr>
<tr>
<td>20</td>
<td>850</td>
<td>170</td>
</tr>
<tr>
<td>40</td>
<td>540</td>
<td>60</td>
</tr>
<tr>
<td>80</td>
<td>620</td>
<td>30</td>
</tr>
</tbody>
</table>

**Alfalfa - N.S.**  
**Johnsongrass**

L.S.D. at 1 percent level = 204 lb.  
L.S.D. at 5 percent level = 160 lb.

It is apparent from the data in Table 9 that TCA had a much more pronounced effect on the Johnsongrass than upon the alfalfa, since at the high rate the proportion of alfalfa to Johnsongrass was nineteen times greater than in the check plot. The decrease in Johnsongrass below the check from any of the rates of TCA is highly significant. The 10 pound rate was significantly different from any of the other rates of chemical, but no differences were evident between the other rates. The consistent decrease in yield with an increase of the rate of chemical, however, is indicated in this particular experiment. The balance between Johnsongrass and alfalfa at the time of harvesting is shown in Figure 25. In Figure 26 is seen the plot receiving 40 pounds of TCA. While based upon a standard analysis of variance the alfalfa did not show any decrease in yield due
Fig. 21—Alfalfa-Johnsongrass mixture treated with 40 pounds, acid equiv., per acre sodium TCA on March 31. No treatment in background. Photo, July 4, 1951.

Fig. 22—Alfalfa-Johnsongrass mixture, untreated. Photo, July 4, 1951.
Fig. 23—Alfalfa-Johnsongrass mixture treated with 10 lb., acid equiv., per acre sodium TCA on August 29, 1950. No treatment in background. Photo, July 4, 1951.

Fig. 24—Alfalfa-Johnsongrass mixture treated with 80 lb., acid equiv., per acre sodium TCA on August 29, 1950. No treatment in background. Photo, July 4, 1951.
Fig. 25—Component yields of an alfalfa-Johnsongrass mixture on July 4, 1951, treated on June 16, 1951.
to treatment, but it was apparent that the growth was reduced on some plots as seen on July 4.

Yields were also taken on August 25 from the regrowth following the second cutting. These data were based upon hand separations of three square yard samples per plot from two replications. The alfalfa regrowth was normal in appearance, and, in contrast to the reduction in yield found on July 4, there was no evidence of a reduction in the alfalfa yield at any of the rates. The low yields are attributable to the extremely dry spell during the last of July and the first of August. The yields were 492, 387, 647, 575 and 590 pounds of dry matter per acre at the 0, 10, 20, 40 and 80 pound rates of TCA, respectively. Despite the similarity in yields, there was an apparent dwarfing of the alfalfa in the treated plots, the alfalfa being about 9 inches tall when treated with 80 pounds of TCA while the check was 12 inches tall.

The control of Johnsongrass top growth was very marked by August 25. The dry weight in pounds per acre of Johnsongrass was 688, 412, 36, 0 and 0 for the 0, 10, 20, 40 and 80 pound rates of TCA, respectively. At the 0 and 10 rates there was as much Johnsongrass in the plots as there was alfalfa. At the two highest rates, however, the Johnsongrass top growth was completely eliminated without marked reduction of the alfalfa yield. A plot receiving 40 pounds of TCA as seen on August 25 is shown in Figure 27. The ready recovery of the
Fig. 26—Alfalfa-Johnsongrass mixture treated with 40 lb., acid equiv., per acre sodium TCA on June 16, 1951. No treatment in background. Photo, July 4, 1951.

Fig. 27—Alfalfa-Johnsongrass mixture treated with 40 lb., acid equiv. per acre sodium TCA on June 16, 1951. No treatment in background. Photo, August 25, 1951.
alfalfa after the treated tops were removed suggests that TCA has much less effect on the bud tissue of alfalfa than upon that of Johnsongrass, since it did not recover.

Supplementary experiments in Johnsongrass control.

Comparison of CMU and TCA

3-p-chlorophenyl-l-l-dimethyl urea, CMU, was applied on an established stand of Johnsongrass at Waverly, Ohio, on May 17, 1951, as the grass was emerging. A sodium TCA application was made on the same date to permit a comparison of the effectiveness of the two materials. The CMU was applied at rates of 0, 12.5, 25, 50 and 100 pounds of 80 percent technical material in 80 gallons of solution per acre on plots 7 by 30 feet replicated three times. CMU is almost insoluble in water, so Nonic 218 at 0.1 percent was added as a dispersing agent. TCA was applied at rates of 0, 12.5, 25, 50 and 100 pounds of the 90 percent sodium salt in 40 gallons of solution per acre.

Compared to TCA, CMU was relatively slow in acting. The 12.5 pound application killed the sweetclover present in the plots but had no apparent effect on the Johnsongrass. The height was reduced one-half by the 25 pound application, but the stand was only slightly affected. The 80 pound application caused a decrease in stand to 10 percent of the check and the remaining plants were only one-third the height of the check.
CMU displayed a marked advantage over TCA in Johnsongrass seedling control. This was attributable to the longer duration of the CMU in the top horizon of the soil. On July 28, 1951, there were no seedlings present in the 50 pound CMU plots, but on the same date the seedlings were 9 to 12 inches high in the 50 pound TCA plots. When the plots were last observed, August 28, they were still free of seedlings. Corn and soybeans planted to test for residual CMU reacted in an unique way. While somewhat chlorotic at emergence, they appeared to grow normally until they were 2 to 3 inches tall. At this stage they died within a few hours. Plantings made on both June 16 and August 25 responded in this way. By July 28 the Johnsongrass stand was 0, 50, 90 and 100 percent of the check at rates of 100, 50, 25 and 12.5 pounds per acre. The two lower rates were definitely less satisfactory in controlling the top growth than TCA at the same rates. A comparison between 25 pounds of CMU and 25 pounds of 90 percent sodium TCA can be seen in Figures 28 and 29. On August 25, 1951, the plots receiving 100 pounds were still barren. Only a few plants, an average of one clump per 10 square feet, were found on the 25 pound rate.

In conclusion, it appears that CMU has considerable promise for Johnsongrass control if rates of 50 pounds or above are used. It has a considerably longer residual effect than TCA which is an advantage in terms of seedling control but a disadvantage in terms of subsequent cropping.
Fig. 28—Control of Johnsongrass top growth with CMU applied on May 17, 1951. Left, 25 lb. per acre. Right, 50 lb. per acre. Photo, July 4, 1951.

Fig. 29—Control of Johnsongrass top growth with TCA applied on May 17, 1951. Left, 25 lb. 90% sodium salt per acre. Right, check plot. Photo, July 4, 1951.
Use of high rates of 2,4-D for treatment of dormant Johnsongrass

Applications of 2,4-dichlorophenoxyacetic acid, 2,4-D, were made on a dormant established stand of Johnsongrass at Waverly, Ohio, on April 11, 1951, about 1 month before Johnsongrass resumed active growth. Rates of 5, 10, 15 and 20 pounds acid equivalent per acre were applied in 40 gallons of water per acre. There was no evidence of control of rhizomatous plants from the 2,4-D. Seedlings were initially prevented from germinating, but by midsummer late germinating seedlings grew normally.

Sodium TCA application at Cleves, Ohio

On June 16, 1950, an application was made on Johnsongrass, about 3 feet high, at rates of 0, 20, 40, 80, 120 and 160 pounds, acid equivalent, per acre in 40 gallons of solution per acre. A split-plot design replicated three times was used with plowing a week prior to treatment and no cultural treatment constituting the main plots and the six rates of TCA the sub-plots. The latter were 1 rod square in size. A rain of over 2 inches fell in the 24 hours immediately after the application.

A report from the owner of the plots on August 2 indicated that the TCA had effectively prevented regrowth from the plowed plots, but the TCA had little if any effect on the intact grass except for scattered contact injury.
On November 2, 1950, there was considerable control on the plowed plots. Plowing alone resulted in a 50 percent decrease in top growth. Most plots receiving more than 40 pounds per acre were free of Johnsongrass. Very little revegetation from Johnsongrass seedlings occurred, but numerous cocklebur and giant ragweed plants were found. On the non-plowed plots the degree of control was low, none of the plots being free of Johnsongrass. The higher rates caused some top kill and largely prevented blooming but had very little effect on the stand in 1951.

The heavy rain which occurred immediately after application of the TCA no doubt was a factor entering into the poor control obtained. Most of the TCA applied on the foliage was probably washed off onto the soil surface. A considerable part of that reaching the soil surface was likely carried off the plots since the plots were sloped and the rainfall was torrential. There was considerably less run-off from the plowed plots since the plots were level and the soil more absorbent. Because of the excessive rainfall, the experiment gave a poor comparison between the applications on the plowed and non-plowed plots.

Post-treatment considerations. Under the field conditions of the present study, TCA as an herbicide for Johnsongrass control had two distinct limitations. It was possible to approach complete control of the rhizomatous plants, but all seedlings were never controlled with a single TCA application. Any control program must taken into
account possible revegetation from seedlings which become established after TCA has disappeared from the soil.

Stamper and Chilton, 1950, have reported the same problem of seedling reinfestation in using TCA for control of Johnsongrass in sugar cane. They have successfully used 2,4-D pre-emergence applications for control of the seedlings without damage to cane. Consideration should be given to the possible use of 2,4-D as a pre-emergence spray on corn since much of the Johnsongrass germinates at about the time corn is normally planted. A preliminary greenhouse test using 2 and 4 pounds, acid equivalent, 2,4-D per acre, amine formulation, was successful. A soil activated herbicide such as Crag Herbicide 1, 2,4-dichlorophenoxyethyl sulfate, should also be considered for killing seedlings which do not germinate until after the corn is well started.

For seedling control, late summer TCA applications would be desirable since those seeds which germinated after the TCA detoxification would not have sufficient time to become established before the time of killing frosts. Such mid-summer applications would have the distinct disadvantage of denying the use of the land for a full season crop.

The period between TCA application and the time the soil could again be used for cropping was judged by the reappearance of Johnsongrass seedlings. Following the March 29, 1950, application, seedlings grew normally after 12 weeks; following the March 31, 1951,
application, after 8 to 9 weeks; following the May 13, 1950, application, after 11 weeks; following the May 17, 1951, application, after 6 weeks and after 15 weeks following the July 15, 1950, application. Rainfall was probably the factor most responsible for the variations in the time required for detoxification. All of these ratings were made on a Genesee soil. Further variation would be expected between soil types.

Three plantings of corn were made following March applications to test the feasibility of applying TCA far enough in advance of the normal planting date to allow for detoxification. Following the March 29, 1950, applications, corn planted on June 17, 11\frac{1}{2} weeks after treatment showed no indication of TCA toxicity. Corn was also planted after the March 31, 1951, application on May 3 and May 23, 33 and 53 days after treatment, respectively. The stand of corn was heavily reduced by the residual TCA when planted 33 days after treatment, but corn planted 53 days afterwards had a normal stand except on those plots where an 80 pound application including 0.1 percent Nonic 218 was used. Sometime within the 20 day period between plantings the TCA in the soil had decreased to a level which was non-toxic to corn.

The results obtained suggest that March applications of TCA would be desirable for two reasons; (1) they were found to be quite effective in terms of Johnsongrass control and (2) the TCA level decreased to a non-toxic level soon enough to permit the planting of
an early maturing hybrid corn the same season. A fair crop of corn can be obtained in any part of southern Ohio from plantings made as late as June 1. Frequent flooding, in the flood plains where Johnsongrass is a serious problem, would preclude March applications in many years and is a practical consideration which must not be overlooked.
Field Control of Quackgrass

Normal development of quackgrass. A cool weather crop, quackgrass was found to remain active well into the winter at Columbus. In fact it was possible to find some green leaf tissue at any time during 1950 and 1951. The rhizomes showed a marked resistance to freezing. In late spring, rhizomes were chipped out of solidly frozen soil and planted in the greenhouse where they grew normally. Further indications of the cold tolerance of quackgrass was observed from the growth from rhizomes under refrigeration. Johnsongrass rhizomes were successfully held in a dormant state in a refrigerator set at about 40 degrees Fahrenheit, but when dormant quackgrass rhizomes were placed in the same conditions, etiolated shoots grew from most of the nodes.

The formation of rhizomes was found to be most abundant in late spring and again in the early autumn, in contrast to the mid-summer formation period in Johnsongrass.

By the time the spike was emerging from the boot (June 7 at Columbus) at the six leaf stage, rhizome development was well advanced. The average length of rhizomes on June 7 was about 5 inches. The new rhizomes originated from the below ground base of the aerial shoots except for a very few which originated from the previous year's rhizomes. Aerial shoots were from the previous year's rhizomes almost entirely, there being no indication of aerial growth from newly
formed rhizomes. The above ground growth came from widely spaced nodes on the rhizomes, there being an average of seven inactive nodes between each node which was active.

In a greenhouse test in which rhizomes a foot in length were planted in vermiculite, intact in one case and with the tip removed in the other case, it was noted that there was a larger number of shoots growing from lateral buds when the tip was removed. This indicated loss of apical dominance when the tips were removed. The greater growth, often noted after plowing a field infested with quackgrass, may be due to the decrease in apical dominance which occurs as the rhizomes are torn apart by the cultural implement.

Quackgrass control as affected by time of application.

Procedure

An area in field No. 5, Ohio State University Farm, severely infested with quackgrass was used for the experiment. The soil type was a Brookston silt loam. The area was not cropped during 1950, but cattle had been grazed. The field was mowed in June and on the last of August.

A two-way whole plot, split plot design was used with three replications. The whole plots which received the cultural treatments were 7 by 60 feet, while the sub-plots receiving the chemical treatments were 7 by 14 feet. The two cultural treatments were (1) plowing
on September 27, 1950, and (2) no plowing. The chemical treatments were 0, 10, 20, 40 and 80 pounds sodium TCA, acid equivalent, per acre applied in 40 gallons of solution per acre.

Applications were made on six dates: October 19, November 16, 1950; January 4, February 17, April 2 and May 28, 1951. In April and May treatments, duplicate applications of TCA were made with one series containing a wetting agent, the other none. In April, Nonic 218 at a concentration of 0.1 percent was used, while in May, 0.1 percent Tween 20 was used. The quackgrass was still growing when the October application was made. In November, the tops were still green. There was very little vegetation when the January and February applications were made. In April, the shoots were just beginning to emerge. The May treatments were made when the quackgrass was about 20 inches tall and in the late boot stage. The panicles averaged 5 inches in length and the base of the inflorescence was about 10 inches from the soil surface.

**Results of applications made during the dormant period**

Treatment with sodium TCA during the October to April period had a stunting effect on the new quackgrass growth which grew in the spring of 1951. A decrease in density of stand was also noted on some plots.

The data on height reduction are given in Table 10. The height of the quackgrass foliage was reduced in proportion to the rate of
Table 10. Height of quackgrass on June 15, 1951, following application of sodium TCA during the dormant season.

<table>
<thead>
<tr>
<th>Sodium TCA acid equiv. per acre, lb</th>
<th>Height of top growth in centimeters, following TCA applied on:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Oct. 19</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>10</td>
<td>55</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>Mean of treated plots</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Not plowed</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td>10</td>
<td>80</td>
</tr>
<tr>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>Mean of treated plots</td>
<td>40</td>
</tr>
</tbody>
</table>
TCA applied in all cases. Only the 80 pound application in April approached complete suppression.

The amount of reduction from month to month is also shown in Figure 30. There is obviously no consistent pattern apparent except for the indication from the means that the TCA was more effective on those plots which were plowed than on the non-plowed plots. The relative difference was greatest when the TCA was applied in October and decreased with each successive date of application. By April no difference was apparent. Since the plowed plots gradually approached their original condition, it was to be expected that the difference would decrease.

Correlated with the height reduction was a reduction in the amount of blooming. As in the case of the height reduction, the least reduction in blooming occurred following the November applications. Following the other applications there was essentially no flowering at the 40 and 80 pound rates. The percentage of flowering at the 10 and 20 pound rates ranged from 90 to 50 percent. The plowed plots showed the least flowering, having about half that of the non-plowed plots. The data in Table 11 summarize the effect of treatment on the stand of quackgrass. Plowing alone reduced the stand somewhat, as of June 15, 1951. When TCA applications were combined with plowing, there was some further reduction of stand following October, November, January and February applications, while there was no reduction when the TCA was applied to undisturbed sod. In
Fig. 30 — Top growth of quackgrass on June 15, following sodium TCA applications.
Table 11. Density of quackgrass on June 15, 1951, following application of sodium TCA during the dormant season.

<table>
<thead>
<tr>
<th>Sodium TCA acid equiv. per acre, lb.</th>
<th>Estimated percentage of total ground cover following treatment on:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Oct. 19</td>
</tr>
<tr>
<td></td>
<td>Tween 20</td>
</tr>
<tr>
<td>Plowed Sept. 27, 1950</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>80</td>
</tr>
<tr>
<td>10</td>
<td>80</td>
</tr>
<tr>
<td>20</td>
<td>80</td>
</tr>
<tr>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>80</td>
<td>50</td>
</tr>
<tr>
<td>Mean of treated plots</td>
<td>61</td>
</tr>
</tbody>
</table>

| Not plowed                           |         |         |         |         |         |         |         |         |         |         |       |
| 0                                    | 90     | 90     | 90     | 100    | 100    | 100    | 90     | 90     | 90     | 100    | 90     | 95    | 80    | 90    | 85    | 92    |
| 10                                   | 90     | 80     | 85     | 100    | 100    | 100    | 90     | 90     | 90     | 90     | 90     | 90     | 95    | 80    | 90    | 85    | 85    |
| 20                                   | 90     | 70     | 80     | 100    | 90     | 95     | 90     | 90     | 90     | 90     | 90     | 90     | 90    | 70    | 90    | 80    | 65    |
| 40                                   | 90     | 70     | 80     | 90     | 90     | 95     | 90     | 90     | 90     | 90     | 90     | 90     | 60    | 60    | 60    | 60    | 78    |
| 80                                   | 80     | 70     | 75     | 100    | 90     | 95     | 90     | 90     | 90     | 90     | 90     | 90     | 10    | 20    | 15    | 10    | 20    | 15    | 63    |
| Mean of treated plots                | 80     | 95     | 90     | 90     | 90     | 44     | 45     |         |         |         |         |         |       |
contrast, following the April treatments, the TCA was as effective on the non-plowed as on the plowed plots.

When applied in April the TCA caused a reduction in density in proportion to the rate of chemical applied, with only 15 percent cover remaining following the 80 pound application. Figure 31 shows the inhibitory, but non-lethal, effect of 10 pounds of TCA, while Figure 32 shows the high degree of top kill obtained from the 80 pound rate of TCA. In contrast, none of the treatments made at earlier dates was of marked effectiveness.

The apparent kill following the April treatments was no longer evident by August 1, 1951. The April treated plots as well as all of those treated earlier had recovered so as to be essentially the same density as the check.

Results of applications made in the boot stage

More complete control of the quackgrass was obtained from the May 28 application than from any earlier treatment. On June 15 the leaves were turning brown at the 20, 40 and 80 pound rates. The blooming of the quackgrass was retarded but not restricted to the extent that the plots treated on April 2 were. At the 40 and 80 pound rates, the spike expanded to about half the height of the check. The retardation in flowering was most apparent on the plots which had been plowed the previous September. Retardation of flowering occurred even at the 10 pound rate, a rate which was below the concentration required
Fig. 31—Suppression of blooming in quackgrass by low rate of sodium TCA. Left, 10 lb., acid equiv., per acre applied April 2, 1951. Right, no treatment. Photo, June 21, 1951.

Fig. 32—Quackgrass top growth reduction from 80 lb., acid equiv., per acre sodium TCA applied April 2, 1951. No treatment in background. Photo, June 21, 1951.
to kill the existing top growth.

The estimated percentage of top growth density on each plot on September 12, 3½ months after treatment, is given in Table 12. Since there were no evident differences between plots plowed the previous September and those not plowed, a pooled estimate was used.

Table 12. Percentage control of quackgrass top growth on September 12, 1951, from May 28 applications of sodium TCA.

<table>
<thead>
<tr>
<th>Acid equiv. per acre, lb.</th>
<th>Sodium TCA alone</th>
<th>Sodium TCA with 0.1 percent Tween 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>40</td>
<td>85</td>
<td>90</td>
</tr>
<tr>
<td>80</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As judged by top growth present, the May application was very effective at the 40 and 80 pound rates. The rating measured essentially the amount of regrowth from the treated rhizomes since all plots were mowed on June 29, 1 month after the TCA was applied.

Results from the addition of a wetting agent

Reference has been previously made to the use of wetting agents in TCA solutions as a possible means of increasing its effectiveness. The April applications represented a stage of growth at which little
top growth was present, while the May applications represented a stage of growth at which the tops were well established.

As indicated in Tables 10 and 11, neither the Nonic 218 used in April nor the Tween 20 used in May resulted in an increased effectiveness of the TCA. On the plowed plots treated in April, the density was 36 percent with Nonic 218 as compared to 41 percent where the Nonic was not used. On the non-plowed plots, the percent was 44 and 45 percent, respectively. The percentage controls following the May applications were 74 percent with Tween 20 and 79 percent without Tween 20.

**Effect of formulation of TCA upon quackgrass control.**

**Procedure**

Another area in field No. 5, Ohio State University Farm, already described, was used. A two-way whole plot, split plot design was used with two replications. The sub-plot size was 7 by 130 feet. The whole plots included plowing in September, 1950, and no plowing. The quackgrass averaged 8 inches in height and was in the boot stage when the TCA was applied. Sodium TCA, calcium TCA and TCA acid were applied on May 10, 1951, at rates of 25 and 50 pounds, acid equivalent, per acre. The salts were applied in 40 gallons of water per acre, while the TCA acid formulation was applied in 40 gallons of No. 1 fuel oil.
On June 25, 1951, all formulations at the 25 pound rate had caused the death of the leaf blades of the quackgrass, but the stems were still green. Flowering was generally restricted with less than half of the spikes emerging from the boot. Many of those that did emerge were malformed, as described on page 35.

At the 50 pound rate the TCA acid gave complete kill of the tops, but the two salts failed to kill the lower part of the stem. The flowering was reduced over 90 percent by all three formulations at this rate. Many of the spikes which did emerge were malformed due to the constriction within the boot. On September 10, 1951, the percent recovery of top growth was rated. The data are given in Table 13.

Table 13. Recovery of quackgrass top growth as percent of check plots on September 10, 1951, as affected by formulation of TCA used.

<table>
<thead>
<tr>
<th>TCA formulation</th>
<th>25 lb. per A.</th>
<th>50 lb. per A.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium TCA</td>
<td>75</td>
<td>100</td>
</tr>
<tr>
<td>Calcium TCA</td>
<td>75</td>
<td>100</td>
</tr>
<tr>
<td>TCA acid</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>

(1) All rates are acid equivalent.
The data indicate a failure of the 25 pound rate to control quackgrass under the conditions of the experiment, while the 50 pound rate gave commercial control in all cases. The TCA acid tended to give a greater kill than the salts, except at the high rate on previously plowed ground. No difference between the two salt formulations was evident. The area which was plowed in September, 1950, showed the least recovery. At the time of treatment there was no obvious difference between the quackgrass on the plowed and unplowed areas. However, at the time of treatment the non-plowed area was uniformly covered with winter cress (*Barbarea vulgaris*) about 1 foot tall and in full bloom. In September, 1950, plowing gave a complete kill of the winter cress. Canada thistle (*Cirsium arvense*) was also present on both areas. The plowing reduced the vigor of the thistle somewhat, as compared to the non-plowed area, but there was no indication of control due to plowing.

The TCA formulations had only a slight effect upon either the winter cress or the Canada thistle. Flowering of Canada thistle was delayed by all formulations, the most marked effect being caused by the sodium and calcium TCA at the 50 pound rate. The TCA salts had no effect on the winter cress, but the TCA acid in oil at both the 25 and 50 pound rates damaged the flowers severely and largely prevented seed set.

The lesser control obtained on the non-plowed area may be due to the absorption of TCA by the resistant species, thus reducing the effective concentration of TCA.
Chemical control of quackgrass in relation to other crops.

Application before corn planting

In cornbelt rotations it is customary to follow corn after a sod crop which is often infested with quackgrass. The feasibility of planting corn after early spring applications of sodium TCA was investigated in the spring of 1950.

Procedure: Applications of 0, 8, 20, 40 and 80 pounds per acre, acid equivalent, were applied in 40 gallons of solution per acre on plots 15 by 28 feet, replicated five times in a randomized block design. Similar applications were made on the Ohio State University Farm on a Miami silt loam soil on April 21, 1950, and at Wooster on a Wooster silt loam on April 22, 1950. The experimental areas were treated in the usual way after the TCA was applied. The plots at Columbus were plowed on April 29 and the Wooster plots on May 9, 1950. Corn was planted at Columbus on May 28, 37 days after treatment, and at Wooster on May 20, 28 days after treatment.

Results and discussion: Table 14 gives the residual effect of the TCA treatments on the growth of corn.
Table 14. Growth of corn following April applications of sodium TCA prior to seedbed preparation, 1950.

<table>
<thead>
<tr>
<th>Sodium TCA acid equiv. per acre</th>
<th>Normal plants</th>
<th>Abnormal plants (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Columbus July 20 (1)</td>
<td>Wooster June 30 (2)</td>
</tr>
<tr>
<td>0 lb.</td>
<td>No. 61.0</td>
<td>No. 44.0</td>
</tr>
<tr>
<td>8</td>
<td>No. 58.6</td>
<td>No. 35.0</td>
</tr>
<tr>
<td>20</td>
<td>No. 15.6</td>
<td>No. 18.0</td>
</tr>
<tr>
<td>40</td>
<td>No. 8.3</td>
<td>No. 5.0</td>
</tr>
<tr>
<td>80</td>
<td>No. 0.0</td>
<td>No. 1.0</td>
</tr>
</tbody>
</table>

(1) Mean count per plot.
(2) Mean count of two center rows of each plot.
(3) Plants failing to expand normally.

It is obvious from the data that on the two soil types used, corn cannot be planted within 4 or 5 weeks of a sodium TCA application on sod being plowed under. The sodium TCA at the rates used tended to be lethal rather than inhibitory in its effect upon corn. At Wooster height reduction in otherwise normal plants was noted on June 30, but there was no marked evidence of reduction due to chemical treatment at Columbus as seen on July 20. The few plants which were malformed were evident from emergence right on through the season. Most evident was the failure of the leaf blade to expand in a normal way. This malfunction is shown in a young plant in Figure 33. In a few plants the internodes failed to elongate. These plants had short, usually bent stems with thickened, leathery leaves as seen in Figure 34. Other plants grew to three-fourths the normal
Fig. 33—Restricted leaf expansion of young corn planted on May 28, following sodium TCA application on April 21. Photo, June 23.

Fig. 34—Restricted elongation of corn planted on May 28, following TCA application on April 21. Photo, July 25.
height, but compaction and contortion of the developing tissues occurred within the tightly rolled leaves which resulted in twisted and often torn leaf blades. This type of development is seen in Figure 35. In a few cases tassel development occurred within the tightly rolled terminal leaf blades. These fully formed tassels rotted in place in the same manner as the confined spike of quackgrass.

To test the duration of the residual effect of the sodium TCA, sweet corn was planted at random on the bare plots on July 25, 1950, 95 days after the TCA application. The normal growth of the corn indicated no residual effect.

Application on an alfalfa-quackgrass mixture

Quackgrass very commonly invades alfalfa meadows. The following experiment was designed to determine the possibility of controlling quackgrass with sodium TCA without damage to the alfalfa.

Procedure: Plots were laid out on Range 45, Agronomy Farm, Ohio State University, in a second year alfalfa stand infested with quackgrass on Miami silt loam soil. On July 18, 1950, sodium TCA was applied at rates of 0, 20, 40 and 80 pounds, acid equivalent, in 40 gallons of solution per acre on plots 14 by 14 feet, replicated four times in a randomized block design. Applications made at later dates included 10 pound rates as well as the above rates but were applied
Fig. 35—Restricted leaf expansion of corn planted on May 28, following TCA application on April 21. Photo, July 25.
on three rather than four replications. Applications were made on October 12, November 15, 1950, and on April 5, 1951. The July, 1950, application was made after the second cutting of alfalfa. The October application was made on about a 12 inch growth of alfalfa. The November application was made on a 12 inch growth of alfalfa which had been severely damaged by frost. The April application was made as the alfalfa was just beginning to resume growth, the shoots being only 1 to 2 inches long.

Results and discussion: Following the TCA treatment in July, 1950, the quackgrass top growth was killed at all rates. The slight initial injury to the alfalfa was a retardation of blooming and abnormal unfolding of newly formed leaflets. By May 15, 1951, however, there was considerable thinning apparent in the alfalfa as well as some recovery of the quackgrass. The top growth of quackgrass was 60, 20 and 5 percent of the check at the 20, 40 and 80 pound rates, respectively, while the density of the alfalfa was 50, 5 and 10 percent of the check at the 20, 40 and 80 pound rates, respectively. On September 19, 1951, there was a 75, 50 and 0 percent recovery of the quackgrass at the 20, 40 and 80 pound rates, respectively. Little change occurred in the density of the alfalfa, but there was no longer any difference in height.

The October applications had a temporary effect only. On April 30, 1951, the top growth of the quackgrass was 100, 50, 10 and 0 percent at the 10, 20, 40 and 80 pound rates, respectively. The top
growth of the alfalfa was 100, 100, 75 and 65 percent of the check at the 10, 20, 40 and 80 pound rates, respectively. By June 7, when quackgrass was heading out, there was no longer any evidence of quackgrass control or reduction in the growth of the alfalfa.

The November applications gave no evidence of treatment effects on any date.

Following the April applications, the percent of quackgrass top growth on April 30 was 25, 15, 10 and 10 percent of the check at the 10, 20, 40 and 80 pound rates, respectively. The top growth of the alfalfa was 85, 80, 50 and 30 percent of the check at the 10, 20, 40 and 80 pound rates, respectively. The height of the alfalfa at the 10 and 20 pound rates was normal, but the height at the 40 and 80 pound rates was markedly reduced. On June 7 there was complete control of the quackgrass tops with no evident reduction in the alfalfa at the 10 and 20 pound rates. A plot receiving the 10 pound application is shown in Figure 36. The height of the alfalfa was considerably reduced by the two higher rates. At the 40 pound rate the height was two-thirds and at the 80 pound rate, one-half of the check. The leaflets were generally stunted in size and at the highest rate the newly formed ones failed to unfold normally.

By August 16, following a cutting of the alfalfa, there were no longer any variations in the regrowth of alfalfa except for greater incidence of leafhopper damage. There was a consistent increase in leaflet tip-burn, characteristic of leafhopper damage, as the rate
Fig. 36—Effect of sodium TCA upon an alfalfa–quackgrass mixture treated with 10 lb., acid equiv., per acre on April 5, 1951. Photo, June 7, 1951.
of TCA increased. The quackgrass top growth was still less than 10 percent of the check at the 20, 40 and 80 pound rates, but there was complete recovery at the 10 pound rate, a rate which had given complete control of top growth in June.

During the course of the experiment the effect of the TCA upon rhizome development was followed. When rhizomes from plots treated with 80 pounds per acre in July, 1950, were inspected on May 15, 1951, they were still intact but discolored. A high percentage of the lateral buds had started to grow, but they had formed stubs and had ceased elongating by the time they were an eighth of an inch long. By October, 1951, 14 months after the time of treatment, the rhizomes treated with 80 pounds were essentially decomposed with only the epidermis still evident. The rhizomes at the 40 pound rate were not as completely decomposed, being in various stages of disintegration. Normal shoots were growing from some of these decaying rhizomes, but there was no evidence of new rhizome growth as was generally found in the untreated plots. Since normal rhizomes usually decay within a year or so after formation, decomposition of the rhizomes inspected could possibly be attributed as much to their age as to the effect of the TCA. If such is the case, the effectiveness of TCA is attributable more to the restriction of new shoot and rhizome formation than to a direct killing of existing rhizomes.

Following the April treatment, the rhizomes were inspected on
May 15. The internodal tissue of the rhizomes showed no effects from the TCA treatment, but a large number of stubs with restricted extension were found on the nodes. There was no new rhizome growth from the base of those above ground shoots which were still present, in contrast to the abundant formation of new rhizomes from the base of untreated shoots. By September 17, however, there was marked activity of the rhizomes on both the treated and the untreated plots. At 20 and 40 pounds, numerous shoots one-half to 1 inch long at the time were starting to grow. At 10 pounds, regrowth had occurred at a considerably earlier date, and the top growth was as great as on the untreated plots. Since the rhizome tips and some of the lateral buds on the treated plots were inactivated by the TCA, it is evident that some buds survived the TCA effects and started growth at a later date.

CMU for quackgrass control. To compare the effectiveness of 3-p-chlorophenyl-1-l-dimethyl urea, CMU, with sodium TCA, an application was made on April 16, 1951, at rates of 0, 12.5, 25, 50 and 100 pounds of 80 percent technical material in 80 gallons of solution per acre. One-tenth percent Nonic 218 was included as a dispersing agent. A randomized block design with three replications was used. The individual plots measured 14 by 14 feet. The quackgrass averaged 5 inches in height.

The treated plots had considerable Canada thistle (Cirsium arvense) mixed with the quackgrass. By June 16, the CMU had more
completely killed the top growth of thistle than of the quackgrass. At the two lower rates many of the quackgrass plants continued normal development. At the two higher rates some new growth developed only to die back after growing a few inches in height.

By July 11 the plots which received the 50 and 100 pound applications were completely barren. A few scattered plants were still growing on the 25 pound plots, but there was very little control on the 12.5 pound plots. Inspection of the rhizomes in the barren plots disclosed that they were in an advanced stage of decomposition.

On September 8, 1951, the plots receiving the two highest rates were still essentially free of quackgrass. The control was 100, 98, 50 and 25 percent at the 100, 50, 25 and 12.5 pound rates, respectively. The Canada thistle showed considerable recovery on the previously bare plots. There were an average of 19 and 39 plants per plot at the 100 and 50 pound rates, respectively. One plot which received a 100 pound application had 12 climbing milkweed (Gonolobus laevis) plants growing normally. Several dandelion (Taraxacum officinale) plants were growing normally in two of the plots receiving the 50 pound rate.

In conclusion, it was evident that CMU at the 50 and 100 pound rates was effective in controlling quackgrass. It had a more toxic effect upon the rhizomatous tissue than TCA, resulting in much faster disintegration. The selective action of CMU was shown by the survival of several perennial species at rates which killed the quackgrass.
Greenhouse Study of TCA Entry into Johnsongrass and Quackgrass

Absorption of TCA into dormant rhizomes as affected by concentration and duration of exposure.

Procedure

Rhizomes of Johnsongrass were dug during the winter months and held in vermiculite under refrigeration until used. The rhizomes were cut into three node sections prior to treatment. Rhizomes were exposed for several time periods in each of several concentrations of TCA. Duration of exposure was for 10, 30, 120 and 480 minutes, while concentrations of 100, 1000, 10,000 and 100,000 ppm of TCA were used. After exposure for the specified time, the rhizomes were rinsed three times so as to remove the TCA which remained on the surface. Any effects from TCA were assumed to be from that which was absorbed during the time the rhizomes were in contact with solution. The rinsed rhizome was then placed in favorable growing conditions. Duplicate rhizome sections were potted by placing them vertically in vermiculite in Dixie cups. The vermiculite proved to be a good medium because of its high water retention. While it provided very few nutrients, it was assumed that the rhizome pieces were able to supply the food needs of the growing rhizomes for the short period of the experiment. The treatments were made on February 16 and the harvest on March 19. All of the stem tissue from each node was weighed and the weights recorded for each cup as the average per shoot.
Results and discussion

The data obtained are given in Table 15.

Table 15. Effect of sodium TCA upon fresh weight in grams of shoot growth from rhizomes treated while dormant.
(Average of three replications)

<table>
<thead>
<tr>
<th>Concentration of TCA solution in ppm.</th>
<th>Duration of rhizome exposure in minutes.</th>
<th>10</th>
<th>30</th>
<th>120</th>
<th>480</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td></td>
<td>11.3</td>
<td>12.6</td>
<td>5.2</td>
<td>5.0</td>
<td>8.5</td>
</tr>
<tr>
<td>1,000</td>
<td></td>
<td>9.6</td>
<td>11.7</td>
<td>10.3</td>
<td>5.6</td>
<td>9.3</td>
</tr>
<tr>
<td>10,000</td>
<td></td>
<td>4.8</td>
<td>6.4</td>
<td>4.2</td>
<td>3.7</td>
<td>4.8</td>
</tr>
<tr>
<td>100,000</td>
<td></td>
<td>5.9</td>
<td>2.9</td>
<td>2.3</td>
<td>1.8</td>
<td>3.2</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>7.9</td>
<td>8.4</td>
<td>5.5</td>
<td>4.0</td>
<td>6.4</td>
</tr>
</tbody>
</table>

Treatment means L.S.D. – 1 percent level – 5.2
5 percent level – 3.4

Within the ranges used, both the concentration and time of exposure were factors in the absorption of TCA. An increase in either the concentration or in time of exposure decreased the amount of growth, with the decrease being primarily evident at the high levels. Based upon the 5 percent level of confidence, the mean weight was lower after a 480 minute exposure was used than when the 10 and 30 minute exposures were used. An increase in concentration to 10,000 ppm. caused a significant decrease while the 100,000 ppm. concentration caused a highly significant decrease over the 100 and 1,000 ppm. concentrations.
The appearance of the shoots at the effective levels was characteristically stublike with the amount of elongation restricted to a few centimeters.

Two conclusions may be drawn: (1) both the concentration of TCA and the duration of exposure of the rhizome are factors in the treatment of dormant rhizomes and (2) rhizomes absorb TCA directly before active growth has started with the effects becoming apparent when growth does start.

**Translocation studies.** While direct entry of TCA into rhizomes is known to be effective, there has been considerable question as to the translocation of TCA absorbed by the tops.

**Experiment A**

Sodium TCA was sprayed at a rate of 20 pounds acid equivalent per acre on Johnsongrass plants 2 feet tall, in the boot stage, well established in 12 inch pots. In one series the TCA was applied to the foliage only. The latter was accomplished by covering the soil surface with a 1 inch layer of cotton prior to spraying. All watering was done so as to preclude washing TCA from the leaves into the soil.

The first evidence of TCA action was contact injury on the leaf blades to which TCA was directly applied. Subsequently necrosis developed on the leaf blade in a fairly consistent pattern starting at the leaf tip and progressing down the leaf margins. Some necrosis developed also in the plants exposed only to soil added TCA.
A systemic effect became evident as a marked reduction in the growth of the treated plants. The younger leaves and inflorescences failed to expand. In time, abnormal tillers, stublike and only a few millimeters in length were formed at the base of each culm. At the end of 40 days, the tops were removed and the regrowth noted. With very few exceptions there was no normal recovery from plants receiving either soil or foliar applications. Eighty days after removing the top growth the experiment was terminated and the rhizomes examined. A number of rhizome buds had started to grow but only malformed, restricted shoots developed, as with the dormant rhizomes soaked in TCA solutions. Stubs arose both from the vertical rhizomes which supported the previous culms and from the established horizontal rhizomes. These few plants which produced top growth after cutting were in bloom and normal in appearance.

Both upward and downward movement of sodium TCA or some derivative of it was shown. Upward movement of TCA applied to the soil only was indicated by the inhibited expansion of the leaf blades and the inflorescence. Downward movement of TCA applied to the foliage only was indicated by the formation of abnormal shoots on the rhizomes.

Experiment B

Johnsongrass plants growing in 8 inch pots with well established rhizome systems were used. The blade tips of several leaves in each pot were submerged in a sodium TCA solution of 3000 ppm. for several
days. One set included 0.5 percent Tween 20 and the other, no wetting agent. Necrosis first became evident on the submerged leaves. Later, other leaves not submerged but on the same culm became necrotic. Necrosis started at the base of the blade and advanced toward the tip. The solution containing Tween 20 caused more rapid necrosis.

Necrosis of leaves not in contact with the TCA indicated movement of TCA or a derivative of TCA within the plant.

**Experiment C**

Quackgrass rhizome sections about 8 inches in length with well developed shoots growing from some nodes were extended between beakers with the rhizome and some of the foliage submerged at each end. One beaker in each replication contained water, while the other contained a sodium TCA solution of 3000 ppm.

Within 2 days all of the foliage on the rhizomes was dead when one end was exposed to the TCA. There was no apparent change when both ends were in water only. Translocation horizontally along the rhizomes was thus demonstrated.
DISCUSSION - GENERAL

It is quite apparent from the data which have been given that the results from TCA applications varied considerably from one time of application to the next. As noted in the review of literature, such variations have been reported by a number of workers.

Considering the high solubility of TCA salts and the results of greenhouse tests in which time of exposure and concentration of TCA were found to be factors in TCA effectiveness, the precipitation data for the period of the field experiments merited study. In Table 16, the rainfall data following most of the TCA applications are given. The distribution is given on an arbitrarily chosen 4 week basis.

The variation in TCA effectiveness in height reduction from monthly TCA applications on dormant quackgrass was clarified by such a study. In Figure 37, a plot has been made of the height of quackgrass and of the 4 week's total precipitation following each of four applications. These applications were made during the season when the grass was inactive and presumably of fairly comparable physiological status. It can be seen that there was a straight line relationship between reduction and rainfall. The greater the precipitation within the range involved, the less reduction in height of the quackgrass. It may be inferred that greater leaching from increased precipitation lowered the TCA concentration remaining around the rhizomes. As was shown in the
Table 16. Precipitation in inches during the period following TCA applications.

<table>
<thead>
<tr>
<th>Location</th>
<th>Date applied</th>
<th>Weekly totals</th>
<th>Total for 4 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1st. 2nd. 3rd. 4th. 4 weeks</td>
<td></td>
</tr>
<tr>
<td>Applications on quackgrass</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Columbus Oct. 19, 1950</td>
<td>40</td>
<td>1.45</td>
<td>1.85</td>
</tr>
<tr>
<td>Nov. 16, 1950</td>
<td>1.55</td>
<td>1.03</td>
<td>.60</td>
</tr>
<tr>
<td>Jan. 5, 1951</td>
<td>.50</td>
<td>.95</td>
<td>.50</td>
</tr>
<tr>
<td>Feb. 17, 1951</td>
<td>1.50</td>
<td>.90</td>
<td>1.15</td>
</tr>
<tr>
<td>Apr. 2, 1951</td>
<td>.25</td>
<td>1.55</td>
<td>.95</td>
</tr>
<tr>
<td>May 20, 1951</td>
<td>.70</td>
<td>.65</td>
<td>.75</td>
</tr>
<tr>
<td>Applications on quackgrass-alfalfa mixture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>July 18, 1950</td>
<td>1.75</td>
<td>1.30</td>
<td>.04</td>
</tr>
<tr>
<td>Oct. 12, 1950</td>
<td>.35</td>
<td>.75</td>
<td></td>
</tr>
<tr>
<td>Nov. 15, 1950</td>
<td>1.55</td>
<td>.95</td>
<td>1.80</td>
</tr>
<tr>
<td>Apr. 5, 1951</td>
<td>1.00</td>
<td>.30</td>
<td>.95</td>
</tr>
<tr>
<td>Applications on Johnsongrass-alfalfa mixture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waverly Aug. 29, 1950</td>
<td>1.13</td>
<td>.29</td>
<td>.23</td>
</tr>
<tr>
<td>Oct. 7, 1950</td>
<td>1.56</td>
<td>.30</td>
<td>.27</td>
</tr>
<tr>
<td>Nov. 18, 1950</td>
<td>1.62</td>
<td>1.65</td>
<td>1.27</td>
</tr>
<tr>
<td>Mar. 31, 1951</td>
<td>.42</td>
<td>1.25</td>
<td>.54</td>
</tr>
<tr>
<td>Applications on Johnsongrass</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oct. 28, 1950</td>
<td>.27</td>
<td>.89</td>
<td>.16</td>
</tr>
<tr>
<td>Aug. 19, 1950</td>
<td>.28</td>
<td>.85</td>
<td>.65</td>
</tr>
<tr>
<td>Mar. 31, 1951</td>
<td>.42</td>
<td>1.25</td>
<td>.54</td>
</tr>
<tr>
<td>May 17, 1951</td>
<td>.91</td>
<td>.95</td>
<td>1.10</td>
</tr>
</tbody>
</table>

Fig. 37—Top growth of quackgrass following TCA applications on dormant rhizomes as affected by precipitation.
greenhouse tests, there was a close correlation between time of rhizome exposure to a given concentration of TCA and the effectiveness of the salt. If the data from the April applications had been plotted, they would not have fitted the line. A high reduction was obtained despite a 3.45 inch rainfall. It should be pointed out that the quackgrass had resumed active growth by this time. The apparent top kill from the April application was good on June 15, but by August 1 the top growth had recovered. This indicated only slight effect upon the rhizomes. The early reduction in growth was primarily due to the killing of newly formed shoots. It would appear that the 3.45 inch rainfall caused the TCA to move too fast.

The variation in results from TCA applications to an alfalfa-quackgrass mixture can also be explained to some extent by study of precipitation data. As indicated previously, the July 18 and April 5 treatments were the most effective in terms of decreasing recovery from rhizomes. Neither October 12 nor November 15 applications had a lasting effect. In the October application, the lack of sufficient precipitation to leach the TCA into the soil was apparently as important as the excessive precipitation after the November application which probably moved the TCA beyond the depth of the rhizomes. Since the total precipitation following the July, November and April applications were about the same, the lesser effectiveness of the TCA in November may be attributed to the more active stage of growth present in both July and April.
The effect of rainfall was strikingly shown in a comparison of the results from applications on March 31, made on alfalfa-Johnsongrass at Waverly, and on April 5, on alfalfa-quackgrass at Columbus. The stages of growth of the alfalfa were equivalent with about 1 inch of top growth present at both places. As previously noted, the applications at Waverly resulted in severe damage to the alfalfa at all rates, while at Columbus there was only a temporary effect on the alfalfa. The precipitation data for the 4 week period show a 2.21 inch rainfall at Waverly as compared to a 4.60 inch rainfall at Columbus. The distribution was also different. At Waverly, 1.67 inches fell during the first 2 weeks. From the second week to the end of the 4 week period there were only .54 inches more. It can be assumed that the 1.67 inches were enough to leach the TCA into contact with the alfalfa roots. The relatively long exposure of the alfalfa roots to the TCA as a result of slight subsequent rainfall caused severe damage. At Columbus, the rainfall was more equitably distributed, consequently the TCA did not stay in contact with the alfalfa roots for a protracted period.

Of the treatments applied on an alfalfa-Johnsongrass mixture at Waverly, the August and March applications were considerably more effective than the October and November applications. The differences between the October and the August - March applications cannot be traced to rainfall since comparable rainfall regimes existed in all
cases. Over 1.5 inches of rainfall fell within 2 weeks of application after which there was a dry spell. The lack of TCA effectiveness in November can, however, probably be traced to the rapid removal of the TCA by the heavy rainfall of 4.54 inches in the 3 weeks following treatment.

Rainfall was also involved in the results obtained from the combined cultural and chemical treatments applied to Johnson grass in the summer of 1950. As has been indicated, while the cultural treatments were considerably more effective in August than in May, the additional effect of TCA treatments in August was less than in May. This can probably be traced to the low rainfall which followed the August application. There was only .28 inches in the 2 weeks following. Loustalot and Ferrer, 1950, as well as others, have reported a reduction in TCA in moist soils without leaching. It is likely, therefore, that in August the TCA concentration was considerably reduced by the time there was enough rain to carry the TCA into contact with the rhizomes. As a general rule, it can be said that the best results, when using TCA, are obtained when a rain of around an inch falls soon after applications. This serves to leach the TCA into contact with the rhizomes but not beyond as may occur with heavier rains. After this it is best if the rainfall is scant for a week or more so as to allow maximum TCA absorption.

Such a pattern occurred following both the March 31 and the May 15, 1951, applications on Johnsongrass, both applications of high ef-
fectiveness. Of course, the stage of growth must be considered as a probable factor as well, since plants which are in a stage of rapid growth are the most susceptible.

A positive correlation between precipitation pattern and TCA effectiveness has been demonstrated. Such correlation offers a reasonable explanation for much of the variation between various applications. The rainfall factor would probably account for many of the apparent inconsistencies in results reported in the literature. This conclusion coincides with that of Watson (1950) and McCall and Zahnley (1949), who emphasized the prime importance of rainfall in quackgrass and Johnsongrass control.

The need for rainfall data in connection with any TCA experiment is quite evident. Total precipitation is not the only thing which should be considered, since distribution is also important. The influence of soil type cannot be divorced when considering precipitation relationships, since a given amount of rainfall will leach TCA further in a sandy soil than in a clay soil.

Of particular importance is the stage of growth at the time of treatment. If the TCA remains in the soil for some time, rhizome buds will absorb TCA showing the effects when growth is resumed. However, the best results were always obtained if TCA was present at a time when active growth was occurring from the rhizomes.
The experimental work, particularly that with Johnsongrass, substantiated the emphasis some workers have placed upon the use of cultural measures for control either alone or in combination with chemicals. It is especially clear that management of the top growth will determine to a large extent the vigor of the rhizomes, collectively a system which must be replaced each year if the plants are to retain their perennial habit.

There can be no doubt as to the effectiveness of TCA in killing many perennial grasses under the right conditions. Its range of usefulness, however, remains to be determined. To be considered are (1) the relatively high degree of variability in the results obtained from its use, (2) the residual soil toxicity of 2 months or more resulting from its use, (3) the high cost per pound of the chemical, and (4) the competitive value of other herbicides and cultural measures both in cost and effectiveness.

The variations in results have been traced in part to the stage of growth when treated and to the environmental variables of soil and precipitation. The former can be controlled to a greater extent than the latter, but the physiologically optimum period for treatment may not be the best time from an economic standpoint. The residual toxicity is important since applications made in the spring or summer may disrupt the usual cropping pattern. At present with 90 percent sodium TCA selling for over fifty cents per pound, there
are distinct limitations in its usage for routine applications. At this date, despite the longer soil residual toxicity and the greater rates required, more sodium chlorate is being used for control of perennial grasses than are trichloroacetates. This is due entirely to the relative advantage in the cost of the chlorate.

While the place for TCA in general farming operations remains to be established, it certainly merits further consideration. Its use as a spotting agent to control perennial grasses which have survived cultural control measures is certainly feasible. It merits consideration as a selective herbicide, for example, for controlling grasses in legumes, since there is considerable difference in tolerance between plant species.
SUMMARY

Of the newer herbicides the salts of trichloroacetic acid (TCA) have been shown to be among the most effective herbicides for perennial grasses.

A study was made of the manner in which TCA exerts its phytotoxic effects on grasses.

Emphasis was placed on the control of Johnsongrass (Sorghum halapense) and quackgrass (Agropyron repens) as representatives of rhizomatous perennial grasses, a group which includes many serious weeds.

Most of the work was in the field with supplementary work in the greenhouse. The field experiments were on natural infestations of Johnsongrass at Waverly and of quackgrass at Columbus, Ohio. The normal development of each grass was studied, since the knowledge is essential in planning control measures.

TCA was applied in the late and early spring months at Waverly on Johnsongrass which was dormant or just starting to grow, in the growing season in combination with cultural control measures and as a selective herbicide on alfalfa infested with Johnsongrass. Applications were made on quackgrass during the fall, winter and spring months, and as a selective herbicide on alfalfa infested with quackgrass. Three different TCA formulations were compared for effectiveness on quackgrass. The effect of residual soil toxicity following TCA applications upon succeeding crops was studied by planting corn.
after spring applications and by recording the floristic changes occurring on the treated plots.

In the greenhouse the absorption and translocation of TCA were studied to establish the mode of entrance into the plant.

The effects of TCA were most evident in the meristematic tissues of the plants where cell enlargement was occurring. Buds or young shoots which absorbed TCA were restricted in elongation and formed thickened, malformed shoots termed stubs. Failure of leaf blades to unroll was characteristic, the confinement of the developing tissues resulting in malformed and limited expansion.

The control obtained from TCA was found to be due more to the reduction in shoot growth obtained than through a direct kill of rhizomes. Rhizome internodes often remained normal in appearance for several months after treatment.

The effectiveness of TCA applications in the field was found to be associated with the stage of growth of the grass and the amount and distribution of the precipitation following treatment. The top growth of Johnsongrass was most readily controlled by making applications prior to or soon after initiation of spring growth. Optimum control was obtained when enough rainfall occurred following treatment to leach TCA into the upper horizon of the soil but not into the subsoil.

Cultural control measures were found to increase the effectiveness of TCA applications. Mowing of the top growth in the summer,
repeated plowing during the summer or plowing so as to more completely expose the rhizomes during the winter was found to increase the control of Johnsongrass. Plowing quackgrass prior to treatment was found to increase the effectiveness of TCA applied as compared to sod applications.

In a limited comparison of sodium TCA, calcium TCA and TCA acid in oil on quackgrass, no differences in effectiveness were found between the two salts. The TCA acid was somewhat more effective than either salt.

The residual soil toxicity from TCA applications was found to vary from 6 to 12 weeks under the experimental conditions concerned. The need for continuous control measures was indicated by the re-vegetation of treated plots by Johnsongrass seedlings which germinated after the TCA had largely disappeared from the soil. In one case corn was successfully grown at Waverly when planted 53 days after TCA application, but corn planted 33 days afterwards was a near failure as was corn planted 37 days afterwards at Columbus.

Selective action from TCA was obtained from applications of TCA on Johnsongrass-alfalfa mixtures and on quackgrass-alfalfa mixtures. Under optimum conditions the grasses were controlled without permanent damage to the alfalfa.

In greenhouse studies, absorption of TCA into the dormant rhizomes was found to occur, with the effects becoming evident only upon resumption of growth. Translocation of TCA or a derivative within Johnsongrass plants and along quackgrass rhizomes was found to occur.


I, Robert Alexander Peters, was born in Sac City, Iowa, June 10, 1920. I received my secondary school education in the public schools of the city of Des Moines, Iowa, and of Montgomery County, Maryland. My undergraduate training was obtained at Iowa State College from which I received the degree Bachelor of Science in 1943. From North Carolina State College, I received the degree Master of Science in 1948. From September 1948 to September 1949, I was employed by the United States Army Chemical Corps at Camp Detrick, Maryland. In September 1949, I received an appointment as a Teaching Assistant in the Department of Agronomy in The Ohio State University. Concurrently, I was enrolled in the Graduate School of The Ohio State University, being admitted to candidacy in the Winter Quarter 1951. The requirements for the degree Doctor of Philosophy were completed in absentia after the acceptance of an appointment as Assistant Agronomist in the Plant Science Department of the University of Connecticut in October 1951.