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Time Interval Required to Measure Effects of Herbicides on Canada-Thistle and Field Bindweed

Charles Ralph Whipple
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TIME INTERVAL REQUIRED TO MEASURE EFFECTS OF HERBICIDES
ON CANADA-THISTLE AND FIELD BINDWEED

by

Charles Ralph Whipple

A thesis submitted in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE in
Weeds and Weed Control

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

1961
ACKNOWLEDGMENTS

I acknowledge the help received from Professor D. C. Tingey in formulating and directing this thesis work. I also thank Drs. Keith Allred and Gene Miller, who served on my graduate committee.

Charles Ralph Whipple
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Canada-thistle and field bindweed are two troublesome weeds in Utah. Jensen\(^1\), in cooperation with county weed committees, conducted a weed survey in the state. Seriousness of weeds was listed by counties. Field bindweed was considered to be either a serious or very serious weed in every county except one, and Canada-thistle was classified in these two categories in over one-half of the counties.

Since the introduction of 2,4-D, farmers have taken a new interest in the use of herbicides for weed control. Vast sums of money are spent annually for herbicides. This has stimulated the introduction of many new chemicals and has made researchers aware of the need for faster methods of testing and evaluating them. Many weed specialists do not determine effects of herbicides on creeping perennials until the following season after they are applied. Evaluation of herbicides could progress at a more rapid rate if their effects could be measured at an earlier date.

The principle objective of the research herein reported was to determine how soon after herbicides were applied their effects could be accurately measured and to what extent this might be influenced by certain environmental factors under which plants were grown.

\(^1\)Louis A. Jensen, Results of 1956 weed survey in Utah. (personal communication) Logan, Utah.
Little research has been reported on the length of time after herbicides are applied that their effects can be accurately measured. The literature indicates a great deal of variability in the time interval used to evaluate effects of herbicides on plants. Fisher et al. (1956), working with mesquite, used 18 months after application of 2,4,5-T to determine the percentage of plants killed. McKay et al. (1959) determined percentage control of Canada-thistle each year for five years. Results at the end of the fifth year were used as the check. Rasmussen (1947) treated dandelion plants with 2,4-D and studied its effects for 25 days.

Methods of Studying Effects of Herbicides on Plants

Rasmussen (1956) stated that one viewpoint taken by many is that a critical or precise evaluation of weed control is not necessary. The weeds are either killed by the herbicide or they are still alive. On the other hand, some weeds are not susceptible enough to be killed outright. When such plants are being used, some may be killed, others retarded in top growth, and some hardly damaged. Adequate control may sometimes be obtained without completely killing the weeds.

Since evaluation of herbicides by methods other than by death of plants is often necessary, some method must be devised which will accurately describe the condition of the plants. One such method is to determine what happens to various constituents in the roots of treated plants. Smith et al. (1947) studied the mechanism of herbicidal action of 2,4-D on field bindweed. They found that treatment with 2,4-D caused changes in carbohydrates, nitrogen fraction, and respiratory
capacities of roots. During the first few days the 2,4-D treatment caused rapid increases in total sugars, followed by decreases to levels of the controls. The starch-dextrins fraction decreased in all parts of the plant, reaching one-third the control levels by the tenth day. Total nitrogen decreased steadily in the leaves but increased in the stems and underground portions. Evidence of stimulated metabolism was found in the increased respiratory activities of treated plants.

Rasmussen (1947) studied the effect of 2,4-D on chemical composition of dandelion roots. He reported that the action of 2,4-D on dandelion was principally the destruction of carbohydrate reserves, with most of the loss being accounted for by increased respiration. It seemed improbable that destruction of carbohydrate reserves alone could account for the lethal action of 2,4-D. He postulated that the destruction of the reserves was a symptom of direct, specific protoplasmic toxicity, rather than the cause of herbicidal injury. The conclusion that weight loss was a symptom and not the cause for the killing action of herbicides was independently reached by Taylor (1947). Rasmussen found that the reducing sugar content of the roots of herbicidal treated plants was increased, but a decrease in the sucrose content more than accounted for this increase. These changes in levels of sugars resulted in a decrease in total sugars. Wolf et al. (1950) reported that the reducing sugar content of soybean plants treated with 2,4-D was consistently higher than non-treated. Klingman and Ahlgren (1951) found that reducing sugars increased in wild garlic plants that were treated with 2,4-D.

Rasmussen (1947) also studied the effects of 2,4-D on respiration rates of dandelion roots. Although the experiment was for only 25 days
duration, the respiration rate of roots of herbicidal treated plants remained high throughout the test, showing only a slight drop after 20 days. This high respiration rate resulted in a decrease in carbohydrate content of dandelion roots and was reflected in a decrease in total dry weight of roots. A comparison of these changes in carbohydrate content gives an indication of the reactions involved. A decrease in dry weight equal to the decrease in carbohydrates suggests utilization of the carbohydrates in respiration, while a decrease in weight less than the decrease in carbohydrates would indicate some synthesis of non-carbohydrate materials. Rasmussen found that the reduction in dry weight was practically equivalent to the loss of carbohydrates. He concluded that respiration could account for the loss of carbohydrates, rather than the carbohydrates being converted into non-carbohydrate material.

Klingman and Ahlgren (1951) studied the effects of 2,4-D on wild garlic plants. In herbicidal treated plants, the "reserve" foods, such as total sugars and total polysaccharides, showed the greatest percentage reduction. Herbicidal treated plants also showed a corresponding loss in dry weight. It was proposed that reserve carbohydrates were rapidly hydrolyzed to reducing sugars, which in turn were oxidized, resulting in a total loss of dry weight. The trend suggested that with death of the plant, the reserve carbohydrates and reducing sugars would be nearly exhausted. Mitchell and Brown (1945) reported that sugar content of 2,4-D treated plants first increased, then decreased, until three weeks after treatment they contained only one-third as much sugar as did check plants.

Datta and Dunn (1959), working with the effects of 2,4-D on mustard and tomato plants, measured the effect of 2,4-D by comparing the actual reduction of dry weight of treated plants with those not
treated. They stated that dry weight was one of the most precise measurements of herbicidal effect, and any reduction in dry weight below that of the control was regarded as an adverse effect due to 2,4-D.

Mitchell and Brown (1945) reported that dry weight of roots of annual morning-glory plants treated with 2,4-D decreased approximately 60 percent within three weeks after the herbicide was applied.

Annual plants, susceptible to 2,4-D, have been used to determine what happens when treated with 2,4-D. Several methods of evaluating effects of herbicides have come from these studies. Meggitt et al. (1956) used as a measure of the effects of DNBP on soybeans (1) height of plants, (2) height of plants from the cotyledonary leaves to the terminal bud, (3) fresh and dry weight of the above parts of the plant, and (4) an injury rating system. Orgell and Weintraub (1957) used the epicotyl curvature method for short term response (four to eight hours). Repression of elongation of the second internode above the cotyledonary node was used as a measure of long term response (72 to 120 hours).

Mitchell and Brown (1946) used stem curvature of bean plants as criteria for evaluating the effect of 2,4-D.

Factors Affecting Susceptibility of Plants to Herbicides

Moisture

Soil moisture has been reported to alter the response of plants to herbicides. Hauser (1955), working with soybean and corn plants, found less 2,4-D was absorbed by plants grown under moisture stress than by plants that received adequate water. When plants were grown under moisture stress, growth was reduced, sugars accumulated, and the cuticle was thickened. Hauser theorized that changes in the cuticle, particularly, contributed to reduced absorption. Also a lower general
physiological activity could be contributory, by reducing plant responses.

Pallas (1959) grew bean plants in continuously sub-irrigated soil. Prior to treatment with 2,4-D he removed plants at one-half hour intervals, so that when 2,4-D was applied, the plants were under soil moisture conditions ranging from field capacity to permanent wilting point. He found that absorption of the herbicide was not affected by soil moisture. Nevertheless, there was a direct relation between soil moisture and the amount of 2,4-D translocated to the epicotyl. As the plants approached permanent wilting, translocation was only one-half that found in those growing in soil at or near field capacity.

In field plot studies on mesquite, Fisher et al. (1956) concluded that under drought conditions not enough 2,4,5-T was translocated to the crown buds to prevent sprouting. Effectiveness of 2,4,5-T was reduced when drought restricted plant growth or intermittent rains caused irregular growth of foliage. Most effective kills of mesquite with 2,4,5-T have been obtained when there was an adequate supply of soil moisture.

Thornton (1945) reported that high soil moisture and high fertility were associated with good control of field bindweed with 2,4-D.

Hauser and Thompson (1959) from work on Johnson grass found an interaction of moisture x herbicide. Reduced moisture level decreased translocation of 2,2,3-TeBA but had little effect of the translocation of dalapon, amitrol, or 4-CPA. Translocation was determined by control, or growth responses following application of the herbicides.

Leonard (1956), working on chemical control of chamise, found soil moisture to be the main factor influencing the kill of two-year-old
sprouts with 2,4-D. His data showed a soil moisture x herbicide interaction. When soil moisture was high, 2,4-D was the most effective herbicide. When soil moisture was low, 2,4,5-T was slightly superior.

Crafts (1933) found that distribution of arsenic compounds, applied as acid-arsenical sprays, was not effective on plants growing in soils abundantly supplied with moisture.

**Soil type**

At 10 locations in Texas, percentage kill of mesquite growing on sandy soils was much higher than on adjoining clay loam soils (Fisher et al., 1956). This was the case even during years when sufficient rainfall was present to rule out the moisture aspect.

**Nutritive conditions**

Wolf et al. (1950) reported that nutritive conditions of plants could be a factor in determining the response to herbicides. Their work was done with soybeans growing in sand nutrient cultures. After three weeks of differential nitrogen applications, 2,4-D was applied to the sand. Plants were harvested 14 days later. Tops of plants receiving high nitrogen solutions were dead. Medium nitrogen plants showed severe chlorosis of leaves and splitting of stems, and low nitrogen plants showed only mild chlorosis. Roots of 2,4-D treated plants receiving high nitrogen were badly decomposed, and medium nitrogen plants showed some decomposition, whereas low nitrogen plants were nearly normal. These results agree with those reported by Freiberg and Clark (1952), where visible responses of 2,4-D treated soybean plants appeared sooner and were more pronounced in those receiving high than in low nitrogen.

According to Wolf et al. (1950), field observations in 1948 showed
that plants growing in soil which had received a high rate of nitrogen fertilizer were more easily killed by 2,4-D than plants growing in soil which had received a low rate of nitrogen fertilizer. They postulated that differences in levels of fertility could be one of the important reasons for the variable plant responses obtained in field application of 2,4-D.

An interesting theory has been advanced by Leopold (1960), that differences in plant constituents which exist at various stages of development could be partly responsible for the differences in selectivity with age of the plant. Soluble nitrogen content of rice plants reached the highest values in the seedling stage and at the time of bolting. These two stages were the most sensitive to 2,4-D injury.

In the control of canada-thistle in Idaho, McKay et al. (1959) found that a high nitrogen level was beneficial for the control of canada-thistle in wheat grown under continuous cropping and sprayed with 2,4-D. The additional nitrogen enhanced the wheat, and thereby increased competition against the canada-thistle. It could be that in this experiment the high nitrogen also made the canada-thistle more susceptible to the herbicides.

Bingham and Upchurch (1959) concluded that nitrogen had very little influence on the effect of diuron on the growth of cotton and Italian rye grass. They found, however, that with each successive addition of P2O5 the susceptibility of Italian rye grass to diuron was reduced.

Temperature

Currier and Dybing (1959) stated that warm temperature, if not excessive, promoted penetration of herbicides by (1) physico-chemical process, such as increased rate of diffusion, and lowered viscosity,
and (2) physiological factors, such as acceleration of photosynthesis and increased rate of phloem transport. Hauser (1955) determined that as temperature increased from 37° to 81° F., there was an increased rate of absorption of 2,4-D by corn and soybean plants. Meggitt et al. (1956) reported that activity of DNBp on soybeans increased as temperature increased. Rice (1948) determined the amount of 2,4-D absorbed by bean plants was positively correlated with temperature. Thimann (1948) and Hamner and Tukey (1946) reported that plants treated during warm weather responded to herbicides more quickly and more completely than plants treated in cool weather.

**Light**

Currier and Dybing (1959) reported that light promoted penetration of herbicides directly by stimulating opening of stomata and indirectly by supporting photosynthesis, thereby increasing the rate of movement of sugars and herbicide into storage organs of the plants. Mitchell and Brown (1946) found the movement of growth stimulus of 2,4-D was closely associated with translocation of organic food materials. Rice (1948) determined that the rate of absorption of 2,4-D by bean plants was not changed between 100 and 900 foot-candles of light, but the rate of translocation was positively correlated with light intensity. Hauser and Thompson (1959) found that low light intensity after treatment with herbicides reduced translocation of amitrol but had little effect on translocation of the other herbicides tested. Meggitt et al. (1956) reported high light intensity following treatment reduced the apparent activity of DNBp. They also demonstrated that light before treatment affected the reaction of the plants, as those grown under low light intensities were injured more than those grown under higher light intensities.
According to Datta and Dunn (1959), light quality was also important in determining the plant's response to herbicides. On tomato and mustard plants, the greatest dry weight reduction due to application of 2,4-D occurred in the red and blue portions of the light spectrum.

**pH**

It has been reported that effectiveness of the spray solution on plant response is greater at acid pH than at alkaline pH (Currier and Dybing, 1959). Hauser and Thompson (1959) and Hauser (1955) determined the effect of the pH spray solution on absorption of dalapon by Johnson grass and of 2,4-D by corn and soybeans. Their data show an inverse relationship between the pH levels and absorption of the herbicide.

**Relative humidity**

According to Currier and Dybing (1959), absorption and translocation of 2,4-D were enhanced by high relative humidity. However, Tschirley and Hull (1959) and Fisher et al. (1956) reported that relative humidity did not effect the susceptibility of mesquite to 2,4,5-T under field conditions.
METHODS AND PROCEDURES

Plants from an experiment designed to determine the effects of certain environmental factors on the susceptibility of weeds to herbicides were used in these studies. Canada-thistle (*Cirsium arvense* L. Scop) and field bindweed (*Convolvulus arvensis* L,) were the weeds concerned.

Plants used in the study were propagated asexually from creeping roots. Root cuttings were obtained from fields at North Logan which were naturally infested with Canada-thistle and field bindweed. Root cuttings of field bindweed were transplanted into cans during the early summer of 1958 and were left in the field through the winter of 1958-59. Root cuttings of Canada-thistle were started later during the summer of 1958 and were moved into the greenhouse during the winter of 1958-59. These were again placed in the field in early spring of 1959.

Plants were grown in cans 7 inches in diameter and 20 inches deep (figure 1). While in the field each can containing a plant was placed inside an 8-inch concrete pipe buried in the soil. The pipes were spaced 3 feet apart. Glass wool insulation was placed around the top of the cans, between the cans and the concrete pipe and covered with soil.

Environmental treatments were the same for both weed species. They consisted of using four soil types, three moisture levels, and two fertility levels.

Soils differed widely in their characteristics. They were as follows:
1. Millville loam, a highly calcareous soil, obtained from the Greenville Farm, located two miles north of Logan, Utah.

2. Nibley silty clay loam, a non-calcareous soil, obtained from the Evans Farm, located three miles south of Logan, Utah.

3. Sandy loam, obtained from an area near Lewiston, Utah.

4. Gravely loam, obtained from a mountainous area near Sterling, Utah.

Irrigation treatments were the same, except for a short time before and after herbicides were applied. They were as follows:

Irrigation treatment 1. The soil was kept continuously moist throughout the entire experiment.

Irrigation treatment 2. Soil was allowed to dry until the plants wilted. Herbicides were then applied. Soil was kept dry until all top growth of plants was dead. Water was then added and the soil kept moist for the duration of the experiment.

Irrigation treatment 3. Soil was allowed to dry down until the herbicide was applied. Water was added immediately after herbicides were applied and the soil was moist for the duration of the experiment.

The following fertility levels were used:

1. No fertilizer was added.

2. The plants received an application of 200 pounds of nitrogen, 200 pounds of P<sub>2</sub>O<sub>5</sub>, and 20 tons of manure per acre.

Herbicides and rates of application on Canada-thistle were:

1. Control. No herbicide was applied.

2. 2,4-D, Ethyl Ester formulation, was applied at the rate of 4 pounds active per acre.

3. Amitrol, wettable powder, was applied as a spray at the rate of
8 pounds active per acre.

Herbicides and rates of application on field bindweed were:

1. Control. No herbicide was applied.

2. 2,4-D, Ethyl Ester formulation, was applied at the rate of 2 pounds active per acre.

3. Poly chloro benzoic acid (TBA) was applied at the rate of 20 pounds active per acre.

Canada-thistle was treated on August 15, 1959, and field bindweed on September 1, 1959.

The date new top regrowth appeared was recorded. From this data it was possible to determine the percentage of treated plants with no top regrowth at any given date and the number of days to recover.

To evaluate the length of time after application of herbicides that their effects could be accurately measured, harvests were made at the time the herbicides were applied and on three dates following their application. These harvests were as follows:

1. At the time the herbicides were applied.

2. When herbicidal treated plants began to recover, as indicated by new top growth. For Canada-thistle this was 40 days and for field bindweed 47 days after the herbicides were applied.

3. When the appearance of new top growth of the herbicidal treated plants was nearly complete. This was 4 months after application of herbicides. Plants to be harvested on the second and third dates were moved into the greenhouse in the fall.

4. The last harvest was made approximately one year after the herbicides were applied and when untreated plants reached the
bloom stage of growth. These plants had remained in the field
during the winter and were harvested during the following
summer. Those for the other harvest dates, as indicated, were
moved into the greenhouse during the winter.

Data from the fourth harvest were used as a standard. It was
thought that a more accurate appraisal could be made of the treatment
effects at that time. Data from the other harvests were compared with
the standard to determine if it was possible to obtain an accurate
appraisal of the herbicidal effects sooner than one year after the
herbicides were applied.

Plants were harvested by emptying the soil from the cans into
boxes 14 by 24 inches, which had a one-fourth inch mesh wire screen
in the bottom. The soil was washed through the screen with water,
leaving the roots on the surface (figure 1, page 12). Roots taken from
the wire screen were wiped dry with absorbent paper and weighed. The
plant material was dried in an oven at 150° F. for a minimum of 24
hours, and dry weights were determined.

The treatments appeared in all combinations of factors and were
arranged in a randomized block design with three replications.

A number of plants died before they became established, and some
died later. This resulted in some treatments with less than three
replications. However, each treatment had at least two replications.
Averages of the replications were used in the statistical analysis, in
place of the individual values. The higher order interactions were
used as an estimate of the experimental error.
RESULTS AND DISCUSSION

**Canada-thistle**

The basis of determining effects of environmental factors on the susceptibility of Canada-thistle to 2,4-D and amitrol were as follows:

1. Percentage of dead plants.
2. Dry weight of roots of plants.
3. Percentage dry weight of roots.
4. Percentage of plants with no top regrowth.
5. Number of days for top regrowth to appear.
6. Dry weight of tops.

Treatments which were statistically significant, by dates, and measure used to evaluate effects of herbicides are listed in table 1. Several interactions of herbicides x irrigation occurred on percentage of plants with no top regrowth, number of days to top regrowth, and dry weight of tops of plants. An interaction of herbicide x fertilizer occurred on dry weight of roots. These interactions show some possibility of one being able to manipulate Canada-thistle by addition of water and fertilizer so as to influence their susceptibility to amitrol.

**Percentage of dead plants by harvests**

Percentage of plants killed is undoubtedly the best measure to use in determining the reaction of weeds to herbicides. However, if as is often done in field experiments plants are assumed to be dead where no top growth is present, some other basis might be more reliable.

Percentage of Canada-thistle plants killed was ascertained by the decomposition of roots. Dead plants were found only at the one-year harvest. At that time irrigation approached significance at the 5
### Table 1. A listing of all significant treatment effects for Canada-thistle

<table>
<thead>
<tr>
<th>Date</th>
<th>Percentage of plants killed</th>
<th>Dry weight of roots</th>
<th>Percentage dry weight of roots</th>
<th>Percentage of plants with no regrowth</th>
<th>Number of days to regrowth</th>
<th>Dry weight of tops</th>
</tr>
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<td>When herbicides were applied</td>
<td>---</td>
<td>None</td>
<td><strong>Fertilizer</strong> <strong>Irrigation</strong></td>
<td>---</td>
<td>---</td>
<td>None</td>
</tr>
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<td>40 days after application of herbicides</td>
<td>---</td>
<td><strong>Soil</strong> <strong>Irrigation</strong></td>
<td><strong>Soil</strong> <strong>Herbicide</strong> <strong>Fertilizer</strong> <strong>Irrigation</strong></td>
<td><strong>Herbicide</strong> <strong>Irrigation</strong></td>
<td>None</td>
<td>Not Available</td>
</tr>
<tr>
<td>95 days after application of herbicides</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td><strong>Herbicide</strong> <strong>Irrigation</strong> <strong>Herbicide</strong> x Irrig.</td>
<td><strong>Herbicide</strong> <strong>Irrigation</strong> <strong>Herbicide</strong> x Irrig.</td>
<td>---</td>
</tr>
<tr>
<td>4 months after application of herbicides</td>
<td>---</td>
<td><strong>Soil</strong> <strong>Herbicide</strong> <strong>Fertilizer</strong> <strong>Irrigation</strong></td>
<td><strong>Herbicide</strong> <strong>Fertilizer</strong></td>
<td><strong>Herbicide</strong> <strong>Irrigation</strong> <strong>Herbicide</strong> x Irrig.</td>
<td><strong>Herbicide</strong> <strong>Irrigation</strong> <strong>Herbicide</strong> x Irrig.</td>
<td><strong>Herbicide</strong> x Irrig.</td>
</tr>
<tr>
<td>Approx. one year after application of herbicides</td>
<td><strong>Herbicide</strong> <strong>Irrig.</strong></td>
<td><strong>Soil</strong> <strong>Herbicide</strong> <strong>Fertilizer</strong> <strong>Irrigation</strong></td>
<td><strong>Herbicide</strong> <strong>Irrigation</strong> <strong>Herbicide</strong> x Irrig.</td>
<td><strong>Herbicide</strong> <strong>Irrigation</strong> <em>Soil</em></td>
<td><strong>Herbicide</strong> <strong>Irrigation</strong> <em>Soil</em></td>
<td><strong>Herbicide</strong> x Irrig.</td>
</tr>
</tbody>
</table>

**Significant at the 1 percent level**
*Significant at the 5 percent level*
#Approaches significance at the 5 percent level
percent level, and herbicide was significant at the 5 percent level (table 1).

Only 3 percent of the herbicidal treated canada-thistle plants that received irrigation 2 were dead compared to 18 percent for irrigation 3 and 20 percent for irrigation 1. Twenty-two percent of the plants treated with amitrol were dead compared to 6 percent of those treated with 2,4-D.

Using percentage of canada-thistle plants killed as a measure of herbicidal damage, it may be that one year is not long enough to obtain an accurate appraisal of herbicides. At the one-year harvest 77 percent of the canada-thistle plants treated with amitrol and receiving irrigation 1 had no top regrowth, but less than one-half of these plants were dead. Whether or not the other half would recover, or die, could not be determined except by a harvest made later than one year after application of the herbicides, which was not done.

Since few plants were killed in this experiment, other measures were used to evaluate the effects of herbicides on plants.

**Dry weight of roots by harvests**

Canada-thistle roots as compared with field bindweed were generally large in diameter, with few small lateral roots (figures 2 and 5).

As previously indicated, plants to be harvested 40 days and 4 months after application of herbicides were moved into the greenhouse shortly after the herbicides were applied. All plants, even controls receiving ample moisture, lost in root weight while they were in the greenhouse (figure 3).

Roots of control plants, and those treated with 2,4-D but left in the field for the one-year harvest, weighed more than comparable treatments at the 4-month harvest, while those treated with amitrol weighed
Figure 3. Dry weight in grams of roots of Canada-thistle plants receiving irrigation treatment 1
less at the one-year harvest.

Based on root weight, there were no significant differences in treatments at the time herbicides were applied. Harvests made after herbicides were applied did show some environmental treatments to be significantly different (table 1).

Soil and irrigation were significant at the 1 percent level at the 40-day harvest (table 1).

Weight of roots was higher for plants receiving irrigation 1 and 3 than for those receiving irrigation 2. Roots of plants in dry soil at the time herbicides were applied, and that remained dry until some plants on other treatments began to show new top growth, lost about one-fourth in weight.

At the 4-month harvest, soil and herbicide were significant at the 1 percent level, and herbicide x irrigation and herbicide x fertilizer interactions were significant at the 5 percent level (tables 1 and 2).

Weight of roots at the 4-month harvest of Canada-thistle treated with amitrol weighed only one-half as much as controls. The 4-month harvest was the earliest date that root weights of plants treated with herbicides were significantly different from controls.

Herbicide x irrigation interaction was due to the weight of roots of control plants being lower for irrigation 2, whereas on plants treated with herbicides the root weights were higher on irrigation 2. These data would indicate that the herbicides were more damaging on plants receiving irrigation 1 and 3 than on those receiving irrigation 2.

Herbicide x fertilizer interaction was due to weight of roots being higher on control plants that were not fertilized, whereas there was no difference due to fertilizer on those receiving herbicides. There was
Table 2. Dry weight of roots of Canada-thistle plants in grams 4 months after application of herbicides

<table>
<thead>
<tr>
<th>Soil</th>
<th>Herbicide</th>
<th>Irrigation</th>
<th>Fertilizerb</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
<td>2,4-D</td>
<td>Amitrol</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Millville loam</td>
<td>9.8</td>
<td>8.3</td>
<td>4.4</td>
<td>8.1</td>
<td>6.5</td>
</tr>
<tr>
<td>Nibley silty clay</td>
<td>12.3</td>
<td>12.8</td>
<td>7.2</td>
<td>12.3</td>
<td>9.6</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>9.1</td>
<td>8.2</td>
<td>4.3</td>
<td>6.6</td>
<td>8.4</td>
</tr>
<tr>
<td>Gravely loam</td>
<td>15.2</td>
<td>10.2</td>
<td>6.4</td>
<td>10.5</td>
<td>10.9</td>
</tr>
</tbody>
</table>

Significant at .01 level

<table>
<thead>
<tr>
<th>Soil</th>
<th>Herbicide</th>
<th>Amitrol</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Millville loam</td>
<td>None</td>
<td>13.2</td>
<td>8.6</td>
<td>13.1</td>
</tr>
<tr>
<td>Nibley silty clay</td>
<td>Herbicide</td>
<td>2,4-D</td>
<td>8.9</td>
<td>11.7</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>Herbicide</td>
<td>Amitrol</td>
<td>6.1</td>
<td>6.4</td>
</tr>
</tbody>
</table>

Significant at .05 level

<table>
<thead>
<tr>
<th>Herbicide x irrigation</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Herbicide x fertilizer</td>
<td>Irrigation</td>
<td>(2)</td>
</tr>
</tbody>
</table>

Average 9.8 8.3 9.0

aSee page 13 for irrigation treatments.
b200 lbs. of N, 200 lbs. of P₂O₅, 20 tons of farm manure per acre.
no reason why weight of roots of control plants should have been lower when fertilized. This interaction was opposite of what might have been expected, and, as will be shown later, it was opposite to the interaction at the one-year harvest. This was probably a chance variation and not a treatment effect.

At the one-year harvest, soil and herbicide were significant at the 1 percent level. Soil x irrigation and herbicide x fertilizer interactions were significant at the 5 percent level (tables 1 and 3).

Weight of roots of herbicidal treated plants was less than for control plants. Those treated with 2,4-D weighed about half as much as controls while those treated with amitrol weighed about one-third as much as controls.

Herbicide x fertilizer interaction was a result of the weight of roots being higher on control plants when fertilized, whereas on herbicidal treated plants it was higher on plants that were not fertilized. It would appear that fertilized plants were more susceptible to the herbicides, particularly to 2,4-D. These data agree with Wolf et al. (1950) who reported that plants with an adequate supply of nitrogen were injured more by herbicides than those growing with less nitrogen.

One cannot determine if the effect of fertilizer was due to nitrogen, phosphorus, barnyard manure, or a combination of the three, as they were all used.

Roots of plants treated with amitrol weighed less than those treated with 2,4-D. This same relationship was true approximately one year after application of herbicides.

**Percentage dry weight of roots by harvests**

It is conceivable that changing the metabolic processes by application of herbicides could change the ratio of water to other substances
Table 3. Dry weight of roots of Canada-thistle plants in grams approximately one year after application of herbicides

<table>
<thead>
<tr>
<th>Soil</th>
<th>Herbicide</th>
<th>Irrigation</th>
<th>Fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>2,4-D</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Amitrol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Millville loam</td>
<td>20.0</td>
<td>13.3</td>
<td>15.7</td>
</tr>
<tr>
<td>Nibley silty clay</td>
<td>35.4</td>
<td>16.8</td>
<td>22.2</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>17.8</td>
<td>10.0</td>
<td>14.0</td>
</tr>
<tr>
<td>Gravely loam</td>
<td>25.6</td>
<td>18.7</td>
<td>10.1</td>
</tr>
</tbody>
</table>

Significant at .01 level
- Soil Herbicide
- Irrigation (1)
- Amitrol (2)
- Significant at .05 level
- Herbicide x irrigation (3)
- Herbicide x fertilizer

Average
- 15.6
- 15.4
- 15.5

---

*aSee page 13 for irrigation treatments.*

*b200 lbs. of N, 200 lbs. of P₂O₅, 20 tons of farm manure per acre.*
in the tissues of the roots. Therefore, the measure of percentage dry weight was used to determine if it was of value as a measure of a plant's reaction to herbicides.

At one harvest or another, all environmental factors resulted in significant differences in percentage dry weight of Canada-thistle roots (Table 1). However, in no case was there an interaction of any environmental treatment with herbicide. Even though differences in percentage dry weight due to environment existed, plants that had been treated with herbicides did not react differently to the environmental factors.

**Percentage of plants with no top regrowth at various dates**

Probably the most common measure used under field conditions to evaluate results of herbicidal application on creeping perennials is the absence of top regrowth. This may be expressed in various ways, such as percentage of plants killed, percentage of plants recovered, change in weed density, or merely the weed density at some time following the application of the herbicide.

Records were kept on the number of days after the herbicide was applied until new top regrowth appeared. From this data it was possible to determine the percentage of plants with no top regrowth at various dates. Dates used for determining percentage of plants with no top regrowth on Canada-thistle were as follows:

1. At the time herbicidal treated plants started to recover, which was 40 days after application of herbicides.
2. At 95 days after application of herbicides, when most of the herbicidal treated plants had recovered.
3. At the date of the third harvest, which was four months after
application of herbicides.

1. At the date of the last harvest, which was approximately one year after application of herbicides.

At the 40-day harvest, based on percentage of plants with no regrowth, herbicide and irrigation were significant at the 1 percent level (table 1). There were 87 percent of the plants treated with amitrol with no top regrowth at this harvest, as compared to 55 percent for those treated with 2,4-D. Likewise, there was 57 percent of the plants receiving irrigation 2 with no top regrowth compared to 80 percent and 77 percent for irrigation 1 and 3, respectively.

As will be shown later, the lower percentage of plants with no top regrowth for irrigation 2 on canada-thistle was opposite of what was obtained for field bindweed at the comparable harvest.

Percentage of plants with no top regrowth at 95 days, 4 months, and approximately one year after application of herbicides are listed in tables 4, 5, and 6. The three dates are considered together as they show approximately the same relationships for treatments.

Herbicide, irrigation, and herbicide x irrigation interaction were significant at the 1 percent level. Percentage of plants with no top regrowth was higher for amitrol than 2,4-D and for irrigation 1 and 3 than irrigation 2. An interaction of herbicide x irrigation occurred at all three dates. Percentage of canada-thistle plants with no top regrowth when treated with amitrol was relatively higher for irrigation 1 and 3 as compared with irrigation 2, whereas there was no difference due to irrigation when treated with 2,4-D.

There was a higher percentage of plants with no top regrowth at all dates on those treated with amitrol than 2,4-D. Difference between the
Table 4. Percentage of Canada-thistle plants with no regrowth 95 days after application of herbicides

<table>
<thead>
<tr>
<th>Soil</th>
<th>Herbicide</th>
<th>Irrigation⁸</th>
<th>Fertilizer⁹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2,4-D</td>
<td>Amitrol</td>
<td>1</td>
</tr>
<tr>
<td>Millville loam</td>
<td>0</td>
<td>67</td>
<td>50</td>
</tr>
<tr>
<td>Mibley silty clay</td>
<td>0</td>
<td>50</td>
<td>42</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>0</td>
<td>67</td>
<td>50</td>
</tr>
<tr>
<td>Gravely loam</td>
<td>0</td>
<td>70</td>
<td>50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>2,4-D</th>
<th>Amitrol</th>
<th>96</th>
<th>19</th>
<th>67</th>
<th>68</th>
<th>58</th>
<th>63</th>
</tr>
</thead>
</table>

Significant at .01 level
Herbicide (1) 46 50 48
Irrigation 19 0 9
Herbicide x irrigation

Significant at .05 level
None (3) 38 38 38

Average 34 29 32

⁸See page 13 for irrigation treatments.

⁹200 lbs. of N, 200 lbs. of P₂O₅, 20 tons of farm manure per acre.
Table 5. Percentage of Canada-thistle plants with no regrowth 4 months after application of herbicides

<table>
<thead>
<tr>
<th>Soil</th>
<th>Herbicide</th>
<th>2,4-D</th>
<th>Amitrol</th>
<th>Irrigationa</th>
<th>Fertilizerb</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Millville loam</td>
<td>0</td>
<td>58</td>
<td></td>
<td>38</td>
<td>12</td>
<td>38</td>
</tr>
<tr>
<td>Nibley silty clay</td>
<td>0</td>
<td>44</td>
<td></td>
<td>33</td>
<td>8</td>
<td>25</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>0</td>
<td>67</td>
<td></td>
<td>50</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>Gravely loam</td>
<td>0</td>
<td>70</td>
<td></td>
<td>50</td>
<td>17</td>
<td>38</td>
</tr>
<tr>
<td><strong>Herbicide</strong></td>
<td>2,4-D</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Amitrol</strong></td>
<td></td>
<td>85</td>
<td>19</td>
<td>75</td>
<td>61</td>
<td>58</td>
</tr>
</tbody>
</table>

Significant at .01 level
- Herbicide (1)
- Irrigation (2)
- Herbicide x irrigation (3)

Significant at .05 level
- None (3)

Average

---

aSee page 13 for irrigation treatments.
b200 lbs. of N, 200 lbs. of P₂O₅, 20 tons of farm manure per acre.
Table 6. Percentage of Canada-thistle plants with no regrowth approximately one year after application of herbicides

<table>
<thead>
<tr>
<th>Soil</th>
<th>Herbicide</th>
<th>Irrigationa</th>
<th>Fertilizerb</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Millville loam</td>
<td>0</td>
<td>58</td>
<td>25</td>
<td>8</td>
</tr>
<tr>
<td>Mibley silty clay</td>
<td>0</td>
<td>42</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>0</td>
<td>50</td>
<td>28</td>
<td>0</td>
</tr>
<tr>
<td>Gravely loam</td>
<td>17</td>
<td>58</td>
<td>25</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>2,4-D</td>
<td>0</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Amitrol</td>
<td>77</td>
<td>6</td>
<td>73</td>
</tr>
</tbody>
</table>

Significant at .01 level
- Herbicide
- Irrigation
- Herbicide x Irrigation

Significant at .05 level
- None

---

aSee page 13 for irrigation treatments.

b200 lbs. of N, 200 lbs. of P₂O₅, 20 tons of farm manure per acre.
two herbicides was apparent as early as 40 days after their application.

Soil moisture appeared to make Canada-thistle more susceptible to amitrol. This is shown by a significant interaction of herbicide x irrigation at all but the first date. Canada-thistle plants receiving irrigation 1 and 3 were more susceptible to amitrol than those receiving irrigation 2. One year after application of herbicides, only 23 percent of the plants treated with amitrol and receiving adequate moisture showed top regrowth, as compared to 94 percent when allowed to suffer from drought before and following the application of the herbicides (figure 4). A difference that great under field conditions could be the difference between success and failure. Therefore, it would appear worth while to treat Canada-thistle with amitrol when the soil is high in moisture.

Irrigation, as measured by top regrowth, appeared to have little or no effect on 2,4-D treated plants.

As will be shown later, a herbicide x irrigation interaction occurred, based on weight of tops and number of days for top regrowth to appear. This differential effect with amitrol, due to irrigation treatment, is of interest from the standpoint of absorption and translocation. However, from data provided by this experiment one cannot determine whether absorption, translocation, some other factors, or a combination of factors is responsible for the reduced effectiveness of amitrol on irrigation 2.

Irrigation treatments 2 and 3 were the same up to the time herbicides were applied. Cuticle thickness on leaves, wax content, and degree of stomatal openings should have been the same for plants receiving these two treatments. However, the response of amitrol treated plants receiving irrigation 2 was greatly different from those receiving
Figure 4a. Plants receiving irrigation 1.

Figure 4b. Plants receiving irrigation 2.

Figure 4c. Plants receiving irrigation 3.

Figure 4. Canada-thistle plants receiving various irrigations. Herbicidal treatments, left to right: amitrol, 2,4-D, control.
irrigation 3.

Skoss (1955) reported that stomates act as the major portal of entry for herbicides. Norman et al. (1950) thought cuticular diffusion to be the usual mode of entry. Currier and Dybing (1959) reported hydrated cuticles were more permeable to polar solvents than less hydrated ones. Since plants receiving irrigation 3 were watered soon after application of herbicides, one would expect changes in the leaf to occur. Among these changes would be hydration of the cuticle and opening of stomates due to increased turgidity of the leaf. These changes could have resulted in increased absorption of the herbicide, which could account for plants receiving irrigation 3 being more susceptible to amitrol than plants receiving irrigation 2.

Several workers, Hauser (1955), Palas (1959), Fisher et al. (1956), and Leonard (1956), determined that lower soil moisture reduced translocation of herbicides. It may have been that the reduced translocation was the main reason for reduced response of plants to amitrol on irrigation 2. However, some amitrol ended up in the roots of plants receiving irrigation 2, since 6 percent of the plants exhibited no top regrowth approximately one year after application of the herbicide. Also, when regrowth began, the leaves were chlorotic, which is the characteristic symptom of amitrol injury. Several of these chlorotic plants died back, only to make regrowth again at a later date.

These data indicate the need for keeping soil moisture high after treating Canada-thistle plants with amitrol.

Number of days for top regrowth at various dates

Results based on number of days for top regrowth to appear were similar to those for percentage of plants with no top regrowth, as the two criteria are related. The main difference between the two criteria
was that when based on percentage of plants with no top regrowth, significant differences due to various treatments were evident at the 40-day harvest, whereas 95 days was required when using number of days for top regrowth to appear (table 1).

Based on number of days for top regrowth, some environmental and herbicidal treatments showed differences at the various dates (table 1). There was a herbicide x irrigation interaction at the last three dates. The nature of this interaction was similar to that for percentage of plants with no regrowth. Number of days for top regrowth of canada-thistle plants to appear when treated with amitrole was relatively longer when they received irrigation 1 or 3, as compared to irrigation 2, whereas when treated with 2,4-D there was no difference due to irrigation.

**Dry weight of tops by harvests**

Absence of tops of treated plants is often used as a measure of herbicidal effects. These data are often expressed as an absence rating, or density. Dry weight of tops of plants was used in determining effects of herbicides to compare with weight of roots. It would be easier and faster to obtain top weight than root weight.

There were no differences in weight of tops, due to environmental factors, at the time herbicides were applied (table 1). Average dry weight of tops of canada-thistle at the time the herbicides were applied was 13.9 grams, compared to 15.7 grams for roots.

Top weights were not obtained for the 40-day harvest as new top growth was just beginning to be initiated.

At the 4-month and one-year harvests, herbicide was significant at the 1 percent level. A herbicide x irrigation interaction at the 4-month harvest was significant at the 5 percent level and approached
significance at the one-year harvest (tables 7 and 8). Tops of plants, at the 4-month harvest, which had not been treated with herbicides, weighed 7.6 grams compared to 7.2 grams for plants treated with 2,4-D and 1.5 grams for those treated with amitrol.

At the one-year harvest, there was a significant difference in top weight between controls and 2,4-D treated plants, as well as between the two herbicides. The interaction of herbicide x irrigation was due to the weight of tops being relatively lower on plants treated with amitrol that received irrigation 1 and 3 as compared with irrigation 2, whereas on those treated with 2,4-D there was no difference due to irrigation.

Using weight of tops as a measure of herbicidal damage, a difference due to herbicides was apparent at the 4-month harvest and showed amitrol to be the most effective, as was the case with weight of roots.

Data for top weight and root weight differed in the interactions that were significant. Root weight showed an interaction of herbicide x fertilizer, but top weight did not. Both top and root weight showed an interaction of herbicide x irrigation. For root weight this interaction was evident only at the 4-month harvest, whereas for top weight it also approached significance at the one-year harvest.

Field Bindweed

Basis of determining effects of environmental treatments on the susceptibility of field bindweed to 2,4-D and TBA were the same as those described for canada-thistle.

Treatments which were statistically significant, by dates, and measure used to evaluate effects of herbicides are listed in table 9. Only two significant interactions of herbicides with environmental treatments occurred, and both were with soils. Although differences due to environment existed, field bindweed did not react differently to
Table 7. Dry weight of tops of Canada–thistle plants in grams 4 months after application of herbicides

<table>
<thead>
<tr>
<th>Soil</th>
<th>Herbicide</th>
<th>Irrigation</th>
<th>Fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
<td>2,4-D</td>
<td>Amitrol</td>
</tr>
<tr>
<td>Millville loam</td>
<td>8.4</td>
<td>7.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Mibley silty clay</td>
<td>6.5</td>
<td>6.7</td>
<td>1.5</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>8.7</td>
<td>8.1</td>
<td>1.6</td>
</tr>
<tr>
<td>Gravely loam</td>
<td>6.8</td>
<td>6.6</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Herbicide (1)
Irrigation (2)
Herbicide x Irrigation (3)

Significant at .01 level  
Herbicide (1) 4.0 5.9 5.0
Significant at .05 level  
Herbicide x Irrigation (3) 5.1 5.4 5.2

Average 4.9 5.9 5.4

*See page 13 for irrigation treatments.

*b200 lbs. of N, 200 lbs. of P₂O₅, 20 tons of farm manure per acre.
Table 8. Dry weight of tops of Canada-thistle plants in grams approximately one year after application of herbicides

<table>
<thead>
<tr>
<th>Soil</th>
<th>Herbicide</th>
<th>Irrigation&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Fertilizer&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None 2,4-D</td>
<td>1 2 3</td>
<td>None Fertilized Average</td>
</tr>
<tr>
<td>Millville loam</td>
<td>16.0 10.5</td>
<td>8.2 11.3 8.4</td>
<td>11.9 8.3 10.3</td>
</tr>
<tr>
<td>Nibley silty clay</td>
<td>22.1 15.3</td>
<td>10.4 11.6 18.0</td>
<td>12.9 15.7 14.3</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>14.2 9.3</td>
<td>7.9 13.0 6.9</td>
<td>9.4 9.1 9.3</td>
</tr>
<tr>
<td>Gravely loam</td>
<td>21.6 9.2</td>
<td>11.2 7.8 10.6</td>
<td>9.8 12.0 10.9</td>
</tr>
</tbody>
</table>

|                     | None 2,4-D|                     |                      |
|                     | None      | 19.4 18.6 17.4      | 16.9 20.1 18.5       |
|                     | 2,4-D     | 9.2 9.9 17.1        | 12.3 9.9 11.1        |
|                     | Amitrol   | 2.0 8.8 1.3         | 3.8 4.2 4.0          |

Significant at .01 level
Herbicide

<table>
<thead>
<tr>
<th>Herbicide x irrigation approaches significance at .05 level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation (1)</td>
</tr>
<tr>
<td>(2)</td>
</tr>
<tr>
<td>(3)</td>
</tr>
</tbody>
</table>

Average 11.0 11.4 11.2

<sup>a</sup>See page 13 for irrigation treatments.

<sup>b</sup>200 lbs. of N, 200 lbs. of P<sub>2</sub>O<sub>5</sub>, 20 tons of farm manure per acre.
Table 9. A listing of all significant treatments on field bindweed

<table>
<thead>
<tr>
<th>Date</th>
<th>Percentage of plants killed</th>
<th>Dry weight of roots</th>
<th>Percentage dry weight of roots</th>
<th>Percentage of plants with no regrowth</th>
<th>Number of days to regrowth</th>
<th>Dry weight of tops</th>
</tr>
</thead>
<tbody>
<tr>
<td>When herbicides were applied</td>
<td>---</td>
<td><strong>Soil</strong></td>
<td>None</td>
<td>---</td>
<td>---</td>
<td>None</td>
</tr>
<tr>
<td>47 days after application of herbicides</td>
<td>---</td>
<td><strong>Soil</strong></td>
<td>#Soil</td>
<td><strong>Herbicide</strong></td>
<td>None</td>
<td>Not available</td>
</tr>
<tr>
<td>86 days after application of herbicides</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td><strong>Herbicide</strong></td>
<td>*<strong>Herbicide</strong></td>
<td>---</td>
</tr>
<tr>
<td>4 months after application of herbicides</td>
<td>Only 3 plants killed</td>
<td><strong>Fertilizer</strong></td>
<td>#Soil</td>
<td><strong>Herbicide</strong></td>
<td><strong>Herbicide</strong></td>
<td><strong>Herbicide</strong></td>
</tr>
<tr>
<td>Approx. one year after application of herbicides</td>
<td>#Irrigation</td>
<td><strong>Fertilizer</strong></td>
<td>#Irrigation</td>
<td><strong>Herbicide</strong></td>
<td><strong>Herbicide</strong></td>
<td><strong>Herbicide</strong></td>
</tr>
</tbody>
</table>

**Significant at the 1 percent level
*Significant at the 5 percent level
#Approaches significance at the 5 percent level
them. From the data it doesn't appear possible that one could manipulate field bindweed by the environmental treatments used to influence their susceptibility to herbicides.

**Percentage of dead plants by harvests**

There were no dead plants in the 47-day harvest, and only three in the 4-month harvest. About 10 percent of herbicidal treated plants were dead at the one-year harvest. Based on dead plants at the one-year harvest, irrigation approached significance at the 5 percent level (table 9). Only 2 percent of the herbicidal treated plants that received irrigation 2 were dead, compared to 7 percent for those on irrigation 3 and 17 percent for those receiving irrigation 1.

Dead plants used as a basis of measuring effects of environmental factors on a plant's reaction to herbicides would have been of no value except at the last harvest, and it was of little value then because of the low percentage of dead plants. There were no significant interactions of herbicides with environmental factors.

As very few dead plants appeared in any harvest, other measures were used to evaluate effects of herbicides on the plants.

**Dry weight of roots by harvests**

Field bindweed roots, when compared to canada-thistle, were generally smaller in diameter with many small laterals (figures 2 and 5).

As previously indicated, field bindweed plants to be harvested 47 days and 4 months after application of herbicides were moved into the greenhouse shortly after the herbicides were applied. All plants, even control receiving ample moisture, lost in root weight while they were in the greenhouse (figure 6).

Control plants and those treated with 2,4-D and left in the field
Figure 5. Roots of a field bindweed plant that was treated with 2,4-D. Note the many shoots arising just below ground level.
Figure 6. Dry weight in grams of roots of field bindweed plants receiving irrigation treatment 1
had higher root weights than those at the 4-month harvest, while those treated with TBA were about the same.

At the time herbicides were applied, soil and soil x fertilizer interaction were significant at the 1 percent level, and irrigation x fertilizer interaction was significant at the 5 percent level (table 9).

At the 47-day harvest soil was significant at the 1 percent level, and irrigation at the 5 percent level (table 9). Weight of roots receiving irrigation 2 was lower than those receiving irrigation 1 or 3. Evidently, plants that were allowed to go without watering until all top growth was dead suffered root damage. In 47 days their roots weighed only two-thirds as much as those that were kept moist during that time. A similar effect of irrigation on weight of roots was found on Canada-thistle.

At the 4-month harvest, fertilizer was significant at the 1 percent level, and soil and herbicide at the 5 percent level (table 9). Root weights of plants treated with 2,4-D were significantly lower than controls at the 4-month harvest, but such was not the case at the one-year harvest (table 10). Plants treated with TBA showed less change in weight of roots from the 4-month harvest to the one-year harvest than controls or those treated with 2,4-D.

Table 10. Dry weight of roots of field bindweed plants, in grams, for the last two harvest dates

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Harvest date</th>
<th>Percent difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4 months</td>
<td>one year</td>
</tr>
<tr>
<td>None</td>
<td>14.7</td>
<td>34.9</td>
</tr>
<tr>
<td>2,4-D</td>
<td>10.7</td>
<td>30.4</td>
</tr>
<tr>
<td>TBA</td>
<td>12.3</td>
<td>17.7</td>
</tr>
<tr>
<td>LSD at .05 level</td>
<td>3.0</td>
<td>8.0</td>
</tr>
</tbody>
</table>


At the one-year harvest soil, herbicide, and fertilizer were significant at the 1 percent level, and irrigation at the 5 percent level (table 9). Weight of roots of plants receiving irrigation 2 was higher than those receiving irrigation 1 or 3. This effect of irrigation was the opposite of what it was at the 47-day harvest.

While roots of plants treated with 2,4-D at the one-year harvest weighed about the same as control plants, those treated with TBA weighed about one-half as much (table 10).

Percentage dry weight of roots by harvests

At the 4-month harvest roots of plants treated with herbicides were lower in percentage dry weight than control plants. There were, however, no differences between the two herbicides. At the one-year harvest, percentage dry weight of roots treated with TBA was lower than control plants or those treated with 2,4-D.

The only environmental treatment that was significant was soil (table 9). It was significant at both the 47-day and 4-month harvests. Even though differences due to soil existed, plants treated with herbicides did not react differently to them.

Percentage of plants with no top regrowth at various dates

Dates used for determining percentage of plants with no top regrowth for field bindweed were slightly different from those for Canada-thistle and were as follows:

1. At the time herbicidal treated plants started to recover, which was 47 days after application of the herbicides.
2. At 86 days after application of the herbicides, when most of the herbicidal treated plants had recovered.
3. At the date of the third harvest, which was 4 months after application of the herbicides.
4. At the date of the last harvest, which was approximately one year after application of the herbicides.

At the 47-day harvest, based on percentage of plants with no top regrowth, herbicide and irrigation were significant at the 1 percent level. Fertilizer and irrigation x fertilizer interaction were significant at the 5 percent level (table 9). There were 89 percent of the plants treated with TBA with no top regrowth, compared to 74 percent of those treated with 2,4-D (table 11).

Table 11. Percentage of field bindweed plants with no top regrowth by dates.

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Days from application of herbicides</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>47 days</td>
</tr>
<tr>
<td>2,4-D</td>
<td></td>
</tr>
<tr>
<td>TBA</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td>89</td>
</tr>
</tbody>
</table>

Differences were significant at all dates.

There was a higher percentage of plants with no top regrowth on those that received irrigation 2 than irrigation 1 or 3. This reaction of field bindweed to irrigation 2, as compared with irrigation 1 and 3, was opposite to that for Canada-thistle at the comparable harvest.

The only significant treatment at the 86-day interval was herbicide and it was at the 1 percent level. A higher percentage of plants with no top regrowth occurred again on plants treated with TBA (table 11). Within 86 days after herbicides were applied, all the check plants allowed to go without watering until tops were dead had recovered. Eighty-five percent of the plants treated with 2,4-D and 58 percent of those treated with TBA had recovered in this same interval.

At the 4-month harvest herbicide was significant at the 1 percent
level and fertilizer at the 5 percent level. A higher percentage of plants with no top regrowth was again from those treated with TBA (table 11).

At the one-year harvest herbicide and soil x herbicide interaction were significant at the 1 percent level (tables 11 and 12). A higher percentage of plants with no top regrowth was from those treated with TBA.

Plants on Mibley silty clay loam and treated with 2,4-D had a higher percentage with no regrowth than those treated with TBA, whereas on the other soils the situation was reversed. This accounted for the significant soil x herbicide interaction.

Even though there was an interaction of herbicide with soils at the one-year harvest, there was a higher percentage of plants with no top regrowth at all dates on those treated with TBA than 2,4-D.

Using percentage of plants with no top regrowth as a measure of herbicidal damage, the difference in the two herbicides was apparent as early as 47 days after their application.

**Number of days for top regrowth at various dates**

Results based on number of days for top regrowth to appear were similar to those for percentage of plants with no top regrowth, as the two criteria are related. Percentage of plants with no top regrowth showed significant differences due to treatments as early as 47 days after application of herbicides, whereas using number of days for top regrowth, it required 86 days for significant differences to appear (table 9).

Only one of the environmental factors, namely soils, resulted in a significant interaction with herbicide. That interaction occurred only
Table 12. Percentage of field bindweed plants with no regrowth approximately one year after application of herbicides

<table>
<thead>
<tr>
<th>Soil</th>
<th>Herbicide</th>
<th>Irrigation(a)</th>
<th>Fertilizer(b)</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2,4-D</td>
<td>TBA</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Millville loam</td>
<td>6</td>
<td>42</td>
<td>25</td>
<td>11</td>
</tr>
<tr>
<td>Nibley silty clay</td>
<td>25</td>
<td>0</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>0</td>
<td>22</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Gravely loam</td>
<td>6</td>
<td>22</td>
<td>11</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>2,4-D</td>
<td>TBA</td>
<td>17</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>27</td>
<td>21</td>
</tr>
<tr>
<td>Significant at .01 level</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herbicide</td>
<td>(1)</td>
<td></td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>Soil x herbicide</td>
<td>(2)</td>
<td></td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>Significant at .05 level</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>(3)</td>
<td></td>
<td>11</td>
<td>4</td>
</tr>
</tbody>
</table>

\(a\)See page 13 for irrigation treatments.

\(b\)200 lbs. of N, 200 lbs. of P\(_2\)O\(_5\), 20 tons of farm manure per acre.
at the one-year harvest and was similar to that for percentage of plants with no top regrowth. Plants treated with TBA showed top regrowth sooner than those treated with 2,4-D on the Nibley silty clay loam, whereas it was reversed on the other soils.

**Dry weight of tops by harvests**

There were no significant differences in dry weight of tops at the time herbicides were applied (table 9). Average dry weight of tops of field bindweed at the time herbicides were applied was 17.6 grams, compared to 27.6 grams of roots.

At the 47-day harvest plants treated with herbicides, as well as the control allowed to dry down due to drought, were just beginning to show new top regrowth, so no weights were obtained at this harvest date.

At the 4-month harvest herbicide and fertilizer were significant at the 1 percent level. Weight of tops was higher on control plants than those treated with herbicides (table 13).

**Table 13. Dry weight of tops of field bindweed plants, in grams, for the last two harvest dates**

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Harvest date</th>
<th>4 months</th>
<th>one year</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>4.9</td>
<td>14.6</td>
<td></td>
</tr>
<tr>
<td>2,4-D</td>
<td>2.5</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>TBA</td>
<td>1.3</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>LSD at .05 level</td>
<td>1.2</td>
<td>4.5</td>
<td></td>
</tr>
</tbody>
</table>

At the one-year harvest herbicide was significant at the 1 percent level and irrigation at the 5 percent level (table 9). Again dry weight of tops was higher on control plants than those treated with herbicides (table 13). There was, however, no significant difference between the two herbicides in weight of tops.
Since the one-year harvest was assumed to supply the most reliable data, based on dry weight of tops, there was no significant difference between the herbicides. If data were taken only at the 4-month harvest, one would have drawn the wrong conclusion as to which herbicide was the most effective on field bindweed.
Canada-thistle and field bindweed were grown under several environmental conditions involving soil, irrigation, and fertilizer, and treated with certain herbicides. Harvests were made at four dates, three of which were after the application of the herbicides, to determine the earliest date the effects of herbicides could be accurately evaluated. Herbicides used on Canada-thistle were 2,4-D and amitrol and on field bindweed 2,4-D and TBA.

Canada-thistle at the 40-day and 4-month harvests and field bindweed at the 47-day and 4-month harvests were moved into the greenhouse shortly after application of herbicides. All plants, even controls receiving ample moisture, lost in dry weight while they were in the greenhouse.

By almost any measure used, it was determined that Canada-thistle plants were injured more by amitrol than 2,4-D and field bindweed more by TBA than 2,4-D.

The earliest date after application of herbicides that their effects could be accurately measured varied with criteria used to evaluate results.

Data obtained at the one-year harvest on Canada-thistle showed amitrol to have killed a higher percentage of plants than 2,4-D. On field bindweed there was no significant difference between the two herbicides on percentage of plants killed.

At the one-year harvest there were many plants with no top regrowth,
yet they had live roots. It would appear that even one year was not long enough for a complete evaluation of herbicidal effects.

Based on dry weight of Canada-thistle roots, differences between the two herbicides, 2,4-D and amitrol, could have been determined as early as the 4-month harvest. On field bindweed, differences between the herbicides, 2,4-D and TBA, could not have been determined at any date earlier than the one-year harvest. Data for the one-year harvest showed fertilized Canada-thistle plants to be more susceptible to herbicides than those not fertilized.

Based on dry weight of tops a difference between the two herbicides was evident as early as 40 days after their application on Canada-thistle and 47 days on field bindweed. Based on percentage of plants with no top regrowth, number of days to top regrowth, and weight of tops, Canada-thistle was affected by irrigations, so its reaction to amitrol was not the same. This indicated that one could expect better results from the application of amitrol on plants growing in soil of high moisture than low moisture.

Based on dry weight of tops, differences between the two herbicides on Canada-thistle could have been determined at the 4-month harvest. On field bindweed there was no difference between the two herbicides at the one-year harvest. If data had been taken only at the 4-month harvest, one would have concluded that 2,4-D was the most effective herbicide.

Data from these experiments indicate that interpretation of effects of environmental factors on the plant's response to herbicides vary with length of time after application of herbicides, measure used to evaluate effects of herbicides, and species involved.
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