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Responses of Oats and Barley to 2.4-Dichlorophenoxyacetic Acid (2.4-D)

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RESPONSES OF OATS AND BARLEY
TO
2,4-DICHLOROPHENOXYACETIC ACID (2,4-D)

By

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his is to certify that, in accordance with the requirements f South Dakota State College for the Master of Science Deree, Mr. Lyle A. Derscheid has presented o this committee three bound copies of an acceptable thesis, one in the major field; and has satisfactorily passed a twoour oral examination on the thesis, the major field, Agronomy, and the minor field, Chemistry.

Head of Major Department

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Date

Head of Minor Department

Rep. of Graduate Committee

TABLE OF CONTENTS

LIST OF TABLES

LIST OF PLATES AND FIGURES

REVIEW OF LITERATURE

At the time this experiment was initiated, there was much information concerning the effect of 2,4-D on weeds, but little on the effect of the growth-regulator on agronomic crops. Since that time, however, several agronomic and horticultural crops have been tested.

Marth and Mitchell (12) used 2,4-D to eliminate narrow-leaved plantain from Kentucky blue grass plots with no detrimental effects to the blue grass, nor to crab grass. Marth et al (13) increased the yield of Kentucky blue grass by controlling plantain with 2,4-D. This would indicate that grasses were tolerant and that broad-leaved plants were susceptible. Hamner and Tukey (6 and 7) and other workers (8,9,16,17 and 19) demonstrated that field bindweed and many other broad-leaved weeds could be eliminated or controlled with 2,4-D. Hanson (8) and Helgeson (9) and other workers (19) report that some broad-leaved plants are not eliminated by 2,4-D application, however. Ennis et al (4) states that 2,4-D may be of value for weed control in potatoes, a broad-leaved crop. Mitchell and Marth (15) demonstrated that various grass species differed in their tolerance to 2,4-D. They injured creeping bent grass with post-emergence applications, but did not damage Kentucky blue grass, red top or creeping red fescue.

It appeared that some strains or varieties of a species might be more susceptible to 2,4-D than others. Albrecht (1) treated 66 strains of bent grass with 2,4-D and concluded that a differential tolerance to this chemical existed. Other workers (17) verified this fact when they pointed out that certain flax varieties were tolerant to a small amount of 2,4-D, and that other varieties were not.

Weaver et al (22) proved that some plants were more susceptible at certain stages of growth than at others when he demonstrated that tomatoes and cabbage are tolerant or only slightly susceptible at certain stages of growth. Marth et al (14) concurred when they stunted timothy by applying two pounds of 2,4-D acid per acre on young timothy. Stahler (21) concluded that cereal crops were more susceptible at some stages of growth than others. Klingman (11) reported that spring wheat yields of weed-free grain were decreased by application of 1, 2, and 3 pounds of 2,4-D acid per acre on several stages of growth. The greatest decrease was obtained from plots treated in the early boot stage of growth. Spraying barley in the boot stage caused lodging. Spraying oats in the pre-joint stage caused the upper leaves to roll up and become stiff. Klingman (11) also states that wheat and barley may be treated with as much as three pounds of 2,4-D acid per acre before jointing without appreciable reduction in yield. Earlier application depressed yields significantly. Many sterile heads were produced from boot stage treatments, but other abnormalities such as twinning in barley heads (4 to 5 florets per rachis node) were caused by treating at or before the jointing stage of growth.

There is some indication that the viability of some crops may be affected by 2,4-D application. Hamner et al (5) reports that the germination and growth of many seeds are impaired when the seeds are planted in soil containing 1 p.p.m. 2,4-D acid. The grass seeds, one of which was wheat, seemed to be more resistant than the seeds from dicotyledonous plants. Allard et al (2) treated 25 seeds of each of several crops with 100 milliliter of solutions which varied in concentrations of .01 to 100 parts per million. Germination was retarded and reduced. The coleoptiles of wheat, oats, and barley became curved and amorphous gall-like growths were produced on the roots. Plumules had not developed in the cereal coleoptiles. When wheat, oats, barley and several other crops were planted in 2,4-D treated soil, the coleoptiles of the cereals were injured, and the roots were inhibited severely. Hsueth and Lou (10) also found that the germination of barley was affected by applying 2,4-D directly to the seed. Germination was speeded up by concentrations of 0.0035 and 0.007 per cent, retarded with a 0.07 per cent solution, and completely inhibited with a 0.10 per cent concentration. Rice germination, on the other hand, was not completely inhibited by any concentration, but was retarded by the two higher rates. Marth et al (13 and 14) report that the viability of Kentucky blue grass and timothy was not impaired, however, when 2,4-D was applied to the growing crop.

MATERIAL AND METHODS

The experiments were conducted on the Weed Control Research Farm located at Scotland, South Dakota. The soil has been classified as a Barnes silt loam. The area used for these experiments was uniformly covered with a relatively heavy stand of field bindweed (Convolvulus arvensis L.). Counts made the first of June in 1946 and 1947 reveal that there was an average stand of 12 to 18 field bindweed plants per square yard.

In 1946, square rod plots of oats and barley were treated with four formulations of 2,4-D when the cereals were in three different stages of growth. The 1947 plots consisted of drilled strips of nine oat varieties and eight barley varieties. Three formulations of 2,4-D were compared with "no treatment" at each of four stages of growth.

Three random square yard samples were harvested by hand and bulked from each square rod plot in 1946; whereas, samples were harvested by hand from the center two by eight-foot area of each plot in 1947. The samples were threshed with an Economy plot thresher and cleaned with a small hand operated Clipper fanning mill.

The grain was weighed to the nearest gram. Bushels per acre were calculated and the data were analyzed statistically. Test weight measurements were made to the nearest one-half pound per bushel. The small amount of seed obtained in 1946, made it necessary to use a small one-half pint test weight scale, but a pint-sized scale was used in 1947. A review of the 1946 test weight data revealed that large intra-sample as well as large inter-sample variations existed. These data were considered inaccurate and were not used. A statistical analysis was applied to the 1947 test weight data, however.

Four 100-seed samples were germinated from each plot each year. The germination samples were pre-chilled, in 1946, for 72 hours at 5° C. and then germinated for 8 to 9 days under a continuous temperature of 20° C. In 1947, the pre-chilling was omitted and all germination tests were allowed to remain at a constant temperature of 17° C. for 9 to 10 days. Samples with low readings were retested by pre-chilling at 5° C. for 72 hours and then germinated at 17° C. for 8 to 9 days. Readings were made for normal and abnormal seedlings and for dead seeds as prescribed in 1944 by the official seed analysts (18). The per cent of normal seedlings from the four 100-seed samples were averaged and analyzed statistically.

Four 100-seed samples from each 1946 plot and each 1947 oat plot were weighed to the nearest 0.001 gram. Time and facilities did not permit the weighing of the 100-seed samples from the 1947 barley plots. The average of the four weights was used in the statistical analysis.

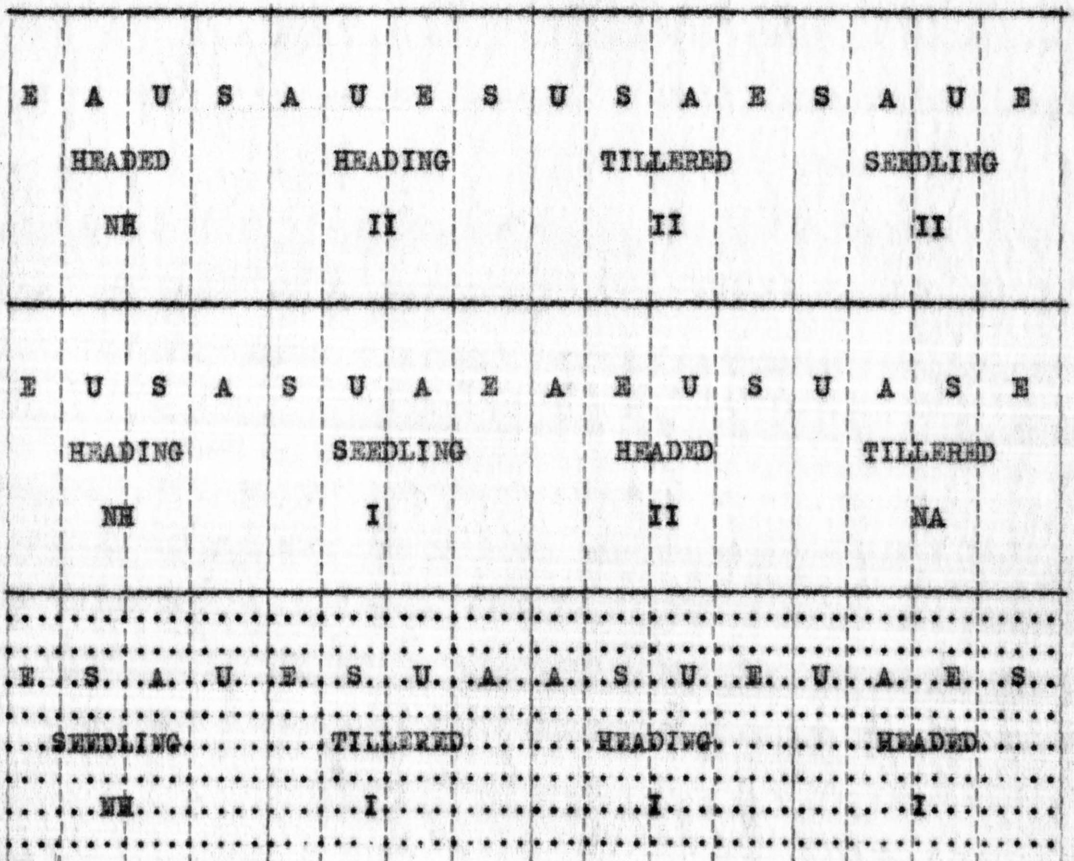
All statistical analyses were made as prescribed by Snedecor (20).

Field Plot Design

The 1946 field plot design consisted of a split plot of square-rod plots with stages of growth as the main effect and treatments as the secondary effect. Two replications were used for each crop in separate experiments.

Barley stands were good; whereas, a rather thin, but uniform stand of oats was utilized. Untreated data were taken from plots outside but adjacent to the experiments and were not included in the statistical analysis.

In 1947, however, a more complex field plot design was used for each crop separately. The experimental design shown in figure 1 is a factorial design in which varieties, treatments, and stages of growth are involved. In this particular lay-out, the variety and treatment effects were split,



Symbols:
- E- Ester
- S- Sodium salt
- A- Amine
- U- Untreated
- ---Border between treatments
- ...Border between varieties
- ___Border between stages of growth

Special symbols for barley experiment:
- I- Data analyzed as first replicate
- II- Data analyzed as second replicate
- NH- Block not harvested
- NA- Data obtained but not used in analysis

Figure 1. The field plot design used for each crop in 1947. The main plot effect, stages of growth, is random and the varieties and treatments are split. Varieties are shown in first replicate only. Three stages of growth in barley experiment were not harvested and the data from a fourth stage were not utilized.

while the main plot effect, stages of growth, was random. Three replications of each crop were treated.

Each variety was drilled in a four-foot strip, consisting of eight rows spaced six inches apart, the entire length of each 12-rod replicate. A one-foot space was left between varieties which were randomized for each replicate.

Each replicate was divided into four sections, each of which included a 48-foot portion of each variety. A three-foot portion of each variety was left at each end of the replicate as "filler". Each 48-foot section was treated at a different stage of growth, but was subdivided into four treatments. Three of the treatments were each a different formulation of 2,4-D and the fourth was an untreated check. Each of the 432 plots was four feet wide and twelve feet long. Samples were taken from the middle eight feet of the center two feet (4 rows) leaving a guard of one foot (2 rows) on each side and two feet on each end.

As shown in figure 1, the data of only two replications of barley were used in 1947. The stand on each of three stages of growth was materially affected because water stood on these blocks for some time during June. The data from the fourth stage of growth were not used, so that data from two complete replicates could be analyzed statistically.

Varieties

Richland oats and Wisconsin #38 barley were tested in 1946 and were included in the 1947 experiments along with Tama, Vikota, Clinton, Mindo, Bonda, Marion, Brunker, and Trojan oat varieties and Plains, Feebar, Kindred, Odessa, Spartan, Manchuria, and Tregal varieties of barley.

Although all oat varieties are common to South Dakota, it was thought that a varietal differential could possibly be traced genetically by using

Richland and two of its progeny, Tama and Vikota. Clinton, Bonda, and Mindo have one common parent and were used for the same reason.

Likewise, it would be possible to trace a hereditary differential by using the half-sister varieties Plains and Feebar and by using Wisconsin #38 and Kindred, the progeny of a sister selection. All other barley varieties are grown widely in South Dakota.

<u>Treatments</u>

A butyl ester and triethanol amine were used both years. An anhydrous sodium salt was used in 1946; but a monohydrate sodium salt, which had just come on the market, was used in 1947. The ammonium salt of 2,4-D was used in 1946, but was not used in 1947 because it was no longer commercially available.

A solution of 1000 p.p.m. of 2,4-D acid in water was applied at the rate of one gallon per square rod in 1946. This is equal to 1.3 pounds of 2,4-D acid in 160 gallons of water per acre. It was found that this was more 2,4-D than was needed to control field bindweed; consequently, only 1 pound of 2,4-D acid was applied in 80 gallons of water per acre in 1947. One rate of application was used for all stages of growth and treatments were made with a knapsack sprayer.

<u>Stages of Growth</u>

Treatments were made when the grain was heading, fully headed, and in the dough in 1946; whereas, the 1947 treatments were made on seedling, fully tillered, heading, and fully headed grain. The dough stage was omitted in 1947 as it was felt that this was an impractical stage to treat. The weeds would have damaged the crop by that time and ground application would also cause mechanical injury.

The seedling stage of growth was treated on May 14, 1947. When the cereal leaves were stretched upward, they reached a height of three to four inches. Most of the field bindweed was in the spring rosette stage of growth, but some of it had not yet emerged.

The fully tillered stage of growth was treated on June 5, 1947, when the small grain was 8 to 12 inches tall and the field bindweed vines were 4 to 8 inches long. Both crops and weeds were growing rapidly.

The heading stage of growth was treated on June 12, 1946, and June 20, 1947. The oats were 30% headed in 1946. Marion was 10% headed and all other varieties were 30 to 40% headed in 1947. Barley was 40% headed in 1946. Plains, Feebar and Spartan were 40 to 50% headed in 1947; whereas, Odessa, Kindred, and Tregal were only 30 to 35% headed and Wisconsin #38 and Manchuria were 20 to 25% headed. Field bindweed vines, which were entwined around cereal culms, had climbed up to a height of 16 to 18 inches and were beginning to bloom both years.

The fully headed stage of growth was treated on June 21, 1946, and June 25, 1947. Both cereals were completely headed each year. The later varieties were beginning to bloom. At this late stage, the field bindweed was entwined around the cereal culms and was about 50% in bloom.

The dough stage of growth was treated on July 1, 1946, when both crops were slightly past the soft dough stage of growth. The field bindweed had climbed to a height of 24 inches on the small grain stems and was beginning to set seed.

Climatological Data

Notes were taken on the clearness of the sky, brightness of the sun, and temperature; and estimates of the wind velocity were made for each date of treatment.

The sky was clear and the sun was bright for all three treatments in

1946, but the sky was cloudy for all four treatments in 1947. The temperature was 65° F. and there was no wind when the seedling stage of growth was treated in 1947. The fully tillered stage of growth was treated in 1947 when the temperature was 70° F. and the wind velocity was estimated to be 10 to 15 miles per hour. The heading and fully headed stages of growth were treated on both years when the temperature was 75° F. The wind velocity was less than 5 miles per hour in 1946, but about 10 miles per hour in 1947. The dough stage of growth was treated in 1946 when the temperature was 85° F. and there was no wind.

Rainfall data at Scotland are not available for years prior to 1946. Records were kept from May 15 to September 1, for 1946 and 1947, however. The U. S. Weather Station at Tyndall is located twenty miles from Scotland and has recorded weather data since 1904. It is expected that the amount of rainfall would be approximately the same. Table 1 shows, however, that there was some variation in 1946 and in 1947.

Table 1. The amount of rainfall received at Scotland and Tyndall, South Dakota for the months of March, April, May, June, and July of 1946 and 1947 and the 1904 to 1938 average reported at Tyndall for the same months.

Month	Amount of rainfall in inches				
	1946		1947		1904-38 average
	Scotland	Tyndall	Scotland	Tyndall	Tyndall
March	--	0.31	--	0.64	1.26
April	--	0.82	--	3.55	2.38
May*	2.50	3.89	2.20	1.96	3.92
June	3.60	3.56	9.30	8.05	3.26
July	1.00	1.13	1.05	1.30	3.11
Total for Tyndall		9.80	--	15.50	13.93

*Records kept at Scotland after May 15, only.

The 1904 to 1938 average of 13.93 inches for the months of March, April, May, and June is higher than the 9.80 inches received in 1946 and is slightly lower than the 15.50 inches that fell in 1947, as is shown in table 1. There was, however, an abundance of soil moisture at the beginning of the growing season each of the two years that this study was being conducted. There was sufficient moisture to produce a good crop. Aside from the fact that there was an abundance of soil moisture at the beginning of the growing season, the two years did not deviate from the average very far.

EXPERIMENTAL RESULTS

The Effect of 2,4-D on Field Bindweed

The field bindweed flowers closed by the end of the second day after being treated with any formulation of 2,4-D. The leaves were curled up by the end of the second day after being treated with an ester or an amine; whereas, from five to seven days were required to bring about the same results with the sodium or ammonium salts.

At harvest time, in 1946, field bindweed counts were made on three one-square-yard areas chosen at random from each square rod plot. No live plants were found on any plot. Counts were made again in July of 1947, and it was found that at least 95 per cent of the plants had been killed on every plot.

Estimates of the field bindweed stand on the 1947 experiments were made at harvest time. It appeared that a reduction in stand of about 65 to 70 per cent had been obtained on plots treated when the grain was in the seedling stage of growth. More satisfactory control appeared to have been obtained on plots treated at later dates. It appeared to be about equal for all treatments for all stages of growth for all varieties.

The Effect of 2,4-D on Oats

Field observations were made and several interesting effects could be detected visually. A statistical analysis was applied to yield, germination, and kernel weight data from each of two years, but test weight data were utilized for the second year only.

Visual Effects of 2,4-D on Oats

The leaves of oat plants that were treated with the anhydrous sodium salt in 1946, had turned slightly brown by harvest time as though the crop were suffering from a mild drought. This phenomena was not observed in 1947 when the monohydrate sodium salt was used.

An "onion top" effect was observed on all nine varieties one week after being treated as seedlings with the ester in 1947. The leaves curled inward tightly from both edges. Although this abnormality was most apparent one week after treatment, it was still present, to a lesser degree, at harvest time. Many of the abnormal sheathes produced two or more panicles. Plate 1 shows one of these plants as it appeared at harvest. Many plants of each variety produced a malformed joint after being treated with the ester when in the seedling stage of growth. One such plant is shown in plate 1. Culms could be broken quite easily at these brittle nodes.

Another interesting observation that was made at harvest time in 1947 was that the 2,4-D treated plots of Marion oats were free of crown rust; whereas, the untreated plots were quite badly diseased.

The Effect of 2,4-D on Yields of Oats

After studying the analysis of variance on yields, as shown in table 3 for 1946, and in table 5 for 1947, it would appear that the oat data for the two years did not agree. This is not the case, however.

A significant change in oat yields due to different treatments was

Plate 1. Abnormalities produced in oats when sprayed in the seedling stage with an ester formulation of 2,4-D. A shows two panicles that were produced from a single sheath. B shows a distorted joint.

not established in 1947, but a highly significant F-test was obtained in 1946. The least significant difference indicates in table 2 that the mean yield, obtained from plots treated with the ammonium salt, in 1946 were significantly higher than the mean yield obtained from plots treated with any of the other three formulations. Since there is no statistically significant difference among the mean yields for the other three treatments and since the ammonium salt was not used in 1947, the data from the two years are in complete agreement as far as the effect on yield by the ester, amine, and sodium salt of 2,4-D is concerned.

different chemicals reacted differently on different stages of growth in 1947. The least significant difference for this interaction reveals in table 4 that this difference is probably due to two facts. The mean yield from plots treated with the sodium salt is significantly higher than the mean yield of untreated plots for the seedling stage of growth, and the mean yield of ester treated plots is significantly lower than the mean yield of untreated plots for the fully tillered stage of growth. The conclusions are further substantiated by the fact that no significant difference exists among the average yields of untreated plots.

Table 4. The average yield of nine varieties of oats when treated with three formulations of 2,4-D and when not treated at four different stages of growth in 1947.

Stages of Growth**	Bushels per acre — Treatments*			
	Ester	Amine	Sodium	Untreated
Seedling	44.6	48.2	54.0	46.4
Tillered	41.8	45.9	44.0	49.1
Heading	45.7	48.7	50.3	46.6
Headed	48.1	47.3	50.2	51.4

* Least significant difference for the various treatments at any stage of growth is 6.6 at 5% level and 8.9 at 1% level.

**Least significant difference for various stages of growth for any treatment is 12.9 at 5% level.

Table 5. The analysis of variance of yields of nine oat varieties when treated with three formulations of 2,4-D and when not treated on four different stages of growth in 1947.

Source of variation	d.f.	Mean square	F
Stages of growth	3	374.14	1.01
Replication	2	1959.54	--
Error A	6	377.37	--
Treatments	3	400.22	2.92
Treat. X Stages	9	366.83	2.67*
Error B	24	137.28	--
Varieties	8	2982.13	22.57**
Var. X Stages	24	126.20	--
Var. X Treat.	24	63.29	--
Var. X Treat. X Stages	72	33.60	--
Error C	256	132.11	--
Total	431	--	--

* Significant at 5% level.

**Significant at 1% level.

Although the analysis of variance indicates in table 5 that there is a significant difference in yields of oat varieties, the non-significant F-tests for the interactions "varieties X treatments", "varieties X stages of growth", and "varieties X treatments X stages of growth" indicate that there was no varietal differential to treatments, nor to treatment at various stages of growth.

The Effect of 2,4-D on the Viability of Oats

Four 100-seed samples from each plot were germinated as prescribed by official seed analysts (18). The average per cent of normal seedlings from the four samples from each plot was used in the statistical analysis.

All of the F-tests from the analyses of variance for both years were non-significant indicating that significant changes in the germination percentage of oats were not caused by the use of the several 2,4-D formulations at the various stages of growth. Also no varietal difference due to treatment was found in the viability of the seed of nine varieties.

All germinations in 1946 and for Richland, Clinton, Bonda, Marion, Brunker and Trojan in 1947, were above 95 per cent. One plot of Mindo, that was treated in fully tillered stage of growth with the ester, had a low germination of 87 per cent. All other plots of Mindo had a germination reading of over 95 per cent. Vikota, likewise, had one untreated plot with a low germination reading of 78 per cent which brought the average of three replicates down to 89 per cent. When the germination reading of this plot is omitted from the averages, all mean germination percentages for this variety are above 93.5 per cent. The low reading on the one plot may be attributed to the characteristic dormant period that Vikota normally possesses. Tama also has a tendency to remain dormant for some time in the fall of the year, which may account for the erratic germination readings. All samples, that had a reading below 90 per cent, were retested by pre-chilling. These readings were almost exactly the same as the originals. The sodium salt and ester treated plots varied five or six per cent among the different stages of growth, but the untreated germinations also varied from 89.7 per cent to 95.6 per cent.

The Effect of 2,4-D on Test Weight of Oats

The method of measuring test weight in 1946 was considered inaccurate and the data are not presented. The test weight data obtained in 1947, however, were analyzed statistically.

The average test weight obtained from the nine oat varieties is given for each treatment at each stage of growth in table 6. The analysis of variance is shown in table 7. It will be noticed that a significant change in test weight due to treatments was not established, however, a highly significant F-test for stage of growth was obtained. Table 6 shows that the average test weight for the heading stage of growth is significantly higher at the one per cent point than the averages for the seedling and fully tillered stages of growth.

A highly significant F-test in table 7 for oats was obtained for the interaction "treatments X stages of growth" which would indicate that different treatments acted differently at different stages of growth in 1947. The least significant difference for this interaction indicates in table 6 that the test weight of oats treated with the ester when the grain is fully tillered is depressed, and that when the sodium salt is used, higher test weights are obtained from later dates of treatment. The validity of these statements is further enhanced by the fact that no significant differences in test weight exist for the several stages of growth of untreated plots.

Although a highly significant F-test was obtained for varieties, it was not demonstrated that a differential change in test weight was caused by treatment or by dates of treatment.

Table 6. The average test weight of nine oat varieties that have been treated with three formulations of 2,4-D and left untreated at four stages of growth.

Stage of Growth	Pounds per bushel				
	Treatment**				
	Ester	Amine	Sodium	Untreated	Average*
Seedling	30.5	31.7	31.3	31.3	31.2
Tillered	30.8	31.4	31.3	32.2	31.4
Heading	32.7	32.6	32.6	32.4	32.6
Headed	32.1	32.1	32.6	32.1	32.2

* Least significant difference for stages of growth is 0.75 at 5% level and 0.95 at 1% level.

**Least significant difference for treatments within a stage of growth is 1.35 at the 5% level and 1.83 at the 1% level.

Table 7. The analysis of variance of the test weight for nine oat varieties that have been treated with three 2,4-D formulations and left untreated at four stages of growth.

Source of variation	d.f.	Mean square	F
Stages of growth	3	47.04	11.73**
Replications	2	1.42	--
Error A	6	4.01	--
Treatments	3	4.82	--
Treat. X Stages	9	6.69	3.78**
Error B	24	1.77	--
Varieties	8	134.53	58.49**
Var. X Stages	24	3.51	1.52
Var. X Treat.	24	1.85	--
Var. X Treat. X Stages	72	1.53	--
Error C	256	2.30	--
Total	431	--	--

**Significant at 1% level.

The Effect of 2,4-D on Kernel Weight of Oats

Four 100-seed samples were weighed for each plot each year. The average weight of the four samples from each plot was used in the statistical analysis.

The average weights of 100 seeds for 1946 is presented in table 8. Changes in the weight of 100 seeds due to treatments or to treatment at different stages of growth was not established.

The average weight of 100 seeds for 1947 is presented in table 9 and

Table 8. The mean weights of 100 seeds of oats after being treated with four formulations of 2,4-D at three stages of growth and when left untreated in 1946.

Stage of Growth	Grams per 100 seeds				
	Treatments				
	Ester	Amine	Sodium	Ammonium	Untreated
Heading	2.513	2.615	2.573	2.534	--
Headed	2.519	2.673	2.541	2.446	--
Dough	2.443	2.538	2.540	2.506	--
Average*	2.492	2.609	2.551	2.495	2.506**

* No significant difference.
**Not included in statistical analysis.

the analysis of variance is set forth in table 10. Changes in kernel weight due to different treatments was not demonstrated. A significant F-test for "stages of growth" was obtained, however. The least significant difference indicates in table 9 that the average weight of 100 seeds was significantly higher from plots treated at the heading stage of growth than from plots treated at any other stage of growth.

A significant F-test was obtained for the interaction "treatment X stage of growth", which indicates that the various treatments did not react the same at all stages of growth. In table 9, it appears that the seed weight was depressed by the ester at the seedling, fully tillered, and fully headed stages of growth; whereas, the sodium salt appears to have depressed the

Table 9. The mean weight of 100 seeds of nine oat varieties after being treated with three formulations of 2,4-D and left untreated at four stages of growth in 1947.

Stage of Growth	Grams per 100 seeds				
	Treatments				
	Ester	Amine	Sodium	Untreated	Average*
Seedling	2.314	2.383	2.378	2.363	2.359
Tillered	2.338	2.350	2.352	2.368	2.352
Heading	2.437	2.443	2.386	2.380	2.411
Headed	2.337	2.364	2.375	2.366	2.360

* Least significant difference for stages of growth is 0.011 at 5% level and 0.015 at 1% level.
**Least significant difference between treatments for any one stage of growth is 0.022 at 5% level and 0.029 at 1% level.

kernel weight at the fully tillered stage of growth and the amine appears to have increased the kernel weight for the seedling and heading stages of growth.

There appears to be a highly significant difference in the weight of 100 seeds for the various varieties, but a differential response to treatment or to treatment at the various stages of growth was not demonstrated.

Table 10. The analysis of variance of the weight of 100 seeds for nine oat varieties when treated with three 2,4-D formulations and when not treated at four stages of growth in 1947.

Source of variation	d.f.	Mean square	F
Stages of growth	3	0.0093	5.47*
Replications	2	0.044	--
Treatments	3	0.026	1.53
Treat. X Stages	9	0.060	3.53*
Varieties	8	7.760	456.50**
Var. X Treat.	24	0.018	1.06
Var. X Stages	24	0.020	1.18
Var. X Treat. X Stages	72	0.020	1.18
Error	286	0.017	--
Total	431	--	--

* Significant at 5% level.
**Significant at 1% level.

The Effect of 2,4-D on Barley

Field observations were made and several interesting effects could be detected visually. Yield and viability data were analyzed statistically for each of the two years; whereas, the test weight data were utilized for 1947 and the kernel weight data were used for 1946.

Visual Effects of 2,4-D on Barley

The maturity of Wisconsin #38 was delayed in 1946 when treated with an ester formulation at any of the three stages of growth that were tested. The ester treated plots were much greener than plots treated with any other formulation or when left untreated. This was not observed in 1947.

Wisconsin #38 lodged quite badly after being treated with the ester kernel weight at the fully tillered stage of growth and the amine appears to have increased the kernel weight for the seedling and heading stages of growth.

There appears to be a highly significant difference in the weight of 100 seeds for the various varieties, but a differential response to treatment or to treatment at the various stages of growth was not demonstrated.

Table 10. The analysis of variance of the weight of 100 seeds for nine oat varieties when treated with three 2,4-D formulations and when not treated at four stages of growth in 1947.

Source of variation	d.f.	Mean square	F
Stages of growth	3	0.0093	5.47*
Replications	2	0.044	--
Treatments	3	0.026	1.53
Treat. X Stages	9	0.060	3.53*
Varieties	8	7.760	456.50**
Var. X Treat.	24	0.018	1.06
Var. X Stages	24	0.020	1.18
Var. X Treat. X Stages	72	0.020	1.18
Error	286	0.017	--
Total	431	--	--

* Significant at 5% level.
**Significant at 1% level.

The Effect of 2,4-D on Barley

Field observations were made and several interesting effects could be detected visually. Yield and viability data were analyzed statistically for each of the two years; whereas, the test weight data were utilized for 1947 and the kernel weight data were used for 1946.

Visual Effects of 2,4-D on Barley

The maturity of Wisconsin #38 was delayed in 1946 when treated with an ester formulation at any of the three stages of growth that were tested. The ester treated plots were much greener than plots treated with any other formulation or when left untreated. This was not observed in 1947.

Wisconsin #38 lodged quite badly after being treated with the ester at the heading stage of growth in both years. After Odessa had been treated with the ester at the heading stage of growth in 1947, it not only lodged badly, but many plants broke off at the lower nodes.

Abnormal spikes were produced by all barley varieties after being treated with 2,4-D in the seedling stage of growth in 1947. The malformations were not observed until the spikes tried to emerge from the boot. The collar of the sheath appeared to be so constricted that only the awns could emerge. The peduncle elongated normally, exerted enough force to break through the side of the sheath, and drew the previously emerged awns back through the collar. The awns remained bent and sterile

Plate 2. Abnormal plants of barley that were treated as seedlings with an ester formulation of 2,4-D in 1947.

florets were observed. Plate 2 shows the malformation as it appeared at harvest time. This abnormality was exhibited by 80 per cent of the plants that were treated with the ester; whereas, only 60 per cent were affected by the amine, and 40 per cent were injured by the sodium salt. There was no varietal difference that could be detected.

The Effect of 2,4-D on Barley Yield

As in oats, the barley yield data for the two years are in very close agreement.

The significant F-tests for treatments, as shown in table 12 for 1946 and table 14 for 1947, indicate that only one time out of twenty should such large differences in yield of the various treatments be expected to occur by chance alone. The least significant difference obtained reveals in table 11 for 1946 and table 13 for 1947 that the mean yield from ester treated plots is significantly lower than the mean yield from plots from any other treatment. When the ester was applied at the fully tillered stage of growth in 1947, the resulting yield was equal to that obtained from untreated plots, however.

Table 11. The mean yields of barley when treated with four formulations of 2,4-D at three different stages of growth and when not treated in 1946.

Stages of Growth	Bushels per acre				
	Treatments				
	Ester	Amine	Sodium	Ammonium	Untreated
Heading	19.45	39.65	32.75	35.15	--
Headed	33.60	36.85	32.75	40.20	--
Dough	37.15	40.40	42.95	36.30	--
Average*	30.07	38.97	36.15	37.22	42.40**

* Least significant difference is 4.9 at 5% level and 7.0 at 1% level.

**Not included in statistical analysis.

A significant change in yield of barley due to treatment at various stages of growth was not established in 1946, but a highly significant

F-test was obtained in 1947. Although the data from the two years appear to conflict, the significant difference obtained in 1947 indicates in table 13 that the mean yield for treatment at the fully tillered stage of growth is significantly higher than the mean yield for treatment at any other stage of growth. The fully tillered stage of growth was not treated in the 1946 experiment and the untreated yields, which were not included in the statistical analysis, appear to be higher than the yields from any of the treated plots. This would indicate that the yield may have been depressed by all treatments at all stages of growth in 1946. This would not conflict with the 1947 data.

Table 12. Analysis of variance for yields of barley when treated with four different formulations of 2,4-D at three stages of growth in 1946.

Source of variation	d.f.	Mean square	F
Stages of growth	2	161.30	9.96
Replication	1	11.48	--
Error A	2	16.19	--
Treatments	3	287.30	20.68**
Treat. X Stages	6	78.80	5.60*
Error B	9	13.89	--
Total	23	--	--

* Significant at 5% level.
**Significant at 1% level.

It is possible that the weed control may have affected the 1947 results. The field bindweed was not satisfactorily controlled for the seedling stage of growth and the control obtained for the heading and fully headed stages of growth may have been after the weed had depressed the yield. Consequently, the mean yield from the fully tillered treatments was significantly higher than for any other stage of growth. This does not seem probable, however, since there was more than average seasonal rainfall that year. It is probable that there was sufficient precipitation to produce a good crop even though there was a relatively heavy stand of field bindweed.

Table 13. The mean yields of eight barley varieties after being treated with three formulations of 2,4-D and not treated at four stages of growth in 1947.

Stage of Growth	Bushels per acre				
	Treatments				
	Ester	Amine	Sodium	Untreated	Average**
Seedling	26.5	25.6	31.2	31.8	28.8
Tillered	31.8	35.8	35.9	31.9	34.1
Heading	22.5	31.4	30.1	30.2	28.5
Headed	24.8	33.5	28.9	28.6	28.9
Average*	26.4	31.5	31.5	30.6	--

* Least significant difference for treatments is 3.1 at 5% level and 4.4 at 1% level.

**Least significant difference for stages of growth is 2.4 at 5% level and 4.2 at 1% level.

Table 14. The analysis of variance of yield of eight barley varieties after being treated with three formulations of 2,4-D and when not treated at four stages of growth in 1947.

Source of variation	d.f.	Mean square	F
Stages of growth	3	429.74	34.52**
Replications	1	0.16	--
Error A	3	12.45	--
Treatments	3	384.15	5.83*
Treat. X Stages	9	113.20	1.72
Error B	12	65.85	--
Varieties	7	307.07	8.40**
Var. X Stages	21	68.76	1.88*
Var. X Treat.	21	36.29	--
Var. X Treat. X Stages	63	34.74	--
Error C	112	36.54	--
Total	255	--	--

* Significant at 5% level.

**Significant at 1% level.

A significant F-test for the interaction "treatments X stages of growth" was obtained in 1946 but not in 1947. This would indicate that different chemicals reacted differently on different stages of growth in 1946 but not in 1947. The mean yields presented in table 11 indicate that this difference is probably due to the high yield obtained when the sodium salt was applied on the dough stage of growth and to the yields from the ester treated plots, which increased with the later dates of treatment.

Table 15. The yield of each of eight barley varieties that were treated with three formulations of 2,4-D and left untreated for each of four stages of growth in 1947.

Variety	Bushels per acre			
	Stage of growth*			
	Seedling	Tillered	Heading	Headed
Plains	29.7	31.8	28.1	27.9
Feebar	30.1	39.3	36.7	33.0
Odessa	33.4	34.3	26.9	26.4
Spartan	25.6	26.6	26.8	28.4
Kindred	27.7	30.2	25.5	28.0
Tregal	34.0	35.2	32.7	31.2
Wisconsin #38	24.6	39.2	29.6	32.2
Manchuria	24.7	34.1	22.4	22.4

* Least significant difference for each variety at various stages of growth is 5.99 at 5% level and 7.91 at 1% level.

A significant difference in the yields of the eight barley varieties was obtained in 1947. It was not established that a differential tolerance to treatments existed, but a significant F-test for the interaction "varieties X stages of growth" indicates that the yield of some varieties is affected by 2,4-D application at certain stages of growth. The data in table 15 indicate that Feebar produced significantly higher yields for the fully tillered stage than for the seedling or heading stage, while Odessa produced significantly higher yields for the fully tillered stage than for heading and fully headed stages. Wisconsin #38 and Manchuria, however, had significantly higher yields for the fully tillered stage than for any other stage. No apparent differences existed for the remaining four varieties.

The Effect of 2,4-D on the Viability of Barley

Four 100-seed samples from each plot were germinated. The average per cent of normal seedlings from the four samples of each plot was used in the statistical analysis. Two years' data are presented.

As in oats, a significant change in the viability of barley due to treatment or to treatment at various stages of growth was not observed in either year.

The analysis of variance as shown in table 16 indicates that all varieties did not germinate the same. A significant F-test was obtained in 1947 for the interaction "varieties X stages of growth" indicating that the germination of some varieties is affected at certain stages of growth. This is shown on table 17.

Table 16. The analysis of variance of the germination of eight barley varieties that were treated with three 2,4-D formulations and left untreated at four stages of growth in 1947.

Source of variation	d.f.	Mean square	F
Stages of growth	3	4.2	--
Replications	1	45.6	--
Error A	3	5.1	--
Treatments	3	28.2	3.24
Treat. X Stages	9	10.0	1.15
Error B	12	8.7	--
Varieties	7	95.5	32.26**
Var. X Stages	21	8.7	2.94**
Var. X Treat.	21	3.0	1.01
Var. X Treat. X Stages	63	8.3	2.80**
Error C	112	2.96	--
Total	255	--	--

**Significant at 1% level.

Table 17. The average germination percentage of each eight barley varieties that have been treated with three formulations of 2,4-D and left untreated at four stages of growth in 1947.

Variety	Per cent Germination Stage of Growth*			
	Seedling	Tillered	Heading	Headed
Plains	91.0	89.6	91.1	92.2
Feebar	90.2	91.0	91.8	92.7
Odessa	92.2	93.1	89.4	92.9
Spartan	89.1	86.5	89.2	88.7
Tregal	87.8	88.4	89.9	89.4
Kindred	91.6	92.6	92.2	91.0
Wisconsin #38	91.2	94.1	90.1	93.7
Manchuria	90.9	91.4	90.4	90.2

* Least significant difference among stages of growth for any one variety is 2.85 at 5% level and 4.87 at 1% level.

By applying the least significant difference it is seen that the viability of Odessa and Wisconsin #38 is significantly higher for the fully tillered stage than for the heading stage. Wisconsin #38 is also higher than for the seedling stage. Wisconsin #38 was not treated for the two earlier stages in 1946; consequently, this depression was not observed. The fact that the ester caused these two varieties to lodge in the heading stage indicates that they were affected. A difference in the remaining six varieties was not apparent, although the F-test for the interaction "varieties X treatments X stages of growth" was significant.

The Effect of 2,4-D on the Test Weight of Barley

The method of measuring test weight in 1946 was considered inaccurate and the data are not presented. The data obtained in 1947, however, were analyzed statistically, and are presented here.

The analysis of variance shown in table 19 indicates that a highly significant difference in the test weight of barley was caused by treatments. The least significant difference indicates in table 18 that the test weight from the ester treated plots is significantly lower than that from untreated plots. The test weight from the amine and sodium salt treated plots is not significantly different from that of the untreated plots.

Table 18. The average test weight of eight barley varieties that were treated with three formulations and left untreated at each of four stages of growth in 1947.

Stage of Growth	Pounds per bushel				
	Treatment***				
	Ester	Amine	Sodium	Untreated	Average**
Seedling	45.6	46.8	47.5	47.3	46.1
Tillered	47.4	48.3	48.3	47.7	47.9
Heading	47.0	48.7	48.7	47.3	47.9
Headed	48.0	47.8	48.5	48.2	48.1
Average*	47.0	48.2	47.9	47.6	--

* Least significant difference for treatments is 0.44 at the 5% level and 0.62 at the 1% level.

** Least significant difference for stages of growth is 0.83 at the 5% level and 1.52 at the 1% level.

***Least significant difference for one treatment at the various stages of growth is 0.88 at 5% level and 1.23 at 1% level.

Table 19. The analysis of variance for the test weight of eight barley varieties that were treated with three formulations of 2,4-D and left untreated at four stages of growth in 1947.

Source of variation	d.f.	Mean square	F
Stages of Growth	3	24.17	11.14*
Replications	1	0.19	--
Error A	3	2.17	--
Treatments	3	17.34	13.24**
Treat. X Stages	9	4.09	3.12*
Error B	12	1.31	--
Varieties	7	95.10	74.88**
Var. X Stages	21	1.97	1.55
Var. X Treat.	21	1.58	1.24
Var. X Treat. X Stages	63	1.69	1.33
Error C	112	1.27	--
Total	255	--	--

* Significant at 5% level.
**Significant at 1% level.

A significant F-test was obtained in table 19 for stages of growth. The least significant difference indicates in table 18 that the test weight of barley from plots treated in the seedling stage of growth was significantly lower than the test weight from plots treated at other stages of growth. This significance may have been caused by the fact that the field bindweed was not satisfactorily controlled and was competing for the limited amount of soil moisture that was available when the kernels were filling. It is also possible that the head damage shown in plate 2, may have caused a depression in test weight. More of these malformed spikes were caused by the ester than the amine, which caused more injury than the sodium salt. The test weight follows this same trend with the ester being the lowest, followed by the amine and sodium salt in that order. The sodium salt test weight is about equal to the untreated.

A significant F-test was also obtained for the interaction "treatment X stage of growth" indicating that different treatments reacted differently at the various stages of growth. Table 18 indicates that this interaction was due to the depressions in test weight by the treatment of the seedling stage with the ester and the amine and by treatment of the heading stage with the ester.

A highly significant difference among varieties is indicated, but a differential change in test weight as a result of using the various treatments was not demonstrated, nor was it established that dates of treatment influenced the test weight.

The Effect of 2,4-D on the Kernel Weight of Barley

Four 100-seed samples were weighed for each plot for 1946, but due to lack of time and facilities these data were not obtained in 1947. The average weight of the four samples from each 1946 plot was used in the statistical analysis. All F-tests were non-significant which would indicate that the kernel weight of one barley variety was not significantly affected in 1946 by the use of any of the four formulations of 2,4-D at any of the three stages of growth. The average weight of 100 seeds is presented in table 20 for the various treatments at the various stages of growth.

Table 20. The average weight of 100 seeds of barley after being treated with four formulations of 2,4-D at three stages of growth and when not treated in 1946.

Stages of Growth	Grams per 100 seeds				
	Treatment				
	Ester	Amine	Sodium	Ammonium	Untreated
Heading	3.055	3.464	3.301	3.207	--
Headed	3.583	3.311	3.123	3.182	--
Dough	3.530	3.366	3.252	3.185	--
Average*	3.389	3.380	3.227	3.191	3.245**

* No significant differences.

**Not included in statistical analysis.

DISCUSSION

Oats

The results of this study of oats are very similar to those reported by Klingman (11), who wrote that oats was more tolerant of 2,4-D than barley or wheat. He stated that when oats was treated in the pre-joint stage of growth, the upper leaves rolled up and became stiff. A similar "onion-top" effect was obtained on nine varieties when an ester was applied to the seedling stage of growth. It was not established, however, that this effect had any influence on yield, viability, test weight, or kernel weight.

The results of this study would indicate that yield and viability of oats are not depressed by any 2,4-D formulation at any stage of growth. This does not agree with unpublished data obtained by L. M. Stahler and the writer in 1947. Ninety-nine plots of bindweed infested Boone oats were treated with 2,4-D when the grain was 30 to 40 per cent headed. Yields from treated plots were 15 to 20 per cent lower than yields from untreated plots. The viability of the seed from the treated plots was not affected.

It appears that yields of bindweed infested oats may have been increased by treatment with 2,4-D in 1946, but no increase was obtained in 1947. These conflicting results may have been caused by the differences in rainfall and stands of oats obtained. The below average seasonal rainfall received in 1946, may have been insufficient to produce a good crop on a relatively heavy stand of field bindweed; consequently, the treated plots, where the weed was controlled, produced the higher yields. The thin stand of oats in 1946 did not offer much competition to the weed. An increase in the yield was, therefore, obtained when the weed was controlled. In 1947, however, the above average seasonal rainfall and the thicker stand of oats permitted the crop to compete more successfully with the bindweed. Consequently, the yield was not significantly increased by controlling the weed with 2,4-D.

The different forms of 2,4-D did not influence the test weight or the kernel weight of oats. Kernel weight was not affected by treatment at different stages of growth in 1946, but kernel weight and test weight were both depressed by treatment at certain stages of growth in 1947. The test weight was not measured in 1946. A significantly higher kernel weight was obtained from plots that were treated at the heading stage of growth than from plots treated at any other stage of growth. The test weight from plots treated at the heading stage of growth was not significantly different from that of plots treated at the fully headed stage, but was significantly higher than that of plots treated at the seedling and fully tillered stages. A stimulation of growth in plots treated at the fully tillered stage may have caused the production of more seed than could fully mature in the rain-free period that existed during the last two weeks of the growing season. This stimulation in growth may have been produced by the more favorable moisture conditions that prevailed after the weeds were controlled with treatments made at the fully tillered stage. Since other physiological effects have been produced by the action of 2,4-D, it is, however, more likely that such a stimulation may be attributed to the action of the chemical.

A differential response of varieties to treatments or to dates of treatment was not demonstrated in yield, viability, test weight, or kernel weight.

Barley

Although Klingman (11) does not report the yields, viability, test weight or kernel weight of barley, many of his observations are similar to those made in this study. He states that as much as three pounds of 2,4-D acid per acre may be applied to weed-free barley at the pre-joint stage of growth without appreciable decrease in yield and infers that this is the most tolerant stage. In this study, abnormal spikes were produced by treating at a similar stage of growth, but this stage was not the most tolerant stage for treating bindweed infested barley.

Although the test weight was, in general, depressed by treatment at the seedling and fully tillered stages of growth, the yield and viability data indicate that certain varieties are more tolerant to 2,4-D at the fully tillered stage. Other varieties are, in general, equally tolerant at all stages. The yield of Feebar was significantly higher from plots treated at the fully tillered stage of growth than from plots treated at the seedling or heading stages. Odessa, also produced a high yield from plots treated at the fully tillered stage. This yield was significantly higher than from plots treated at either of the later stages. The yields of Wisconsin #38 and Manchuria also were high from plots treated at the fully tillered stage. They were significantly higher than those from plots treated at any other stage.

Plants of Odessa and Wisconsin #38 treated at the fully tillered stage produced a higher number of viable seeds than when treated at certain other stages. The viability of Odessa was depressed by treating at the heading stage, while that of Wisconsin #38 was decreased by treating at both the heading and seedling stages.

It is not clear why these varieties have responded as they have. The large number of immature seeds produced by plants of Feebar, Odessa, Wisconsin #38, and Manchuria after being treated at the fully tillered stage of growth, however, indicate that profuse tillering may have been induced at that stage. Excessive tillering, followed by the rain-free period that existed during the last ten days of the growing season, may have caused the production of more seed than could fully mature. This would explain the high yields and low test weights obtained from plots of Odessa, Feebar, Wisconsin #38, and Manchuria that were treated at the fully tillered stage of growth.

This extensive tillering may have been the result of weed control, but it is possible that the chemical produced some physiological effect on the barley plant.

The early and effective weed control obtained by treating at the fully tillered stage of growth may have created more favorable moisture conditions. It is possible that these four varieties were able to take better advantage of these moisture conditions than the other varieties. In view of the fact that the control of field bindweed in barley with 2,4-D has, in general, not affected the yield of the crop, this explanation does not seem probable.

Klingman (11) reports that twinning of florets was caused by treating with 2,4-D at the pre-joint stage of growth. In this study, malformed spikes were produced by treating plants at the seedling stage and two varieties lodged after being treated with the ester at the heading stage. It is reasonable to expect that a physiological effect may also have been produced by treating at the fully tillered stage of growth.

The viability of Odessa and Wisconsin #38 was reduced by treating at the heading stage of growth. Both varieties lodged badly after being treated with the ester at this stage, indicating that the chemical produced some effect upon the plant. It is, therefore, probable that the depression of viability was a result of this effect.

When treatments are considered alone, it is seen that the yield and test weight from ester treated plots were significantly lower than those from untreated plots. The yield and test weight from plots that received treatment with other 2,4-D formulations were not significantly different from those of untreated plots. This would indicate that the ester was more injurious to barley than the other formulations. The yield, however, was not depressed by applying the ester at the fully tillered stage.

Although it cannot be proven in this study that the responses obtained are directly attributable to the action of 2,4-D on the plant, the evidence presented indicate that such action was, at least, partially responsible. The evidence also indicate that some of the effects produced by the chemical may be attributed to the ester formulation.

Four varieties showed a similar differential response to 2,4-D. They have dissimilar parentage making it improbable that they would contain the same genetic factor effecting the response.

SUMMARY

An attempt was made to determine the effect of various 2,4-D formulations on yield, viability, test weight, and kernel weight of oats and barley when infested with field bindweed. Richland oats and Wisconsin #38 barley were tested in 1946. In 1947, the experiment was amplified to include an additional eight oat and seven barley varieties. The butyl ester, triethanol amine, and sodium salt forms were applied at stages of growth ranging from the seedling stage to the soft dough stage.

1. The yield, viability, test weight, and kernel weight of bindweed infested oats was not depressed by using one pound or slightly more 2,4-D acid per acre in the butyl ester, triethanol amine,

and sodium salt forms.

2. The yield and viability of oats were not affected by applying 2,4-D at the seedling, fully tillered, heading, fully headed, and soft dough stages of growth. The test weight was depressed when treatments were applied to seedling and fully tillered stages. The kernel weight was depressed by applying 2,4-D to the seedling, fully tillered, and fully headed stages of growth.
3. Richland, Vikota, Tama, Clinton, Mindo, Bonda, Marion, Brunker, and Trojan appear to be equally tolerant to 2,4-D treatments of one pound or less 2,4-D acid per acre when applied at the various stages of growth that were treated.
4. Significant depressions in yield and test weight of barley were obtained from plots treated with the ester formulation; whereas, other forms of 2,4-D did not affect these factors.
5. The yield of Feebar, Odessa, Wisconsin #38, and Manchuria was significantly higher when treated at the fully tillered stage of growth than when treated at certain other stages. There was no apparent effect on the yield of Plains, Spartan, Tregal, and Kindred when treatments were made at different stages of growth.
6. The viability of Odessa and Wisconsin #38 was significantly higher when treated at the fully tillered stage of growth than when treated at certain other stages. The viability of the other varieties tested did not appear to be affected by treating at different stages of growth.
7. The test weight of barley was lower from plants treated as seedlings than from plants that were treated at later stages of growth.

8. Oats was, in general, more tolerant of 2,4-D than barley.

The results of this study indicate that 2,4-D, when properly applied, will control field bindweed in oats and barley without decreasing the yield of the crop.

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