AN ABSTRACT OF THE THESIS OF

FRANCIS H. MC NEAL For the M. S. in Farm Crops

Date Thesis Presented March 1948

Title THE EFFECT OF 2,4-D ON GROWTH AND DEVELOPMENT OF SMALL GRAIN AND ON CERTAIN ANNUAL WEEDS

Abstract Approved [redacted]

Major Professor

As the result of an effective advertising campaign, 2,4-D was widely accepted when it was first introduced to the American farmer in 1944. Very little was known about this material, and many research workers designed and completed experiments in a short time in order to provide farmers with answers as to what effect 2,4-D has on weeds. Since 1944 there has been considerable research work done on the effect of 2,4-D to weeds, but there has been very little work done on the effect of 2,4-D to small grain plants.

The author wishes to point out certain injuries to small grain plants from use of 2,4-D, as well as agree with many workers on its ability to control certain broad-leaved weeds.

Investigations were carried on to determine if agronomic characters of small grain and certain weed plants are affected by use of 2,4-D. Preliminary field work was carried on at the Union Experiment Station during the summer of 1946. During the winter of 1946-47, experiments were conducted in the Oregon State College greenhouse on the effect of 2,4-D to small grain seedlings. Results of this preliminary work provided the basis for a more comprehensive field experiment conducted in 1947 on a farm near Pendleton, Oregon. All applications of 2,4-D were made at the rate of one pound of parent acid per acre,

except that at Pendleton an additional experiment was carried on using different rates of application. These rates varied in half pound amounts from 1.5 to 4.0 pounds.

Experimental work conducted by the author in 1946 and 1947 shows clearly that 2,4-D causes injury to small grain plants. A statistical analysis of yield data obtained in 1947 shows yields from treated plots to be significantly lower than yields from untreated plots. In this experiment, a uniform weed population of about one plant to every four square feet was present.

In addition to observing the depressing effect on yield, the effect on other agronomic characters was also noted. Plant height was generally reduced as a result of using 2,4-D. Test weight and date of first heading did not seem to be materially affected. Germination of grain from treated plants was not affected by the 2,4-D materials. Protein content of grain (nitrogen calculated to protein) from plants treated at the rate of one pound of parent acid per acre did not vary much from the protein content of grain from untreated check plots. However, grain from plots treated with 1.5 to 4.0 pounds of parent acid per acre showed an average increase of approximately one per cent in protein above the protein content of grain from untreated plots.

It is concluded from these investigations that 2,4-D is injurious to small grain plants. While 2,4-D is not as injurious to small grains as it is to broad-leaved weeds, it can be seen from these investigations that application of 2,4-D to grain fields lightly infested with weeds may prove economically unsound from the standpoint of obtaining higher grain yields.

THE EFFECT OF 2,4-D ON GROWTH AND DEVELOPMENT OF SMALL GRAIN AND ON CERTAIN ANNUAL WEEDS

by

FRANCIS HARRISON MC NEAL

A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

March 1948

APPROVED:

[redacted]

Head of Department of Farm Crops

In Charge of Major

[redacted]

Chairman of School Graduate Committee

[redacted]

Dean of Graduate School

ACKNOWLEDGMENTS

To Dr. D. D. Hill, Head of the Department of Farm Crops, the writer expresses sincere appreciation for the many suggestions and the excellent criticism given during preparation of this thesis.

Appreciation is expressed to Mr. Virgil H. Freed, associate agronomist, Farm Crops Department, for his advice on the original outline of this thesis and for the many valuable suggestions he made prior to its completion.

The author expresses appreciation to Mr. Harry G. Avery, Superintendent of the Eastern Oregon Branch Livestock Experiment Station, and to Mr. Bert Haines, farmer at Pendleton, Oregon, for furnishing land to develop this project.

To Dr. Jerome C. R. Li, assistant professor, Mathematics Department, a word of appreciation for his assistance in preparing and analyzing the statistical data contained in this paper.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
REVIEW OF LITERATURE	3
MATERIALS AND METHODS	10
Winter and Spring Barley at the Union Experiment Station	11
Grain Seedlings at the Oregon State College Greenhouse	12
Winter Wheat Near Pendleton, Oregon	14
Statistical Determinations	15
EXPERIMENTAL RESULTS	16
Spraying Winter Barley at the Union Experiment Station	16
Spraying and Dusting Spring Barley at the Union Experiment Station	19
Spraying and Dusting Wheat Seedlings in the Oregon State College Greenhouse	22
Spraying and Dusting Winter Wheat on a Farm Near Pendleton, Oregon	32
DISCUSSION	48
SUMMARY AND CONCLUSIONS	51
BIBLIOGRAPHY	

THE EFFECT OF 2,4-D ON GROWTH AND DEVELOPMENT OF SMALL GRAIN AND ON CERTAIN ANNUAL WEEDS

INTRODUCTION

When 2,4-D was first introduced to the American grain farmer, it was publicized for its selective action on different plants. The term "selective" was applied because of its effect on broad-leaved weeds in small grain crops with no apparent injury to the grain crop itself.

This material was acclaimed by commercial companies as the answer to weed control problems. Farmers in many parts of the country started using 2,4-D in a short time after its appearance on the market. Different commercial preparations were manufactured so rapidly that for a time research workers found themselves unprepared to answer many of the questions regarding the use of 2,4-D.

During the few years since 2,4-D was first used for weed control, many research workers have presented experimental evidence to show that most annual, broad-leaved weeds and some perennial, broad-leaved weeds can be controlled by its use. Control of weeds is of prime importance, but it is also essential to know what effect, if any, 2,4-D has on the growing crop. While there is extensive literature which shows the effect of 2,4-D on weeds, there has been very little experimental evidence presented to show its effect on small grain plants. Some workers have recently observed that small grains are adversely affected by application of 2,4-D, but the extent of this damage has not been determined.

Results of preliminary investigations by the author on control of Canada thistle in barley in 1946 indicated that 2,4-D has a depressing effect on grain yield. Further experiments were designed and completed in 1947. The objective of these experiments was to determine the effect of 2,4-D on agronomic characters of small grain and on certain annual weeds. Results of these experiments are presented in this paper.

REVIEW OF LITERATURE

The U. S. Department of Agriculture points out that many scientists gave attention to chemical growth-regulators during the recent war (22, p. 28). A large number of these growth-regulators were used and among them was one known as 2,4-Dichlorophenoxyacetic acid. When one of these materials is applied to a plant, a response in growth is desired. On this basis, 2,4-D was at first discarded because it gave too much response. When plants were treated with this material, they seemed to grow too fast. Food reserves stored in the plant were apparently used up, and death soon resulted. While this was undesirable for increasing crop yields, it soon came to the attention of research workers that such a chemical might be of practical importance if used for control of weeds.

According to Kephart (6, p. 38), 2,4-D was first introduced to the American public during the summer of 1944. Sufficient research had not been carried on with this material and exaggerated claims were soon forthcoming on its ability to control weeds. Research workers quickly organized tests and found 2,4-D very efficient in controlling some weeds, but not as efficient on all weeds as many claims had contended. However, use of 2,4-D is one of the best ways ever found for controlling weeds in fields without apparent injury to grass or grain crops. Even in view of this last statement, it is probably true that no plant is entirely resistant if the chemical comes in contact with its roots or aerial parts.

during certain phases of the growth period.

Mitchell and Brown (14, p. 393) point out that if 2,4-D is applied to a succulent plant, such as tomato or bean, curvature of the stem or leaf may result. This would indicate one side of the leaf or stem is growing and elongating faster than the other. There is also evidence, as pointed out by Tukey and others (21, p. 62), that underground parts of plants may become distorted and proliferated by use of 2,4-D. Other growth responses exhibited by susceptible plants are inhibition of bud growth (particularly the terminal ones) and the occasional formation of galls in the plant's stem, according to Marth and Mitchell (10, p. 231). These distorted conditions are often apparent for a period of two to three weeks. Plants so affected usually die.

While the exact reason for death to plants by use of 2,4-D is not fully understood, several workers are agreed on the physiological action of this chemical within the plant. Rasmussen (18, p. 389) agrees with Mitchell and Brown (13, p. 127) that sugar content of susceptible plants increases rapidly following application of 2,4-D. It later tends to decrease to the original level. Rasmussen further states (18, p. 390), the increase in sugar is more than off-set by a rapid decrease of carbohydrate reserves. He found that loss of carbohydrates could be accounted for by the increased rate of respiration. This would indicate little utilization of sugars for direct growth response.

Work with annual morning glory, by Mitchell and Brown (13,

p. 128), seemed to indicate that reproductive parts of the plant are very sensitive to 2,4-D. Necrotic tissues were first exhibited by the flower buds. This necrosis seemed to be associated with rapid decrease of carbohydrates in the bud. Readily available carbohydrates in all parts of the plant were essentially depleted within a period of three weeks. Tukey, Hamner and Imhofe (21, p. 72) in working with bindweed found the reproductive organs were definitely inhibited and chlorophyll development seemed to be checked. While depletion of carbohydrates definitely contributes to the death of plants, Rasmussen (18, p. 387) believes it is doubtful that plants are actually starved to death.

Rasmussen (18, p. 383) found dandelions show an increase in protein nitrogen following treatment with 2,4-D. The increase seemed to reach a maximum about 15 days after treatment. This increase in nitrogen would suggest increased absorption of nitrogen compounds from the soil. Amino acids and proteins would thus be synthesized and show an increase in protein nitrogen.

While it is evident that action of 2,4-D on plants is physiological, there is evidence that factors external to the plant play a part in this process. Marth and Davis (9, p. 471) point out that since actively growing and succulent plants are most susceptible to 2,4-D, it is to be expected that temperatures must be considered. They found temperatures between 65 to 90 degrees Fahrenheit after 2,4-D application caused death to plants within 18 to 21 days. At temperatures of 32 to 40 degrees, plants were still living after 50 days had elapsed. Although lower temperatures tend to slow up speed

of action of 2,4-D, they apparently do not reduce the final effect, according to Willard and Welton (26, p. 36). Also in line with temperatures, it has been stated by the Dow Chemical Company (3, p. 8) that growth-regulating substances produce more pronounced effects on plants in direct sunlight.

There is no doubt that 2,4-D is excellent for controlling certain weeds. There is concern, however, as voiced by Marth and Mitchell (11, p. 77), over possible accumulative effect in the soil of this chemical if it is used repeatedly on the same area. Willard and Welton (26, p. 33) and Mitchell and Marth (15, p. 283) seem to be agreed that soil toxicity will not affect germination of seeds after a period of two months has elapsed. Arid or semi-arid regions tend to present the most problems of soil toxicity, according to Crafts (2, p. 36). However, as pointed out by Nutman and others (17, p. 499), while 2,4-D persists in the soil long enough to produce marked toxic effects, it does possess the advantage of losing this toxicity very soon. Mitchell and Marth (16, p. 416) point out that 2,4-D is most readily inactivated in warm, moist soils.

While 2,4-D is harmful to some plants, it seems to be less so to others. In general, this chemical is effective in controlling broad-leaved weeds, but shows no apparent injury to true grasses, as shown by Barr and Brown (1, p. 341) and Taylor (19, p. 610). When these broad-leaved weeds are in a young and succulent stage of growth, they are especially affected by 2,4-D, according to Hamner and Tukey (4, p. 243). Some of the most extensive use of 2,4-D has been on common lawn weeds such as dandelion and buckhorn plantain.

Willard (25, p. 445) and Tingey and Evans (20, p. 1) point out that good control has been obtained on these annuals with no apparent injury to the grass. Aerial parts of broad-leaf plants treated with 2,4-D by Kraus and Mitchell (8, p. 348) showed extreme toxicity. However, on such perennial weeds as morning glory, white top, and Canada thistle, results have not been as satisfactory. Although top growth may be killed, the roots are usually not materially injured, according to Tingey and Evans (20, p. 1).

Most workers have observed the effect of 2,4-D on weeds, but only a few have paid particular attention to its effect on grain and grass plants. Since weeds show a definite physiological effect from 2,4-D, it is not entirely inaccurate to suppose that some of the same changes occur in grass and grain plants.

Tingey and Evans (20, p. 20) believe grasses and small grains can be injured by too strong an application of 2,4-D. Mitchell and Marth (15, p. 283) found Kentucky bluegrass, redtop, and creeping red fescue sensitive to 2,4-D in amounts equivalent to three-fourths of a pound of parent acid per acre. Weekly weights of clippings were lower than unsprayed areas for a period of one to two months after treatment. Greenhouse experiments conducted by Taylor (19, p. 610) with several different plants, including wheat and corn, showed the dry weight of these plants was decreased with concentrations of 2,4-D as low as 0.5 ppm.

Although it might be supposed that action of 2,4-D on the plant would cause lower seed viability, Crafts (2, p. 36) points out

that normal concentrations used for weed control seem to have little effect on germination. Results reported by Marth and Toole (12, p. 782) agree with this. However, Hsueh and Lau (5, p. 285) point out that 2,4-D at low concentrations (0.01 per cent) promotes germination, while at higher concentrations (0.1 per cent) it seems to inhibit germination.

Kephart (6, p. 83) indicates no injury should result to cereal crops if 2,4-D is applied when the leaves are about six inches long. It is pointed out, however, by Barr and Brown (1, p. 341) and by Kraus and Mitchell (8, p. 349), that rice and barley seedlings may be injured by very high concentrations of 2,4-D. Willard (24, p. 53, 25, p. 452) further points out that corn may be severely injured if 2,4-D is applied directly on the plant prior to the milk stage. Such action may result in reduction of yield by as much as one-third to one-half.

An experiment by Klingman (7, p. 446) concerning the effect of 2,4-D on weed-free wheat plots is reviewed here in detail. Applications of 2,4-D were made on three dates at three rates. The equivalent of one, two, and three pounds of parent acid per acre was used. Plants were treated when four to eight inches high, when 12 inches high (early boot) and when they were just beginning to head. Grain yields for all treated plots were significantly lower than grain yields of the check plot. Treating when plants were in the early boot stage produced lowest yields for all three rates of application. Height of plants was not materially lower except in plots treated at the boot stage. Test weight of the grain seemed to decrease as rate

of application increased. It was lowest in plots that had been treated at the boot stage. Some growth abnormalities were noted in plants sprayed when they were four to eight inches high.

In view of results obtained to date concerning reaction of 2,4-D on plants, there is definite need for more information as to the effect of this chemical on small grains. If small grains are injured by 2,4-D, it is important to know the extent of this injury.

MATERIALS AND METHODS

Experiments on which this paper is based were carried on at the Union Experiment Station in 1946, at the Oregon State College greenhouse during the winter of 1946-47, and on a farm near Pendleton, Oregon, in 1947. Preliminary experiments at the Union Experiment Station on barley plots were followed by greenhouse experiments at Oregon State College on wheat seedlings. With data from these experiments in mind, a more comprehensive experiment was designed for 1947.

Work carried on in 1946 by the author indicated some reduction in grain yield by use of 2,4-D, and a series of greenhouse experiments during the winter of 1946-47 indicated there was injury to the growing plant. Experimental work for 1947 was done in an area lightly infested with weeds in order to determine what effect 2,4-D has on the grain crop. Sprays and dusts that seemed to be representative of 2,4-D preparations now available to farmers were selected for this work. In all the work, square rod plots were used as the smallest unit for 2,4-D application. All plots were taken from grain fields which had been planted with seven-inch spacing between the rows. Only a few counts, plus observations, were made on the effect 2,4-D has on weeds. Some perennial weeds, such as Canada thistle (Cirsium arvense) and wild morning glory (Convolvulus spp.) were observed but no definite procedure was followed in these observations.

Most of the chemical materials used were furnished by Mr.

Virgil H. Freed of the Farm Crops Department at Oregon State College. Experiments at the Union Experiment Station were conducted on land that is sub-irrigated with almost no slope. Annual precipitation averages about 13 inches and summer temperatures rarely exceed 100 degrees. The land used in these experiments was infested with Canada thistle.

Work carried on in 1947 was done on a farm operated by Mr. Bert Haines about ten miles northeast of Pendleton, Oregon. Annual precipitation averages about 15 inches and summer temperatures generally exceed those at Union, Oregon, by five or ten degrees. The land used had a slope of two or three per cent, and it was relatively free of weeds. Tarweed (Amsinckia spp.) and mustard (Brassica spp.) were the principal weeds.

Winter and Spring Barley at the Union Experiment Station

Treatments in the spring of 1946 at the Union Experiment Station consisted of spraying and dusting both winter and spring barley that was infested with Canada thistle. The winter barley (Wong variety) was treated on April 26 when the grain was about six inches high. A commercial preparation of 2,4-D containing 40 per cent parent acid and known as Tufor-40 was used. Four square rod plots were treated with this material and four square rod plots were left untreated for checks. Applications were made with a motor-driven sprayer, and the material was applied at the rate of one pound of parent acid per acre. Height measurements of thistle and grain in the treated and untreated plots were taken at harvest time.

All the grain in each plot was cut by hand, and threshing was done with a small nursery thresher. Grain weights were taken in pounds, and yield per acre was calculated from these weights.

On June 4, 1946, two dusts and two sprays were applied to spring barley (Union Beardless variety). The grain was approximately six inches high at time of treatment. Two replications of each treatment were used, and the plots were arranged systematically. Two untreated check plots were used. The two dusts used were methyl ester and sodium salt. The two sprays used were sodium salt and a commercial preparation, Tufor-40, containing 40 per cent parent acid. The sprays were applied with a three-gallon hand sprayer, and the dusts were applied with a small hand, pump-type duster. All applications were made at the rate of one pound of parent acid per acre. All the barley plants from each plot were cut by hand on August 5. Threshing was done with a small nursery thresher, and the threshed weights were converted to yield per acre.

Grain Seedlings at the Oregon State College Greenhouse

Two greenhouse experiments were carried on during the winter of 1946-47. Wheat was planted in gallon cans and thinned to ten plants per can after emergence. This was then treated with different 2,4-D dust and spray preparations, using three replications of each treatment. Applications of the material was made at the rate of one pound of parent acid per acre.

Sprays were applied by using a small test tube with a rubber stopper inserted in the neck. Two holes in the rubber stopper

allowed two hollow glass tubes to be inserted into the test tube. Pressure through one of the glass tubes from a spray gun forced the material out through the other tube in a fine mist. For applying the dusts, a piece of fine cheese cloth was placed over the end of a hollow glass tube. The dust was put into this tube and applied by tapping the tube gently to get even coverage.

In the first experiment, the grain used was Huston, spring wheat, and it was planted on October 12, 1946. The sprays and dusts were applied 21 days later on November 2. Ten dusts and five sprays were used in this experiment and seven cans were left untreated as checks, giving a total of 52 cans. On November 26, the green plants were measured for height and then cut for green weights. Each plant was cut at the ground level, and all ten plants from each can were composited for weighing. Plant heights were taken to the nearest tenth of an inch and plant weights were taken to the nearest hundredth of a gram.

In the second experiment, the grain used was White Holland, winter wheat. This was planted on November 30, 1946, and treated with 2,4-D dusts and sprays 14 days later on December 14. Three replications of eight dusts and eight sprays were used, and eight cans were left untreated for checks. This gave a total of 56 cans. Green weights and plant height measurements were taken on January 13, 1947, in exactly the same way as they were taken in the first experiment.

Winter Wheat Near Pendleton, Oregon

Work conducted in 1947 on a farm near Pendleton, Oregon, was set up on the basis of treated plots, hand-weeded check plots, and check plots receiving no treatment. Four sprays and three dusts were applied on April 15 to Federation wheat which had been planted in the fall of 1946. The wheat was about six inches high at time of treatment. Plots were arranged systematically with six replications of each treatment. Every other plot was used as a check which gave a total of 42 treated plots and 41 check plots. Of the 41 check plots, 11 of them were selected at random for hand weeding.

Sprays were applied with a three-gallon hand sprayer and the dusts were applied with a small hand, pump-type duster. Applications were made at the rate of one pound of parent acid per acre.

Heading notes, based on ten per cent of the heads showing, were taken. Plant height measurements were taken at the time of harvest. Three 16-foot rows of grain were cut by hand from each plot and threshed with a Vogel-type nursery thresher for yield. Test weights were taken on the grain from each plot.

In this same field of Federation wheat, different rates of sodium salt of 2,4-D were applied in a spray form. Plots were arranged systematically using two untreated plots as checks and two replications of each rate of treatment. Treatments were applied in one-half pound amounts from 1.5 to 4.0 pounds of parent acid per acre. This gave six treatments or a total of 12 treated plots. Sprays were applied on April 16 using the three-gallon hand sprayer mentioned

previously. Heading notes and plant height measurements were taken in the same manner as described above. Three 16-foot rows were hand cut from each plot and threshed with the Vogel-type nursery thresher for yield. After test weights were taken, grain from plots receiving the same treatment was composited. This was also done with grain from the experiment where four sprays and three dusts were used. Samples were then drawn from each of these composited lots of grain for germination and protein determinations.

Statistical Determinations

A statistical analysis was made on grain yields obtained at Pendleton, Oregon, for treatments made at the rate of one pound of parent acid per acre. The analysis of variance was used in analyzing this data. The standard error of the difference between the mean of any treatment and the mean of unweeded checks and the standard error of the difference between the mean of any treatment and the mean of weeded checks was calculated.

EXPERIMENTAL RESULTS

Spraying Winter Barley at the Union Experiment Station

In this experiment carried on at the Union Experiment Station, only one type of 2,4-D spray was used. This spray was applied at the rate of one pound of parent acid per acre. Application was made on April 26, 1946. Agronomic data for this experiment are presented in Table 2.

Plots were selected in an area where the grain was very thin and where a heavy stand of Canada thistle was growing. Four square rod plots were treated with 2,4-D spray and four square rod plots were marked off and left untreated for checks.

Weed counts of one square foot in each plot for annual weeds and two square feet in each plot for Canada thistle were made at the time of treatment. These counts were made only in treated plots. Annual weed counts showed 98, 79, 67, and 44 plants, respectively. Observations indicated that by May 1 almost 100 per cent of the annual weeds, which included mustard (Brassica spp.) and fan weed (Thlaspi spp.), exhibited chemotropism (twisting and curling of plant parts). By May 9 most of the annual weeds were dead and, when observations were made on June 6, only a few green plants could be found. It was thought these few came from new seed after treatment.

Plant counts for Canada thistle before and after treatment gave the figures listed in Table 1. Most thistle plants showed chemotropism within a week after treatment with 2,4-D. This condition continued to become more evident, and many of the plants

gradually lost their green color. It appeared from above ground that many of the plants were dead. However, the roots were apparently not seriously injured, as new top growth soon started. Most of the treated thistle plants did not set seed and original top growth was definitely inhibited (Table 2).

TABLE 1. Number of Canada Thistle Plants in Plots Treated with 2,4-D Spray

Plot Number	At Treatment (4-26-46)	At Harvest (7-22-46)
1	7	7
	11	8
2	12	9
	7	4
3	9	8
	14	12
4	15	12
	10	9

The most evident visible effect of 2,4-D on the grain crop was difference in height between treated and untreated plots. There was some evidence of leaf curling, but the grain plant appeared healthy during its entire growth.

As indicated in Table 2, there was a difference in height of five inches between the average of untreated and treated barley plants. Plants from treated plots were shorter, which seemed to indicate some injury from use of 2,4-D. This was further verified by the depressing effect on yield of grain. There was a difference of 1.7 bushels in favor of the untreated plots. Converting this to a comparative basis, the treated plots yielded 90.3 per cent as much grain as the untreated plots.

TABLE 2. Agronomic Data for Wong, Winter Barley Treated with a Commercial Preparation of 2,4-D Spray (Tufor-40) Containing 40 Per Cent Parent Acid. Union Experiment Station.

Plot No.	Treatment**	Height of Thistle*	Average Height of Thistle	Height Of Barley*	Average Height of Barley	Yield Per Square Rod Plot	Yield Per Square Rod Plot	Average Yield Per Acre
		in.	in.	in.	in.	lbs. oz.	bu.	bu.
1.	Untreated	46	40	39	35	6 10	17.7	17.6
2	Checks	43		35		7 3	19.2	
3		38		33		6 6	17.0	
4		32		33		6 3	16.5	
5	Treated	10	8	29	30	5 1	13.5	15.9
6	Plots	7		29		6 5	16.8	
7		10		30		6 2	16.3	
8		6		32		6 6	17.0	

** Treated on April 26, 1946

* Height measurements were taken at time of harvest on July 22, 1946

Spraying and Dusting Spring Barley at the Union Experiment Station

Agronomic data obtained from application of 2,4-D to spring barley at the Union Experiment Station in 1946 are presented in Table 3. Two dusts and two sprays were used in this experiment with two replications of each. All materials were made up to a ten per cent parent acid content except the Tufor-40 which contained 40 per cent parent acid. Application of these materials was made at the rate of one pound of parent acid per acre.

In analyzing the data in Table 3, it can be seen that plots three and eight gave the highest average grain yield, even exceeding that of the untreated check plots. Plot eight gave a yield corresponding to what might be expected, but plot three gave a yield higher than normal as indicated by check plots one and six. Plot three had a much heavier growth of Canada thistle at harvest time and also a much more vigorous growth of grain than any other plots. Since this experiment was located on sub-irrigated land that had been summer-fallowed the year previous, it is possible that a higher yield was obtained in plot three due in part to competition from Canada thistle. Another possible explanation for the high yield of grain from plot three is that the 2,4-D material used on this plot (sodium salt dust) was less damaging to the grain crop than any of the other three materials that were used.

In comparing the average yield of other treatments with the average yield of check plots, it can be seen that Tufor-40 spray gave yields identical to that of the checks. However, treatments

TABLE 3. Agronomic Data for Union Beardless, Spring Barley Treated with Two Dust and Two Spray Preparations of 2,4-D. Union Experiment Station

Plot No.	Treatment**	Yield Per Square Rod Plot* lbs.	oz.	Yield Per Square Rod Plot* bu.	Average Yield Per Acre bu.	Deviation from the Check bu.
1	Untreated check	7	13	20.8	20.8	0.0
6		7	12	20.7		
2	Methyl ester 2,4-D dust	5	2	13.7	18.3	-2.5
7		8	9	22.8		
3	Na. salt 2,4-D dust	9	5	24.8	23.0	+2.2
8		7	15	21.2		
4	Tufor-40 spray	9	2	24.3	20.8	0.0
9		6	7	17.2		
5	Na. salt 2,4-D spray	7	13	20.8	17.3	-3.5
10		5	3	13.8		

** Treated on June 4, 1946
* Harvested on August 5, 1946

with methyl ester dust and sodium salt spray gave average yields of 2.5 and 3.5 bushels below the average yield of the checks.

Canada thistle was the only weed problem in these plots and no counts were made. In all the plots except three and eight, there appeared the characteristic curling of leaves and twisting of stems of the Canada thistle plants. Most of the top growth died, but new growth soon appeared. Very little seed was set except in the check plots and in plots treated with sodium salt dust. Observations made throughout the summer indicated plots four and nine gave best control of weeds followed by plots two and seven. Plots three and eight gave the poorest control of weeds.

Very little effect was noted on external parts of the barley plants from use of 2,4-D. This would indicate that internal injury to the grain plant could be responsible for lower yields on treated plots.

Spraying and Dusting Wheat Seedlings in the Oregon State College Greenhouse

During the winter of 1946-47, two experiments were carried on in the greenhouse at Oregon State College. In both these experiments, grain was planted in gallon cans and treated with different 2,4-D dust and spray preparations after it had emerged. Each can covered an area of two-tenths of a square foot. Materials were applied at the equivalent rate of one pound of parent acid per acre. About 20 kernels of wheat were planted in each can and these were thinned to ten of the most uniform plants before treating. Three replications of each treatment, plus seven checks in the first experiment and eight checks in the second experiment, were used. Agronomic data for these two experiments are presented in Tables 4 and 5.

In the first experiment, Huston, spring wheat was seeded on October 12 and treated 21 days later on November 2. The plants were about three to four inches high at time of treatment. They were harvested for green weights 19 days after treatment, on November 26. In the second experiment, White Holland, winter wheat was seeded on November 30. These plants were about two to three inches high at time of treatment. Treatment was done 14 days after seeding, and the plants were harvested for green weights 30 days later on January 13.

In analyzing data from Table 4, it can be seen that in all cases the average height of plants from untreated check plots is equal to or exceeds the average height of plants from treated plots. This

TABLE 4. Agronomic Data for Huston, Spring Wheat Planted in the Greenhouse in Gallon Cans on October 12, 1946 and Treated After Emergence with Different 2,4-D dust and spray Preparations. Oregon State College, Corvallis, Oregon.

Treatment**	Height of Plant*	Green Plant Weight*	Average Height Per Treatment	Deviation from the Check	Average Weight Per Treatment	Deviation from the Check
	in.	gms.	in.	in.	gms .	gms.
Untreated checks	12.6	5.42	12.6	0.0	5.55	0.00
	12.2	5.68				
	13.0	5.61				
	12.3	5.90				
	12.8	6.29				
	12.7	4.82				
	12.6	5.15				
Methyl ester methoxone dust[2]	10.5	4.15	11.4	-1.2	4.46	-1.09
	12.1	5.13				
	11.6	4.11				
Methyl ester 2,4-D dust[2]	12.5	5.69	11.8	-0.8	4.57	-0.98
	12.4	4.60				
	10.6	3.42				
Methoxone acid dust[2]	12.5	5.34	11.9	-0.7	4.66	-0.89
	11.6	4.18				
	11.7	4.47				
Methyl ester 2,4-D dust[2]	12.1	4.90	12.0	-0.6	4.86	-0.69
	11.5	4.32				
	12.3	5.37				

TABLE 4. (continued)

Treatment**	Height of Plant*	Green Plant Weight*	Average Height Per Treatment	Deviation from the Check	Average Weight Per Treatment	Deviation from the Check
	in.	gms.	in.	in.	gms.	gms.
Acid 2,4-D dust[1]	12.5	5.97	11.6	-1.0	5.00	-0.55
	12.1	5.24				
	10.1	3.80				
Acid 2,4-D dust[2]	11.8	6.57	11.5	-1.1	5.06	-0.49
	11.4	4.15				
	11.3	4.45				
Na. salt 2,4-D dust[2]	12.9	5.67	12.4	-0.2	5.13	-0.42
	12.5	4.95				
	11.9	4.78				
Methyl ester 2,4-D dust[1]	12.4	4.69	12.2	-0.4	5.50	-0.05
	12.6	6.47				
	11.6	5.33				
Methyl ester methoxone dust[1]	12.1	6.44	12.1	-0.5	5.55	0.00
	11.9	4.77				
	12.3	5.43				
Methyl ester methoxone dust[2]	13.2	5.83	12.6	0.0	6.04	+0.49
	12.5	5.67				
	12.1	6.62				

TABLE 4. (continued)

Treatment**	Height of Plant*	Green Plant Weight*	Average Height Per Treatment	Deviation from the Check	Average Weight Per Treatment	Deviation from the Check
	in.	gms.	in.	in.	gms.	gms.
Dow selective 2,4-D spray[2]	8.0	1.01	8.4	-4.2	1.58	-3.97
	6.2	0.96				
	11.1	2.77				
Ammonium salt 2,4-D spray[2]	8.1	2.13	10.4	-2.2	3.41	-2.14
	12.1	4.12				
	11.1	3.97				
Na. salt methoxone spray[2]	13.8	6.63	11.9	-0.7	4.32	-1.23
	9.9	2.54				
	12.1	3.79				
Sinox spray[2]	12.5	4.41	12.3	-0.3	5.04	-0.51
	13.2	6.00				
	11.1	4.70				
Na. salt 2,4-D spray[2]	12.2	4.68	12.4	-0.2	5.38	-0.17
	12.8	6.52				
	12.3	4.93				

** Treated on November 2, 1946
* Data taken on November 26, 1946, at harvest time
1 With 0.5 per cent addition of glycerin
2 Without glycerin

same thing occurs in Table 5 with the exception of plants that were treated with sinox spray. However, this material is not a 2,4-D preparation. Sinox and the methoxone preparations were used in these experiments for additional checks. Although plants treated with the two sprays, Dow selective and ammonium salt of 2,4-D, are shortest in height in the first experiment (Table 4), this is not true in the second experiment (Table 5). In fact, if the depressing effect of the above two sprays in Table 4 and that of 2,4-D acid spray in Table 5 is disregarded, it would appear from these experiments that dust materials reduce plant height equally as much as spray materials when applied at the same rate.

With one exception, the average green weight of untreated plants is equal to or exceeds that of treated plants in both experiments. This exception is methyl ester of methoxone dust in the first experiment which gave a yield of 0.49 grams greater than the check average. Average yields of other treated plants range from zero to 3.97 grams less than the check. The lowest yield in the first experiment of 3.97 grams less than the check was obtained from plants treated with Dow selective spray. The lowest yield in the second experiment of 3.53 grams less than the check was obtained from plants treated with 2,4-D acid spray. With few exceptions, lower yields were obtained from plants treated with 2,4-D sprays than from plants treated with 2,4-D dusts.

A consolidation of yield and height data in Table 6 shows the average of the two greenhouse experiments. All plants treated with a 2,4-D application are shorter in height than the average of the

TABLE 5. Agronomic Data for White Holland, Winter Wheat Planted in the Greenhouse in Gallon Cans on November 30, 1946, and Treated After Emergence with Different 2,4-D Dust and Spray Preparations. Oregon State College, Corvallis, Oregon.

Treatment**	Height of Plant*	Green Plant Weight*	Average Height Per Treatment	Deviation from the Check	Average Weight Per Treatment	Deviation from the Check
	in.	gms.	in.	in.	gms.	gms.
Untreated checks	10.6	4.97	11.3	0.0	6.58	0.00
	11.2	5.70				
	11.4	7.01				
	12.5	8.08				
	12.3	8.09				
	10.4	5.43				
	11.2	6.38				
	10.9	7.01				
Methyl ester methoxone dust[2]	11.4	5.90	10.3	-1.0	4.38	-2.20
	9.4	2.78				
	10.2	4.47				
Methoxone acid dust[2]	9.9	4.70	9.9	-1.4	4.50	-2.08
	9.8	4.67				
	10.1	4.12				
Methyl ester 2,4-D dust[2]	11.6	6.12	10.9	-0.4	5.39	-1.19
	10.3	4.68				
	10.8	5.38				
Acid 2,4-D dust[1]	11.2	4.87	11.1	-0.2	5.74	-0.84
	10.9	6.32				
	11.3	6.03				

TABLE 5. (continued)

Treatment**	Height of Plant*	Green Plant Weight*	Average Height Per Treatment	Deviation from the Check	Average Weight Per Treatment	Deviation from the Check
	in.	gms.	in.	in.	gms.	gms.
Methyl ester methoxone dust[1]	10.1	5.51	10.6	-0.7	5.78	-0.80
	11.2	6.47				
	10.6	5.37				
Methyl ester 2,4-D dust[1]	9.9	5.22	10.5	-0.8	5.79	-0.79
	10.9	5.57				
	10.6	6.57				
Methyl ester 2,4-D dust[2]	11.6	7.01	11.1	-0.2	6.32	-0.26
	10.4	6.27				
	11.2	5.69				
Na. salt 2,4-D dust[2]	10.2	4.99	11.1	-0.2	6.40	-0.18
	11.8	6.97				
	11.4	7.24				
Acid 2,4-D spray[2]	7.8	2.46	8.2	-3.1	3.05	-3.53
	8.2	2.07				
	8.5	4.63				
Na. salt methoxone spray[2]	11.9	6.37	11.0	-0.3	5.52	-1.06
	10.2	4.60				
	10.9	5.58				
Na. salt 2,4-D spray[2]	11.2	5.90	11.1	-0.2	5.53	-1.05
	10.4	4.96				
	11.7	5.74				

TABLE 5. (continued)

Treatment**	Height of Plant*	Green Plant Weight*	Average Height Per Treatment	Deviation from the Check	Average Weight Per Treatment	Deviation from the Check
	in.	gms.	in.	in.	gms.	gms.
Ammonium salt 2,4-D spray[2]	10.2	5.20	10.4	-0.9	5.69	-0.89
	10.5	6.79				
	10.6	5.08				
Sinox spray[2]	11.6	5.94	11.9	+0.6	5.74	-0.84
	11.8	5.11				
	12.2	6.16				
Dow selective 2,4-D spray[2]	11.2	7.10	11.0	-0.3	5.78	-0.80
	10.9	5.11				
	10.9	5.13				
Methyl ester 2,4-D spray[2]	11.9	6.62	11.3	0.0	6.50	-0.08
	10.1	5.46				
	12.0	7.42				
Methyl ester methoxone spray[2]	11.2	6.95	11.1	-0.2	6.56	-0.02
	10.9	6.86				
	11.2	5.87				

** Treated on December 14, 1946
* Data taken on January 13, 1947, at harvest time
1 With 0.5 per cent addition of glycerin
2 Without glycerin

checks. The same thing is true when comparing green weights of the plants. Methyl ester of 2,4-D spray, the only 2,4-D material in Table 6 showing a higher green weight of plants than the check average, was used in the second experiment only. It yielded lower than the check as indicated in Table 5.

Weeds were not given any consideration in these experiments. Cans were kept free of weeds in order that the wheat plants would have no competition for plant food or water.

TABLE 6. A Consolidation of Agronomic Data for the Two Greenhouse Experiments from Tables 4 and 5.

Treatment	Average Height of Plants Both Exp.	Deviation from the Check	Average Weight of plants Both Exp.	Deviation from the Check
	in.	in.	gms.	gms.
Untreated checks	12.0	0.0	6.07	0.00
Methyl ester methoxone dust[2]	10.9	-1.1	4.42	-1.65
Methoxone acid dust[2]	10.9	-1.1	4.58	-1.49
Methyl ester 2,4-D dust[2]	11.4	-0.6	4.98	-1.09
Acid 2,4-D dust[2]*	11.5	-0.5	5.06	-1.01
Acid 2,4-D dust[1]	11.4	-0.6	5.37	-0.70
Methyl ester 2,4-D dust[2]	11.6	-0.4	5.59	-0.48
Methyl ester 2,4-D dust[1]	11.4	-0.6	5.65	-0.42
Methyl ester methoxone dust[1]	11.4	-0.6	5.67	-0.40
Na. salt 2,4-D dust[2]	11.8	-0.2	5.77	-0.30
Methyl ester methoxone dust[2]*	12.6	+0.6	6.04	-0.03
Acid 2,4-D spray[2]*	8.2	-3.8	3.05	-3.02
Dow selective 2,4-D spray[2]	9.7	-2.3	3.68	-2.39
Ammonium salt 2,4-D spray[2]	10.4	-1.6	4.55	-1.52
Na. salt methoxone spray[2]	11.5	-0.5	4.92	-1.15
Sinox spray[2]	12.1	+0.1	5.39	-0.68
Na. salt 2,4-D spray[2]	11.8	-0.2	5.46	-0.61
Methyl ester 2,4-D spray[2]*	11.3	-0.7	6.50	+0.43
Methyl ester 2,4-D spray[2]*	11.1	-0.9	6.56	+0.49

1 With 0.5 per cent addition of glycerin
2 Without glycerin
* data from only one experiment

Spraying and Dusting Winter Wheat on a Farm Near Pendleton, Oregon

Federation wheat seeded in the fall of 1946 on a farm near Pendleton, Oregon was treated on April 15, 1947, with different 2,4-D dusts and sprays. The plants were from four to six inches high at time of treatment. They had not reached the boot stage. This experiment was designed for use of paired plots, with every other plot as a check. Approximately one-fourth of these check plots were kept free of weeds by hand weeding, while the other three-fourths were left undisturbed. Six replications of each treatment were used in this experiment. All applications were made at the rate of one pound of parent acid per acre. Agronomic data from this experiment are presented in Table 7.

Plots treated with dust preparations of methyl ester and acid 2,4-D gave higher yields of grain than plots treated with spray preparations of the same material. This was not true with sodium salt. Sodium salt dust gave a yield of 1.1 bushels per acre lower than the spray preparation. In considering height measurements of dusted versus sprayed plots, it can be seen that taller wheat plants, more like those in the weeded and unweeded checks, were present on all dusted plots. Variation in test weight and first date of heading of dusted and sprayed plants are so small, they are probably not significant.

When comparing all treated plots with weeded and unweeded check plots, it can be seen that yield is higher, test weight is generally lower and the plants are taller on check plots. Methoxone

and sodium salt of 2,4-D materials gave highest yields; comparable to those of the unweeded checks. Acid 2,4-D spray gave a yield of 6.4 bushels per acre less than the unweeded checks while methyl ester of 2,4-D spray gave a yield of 4.6 bushels per acre less.

These results indicate sprays have a more harmful effect on grain plants than dusts when applied at the same parent acid rate. They also indicate that methyl ester and acid preparations of 2,4-D are more harmful to grain plants than the sodium salt of 2,4-D preparation.

Hand weeding increased grain yield from 35.6 bushels in the case of unweeded checks to 38.5 bushels in the case of weeded checks. This is an increase of 2.9 bushels per acre.

Weed population in all plots was fairly uniform and very light. No weed counts were taken, but an estimate of mustard and tar weed plants was made. Other small, annual weeds were found occasionally, but these were disregarded in the estimate. The average was approximately 42 mustard plants and 23 tar weed plants per square rod. This gives an average of one weed plant to about every four square feet. An estimate of 100 per cent kill on mustard plants and about 35 per cent kill on tar weed plants was made.

Some curling of leaves and distortion of heads was noted on the wheat plants. However, the distorted heads were well filled and contained as much grain as a normal head.

As indicated in Table 7, there was a definite variation in height of grain between treated and untreated plants. This difference of height, plus higher yields from untreated plants, indicates a

TABLE 7. Agronomic Data for Federation, Winter Wheat Treated on April 15, 1947, with Different 2,4-D Dusts and Sprays. Pendleton, Oregon.

Treatment	Date Headed first	Height of Plant* in.	Grain Weight of Three 16' Rows gms.	Average Grain Weight Each 16' Row gms.	Yield Per Acre bu.	Test Weight Per Bushel lbs.	Average Test Weight Each Treatment lbs.	Average Yield Each Treatment bu.
Methyl ester 2,4-D spray	5-22	38	853	284.3	28.4	60.5	60.2	31.3
	5-22	34	948	316.0	31.6	60.2		
	5-22	37	930	310.0	31.0	60.3		
	5-22	36	1221	407.0	40.7	60.7		
	5-23	33	706	235.3	23.5	60.3		
	5-23	35	977	326.0	32.6	59.1		
Methyl ester 2,4-D dust	5-20	35	773	258.0	25.8	60.6	60.2	33.1
	5-20	34	947	316.0	31.6	60.5		
	5-20	41	1048	349.0	34.9	60.2		
	5-20	39	1148	383.0	38.3	60.0		
	5-20	43	970	323.0	32.3	60.0		
	5-20	40	1064	355.0	35.5	60.1		
Acid 2,4-D spray	5-22	33	873	291.0	29.1	60.0	60.2	29.5
	5-22	33	722	241.0	24.1	60.2		
	5-22	35	960	320.0	32.0	60.2		
	5-23	36	998	333.0	33.3	60.4		
	5-22	34	862	287.0	28.7	60.7		
	5-23	32	891	297.0	29.7	59.7		

TABLE 7. (continued)

Treatment	Date Headed first	Height of Plant* in.	Grain Weight of Three 16' Rows gms.	Average Grain Weight Each 16' Row gms.	Yield Per Acre bu.	Test Weight Per Bushel lbs.	Average Test Weight Each Treatment lbs.	Average Yield Each Treatment bu.
Acid 2,4-D dust	5-20	34	829	276.0	27.6	59.6	59.6	33.7
	5-20	36	896	299.0	29.9	60.0		
	5-20	40	965	322.0	32.2	59.3		
	5-20	39	1208	403.0	40.3	59.9		
	5-20	42	1098	366.0	36.6	59.4		
	5-20	41	1075	358.0	35.8	59.6		
Sodium salt 2,4-D spray	5-20	35	1018	339.0	33.9	59.9	59.7	35.1
	5-20	34	1106	369.0	36.9	60.1		
	5-20	40	1098	366.0	36.6	59.8		
	5-21	39	1107	369.0	36.9	59.4		
	5-20	40	1006	335.0	33.5	59.3		
	5-20	40	977	326.0	32.6	59.8		
Sodium salt 2,4-D dust	5-20	38	1170	390.0	39.0	59.6	60.0	34.0
	5-20	37	998	333.0	33.3	60.2		
	5-20	42	1085	362.0	36.2	59.8		
	5-20	40	1128	376.0	37.6	60.1		
	5-20	39	915	305.0	30.5	59.7		
	5-20	41	828	276.0	27.6	60.3		
Methyl ester methoxone spray	5-20	39	1180	393.0	39.3	60.5	59.9	33.9
	5-20	38	977	326.0	32.6	59.8		
	5-20	42	1165	388.0	38.8	60.2		
	5-20	42	994	331.0	33.1	59.6		
	5-20	41	891	297.0	29.7	60.0		
	5-20	42	901	300.0	30.0	59.3		

TABLE 7. (continued)

Treatment	Date Headed	Height of Plant*	Grain Weight of Three 16' Rows	Average Grain Weight Each 16' Row	Yield Per Acre	Test Weight Per Bushel	Average Test Weight Each Treatment	Average Yield Each Treatment
	first	in.	gms.	gms.	bu.	lbs.	lbs.	bu.
Weeded checks	5-20	36	980	327.0	32.7	58.8	59.7	38.5
	5-20	37	1281	427.0	42.7	59.8		
	5-20	40	1245	415.0	41.5	59.9		
	5-20	40	1128	376.0	37.6	59.9		
	5-20	39	1172	391.0	39.1	59.7		
	5-20	41	1225	408.0	40.8	59.4		
	5-20	42	1292	431.0	43.1	60.1		
	5-20	45	1230	410.0	41.0	59.9		
	5-20	40	1034	345.0	34.5	59.9		
	5-20	41	1243	414.0	41.4	59.3		
	5-20	41	884	295.0	29.5	60.3		
Unweeded checks	5-20	42	906	302.0	30.2	60.3	59.8	35.6
	5-20	37	935	312.0	31.2	60.3		
	5-20	37	932	311.0	31.1	60.0		
	5-20	36	1073	358.0	35.8	59.8		
	5-20	34	940	313.0	31.3	59.5		
	5-20	35	1046	349.0	34.9	60.2		
	5-20	38	1149	383.0	38.3	59.4		
	5-20	38	1043	348.0	34.8	59.6		
	5-20	39	971	324.0	32.4	60.4		
	5-20	40	1075	358.0	35.8	59.2		
	5-20	43	1200	400.0	40.0	59.6		
	5-20	42	1214	405.0	40.5	60.1		
	5-20	31	1376	459.0	45.9	60.0		
	5-20	41	1334	445.0	44.5	59.9		

TABLE 7. (continued)

Treatment	Date Headed	Height of Plant*	Grain Weight of Three 16' Rows	Average Grain Weight Each 16' Row	Yield Per Acre	Test Weight Per Bushel	Average Test Weight Each Treatment	Average Yield Each Treatment
	first	in.	gms.	gms.	bu.	lbs.	lbs.	bu.
Unweeded checks (cont.)	5-20	40	1127	376.0	37.6	59.3		
	5-20	39	1265	422.0	42.2	59.8		
	5-20	43	1117	372.0	37.2	59.7		
	5-20	40	1226	409.0	40.9	59.8		
	5-20	42	1159	386.0	38.6	60.2		
	5-20	42	1109	370.0	37.0	59.9		
	5-20	41	921	307.0	30.7	59.6		
	5-20	41	1022	341.0	34.1	59.5		
	5-20	40	1047	349.0	34.9	59.7		
	5-20	38	940	313.0	31.3	59.5		
	5-20	42	1067	356.0	35.6	59.6		
	5-20	41	1015	338.0	33.8	59.3		
	5-20	40	1046	349.0	34.9	58.8		
	5-20	40	984	328.0	32.8	59.8		
	5-20	40	909	303.0	30.3	59.8		
	5-20	44	775	292.0	29.2	60.2		

* Data taken on July 6, 1947 at harvest time

definite injury from use of 2,4-D.

Statistical analysis of yield data from this experiment shows the average yields between certain treatments to be significant. The statistical problem, as set up in Tables 8, 9, and 10, is based on total grain weight in grams from each individual square rod plot. This grain weight is listed in column 4 of Table 7.

Table 8 shows total grams for each treatment (SX), number of replications (k), the mean yield in grams for each treatment ($\bar{x}$), and the sum of squares of each treatment $S(X-\bar{x})^2$. Table 9 gives the Chi-square test for homogeneity of variances of the different treatments. Table 10 gives the analysis of variance, standard error between any treatment mean and the mean of unweeded checks and standard error between any treatment mean and the mean of weeded checks.

A difference of 115.12 (Table 10) between the mean of unweeded checks and any treatment mean is significant at the five per cent level. It can be seen that methyl ester and acid sprays have yields significantly lower than the unweeded checks ($\bar{x}$ in Table 8). A difference of 130.64 (Table 10), between the mean of weeded checks and the mean of any treatment, is significant at the five per cent level. This shows that yields from all treated plots are significantly lower than yields from weeded checks, with one exception. Sodium salt spray has an average yield high enough to fall outside this classification. Sodium salt dust, methoxone spray, and acid dust were all just under the border line of having yields significantly lower than weeded checks.

In analyzing data in Tables 8, 9, and 10, it can be concluded

TABLE 8. Original Data and the Calculation of the Sums of Squares, Using Total Weight of Wheat (in Grams) from Three 16-Foot Rows, Table 7.

Symbol	Methyl Ester Spray	Methyl Ester Dust	Acid Spray	Acid Dust	Sodium Salt Spray	Sodium Salt Dust	Meth-oxone Spray	Weeded Checks	Unweeded Checks		Total
X	853	773	873	829	1018	1170	1180	980	906	1265	
	948	947	722	896	1106	998	977	1281	935	1117	
	930	1048	960	965	1098	1085	1165	1245	932	1226	
	1221	1148	998	1208	1107	1128	994	1128	1073	1159	
	706	970	862	1098	1006	915	891	1172	940	1109	
	977	1064	891	1075	977	828	901	1225	1046	921	
								1292	1149	1022	
								1230	1043	1047	
								1034	971	940	
								1243	1075	1067	
								884	1200	1015	
									1214	1046	
									1376	984	
									1334	909	
									1127	775	
ΣX	5,635	5,950	5,306	6,071	6,312	6,124	6,108	12,714	31,923		86,143
k	6	6	6	6	6	6	6	11	30		83
$\bar{x}$	939.17	991.67	884.33	1,011.83	1,052.00	1,020.67	1,018.00	1,155.82	1,064.10		
ΣX^2	5435019	5983542	4737942	6241775	6657178	6337322	6297872	14875804	34510781		91077235
$(\Sigma X)^2$	31753225	35402500	28153636	36857041	39841344	37503376	37307664	161645796	1019077929		7420616449
$\frac{(\Sigma X)^2}{k}$	5292204	5900416	4692272	6142840	6640224	6250562	6217944	14695072	33969264		89405017
$S(X-\bar{x})^2$	142,815	83,126	45,670	98,935	16,954	86,760	79,928	180,732	541,517		1,672,218

TABLE 9. Test of the Homogeneity of the Variances of Total Weights of Wheat (in Grams) from Three 16-Foot Rows. (continued from Table 8)

Sample	$S(X-\bar{x})^2$	Degrees of Freedom k-1	Reciprocal 1/(k-1)	Variance V $\frac{S(X-\bar{x})^2}{k-1}$	Log of V	(k-1)Log V
Methyl ester spray	142,815	5	.20000	28,563.00	4.45581	22.27905
Methyl ester dust	83,126	5	.20000	16,625.20	4.22076	21,10380
Acid spray	45,670	5	.20000	9,134.00	3.96066	19.80330
Acid dust	98,935	5	.20000	19,787.00	4.29638	21.48190
Sodium salt spray	16,954	5	.20000	3,390.80	3.53030	17.65150
Sodium salt dust	86,760	5	.20000	17,352.00	4.23935	21.19675
Methoxone spray	79,928	5	.20000	15,985.60	4.20372	21.01860
Weeded checks	180,732	10	.10000	18,073.20	4.25704	42.57040
Unweeded checks	541,517	29	.03448	18,673.00	4.27122	123.86538
Total	1,276,437	74	1.53448			310.97068

$Vo = \frac{1,276,437}{74} = 17,249$; log Vo = 4.23677; (log Vo)74 = 313.52098

Chi-square = 2.3026(313.52098-310.97068)

= 2,3026(2.55030)

= 5.87

Since this value is so small, no correction is necessary.

The chi-square test shows that the variances of the different treatments are homogeneous.

The pooled variance, 17,249, may be used as the experimental error

TABLE 10. Analysis of Variance.

Source of variation	d. f.	Sum of Squares	Variance	F*
Treatment	8	395,781	49,473	2.87
Error	74	1,276,437	17,249	
Total	82	1,672,218		

* This F value is significant at 1%

I. The standard error between any treatment mean and the mean of unweeded checks is the square root of the quantity $17{,}249\ (\frac{1}{6} + \frac{1}{30})$. This is equal to 58.735. A difference of 1.96 (58.735) equals 115.12, and this is significant at the five per cent level.

II. The standard error between any treatment mean and the mean of weeded checks is the square root of the quantity $17{,}249\ (\frac{1}{6} + \frac{1}{11})$. This is equal to 66.655. A difference of 1.96 (66.655) equals 130.64, and this is significant at the five per cent level.

that methyl ester and acid sprays are more injurious to grain yield than any other materials used. By comparing grain yields of weeded check plots with grain yields of treated plots, it can be concluded that treating grain which is free of weeds results in significantly lower yields if the material used is a methyl ester or acid preparation of 2,4-D.

At the same time data in Table 7 were being collected, an adjoining experiment was being conducted on the effect of 2,4-D to wheat plants when applied at different rates. Data from this work are included in Table 11.

Only one type of material was used for this work. A sodium salt of 2,4-D was selected and, as indicated by Table 7, this material is less damaging to grain yield and plant height than some other 2,4-D preparations.

Applications were made on the basis of parent acid per acre. These applications varied in half-pound amounts from 1.5 pounds to 4.0 pounds. Two replications of each treatment were used with two untreated check plots. Untreated check plots gave highest yields and also the tallest plants. With one exception, yields for the treated plots declined progressively as rate of application was increased. Application made at the rate of 3.5 pounds per acre gave a yield of 34.6 bushels and this yield was second only to the 35.9 bushels from application of 1.5 pounds per acre. Table 11 shows that one plot treated at the rate of 3.5 pounds is fairly well in line, while the other exceeds almost all plots in yield. This variation might be due to lack of uniformity in the soil.

TABLE 11. Agronomic Data for Federation Wheat Treated on April 16, 1947, with a Sodium Salt of 2,4-D Spray Using Different Rates of Application. Pendleton, Oregon.

Treatment	Date Headed first	Height of Plant* in.	Grain Weight of Three 16' Rows gms.	Average Grain Weight Each 16' Row gms.	Yield Per Acre bu.	Test Weight Per Bushel lbs.	Average Test Weight Each Treatment lbs.	Average Yield Each Treatment bu.
Untreated checks	5-20	42	1085	362.0	36.2	59.1	59.4	37.6
	5-20	42	1168	389.0	38.9	59.6		
2,4-D spray at 1.5 lbs.	5-21	34	976	325.0	32.5	59.7	59.8	35.9
	5-21	40	1179	393.0	39.3	59.9		
2,4-D spray at 2.0 lbs.	5-22	37	904	301.0	30.1	60.2	60.0	33.3
	5-22	37	1096	365.0	36.5	59.7		
2,4-D spray at 2.5 lbs.	5-22	38	882	294.0	29.4	60.5	60.1	32.5
	5-22	37	1068	356.0	35.6	59.7		
2,4-D spray at 2.0 lbs.	5-23	38	860	287.0	28.7	60.1	59.7	30.6
	5-23	37	975	325.0	32.5	59.2		
2,4-D spray at 3.5 lbs.	5-23	37	969	323.0	32.3	60.0	60.1	34.6
	5-23	37	1105	368.0	36.8	60.2		
2,4-D spray at 4.0 lbs.	5-23	36	858	286.0	28.6	60.2	60.0	30.4
	5-23	36	965	322.0	32.2	59.7		

* Data taken on July 6, 1947 at harvest time

Date of heading was postponed three days by the heaviest treatment. No uniform increase is evident in test weight as rate of application increased, but all the treated plots do have a higher test weight than the untreated check plots.

To get a better comparison of all agronomic data from Tables 7 and 11, an average of these data is presented in Table 12. The untreated checks from Table 11 are added to the total of unweeded checks from Table 7.

Wheat from the same treatments was composited and one sample drawn from each lot, except that three samples were drawn from the unweeded checks. These samples were then given germination and protein tests. Some variation in germination was noted, but this variation was attributed to cracked grain in the samples. Variation in protein of different samples is quite interesting, however. As indicated in column 6, Table 12, nitrogen of grain was calculated to protein per cent by the formula, nitrogen x 6.25. Pounds of protein per acre (column 7, Table 12) was obtained by multiplying column 6 by the number of pounds of grain produced per acre (60 x column 9). Weeded and unweeded checks had approximately the same protein content with 8.1 and 8.0 per cent, respectively, in the threshed grain. Treatments at the rate of one pound of parent acid per acre gave varying increases in protein; the most active 2,4-D materials giving a higher per cent of protein in the grain. Samples 12 to 17 were taken from the various rates of 2,4-D application, and these show the greatest increase in per cent of protein. There is little variation in protein per cent between the different rates. The average protein

TABLE 12. A Compilation of Agronomic Data from Tables 7 and 11. Two Columns Containing Per Cent Germination and Per Cent Protein of Threshed Grain are Added to this Table.

Sample Number	Treatment*	Date Headed	Height of Plant	Germination of Grain	Nitrogen Calc. as Protein **	Nitrogen Calc. as Protein Per Acre	Average Test Weight Each Treatment	Average Yield Each Treatment
		first	in.	pct.	pct.	lbs.	lbs.	bu.
1	Weeded checks (a)	5-20	40	93	8.1	187.1	59.7	38.5
2	Unweeded checks (b)	5-20	40	96	8.3	170.9	59.7	35.6
3				96	7.9			
4				96	7.9			
5	Sodium salt 2,4-D spray	5-20	38	95	8.5	179.0	59.7	35.1
6	Sodium salt 2,4-D dust	5-20	40	93	8.4	171.4	60.0	34.0
7	Methyl ester methoxone spray	5-20	41	97	8.1	164.8	59.9	33.9
8	Acid 2,4-D dust	5-20	39	93	8.4	169.8	59.6	33.7
9	Methyl ester 2,4-D dust	5-20	39	95	8.6	170.8	60.2	33.1
10	Methyl ester 2,4-D spray	5-22	36	94	8.8	165.3	60.2	31.3
11	Acid 2,4-D spray	5-22	34	92	8.7	154.0	60.2	29.5
12	2,4-D spray 1.5 lbs. (c)	5-21	37	97	9.2	198.2	59.8	35.9
13	2,4-D spray 3.5 lbs. (c)	5-23	37	95	9.2	191.0	60.1	34.6
14	2,4-D spray 2.0 lbs. (c)	5-22	37	97	9.2	183.8	60.0	33.3
15	2,4-D spray 2.5 lbs. (c)	5-22	38	95	9.2	179.4	60.1	32.5
16	2,4-D spray 3.0 lbs. (c)	5.23	38	91	9.0	165.2	59.7	30.6
17	2,4-D spray 4.0 lbs. (c)	5-23	36	95	9.3	169.6	60.0	30.4

* Six plots in each treatment unless otherwise indicated

** Formula used in converting nitrogen to protein is: N. X 6.25

(a) Eleven weeded plots

(b) Thirty-two unweeded plots

(c) Two plots in each treatment treated with sodium salt of 2,4-D

content is about 9.2 per cent for grain from treated plants as compared to the 8.1 and 8.0 per cent protein for grain from weeded and unweeded check plots. However, when protein per cent is converted to pounds of protein produced per acre, there is far less variation evident between the different treatments. The different rates of application (samples 12 to 17) show a few more pounds per acre of protein than do the other treatments, but only the 1.5 pound rate of application is materially higher than the weeded check plot. There is a tendency for the amount of protein produced to decrease as yield decreases. The amount of protein varied from 198.2 to 154.0 pounds per acre from different treatments, while weeded checks had 187.1 and unweeded checks had 170.9 pounds per acre. In view of the above figures, it appears that higher protein content of threshed grain from treated plots is due to approximately the same amount of protein being produced by all plots. This more or less equal amount of protein remains in the grain and expresses itself as a higher per cent of protein in lower yielding plots. If such is the case, 2,4-D apparently has little or no influence on the per cent of protein content of grain other than by causing a lower yield of grain.

Test weight for grain in weeded and unweeded checks is the same. This is equaled, except in the case of acid 2,4-D dust, by all treatments, and in most cases it is exceeded from one-tenth to five-tenths of a pound.

In a final analysis of Table 12, it is apparent that protein percent (as calculated from nitrogen) tends to increase as yield decreases, and yield tends to decrease as the amount of 2,4-D applied

is increased.

DISCUSSION

It is obvious, from results contained in this paper, that 2,4-D affects agronomic characters of small grains when the applications are made to young, growing plants. Since the changes in agronomic characters seem to be brought about by internal conditions within the plant, it appears that the explanation for these changes is a physiological one. While the physiological causes for these changes were not investigated, it seems plausible to assume that 2,4-D, when applied to young grain plants, causes a growth response as in weeds. Van Overbeek (23, p. 450) theorizes that application of 2,4-D may cause an exaggerated energy release in the treated plant. He believes that such an energy release could affect the behaviour of a plant and might cause complete cessation of growth.

In view of Van Overbeek's work, the author proposes that a temporary growth response, or release of energy, occurs in a grain plant when 2,4-D is applied. This response is sufficient to cause the plant to undergo a metabolic upset, causing a stunted condition from which the plant never fully recovers. This opinion is advanced as a possible explanation for the reduction in height and decrease in yield of grain plants treated with 2,4-D.

As pointed out in the experimental results, plant height is generally lower on plots treated with 2,4-D than on untreated plots. The evidence is not entirely conclusive, but there is sufficient evidence to indicate that plant height is affected by 2,4-D. From results obtained in 1947, it appears that methyl ester and acid spray

caused the greatest reduction in plant height.

While test weight, date of heading, per cent nitrogen as calculated to protein in grain and per cent germination of seed from small grain plants may or may not be affected by 2,4-D, it is quite safe to assume that yield of grain per acre will be affected. It is shown in this paper that yield of grain is lower from treated plots than from untreated plots. Treated grain, as compared to untreated and weed-free grain, gives a decrease in yield which is statistically significant. When comparing yields of these treated plots to untreated plots, only the more active 2,4-D materials gave significant yield decreases. At this time, the reader is reminded that the main experimental work on which this paper is based was carried on in 1947 on land lightly infested with weeds. As pointed out in the experimental results, the average weed population was approximately one plant to every four square feet. Mr. Virgil H. Freed, associate agronomist, Farm Crops Department, Oregon State College, has made the statement, "Weeds may become a factor in grain fields when they reach the density of one plant per square foot". In view of Mr. Freed's statement, there is a point in weed density beyond which it is practical to spray grain fields. Grain yield will be reduced by application of 2,4-D, but the destruction of weeds will reduce plant competition and provide a corresponding increase in yield. This increase in yield, due to lack of competition from weeds, should more than offset the decrease in yield due to 2,4-D.

It is important to know which 2,4-D materials are most effective on weed plants and at what rate they must be applied. Applying one

pound of parent acid per acre should give control of all susceptible, annual weed plants. Frequent applications of the one-pound amount, rather than larger amounts at one application, should prove the most satisfactory. It is pointed out here that rates lower than one pound of parent acid per acre may be effective on many annual, broad-leaved weeds.

It is generally recognized that sprays are more effective than dusts when applied at the same parent acid rate. This is probably due to the amount of drift from dust, to its failure to adhere to plant parts as well as sprays do, and also to the fact that certain dust carriers may adsorb some of the active 2,4-D acid. Certain of the 2,4-D chemicals appear to be more active than others. Methyl ester preparations and the acids seem to have more effect on plants than do salt preparations, such as sodium salt.

SUMMARY AND CONCLUSIONS

Experiments were conducted during the summer of 1946, during the winter of 1946-1947, and during the summer of 1947 to determine the effect of 2,4-D on small grains and certain annual weeds.

In reviewing the results of this work, it appears that sprays have a more harmful effect on small grain than dusts when both are applied at the same parent acid rate. Acid and methyl ester materials of 2,4-D were more active and showed more effect on grain and weeds than did the sodium salt.

Plant height was retarded when 2,4-D was applied. In some instances, date of heading in grain was retarded for a day or two. Test weights were affected very little by 2,4-D, although there was a general tendency for them to increase as yields decreased. Grain from treated plants was normal in appearance and its germination did not seem to be inhibited.

Results in Table 12 indicate an increase in protein per cent of grain when 2,4-D is applied to the growing plant. This increase reached its maximum at the 1.5 pound rate of application. This percentage increase of protein is attributed to the effect of 2,4-D in causing lower yields and thus a higher per cent of protein in the grain, rather than to the fact that treating with 2,4-D causes a plant to produce more protein than an untreated plant.

Each experiment in this paper indicates some reduction in yield to the grain crop as a result of using 2,4-D. Yield was generally reduced more by use of sprays than by use of dust. It was

generally reduced gradually as the amount of 2,4-D used was increased.

Most annual broad-leaved weeds were held in check or killed by application of 2,4-D. This is to be expected since applications at the rate of one pound of parent acid per acre, using either a dust or spray, are usually strong enough to control such annual weeds as fan weed and mustard. Some perennial weeds like morning glory and Canada thistle are very difficult to control and more work must be done with them before satisfactory control measures can be recommended.

Summarizing results of experimental work reported in this paper has led the author to draw the following conclusions:

Sprays are more harmful to grain and weed plants than dusts when applied at the same parent acid rate.

Height of grain plants is inhibited by application of 2,4-D.

Germination of threshed grain from plants treated with 2,4-D is apparently not affected.

Protein per cent (nitrogen calculated to protein) of threshed grain, from plants treated with 2,4-D, is increased by applications of from one to one and a half pounds of parent acid per acre.

Test weight of grain is affected very little, but there is a tendency for it to increase as yield decreases.

Date of heading is prolonged for a day or two by application of some 2,4-D preparations, but this difference may not be significant.

Grain yield is reduced when 2,4-D is applied to growing plants.

Head abnormalities of grain were noted in plots treated in 1947, but no sterile heads were found.

Application of 2,4-D to grain where weeds are not a definite

factor would be economically unsound, as reduction in grain yield might result.

If weeds are a definite factor in reducing grain yield and the prevention of their spread is necessary, use of 2,4-D plus proper tillage methods should be recommended as control measures.

Most annual broad-leaved weeds are controlled quite satisfactorily by application of 2,4-D at the rate of one pound of parent acid per acre.

No conclusions are drawn as to recommendations for applying 2,4-D to perennial weeds.

1. Barr, H. T. and Brown, C. A. Weed control with 2,4-D. Agricultural engineering 28: 341-342, Aug. 1947.

2. Crafts, A. S. The 2,4-D weed killers. A warning. California Department of Agriculture bulletin 35: 34-36, 1946.

3. Dow Chemical Company. 2,4-D holds spotlight at weed control conference. Illinois horticulture 35: 8, April 1946.

4. Hamner, C. L. and Tukey, H. B. Selective herbicidal action of midsummer and fall applications of 2,4-Dichlorophenoxyacetic acid. Botanical gazette 106. 232-245, Dec. 1944.

5. Hsueh, Y. L. and Lau, C. H. Effects of 2,4-D on seed germination and respiration. Science 105: 283-285, 1947.

6. Kephart, L. W. Where does 2,4-D pay? Successful farming 45: 38 and 83-84, March 1947.

7. Klingman, D. L. Effects of spraying cereals with 2,4-Dichlorophenoxyacetic acid. Journal of American society of agronomy 39: 445-447, May 1947.

8. Kraus, E. J. and Mitchell, J. W. Growth-regulating substances as herbicides. Botanical gazette 108: 301-349, March 1947.

9. Marth, P. C. and Davis, F. F. Relation of temperature to the selective herbicidal effects of 2,4-Dichlorophenoxyacetic acid. Botanical gazette 106: 463-472, June 1945.

10. Marth, P. C. and Mitchell, J. W. 2,4-Dichlorophenoxyacetic acid as a differential herbicide. Botanical gazette 106: 224-232, Dec. 1944.

11. Marth, P. C. and Mitchell, J. W. Period of effective weed control by the use of 2,4-Dichlorophenoxyacetic acid. Science 104: 77-79, July 1946.

12. Marth, P. C., Toole, V. K. and Toole, E. H. Influence of 2,4-D spray applications on vegetative growth and seed development in timothy. Journal of American society of agronomy 39: 780-783, Sept. 1947.

13. Mitchell, J. W. and Brown, J. W. Effect of 2,4-Dichlorophenoxyacetic acid on the readily available carbohydrate constituents in annual morning glory. Botanical gazette 107: 120-129, Sept. 1945.

14. Mitchell, J. W. and Brown, J. W. Movement of 2,4-Dichlorophenoxyacetic acid stimulus and its relation to the translocation of organic food materials in plants. Botanical gazette 107: 393-407, March 1946.

15. Mitchell, J. W. and Marth, P. C. Effects of 2,4-Dichlorophenoxyacetic acid on the growth of grass plants. Botanical gazette 107: 276-284, Dec. 1945.

16. Mitchell, J. W. and Marth, P. C. Germination of seeds in soil containing 2,4-Dichlorophenoxyacetic acid. Botanical gazette 107: 408-416, March 1946.

17. Nutman, P. S., Thornton, H. G. and Quastel, J. H. Inhibition of plant growth by 2,4-Dichlorophenoxyacetic acid and other plant-growth substances. Nature 155: 498-500, 1945.

18. Rasmussen, L. W. The physiological action of 2,4-Dichlorophenoxyacetic acid on dandelion. Plant physiology 22: 377-392, Oct. 1947.

19. Taylor, D. L. Observations on the growth of certain plants in nurtient solutions containing synthetic growth-regulating substances. Botanical gazette 107: 597-611, June 1946.

20. Tingey, D. C. and Evans, R. J. 2,4-D for weed control in Utah. Farm and home science, Utah agricultural experiment station 8: 1 and 19-20, June 1947.

21. Tukey, H. B., Hamner, C. L. and Imhofe, B. Histological changes in bindweed and sow thistle following applications of 2,4-Dichlorophenoxyacetic acid in herbicidal concentrations. Botanical gazette 107: 62-73, Sept. 1945.

22. U. S. Department of Agriculture page. 2,4-D knocks weeds out of small grains. Country gentleman 117: 28, March 1947.

23. Van Overbeek, J. Use of synthetic hormones as weed killers in tropical agriculture. Economic botany 1: 446-459, 1947.

24. Willard, C. J. How are farmers using 2,4-D? Successful farming 45: 31 and 52-53, July 1947.

25. Willard, C. J. Using 2,4-D for weed control. Hoard's dairyman 92: 429, 445 and 452, May 1947.

26. Willard, C. J. and Welton, F. A. Killing weeds with 2,4-D. Farm and home research, Ohio agricultural experiment station 32: 31-42, 1947.