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A Comparison of Aerial and Ground Application of 2,4-D, Using Different Formulations and Rates of 2,4-D, and Different Kinds and Volumes of Carrier

Russel L. Nash

A Comparison of Aerial and Ground Application of 2,4-D, Using Different Formulations and Rates of 2,4-D and Different Kinds and Volumes of Carrier

By

Russel L. Nash

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A COMPARISON OF AERIAL AND GROUND APPLICATION OF 2,4 D USING DIFFERENT FORMULATIONS AND RATES OF 2,4-D AND DIFFERENT KINDS AND VOLUMES OF CARRIER

This thesis is approved as a creditable, independent investigation by a candidate for the degree, Master of Science, and acceptable as meeting the thesis requirements for this degree; but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Advisor

Head of the Major Department

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INTRODUCTION

In the years that 2,4-D[1] has been used as a selective herbicide in agricultural areas, an increasing number of reports of injury to crops has been reported. As a result of extensive investigations, lists of susceptible and resistant crops have appeared. Many crops have been found to be extremely susceptible to 2,4-D and morphological injuries of small grain may be just as severe at certain stages of development. Wheat is no exception.

In South Dakota several cases of injury to wheat from airplane application of 2,4-D by commercial applicators were reported. Some 120,000 acres of wheat were sprayed in South Dakota by commercial airplane applicators in 1953. Wheat growers, farm advisors, and research workers in weed control could not explain (1) why the injury was so variable in certain wheat growing regions during a given season, (2) why injury was not serious during some seasons and was an important factor in reduction of yields in others, (3) the conditions under which the injury occurred, (4) why no damage to wheat was reported from ground spraying, and (5) how injury might be prevented. Thus an investigation was begun in 1952 in South Dakota (20) to answer these questions. This study is a continuation of that investigation.

Since very little research data concerning aerial application were available, it seemed that present recommendations should be reviewed in order to determine the cause of such damage and perhaps the need for separate recommendations for ground and aerial spraying.

Research and practical information presently available can be used

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[1] 2,4-Dichlorophenoxyacetic acid

to make predictions of the probable extent of drift based on such factors as nozzle design, pressure, temperature, wind velocity, etc. However, no simple regulation has been formulated which will insure complete freedom from drift damage and still permit unrestrained use of 2,4-D. Specific information is needed in treating our type of crops for the type of problems which we encounter.

The objectives of this study were:

(1) To compare the effect of aerial and ground application of 2,4-D on wheat yields and control of annual weeds (a) when different volumes of oil and water were used as a carrier, (b) when different esters of 2,4-D were used and (c) when several rates of 2,4-D were applied per acre.

(2) To determine the percentage of spray retained by wheat when applied by aerial and ground sprayers in several volumes of oil and water as carrier and to correlate this percentage with crop yield.

(3) To compare water and two oils as carriers for aerial application of 2,4-D.

(4) To compare aerial spray patterns when several carriers at different volumes were used.

(5) To correlate environmental factors at time of treatment with the effect of commercial aerial applications of 2,4-D on crop yield.

(6) To compare the driftability of 2,4-D forms when applied by an aerial sprayer.

REVIEW OF LITERATURE

The most apparent difference between air and ground application of sprays is the volume of carrier used per acre. The larger volumes usually give larger spray particles which tend to drop to the ground more rapidly and roll off the leaves of plants more easily. The smaller volume applied by air leaves the spray boom in small droplets that are broken up into minute particles by air turbulences. They may hang in the air longer and increase evaporation and they may not roll off the leaves as easily as large droplets, which in turn might affect the amount of spray retained on the leaves.

Shafer (18) has found extreme lack of uniformity in the spray pattern delivered from an airplane with variations as great as 1:10 when comparing locations across the swath. These variations have been attributed to turbulent areas which are set up by the propeller, the fuselage and the wing tips. Fogg (12) showed that distinct and sometimes considerable variation in the degree of wetting of leaves by water may occur not only between species or varieties but also from place to place on the same plant and within a short period of time on the same leaf.

Blackman (6) found that the total amount of herbicide retained by the plant, when applied uniformly, is an important factor in determining the net effect of application. Characteristics of spray, such as droplet size, velocity of the droplets and surface tension can be altered, but characteristics of the plant cannot. Thus spray retention is dependent upon the characteristics of the plant. Crafts (8) pointed out that grasses are difficult to wet with water, that plants with a spreading open structure may be almost completely wet by aqueous sprays. Oils generally used, have low viscosities and surface tension and wet plants by spreading out and creeping downward. The surfaces of cereal leaves are usually minutely ridged and are covered with a cuticle of minute particles of waxy bloom making it difficult for spray to be retained. Broad-leaved plants spread out more and the leaves are not as vertical as with grassy plants.

Ennis, Williamson and Dorschner (10) suggest that the selectivity of herbicidal sprays may be improved by exercising care in choosing the form of herbicide and carrier used. Retention of droplets of different liquids varied considerably. Sprays with surface-acting agents were retained better than wholly aqueous sprays. Leaves in a horizontal position retained more spray than when at a 45-degree angle. Ennis (9) also states that oil and oil-emulsion sprays of 2,4-D and 2,4,5-T were more inhibitory to soybeans than wholly aqueous sprays. The inhibitory effectiveness was improved by incorporating five per cent of emulsified oil into the formulation.

Holly (14) found that the more carrier that was used the less the amount of agent that was retained on barley. He found that approximately 3.5 times the amount of agent was retained on barley at ten gallons per acre as at 175 gallons per acre.

Wallace (20) found little consistent difference between water and oil as carriers, and between aerial and ground application as affecting yield of wheat. The most consistent treatment was an oil application by air at five gallons per acre which gave significant increases in five out of six treatments thus applied. His results show that, in a year when there is ample soil moisture, spraying does not increase wheat yields by controlling weeds, but that harvesting is facilitated. His data also indicate that at least one-third pound of 2,4-D per acre and probably more is needed to prevent regrowth of sunflowers.

Several workers have done work concerning spray retention. Woofter and Lamb (21) incorporated dyes into the spray solution, then took samples of sprayed plants and washed them with water and determined the concentration of dye with a colorimeter.

Saunders (17) incorporated dyes into sprays and dusts and collected samples on pans representing one twenty-thousandths of an acre, washed the pans with water and measured the concentration of dye with photometric equipment.

Buchholts (7) placed one-inch by three-inch glass slides in the area to be sprayed. After spraying, the slides were washed with water and the concentration of dye measured with a spectrophotometer as described by Bandurski (4).

Greenshields and White (13) found that sweet clover seed yield was reduced by shedding of the leaves, stems and flowers caused by drift, even at a distance of 96 rods with a 15-17 mile per hour wind. The drift did not kill the plants but delayed maturity of the seed. Seed quality improved with distance from sprayed area.

Young (22), using tomato plants as indicators, found that oil as a carrier increased drift in all cases. Other workers using tomato plants to determine drift and volatility of 2,4-D were Anderson and Mantell (3), Baskin and Walker (5), Fawcett, et al. (11), Mullison (16) and Zimmerman, et al. (23).

Shanks (19) showed that particles below 50 microns in diameter are undesirable where drift may occur. With volatile sprays, a secondary application results from evaporation. Low gallonage spraying involves a loss of spray material and increases drift hazard.

Akesson (1) states that a field under question should not be sprayed if susceptible commercial crop is within one-half mile in any direction. No turns during treatment, take-offs, or landings should be permitted over any susceptible crop.

Since this study consists of six experiments, this manuscript will depart somewhat from the usual outline of a research paper. In order to lend better continuity, each part of the study will be presented separately as far as "Materials and Methods" and "Results" are concerned. The "Discussion" and "Summary" will serve to tie the several parts together.

PART A - VOLUMES OF SPRAY PER ACRE

Materials and Methods

Six replicates of plots (plot size of 50' X 60' for air and 20' X 60' for ground) were treated with a n-butyl ester of 2,4-D at one-third pound acid equivalent per acre at two locations (Strool and Huron, South Dakota) using water and oil as carriers. Volumes of one-half, one, and two gallons per acre of oil and water were applied by airplane and the two-, five- and ten-gallon volumes were applied in oil and water by ground rig except that a ten-gallon volume of oil was not applied. Split-plot design was used, with volumes as main plots and treatments as sub-plots. Applications were made June 3 and June 4 at Strool (in northwestern S. D.) and June 9 at Huron (in central S. D.). Wheat was in the 5-leaf stage at the time of application and moderately infested with annual weeds. The oil used as carrier was heater oil (No. 1 diesel fuel).

Due to size of plots necessary for air application, complete randomization was not possible. Because of the large area covered, some variation no doubt resulted due to soil heterogeneity. A diagram of the design is given in Figure 1 and treatments are given in Table 1.

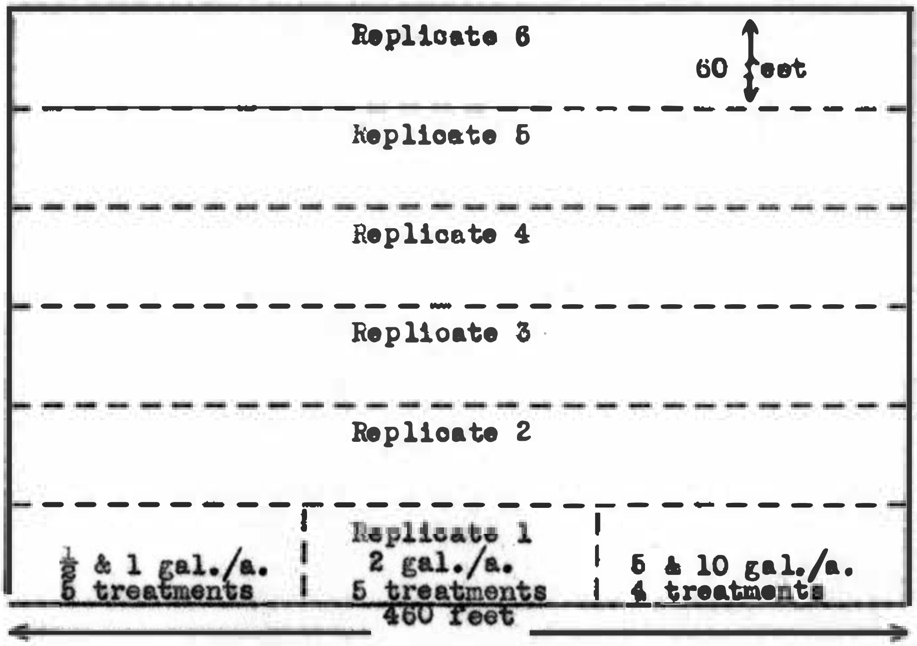

Figure 1. Field Plot Design Used in Comparing Five Different Volumes of Carrier Applied by Air and by Ground Showing Six Replicates. The First Replicate is Divided into Three Main Plots. Treatments for Each Main Plot are Given in Table 1.

Table 1. List of Treatments made in Comparing Different Volumes of Carrier per Acre Using One-third Pound Acid Equivalent per Acre of Butyl Ester 2,4-D at Strool and Huron.

Gal./A. Carrier	Kind of Carrier	Applicator
1/2	oil	air
1/2	water	air
1	oil	air
1	water	air
-	-	-
2	oil	air
2	water	air
2	oil	ground
2	water	ground
-	-	-
5	oil	ground
5	water	ground
10	water	ground
-	-	-

Spray retention studies were carried out by incorporating blue dye in the spray solution. Dupont oil blue A dye at two-tenths percent was used with oil as the carrier and Dupont Anthraquinone blue B dye at four-tenths percent was used with water as the carrier.

At the time of treatment three square-yard samples of wheat (one in the center and one toward each edge of the spray pattern) were taken from each of the first three replications. The samples from each of the three replicates were washed separately with either one-hundred or two-hundred milliliters of the carrier, the amount depending on the size of the sample being washed. Samples of the wash solution were taken at both locations.

Concentration of dye in these samples was determined by making colorimeter readings in the laboratory and comparing them with a curve plotted from readings of a series of known concentrations of the same dye. The amount of dye retained was then calculated and divided by the amount applied to the area sampled to give percentage of spray retention. These data were then analysed statistically.

At time of treatment a piece of adding machine tape was placed across the spray path of each plot sprayed by airplane on which spray retention studies were to be made. These tapes were to serve two purposes: first, to determine if the spray pattern was being deposited within the desired plot, second, to determine whether spray deposit was uniform.

Just prior to harvest, injury to wild buckwheat and lamb's quarters was recorded for weeds present at that time. The following index of injury was used in recording weed reactions to treatment and will be used in tables of this manuscript pertaining to these reactions:

0 Weed not present
1 Dead and brown
2 Stunted - no regrowth
3 Stunted, but growing
4 Shows no damage

Five square-yard samples were harvested and bulked from each plot at both locations. These samples were threshed and the weight per bushel and sample weight were recorded. Yield in bushels per acre was then calculated and analysed statistically.

Results

No visible damage from spraying was detectable on the wheat prior to harvest; however, statistical analyses of the yields and percentage of spray retention showed some significant differences. The differences at Strool are not in complete agreement with those at Huron. The wheat at both locations was heavily infested with stem rust at harvest time and possibly this could have had a masking effect on differences in yield due to treatments since the wheat grown at Strool was of the variety Mida and that at Huron, Rushmore, a variety that is less susceptible to rust.

The correlations between wheat yields and percentage of spray retention gave "r" values of 0.114 at Strool and 0.257 at Huron. Neither correlation was significant. Possibly the technique used in washing the samples accounted for the low percentage of spray retention as many of the samples were quite large in relation to the amount of wash used.

The mean wheat yields and percentage of spray retention are given in Table 2 and the analyses of variance in Table 3.

Table 2. The Mean Wheat Yields in Bushels per Acre and Percentage of Spray Retention when Treatment was made with Five Different Volumes of Carrier.

	Strool		Huron	
Volumes/A.	Yield	% Ret.	Yield	% Ret.
½ gal.	9.1	24.8	8.9	12.0
1 gal.	6.1	9.0	8.3	15.6
Mean	7.6	16.9	8.6	13.8
2 gal. (air)	5.5	2.9	6.9	13.5
2 gal. (ground)	5.8	9.6	7.9	9.1
Mean	5.7	6.3	7.4	11.3
5 gal.	5.7	13.7	6.5	11.0
10 gal.	6.0	20.0	5.8	7.6
Mean	5.9	16.9	6.2	9.3

Table 3. Analyses of Variance of Wheat Yields and Percentage of Spray Retention when Treatment was made with Five Different Volumes of Carrier.

	Strool				Huron			
	Yield		% Ret.		Yield		% Ret.	
Source of Variation	d f	M S	d f	M S	d f	M S	d f	M S
Total	83	5.09	32	129.99	83	4.11	29	38.23
Reps.	5	10.16	2	6.14	5	2.55	2	8.14
Among volumes	2	26.90	2	397.21**	2	29.53**	2	46.16
½, 1 & 2 vs 5 & 10	1	5.8	1	112.81	1	45.13**	1	41.19
½ & 1 vs 2	1	51.9*	1	681.6**	1	13.92	1	51.12
Error A	10	7.58	4	16.06	10	3.23	4	6.72
Within volumes	11	8.03**	8	382.99**	11	3.92	7	115.82**
Error B	55	2.72	16	14.04	55	3.52	14	11.59

* Significant at .05 level
** Significant at .01 level

Variance for treatments among volumes showed significant differences at Huron only for wheat yields and at Strool only for percentage of spray retention. The comparison of one-half and one-gallon versus two-gallon volumes showed a significantly lower wheat yield and lower percentage of spray retention for the two-gallon volumes at Strool, but no significant differences at Huron.

The comparison of one-half-, one- and two-gallon volumes versus the five- and ten-gallon volumes showed wheat yields to be significantly higher for the smaller volumes at Huron, but no differences in yield were present at Strool.

Variance for treatments within volumes showed there were significant differences for wheat yields at Strool, but not at Huron; however, there were significant differences in percentage of spray retention at both Strool and Huron. The within volumes variance was subdivided into its component parts and presented separately for each volume.

Within One-half- and One-gallon Volumes

Mean wheat yields and percentage of spray retention for the one-half- and one-gallon-per-acre volumes are given in Table 4 and the subdivision of analyses of variance is presented in Table 5.

Table 4. Mean Wheat Yields in Bushels per Acre and Percentage of Spray Retention when One-half and One Gallon of Carrier per Acre were Used to Apply One-third Pound of 2,4-D* Acid Equivalent per Acre by Air at Two Locations Using Oil and Water as Carriers.

	Strool		Huron	
Treatment	Yield	% Ret.	Yield	% Ret.
½ gal. oil	10.4	9.4	9.3	8.2
½ gal. water	7.8	40.5	8.5	15.7
Mean ½ gal.	9.1	24.9	8.9	12.0
1 gal. oil	6.6	4.9	9.5	25.1
1 gal. water	5.6	13.1	7.1	6.0
Mean 1 gal.	6.1	9.0	8.3	15.6
Mean treatments	7.6	16.9	8.6	13.8
Untreated	6.7		8.1	

* Butyl ester of 2,4-D

Table 5. Subdivision of Analyses of Variance of Wheat Yields and Percentage of Spray Retention when One-half- and One-gallon Volumes were Used to Apply One-third Pound of 2,4-D Acid Equivalent per Acre by Air at Two Locations Using Oil and Water as Carriers.

	Strool				Huron			
	Yield		% Ret.		Yield		% Ret.	
Source of Variation	df	MS	df	MS	df	MS	df	MS
Within ½ & 1 volumes	4	19.88**	3	761.7**	4	5.8	3	223.36**
Treated vs untreated	1	3.85			1	1.2		
½ gal. vs 1 gal.	1	52.51**	1	748.92**	1	2.28	1	39.24
½ gal. oil vs ½ gal. water	1	20.54*	1	1435.31**	1	1.66	1	83.63*
1 gal. oil vs 1 gal. water	1	2.61	1	100.87	1	18.01	1	547.22**
Error	20	3.04	6	24.84	20	5.47	6	12.90

* Significantly different at .05 level.
** Significantly different at .01 level.

Variance for treatments within one-half- and one-gallon volumes showed significant differences for wheat yield at Strool, but not at Huron. Variance for percentage of spray retention showed significant differences at both locations.

There was no significant difference between the untreated and treated plots.

The comparison of the one-half-gallon versus the one-gallon volume showed significantly higher wheat yield and percentage of spray retention on plots treated with one-half gallon per acre at Strool but no significant difference at Huron.

The comparison of one-half gallon of oil with one-half gallon of water per acre showed significantly higher wheat yields on plots treated with oil at Strool, while the percentage of spray retention was significantly higher on plots treated with water at both Strool and Huron. These data indicate that a higher percentage of spray retention results in lower yields.

The comparison of one gallon of oil with one gallon of water per acre gave no significant difference in wheat yields at either location, but at Huron one gallon of oil per acre gave a significantly higher percentage of spray retention than the one gallon of water.

Within Two-gallon Volumes

Mean wheat yields and percentage of spray retention for the two-gallon-per-acre volume are given in Table 6 and the subdivision of analyses of variance is presented in Table 7.

Table 6. Mean Wheat Yields in Bushels per Acre and Percentage of Spray Retention when Two Gallons of Carrier were Used to Apply One-third Pound of 2,4-D Acid Equivalent per Acre by Ground and by Air at Two Locations Using Oil and Water as Carriers.

	Strool		Huron	
Treatments	Yield	% Ret.	Yield	% Ret.
2 gal. oil (air)	5.5	2.8	---	---
2 gal. water (air)	5.6	3.0	6.9	13.5
Mean	5.6	2.9	6.9	13.5
2 gal. oil (ground)	5.3	10.4	7.2	7.6
2 gal. water (ground)	6.4	8.8	8.6	10.6
Mean	5.9	9.6	7.9	9.1
Total treatments mean	5.7	6.3	7.4	10.0
Untreated	5.0		8.2	

Variance for treatments within the two-gallon-per-acre volume showed no significant difference in wheat yields at either Strool or Huron. Variance for percentage of spray retention within the two-gallon volume showed there were significant differences at Strool.

There was no significant difference in wheat yield between the treated plots and the untreated at either location, nor was there any significant difference between the two untreated plots at Huron. (Due to a mechanical failure on the airplane at Huron, 2,4-D was not applied

Table 7. Subdivision of Analyses of Variance of Wheat Yields and Percentage of Spray Retention when Two Gallons of Carrier were Used to Apply One-third Pound of 2,4-D Acid Equivalent per Acre by Air and by Ground at Two Locations Using Oil and Water as Carriers.

	Strool				Huron			
	Yield		% Ret.		Yield		% Ret.	
Source of Variation	d f	M S	d f	M S	d f	M S	d f	M S
Within 2 gal. vol.	4	1.71	3	45.91**	4	3.82	2	26.11
Treated vs untreated	1	2.47			1	.18		
Untreated vs untreated					1	5.20		
Air vs ground	1	.60	1	134.00**	1	4.41	1	39.01
Oil ground vs water ground	1	3.74	1	3.68	1	5.60	1	13.20
Oil air vs water air	1	.02	1	.06				
Error	20	2.14	6	3.65	20	2.40	4	17.74

** Significant at .01 level.

in two gallons of oil per acre, consequently there were two untreated plots in each replicate).

In the comparison of aerial spraying with ground application there was no significant difference in wheat yields at either location, however, the ground application gave significantly higher percentage of spray retention at Strool.

Within Five- and Ten-gallon Volumes

Mean wheat yields and percentage of spray retention for the five- and ten-gallon-per-acre volumes are given in Table 8 and the subdivision of analyses of variance is presented in Table 9.

Variance for treatments within the five- and ten-gallon-per-acre volumes showed significant differences for percentage of spray retention at both Strool and Huron, but no significant differences were found in wheat yields at either location.

Table 8. Mean Wheat Yields in Bushels per Acre and Percentage of Spray Retention when Five and Ten Gallons of Carrier were Used to Apply One-third Pound of 2,4-D Acid Equivalent per Acre by Ground at Two Locations Using Water and Oil at the Five-gallon Volume and Water only at the Ten-gallon Volume.

	Strool		Huron	
Treatment	Yield	% Ret.	Yield	% Ret.
5 gal. oil	5.8	4.0	6.6	7.6
5 gal. water	5.5	23.3	6.3	14.3
5 gal. mean	5.7	13.7	6.5	11.0
10 gal. water	6.0	20.0	5.8	7.6
Total treatment mean	5.9	16.9	6.2	9.3
Untreated	6.3		6.8	

Table 9. Subdivision of Analyses of Variance of Wheat Yields and Percentage of Spray Retention when Five and Ten Gallons of Carrier were Used to Apply One-third Pound of 2,4-D Acid Equivalent per Acre by Ground at Two Locations.

	Strool				Huron			
	Yield		% Ret.		Yield		% Ret.	
Source of Variation	d f	M S	d f	M S	d f	M S	d f	M S
Within 5 & 10 gal. vol.	3	.64	2	320.54**	3	1.57	3	44.23*
Treated vs untreated	1	1.36			1	1.20		
5 gal. vs 10 gal.	1	.42	1	82.34	1	1.82	1	22.45
5 gal. oil vs 5 gal. water	1	.14	1	558.74**	1	1.69	1	66.00*
Error	15	2.74	4	13.50	15	2.42	4	3.50

* Significant at .05 level.
** Significant at .01 level.

In comparing treated plots with the untreated no significant differences were found for wheat yields at either location.

In comparing the five-gallon volume with the ten-gallon-per-acre volume, no significant difference was found in wheat yields or in percentage of spray retention at either Strool or Huron.

The comparison of five gallons per acre of oil with five gallons per acre of water gave no significant difference in wheat yields at either location, but the five-gallon volume per acre of water gave significantly higher percentage of spray retention than the five-gallon-per-acre volume of oil at both Strool and Huron.

Effect of Treatment on Wild Buckwheat and Lamb's Quarters

The reactions of wild buckwheat and lamb's quarters to treatments are presented in Table 10.

Wild buckwheat was not completely killed by any treatment, but was stunted so much by all treatments that it did not interfere with harvest operations. Lamb's quarters was either completely killed or stunted to the extent that no regrowth occurred by all treatments except the two-gallon-per-acre volume of carrier at Strool where all lamb's quarters were at least stunted enough to prevent seed production. Differences in the reactions of the wild buckwheat and the lamb's quarters were not important from a weed control standpoint; therefore, statistical analysis was not applied.

Table 10. Mean Index of Injury* Recorded for Wild Buckwheat and Lamb's Quarters at Harvest Time when One-third Pound of 2,4-D Acid Equivalent per Acre** was applied with Five Different Volumes of Carrier at Strool and Huron.

Carrier	Volume	Applicator	Wild Buckwheat Strool	Wild Buckwheat Huron	Wild Buckwheat Mean	Lamb's Quarters Strool	Lamb's Quarters Huron	Lamb's Quarters Mean
Oil	½	air	2.0	2.8	2.4	1.0	1.0	1.0
Water	½	air	3.0	1.2	2.1	2.0	1.0	1.5
Oil	1	air	3.0	2.6	2.8	1.0	1.0	1.0
Water	1	air	3.0	3.0	3.0	1.0	1.5	1.2
Mean ½ and 1			2.8	2.4	2.6	1.2	1.1	1.1
Untreated			3.3	3.2	3.2	1.0	1.0	1.0
Oil	2	air	3.0	---	3.0	3.0	---	3.0
Water	2	air	4.0	3.2	3.6	2.0	1.0	1.5
Oil	2	ground	2.7	2.7	2.7	2.5	1.0	1.7
Water	2	ground	1.8	3.2	2.5	1.3	1.2	1.2
Mean 2			2.9	3.0	2.2	2.2	1.1	1.6
Untreated			3.2	3.8	3.5	3.2	3.7	3.4
Oil	5	ground	3.4	3.0	3.2	2.7	1.0	1.8
Water	5	ground	2.2	2.0	2.1	1.3	1.0	1.1
Water	10	ground	1.6	2.6	2.1	1.5	1.0	1.2
Mean 5 and 10			2.4	2.5	2.4	1.8	1.0	1.4
Untreated			3.0	3.0	3.0	1.5	1.4	1.4

* 0., weed not present; 1. dead and brown; 2, stunted, no regrowth; 3, stunted, but growing; 4, shows no damage.
** Butyl ester of 2,4-D, six pounds per gallon.

Spray Patterns

Photographs of sections cut from adding machine tapes used in recording aerial spray patterns are presented for one-half gallon of oil and one-half gallon of water in Plate 1, one gallon of oil and one gallon of water in Plate 2, and two gallons of oil and two gallons of water in Plate 3.

These photographs show wide variations in spray pattern at different points across the spray swath. In nearly every case more spray was deposited toward the left side of the airplane. With the one-gallon-per-acre volume there was less spray deposited in the center of the spray swath. The two-gallon volumes per acre gave a fairly uniform pattern, probably due to the size of the spray droplets being deposited. The larger droplets tend to drop straight down and do not drift as far as the smaller droplets resulting from smaller volumes of application. There was very little difference in spray patterns between the oil and water as carriers with any of these volumes used.

PART B - FORMULATIONS OF 2,4-D

Materials and Methods

Six replicates with plots of the same size as used in Part A were treated with three formulations of 2,4-D at one-third pound acid equivalent per acre at both Strool and Huron at the same time as treatment was made in Part A. A randomized block design was used. Due to the size of the plots necessary for air application, complete randomization was not possible. A diagram of the plot design is given in Figure 2 and treatments are given in Table 11.

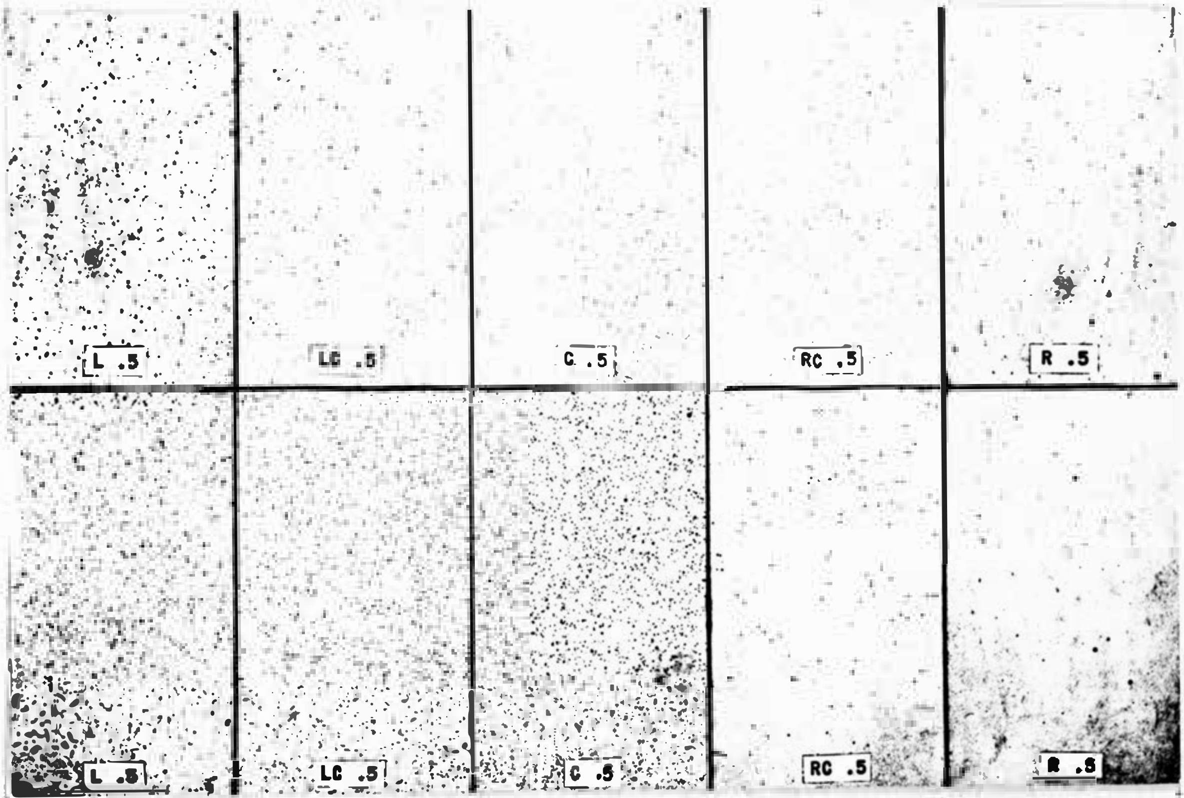

Plate 1. Six-inch sections cut from adding machine tape which was placed across plots sprayed by airplane with one-half gallon of oil per acre (upper) and one-half gallon of water per acre (lower) as carrier. L, 20 feet left of center of the spray swath; LC, 10 feet left of center; C, center; RC, 10 feet right of center; R, 20 feet right of center. Pictures show tapes reduced to approximately one-third actual size. A slight breeze was blowing from the right when oil was applied; wind was nil when water was applied.

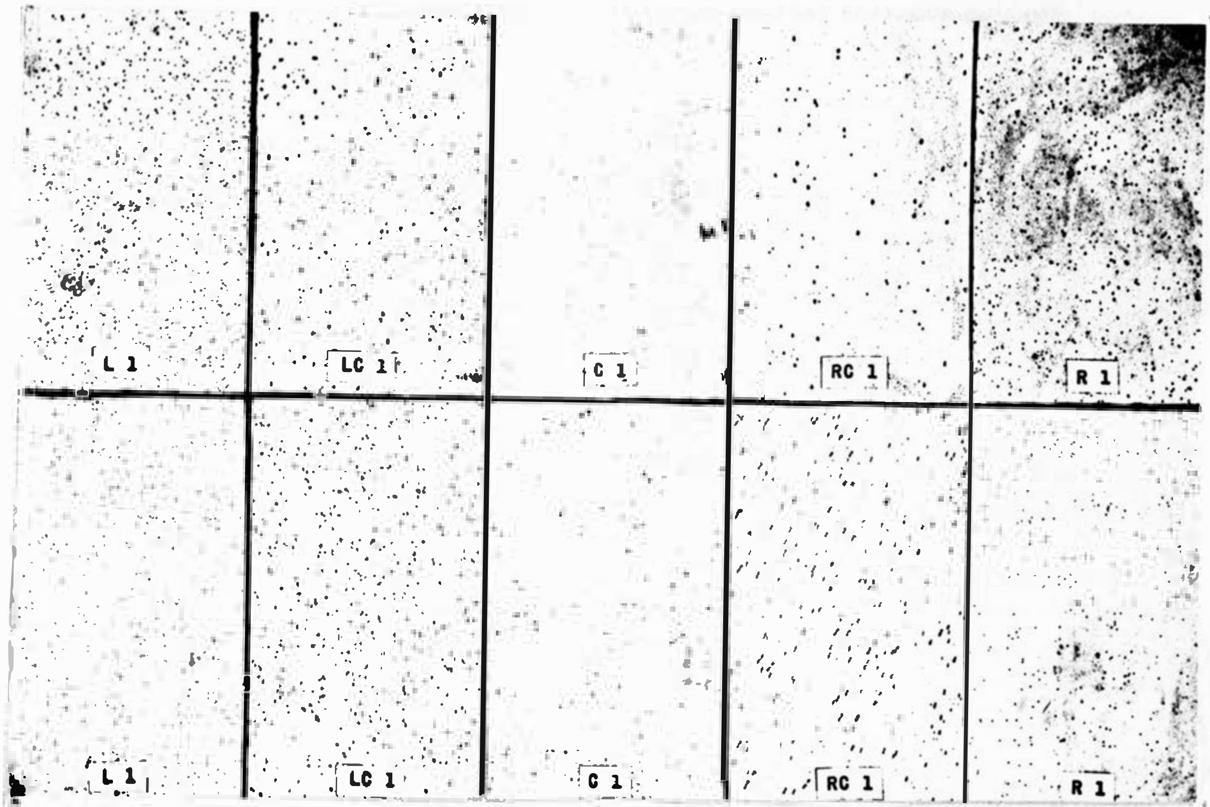

Plate 2. Six-inch sections cut from adding machine tape which was placed across plots sprayed by airplane with one gallon of oil per acre (upper) and one gallon of water per acre (lower) as carrier. L, 20 feet left of center of the spray swath; LC, 10 feet left of center; C, center; RC, 10 feet right of center; R, 20 feet right of center. Pictures show tapes reduced to approximately one-third actual size. Wind was practically nil.

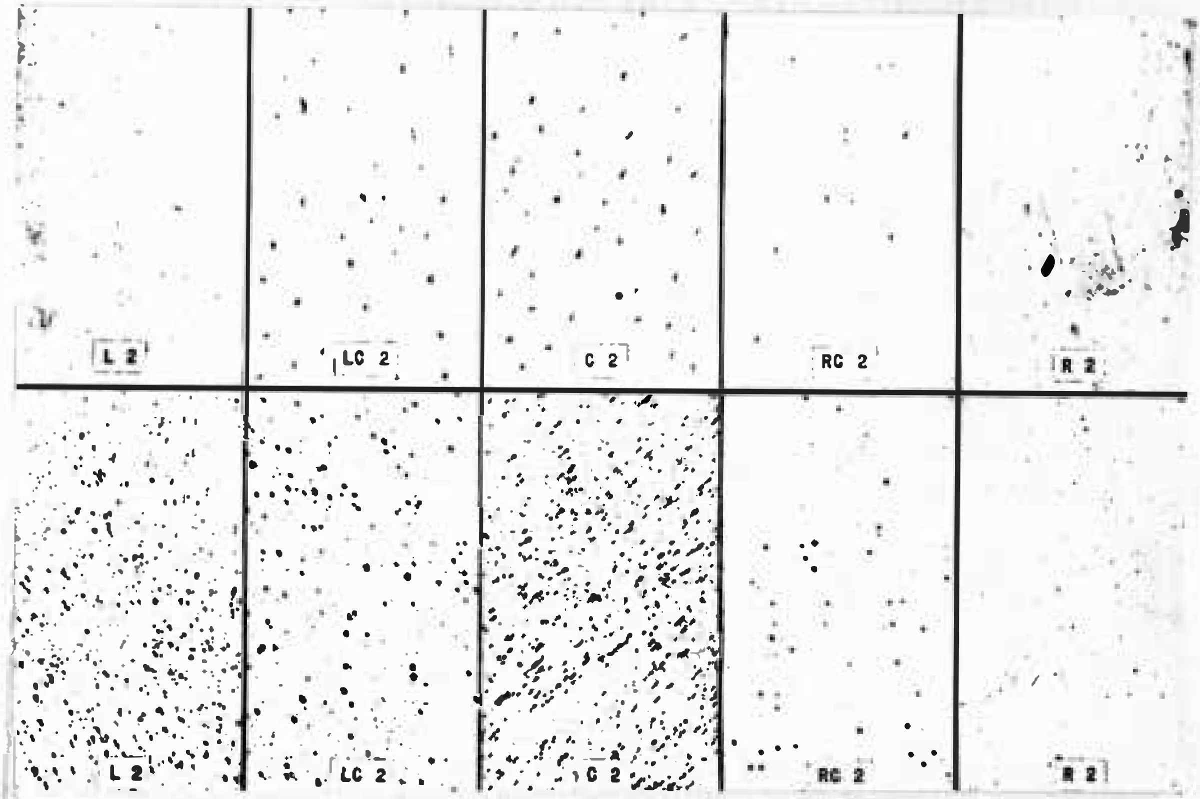

Plate 3. Six-inch sections cut from adding machine tape which was placed across plots sprayed by airplane with two gallon of oil per acre (upper) and two gallon of water per acre (lower) as carrier. L, 20 feet left of center of the spray swath; LC, 10 feet left of center; C, center; RC, 10 feet right of center; R, 20 feet right of center. Pictures show tapes reduced to approximately one-third actual size. Wind was practically nil when oil was applied; a slight breeze was blowing from the right when water was applied.

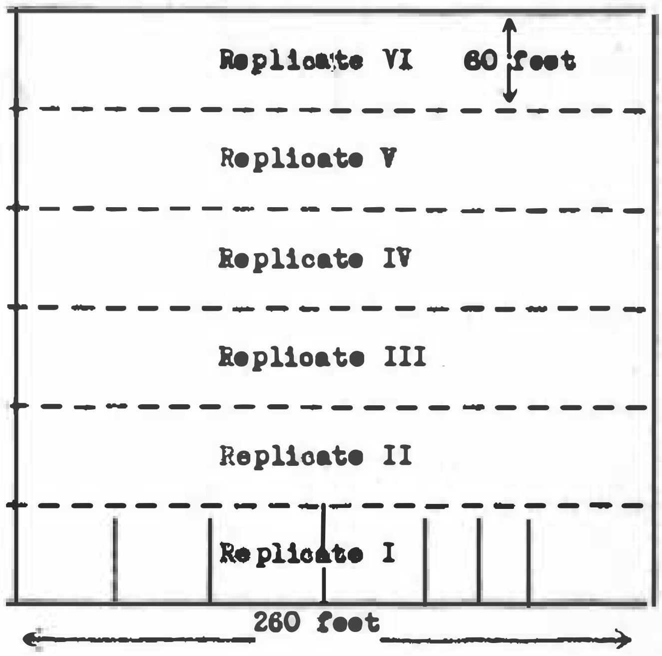

Figure 2. Field Plot Design Used in Comparing Three Formulations of 2,4-D Applied by Air and by Ground Showing Six Replications. The First Replicate is Sub-divided into the Seven Treatments Listed in Table 11.

Table 11. Treatments made in Comparing Three Formulations of 2,4-D when Applied by Air and by Ground at Two Locations, Using Oil and Water as Carriers at Normal Volumes.

Treatment*	Carrier Kind	Carrier Gal./A.	Applicator
Butyl ester (water emulsifiable-oil soluble)	oil	1	air
Butyl ester (water emulsifiable-oil soluble)	water	1	air
Butyl ester (oil soluble)	oil	1	air
Isopropyl-butyl ester (water emulsifiable-oil soluble)	water	1	air
Isopropyl-butyl ester (water emulsifiable-oil soluble)	water	10	ground
Butyl ester (water emulsifiable-oil soluble)	water	10	ground
Untreated	---	--	---

* Butyl ester contains six pounds acid equivalent per gallon and the mixture of esters contains four pounds per gallon.

Two volumes of carrier were used, one gallon per acre for air application and ten gallons per acre for ground application. These are considered normal volumes. An oil soluble-water emulsifiable butyl ester was applied in one gallon of oil, one gallon of water, and ten gallons of water per acre; an oil soluble butyl ester was applied in one gallon of oil and an isopropyl-butyl ester mixture in one and ten gallons of water per acre.

At harvest time weed injury readings and wheat yields were taken in the same manner as in Part A.

Results

Mean wheat yields and weed readings are presented in Table 12 with the analyses of variance of wheat yields presented in Table 13.

Table 12. Mean Wheat Yields in Bushels per Acre and Mean Index* of Weed Readings when Comparing Three Different Formulations of 2,4-D at One-third Pound Acid Equivalent per Acre Using Normal Volumes of Carrier.

	Strool			Huron		
		Weed Readings			Weed Readings	
Treatments**	Yield	W. Buck-wheat	Lamb's Quarters	Yield	W. Buck-wheat	Lamb's Quarters
Oil air 1	7.3	3.0	1.0	8.5	2.0	1.0
Oil air 2	5.1	3.0	1.0	7.9	2.8	1.0
Water air 1	7.0	3.0	2.0	8.1	2.0	1.0
Water air 3	8.1	3.0	1.0	7.9	2.7	1.0
Water ground 1	6.9	1.8	1.2	7.9	2.5	1.0
Water ground 3	6.4	2.0	1.5	7.9	2.6	1.0
Untreated	7.5	2.0	1.2	8.5	3.4	4.0

* Index of injury: 0, weed not present; 1, dead and brown; 2, stunted, no regrowth; 3, stunted, but growing; 4, shows no damage.

** 1, butyl ester (oil soluble-water emulsifiable).
2, butyl ester (oil soluble) 3, mixture of isopropyl and butyl esters.

No significant differences were found between treatments at Huron. The only significant difference found at Strool indicated that the oil soluble-water emulsifiable butyl ester gave significantly higher yields than the oil soluble form when applied in oil from the air.

Table 13. Analyses of Variance of Wheat Yields when Treatment was made with Three Different Formulations Using Normal Volumes of Carrier.

Source of Variation	Strool d f	Strool M S	Huron d f	Huron M S
Total	41		41	
Replications	5	2.20	5	11.79
Treatments***	6	5.90	6	.38
Treated vs untreated	1	4.09	1	.05
Oil vs water	1	7.67	1	.72
Oil air 1 vs oil air 2	1	14.52*	1	.96
Water air vs water ground	1	4.95	1	.00
Water air 1 vs water air 3	1	3.85	1	.52
Water ground 1 vs water ground 3	1	.61	1	.00
Error	30	2.70	30	2.04

* Significant at .05 level.
***1, Butyl ester (oil soluble-water emulsifiable) 2, Butyl ester (oil soluble) 3, Mixture of isopropyl and butyl esters.

Wild buckwheat was stunted by all treatments but some regrowth occurred; however the treatments did prevent seed production. Lamb's quarters was either killed or stunted, with no regrowth, by all treatments.

PART C - KINDS OF CARRIER

Materials and Methods

Six replicates with plots of the same size as described in Part A were treated with three different carriers, heater oil (No. 1 diesel fuel), furnace oil (No. 2 diesel fuel) and water with a butyl ester of 2,4-D at one-third pound acid equivalent per acre and with carrier alone. Treatments were made the same time as stated in Part A at both Strool and Huron. All treatments were made by air application, thus, randomization was not possible. A diagram of the plot design is given in Figure 3 and treatments are given in Table 14.

At harvest time weed readings and wheat yields were taken in the same manner as in Part A.

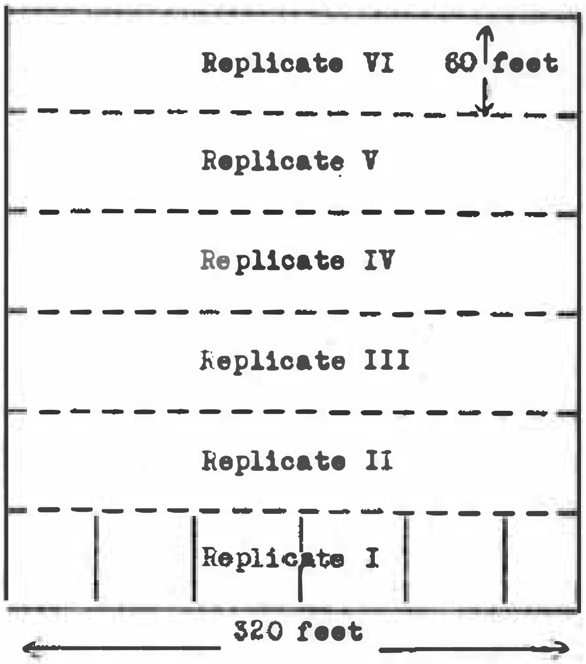

Figure 3. Field Plot Design Used in Comparing Three Carriers with and Without 2,4-D, when Applied by Air. The First Replicate is Sub-divided into the Seven Treatments Listed in Table 14.

Table 14. Treatments made in Comparing Three Different Carriers with and without One-third Pound 2,4-D Acid Equivalent per Acre of Butyl Ester at Strool and Huron.

Carrier			2,4-D
Gal./A.	Kind	Applicator	Pound/A.
1	Heater oil	air	1/3
1	Water	air	1/3
1	Furnace oil	air	1/3
1	Heater oil	air	none
1	Water	air	none
1	Furnace oil	air	none
---	Untreated	---	---

Results

Mean wheat yields and weed readings are presented in Table 15 with analyses of variance of wheat yields shown in Table 16.

The comparison of treated plots with untreated plots showed that the untreated plots had significantly higher yields at Strool, but at

Table 15. Mean Wheat Yields in Bushels per Acre and Mean Index of Wild Buckwheat and Lamb's Quarters Readings when Comparing Three Different Carriers with and without 2,4-D* with Airplane Application.

	Strool			Huron		
		Weed Readings**			Weed Readings**	
Treatment	Wheat Yield	W. Buckwheat	Lamb's quarters	Wheat Yield	W. Buckwheat	Lamb's quarters
H. oil - 2,4-D	8.4	3.0	1.0	8.9	2.0	1.0
H. oil alone	10.4	3.0	3.0	8.6	3.7	3.7
F. oil - 2,4-D	7.6	1.0	1.0	8.2	2.0	1.0
F. oil alone	12.3	3.0	2.0	10.1	2.8	1.3
Water - 2,4-D	7.1	2.0	1.0	7.6	2.7	1.3
Water alone	11.8	4.0	4.0	9.3	3.8	3.7
Untreated	16.4	4.0	4.0	8.5	3.8	3.7

* Butyl ester 1/3 lb. acid equivalent per acre.
** Index of Injury: 0, weed not present; 1, dead and brown; 2, stunted, no regrowth; 3, stunted, but growing; 4, shows no damage.

Table 16. Analyses of Variance of Wheat Yields when Treatments were made with Three Different Carriers with and without 2,4-D.

	Strool		Huron	
Source of Variation	d f	M S	d f	M S
Total	41		41	
Replications	5	32.6	5	2.8
Treatments	6	64.9**	6	3.83
Treated vs. untreated	1	199.52**	1	.42
Oil vs. water	1	.27	1	2.31
Heater oil vs. furnace oil	1	4.0	1	.51
Heater oil vs. heater oil - 2,4-D	1	39.24**	1	.21
Furnace oil vs. furnace oil - 2,4-D	1	68.69**	1	7.84
Water vs. water - 2,4-D	1	59.85*	1	11.60*
Error	30	8.8	30	2.66

* Significant at .05 level.
** Significant at .01 level.

Huron there was no significant difference. The significant difference at Strool was probably due to the fact that the plots were not randomized and the untreated plots were located along the edge of the field where higher fertility prevailed.

There were no significant differences between the yield of wheat on plots treated with heater oil as a carrier and that of plots treated with furnace oil.

The addition of 2,4-D to heater oil resulted in a significantly lower yield than heater oil used alone at Strool, but there was no significant difference at Huron. Identical results were obtained when furnace oil or water was used instead of heater oil.

PART D - RATES OF APPLICATION

Materials and Methods

Six replicates, of plots of the same size as described in Part A, were treated with an oil soluble-water emulsifiable butyl ester of 2,4-D at one-eighth, one-quarter, one-third, one-half, and three-quarters pound acid equivalent per acre. Treatment was made the same time as in Part A at both Strool and Huron, using one gallon of oil per acre as a carrier for aerial applications and ten gallons of water per acre for treatment applied from the ground rig. A randomized block design was used, but here again, due to the size of the plots necessary for aerial application, complete randomization was not possible. A diagram of the plot design is given in Figure 4 and treatments are given in Table 17.

At harvest time weed readings and wheat yields were taken in the same manner as described in Part A.

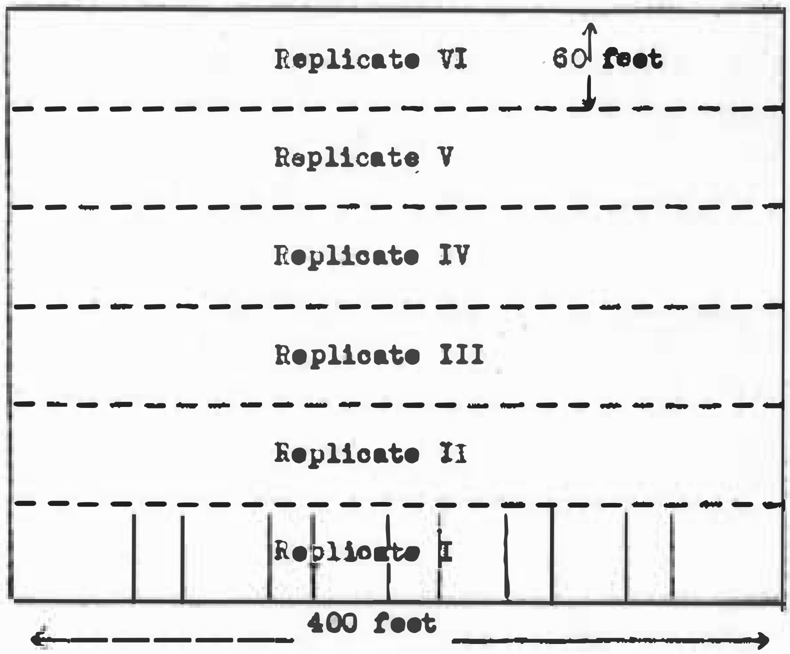

Figure 4. Field Plot Design Used in Comparing Five Rates of 2,4-D Using Water and Oil as Carriers when Applied by Air and by Ground. The First Replicate is Sub-divided into the Eleven Treatments Listed in Table 17.

Table 17. Treatments made in Comparing 2,4-D at Five Different Rates Using Oil and Water as Carriers and Application by Air and Ground.

2,4-D Lb./A.	Applicator	Carrier Gal./A.	Carrier Kind
1/8	air	1	oil
1/8	ground	10	water
1/4	air	1	oil
1/4	ground	10	water
1/3	air	1	oil
1/3	ground	10	water
1/2	air	1	oil
1/2	ground	10	water
3/4	air	1	oil
3/4	ground	10	water
Untreated	--	--	--

Results

Mean wheat yields and weed readings are presented in Table 18, with analyses of variance of wheat yields presented in Table 19.

Table 18. Mean Wheat Yields in Bushels per Acre and Mean Index of Wild Buckwheat and Lamb's Quarters Readings when Comparing Rates of 2,4-D Using Normal Volumes of Carrier.*

2,4-D**		Wheat Yields		Mean Weed Readings***			
				Strool		Huron	
Lb./A.	Applicator	Strool	Huron	W. Buck.	Lamb's.	W. Buck.	Lamb's.
1/8	air	6.2	7.3	1.0	1.0	3.0	1.0
1/8	ground	6.8	7.7	1.5	1.5	2.7	1.0
Mean		6.5	7.5	1.3	1.3	2.9	1.0
1/4	air	6.2	8.9	3.0	1.0	2.5	1.0
1/4	ground	6.3	7.4	2.0	1.2	2.2	1.0
Mean		6.3	8.2	2.5	1.1	2.4	1.0
1/3	air	7.8	7.4	4.0	3.0	2.0	1.0
1/3	ground	5.0	8.4	1.7	1.0	2.0	1.0
Mean		6.4	7.9	2.9	2.0	2.0	1.0
1/2	air	5.8	7.0	3.0	3.0	2.0	1.0
1/2	ground	5.7	8.3	1.7	1.0	2.0	1.0
Mean		5.8	7.7	2.4	2.0	2.0	1.0
3/4	air	4.3	6.9	4.0	2.0	2.2	1.0
3/4	ground	5.6	7.1	2.3	1.5	2.3	1.0
Mean		5.0	7.0	3.2	1.8	2.3	1.0
Untreated		5.6	9.3	2.6	2.6	3.2	2.2

* One gallon oil per acre for air and ten gallons water per acre for ground.

** Butyl ester, six pounds acid equivalent per gallon.

*** Index of injury: 0, weed not present; 1, dead and brown; 2, stunted, no regrowth; 3, stunted, but growing; 4, shows no damage.

Table 19. Analyses of Variance of Wheat Yields when Treatments were made with Five Rates of 2,4-D Using Oil and Water as Carriers when Applied by Ground and Air.

Source of Variation	Strool d f	Strool M S	Huron d f	Huron M S
Total	65		65	
Replication	5	4.03*	5	1.78
Treatments	10	4.90**	10	4.15
Treated vs untreated	1	.70	1	15.27*
1/8 & 1/4 lb. vs 1/3, 1/2 & 3/4 lb.	1	6.01*	1	1.51
1/8 lb. vs 1/4 lb.	1	.45	1	2.47
1/3 lb. vs 1/2 & 3/4 lb.	1	8.82*	1	2.68
1/2 lb. vs 3/4 lb.	1	4.00	1	2.60
1/8 lb. air vs ground	1	1.08	1	.85
1/4 lb. air vs ground	1	.02	1	7.52
1/3 lb. air vs ground	1	23.52**	1	3.41
1/2 lb. air vs ground	1	.01	1	5.33
3/4 lb. air vs ground	1	4.44	1	.10
Error	50	1.48	50	3.37

* Significant at .05 level.
** Significant at .01 level.

In comparing treated plots with untreated plots it was learned that the untreated plots had a significantly higher yield than the treated at Huron, but at Strool there was no significant difference.

The comparison of the mean of one-eighth- and one-fourth-pound-per-acre rates of application with the mean of one-third-, one-half-, and three-fourths-pound-per-acre rates, indicated that the higher rates gave significantly lower wheat yields at Strool, but at Huron there was no significant difference. The one-eighth-pound-per-acre rate was not significantly different from the one-fourth-pound-per-acre rate at either Strool or Huron. The one-third-pound-per-acre rate gave significantly higher yields than the one-half- and three-fourths-pound-per-acre rate at Strool but not at Huron. The one-half-pound rate and the three-fourths-pound rate were not significantly different at either location.

In comparing aerial application with treatment with a ground rig, it was not established that method of application had any effect on yield when one-eighth-, one-fourth-, one-half- or three-fourths-pound-per-acre rates were applied. However, aerial application of the one-third pound rate gave significantly higher yields at Strool. This difference may be accounted for by the fact that there were two very low yielding ground-sprayed plots which brought the mean yield down. At Huron there was no significant difference between air and ground application at this one-third pound rate.

PART E - AERIAL OBSERVATION

Materials and Methods

This part of the investigation consisted of observing commercial airplane spraying operations in the Huron, South Dakota area during the summer of 1954. Spraying was done between June 15 and June 23 and the grain was harvested on July 16. Arrangements were made to have the pilot leave a small unsprayed area on the upwind side of each field in order that yields could be taken from a treated and an untreated area. These yields were taken in the same manner as described in Part A. After the samples were threshed and calculated in bushels per acre, the data were then analysed statistically. Data were also recorded on kind of crop, percentage of soil moisture, temperature, humidity, kind and amount of carrier, formulation and amount of 2,4-D, wind direction and velocity, stage of growth, time of day and weeds present.

The data sheet used is presented in Figure 5.

Field No. ____________ Date ____________

Legal Description ________________________________

Direction from town ________________________________

Owner ____________________

Kind of crop ____________________

No. of acres ____________________

Stage of growth ____________________

Kind of 2,4-D ____________________

#/acre 2,4-D ____________________

Carrier (kind & amt.) ____________________

Time ____________________

Humidity ____________________

Temperature ____________________

N

Sketch of field (indicate location of unsprayed strip, location where data were taken, and dimensions of field)

Soil Moisture ________ % bag wt. ______ Wet wt. ________ Dry wt. ______

Wind direction - velocity ________________________________

Weeds ________________________________

Remarks (General soil condition) ________________________________

One week later Date ____________

Condition of crop ________________________________

Weeds ________________________________

Harvest Date ____________

Yield unsprayed ____________ Yield sprayed ____________

Weeds ________________________________

Remarks ________________________________

Figure 5. Data Sheet Used in Recording Field Observations while Observing Commercial Airplane Spraying in Huron, S.D. Area during Summer of 1954.

Results

In three fields, brittleness of stems was noted and in one case the spray pattern could be seen on the leaves where the leaves appeared to be burnt wherever a droplet of spray came in contact with them. One field showing brittleness was a field of oats which was sprayed with one-third pound per acre of 2,4-D amine when oats was in the early boot stage. Another field showing brittleness was a field of oats which was sprayed in the early boot stage with an ester of 2,4-D at one-fourth pound per acre. The other field showing brittleness was also a field of oats which was sprayed in the late boot to milk stage with an ester of 2,4-D at one-fourth pound per acre. Water at the rate of one gallon per acre was used as carrier in all observations.

Data recorded on airplane observations in the summer of 1954 are presented in Table 20. The yield difference for each crop were analysed statistically with no statistical difference found between sprayed and unsprayed areas. Since there were no significant differences between treated and untreated areas no analysis was run to correlate yield reduction with any of the field observations.

Table 20. Data Recorded on Field Observation of Commercial Airplane Spraying.

Crop	Stage of Growth	Yield Unsprayed	Yield Sprayed	% Soil Moisture	Temp.	Humidity	2,4-D Lb./A.	Wind Velocity	Time	Carrier Kind	Carrier Gal./A.
Wheat	5-leaf	7.0	7.0	13.3	68	76	.25	6	6:45 AM	water	1
Wheat	5-leaf	6.9	4.2	15.4	69	81	.25	8	8:25 AM	water	1
Wheat	early boot	6.0	4.5	8.9	74	72	.25	20	10:45 AM	water	1
Wheat	boot	14.1	13.8	21.7	78	60	.27	8	4:15 PM	water	1
Wheat	early boot	7.3	7.2	15.9	79	64	.27	0	6:45 PM	water	1
Barley	5-leaf	19.4	17.3	11.7	64	84	.25	6	6:30 AM	water	1
Barley	5-leaf	22.6	17.1	18.4	70	77	.25	3	7:30 PM	water	1
Oats	boot	29.3	33.0	14.4	78	46	.33*	8	10:45 AM	water	1
Oats	early boot	47.9	45.8	16.6	63	89	.25	3	7:15 AM	water	1
Oats	boot	35.7	35.7	12.8	70	81	.25	3	9:30 AM	water	1
Oats	5-leaf	41.1	41.7	17.3	78	60	.29	8	3:30 PM	water	1
Oats	late boot	35.9	32.1	14.8	79	64	.25	0	6:30 PM	water	1

* An ester of 2,4-D was applied to all fields, except this one field of oats, where an amine form was applied.

PART F - AERIAL SPRAY DRIFT STUDY

Materials and Methods

A study was conducted at Brookings, South Dakota during the summer of 1955, to determine the extent of drift of an ester of 2,4-D in water, an ester of 2,4-D in oil and an amine salt of 2,4-D in water. The treatments consisted of one-third pound of 2,4-D acid equivalent per acre in one and one-fourth gallons of spray per acre. The distance that the spray drifted was determined by its effect on tomato seedlings that were spaced at intervals across the spray swath.

Tomato seedlings, of the variety Earliana, were grown in pots in the greenhouse to a height of approximately six inches and transferred to the test area prior to treatment. Each of the three formulations was applied three times during the summer. In the first trial the plants were spaced every twenty feet for a distance of 560 feet in four rows that were 45 feet apart. The second and third trials were the same except that only three rows were used. The rows were laid out parallel to the wind with the formulation applied 60 feet in from the upwind end of the rows, the plane flying crosswind at a height of approximately six feet. Therefore, the last tomato plants on the downwind end were 500 feet from the center of the spray swath and the last plants upwind were 60 feet from the center of the spray swath. The first set of treatments was applied on June 25 with a wind velocity of 5 to 8 miles per hour. The second and third sets were applied on September 24 with wind conditions very similar to those of June 25.

The plants were left five minutes after treatment before any of them were picked up, the last being picked up within twenty minutes after treatment. The plants were then taken to the greenhouse and placed in the same order as in the field. Eleven days later notes were taken to determine the amount of injury of each plant. The following index of injury, based on epinasty and stem swelling was used in recording tomato reactions:

1. No apparent response.
2. Epinasty 1-20° compared to normal; no curling; slight swelling of stems.
3. " 21-40° " " " ; slight curling; stems swelled.
4. " 41-60° " " " ; mod. curling; stems swelled.
5. " 61-80° " " " ; mod. severe curling; stems swelled.
6. " 81-greater than 90°; twisting of main stem, distortion of leaflets and petioles or the plant is dead.

Plate 4. Index set up for measuring tomato plant injury based on epinasty and stem curling and swelling. The index is listed above.

Results

The mean readings of injury for each treatment at each distance are presented in graphical form in Figure 6. Analysis of variance is presented in Table 21. Statistical analysis showed there were significant differences among distances, treatments, trials within treatments and the interaction of treatments x distance.

Table 21. Analysis of Variance of Readings for Tomato Plant Injury when Treated with Three 2,4-D Sprays at Three Different Times. Each Treatment Containing Ten Rows with Twenty-nine Distances in Each Row.

Source of variation	d f	M S
Total	869	
Distance	28	67.31**
Treatments	2	109.64**
Treatments x distance	56	2.16**
Trials within treatments	6	18.51**
Error	168	1.21
Sampling error	609	

** Significant at .01 level.

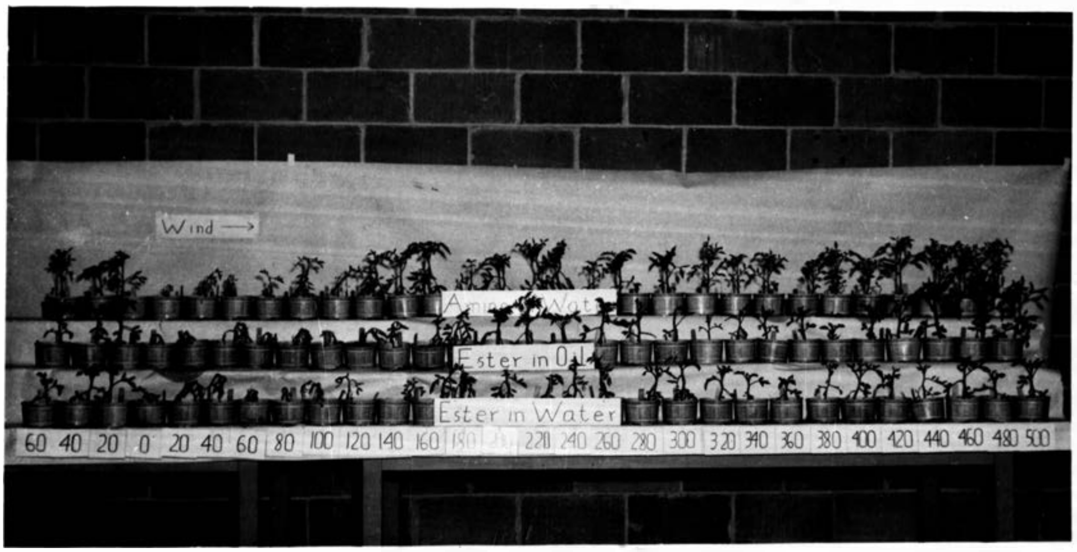

Plate 5. The effect of three 2,4-D sprays on tomato seedlings measured in feet, both upwind and downwind, when wind was between five and eight miles per hour. Mean readings of injury are given in Figure 6.

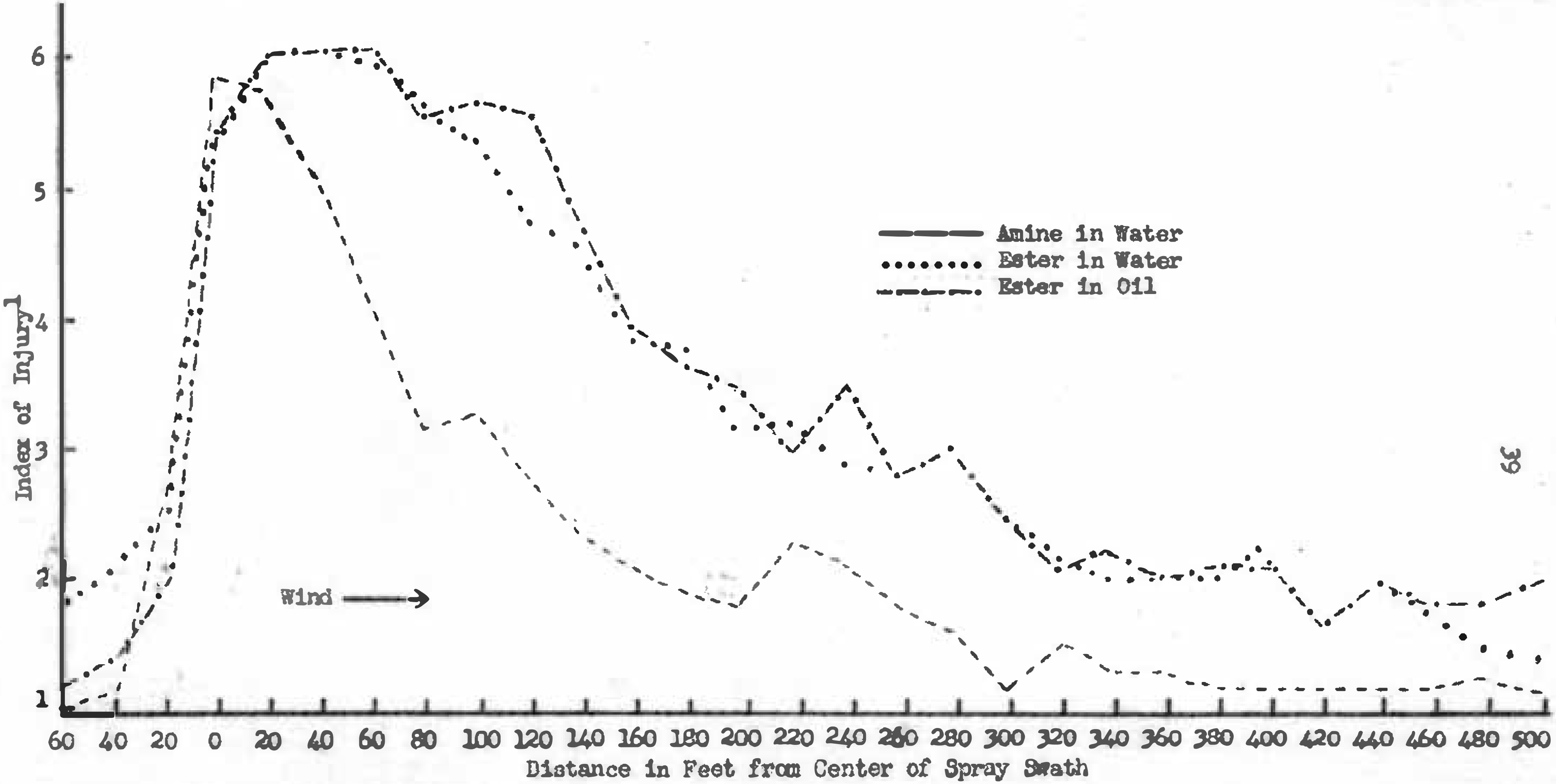

Figure 6. Mean Injury Readings of Tomato Plants when Treated with Three 2,4-D Sprays.

[1] Index of Injury; 1. No apparent response.
2. Epinasty 1-20° compared to normal; no curling, slight swelling of stems.
3. " 21-40° " " " ; slight curling, swelling of stems.
4. " 41-60° " " " ; moderate curling, swelling of stems.
5. " 61-80° " " " ; mod. severe curling, swelling of stems.
6. " 81-greater than 90° twisting of main stems, distortion of leaflets and petioles or the plant is dead.

A subdivision of analysis of variance shows that the first significant difference downwind was at the 40-foot point. At this point, the two ester sprays gave equal injury; and injury from both was significantly more than from the amine. Table 22 shows the analysis of variance at the 40-foot point downwind from the center of the spray swath.

Table 22. Subdivision of Analysis of Variance, at the 40-Foot Point, for the Interaction of Treatments x Distance.

Source of variation	d f	M S
Total	29	
Rows	9	.593
Treatments	2	3.335*
Ester vs amine	1	6.667**
Ester in oil vs ester in water	1	.000
Error	18	.592

* Significant at .05 level.
** Significant at .01 level.

From the 40-foot point on, injury to the tomato plants was considerably less when treated with amine in water than when treated with ester in either oil or water. The two ester sprays gave very nearly the same injury symptoms for a distance of 460 feet downwind. From this point on the injury produced by the ester in oil was more pronounced than that caused by the ester in water. Injury symptoms caused by the ester in oil at the 500-foot point were slight swelling of stems and epinasty of between one and twenty degrees, while the ester in water produced less severe epinasty. The amine caused no apparent injury after the 400-foot point downwind. The analysis of variance for the 500-foot point is given in Table 23.

Table 23. Subdivision of Analysis of Variance, at the 500-Foot Point, for the Interaction of Treatments x Distance.

Source of variation	d f	M S
Total	29	
Rows	9	.519
Treatments	2	1.732**
Ester vs amine	1	1.667*
Ester in oil vs ester in water	1	1.800*
Error	18	.252

* Significant at .05 level.
** Significant at .01 level.

The ester in water drifted upwind the farthest. Slight curling and some swelling occurred with all three treatments at the 20-foot point. Plants treated with ester in water 40 feet upwind showed some epinasty and slight swelling of the stems, while those treated with the ester in oil or the amine formulation showed very few symptoms of injury. At 60 feet the plants treated with the amine and ester in oil showed no apparent response while those treated with ester in water showed some evidence of drift.

DISCUSSION

After many years of research, field recommendations for 2,4-D spraying of crops have been made with the aim of achieving the most effective weed control and the least possible injury to the crops.

In these experiments, results at one location were not always in complete agreement with results at the other location. The presence of rust may have had a masking effect on differences in wheat yields as different varieties were being grown at the two locations. Wallace (20) reported similar results in his experiments.

There were fourteen comparisons of aerial application versus ground application as affecting yield of wheat. Thirteen statistical comparisons showed no difference in wheat yield. In the other comparison, aerial application gave a higher yield, which was due to two very low yielding plots located on a hard-pan type of soil where application was made with a ground rig. In comparing rates of 2,4-D the higher rates applied by a ground rig gave better weed control than the aerial applications. These results indicate that, with the volumes and kinds of carrier used and formulations and rates of 2,4-D used, there is no difference between ground and aerial application and is in agreement with the results obtained by Wallace (20). Therefore, it appears that present 2,4-D recommendations for ground application are satisfactory as recommendations for aerial application from the standpoint of effect on wheat yield.

In comparing volumes of carrier some of the differences may be due to the fact that volumes were set up as main plots and comparisons are not as reliable due to the distance between plots and the heterogeneity of soil which may occur. Of eight statistical comparisons of yields of wheat on plots treated with different volumes of carrier per acre, the smaller volumes gave higher yields in three comparisons and there were no differences in five. It appears, from these comparisons, that the smaller volumes of carrier may give higher wheat yields; however, none of the treated plot yields were significantly different from the untreated plots. These results are somewhat in contrast with the results of Wallace (20), where the smaller volumes gave lower wheat yields.

Six comparisons were made involving an oil soluble-water emulsifiable butyl ester, an oil soluble butyl ester and an oil soluble-water emulsifiable mixture of isopropyl and butyl esters. There were no significant differences in wheat yield in five comparisons and one showed significantly higher yields from the oil soluble-water emulsifiable butyl ester than for the oil soluble butyl ester when applied in oil from the air. It appears from these results that the kind of 2,4-D used had little effect on wheat yield and were of equal toxicity as to effect on weeds. This is further substantiated by Wallace's work (20).

Eight comparisons of rates of 2,4-D were made with two comparisons showing higher yields for the lower rates and six comparisons showing no difference in wheat yield. The rates of one-third pound of 2,4-D acid equivalent per acre and more gave significant yield reductions as compared to rates of less than one-third pound in one comparison and the one-third-pound gave higher yields than the one-half- and three-fourths-pound rate in another comparison. These comparisons indicate that rates of one-third pound per acre and less gave higher yields than the higher rates. Wallace (20) also found the one-third-pound rate to give higher yields than the one-half- or three-fourths-pound rate. These results are in accord with the findings of others, which are summarized in the 1954 recommendations of the research committee of the North Central Weed Control Conference.

When a range of rates of 2,4-D application were applied by air and by ground rig, the results indicated that method of application had little effect on wheat yields, or weed kill. Therefore, it appears that rates recommended for use in ground sprayers are satisfactory rates for use in aerial sprayers under the same conditions.

The great variability in spray retention data indicated that the technique used was not entirely satisfactory. Ameson (1) says it is impractical to determine the volume of spray retention by subtracting the volume of spray measured on the plants from the total amount being applied. The amount retained is only a certain percentage of the total due to evaporation and present field spray volume techniques are not accurate enough to establish a difference which would represent the percentage of retention. Wallace (20) using Woofter's technique (21) also, found great variability in amount of spray retained. He also found, as in this study, there was no significance in correlating the mean wheat yields and the percentage of spray retention. Wheat retained less spray, in one comparison, when application was by airplane than when by a ground rig. Another statistical comparison of aerial versus ground application showed no difference in amount of spray retained. Water and oil used as carriers showed no difference in percentage of spray retention in four comparisons. Oil treated plots gave lower percentage of spray retention in four comparisons and the water treated plots lower in one.

It appears that volume of carrier is an important factor affecting amount of spray retained on the plant. Holly (14), using larger amounts of carrier than was used in these experiments, found that the more carrier that was used the less the amount of agent that was deposited on barley leaves. There is more runoff from the larger volumes of carrier. Wallace (20) used low volumes similar to those used in this study and obtained similar results. In this study there is some indication that a smaller volume gives a higher percentage of spray retention. This was true in two comparisons while six comparisons showed no difference. It appears then, that a higher percentage of spray is retained when smaller volumes of carrier are used.

Of the thirteen comparisons made between oil and water as carriers the oil treated plots yielded higher in one comparison and there was no difference in twelve. One comparison was made between heater oil, which Loomis (15) reported to be less phytotoxic than lower grade oils, and furnace oil with no significant difference noted. These data indicate that type of carrier had little effect on wheat yields, which is in agreement with Wallace's (20) work. Likewise, kind of carrier used showed very little differences in degree of weed kill.

When heater oil, furnace oil and water were applied alone and with 2,4-D added, yields were reduced by the addition of 2,4-D to all three carriers at one location and by the addition of 2,4-D to water at the other location. These results indicate that the carrier alone is not the cause of reduction in yield at these volumes. Wallace's work (20) indicated similar results.

From the photographs of adding machine tapes laid across the airplane sprayed plots, it was found that wide variation in the amount of spray deposited occurred across the swath. In nearly every case more spray was deposited to the left of the airplane. According to Shafer (18), the turbulent areas, set up by the fuselage, wing tips and propellor, pull spray from beneath and to the right of the fuselage and deposit it on the left side of the plane. He also found that the edge of the spray pattern is not in a straight line, but weaves in and out. This would explain the results observed on these photographs as well as those reported by Wallace (20). It was also observed that the larger spray particles tended to drop straight down; whereas, the smaller particles resulting from smaller volumes seemed to be picked up by the turbulent areas. The larger particles may have been broken up by the turbulent areas and deposited closer to the spray pattern edge. The type of carrier used didn't alter the spray pattern to any noticeable extent.

In studying environmental conditions at time of spraying by aerial application it was not established that any one factor could be singled out as a possible cause for wheat yield reduction. Several cases of injury were observed in the field on oats but the yield differences between sprayed and unsprayed were not significant. Alban (2) found temperatures five to ten days preceeding date of spraying were more important in causing damage to the crop than temperature at time of application of 2,4-D to sweet corn. If the temperature has been high preceeding treatment more breakage is apt to occur in corn when treated after this hot period. Wallace (20) found no significant correlation between reductions in yield and other recorded data in his observations of commercial airplane spraying.

The analysis of the factors considered for reduction of 2,4-D drift damage is aimed specifically at those areas where the use of 2,4-D may be expected to become a problem, or where it has already done so as evidenced by damage and lawsuits. This study indicates that the ester in oil formulation drifted farther than the ester in water and that the latter drifted farther than amine in water when wind velocity was between five and eight miles per hour. Damage to tomato plants 600 feet downwind, with a five to eight mile per hour wind, was detected from the use of an ester in oil. The ester in water caused little injury to tomato seedlings beyond 460 feet and the amine in water produced no visible effects beyond 400 feet. Greenshields and White (13) have observed damage to sweet clover for a distance of 96 rods downwind from the sprayed area with a 13-17 mile per hour wind. These experimental results hold true to popular belief that the lighter oil and ester formulation tend to drift farther due to smaller and lighter particles. Young (22), working with tomato plants, found that oil increased drift in all cases. Water and amine 2,4-D particles being heavier, would, therefore, drop to the ground more rapidly and hence not drift as far. The fact that the water and ester did more damage upwind may be due to the lighter oil particles being carried downwind more rapidly. According to Akesson (1) the distance spray is carried horizontally will depend on horizontal air velocity and a separation of the drops composing the spray will take place with the larger drops settling out rapidly and the finer particles being carried for distances which increase as the drop size decreases. There may be very little wind, if any, and still damage could occur. This type of situation may not effect susceptible crops adjacent to the sprayed area but small aerosol particles may drift slowly with the air currents and be deposited on a susceptible crop a mile or two away. The damage to any given field is proportional to the concentration of the 2,4-D in the air mass multiplied by the time of exposure. The exposure time is the time it takes for the spray laden air to pass over the susceptible field. Spraying a field should be started and continued only as long as air motion continues in a definite direction.

SUMMARY AND CONCLUSIONS

During the past several years, damage to crops from aerial spraying has been reported. An investigation was begun in 1952 to determine the cause of such damage. This study is a continuation of that investigation.

The objectives of this study were:

1. To compare the effect of aerial and ground application of 2,4-D on wheat yields and control of annual weeds (a) when different volumes of oil and water were used as a carrier, (b) when different esters of 2,4-D were used and (c) when several rates of 2,4-D were applied per acre.
2. To determine the percentage of spray retained by wheat when applied by aerial and ground sprayers in several volumes of oil and water as carrier and to correlate this percentage with crop yield.
3. To compare water and two oils as carriers for aerial application of 2,4-D.
4. To compare aerial spray patterns when several carriers at different volumes were used.
5. To correlate environmental factors at time of treatment with the effect of commercial aerial applications of 2,4-D on crop yield.
6. To compare the driftability of 2,4-D forms when applied by an aerial sprayer.

The results indicate that:

1. There were no differences between airplane and ground applications of 2,4-D on wheat yield or weed kill under the condition studied when different volumes and kinds of carrier were used or when different kinds and rates of 2,4-D were used.
2. There was no significant correlation between percentage of spray retention and wheat yield.
3. There were no differences between water and oil as carriers as affecting wheat yield.
4. Aerial spray patterns revealed wide variation in amount of spray deposited across the spray swath.
5. No correlation was found between any single environmental factor and reduction in yield of crops from aerial application.
6. Oil as a carrier increased drift over water and the ester of 2,4-D drifted farther than the amine.

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