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Some Factors Influencing Fungicide Control of Leaf Rust and Stem Rust of Wheat

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SOME FACTORS INFLUENCING FUNGICIDE CONTROL OF LEAF RUST AND STEM RUST OF WHEAT

BY

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OF LEAF RUST AND STEM RUST OF WHEAT

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is 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 Date

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TABLE OF CONTENTS

LIST OF TABLES

Table		Page

LIST OF FIGURES

INTRODUCTION

Stem rust, Puccinia graminis tritici Eriks. and Henn., and leaf rust, Puccinia recondita Rob. ex Desm., destroyed an estimated 70% of the South Dakota winter wheat crop in 1962, a loss of more than 12 million bushels valued at $24 million (30). Similar losses have occurred periodically in South Dakota. Breeding programs have produced resistant varieties of spring and winter wheat; however, new races of rust have developed and attacked varieties heretofore resistant. For example, until 1952, the spring wheat varieties Pilot, Rival, and Mida were resistant to stem rust race 56, which had been the most prevalent race in the midwest since the 1930's. Race 15-B erupted in epiphytotic proportions destroying large acreages of these varieties and resulting in their replacement by Selkirk, a variety resistant to races 56 and 15-B. The resistance provided by Selkirk has been supplemented by resistant Crimm, Chris, and other varieties. In spite of this progress, stem rust races have been found that are capable of damaging all of these varieties.

The winter wheat varieties Omaha, Pawnee, Nebred, and Warrior were widely grown until 1962 when race 56 destroyed 70% of the South Dakota crop. These varieties have been replaced primarily by Hume, Lancer, Scout, and Gage, which are resistant to the common races but, again, are susceptible to potentially destructive races.

Resistance to leaf rust is less common in current varieties than is stem rust resistance; moreover, this resistance has a narrow genetic base and is even less reliable than stem rust resistance.

Several investigators have found that certain fungicides control both stem and leaf rust when applied at the proper time. One primary limitation of chemical control is cost of application. The first part of this study is an attempt to assess the feasibility of rust control and weed control by combining fungicides with 2,4-D.

To gain maximum benefit from a protective fungicide spray, the fungicide must thoroughly cover the plant where the pathogen most commonly penetrates. Foliage density, wind direction, wind velocity, and the type of applicator are factors which may affect spray deposition on wheat plants.

The second part of this study is an investigation to determine the effect of foliage density on spray deposition.

REVIEW OF LITERATURE

The cost of frequent applications of chemicals to a relatively low-cash value crop has always been a major obstacle in fungicidal control of wheat leaf rust and stem rust. Chemical control was first attempted between 1891 and 1894 with sulfur and copper. Although control was obtained, the practice was economically impractical because large quantities and frequent applications of fungicides were required.

Investigations were conducted in 1925 using inorganic sulfur applied as a dust, but economic considerations again precluded its use (7).

In 1934 Tisdale and Williams (28) discovered the toxicity of carbamates to fungi, but cost was still considered impractical.

Semeniuk (27) worked with many chemicals searching for an eradicant fungicide. Calcium sulfamate showed potential in controlling rust but its use was not practical because it was phytotoxic to wheat and it reduced milling and baking qualities of the flour.

Keil et al. (16, 17) found that nickel derivatives acted as eradicative fungicides against rye leaf rust. Forsyth and Peturson (8, 21), working on wheat rusts, supported their conclusions regarding the eradicative action of nickel compounds and also noted some protective effect. In 1960 Forsyth and Peturson (9) reported economic control of leaf rust and stem rust with nickel and zineb.

Hobbs and Futrell (12) used various compounds of nickel sulfate with maneb and zineb against stem rust and increased wheat yield an average of 60% with 2 spray applications, the first at 5% infection and the next 14 days later. Rowell (25) worked with nickel salts and dithiocarbamates to control wheat leaf rust and stem rust in the field and found that timing of fungicide application was critical for rust control. One spray applied at an incidence of 10 - 100 uredia/culm and another 10 days later gave up to 66% rust control.

Buchenau and Carlson (2) using maneb and zineb as foliage sprays demonstrated that 2 applications, one at heading and the other 10 days later were effective enough to be economically beneficial under moderately severe rust conditions. Applications between jointing and boot were often effective against leaf rust but not stem rust. Wood (31) also demonstrated this using aerial application.

Effective results in controlling stripe rust, Puccinia striiformis West., on wheat with Plantvax used as a seed and soil treatment were obtained by Hardison (11) and Powelson and Shaner (24). Control was based on the systemic action of the fungicide. Rowell (25) demonstrated that Plantvax used as a soil treatment plus one midseason foliage spray controlled leaf rust and stem rust as effectively as 2 late season sprays of a nickel sulfate hexa-hydrate plus maneb fungicide.

For the past 19 years South Dakota small grain farmers have used 2,4-D to control broadleaf weeds. Grigsby (10) recommended that winter wheat should not be sprayed with 2,4-D in the fall or between the tillering and boot stage in the spring. Olson et al. (20), Derscheid et al. (5), and Wallace (29) found that there were 2 critical periods in spring wheat and barley development when yield was reduced sharply, one when plants were 1 to 5 in. tall and the other from late boot stage to a few days before heading.

Ibrahim (15) reported that 2,4-D at a concentration of 50 ppm or greater reduced the number of stem rust pustules on oats.

Phillips et al. (23) found that heavy applications of 2,4-D to wheat 7, 14, and 21 days before harvest had no significant effect on yield, chemical composition, or milling and baking qualities of the grain.

Recommended application of 2,4-D in ester form is 1/2 pt/acre or in amine form is 3/4 lb/acre applied between the 5 leaf and early boot stages (4).

No literature has been found concerning simultaneous application of fungicide and 2,4-D.

MATERIALS AND METHODS

Compatability of Fungicides with 2,4-D

Field plots (experimental units, 3) were planted with Ceres spring wheat, Triticum vulgare Vill., a variety susceptible to common races of stem and leaf rust, in 8 x 12 ft plots using a 4 row planter mounted on a model G, Allis Chalmers tractor. As an indicator plant for testing 2,4-D activity, red clover, Trifolium pratense L. was seeded on the plots but failed to emerge. A natural infestation of lambsquarter, Chenopodium album L. served as an adequate substitute.

Fungicides and 2,4-D and their dosage rates are in Tables 1 and 2.

A John Bean 30 gallon model 33-LD Spartan Sprayer attached to an 88 in. boom applicator containing 12 hollow cone nozzles with D-3 discs and #23 cores was mounted on bicycle wheels and used to apply each treatment as a foliage spray. Single nozzles at each end were suspended 19 in. below the boom on flexible drop hoses. Four nozzles were mounted directly on the boom and alternated with three flexible drop hoses containing 2 nozzles placed opposite each other. The sprayer was calibrated to deliver 100 gallons/acre at 100 psi to spray the 6 center rows of each plot (Figure 1).

The combination fungicide 2,4-D spray was applied when the spring wheat was in the early boot stage (stage 9, 18) and a second application using only fungicides was applied 10 days later. Ten wheat stems collected at random at weekly intervals from each plot from early boot

Table 1. Formulations of Fungicides and 2,4-D Used in Rust and Weed Control Studies, Brookings, 1966.

Chemical	Active Ingredient	% Active Ingredient
Dithane M-45	Mg++ 16% Zn++ 2%, Maneb (Manganese ethylene bisdi-thiocarbamate) 62%	80
Dithane S-31	Nickel sulfate 19% Maneb 53%	72
Manzate D	Maneb 63.5% Mg++ 16.5%	80
Parzate C	Zineb (Zinc ethylene bisdi-thiocarbamate)	75
Plantvax	2, 3-dihydro-5-carboxamilido-6-methyl-1, 4 oxathiin 4, 4-dioxide	75
Esteron 99	2, 4-dichlorophenoxyacetic acid (butyl ester)	73

Table 2. Combinations of Fungicides and 2,4-D Used on Field Plots, Brookings, 1966.

2,4-D	Fungicides [a]				
pt/acre	Dithane M-45	Manzate D	Parzate C	Plantvax	0
0	+	+	+	+	+
1/4	+	+	+	+	+
1/2	+	+	+	+	+

[a] Dithane M-45, Manzate D, and Parzate C applied at 2 lbs/acre; Plantvax at 3 lbs/acre

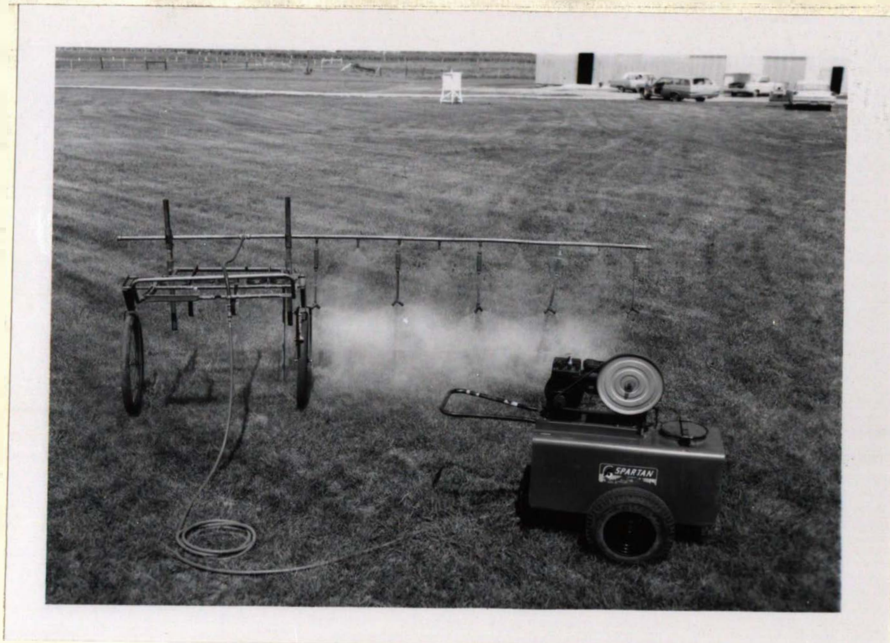

Figure 1. Ground Spray Equipment Used on Brookings Plots.

stage to maturity were examined for leaf rust and stem rust but due to the low rust prevalence in 1966, significant results were not obtained.

The number of lambsquarter plants/plot was determined before and 10 days after the first application. Effectiveness of 2,4-D was assessed by the number of plants killed.

Laboratory experiments were conducted to obtain information regarding the compatibility of the 4 fungicides and 2,4-D in controlling rust. Initially, an excised leaf method (1) was used to evaluate fungicide alone and fungicide-2,4-D mixtures against leaf rust and stem rust infection. Glass slides with excised wheat leaves attached to them were placed at the end of a horizontal 3 in. x 3 ft cylinder (14), sprayed at a pressure of 10 psi, inoculated with rust spores in a settling tower (20) removed and incubated in a moist chamber for 9 hours. The glass slides and a portion of the leaves were examined under a microscope for spore germination. The remaining leaves were placed in test tubes containing a 60 ppm benzimidazole solution, maintained in a growth chamber (programmed for a 16 hour day period at 75°F and 65% relative humidity) for 10 days and observed for rust development. Spore kill and rust control for each dosage was then calculated.

Another method was devised to determine the dosage of fungicide required to kill 50% of the spores (LD-50, 1, 18) of each fungicide for leaf rust and stem rust spores. Two percent agar blocks 6 mm high with a diameter of 16 mm were placed on glass slides and covered with water permeable, boiled cellophane. These blocks were sprayed and inoculated with rust spores in the same manner as the excised leaves. The inoculated blocks were incubated in plastic containers placed in a dark room at 75°F for 9 hours. Blocks were examined under a microscope and the percent rust spore germination determined. Control was calculated by the formula: % control =

$$\frac{\%\ \text{check germinated} - \%\ \text{treatment germinated}}{\%\ \text{check germinated}} \times 100$$

One hundred percent control equals no germination of the treated spores.

Fungicides were added to aqueous solutions of 2,4-D or to water and kept in suspension with a magnetic stirrer. Dosage was varied by regulating the time of exposure to the spray.

Spray deposit was determined using corn smut spores, _Ustilago maydis_ (DC.) Cda, because they were easy to see, would go through the sprayer, and formed a uniform spray pattern. Smut spores were suspended in water and the number of spores/ml was determined by counting a sample in a hemacytometer. The smut suspension was sprayed on glass slides for uniform time periods. The number of spores deposited per unit area was counted and the volume of liquid deposited was then calculated. Knowing the percent active ingredient and the amount of fungicide/ml of water, the amount of fungicide per unit area was then calculated as micrograms deposited per square centimeter (ug/cm^2).

The LD-50 was determined by plotting the percent control against ug/cm^2 of fungicide and averaged for three replications of 500 spores each. Analyses of variance were conducted on LD-50 data (6, 18).

Study of Factors Affecting Spray Coverage

Various stem densities were established by using different seeding rates. At Brookings, experimental plots 8 x 12 ft were seeded at rates of 12, 24, 48, and 96 lbs/acre of Ceres spring wheat. These plots were sprayed with the ground sprayer previously described. Experimental plots at Huron were seeded at rates of 30, 45, 60, and 75 lbs/acre of Pembina spring wheat using a 28 ft drill with separate adjustments for each 7 ft section. After germination, the plots were trimmed to 5 x 40 ft separated by 5 ft alleys. A fixed wing airplane equipped with 28 nozzles (#45 cores and D-8 discs) spaced 12 in. apart delivered 5 gal/acre at a pressure of 35-40 psi. Plots at Huron were sprayed from west to east 4-6 ft above the wheat at a speed of 95 mph.

Number of tillers/plant, total number of stems, and number of plants were determined by pulling plants from 4 one ft subsamples in each plot. Subsamples from each treatment were averaged to provide 1 unit/experimental plot for each variable.

Light meter readings were made on a white 3 x 5 in. card placed within the plot on a wire 3, 9, and 18 in. above the card. A Weston Mark IV light meter was used to record the reflected light. Care was taken to keep the shadow of the light meter from the card. Readings were made in open sunlight before and after reading each plot. Percent reduction of light within the foliage canopy was calculated by using the formula: % reduction =

$$\frac{\text{Light in open} - \text{Light in plot}}{\text{Light in open}} \times 100$$

Four readings were taken in each plot and averaged to provide one unit per experimental plot. The data were then statistically analyzed.

Spray deposition was recorded on black plastic tape attached to each leaf and midway between each internode on wheat plants (Figure 2). Plants were taped before each application and then removed immediately after spraying. Ten plants were taped in each plot with the flat surface on the stems facing north and south on 5 and east and west on the other 5. Deposition was estimated on the black tape by observing the spray patterns through a binocular dissection scope equipped with a one square centimeter wire divided into equal quadrants. Deposition was estimated for each quadrant and all were averaged together. The Horsfall-Barratt (13) conversion scale (Table 3) was used for converting data to deposition indecies which were then analyzed factorially in a randomized complete block design.

Table 3. Scale Used for Converting Spray Deposition Data from Percent Coverage to Deposition Index (Horsfall-Barratt, 13).

Index	Plant Surface Covered	Index	Plant Surface Covered	Index	Plant Surface Covered
1	0	5	12-25	9	87-94
2	1- 3	6	25-50	10	94-97
3	3- 6	7	50-75	11	97-99
4	6-12	8	75-87	12	100

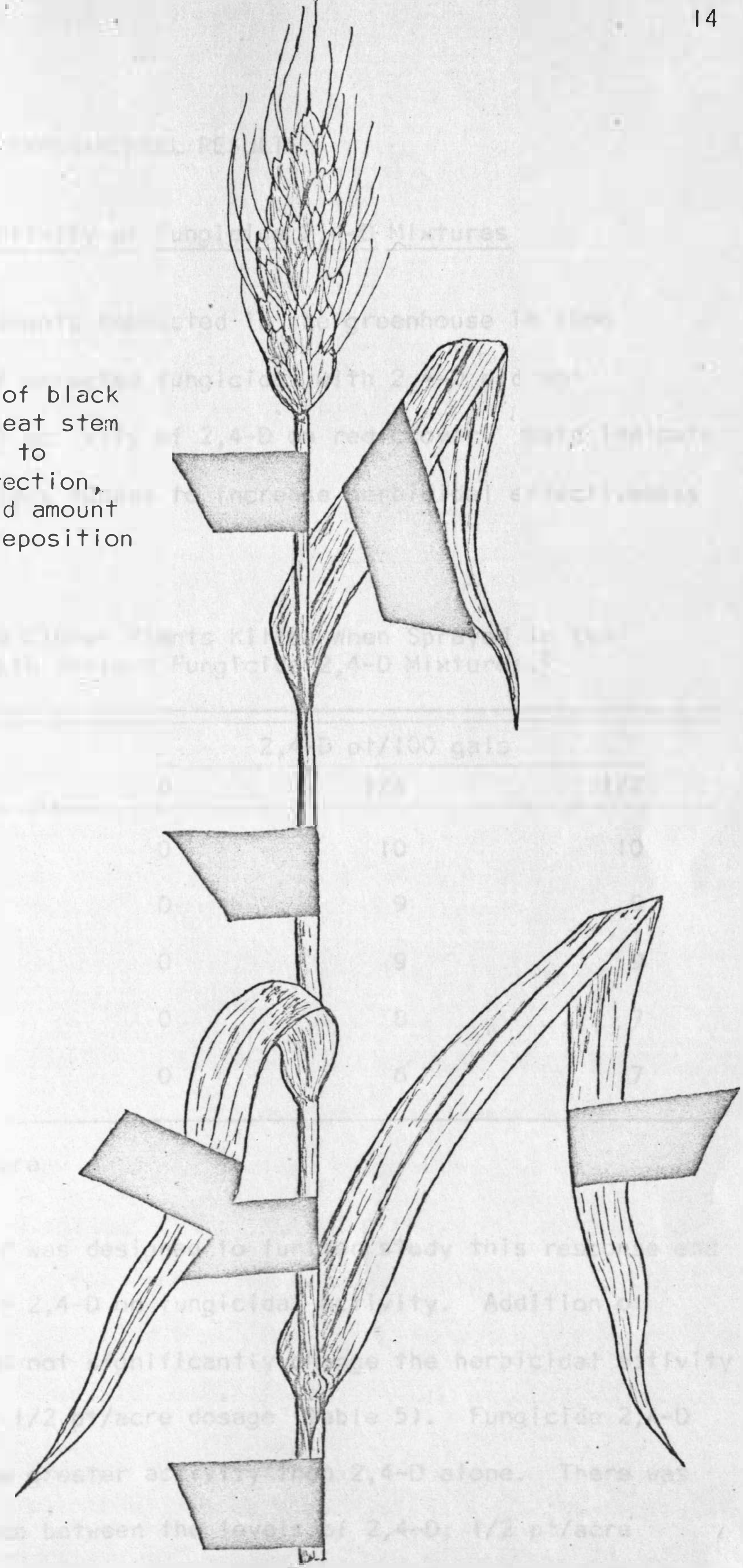

Figure 2. Placement of black tape on wheat stem and leaves to record direction, source, and amount of spray deposition

EXPERIMENTAL RESULTS

Herbicidal Activity of Fungicide 2,4-D Mixtures

Preliminary experiments conducted in the greenhouse in 1966 showed that mixtures of selected fungicides with 2,4-D did not decrease the herbicidal activity of 2,4-D on red clover. Data indicate the presence of fungicides tended to increase herbicidal effectiveness (Table 4).

Table 4. Number of Red Clover Plants Killed When Sprayed in the Greenhouse with Various Fungicide 2,4-D Mixtures.[a]

Treatments	2,4-D pt/100 gals		
	0	1/4	1/2
Dithane S-31	0	10	10
Plantvax	0	9	9
Parzate C	0	9	9
Manzate D	0	8	7
0	0	6	7

[a] 10 plants/spray mixture

A field experiment was designed to further study this response and to assess the effect of 2,4-D on fungicidal activity. Addition of fungicides to 2,4-D did not significantly change the herbicidal activity of 2,4-D at the 1/4 or 1/2 pt/acre dosage (Table 5). Fungicide 2,4-D mixtures tended to show greater activity than 2,4-D alone. There was a significant difference between the levels of 2,4-D; 1/2 pt/acre killed 96% and 1/4 pt/acre killed 85% of the test plants.

Table 5. Percentage Lambsquarter Plants Killed in Field Wheat Plots When Sprayed with Fungicide 2,4-D Mixtures.[a]

Treatment	2,4-D pt/acre		
	0	1/4	1/2
Manzate D	0	94	100
Parzate C	0	83	100
Plantvax	0	89	100
Dithane M-45	0	80	94
0	0[b]	78	93
Avg	0	85	96

[a] Statistical comparisons
X^2 .05 - significant
Fungicide mixtures containing 1/4 pt of 2,4-D/acre vs.
Fungicide mixtures containing 1/2 pt of 2,4-D/acre
X^2 .05 - not significant
Comparison of treatments containing 1/4 pt of 2,4-D/acre
Comparison of treatments containing 1/2 pt of 2,4-D/acre

[b] Average of 12 replications; other are average of 6 replications

Table 6 shows the effect of fungicides and 2,4-D used alone and in combination on Ceres spring wheat yields. There were no significant differences within 2,4-D dosage levels; however, Manzate D or Parzate C with 1/2 pt of 2,4-D/acre resulted in significant yield reductions of 9.5 and 10.1 bu/acre respectively when compared with untreated check. Plantvax or Dithane M-45 used in combination with 1/2 pt of 2,4-D/acre did not significantly decrease yield. Comparison of no 2,4-D with 1/4 pt of 2,4-D/acre showed that the latter reduced yield by 6.3 bu/acre which was significant at the 1 percent level. Overall effects indicate an inverse relationship between yield and 2,4-D dosage.

Table 6. Yields of Ceres Spring Wheat Sprayed with Various Fungicide 2,4-D Mixtures.[a]

Fungicide	2,4-D pt/acre			Mean
	0	1/4	1/2	Yield
		bu/acre		
Manzate D	34.4	30.7	24.9	30.0
Parzate C	37.5	34.7	27.1	33.1
Plantvax	33.1	31.3	30.0	31.5
Dithane M-45	37.5	34.5	33.5	35.2
0	33.5[b]	31.6	29.3	31.5
Mean yield	35.2	32.6	28.9	
lsd .05	5.79			

[a] Statistical comparisons
F .01 - Significant
No 2,4-D vs. 2,4-D
1/4 pt of 2,4-D/acre vs. 1/2 pt of 2,4-D/acre
F .05 - Not Significant
No 2,4-D vs. 1/4 pt of 2,4-D/acre
No fungicide vs. fungicide and 1/2 and 1/4 2,4-D/acre
No fungicide vs. fungicide and 1/2 pt of 2,4-D/acre

[b] Average of 12 replications; others are an average of 6 replications

Effect of 2,4-D on the Action of Fungicides

Excised wheat leaves sprayed with fungicides and 2,4-D alone and in combination and inoculated with stem rust were used to study the effect of 2,4-D on the action of fungicides. Results obtained using this method were inconsistent from one test to the next (Table 7).

An agar block method was devised which gave more consistent results.

Leaf rust or stem rust spores were germinated on agar blocks previously sprayed with fungicides or fungicide 2,4-D mixtures. Inhibition of germination varied directly with fungicide dosage for all fungicides except Plantvax (Tables 8, 9). Fungicide action was not affected by 2,4-D.

The amount of Parzate C required to obtain 50% control of germination was significantly higher than the amount of either Manzate D or Dithane M-45 with both stem rust and leaf rust. It may also be noted that higher dosage rates were required to kill stem rust spores than leaf rust spores (Table 10 and Figure 3).

Effect of Stem Density on Spray Deposition

Various stem densities were obtained at each of 2 locations by controlling seeding rate. Experimental plots at Brookings were sprayed with ground equipment; plots located at Huron were sprayed with a fixed wing airplane. Two spray applications were made at each location; one at heading and the other 10 days later.

Data from the Brookings plot are presented in Table 10. Significantly higher numbers of stems were obtained for each increased seeding rate. Number of stems/4 ft of row was considered to be a suitable measure of foliage density, although light penetration through the foliage represents a more direct measurement.

Tables 12 and 13 show that light penetration was not significantly different between the 4 rates of stem densities. Light penetration around the base of wheat plants was very low and increased as the readings were taken at higher levels.

Table 7. Control of Rust Pustules Development on Excised Marquis Wheat Leaves Sprayed with Different Amounts of Manzate D.

Trial	Manzate D amounts (ug/cm)					
number	0	0.1	0.208	0.224	0.432	0.423
			% Disease Control [a]			
1	0	69	89	85	95	85
2	0	35	-4	54	88	100
3	0	79	79	100	74	100
4	0	25	-106	33	39	53
5	0	50	70	77	34	88
6	0	-189	-150	22	8	-6
7	0	13	66	73	94	81
8	0	15	65	85	92	96
9	0	99	86	90	80	98
Avg		41	60	81	81	90

[a] 100% = complete control

Table 8. Percentage Control of Leaf Rust Spore Germination on Agar Blocks Sprayed with Different Fungicide 2,4-D Mixtures.[a]

Fungicide Dosage ug/cm²	Dosage 2,4-D (ug/cm²) x 10^4					
	0	2.87	5.92	12.29	Diff.	Lsd
Manzate D						
0.025	18 [a]	20			2	28.5
0.052	54		40		-14	
0.102	88			86	-2	
Dithane M-45						
0.025	38	27			-11	50.1
0.052	70		61		-9	
0.102	98			98	0	
Parzate C						
0.378	22	16			-6	16.6
0.780	44		31		-12	
1.620	75			76	1	
Plantvax						
0.378	0	0				
0.780	1		1			
1.620	2			0		
No fungicide	0	0	2	0		

[a] Average of 3 replications of approximately 500 spores each

Table 9. Percentage Control of Stem Rust Spore Germination on Agar Blocks Sprayed with Different Fungicide 2,4-D Mixtures[a]

Fungicide Dosage ug/cm^2	Dosage 2,4-D (ug/cm^2) x 10^4					
	0	2.87	5.92	12.29	Diff	Lsd
Manzate D						
0.10	42	37			-5	22.0
0.21	76		70		-6	
0.43	98			97		
Dithane M-45						
0.10	9	18			9	18.2
0.21	34		36		2	
0.43	75			83	8	
Parzate C						
0.76	23	25			2	15.6
1.56	41		43		2	
3.24	66			77	11	
Plantvax						
0.76	0	0				
1.56	0		0			
3.24	0			0		
No fungicide	0	0	0	0		

[a] Average of 3 replications of approximately 500 spores each

Table 10. LD-50's of Fungicide and Fungicide 2,4-D Combinations on Leaf Rust and Stem Rust Spores Germinated on Agar Blocks.[a]

Treatment	LD-50 ug/cm²			
	Leaf Rust		Stem Rust	
	Fungicide		Fungicide	
	Alone	2,4-D	Alone	2,4-D
Parzate C	0.880	0.990	2.200	1.763
Manzate D	0.052	0.058	0.127	0.153
Dithane M-45	0.035	0.048	0.270	0.260
lsd .05	0.260	0.396	0.179	0.249

[a] Average of 3 trials of approximately 500 spores each

Table 11. Relation of Seeding Rates on Emergence, Tillers/Plant, Number of Stems, and Yield, Brookings, 1966.

Seeding rate	Emergence[a] No. Plants	Tillers/plant No.	Stems No.	Yield bu/acre
24 lb/acre [b]	68	3.6	247	29.4
48 lb/acre [c]	132	2.5	337	30.2
96 lb/acre [b]	271	1.4	395	35.3
192 lb/acre[c]	484	1.0	494	34.0
lsd .05	55	1.02	56	4.45

[a] Average per 4 ft of row
[b] Average of 3 replications
[c] Average of 4 replications

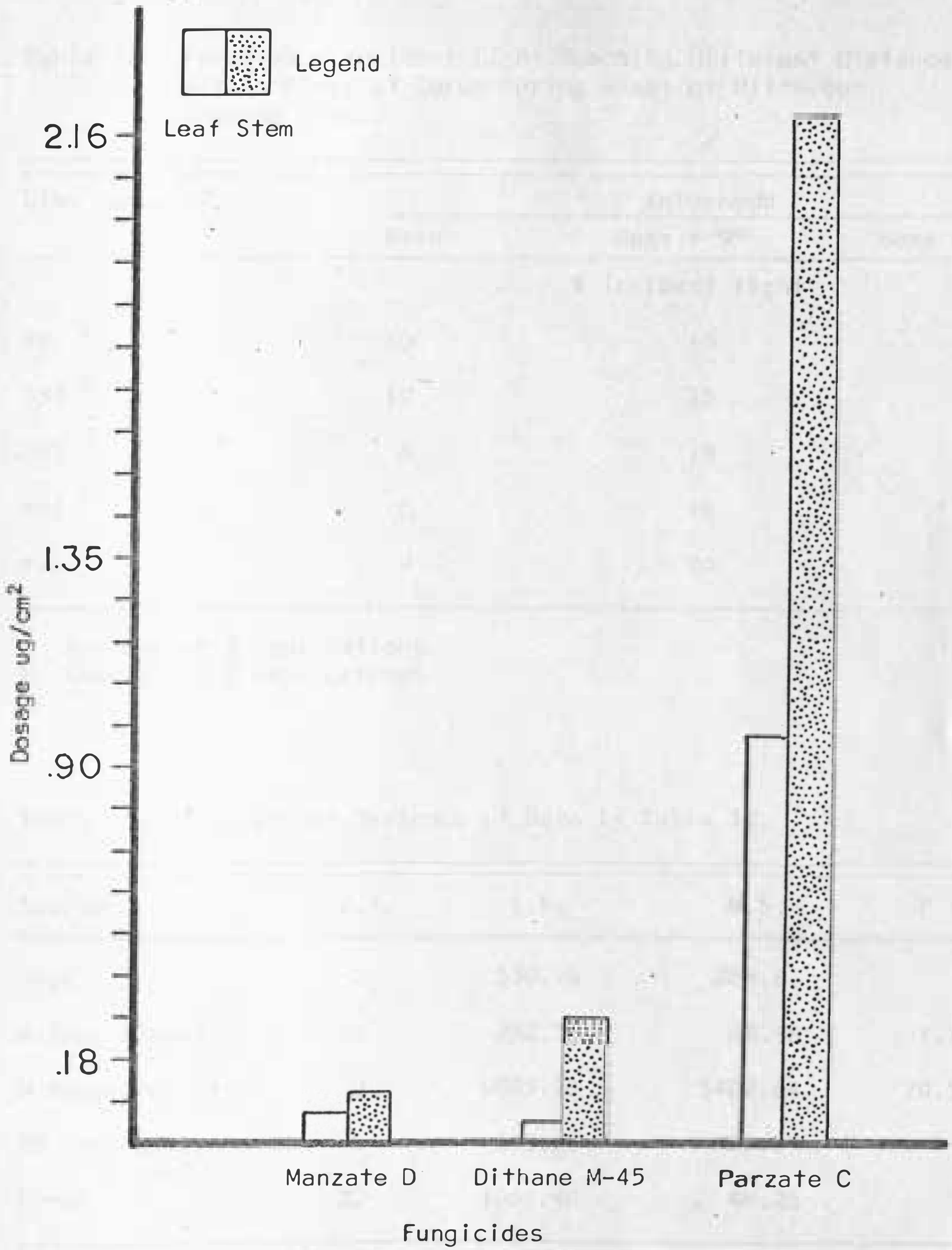

Figure 3. Comparison of LD-50's of fungicide on Leaf Rust and Stem Rust Spore Germination

Table 12. Percentage Incident Light Reaching Different Distances Within Plots of Ceres Spring Wheat of Different Seeding Rates.

Stem numbers	Internode		
	Base	Base + 9"	Base + 15"
	% Incident light		
247 [a]	10	19	36
337 [b]	10	25	47
395 [a]	8	18	45
494 [b]	6	18	38
Avg	9	20	41

[a] Average of 3 replications
[b] Average of 4 replications

Table 13. Analysis of Variance of Data in Table 12.

Source	d.f.	S.S.	M.S.	F test
Reps	2	530.76	268.8	
A Stem density	3	248.59	82.86	1.717
B Recording ht	2	6805.28	3402.64	70.52 **
AB Interaction	6	143.22	23.87	
Error	22	1061.48	48.25	

** Significant at 1% confidence level

Table 14. Percent of Leaf Under Surface Covered with Manzate D Fungicide in Ceres Wheat at Low, Middle, and Flag Leaf Heights, at Different Stem Densities, at Heading and at Ten Days Post Heading Time.

Number of Stems	% Deposition on leaves					
	Heading			Heading + 10 Days		
	Flag	Middle	Lower	Flag	Middle	Lower
247 [a]	18	16	2	22	3	1
337 [b]	17	15	1	18	5	3
395 [a]	12	19	4	26	7	1
494 [b]	16	11	1	16	7	2
Avg	16	15	2	20	5	2

[a] Average of 3 replications
[b] Average of 4 replications

Table 15. Deposition on Upper and Under Leaf Surfaces, Flag, Middle, and Lower Leaves Sprayed at Heading and Ten Days Post Heading.[a] (Converted data)

Leaf position	Leaf Surface			
	Heading		Heading + 10 days	
	Upper	Under	Upper	Under
Flag	6.83	4.58	7.00	5.00
Middle	6.75	4.58	6.17	2.83
Lower	6.50	2.17	5.67	1.83
Mean	6.69	3.78	6.33	3.22
lsd .05	0.53		0.53	

[a] Average of 14 replications

Table 16. Analysis of Variance of Data in Table 15.

Source	d.f.	S.S.		M.S.		F	
		H[a]	H+10	H	H+10	H	H+10
Reps	2	0.70	0.44	0.35	0.22		
A Stem density	3	0.27	1.22	0.13	0.41		
B Leaf position	2	29.37	44.32	14.69	22.16	34.16**	51.53**
C Leaf Surface	1	153.13	174.22	152.13	174.22	356.22**	405.16**
AB	6	4.85	19.90	0.81	3.33		7.74**
AC	3	0.48	0.11	0.24	0.03		
BC	2	18.07	4.23	9.03	2.23	21.00**	5.19**
ABC	6	2.63	10.44	0.44	1.74		4.05**
Error	46	19.97	19.56	0.43	0.43		

[a] H = Heading; H + 10 = Heading + 10 Days

**Significant at the 1% confidence level

Spray deposition on stems was influenced by several factors but not by stem density (Table 17). There were significantly higher depositions on those stem segments facing the wind and sprayer than on segments opposite the wind and sprayer. There were no significant differences in deposition on segments facing the sprayer vs. segments facing the wind (west) and no significant differences in segments opposite the sprayer vs. segments opposite the wind. Basal portions of the stem received significantly lower depositions than the upper portions. The wind was blowing at 4 mph from the northwest during the application at heading and from the southwest at 17 mph during the second application, hence the higher deposition on the west side of the plants.

The results obtained from the Huron experiments were similar to those obtained at Brookings; although deposition was much lighter at Huron (Tables 18, 19, 20). The data for the heading + 10 days application were not included because excessive wind drift resulted in sporadic coverage of 2 replications. Plots at Huron received less rainfall, had shorter stems, and relatively low stem densities than those plots at Brookings.

Table 17. Deposition of Neck, Middle, and Lower Stem Portions and Portions Facing and Opposite the Sprayer (Converted data).

Orientation around stem	Deposition Index [a]					
	Heading			Heading + 10 days		
	Neck	Middle	Lower	Neck	Middle	Lower
Side facing sprayer	6.50	5.67	4.00	5.75	6.33	5.25
East	5.17	2.92	2.25	7.00	5.17	2.83
Side opposite sprayer	4.17	3.25	1.75	5.58	4.75	3.17
West	6.42	5.33	4.08	7.00	6.08	5.08
lsd .05 Heading	0.58					
lsd .05 Heading + 10				0.52		

[a] Average of 14 replications

Table 18. Comparison of Spray Deposition Using Ground Equipment and a Fixed Wing Airplane on Spring Wheat Leaves.[a]

Applicator	% Spray deposition on leaves					
	Upper Surface			Lower Surface		
	Flag	Middle	Lower	Flag	Middle	Lower
Ground	65	61	53	16	16	2
Airplane	18	5	4	1	t	t

[a] Statistical comparison of ground vs. airplane not valid

Table 19. Deposition on Both Upper and Under Leaf Surfaces of Flag, Middle, and Lower Leaves of Pembina Spring Wheat, Huron, 1966.[a] (Converted data)

Leaf surface		Deposition index on Leaves		
		Flag	Middle	Lower
Upper		4.83	3.25	2.41
Under		1.67	1.33	1.17
lsd .05	0.50			

[a] Average of 4 replications

Table 20. Deposition on Neck and Lower Stem Portions Facing Each Direction, Huron, 1966.[a] (Converted data)

Orientation around stem	Deposition index on stems		
	Neck		Lower
West	4.08		2.58
North	1.83		1.58
East	1.67		1.75
South	3.67		2.25
lsd		0.50	

[a] Wind from southwest at 15 mph, direction of sprayer travel; west to east; average of 4 replications

DISCUSSION

Successful use of fungicides and 2,4-D in a combination spray to control leaf and stem rust and weeds depends on several factors: 1. Effective control of rust, 2. Effective control of weeds, 3. Lack of toxicity to wheat, 4. Physical compatibility of fungicide with 2,4-D.

Each of the fungicides tested has been used successfully to control rust. Plantvax is not a contact killer so its potential to control rust in combination with 2,4-D was not established. The quantity of active ingredient of Manzate D, and Dithane M-45 used to obtain stem rust and leaf rust spore LD-50's was almost the same, whereas Parzate C required a significantly higher dosage.

The addition of fungicides did not significantly alter the herbicidal action of 2,4-D although a trend toward greater weed control following the addition of fungicides did occur, especially with Plantvax and Manzate D.

Yield depression occurred when 2,4-D was applied to wheat at the recommended dosage of 1/2 pt/acre at the early boot stage. Parzate C and Manzate D tended to increase this toxicity whereas Plantvax and Dithane M-45 did not. All fungicides except Plantvax tended to increase yield when applied alone as a foliage spray under light rust conditions, but only Dithane M-45 resulted in a consistent increase when mixed with 2,4-D.

In Table 6, Manzate D and Parzate C significantly reduced yield when mixed with 1/2 pt of 2,4-D/acre and compared with the check.

When these combinations are compared with the 1/2 pt of 2,4-D/acre dosage rather than the check, the trends support this conclusion although the differences are not statistically significant at the 5% level.

Physical compatability was satisfactory with all fungicide 2,4-D mixtures used. Each fungicide went into suspension with 2,4-D as easily as with water.

Average estimated cost/acre for aerial spray application in South Dakota is presented in Table 21.

Table 21. Comparative Costs of Fungicides and 2,4-D Used Alone and in Combination as Foliage Sprays (Airplane Application).

Application	Cost/ acre	Application	Cost/ acre	Application	Cost/ acre
Separate					
Manzate D	$3.40	Dithane M-45	$3.40	Parzate C	$2.80
2,4-D	1.25		1.25		1.25
Total	4.65		4.65		4.05
Combination	3.63		3.63		3.03
Difference	1.02		1.02		1.02

The combination spray would save farmer $1.02/acre during years of moderate to heavy rust severity.

The 4 planting rates established significantly different stem densities as measured by the number of stems/4 ft of row. Light meter readings did not indicate significant differences in foliage density at any of the heights where light penetration was recorded. Stem density had no significant effect on spray deposition on any leaf or stem position, leaf surface, or side of the stem.

It is possible that stem density did not reflect foliage density because of size variation from plants in each of the seeding rates. It was noted that plants from light seeding rates had larger stems than those from heavy seeding rates. These 2 factors, stem density and stem size appeared to vary inversely and thereby stabilized foliage density. Assuming the light meter readings to be a good indicator of foliage density, it may then be noted that only 10 percent of the light at Brookings reached the basal area. This indicates that the foliage canopy was quite dense. Thinner or lighter densities may have been obtained by widening the row spacing and varying the seeding rate accordingly.

Upper leaf surfaces received more spray than under leaf surfaces especially near the base of the plant. Deposition on upper leaf surfaces was nearly the same for all 3 leaves after the application at heading. There was significantly lower deposition on the leaves near the ground for the application made 10 days later. The difference between the 2 applications was probably caused by raising the sprayer boom to compensate for wheat plant elongation. The under leaf surfaces showed a marked reduction in spray deposition from upper to lower leaves after both applications.

Deposition on stems followed the same trends as that on leaves. Upper portions of stems received significantly higher spray deposition than lower portions.

Several factors influenced spray deposition on the stem. Those portions facing the sprayer and wind received the highest deposition whereas portions opposite the sprayer and wind received much less.

Rust spores generally are blown into South Dakota from states to the south and southwest. In late spring and early summer, during the period of local rust buildup, winds are also primarily from the southwest. Presumably the majority of rust spores are deposited on those portions of the plants facing the wind. Supporting data for this suggestion are not available. If this assumption is correct, chemical control of rust should be improved by spraying with a southwest wind or spraying in one direction from southwest to northeast on a calm day. This would provide maximum spray deposition in the areas most likely to be exposed to rust spores.

The experimental design did not permit a comparison between ground and airplane application, although spray deposition patterns were strikingly different. Ground equipment provides more thorough deposition and presumably better rust control than airplane spraying, however, it is slower, cannot be used on a wet field, and does some physical damage to the crop. In spite of poorer coverage, aerial spraying controls rust effectively enough to more than pay for itself in years of moderate to heavy rust infections.

SUMMARY

The following information was gained from these studies:

1. The fungicides Dithane M-45, Manzate D, and Parzate C are physically compatible with 2,4-D, and neither rust control nor herbicidal properties of the components were significantly affected.

2. Higher dosages of Parzate C are required for rust control than are required of Manzate D or Dithane M-45.

3. Stem rust spores were more difficult to kill than leaf rust spores with all fungicides tested.

4. Planting rates were varied to successfully establish a series of stem densities. These densities, however, did not provide different foliage canopy densities as measured by light penetration or spray penetration.

5. Spray deposit primarily occurred on wheat stem segments facing a moving sprayer and also on wheat stem segments facing the wind.

6. Spray deposit was poor on lower plant parts and on under surfaces of leaves.

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