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Wind-Blown Soil Abrasive Injuries to Winter Wheat Plants[1]

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SYNOPSIS

Winter wheat plants were given fall and spring exposures to blowing soil in a wind tunnel. Average yields, weights of plant material, and number of heads for spring treatments were 46.4, 29.4, and 23.9% less, respectively, than fall treatments. Heading and ripening of grain was delayed 1 week to 10 days on severely exposed plants. The total amount of soil striking a plant was more important in depressing products of plant growth than was the length of time between exposures. The plants were shown to have remarkable recovery powers if given water after severe abrasive injury.

SERIOUS wind erosion can cause damage to vast areas of valuable agricultural land. One of the initial stages in the process of wind erosion is the destruction of plant growth by the mechanical force of wind and the abrasive action of moving soil. The extent of injury to plants varies with the age of the plant, the available soil moisture, the velocity of the wind, and the quantity of soil moving past the plant. Of all agricultural crops, winter wheat is probably most subject to injury by wind erosion. This crop is grown in areas of limited rainfall and is a young, tender plant in the spring months when the wind erosion hazard is at a maximum in the Great Plains.

A review of literature indicates that only a few studies of the effects of blowing soil on plants have been made. One of these concerning soil borne mosaic (6) gave some information on the amount of time required for soil-blowing to cause lethal damage to plants. Another (7) in Japan considered the influence of wind erosion on wheat from the standpoint of sand removal and/or burial around the root area of the plants.

The purpose of this study was to make quantitative measurements of the extent of damage to winter wheat plants caused by soil blowing. The study was concerned primarily with damage occurring with varying degrees and amounts of blowing soil less than that required for lethal damage; i.e., how much injury will the plant withstand and still produce grain and plant material? The wheat plants used were subjected to varying intensities of blowing soil in the fall and in the spring in an attempt to evaluate the extent of injury occurring at these two different periods of growth. This report summarizes the results of 2 years' work. In some respects differences appear between the 2 years' results; however, these differences apparently are quantitative in nature. The 2 years' data appear to provide reasonably dependable information for conclusions on the relative effects of given treatments.

METHODS AND PROCEDURES

Wheat plants were grown in 18- by 6- by 5-inch flats. Immediately after planting in the fall, the flats were placed out-of-doors. This procedure not only simulated natural conditions but also permitted vernalization to take place. The plants were brought into the laboratory wind tunnel at the time of fall and spring exposure and returned to the field immediately following treatment. One week after completion of the last spring treatment the

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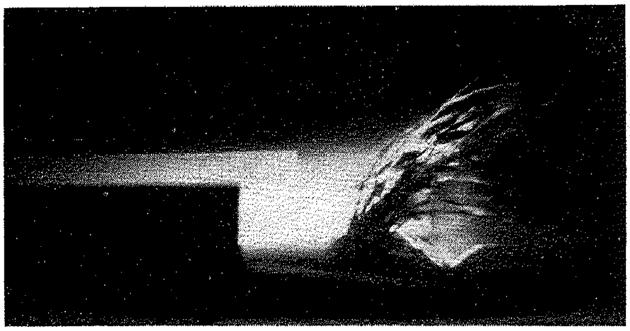

FIG. 1.—View of wheat plants during exposure to blowing soil with 25.0 mph wind in laboratory wind tunnel.

flats were moved to the greenhouse. At this time 10–20–10 fertilizer was added at a rate of 300 pounds per acre.

Natural cultural and agronomic methods were followed as closely as possible in raising the plants. Pawnee wheat was planted in one row across the length of the box. After the plants had reached a substantial size they were thinned to 10 plants per box. Planting date for the 1953–54 season was Oct. 15 and for the 1954–55 season Oct. 4.

Climatic data obtained at the weather station located near the experimental site indicated that the total precipitation during the period the plants were out-of-doors (Oct. 15 to May 10) was 10.65 inches for the 1954–55 season. This was approximately 1.0 inch more than received during the 1953–54 season. Average temperature for the 1954–55 season was 45.0° F., or 1 degree higher than the 1953–54 season. The 1953–54 season, however, had 23 days on which 0.1 inch or more of rain fell, or 3 more days than 1954–55. In addition, there were 171 days during the 1953–54 season when the average temperature fell below 55.0° F. This compared with 158 days for the 1954–55 season.

The plants were grown in a silt loam soil representative of the western Kansas wheat area. Only fractions of this soil less than 0.84 mm. in size were used as the abrasive material. Intensities and number of exposures were as follows:

Intensity of wind		No. 10-minute exposures to blowing soil		Average rate of soil movement
Relative	Velocity at 6 in. height	1953–54	1954–55	ton/ft. width/day
	mph			
Low	17.7	1	1	0.29
Low	17.7	2*	2*	0.94
Intermediate	19.6	—	1	1.10
Moderate	21.3	1	1	1.34
Moderate	21.3	2*	2*	2.59
High	25.0	1	1	2.29
High	25.0	2*	2*	4.73
Very high	27.5	—	1	3.46

* Exposures 10 days apart.

All the above treatments were replicated four times. Four flats of plants were used as checks during the 1953–54 season. Eight flats were used for the 1954–55 checks. One group of four flats was selected at the time of fall treatment and the other at time of spring treatment. One-half the plants was exposed from Dec. 8 to 15; the other half was exposed from April 26 to May 2. The wind carrying abrasive soil was allowed to pass over the plants for a 10-minute period. Rates of movement were determined by weighing the trays of abrasive soil material before and after exposure. A view of the plants in the wind tunnel is shown in figure 1.

FIG. 2.—Typical view of plants after heading. From left to right the plants were treated as follows: single low exposure in fall with 17.7 mph wind, single medium exposure in spring with 21.3 mph wind, double high exposure in spring with 25.0 mph wind and the unexposed check.

RESULTS

Visual Observations

Observations were made at 1-week intervals after exposure during both seasons. In general the effect of a given treatment seemed to be similar for each year. The 1954–55 plants, however, appeared to be in a slightly more drouthy condition than the 1953–54 plants as measured by the amount of plant growth. Insofar as individual treatments were concerned, the following observations were made:

1. Single fall exposures at low, intermediate, and moderate winds caused only slight damage. Roughly 30% of plant tillers were burned.

2. Single fall exposures at high and very high winds caused more severe damage, with some burying of tillers and approximately 40% of the tillers burned.

3. Double fall exposures at low and intermediate winds were only slightly more damaging than single exposures at the same velocities.

4. Double fall exposures at moderate, high, and very high winds caused moderate to severe damage, with some flats having the entire top growth of the plant killed.

5. Spring exposures both double and single caused much more severe damage than fall exposures. Immediately after exposure all plants in the groups receiving exposures at high and very high winds appeared to be dead.

6. Spring exposed plants made remarkable recovery after being placed in the greenhouse and receiving water. New tillers began forming 4 days after the plants were placed in the greenhouse.

7. Heading and ripening of grain was delayed 1 week to 10 days on the severely damaged plants.

8. The general appearance of the severely damaged plants at harvest time was sparse plant growth, short stems, and short stunted heads.

Figure 2 indicates the general appearance of the plants after heading and prior to ripening.

A summary of pertinent data obtained in the study is presented in table 1. Values for yield, number of heads, and plant material are averages of four replications of each treatment.

Table 1.—Summary of average yields, number of heads, and total plant material.

Number of exposures and relative rate of soil movement	Yield				Number of heads/0.0001 acre				Plant material			
	1954		1955		1954		1955		1954		1955	
	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring
	bu./acre								tons/acre			
Single low	7.1	9.0	8.2	6.3	171	183	100	166	0.67	0.72	0.73	1.29
Double low	8.9	5.7	12.1	4.2	196	162	156	104	.64	.54	.93	.86
Single intermediate	—	—	4.7	5.8	—	—	69	100	—	—	.60	.82
Single moderate	8.1	5.5	10.7	5.3	165	150	138	81	.66	.64	1.13	.73
Double moderate	10.3	6.5	11.9	3.5	180	165	144	50	.63	.51	1.19	.22
Single high	10.8	6.6	11.7	4.3	196	153	150	78	.88	.49	1.08	.65
Double high	7.7	2.4	12.2	2.6	153	93	156	46	.82	.31	1.05	.35
Single very high	—	—	13.3	1.9	—	—	147	42	—	—	1.14	.30
Fall and spring average			11.2*	4.4*			141*	88*			1.02*	.68*
	8.8	6.0	10.6	4.3	177	151	133	84	.72	.54	.98	.65
Yearly average	7.4		7.4		164		108		.63		.82	
Check	11.2		12.6†	13.6†	224		171†	202†	1.12		1.47†	1.39†

* Average based on 6 treatments used in 1954 and in analysis of variance.
† Separate groups of 4 flats each selected as fall and spring checks.

Statistical Analysis

Analysis of variance procedures (5) were used to ascertain significant differences between seasons, times of year, and treatments. Only comparable data from both years were used, thus including checks and double and single treatments at 17.7, 21.3 and 25.0 mph winds. Results of this analysis on yield, heads, and plant material data are presented in table 2A. Treatment and yearly mean comparisons are presented in tables 2B and 2C.

Non-linear correlation procedures (2) were used to establish average relationships between rate of soil movement and the measured products of plant growth. All fall and spring measurements at all wind velocities for both years were used in this analysis. The figures showing the derived fall and spring curves for yields, numbers of heads, and plant material will be found under appropriate section titles. The regression equation, the index of correlation ρ, and the standard error of estimate σys are given on the figures. The values of the correlation index required for significance at the 1 and 5% levels are 0.342 and 0.264, respectively.

Soil movement—yield relationships.—The relationship between yield and rate of soil movement is shown in figure 3. The curves show the different effect of the same treatment when given in the fall as compared with spring. The index of correlation indicates that both spring and fall correlations are significant at the 1% level.

Rates of soil movement associated with yields from double exposures 10 days apart are plotted as the sum of the 2 exposures. Yields obtained from these treatments were found to be comparable to those obtained from single exposures having soil movement rates equal to the sum of the double exposures. This indicates that the damage to the plant is a function of the total amount of soil striking the plant rather than the time interval between exposures.

Soil movement—head relationships.—The relationship between number of heads and rate of soil movement is shown in figure 4. The spring treatment correlation is significant at the 1.0% level but the fall treatment is significant only at the 5.0% level indicating that fall treatment had little influence on the number of heads produced. Examination of the plotted data shows the 1953–54 spring treatments apparently had less effect on number of heads than the 1954–55 spring treatments. The opposite is true for the fall data.

Table 2A.—Summary of analysis of variance on yield, number of heads, and total plant material.

Factors	Degrees of Freedom	Variance					
		Yield, bu./acre		Number of heads/0.0001 acre		Plant material, tons/acre	
		Fall	Spring	Fall	Spring	Fall	Spring
Total	55						
Treatment	6	16.22*	76.74**	3,185	17,825*	0.29*	0.89*
Years	1	66.66**	15.33	20,828**	46,057**	1.31**	0.39**
Treatment × year	6	3.32	7.44	1,049	2,248	0.06	0.14
Error	42	7.46	6.71	1,019	1,941	0.07	0.05

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

Table 2B.—Treatment comparisons—combined 1954–55 fall and spring averages.

Treatment	Yield, bu./acre		Number of heads/0.0001 acre		Plant material, tons/acre	
	Fall	Spring	Fall	Spring	Fall	Spring
Single low	7.7	7.7	136	175	0.70	1.00
Single moderate	9.4	5.4	152	116	0.90	0.68
Single high	11.2	5.4	173	116	0.98	0.57
Double low	10.5	5.0	176	133	0.79	0.70
Double moderate	11.1	5.0	162	108	0.91	0.37
Double high	9.9	2.5	155	70	0.93	0.33
Check	11.9	12.2	198	213	1.29	1.26
5% L.S.D.	2.2	3.3	N.S. (Table 2A)	58	0.27	0.46

Table 2C.—Yearly comparisons—fall and spring averages.

Year	Yield, bu./acre		Number of heads/0.0001 acre		Plant material, tons/acre	
	Fall	Spring	Fall	Spring	Fall	Spring
1954	8.8	6.0	177	151	0.72	0.54
1955	11.2	4.4	141	88	1.02	0.68
5% L.S.D.	1.4	N.S. (Table 2A)	17	23	0.14	0.12

Soil movement—plant material relationships.—The soil movement-total plant material relationship is shown in figure 5. The spring correlation is significant at the 1% level, but the fall correlation is significant only at the 5% level. The plotted data show the 1953–54 fall treatments reduced the amounts of plant material more than did the 1954–55 fall treatments. Spring treatments had a reversed effect for the two years.

Yield—Head and Yield—Plant Material Relationships.—The analysis did not indicate a real difference in yields between years for spring treatments. It did, however, indicate differences between years for fall treatment yields and for both fall and spring treatment number of heads and total weight of plant materials. It is apparent that the yield—head and yield—plant material relationship is different for the 2 years. Table 3 presents average head and plant material requirements for production of a bushel of grain for fall and spring treatments for both years.

Table 3.—A summary of yield—head and yield—plant material requirements.

Year and season		Number of heads/bu.	Tons of plant material/bu.
1954	Fall	20,114	0.082
	Spring	25,167	0.090
1955	Fall	12,547	0.092
	Spring	19,535	1,510

The data of table 3 show that more heads were required to produce a bushel of grain in 1954 than in 1955 but 1954 produced more yield per pound of plant material than did 1955.

DISCUSSION

Considerable variation exists in some of the data obtained in this study. This would be expected, however, in a study where climate is uncontrolled and a small mass of soil is isolated from the surrounding area. Actually total amounts of precipitation mean little because of high evaporation and runoff rates. It is probable, therefore, that some of the variation between the 2 years is caused by differences in number of days with growing temperatures and with rain. General trends and effects of any given treatment, time of treatment, or season are the same for the 2 years; i.e., spring treatment is more severe than fall; and, further, spring treatment affects the yield, number of heads, and plant material in one way while fall treatment does so in another. For these reasons it is believed that 2 years' data provide a sufficient amount of information from which conclusions may be drawn.

Most of the data follows expected and straight-forward trends. Several unexpected and rather interesting points, however, have been revealed by the study. Examples are: *(1)* the remarkable recovery powers of the wheat plant when given moisture after being severely damaged, *(2)* the 7- to 10-day delay in heading and ripening of the grain, *(3)* the indication that the damage to the plant is a function of the total amount of soil striking the plant rather than the time interval between exposures.

The effect of date of treatment on the products of plant growth also is interesting. Average yields, weights of plant material, and number of heads for spring treatments were 46.4, 29.4, and 23.9% less, respectively, than fall treatments. It is apparent that the plants suffer much more severe damage and have less time and ability to recover in the spring than in the fall. Another effect of date of treatment is indicated by the cycloid nature of the fall curve. While the reasons for the shape of this curve are not clearly understood, two possible factors appear to be responsible for its shape. The first, and probably the most important, is the burial of the small fall plant by the moving soil, figure 1. It is noted that a considerable amount of soil accumulates about the base of the plants. During the short exposure time this accumulated soil would tend to protect the plants from the abrasive action of the moving soil. Actually this soil accumulates to greater depths under conditions of high wind where greater amounts of soil are moving. It is possible, therefore, that at rates of movement from about 0.10 to 0.25 ton/ft/day, more of the plant is exposed, thus suffering more severe damage than it does when soil is moving at a rate of 0.25 to 4.0 ton/ft/day, a rate at which accumulation takes place and protects the plant. In the spring, this accumulation offers little protection to the plant because of the greater amount of vulnerable leaf area exposed. Under these conditions, increasing amounts of soil movement cause a progressive decrease in products of plant growth.

A second factor or factors which may possibly influence the shape of the curve is the opening and closure of the plant stomata and the associated transpiration rate. Previous studies (3) have indicated that initial exposures of *Helianthus annus* plants to winds greater than 2 mph cause first a rapid increase in transpiration, then closure of the stomata in 15 minutes or less, with a consequent reduction in transpiration, and finally a gradual increase in transpiration. The time interval between initial exposure and closure of the stomata depends on the intensity of the wind. When the stomata are closed and the transpiration rate reduced, the damage to the plant is limited to the pure mechanical action of the wind or, in this case, to the abrasive action of the soil.

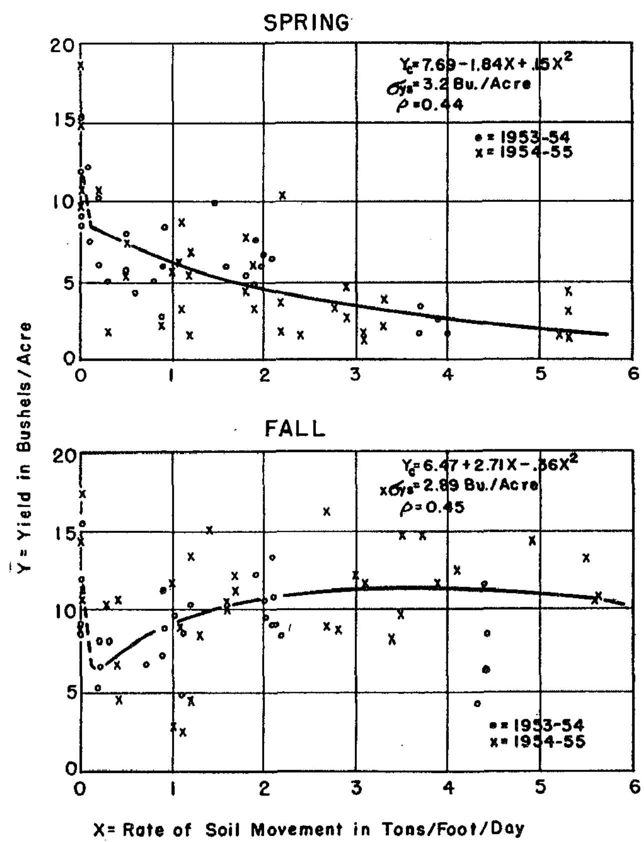

FIG. 3.—Relationship between wheat yield and rate of soil movement for fall and spring treatments.

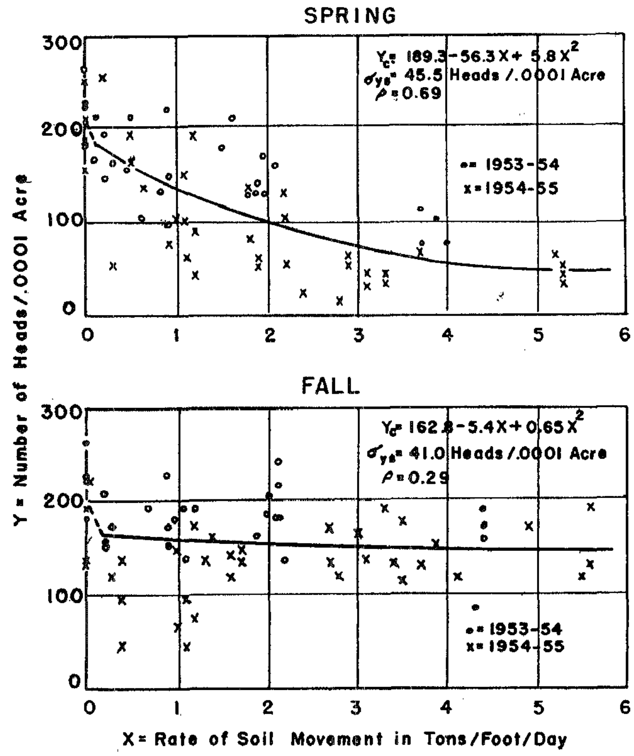

FIG. 4.—Relationship between number of wheat heads and rate of soil movement for fall and spring treatments.

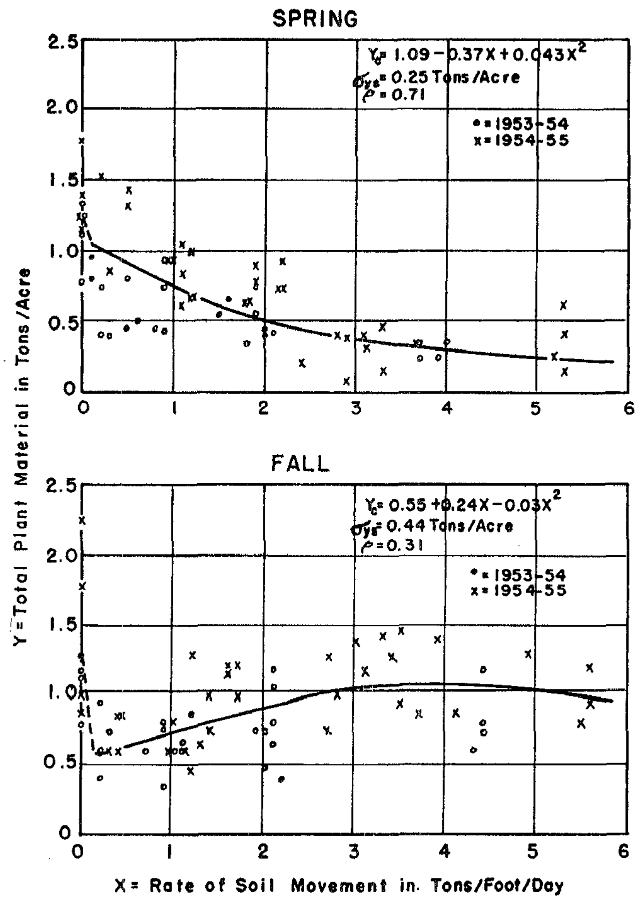

FIG. 5.—Relationship between total plant material and rate of soil movement for fall and spring treatments.

In view of these facts there is a possibility that in the fall, when the leaf area of the plant is small, low intensities of wind and soil movement delay closure of the stomata; hence both the depressing forces of rapid transpiration and mechanical abrasion are in effect. This could cause a reduction in products of plant growth. Increasing the intensity of soil movement from about 0.25 to 4.0 ton/ft/day might cause quicker closure of the stomata, thus reducing the transpiration force. Most of the damage to the plant, therefore, would be due to mechanical abrasion alone. If this force were not so great as the previous transpiration plus abrasive forces, then increased products of plant growth might result. The abrasive forces associated with rates of movement greater than 4.0 ton/ft/day would probably be great enough to offset the reduced transpiration; hence products of plant growth would be reduced. In the spring, on the other hand, it is probable that the abrasive force alone striking the larger leaf area of the plant is great enough to overcome the effect of lessened transpiration; thus yields and plant material are depressed at an increasing rate with increased rates of soil movement.

The validity of the above hypothesis is, of course, dependent on similar stomata action under wind stress for wheat plants and broad leaf plants and on stomata closure taking place within the 10-minute test period. Additional studies are needed to substantiate or contradict this conclusion.

In general, the data show the same trends of effect of treatments on yield, plant material, and number of heads; i.e., if plant material and head numbers are reduced, then yield is also reduced. One or two exceptions occur, however, in some phases of the comparison. For example, increasing vigor of fall treatment reduces yields but has little effect on numbers of heads. Another exception to comparable effects on yield, plant material, and number of heads is indicated in the levels of maximums and minimums which occur in connection with their individual measurements. For example, within the limits of the data, minimum yields from spring treatments would occur with soil movements of approximately 6.0 ton/ft/day, but minimum numbers of heads occur at approximately 4.9 ton/ft/day. These differences in required rates of movement for minimums are partially accounted for by the information given in tables 1 and 3. Yields for the 2 years were nearly equal, but it is evident that numbers of heads and amounts of total plant material varied between years. This indicates the importance of the seasonal factor on the amount of plant material produced and the filling of the wheat heads.

The nature of the empirical regression equations do not permit extrapolation to points of zero yield, plant material, or numbers of heads. Further investigation would be necessary to evaluate rates of movement causing lethal damage. It would seem, however, that any yield below 2.0 bu/acre, the minimum indicated in this study, for all practical purposes could be considered a failure since it would not be economically feasible to harvest such a crop.

Interpretation and Application

This was a laboratory study wherein abrasive injuries were accelerated by exposing wheat plants to very high concentrations of moving soil for periods of short duration. However, since the data show the extent of injury to be dependent on the total quantity of soil striking the plant rather than on the rate or length of time between exposures, the results should be applicable to field conditions. Interpretation of the results in terms of field conditions would be dependent on information on the number, duration, and intensity of dust storms occurring in wheat growing areas. While some information regarding intensity-frequency of winds on the Great Plains (8) and on rates of sand and soil movement (1, 4) is available, detailed information relating these variables to intensity, number, and duration of dust storms is not available. Quantitative evaluation and interpretation of the data obtained in this study in terms of the condition of a wheat crop after having experienced a given number of dust storms would, therefore, be contingent upon further information regarding these factors.

SUMMARY

Winter wheat plants were given fall and spring exposures to blowing soil in a wind tunnel to evaluate the extent of injury occurring at these two periods of growth.

The plants were grown in flats placed out-of-doors. Five different intensities of soil movement were used on different groups of plants. Upon completion of all exposures in the spring, the plants were placed in a greenhouse until harvest. Measurements of damage were made in terms of yield, numbers of heads, and weights of plant material.

Results show: *(1)* heading and ripening of grain to be delayed 1 week to 10 days on severely exposed plants, *(2)* the total amount of soil striking a plant was more important in depressing products of plant growth than was length of time between exposures, *(3)* average yields, numbers of heads, and weights of plant material for spring treatments were 46.4, 23.9, and 29.4% less, respectively, than fall treatments, *(4)* increased rates of soil movement caused an increased depression in products of plant growth in the spring. Fall treatment showed the greatest depression with initial low rates of soil movement followed by a lesser effect as the soil movement increased, *(5)* increased vigor of treatment in the fall had little effect on the formation of heads; i.e., head numbers were nearly the same whether the movement was 0.5 ton/ft/day or 5.0 ton/ft/day, *(6)* winter wheat plants have remarkable recovery powers if given sufficient moisture after severe abrasive injury.

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