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PRELIMINARY STUDY USING A WIND TUNNEL TO DETERMINE THE EFFECT OF HOT WIND ON A WHEAT CROP

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ABSTRACT

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Damage caused by hot, dry winds during kernel formation and development of winter wheat (*Triticum aestivum* L.) is difficult to assess because under natural field conditions there is never a nonaffected area for direct comparison. An attempt to evaluate damage from hot wind was made by placing a portable wind tunnel, with an auxiliary heat source at the intake, over field-grown winter wheat during the "boot" and the "milk" growth stages. Five 2-h tests were made on wheat plants that had been grown either where soil water was never limiting or where soil water was always limiting. Air temperature, dew point temperature, and vapor pressure deficit differences from ambient air were determined during each test. Plant water potential (Ψ_p) was determined at the beginning and end of each test and soil water content, at the time of the test. At maturity, kernels/head, heads/m² of soil surface area, weight/kernel and grain yield were determined.

Air temperatures in the tunnel ranged from 4.6 to 8.4° C above ambient air temperature during the five tests. Vapor pressure deficit in the tunnel increased from 0.73 to 2.57 kPa and relative humidity decreased by 4.9 to 14.6% compared with ambient. Reductions in kernels/head, heads/m², and kernel weight, compared with the nontreated area ranged from 2.9 to 32.9, 0 to 54.8, and 2.5 to 18.8%, respectively. Maximum grain yield reduction was 65.1%. In two of the tests, grain yield reduction was greatest at 2.5 m past the end of the tunnel. Reduction measured at that location probably more realistically reflects expected reductions than those measured within the tunnel.

Many countries of the world experience hot, dry winds during the heading to maturation growth stages of winter wheat (*Triticum aestivum* L.). These winds are referenced by various names: "siroccu" in North Africa, "khamsin" in the Middle East, "chili" in Tunisia, "gibli" in Libya, "larrechi" in Spain, "sharav" in Israel, and "sukhovei" in the USSR. These winds characteristically have low relative humidity (< 20%), high temperature (> 33° C), and high wind speeds (> 16 kph) (Cheng and Teng, 1964; Lomas and Shashoua, 1974).

Actual damage to a wheat crop exposed to hot, dry winds is impossible to measure because there is no way to determine what the crop would have produced without the wind. A grain yield reduction of 0.76 kg/ha was calculated for each hot, dry day that occurred between flowering and grain filling during a 17-year period in Israel (Lomas and Shashoua, 1974). When wheat grown under controlled conditions was exposed to 40.5°C during the day during anthesis, kernel number/spikelet was reduced by 2 and weight/kernel was reduced by 26 mg. The same temperature treatment during kernel formation reduced the number of kernels/spikelet by only 0.2 but weight/kernel by 24 mg. In both cases, the reduction in kernel number per spikelet was related to an increase in number of sterile florets (Langer and Olugbami, 1970). In another controlled environment study, wheat grown at 32.3°C during a 9-h day during anthesis to maturity produced grain weighing 11.4 mg/kernel less than wheat grown at 24.7°C (Asana and Williams, 1965). Kernel weight loss as a result of hot, dry winds is due to rapid loss of grain water content during maturation, caused by a drying from the outside towards the kernel center rather than the normal drying progressing from the inside toward the kernel outside. This results in shriveled grain with a reduced starch content (Asana and Williams, 1965).

The previously cited literature documents the damaging effect of high temperatures on wheat kernel formation and development. Although yield losses due to hot, dry winds have been calculated, comparisons are lacking of yields within a given field affected and not affected by hot, dry wind. Our only objective was to determine if hot wind from a wind tunnel over wheat growing in a field would produce measurable effects on yield or yield producing components. We believed this was the initial step in being able to document yield losses from hot winds. If artificially applied hot wind would produce yield reductions, valid comparisons from affected and nonaffected areas within the same field can then be made.

PROCEDURES

A portable wind tunnel was placed over winter wheat (cv. Centurk) grown with irrigation and adequate fertilization at the Central Great Plains Research Station, Akron, CO. Tests were made in May and June on winter wheat seeded the previous September in rows 30 cm apart and grown under two water regimes. One area was seeded without a soil water reserve and received supplemental water applications (rain + irrigation) weekly of approximately 0.9 of the estimated evapotranspiration using techniques described by Jensen et al. (1971) (water stressed); the other was seeded where the soil profile contained 18 cm of available water to a depth of 180 cm and was irrigated weekly to refill the profile (well watered). Soil water content was determined the day of each test with a neutron probe at 30-cm increments to a depth of 180 cm, except for the surface 30 cm which was determined gravimetrically. Access tubes were within 4 m of each test site. Test 1 was made between 14.20 and 16.20 h on stressed wheat 22 cm tall in the "boot" growth stage;

test 2 was made between 14.20 and 16.20 h on well-watered wheat 31 cm tall in the "boot" growth stage. Test 3 was made between 13.30 and 15.30 h on well-watered wheat 60 cm tall in the "milk" growth stage, and test 4 was made between 11.45 and 13.45 h on well-watered wheat 63 cm tall also in the "milk" growth stage. Test 5 was made between 09.20 and 11.20 h on stressed wheat 41 cm tall in the soft dough growth stage. Tests 1, 2, 3, and 5 were made when the soil surface was dry, test 4 was made when the soil surface was wet.

The all-metal wind tunnel would have intercepted all sunlight from the north—south orientated three adjacent wheat rows 30 cm apart that were within the 1 m^2 by 9 m long tunnel. Wind speed was measured at the exhaust end of the tunnel, and 2.5 and 4.5 m past the end of the tunnel. A portable fuel oil space heater with heat exchanger was placed at the intake of the tunnel to increase air temperature within the tunnel above ambient. Water potential of whole plants (Ψ_p) was determined by the pressure bomb technique just before and immediately after each test on plants within the tunnel, 2.5 m and 4.5 m past the end of the tunnel, and about ten rows away from but parallel to the tunnel. Plant canopy temperature at 2.5 and 4.5 m past the end of the tunnel was measured with an infrared thermometer at approximately 15-min intervals during each test and all the values averaged for each test.

Temperature within the tunnel was measured at 1-min intervals with thermocouples located 1/3 the distance from the intake end and at the outlet end of the tunnel. Ambient air temperature was measured continuously on a thermograph. An air sample was drawn continuously from a port in the center of the tunnel. Dew point of the air was determined by a dew point hygrometer, with the output recorded at 1-min intervals. Ambient dew point was determined before and after each test. From the measured air temperature and dew point temperature, the saturated vapor pressure (e_s), actual vapor pressure (e), and vapor pressure deficit (d) were determined using meteorological tables (List, 1971) as follows: (i) $e_s = F(T_a)$, (ii) $e = F(T_d)$, and (iii) $d = e_s \sim e$ (k Pa) where T_a = air temperature and T_d = dew point temperature. Data for each test were summarized by calculating an average T_a and T_d for five consecutive 1-min data values to provide a 5-min running average for each test. The calculated values (e_s, e, d) were determined from these 5-min averages. Wind test averages were also calculated from all 1-min values, and start and end conditions were calculated from the first and last ten 1-min values for each test.

At maturity the number of heads/m^2, number of kernels/head, weight/100 kernels and grain yield was determined. Samples were collected from two adjacent rows 1 m long from an area near the center of where the tunnel had been placed, between 1.5 and 2.5 m past the end of the tunnel, between 3.5 and 4.5 m past the end of the tunnel, and ten rows away from but parallel to the tunnel near where plants for water potential measurements were selected during the tests. A two-way statistical analysis of variance (Snedecor,

1956) was made on the yield components for each test. This permitted statistical differences to be determined between measurement sites.

RESULTS

At 2.5 m from the tunnel exit both wind speed and temperature were higher than ambient. At 4.5 m past the end of the tunnel, canopy temperature was no longer higher, but wind speeds were still above ambient.

During each test, wind speed within the tunnel, at 2.5 m, and 4.5 m past the end of the tunnel averaged 70, 52, and 35 km/h, respectively. Ambient wind averaged 4.1 and 18.9 km/h during tests 1 and 2, respectively, 5.6 km/h during tests 3 and 5, and 9.6 km/h during test 4. Data for T_a, T_d, and d, differences between the tunnel conditions and ambient for the initial and final 10 min and the 2-h average of each test are summarized in Table I.

TABLE I

Wind tunnel air temperature (T_a), dew point temperature (T_d), and vapor pressure deficit (d), differences from ambient and canopy temperature difference from ambient at 2.5 and 4.5 m past the tunnel end

Measurement time	Environmental measurement differences			Canopy temp. (°C)	
	T_a (°C)	T_d (°C)	d (k Pa)	2.5 m	4.5 m
Test 1 (Boot-stressed, soil surface dry)					
Initial 10 min	+4.5	−1.6	+0.74	—	—
Final 10 min	+4.4	−0.7	+0.68	—	—
2-h avg.[a]	+4.6	−1.2	+0.73	+3.8	+0.7
Test 2 (Boot-well-watered, soil surface dry)					
Initial 10 min	+5.4	+0.6	+1.22	—	—
Final 10 min	+2.6	−4.4	+0.78	—	—
2-h avg.[a]	+4.8	−2.0	+1.23	+4.0	+0.7
Test 3 (milk-well-watered, soil surface dry)					
Initial 10 min	+6.1	+0.8	+1.89	—	—
Final 10 min	+8.1	−0.1	+2.46	—	—
2-h avg.	+8.4	+0.5	+2.57	+5.7	+1.0
Test 4 (milk-well-watered, soil surface wet)					
Initial 10 min	+2.0	+0.8	+0.63	—	—
Final 10 min	+6.6	+4.7	+2.04	—	—
2-h avg.[a]	+5.8	+1.2	+2.19	+4.3	+0.8
Test 5 (Soft dough-stressed, soil surface dry)					
Initial 10 min	+7.0	+2.2	+1.30	—	—
Final 10 min	+5.2	+0.9	+1.34	—	—
2-h avg.[a]	+6.2	+1.7	+1.35	+4.9	+0.8

[a]Environment measurements are averages of 1-min readings for 2-h period while canopy average is for readings at 15-min intervals.

Plant water potential and available soil water at the time of each test are presented in Table II. Grain yield and yield component measurements made at maturity are summarized in Table III.

During test 1 on water stressed wheat in the "boot" growth stage, T_a within the tunnel averaged 4.6°C above ambient and T_d was 1.2°C below ambient, increasing d above ambient, which increased the evaporative demand on the plants. At 2.5 m past the end of the tunnel average canopy temperature was 3.8°C above canopy temperature of wheat not subjected to the hot winds, and Ψ_p was more negative than that of nonexposed plants at the end of the test. Grain yield reduction was greatest at 2.5 m from the tunnel end and was largely due to a reduction in number of heads/m^2.

On well-watered wheat in the boot growth stage in test 2 T_a increase averaged 4.8°C above ambient for the 2-h test and average T_d decrease from ambient was 2.0°C. Average d was 1.23 k Pa above ambient, suggesting that stress conditions existed within the tunnel. At 2.5 m past the tunnel the canopy air temperature increased 4°C over wheat not subjected to the wind. Grain yield reduction was greatest in the tunnel, the percentage reduction being nearly equal for number of heads/m^2 and kernels/head. At the measure-

TABLE II

Plant water potential just before and immediately after each test and available soil water at the time of each test

Measurement time	Avail. soil water[a] (cm)	Measurement site (× 100 k Pa)			
		Parallel	Inside	2.5 m past	4.5 m past
Test 1 (Boot-stressed, soil surface dry)					
Initial	—	− 9.7	− 9.5	− 9.7	− 9.7
Final	2.09	−15.0	−18.8	−24.6[b]	−24.4[b]
Test 2 (Boot-well-watered, soil surface dry)					
Initial	—	−15.4	−15.6	−15.3	−15.5
Final	17.88	−21.8	>−22.0	>−22.0	>−22.0
Test 3 (Milk-well-watered, soil surface dry)					
Initial	—	−16.0	−16.2	−15.9	−16.3
Final	10.47	−19.5	−23.5	−21.0	−20.0
Test 4 (Milk-well-watered, soil surface wet)					
Initial	—	− 9.2	− 9.3	− 9.2	− 9.1
Final	13.61	−16.2	−17.2	−21.0[b]	−19.2
Test 5 (Soft dough-stressed, soil surface dry)					
Initial	—	− 9.0	− 9.9	− 9.3	− 9.2
Final	0.85	−22.2	−24.5	−26.9	−26.0

[a]Total to a depth of 180 cm.
[b]Denotes significant difference between treated measurement sites and parallel measurement site.

TABLE III

Yield component and grain reductions[a] of wheat subjected to hot wind as compared with nontreated wheat

Site of measurement	Yield component reduction							
	Kernels/head		Heads/m²		Wt/kernel		Grain	
	No.	%	No.	%	mg	%	kg/ha	%
Test 1 (Boot-stressed, soil surface dry)								
Within tunnel	0.7	5.6	65	14.2	4.2[b]	16.2	474	32.1
2.5 m past	0.7	5.6	181[b]	39.4	4.2[b]	16.2	767[b]	52.0
4.5 m past	0.9	7.2	0	0	3.9[b]	15.1	113	7.7
Test 2 (Boot-well-watered, soil surface dry)								
Within tunnel	3.3[b]	32.9	140[b]	35.5	4.9[b]	18.0	907[b]	59.1
2.5 m past	2.2[b]	15.3	73	18.5	3.4[b]	12.5	607	39.6
4.5 m past	0.6	4.2	15	3.8	1.2[b]	4.4	180	11.7
Test 3 (Milk-well-watered, soil surface dry)								
Within tunnel	2.9[b]	17.0	0	0	3.3[b]	10.2	487	22.4
2.5 m past	1.7	9.9	0	0	2.3[b]	7.1	113	5.2
4.5 m past	1.1	6.4	0	0	0.8[b]	2.5	47	2.1
Test 4 (Milk-well-watered, soil surface wet)								
Within tunnel	1.8	2.9	+23	+ 7.6	1.0	3.7	0	0
2.5 m past	3.1	11.4	157[b]	54.8	3.0	11.2	1334[b]	65.1
4.5 m past	3.8	10.3	19	6.8	2.0	7.4	454	22.1
Test 5 (Soft dough-stressed, soil surface dry)								
Within tunnel	0.7	5.5	20	4.9	4.9[b]	18.8	354	27.2
2.5 m past	0.8	6.5	0	0	4.6[b]	17.7	287	22.2
4.5 m past	0.5	4.0	0	0	1.3[b]	5.0	67	5.1

[a]Reduction = measurement from nontreated — measurement from treated area (all values negative except where noted).
[b]Denotes significant reduction compared to nontreated at $P = 0.05$.

ment sites past the end of the tunnel the percentage loss was distributed about equally among the three yield components measured.

Wheat in the grain filling growth stage subjected to hot wind, had extremely high d value within the tunnel where the wheat was being grown under well-watered conditions (tests 3 and 4). With stressed plants, d was greater than ambient, indicating the plants within the tunnel were under greater stress than plants not receiving the hot wind. Initial Ψ_p of the stressed plants was about -900 k Pa, indicating that these plants had partially recovered overnight from water stress of the previous day. With tests 3 and 5 grain yield reduction was again greatest within the tunnel, but with the stressed wheat (test 5) the greatest loss was in weight/kernel whereas with well-watered wheat (test 3) the greatest loss was in kernels/head.

Test No. 4 was also made on well-watered wheat in the "milk" growth stage, but with the soil surface wet. There was a higher evaporative demand (d) for the plants within the tunnel than for plants not receiving the hot wind. However, because of the readily available water from the soil surface, plants were only minimally affected. Effect of the hot, dry wind was greatest at 2.5 m past the end of the tunnel, where Ψ_p was 500 k Pa more negative than for nontreated plants. The severe effect of the hot, dry winds at this distance was further reflected in the 65% grain yield reduction due to a 54.8% loss in heads/m^2. At 4.5 m past the end of the tunnel the loss in kernels/head caused the greatest yield loss. Yield of wheat within the tunnel was not reduced, probably because there was ample water in the air within the tunnel plus the darkness of the tunnel tended to cause plant stomata to close. Thus, plants just past the tunnel exhaust were actually subjected to a more severe stress than plants within the tunnel even though wind speed and canopy temperature were lower than within the tunnel.

CONCLUSIONS

Although data between tests were not compared since they were carried out at different times of the day, we believe some very important information was obtained. First, hot winds artificially applied at either the "boot" or kernel filling growth stages can reduce wheat yield; second, the major yield component reduced was number of heads/m^2 of area, since some heads were completely sterile; and third, loss in kernels/head and weight/kernel were about equal in their contribution to loss in yield. Additional tests with varying wind speeds, duration, and temperature increases should be conducted so that when hot, dry winds do occur their damage can be properly assessed.

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