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TALL WHEATGRASS BARRIERS AND WINTER WHEAT RESPONSE*

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ABSTRACT

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Effects of tall wheatgrass (*Agropyron elongatum*) barriers on microclimate and development of winter wheat (*Triticum aestivum*) were investigated on a dryland farm near Culbertson, Montana, U.S.A. Growth and development of winter wheat benefited more from the barriers during a year of average rainfall than during a year of above-average rainfall. Influence of the barriers on air temperatures was not consistent. Early-season soil temperatures were higher near the barriers than in the check area. Wind reduction, during the early part of the season when protection is most essential, was substantial.

INTRODUCTION

Tree shelterbelts and windbreaks are used extensively for crop and farmstead wind protection in the Great Plains of the United States and Canada and in similar areas of other countries. This use, along with advantages and disadvantages, is documented by several authors (Ferber, 1958; George, 1961; Marks, 1962; Sturrock, 1969).

Yield increases due to shelters are highly variable. Sturrock (1970a) recorded from 0 to 600% increases in New Zealand, depending on the crop. Staple and Lehane (1955) in the semiarid plains of Canada, found that spring wheat yielded 47 kg/ha more behind shelterbelts than on open check areas. Skidmore et al. (1974) found no consistent yield increase in winter wheat grown behind slat-fence wind barriers in the subhumid region of Kansas. Brown and Rosenberg (1970, 1972), working with irrigated sugarbeets sheltered by two corn rows, reported 6% increases in photosynthetic rates and as much as 25% yield increases in shelter as compared with no shelter in low-yielding years. In subhumid Minnesota, Radke and Burrows (1970) did

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not establish whether the 10% better performance by soybeans sheltered by corn windbreaks was due to reductions in water stress, light stress, physical stress, or a combination of these.

Most yield benefits from shelterbelts have been attributed to improved soil-water regimes as compared with nonsheltered areas. The greatest percentage yield increases, attributed to shelter influences, have been obtained in dry years (Staple and Lehane, 1955; Van Eimern, 1964). The better soil-water regime behind shelters is attributed not only to increased snow catch, but also to decreased evaporation and increased vapor pressure (Stoeckeler, 1962; Van Eimern, 1964; Marshall, 1967; Konstantinov and Struzer, 1969). However, total water use has been about the same behind barriers as in the open. This apparent discrepancy is accounted for by more vigorous growth and greater leaf area of plants behind barriers, resulting in greater water-use efficiency (Van Eimern, 1964; Rosenberg, 1966a; Bouchet et al., 1968; Sturrock, 1970b). Other reported common benefits of shelterbelts are high air and soil temperatures in sheltered as compared with nonsheltered areas (Woodruff et al., 1959; Van Eimern, 1964; Marshall, 1967).

Most shelter research has involved multiple rows of trees, although temporary barriers, such as snowfences, sorghum, sudangrass, and corn, have also been tested (Rosenberg, 1966b; Pelton, 1967; Radke and Burrows, 1970; Greb and Black, 1971; Skidmore et al., 1974). In the more arid parts of the Great Plains, tree barriers are difficult to establish and maintain so alternative solutions to tree shelters have been sought. Black and Siddoway (1971) described the establishment of tall wheatgrass (*Agropyron elongatum*) barriers and discussed their role in soil-water conservation. Our purpose was to determine the influence of a tall wheatgrass barrier system on modification of the microclimate, and the effect of this modification on the growth and development of winter wheat.

MATERIALS AND METHODS

The effect of microclimate modification by permanent tall wheatgrass barriers on the development of winter wheat (*Triticum aestivum*) was investigated on a dryland farm near Culbertson, Montana, U.S.A. The soil was Dooley sandy loam (fine-loamy, mixed, Typic Argiborolls) with about a 2% slope. Barrier systems with and without snow are shown in Fig.1.

The barriers were formed by planting double rows (0.9 m apart) of tall wheatgrass in the north—south direction at cropping intervals of 15.2 m. The 120-cm-tall barriers were 500 m long with 10 barrier intervals. Although barrier porosity was not directly measured, it ranged from near zero at the densely vegetative base to almost 100% at the top of the seedheads. In 1971, the second interval from the east was used for the study; in 1972, the third interval from the east was used. Instrumentation and sampling locations were approximately 130 m from the south end.

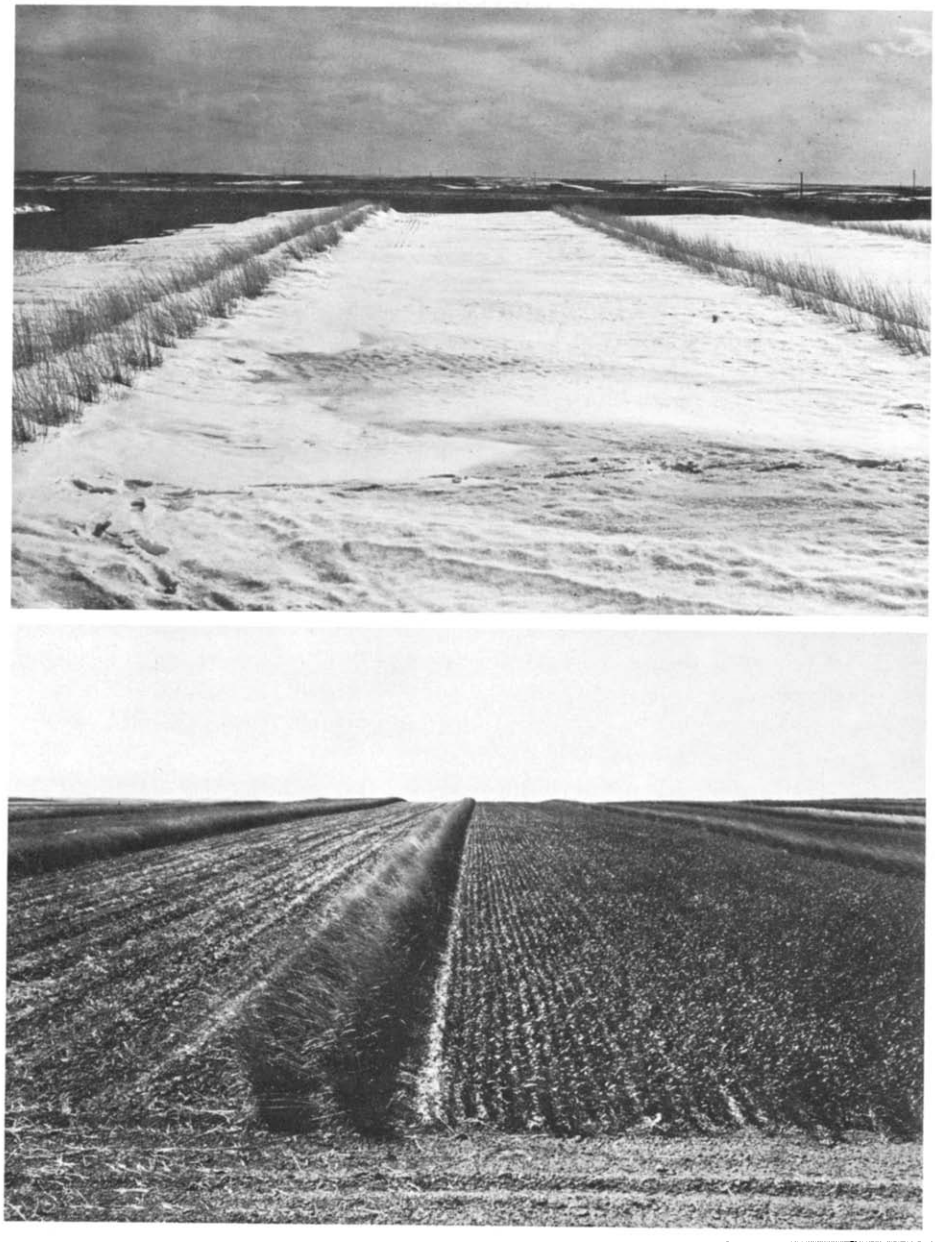

Fig. 1. Barrier systems with and without snow.

In 1971, the unsheltered (check) area was located in a winter wheat block adjacent to the easternmost barrier of the system, with the instrumentation placed about 40 m from the barrier and about 20 m from a fallow area on the east side of the block. In 1972, the instrumentation on the check area

was located 20 m into a winter wheat block, which was separated from the easternmost barrier by a 60-m-wide fallow strip.

Winter wheat (var. Froid), selected for its winter hardiness, was seeded at the rate of 42 seeds per meter on fallow ground in September 1970 and 1971 in north—south rows, 25 cm apart. After seeding, 28 kg/ha of nitrogen was broadcast. The land had previously received enough phosphorus (78 kg/ha) to insure its adequacy.

Shielded, ventilated copper-constantan thermocouples (30 gauge) were used to measure air-temperature profiles, and 20 gauge copper-constantan thermocouples were used to measure soil-temperature profiles. Wind profiles were measured with lightweight cup anemometers (Teledyne Geotech*). All measurements were made at the following distances (in barrier heights, H) from either the west or east barrier: 1, 3, 6, 9, and 11 H, as well as in the check area.

Temperatures at each point in a profile were measured independently and normally recorded 20 times per day throughout the season on an automatic data acquisition system. Scanning time, since the limiting factor was the paper tape punch, was 1 sec per point. The thermocouples were referenced against a Joseph Kaye & Co. Inc., Model OEM ice point. Windspeed was recorded by a system of mechanical counters and appropriate electronics housed in a trailer with the data acquisition system. A camera, rigged with a timer and solenoid, snapped pictures of the counters, usually every 4 h. Windspeed was later calculated from recorded counts. Wind direction was recorded on a strip chart recorder.

Soil-water content was measured weekly by the neutron scattering method at the same distances from the barriers as the temperature and wind measurements, and in addition, at a distance of ½ H from either barrier and between the two rows of the barrier.

To measure incoming, reflected shortwave, and net radiation, we mounted two Moll-Gorzynski-type (Kipp) solarimeters (one inverted) and one Fritschen net radiometer on a trolley, traversing the barrier interval in about 3 min. For position identification, the trolley paused ½ min at the west, and 1 min at the east barrier, before starting its return trip. Net and reflected radiation were measured about 1 m above the crop. Incoming radiation was measured at crop level. The transducer outputs were recorded on a strip chart recorder traveling with the trolley.

Plant height, growth stage, dry-matter production, and leaf area index (LAI) were determined weekly at the same positions inside and outside the system as were the temperature and wind profiles. Plant sampling began in the spring when the wheat was in the one-shoot stage. Leaf area index was determined by using an airflow planimeter. Additional plant characteristics

*Trade and company names are included for the benefit of the reader and do not imply any endorsement or preferential treatment by the USDA of the product listed.

determined included stand count, number of tillers, number of heads, kernels per head, and weight per kernel.

RESULTS AND DISCUSSION

Wind

The barriers provided good wind protection in the early part of the growing season. For example, Fig.2 shows average wind profiles for three positions in the barrier interval and in the open for a 24-h period with steady east to southeast winds. Compared with the check, at 30-cm height, wind velocity near the east barrier was reduced 84%, and near the west barrier (least protection), 24%. The reduction pattern was nearly the same for lower wind

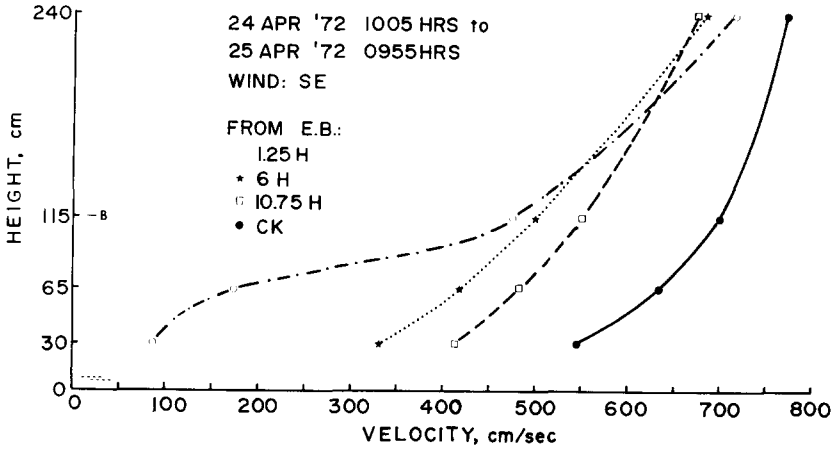

Fig.2. Average wind profiles for a 24-h period for three positions in the barrier interval, and on the check with wind steady from SE. *B* indicates height of barrier; dashed horizontal lines, estimated wheat height inside (upper line) and outside (lower line) the barrier system.

velocities. Velocities of winds from westerly directions were reduced most near the west barrier and least near the east barrier.

As indicated in Fig.3, windspeed also was substantially reduced when wind was more nearly parallel to the barriers and when the barrier influence was reduced because of increased crop growth. When crop growth was the same height as the barriers, wind profile patterns from any direction were entirely different from earlier patterns (Fig.4). The wind essentially swept over a solid wall, causing the highest windspeeds nearest the leading edge, with speeds progressively decreasing as the distance from the leading edge increased. At this crop growth stage the check area speeds were the lowest.

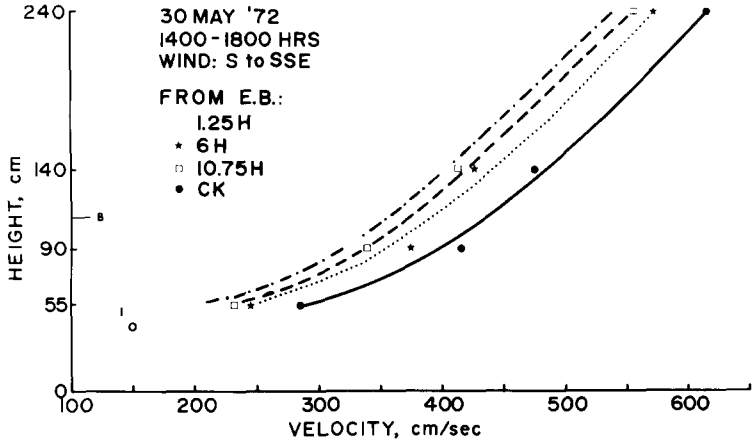

Fig.3. Average wind profiles for three positions in the barrier interval, and on the check with winds nearly parallel to barriers. *B* indicates height of barrier; dashed horizontal lines, estimated wheat height inside (upper line) and outside (lower line) the barrier system.

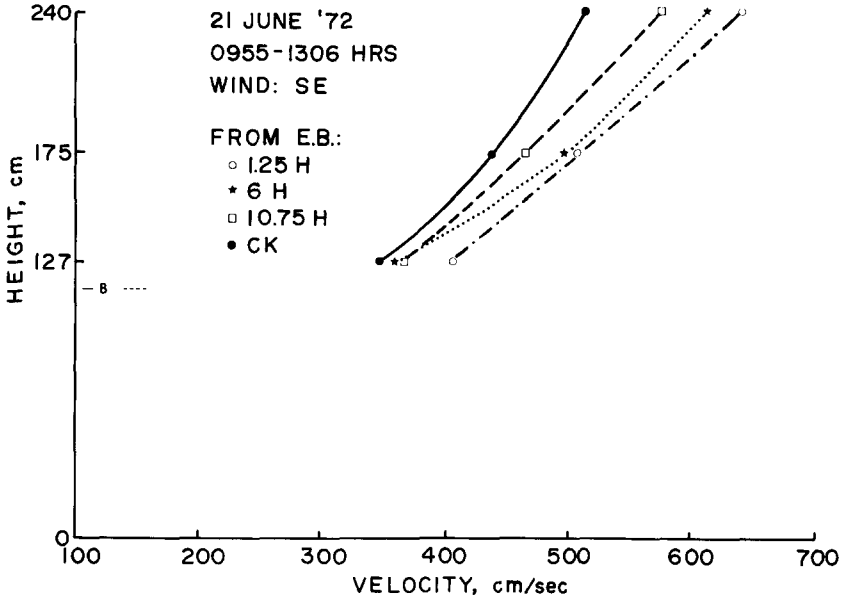

Fig.4. Average wind profiles for three positions in the barrier interval, and on the check with winds from SE. *B* indicates height of barrier; dashed horizontal line, estimated canopy height of all wheat.

Air temperatures

Examples of air temperature profiles are shown in Fig.5 for the same 24-h period as in Fig.2. Skies were clear (98% of maximum possible global radiation) and wind was steady from east to southeast, averaging 773 cm/sec in the open at the 240-cm height. In the barrier interval, LAI averaged 0.14; on the check, 0.08.

Only temperature profiles near the east barrier of the third interval (most protected) are compared with the temperature profiles on the check in Fig.5. The relation of the other sheltered temperature profiles to the check were similar, although some of the profile transitions were more noticeable in one location than in others. For example, the unexplained reversal of the sheltered temperature profiles in relation to the check, beginning at 12h43, was more pronounced in the most sheltered position. By 16h19, the reversal was complete in all cases. An hour later, the temperatures were again nigher in the protected area, with the temperature profile in the least protected position slightly inverted. During the night, although the temperatures in the

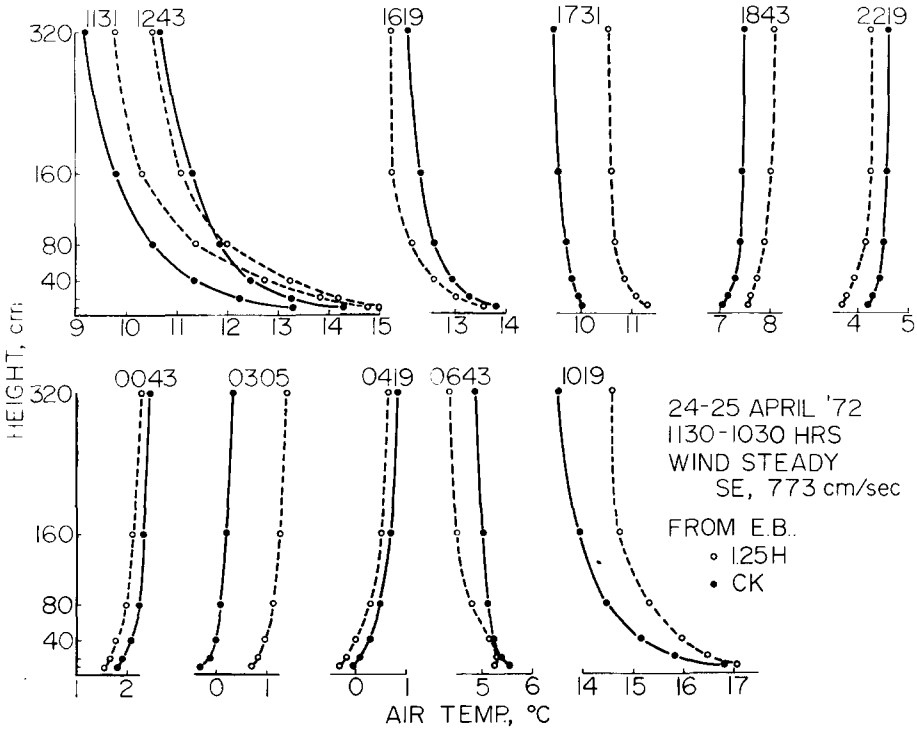

Fig.5. Temperature profiles in most protected position and on check for a 24-h period under clear sky conditions and winds steady from SE. Time of measurement is indicated above each profile. Windspeed is indicated for check at 240-cm height.

open were generally higher than in the barrier interval, those in the open area reached a lower minimum earlier than in the protected area. The portion of the temperature mast below about 120 cm near the east barrier was shaded in the morning, and the change from nighttime inversion to daytime lapse conditions was delayed at that position compared to other positions across the barrier interval.

The profiles in Fig.5 are typical of many obtained throughout the season on clear and partly cloudy days, and the same relationships existed when winds were westerly as well as easterly. Fig.6 shows profiles on a heavily overcast day with the soil surface moist in the barrier system and dry outside. More of the energy reaching the soil surface inside the barrier system apparently was used in latent heat exchange than on the check, where less wind protection and less ground cover hastened soil drying. Thus, more of the energy was converted to sensible heat which resulted in higher air temperatures on the check.

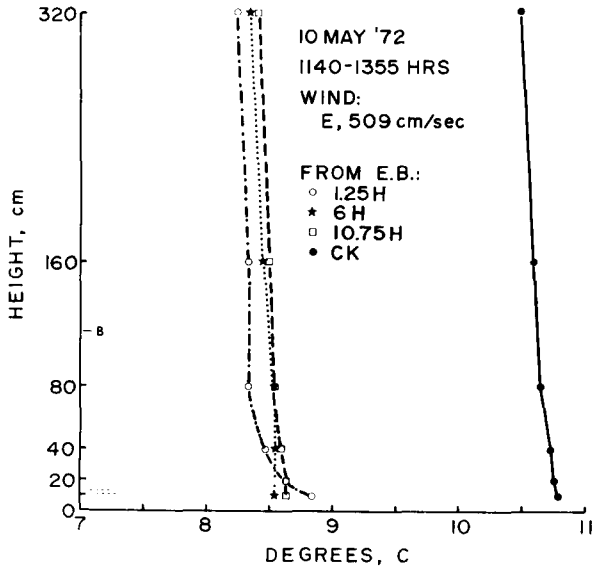

Fig.6. Temperature profiles at three locations in the barrier interval, and on the check under cloudy conditions and with soil surface moist inside barrier interval and dry on the check. Each point is an average of five measurements.

Soil temperatures

Soil temperatures for the 5- and 15-cm depths are summarized as 5-day averages (Fig.7), from spring (before active growth started) until early boot stage. Equipment failure caused several gaps in temperature records.

The lines connecting the points for the two depths are essentially parallel

throughout the season. A 14-cm snowfall on 26 and 27 March, in conjunction with an easterly wind, caused drifting on the west side of the east barrier. The influence of this snowdrift and of the melting snow can be seen on the 31 March to 4 April and 5—9 April temperatures. Except for these periods, the predominant pattern was higher temperatures near the barriers, with a depression in the middle of the barrier interval. As the season progressed, the check soil temperatures became progressively higher than any of the soil temperatures in the barrier interval, apparently because of more vigorous

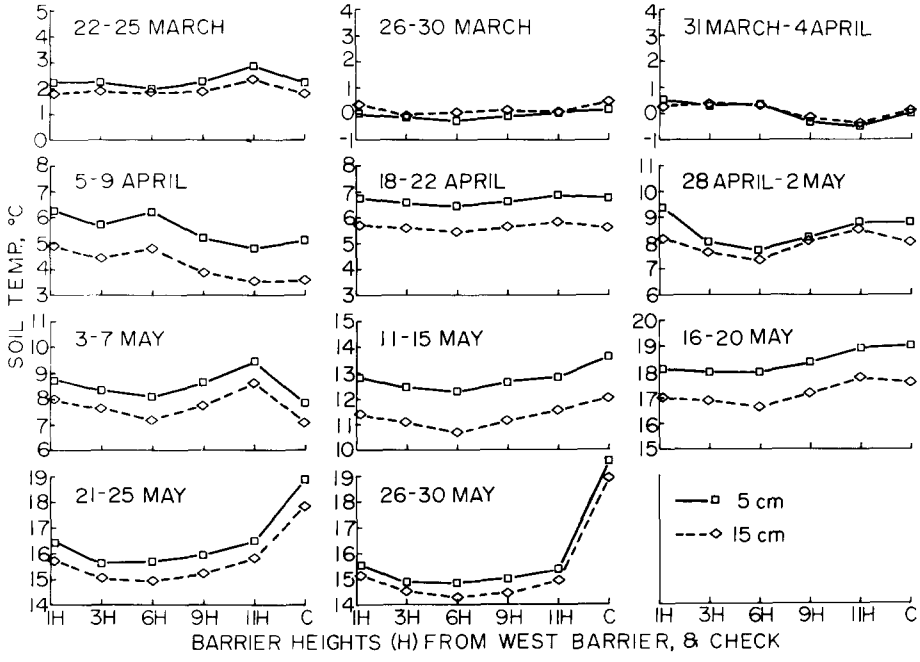

Fig.7. 5-day daily average soil temperatures at 5- and 15-cm depths, 1972.

growth and higher LAI in the barrier interval compared with the check. The less vigorous growth on the check area allowed more solar radiation to impinge on the soil surface, which caused higher soil temperatures than in the barrier area.

Diurnal temperature curves for the 5-cm depth at three locations in the barrier interval, and on the check are shown in Fig.8 for the same period described in Figs.2 and 5. Maximum differences between check and barrier soil temperatures occurred during midafternoon, and point-to-point, check soil temperatures were more variable than barrier soil temperatures. Soil

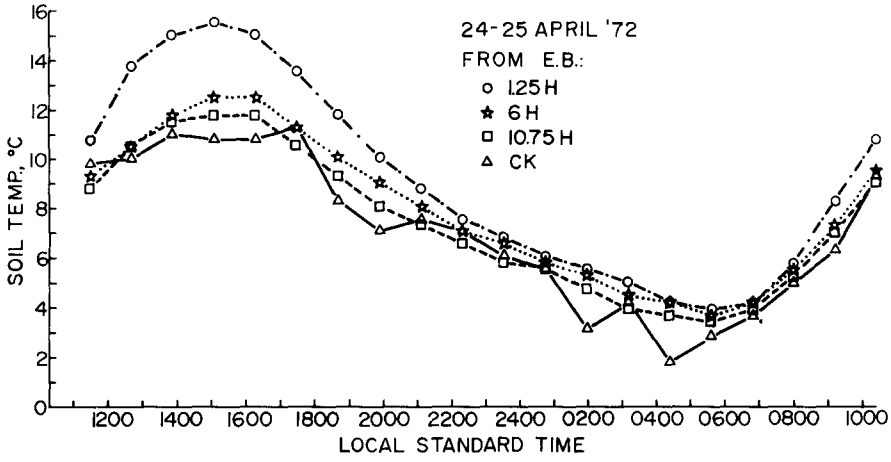

Fig. 8. Diurnal soil temperatures at three locations in the barrier interval, and on the check at 5-cm depth. Clear sky conditions, winds steady from SE.

temperatures and differences between check and barrier interval were maximum near the east barrier at the most protected location. The relationship among positions was reversed when winds were westerly.

Radiation

Radiation measurements illustrated reflection and shading by the barriers (data not shown). For example, net radiation increased about 12% and reflected shortwave radiation decreased about 43% next to the east barrier on 17 May 1972 at 08h30 as compared with the middle of the barrier interval. Net and reflected shortwave radiation gradually leveled off to constant values at about 3.5 m from the barrier. Total incoming shortwave radiation was about 5% lower next to the east barrier and about 3% higher next to the west barrier as compared with the middle of the barrier interval. Incoming shortwave radiation reached constant values about 3 m from the barrier. The influence of the barriers decreased as solar elevation increased and radiation essentially did not vary by position at noon. The reverse of the morning situation was true in the afternoon. No variation in net radiation was detected at night.

Root competition from the tall wheatgrass for water and nutrients probably negated any radiation influence on the first two rows of wheat, equivalent to about ½ m from the barrier. Although the barrier-influenced radiation extended beyond this point, it became small and, radiation by itself probably had a minimal effect on crop production. Other researchers also have concluded that radiation changes due to barrier influences had minimal effects on plant development (Rosenberg, 1966b; Marshall, 1967).

Soil water

Table I shows soil-water content by position for fall, spring, and harvest time for the 1971 and 1972 seasons. It is apparent that the barriers are heavy water users and compete for soil water at ½ *H*, as evident from the lower soil-water content at that position. The check area was drier than the barrier interval in the fall of 1970 and although it gained more water over winter, it was still drier throughout 1971. However, growing-season water-use was the same by the wheat in both the check area and barrier interval.

During the fall of 1971 unusually large rainfall events occurred (Fig.9), and the soil profile was near field capacity as winter began. Soil-water content in the check area was actually a little higher than in the barrier interval. Winter recharge brought the soil profile to approximately field capacity for both check area and barrier interval. Because of the distribution of the unusually high rainfall in 1972 (Fig.9), soil-water content remained high throughout the growing season. Water use was high and, as in 1971, similar for check and barrier wheat.

As compared with the check area the soil surface in the barrier interval was observably wetter for a longer period after rains. The soil surface on the check area cracked sooner (Fig.10), indicating more rapid soil-surface evaporation

TABLE I

Soil water content and soil water use (cm) by winter wheat grown between tall wheatgrass barriers and on the check, based on a 150-cm profile

Location	Content			Use	Content			Use
	6 Nov. 1970	1 Apr. 1971	21 July 1971	1 Apr.–21 July 1971*[1]	6 Oct. 1971	4 Apr. 1972	3 Aug. 1972	4 Apr.–3 Aug. 1972*[2]
WB*[3]	18.6	21.9	17.5	21.1	16.7	23.9	24.3	29.5
½ *H*	33.4	35.5	22.5	29.7	31.4	36.4	28.0	38.3
1 *H*	37.6	37.5	25.0	29.5	37.4	41.1	31.1	39.9
3 *H*	37.7	38.2	25.5	29.4	37.1	40.1	28.8	41.2
6 *H*	37.0	35.8	22.5	30.3	38.8	41.7	28.9	42.7
9 *H*	32.0	35.6	22.0	30.5	36.4	40.9	27.9	42.9
11 *H*	35.1	35.8	25.0	27.7	35.6	40.5	28.3	42.1
11½ *H*	32.0	34.8	23.5	28.4	33.1	39.4	27.9	41.4
EB*[3]	17.8	19.5	16.0	20.5	17.9	26.1	22.3	33.7
Avg.*[4]	35.0	36.2	23.5	29.8	35.7	40.5	28.6	41.8
Check	27.6	30.4	18.0	29.3	37.9	39.2	27.1	42.0

*[1] Rainfall = 16.8 cm.
*[2] Rainfall = 29.9 cm.
*[3] WB = west barrier; EB = east barrier.
*[4] Exclusive of soil water at barriers.

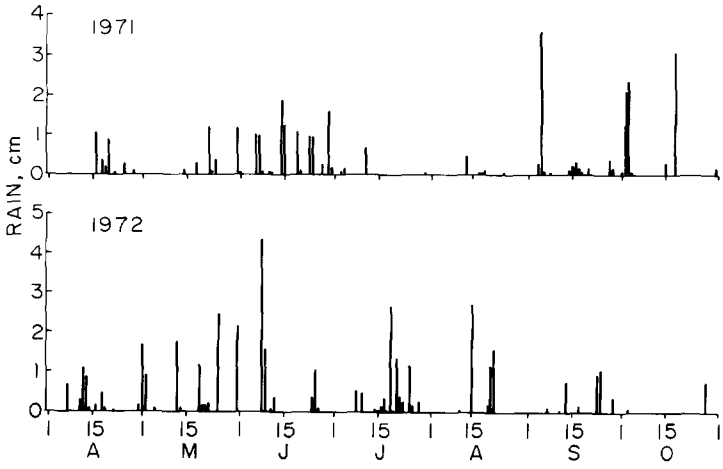

Fig.9. Daily precipitation for the 1971 and 1972 seasons.

from the check area. Gravimetric soil-water measurements, from 1 to 5 days after rains, showed that water in the top 5 cm of soil in the check area ranged from 72 to 97% of the water in the barrier interval, depending on amount of rain and stage of plant development.

Dry matter, yield, and wheat characteristics

A definite growth pattern was apparent across the barrier interval from early season to maturity. Dry-matter production across the barrier interval was essentially symmetrical about an imaginary line along the middle of the interval and parallel to the barriers. The first two rows of wheat next to the barriers were poor. Production peaked at about 1 to 3 H from the barriers, with a level area of growth in the middle of the barrier interval. All the barrier wheat, except the two rows next to each barrier, grew more vigorously than the check wheat. The wheat at about 2 H headed about 3 days earlier than the rest of the wheat. These three areas of growth, along with the check, are shown in Fig.10, where the differences in early season (12 May 1971) growth and ground cover are apparent.

Dry matter production from the three definite growth areas (represented by 0.5 H, 2 H and 6 H) on either side of the imaginary line was combined, and average values are presented in Fig.11. The two rows next to the barriers obviously suffered from competition with the tall wheatgrass and produced much less dry matter than the check. The area of peak production (2 H) is readily apparent in 1971; but, because of the abundant rainfall in 1972 (Fig.9), some of the growth differences were masked and final dry-matter production was only slightly higher in the barrier interval than on the check (Fig.11, Table II).

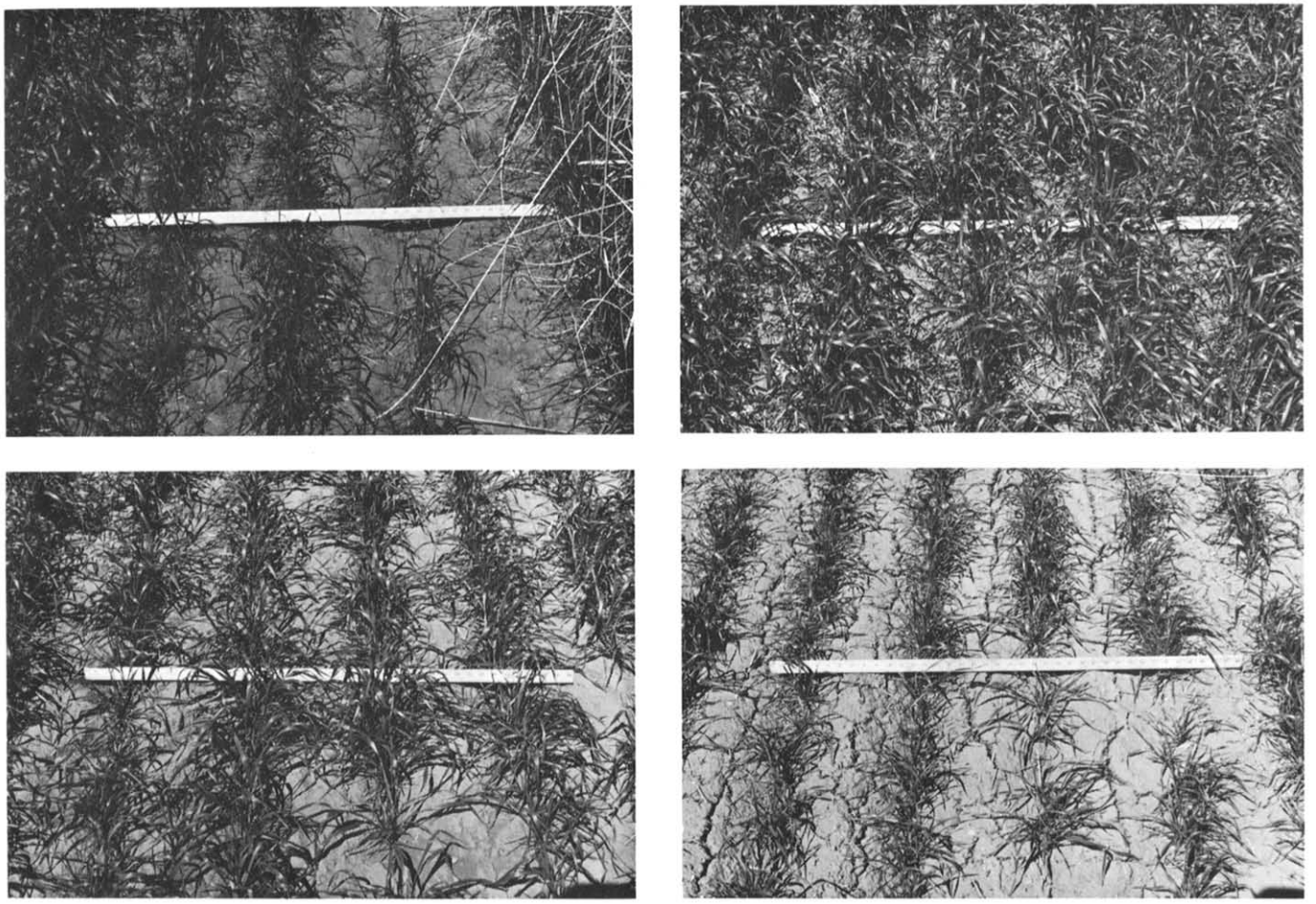

Fig. 10. Illustration of early growth (12 May 1971) of winter wheat: top left, 0—1 *H*; top right, 1 *H*—2 *H*; bottom left, 5.5 *H*—6.5 *H*; bottom right, check area, note cracking of soil surface.

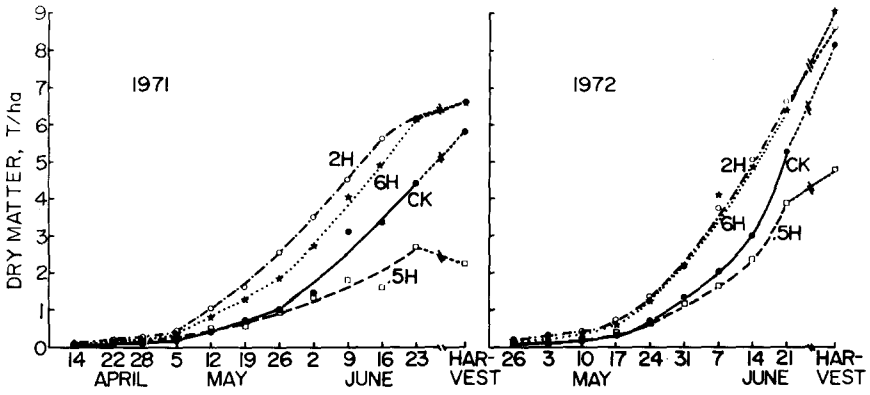

Fig. 11. Dry matter production for three "symmetrical growth areas" in the barrier interval designated as 0.5 *H*, 2 *H*, and 6 *H*, and on the check, *CK* (see text).

TABLE II

Yield and water-use efficiency of winter wheat grown between tall wheatgrass barriers and on the check

Treatment	Dry matter		Grain	
	yield ($kg\ ha^{-1}$)	WUE ($kg\ ha^{-1}\ cm^{-1}\ H_2O$)	yield ($kg\ ha^{-1}$)	WUE ($kg\ ha^{-1}\ cm^{-1}\ H_2O$)
	1971:			
Barrier	6,293*	211*	2,770*	93*
Check	5,723	196	2,519	86
	1972:			
Barrier	8,545	204	3,545	85
Check	8,243	196	3,482	83

*Comparisons within years different at the 5% level of significance.

In 1971, the wheat in the barrier interval and on the check was ready for harvesting on 20 July. In 1972, the wheat in the barrier interval was ready for harvesting 12 days before that on the check. This increased time for wheat development in 1972 may help account for the small differences in final yield between check and barrier wheat. It is as if the check wheat got a later start, or was planted later, and as the season progressed it almost caught up with the barrier wheat.

The increased dry-matter production in sheltered areas is also illustrated by LAI values in Fig.12 for 1971. The curve for sheltered area (*B*) is an average of values from five locations across the interval. Shelter obviously enhanced LAI development. The greatest relative difference in LAI develop-

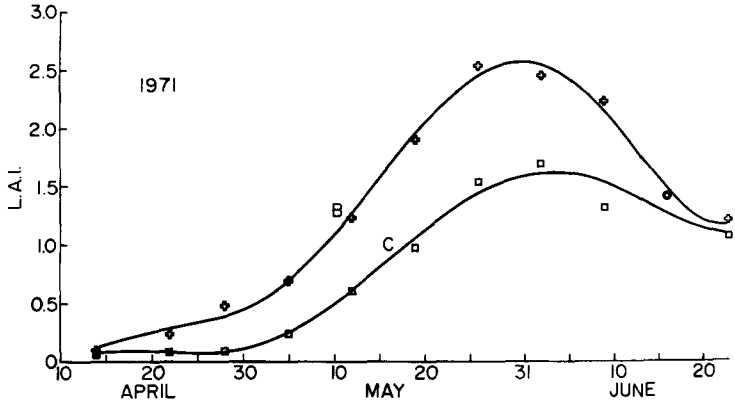

Fig. 12. Leaf area index for barrier interval (*B*) and check area (*C*).

ment between check and barrier wheat occurred in the early season when plant protection is most needed. For example, by 28 April, LAI in the barrier interval was about 4 times that of the check area. By 19 May, the difference was about 2-fold, and at maximum LAI development the difference was about 1.6-fold. The same pattern of LAI development held for 1972, even though the abundant rainfall reduced differences between sheltered area and check.

The differences in grain yields, and consequently in water-use efficiency, were greater in the drier year of 1971 (Table II). The increase in precipitation and in available soil water in 1972, almost masked the influence that barriers *per se* might have had on grain yield. The same influence of soil water on yields by other types of barriers have been observed by others (Staple and Lehane, 1955; Van Eimern, 1964). Wadsworth (1964) suggested that plant-water status may be the most important factor in producing variation in wind effect on growth and that increased soil-water supply reduces the adverse effect of wind.

From our observations, the cause of the higher yield in the barrier system compared with the check is unclear, as is the cause of peak production at about 2 *H*. There seemed to be no consistent air-temperature moderation near the crop surface that would favor the crop in the protected area. Soil temperatures increased slightly next to the barriers in the early part of the season compared with the check. The production peak may be explained partly by this increase, in conjunction with the slight increase in radiation next to the barriers. However, although the early-season soil temperatures, in the middle of the barrier interval, were not greatly different from check, dry-matter production was greater. Wheat growth in the barrier interval may have been augmented by the lower soil temperatures later in the season in the barrier interval, since wheat is a cool-season crop. Walker (1969) indicated that small differences in soil temperatures may greatly influence the

development of a crop. Waggoner (1969) discounts the small difference in CO_2 concentration that may occur behind barriers as having any influence on yield. Brown and Rosenberg (1972) and Miller et al. (1973) arrived at similar conclusions.

The only consistent microclimatological pattern found was in wind reduction from any direction. In a laboratory study, Todd et al. (1972) found that winds in excess of 360 cm/sec stimulated dark respiration in a number of species, including wheat. They suggested that higher rates of dark respiration might interfere with net assimilation and lower yields in windy regions. The substantial wind reductions obtained near crop level behind the barriers (Figs.2 and 3) may be related to the hypothesis of Todd et al. However, tiller production was much greater in the barrier interval than on the check (Table III), indicating that some intricate relationship may exist among dark respiration and other factors that accounts for the increased dry-matter production and yield in the barrier interval.

TABLE III

Characteristics of winter wheat grown between tall wheatgrass barriers and on the check

Characteristic	1971		1972	
	barrier	check	barrier	check
Height (cm)	102*	94	109*	106
Stand count/m	—	—	42.0	39.7
Tillers/m	—	—	151.2*	126.2
Heads/m	99.4*	87.2	128.8*	109.0
Kernels/head	31.926	31.009	27.838	29.569
Weight/kernel (g)	.0264*	.0249	.0286*	.0320

*Comparison within years different at the 5% level of significance.

Wadsworth (1964) suggested that, under favorable growing conditions, optimum windspeeds range from 50 to 300 cm/sec. With higher windspeeds, plants were smaller and net assimilation rates were less. He further suggested that low windbreaks, placed close together, may better protect young plants when protection is more essential. Tall wheatgrass barriers would seem to meet his suggestions.

Of the characteristics listed in Table III, probably the most revealing concerning yield increases in the barrier system are numbers of tillers and heads per meter. Both increased significantly in each year. The reductions in kernels per head and weight per kernel in the barrier system in 1972, as compared with the check, account, in part, for the small yield differences that year.

SUMMARY AND CONCLUSIONS

The protective influence of tall wheatgrass barriers increased dry-matter production, LAI, and grain yield of winter wheat, especially in the average rainfall year of 1971. Abundant rainfall during 1972 masked any effects the barriers *per se* might have had on winter wheat production. Effects of the barriers on air temperatures were not definitive. Effects on soil temperatures were more clearly defined, with slight increases near the barriers in the spring. Later in the season, as plant cover increased more rapidly in the protected area, soil temperatures became higher in the check area than in the barrier system.

The greatest differences in wheat growth between barrier and check wheat appeared in early season. In both years, wind was reduced substantially in the barrier interval during the early part of the season when wind protection is most essential. Direct effects of wind on respiration and consequently on net assimilation along with early-season higher soil temperatures in the barrier system may account for some of the more rapid growth and development of the wheat in the barrier system as compared with the wheat in the check area.

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