Effects of Taller Wheat Residue After Stripper Header Harvest on Wind Run, Irradiant Energy Interception, and Evaporation

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ABSTRACT

Storage of precipitation as soil water is critical to stable dryland crop production in the semiarid southern Great Plains. The region is characterized by high winds that promote evaporation and reduce precipitation storage efficiency. Evaporation may be reduced by residues that intercept irradiant energy and increase the aerodynamic resistance. Combine harvesters with stripper-type headers remove grain while leaving taller, erect straw that is not left by conventional platform headers; and thus, they potentially reduce evaporation. Our objectives were to characterize the effect of residue height after wheat (*Triticum aestivum* L.) harvest with stripper or conventional sicklebar platform headers on wind velocity, intercepted solar irradiance, and evaporation. We measured wind velocity, solar irradiance at the soil surface, and evaporation with Bowen ratio radiation and energy balance systems in two contiguous 16-acre wheat fields after stripper header harvest, SHH, or platform header harvest, PHH. Compared with PHH wheat residue, the taller residue after SHH reduced mean wind velocity and, consequently, the potential transport of water vapor (especially for evaporation from wet soil). Measured irradiant energy at the soil surface was 12% lower in the taller residue left by the SHH compared with short residue left by the PHH. Consequently, Bowen ratio estimated soil evaporation from SHH plots was reduced 26% compared to PHH plots during a 4-day evaluation interval. However, the differences in evaporation between the tall and short residue were very small because of the dry soil conditions during our experiment. We conclude that water conservation will be increased when using stripper type combine headers to harvest wheat because taller residue reduced wind velocity and increased interception of irradiant energy.

KEYWORDS

Stripper header, wind profile, intercepted irradiance, Bowen ratio, latent heat transport

INTRODUCTION:

The semiarid climate of the southern Great Plains is characterized by high winds that promote evaporation and precipitation that is erratic in amount (ranging from 15.7 to 23.6 inches annually) and in frequency, resulting in drought periods. Although sixty-five percent of the precipitation at Bushland falls as rain during the May-August (summer) growing season, the mean annual pan evaporation at Bushland is 90 inches or more than 4 times the 19 in. annual precipitation. For each inch of precipitation stored as soil water during fallow after wheat, the subsequent grain sorghum [*Sorghum bicolor* (L.) Moench] yield increased from about 385 lbs acre-1 (Jones and Hauser, 1975) to 430 lbs acre-1 (Baumhardt *et al*., 1985). Therefore, most dryland cropping systems in the southern Great Plains rely on fallow periods between crops to store precipitation as soil water, which stabilizes and increases yields of subsequent crops.

A commonly used cropping sequence is the three-year wheat-sorghum-fallow (WSF) rotation that produces two crops (Jones and Popham, 1997). Wheat is established in October of the first year and then harvested 10 months later in July. The soil is fallowed for 11 months until June of the second year when grain sorghum is grown using the stored soil water to augment rainfall. After sorghum harvest in November of the third year the soil is again fallowed for 10 months when wheat is planted and the cycle repeated. During fallow, crop residue increases infiltration (Baumhardt *et al*., 1993) and reduces evaporation; thus, conserving precipitation for dryland crop production (Steiner, 1994). For example, a no-tillage residue management system significantly increased profile soil water contents compared to stubble mulch tillage (Jones *et al*., 1994) because of reduced evaporation. Water loss due to evaporation during fallow, however, was 48% of total precipitation with the WSF rotation (Stewart and Burnett,

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1987).

Other studies have shown that residue amount reduced evaporation either by intercepting irradiant energy or by increasing aerodynamic resistance to evaporative flux (Heilman *et al*., 1992). In comparisons of bare soil with wheat-stubble protected soil, Lascano and Baumhardt (1996) related significant reductions in evaporation, primarily due to reduced net irradiance at the soil surface (R_n). More or taller residue may further reduce net irradiance. McMaster *et al*. (2000) reported that recently developed stripper type headers used with combine harvesters increased residue height compared to conventional sicklebar-type platform headers and reduced wind velocity. In that study, they concluded that taller residue architecture retained when using a stripper header harvesters, SHH, compared to conventional platform header harvesters, PHH, reduced the near surface wind velocity and consequently decreased potential evaporation and soil erosion. The effects of residue retained when using a SHH compared to the residues after a PHH on R_n and evaporation has not been reported. Our objectives are to characterize the effect of residue height after wheat harvest with stripper or conventional headers on wind velocity, intercepted solar irradiance, and evaporation.

MATERIALS AND METHODS

We conducted an experiment to quantify residue height effects on the wind velocity, interception of solar irradiance, and evaporation of soil water during the fallow after wheat-harvest phase of the WSF rotation at the USDA-Agricultural Research Service, Conservation and Production Research Laboratory, Bushland, TX (35° 11' N, 102° 5' W). A 33-acre (950 x 1500 ft) nearly level Pullman clay loam (fine, mixed, superactive, thermic Torrertic Paleustoll) was cropped to winter wheat (TAM 110) sown 1 November 2000 at a 35 lbs acre-1 rate on a 12" row spacing and north-south orientation using a high-clearance grain drill with hoe openers and press wheels. At wheat harvest (19 June 2001), the field was divided into two 950 x 750 ft plots that were harvested using either a conventional sicklebar platform header, PHH, or stripper header, SHH, (Shelbourne Reynolds Inc., Colby, KS). The resulting straw heights were 15.5 ± 0.8 inches with PHH and 23.4 ± 1.3 in. with SHH. The fallow after wheat was maintained under no-till conditions by applying 3.5 lbs a.i. acre-1 atrazine [6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine] and 1 lbs a.i. acre-1 2,4-D [(2,4-dichlorophenoxy) acetic acid] resulting in no soil disturbance.

Inter-row near soil surface pyranometers and anemometer arrays were measured by a centrally located data logger (Model 23X, Campbell Scientific, Logan, UT) at a 0.1Hz scan frequency and averaged (recorded) on 3, 20, 60, and 1440 -minute intervals. Near soil-surface shortwave solar irradiance was measured between the north-south wheat rows using triplicate pyranometers (Model LI200X, Campbell Scientific) mounted on 2x6x8 inch wood blocks. Because of the north-south row orientation and the resulting symmetry in energy interception, measurements centered between rows reflect a spatially averaged treatment value (Lascano *et al*., 1994). Pyranometers were exchanged between the two straw height plots at 37 days and compared after 74 days to quantify any sensor bias. Treatment effects on solar irradiance were contrasted using unpaired t-tests and regression analyses.

Wind velocity was measured using cup anemometers (Met-One 014A, Campbell Scientific) arrayed on two masts positioned with > 200 ft. fetch for winds originating from 210° ± 10° as determined by a vane (R.M. Young 03001, Campbell Scientific). Anemometers were positioned at heights of 14, 26, 43, and 79 inches and connected to the data logger (100 ft away) via remote input modules (Model SDM-SW8A, Campbell Scientific). Anemometer orientation was necessarily inverted near the soil surface, but prior instrument calibrations established that sensor orientation had negligible effect on indicated wind velocity, $P(T<=t)$ of 0.73, and that instrument measurements were not different, $P(T<=t)$ of 0.35, between the two array-masts. Wheat residue effects on wind velocity, *U*, with height, *z*, was described by the logarithmic wind velocity equation:

where U^* is the friction velocity, *k* is the von Karman constant, z_0 is surface roughness length, and *d* is the displacement height. We assumed that the log wind profile extended below the height of the sparse (29 stems/ft^2) wheat stubble canopy (Jacobs and van Boxel, 1991) and that z_0 and *d* could be estimated using nonlinear regression from a

$$U(z) = \frac{U^*}{k} \ln\left[\frac{(z-d)}{z_0}\right]$$

subset of wind data taken from day of year, DOY, 217 for tall (SHH) and short (PHH) stubble.

Soil water evaporation was estimated using the Bowen ratio-energy balance (BREB) method for day of year (DOY) 242-248. The BREB method uses measurements of the total available energy (net radiation), the energy absorbed in soil (soil heat flux), and air temperature and humidity at two heights to calculate the energy used to evaporate water as described by Todd *et al.* (2000b). Temperature and humidity sensors are influenced by an upwind "fetch" distance, which, if sufficient, results in evaporation estimates that are uninfluenced by the field edges. We used two BREB systems (Radiation and Energy Balance Systems, Seattle, WA) installed in the northeast corner of each treated field, 65 ft. from the north and 330 ft.

from the east boundary, to maximize fetch in the direction of the prevailing winds, i.e., fetch to the south and southwest varied from 900 ft to greater than 1000 ft. Each BREB system consisted of aspirated temperature and humidity sensors, a net radiometer, two soil heat flux transducers, and two soil temperature sensors. Measurements were averaged over 30 minutes, stored on automatic dataloggers, and, subsequently, screened for validity using the methods of Ohmura (1982). Calculations of the temperature and vapor pressure gradients, Bowen ratio, and BREB latent heat flux followed Bausch and Bernard (1992) using valid common measurement periods between the two BREB systems.

RESULTS AND DISCUSSION

Solar irradiance measured at the soil surface in the taller residue is plotted as a function of the corresponding value of solar irradiance measured in the short residue (Fig. 1) for the period from DOY 178-253. The resulting slope of a least squares regression line forced through the origin (i.e., measured solar irradiance at night would be zero regardless of straw height) shows that the taller stubble left by the stripper header had approximately 12% less irradiance at the soil surface than with the shorter straw. The intercepted irradiance during the first 37 days (plotted as open circles) was 11.4 % compared to 12.4 % for the 37 days following instrument exchange between treatments (plotted as closed circles) These data varied less than the limits ($P<0.95$) around the 11.8% calculated for the combined data; thus, indicating that there was no instrument bias. The effect of taller SHH residue was to lower irradiance at the soil surface compared to PHH residue and, consequently, reduce more of the energy that drives evaporation in the SHH plots.

Examples of mean solar irradiance at the soil surface for platform or stripper header residue treatments are plotted with time (Fig. 2) for DOY 217-218. The primary difference in the amount of shortwave solar irradiance at the soil surface occurs in the morning and evening periods. Compared to the PHH residue, the taller SHH residue shaded the soil in the morning and evening; thus, shortening the time when soil was exposed to the sun. Peak solar irradiance occurred near solar noon and tended to be greater with tall residue, probably because of in-canopy reflectance. The mean daily solar irradiance for the tall residue left by the stripper header was 540 cal cm^{-2} compared to 614 cal cm^{-2} measured in the shorter residue, about 77 and 88 % of the 700 cal cm^{-2} reference irradiance measured at 80 inches above the soil surface. The energy needed to drive evaporation is reduced by the taller residue architecture retained after stripper header harvest.

Daily wind velocity averaged using anemometers at all heights during the same period, DOY 178-253, was 5.0 ± 1.2 mph in taller SHH wheat residue compared with 5.4 ± 1.3 mph measured in the short PHH residue. The pair-wise t-test comparisons of mean daily wind velocity in the taller SHH wheat residue was significantly ($P>0.99$) lower than for the corresponding short PHH residue. An example 15-minute wind profile plot (Fig. 3.) for DOY 217 when the wind originated from approxi-
°, i.e., from the prevail-
rection (R. Nolan Clark,
n.), conforms to a log-
resulting displacement
the short PHH residue
compared to the 8.8 in.
for the taller SHH
ue. We expected that the
residue would vertically
pwardly) the wind ve-
le compared with PHH
nich is similar to results
McMaster *et al.* (2000).
Master *et al.* (2000) dif-
mean wind velocity due
height effects on mo-
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heights of at least 80 inches.

Increased aerodynamic resistance will reduce vapor transport, i.e, evaporation and was calculated for DOY 217 from surface roughness, z_0, values of 1.1 in. for the taller

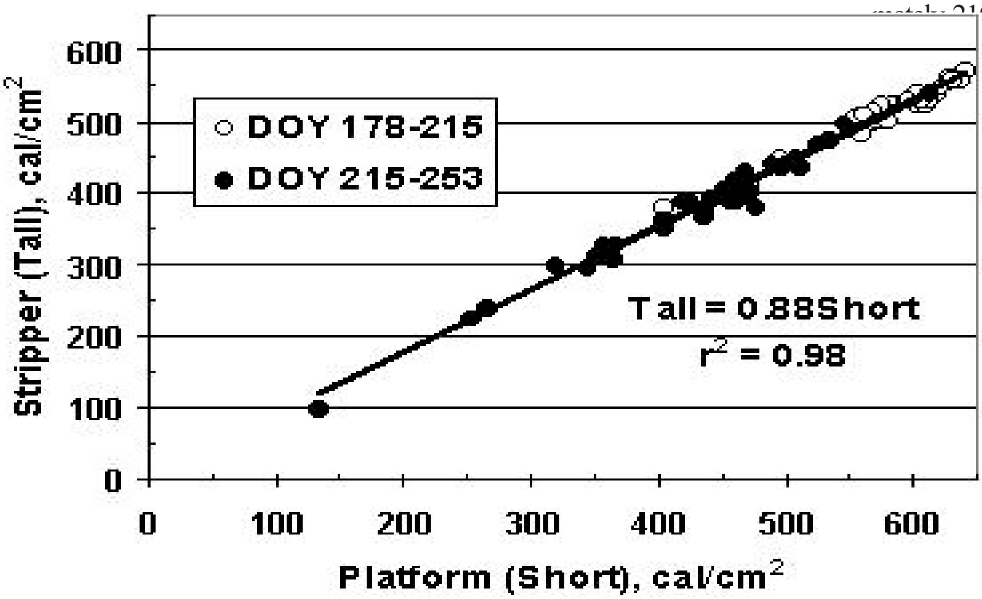

Fig. 1. Mean daily solar irradiance measured at the soil surface after stripper header harvest, SHH, plotted relative to the corresponding solar irradiance after platform header harvest, PHH, for day of year, DOY, 178-253. Sensors were exchanged after 37 days, but the values from DOY 178-215 (open circles) and 216-253 (closed) indicated no sensor bias and that 12% more interception of radiation with tall SHH residue than with short PHH residue.

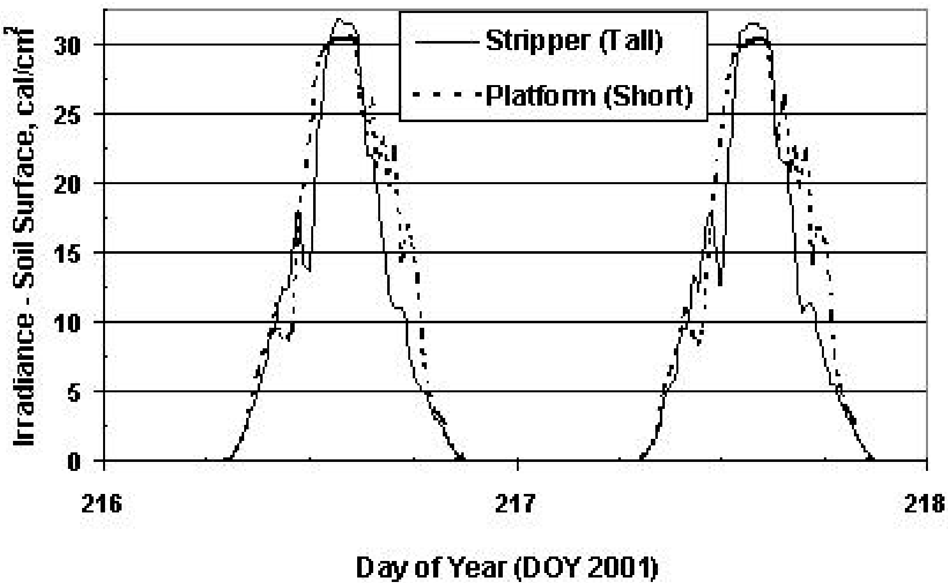

Fig. 2. Mean solar irradiance measured at the soil surface after platform header harvest, PHH, (dashed line) and after stripper header harvest, SHH, (solid line) plotted with time. Taller SHH residue intercepted morning and evening irradiance, resulting in a shorter (narrower) period when irradiance reached the soil.

SHH residue compared to 1.7 in. for the shorter PHH residue and the corresponding friction velocities, *U**, of 0.6 and 0.7 mph (Shuttleworth and Gurney, 1990). The resulting total aerodynamic resistance in the tall SHH residue (20.4 s/ft) was 15 % greater than for shorter residue of conventional PHH (18 s/ft). Our data show that the greater aerodynamic resistance to evaporation with the tall SHH residue has the potential to reduce soil evaporation compared with the PHH wheat residue. The potential impact of aerodynamic resistance on evaporation, however, will be most important immediately after a rainfall because the initial soil water evaporation is often limited by vapor transport and energy.

Bowen ratio measurements of daily soil water evaporation (E) from the SHH field varied from 18 - 36 % less E than from the PHH field (Fig 4.) during the period DOY 242-245 and 248. Measurements of evaporation on DOY 246 and 247 could not be used because a net radiometer malfunctioned. Todd *et al*. (2000b) calculated a root mean square difference of 8% between these two BREB systems, which was less than the range of differences we observed between the two harvest treatments in this study. Total E from the SHH field was 0.13 in. compared with 0.18 in. from the PHH field, resulting in an overall mean evaporation reduction with SHH of 26 % compared with PHH. The surface soil was dry during these measurements; however, our reported evaporation rates were consistent with the range of soil-limited E rates measured for a bare Pullman soil using small lysimeters (Todd *et al*., 2000a). We attributed the reduced evaporation in the SHH plots compared with PHH plots to (i) a reduction in net radiation (R_n) in the stripper header field that averaged 9% less than that measured in the shorter residues of the platform header field, and (ii) greater (more negative) soil heat flux (G) in the PHH field, averaging about 5% more. The calculated daily Bowen ratios were always positive, ranging from 1.3 to 4.0 in the PHH field and from 1.5 to 6.1 in the SHH field.

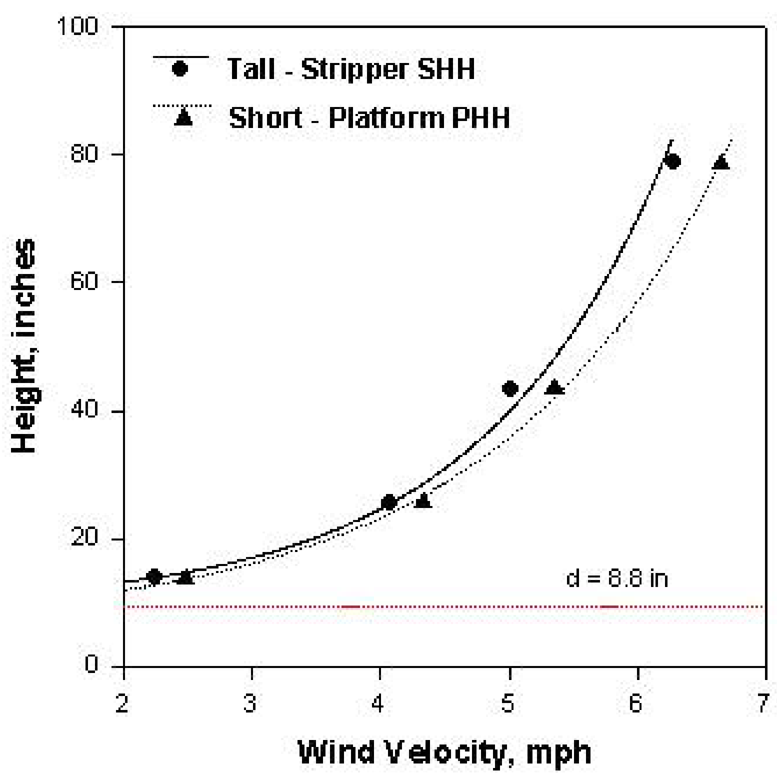

Fig. 3. Wind profiles over wheat residues harvest with platform headers, PHH, or stripper headers, SHH. The displacement height (*d*) of the taller SHH wheat residue is 8.8 inches above the surface compared with the shorter PHH residue displacement height (not shown) of 6.5 inches.

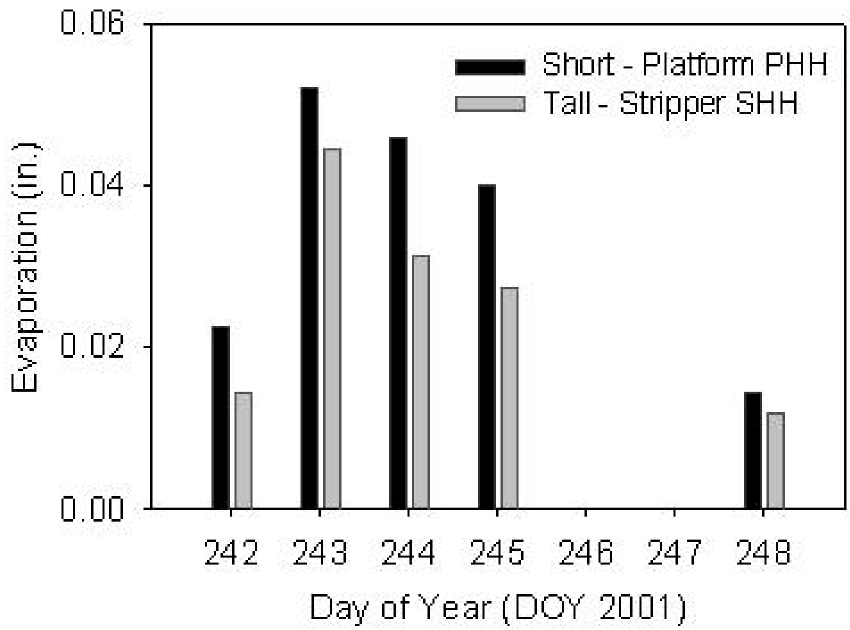

Fig. 4. Soil water evaporation estimated by Bowen ratio-energy balance from two wheat fields harvested by platform header, PHH, (short residue) or by stripper header, SHH, (tall residue).

Under the conditions of our experiment, the measured differences in E between SHH plots, tall residue, and PHH plots, short residue, was significant.

SUMMARY AND CONCLUSIONS

We compared shortwave solar irradiance, wind velocity, and evaporation in fields with 23.4 in. residue after stripper header harvest or with 15.5 in. residue after platform header harvest. Measured irradiant energy at the soil surface was reduced approximately 12 % by the taller residue SHH plots compared with short residue in PHH plots. Compared to PHH residue, the taller SHH residue architecture reduced the wind velocity and, consequently, reduced potential transport of water vapor (especially for evaporation from wet soil). Evaporation measured during a 4-day evaluation interval using the Bowen ratio method was 26% less in residue after stripper harvest compared with the short residue after platform header harvest. The differences, however, were very small because of the dry soil conditions during our experiment. Nevertheless, we conclude that water conservation will be increased when using stripper type combine headers to harvest wheat, because of reduced wind velocity profiles and increased interception of irradiant energy compared with platform header harvested wheat.

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