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## Soil Water Change as Related to Position of Wheat Straw Mulch on the Soil Surface<sup>1</sup>

D. E. SMIKA<sup>2</sup>

### ABSTRACT

A field study was conducted in the Central Great Plains to determine the effects of the position of wheat straw mulch on soil water change of a silt loam soil (a montmorillonitic, mesic Aridic Paleustoll) during three 14-month fallow periods. Treatments of 4600 kg/ha of wheat straw mulch flat on the soil surface,  $\frac{3}{4}$  flat and  $\frac{1}{4}$  standing, or  $\frac{1}{2}$  flat and  $\frac{1}{2}$  standing (normal position following standard combine harvesting) were compared with bare soil. Standing stubble was 0.46 m tall. Soil water content of one 1-m<sup>3</sup> hydraulic lysimeter within each treatment was measured daily and changes summed for each week, and at a distance of 2 m from each side of the lysimeter a neutron depth probe was used to determine soil water content weekly except when the soil was frozen. The relationship of soil water change for each weekly period with weekly values of total precipitation, total open-pan (U.S. Weather Bureau Class A) evaporation, average daylight-hour vapor pressure deficit, average maximum air temperature, average daily air temperature, average daylight-hour air temperature, total solar radiation, and average daily wind movement, was determined by single and multiple-correlation techniques. Soil water increases were related only to precipitation events with the highest correlation resulting from the  $\frac{1}{2}$  flat  $\frac{1}{2}$  standing wheat straw position treatment. Soil water losses were best correlated with wind movement with  $r^2$  values of 0.55, 0.41, 0.41, and 0.32 for bare soil, flat  $\frac{3}{4}$  flat- $\frac{1}{4}$  standing, and  $\frac{1}{2}$  flat- $\frac{1}{2}$  standing treatments, respectively. Soil water loss occurred from both bare soil and where the mulch was flat with winds of 0.08 MS<sup>-1</sup>. When  $\frac{3}{4}$  or  $\frac{1}{2}$  of the mulch was standing, a wind of at least 0.55 MS<sup>-1</sup> was needed before soil water loss occurred. Standing wheat straw does not function as a wick for loss of water from the soil.

**Additional Index Words:** wind, precipitation, soil surface temperature, wick action.

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**S**TORED SOIL WATER at seeding in the Central Great Plains is more efficiently used by plants than water received while the crop is growing (3). This fact is a primary reason why fallow has been shown to be the most water-use efficient system for wheat production in the Central Plains (5). In a region of erratic precipitation amounts and frequency, water shortage is the primary factor limiting dryland crop production; therefore, every effort should be made to increase the efficiency of the best system that is available. Soil water loss by evaporation from the soil surface is probably the greatest factor contributing to low fallow water storage efficiencies in the Great Plains.

Soil water storage during fallow increases with increasing amounts of residue on the soil surface (4, 7). The placement of equal quantities of wheat residue on the soil surface in concentrated zones vs. uniform distribution over the entire soil surface has been estimated to be beneficial for reducing soil water evaporation (1). The research reported herein was conducted to evaluate (i) the role that various positions of straw mulch on the soil surface plays in soil water change

and soil surface microclimate during fallow compared to bare soil; and, (ii) if standing wheat stubble attached to its root system removes soil water by wick action.

### METHODS AND MATERIALS

This field experiment was conducted at the Central Great Plains Research Station near Akron, Colo. The soil of the experimental area is a Weld silt loam which is a member of the fine, montmorillonitic, mesic Aridic Paleustolls. Soil water change data were collected during three 14-month fallow periods, and data on soil water loss by wick action of standing stubble were collected in the fourth year.

Residue position treatments were established each year following combine harvesting of the area and were: all straw flat on the soil surface, straw  $\frac{3}{4}$  flat- $\frac{1}{4}$  standing, and straw  $\frac{1}{2}$  flat- $\frac{1}{2}$  standing. These treatments were compared to a bare soil treatment where all residue had been removed by mowing and hand raking. The all-flat treatment was obtained by cutting all remaining standing residue at the soil surface and uniformly distributing it on the soil surface. The  $\frac{3}{4}$  flat- $\frac{1}{4}$  standing treatment was obtained by randomly cutting  $\frac{1}{2}$  of all remaining standing straw at the soil surface and uniformly distributing it on the soil surface. The  $\frac{1}{2}$  flat- $\frac{1}{2}$  standing treatment is the distribution obtained by the combine harvesting. The standing residue was 0.46 m tall and the total amount of residue was 4600 kg/hg. Seeding drill rows were 0.30 m apart and oriented east-west during 2 years and north-south in 1 year. Plots were 9 by 9 m with a 1-m<sup>3</sup> hydraulic lysimeter located in the center. The block of 8 plots was located in an area of standing wheat stubble that extended for at least 60 m in all directions from the edges of the plots. The lysimeter gauges were read daily at 0730 with differences in daily readings summed to obtain weekly soil water content values. Two and one-half meters north, south, east, and west from the center of each lysimeter, soil water content was determined weekly with a neutron probe at 0.30-m increments to a depth of 1.80 m. Readings in both systems were taken during the time when the soil was not frozen or covered with snow. During the 3 years, 140 weeks of data were available and soil water during these weeks was classified as increases (74), loss (27), or no change (39) weeks.

Chang (2) states that evaporation depends on temperature, wind, humidity, and radiation. In this paper humidity is expressed in terms of vapor pressure deficit and simple or multiple regression techniques were used to establish relationships of weekly soil water increase or loss values with weekly values of: total precipitation, total U.S. Weather Bureau Class A open-pan evaporation, average daylight-hour vapor pressure deficit, average maximum air temperature, average daily air temperature, average daylight-hour air temperature, total solar radiation, and average daylight-hour air temperature, and average daily wind at 1 m above the soil surface. Weeks with no soil water change were not evaluated separately in this study.

All weed growth in all plots was controlled through the use of combinations of residual and/or contact herbicides as needed and appropriate for the weed species to be controlled.

Wind velocities at the soil surface at the top of the flat mulch layer, and at 0.23-, 0.46-, and 1.0-m distances above the soil surface were determined by averaging 6 to 10 instantaneous readings at each height as obtained with an omnidirectional, linearized, constant-temperature, platinum-resistance wire sensor accurate for wind velocities from 0.02 to 29.72 MS<sup>-1</sup>. Wind measurements were made only when

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<sup>2</sup> Soil Scientist, Central Great Plains Res. Stn., Akron, CO 80720.

wind direction was 10 degrees or more from parallel to the row direction of the stubble. Soil surface and composite soil and straw on the soil surface temperatures (hereafter all will be referred to soil surface temperature) were measured daily at 1000, 1200, and 1500 h MDT using an infrared radiation thermometer with a 10.5- to 12.5- $\mu\text{m}$  spectral region with a 2.0-degree field of view. Air temperatures were measured hourly with a copper-constantan thermocouple shielded from direct radiation at 0.23 and 1 m above the soil surface.

To determine if standing wheat straw has a wick action on soil water loss, during the fourth year of the study, four lysimeters had all stubble removed and four lysimeters had  $\frac{1}{2}$  flat- $\frac{1}{2}$  standing stubble, and all lysimeters were wetted to field capacity. Two of the bare and two of the  $\frac{1}{2}$  flat- $\frac{1}{2}$  standing stubble lysimeters had the entire soil surface covered to a depth of at least 2 cm with a mixture of paraffin and beeswax (20:1 ratio) to completely seal the soil surface. All lysimeters were read daily at 0730 for 34 d from 31 July to 2 September.

## RESULTS AND DISCUSSION

Lysimeter and neutron probe water content measurements produced almost identical results for each weekly period so all soil water storage values given in Table 1 are an average of both measurement methods for the 3 years. For all weeks of the fallow period, straw position significantly influenced both total fallow period water storage and storage efficiency with  $\frac{1}{2}$  flat- $\frac{1}{2}$  standing  $>$   $\frac{3}{4}$  flat- $\frac{1}{4}$  standing  $>$  all flat  $>$  bare soil (Table 1). These storage amounts and efficiencies are similar to values obtained on larger fields with comparable treatments (6).

Soil water increase weeks were related only to total weekly precipitation with  $r^2$  values of 0.86\*\*, 0.85\*\*, 0.84\*\*, and 0.92\*\* for the bare soil, flat,  $\frac{3}{4}$  flat- $\frac{1}{4}$  standing, and  $\frac{1}{2}$  flat- $\frac{1}{2}$  standing straw treatments, respectively. These relationships were all essentially identical except for the  $\frac{1}{2}$  flat- $\frac{1}{2}$  standing treatment. While a net soil water gain may have been recorded for a specific week, there may have been some days during the week when water was lost from the soil.

Of the factors tested, soil water losses were correlated the best to wind movement of 1 m above the soil surface with  $r^2$  values of 0.55\*\*, 0.41\*, 0.41\*, and 0.32 for the bare, flat,  $\frac{3}{4}$  flat- $\frac{1}{4}$  standing, and  $\frac{1}{2}$  flat- $\frac{1}{2}$  standing straw position treatments, respectively. These  $r^2$  values increased by amounts of 0.05 or less when soil water loss was correlated to combination of the various factors. Thus, clearly showing that wind was the dominant factor influencing soil water loss. The regression equations for soil water loss as related

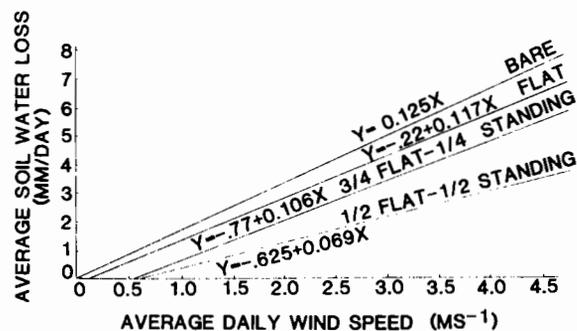


Fig. 1—Relation of soil water loss per day to average daily wind velocity for bare soil and soil with straw mulch in different positions on the soil surface during soil water loss weeks.

to wind speed for the  $r^2$  values and treatments in the same order as listed above are:  $Y = 0.125x$ ,  $Y = -0.22 + 0.117x$ ;  $Y = -0.77 + 0.106x$ ; and  $y = -0.625 + 0.069x$ , respectively (Fig. 1), where  $x$  = average daily wind velocity in  $\text{MS}^{-1}$  and  $Y$  = mm of water loss per day during weeks when soil water loss occurred. From these analyses water loss from bare soil was found to occur when wind occurred at the soil surface and that an average of 0.45 mm loss occurred for each 0.28  $\text{MS}^{-1}$  increase in wind. With flat stubble, water loss from the soil did not occur until a wind speed of at least 0.14  $\text{MS}^{-1}$  occurred, but thereafter average water loss of 0.42 mm occurred for each 0.28  $\text{MS}^{-1}$  of wind. This loss rate is only a 7% reduction over that found with bare soil. When  $\frac{1}{4}$  of the straw was flat  $\frac{1}{4}$  was standing an average daily wind velocity of 0.56  $\text{MS}^{-1}$  was needed before water loss occurred. Thereafter an increase of 0.28 mm of water loss was lost for each 0.28  $\text{MS}^{-1}$  of wind speed. This latter straw position decreased water loss by 16% when compared to bare soil and 10% when compared to flat straw.

With  $\frac{1}{2}$  flat- $\frac{1}{2}$  standing straw, an average daily wind velocity of 0.69  $\text{MS}^{-1}$  was needed before water loss occurred, and each 0.28  $\text{MS}^{-1}$  increase in wind movement above this level resulted in an average water loss of 0.25 mm. The  $\frac{1}{2}$  flat- $\frac{1}{2}$  standing treatment decreased water loss associated with wind by 44, 40, and 34% when compared to the bare soil, flat straw, and  $\frac{3}{4}$  flat- $\frac{1}{4}$  standing treatments, respectively.

One of the factors causing the decrease in water loss with standing straw is the decrease in wind velocity at the soil surface (Fig. 2). With the  $\frac{1}{2}$  flat- $\frac{1}{2}$  standing straw treatment of a wind of 4.4  $\text{MS}^{-1}$  was required at the top of the stubble before wind could be measured at the soil surface. With the  $\frac{3}{4}$  flat- $\frac{1}{4}$  standing treatment, a wind of 3.3  $\text{MS}^{-1}$  resulted in measurable wind at the soil surface. Soil surface wind with the  $\frac{3}{4}$  flat- $\frac{1}{4}$  standing treatment with straw length of 0.46 m was identical to that obtained where standing wheat straw was 0.38 m long. For additional comparisons standing wheat straw of 0.30 and 0.61 m are also presented to show the importance of standing wheat straw for reducing wind movement at the soil surface.

Loss of water from the soil occurred when wind velocities at the top of the straw were lower than was necessary to create wind movement at the soil surface. Water loss during these periods is attributed to air movement caused by turbulence and buoyancy of air flow upward due to the temperature differential and

Table 1—Fallow period water storage to a depth of 1.8 m and storage efficiency for bare soil and different straw positions on the soil surface, 3-year average.

Straw position	Water storage	
	Amount	Efficiency†
	mm	%
Bare soil	96 a**	18.6 w**
Flat straw	137 b	26.5 x
$\frac{3}{4}$ flat- $\frac{1}{4}$ standing	234 c	45.3 y
$\frac{1}{2}$ flat- $\frac{1}{2}$ standing	272 d	52.9 z

\* Values accompanied by different letters are significantly different at  $P = 0.01$ .

† Storage efficiency is the water stored divided by precipitation received during storage period multiplied by 100.

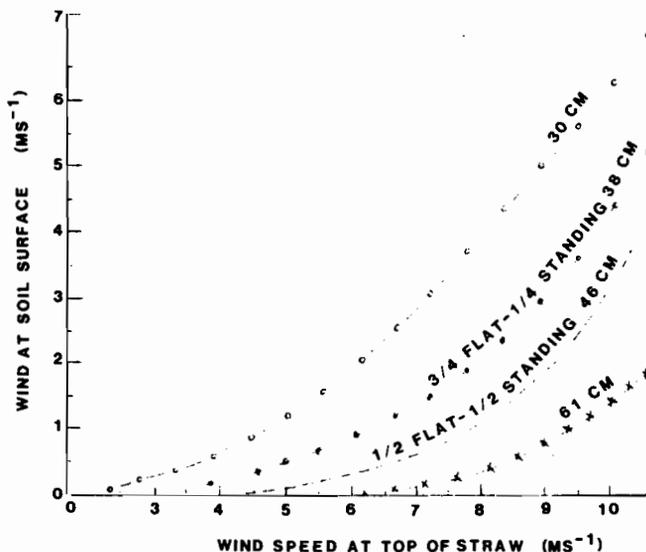


Fig. 2—Relation of wind velocity at the soil surface to wind velocity at the top of the straw for straw heights of 30, 38, 46, and 61 cm.

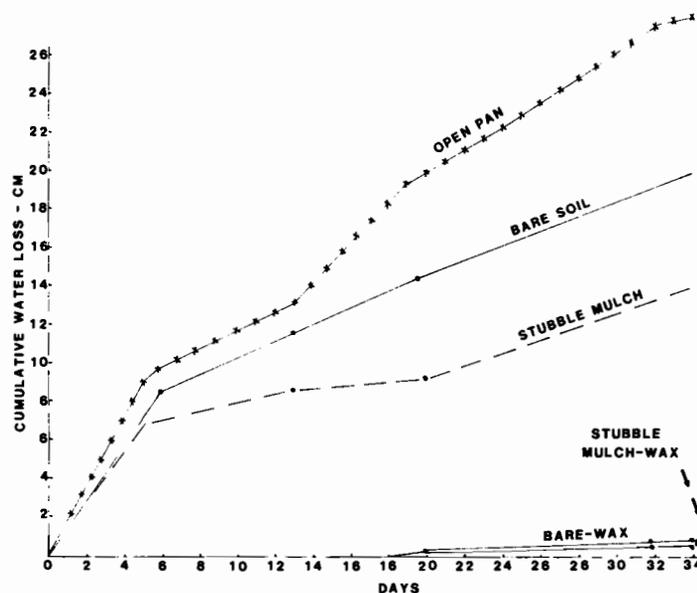


Fig. 3—Cumulative water loss from soil with and without standing straw, and with and without wax sealing of the soil surface for a 34-d period from 31 July to 2 September.

the rate of change of wind speed between the soil surface and the top of the standing straw.

The longest continuous water loss period was 5 weeks and occurred during part of August and the first 10 d of September of the 3rd year of the study. This period began the day after 16.8 mm of rain. During this 5-week period, average daily water and total water losses were highest with bare soil and lowest with the 1/2 flat-1/2 standing straw treatments (Table 2). The flat and 3/4 flat-1/4 standing straw treatments resulted in about equal daily loss rates and total losses, both of which were about midway between those for the other two treatments. Only the 1/2 flat-1/2 standing treatment ended the 5-week period with any of the 16.8-mm rain remaining as soil water, and even that was 0.14 mm.

In addition to the previously discussed influence of wind reduction and straw position on soil water loss, straw position affected soil surface temperature (Table 2) which also influenced daily water loss and water loss for the total 5-week period. Total soil water loss during this 5-week period was highly related to soil surface temperature,  $r^2 = .996^{**}$ . Each degree celsius increase in temperature resulted in 0.014 mm of water loss per day. The decrease in soil surface temperature with the different straw positions compared to air temperature above the standing straw positions compared

Table 2—Soil water loss and average daily soil surface temperature as affected by bare soil and straw position during a 5-week August–September period without precipitation.

Straw position	Soil water loss		Soil surface temperature†
	Average daily	Total	
	mm		°C
Bare soil	0.66 c**	23.1 f**	47.8 z**
Flat straw	0.56 b	19.6 e	41.7 y
3/4 flat-1/4 standing	0.53 b	18.6 e	39.6 y
1/2 flat-1/2 standing	0.43 a	15.1 d	32.2 x

\*\* Values accompanied by different letters are significantly different at  $P = 0.01$ .

† Average of measurements at 1000, 1200, and 1500 h with a radiation thermometer.

to air temperature above the standing straw would contribute to air turbulence within the straw canopy. The decrease in soil surface temperature with the different straw position treatments compared to bare soil may be the reason that no air temperature measurements were correlated with water loss ( $r^2 \leq 0.10$ ) except from the bare soil treatment ( $r^2 = 0.26$ ). On days between 0600 and 1800 h, when wind velocity was  $5.56 \text{ MS}^{-1}$  or less, air temperature at 0.23 m above the soil surface was 1.1 and  $2.2^\circ\text{C}$  cooler than air temperature at 1 m for the 3/4 flat-1/4 standing and 1/2 flat-1/2 standing straw position treatments, respectively. For the bare and flat straw treatments air temperature was the same at both heights. At winds  $> 5.56 \text{ MS}^{-1}$ , temperatures were the same at both measurement heights for all treatments.

Standing straw did not serve as a wick for water loss from the soil (Fig. 3). Essentially no water loss occurred from either the bare lysimeters or those with standing straw when the soil surface was sealed. However, the bare soil surface lysimeters and those with standing straw not having the soil surface sealed lost 0.20 and 0.14 m of water, respectively, during the 34-d period. For the first 13 d of the 34-d period, water loss from the bare nonsealed soil was close to the open pan evaporation water loss.

The results of this study show that for the residue rates used, the major role straw position has on soil water storage from rainfall lies in its influence on water retention and loss from the soil. Standing stubble is the most effective position for minimizing water loss. As amount and height of straw increases it becomes more effective due to decreasing wind velocity at the soil surface and cooler soil surface temperatures. Further, standing straw does not contribute to soil water loss by functioning as a wick.

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