Reprinted from the *Soil Science Society of America Journal*
Volume 53, no. 3, May–June 1989
677 South Segoe Rd., Madison, WI 53711 USA

Tillage and Surface Residue Effects on Evaporation from Soils

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ABSTRACT

Many crop growth models require modification for dryland farming systems because they do not predict an effect of residues on the soil water balance. Daily evaporation (E) from a Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll) was measured in three experiments using laboratory cores or field microlysimeters to determine effects of tillage and residues on cumulative E and on E rate. The first experiment showed that the disk treatment had the highest rate of Stage 1 E and a lower slope of the Stage 2 E curve than sweep and no-tillage treatments. Effects of tillage on surface wheat (*Triticum aestivum* L.) residues and on soil physical properties both seemed related to E. In a subsequent experiment, no effect of tillage-induced differences in soil properties on daily E was measured when wheat residues were removed before tillage. In the third experiment the effect of cotton (*Gossypium hirsutum* L.), sorghum [*Sorghum bicolor* (L.) Moench], or wheat residue (x, m^3 m^{-2}) on the initial, energy-limited rate of E (y, the potential E at the surface relative to bare soil E) was described by a logarithmic relationship [$y = -0.99 - 0.236 (\ln x)$, $n = 36$, $r^2 = 0.87$]. With residues described on a mass/unit area basis, crop-specific curves were obtained; but with residues described on a thickness or volume/unit area basis, the curves obtained with the different crop residues were very similar to the pooled relationship given above. This simple relationship between residue level and daily E can be incorporated into water balances of commonly used crop growth models to increase the accuracy of water balance prediction for different cropping systems.

EVAPORATION (E) from a bare soil surface has been described as a three-stage process (Idso et al., 1974). An initial, energy-limited stage occurs at the potential E rate; a second, falling rate stage is limited by water flow to the surface, while the third stage is a very low, nearly constant rate from very dry soil. Lemon (1956) showed soil drying curves that had a constant stage, a linear falling stage, and a nonlinear falling stage as soil water decreased from about 45% to near 0%. Gardner (1959) showed that from a theoretical viewpoint, cumulative Stage 2 E was a linear function of the square root of time; and Black et al. (1969) described lysimeter drying curves with the Eq. [1]

$$E_c = C \cdot t^{1/2} \quad [1]$$

where E_c is cumulative soil evaporation (mm), C (mm $d^{-1/2}$ is dependent on soil diffusity, and t is the days of drying. Van Bavel and Hillel (1976) conducted a numerical analysis of soil drying curves but did not find a third stage distinct from Stage 2 E.

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Published in Soil Sci. Soc. Am. J. 53:911–916 (1989).

Ritchie (1972) made some of the earliest efforts to separate the soil water E process from the transpiration process. Energy to drive the two processes was partitioned as a function of leaf area index of the crop. He developed a simple mathematical description of the E process in two stages, where two soil-specific constants controlled the shape of the E curve. The first of these two constants is U, which describes the quantity of water which evaporates at the Stage 1 rate and the second is C from Eq. [1]. Ritchie (1972) showed that U and C depend on soil characteristics and that values for four soils decreased as hydraulic conductivity at −100 kPa decreased. His model of daily E provides the basis for the water balance of numerous crop growth models (e.g., Arkin et al., 1976; Baker and Acock, 1985; Kanemasu et al., 1976; Smith et al., 1985; Williams et al., 1984).

Tillage affects the rate of E from a soil, not only immediately but also over longer time periods. Physically based models such as those described by Hammel et al. (1981) or Lascano and Van Bavel (1986) can be used to analyze tillage effects on E processes, but they require detailed inputs of soil physical properties and initial conditions. Linden (1982) mathematically described many of the effects of tillage-induced soil physical changes on E but did not consider the effects of residues per se on E. Van Doren and Allmaras (1978) mathematically described the effect of residues on soil surface processes, including E. They described reduced potential E at the soil surface in algorithms requiring several inputs regarding the nature and condition of the residue layer.

A simple quantitative description of tillage and residue effects using limited data inputs has not been broadly accepted nor incorporated into soil water balance models. Most commonly used crop growth models do not predict tillage or residue effects on E and soil water storage because they do not include such information in the E logic or input variables. Improvement of soil water balance models is necessary before they can be used to analyze E in dryland cropping systems where the water balance between crops critically affects the cropping season water balance.

The objective of this study is to quantitatively describe tillage and residue effects on the parameters that affect daily soil E rate in forms that can be used in existing water balance models, particularly those based on the two-stage E model as described by Ritchie (1972). An additional objective is to illustrate the impact such modification can have on a soil water balance simulation.

MATERIALS AND METHODS

Three experiments were conducted at the USDA-ARS Conservation and Production Research Laboratory, Bushland, TX on a Pullman clay loam soil to show the effects of tillage and residues on soil E. Experiment 1 was conducted using monolithic soil cores dried in a constant temperature laboratory to determine tillage effects on soil E parameters (U and C). Experiment 2 was developed to measure the tillage-induced soil physical property effects on E because the treatments in Exp. 1 confounded soil and residue effects. Experiment 2 was conducted under field conditions using the microlysimeter technique of Boast and Robertson (1982). Experiment 3 was conducted to examine the effects of residues on E. Data previously reported by Unger and Parker (1976) involving crop residue placement on sieved soil cores dried in a constant temperature laboratory were used.

Experiment 1—Laboratory Drying of Soil Monolithic Cores

Soil cores were collected from a field that had been fallowed with no-tillage management following an irrigated wheat crop grown in 0.25-m spaced rows on 1-m spaced beds. Wheat (initially 770 g m^{-2} of nongrain material) was combined about 0.25 m above the bed surface and the residues had weathered for 36 wk prior to the beginning of the experiment. On 23 Apr. 1985, two additional tillage treatments were established to provide no-till (N), disk (D), and sweep (S) tillage areas. The D area was tilled twice with a one-way disk to a depth of about 100 mm. The S area was tilled to a depth of about 150 mm with a sweep plow that had 0.8-m blades. The following day, monolithic soil cores were collected in cylinders constructed from 0.25-m i.d. PVC irrigation pipe cut into 0.5-m lengths, with the bottom edge of each core beveled. Cylinders were positioned on the center of the bed (or where a bed had been in the D plots) and were pushed into the ground with the shovel of a backhoe until a 0.04-m lip remained. Cylinder lips were protected with an iron cap during pushing. The cores were excavated manually.

Each core was used to monitor E during two drying cycles. For each cycle, the cores were brought to field capacity by applying 38 mm of water with a rainfall simulator that was designed (Morin et al., 1967) to give a uniform application rate of 25 mm h^{-1} over the area where the cores were arranged. Water was sprinkled in three sequential showers to minimize ponding. The cores were covered with plastic to equilibrate for 3 d. After equilibration, cylinders were cleaned and the bottoms were sealed with plastic.

Ten cores, three of each tillage treatment and one which was sealed at the base for measurement of the free water E rate, were placed at the outer edge of a 1.14-m diam. turntable that rotated at 1.2 rpm under a ring of 125-W heat lamps. The free water E rate, controlled by the number of heat lamps used, was 8.5 and 5.3 mm d^{-1} during the first and second cycle, respectively. The lower evaporative rate in Cycle 2 was used to provide better determination of the end of Stage 1 E. Heat lamps were on for 16 h d^{-1}. Air temperature in the room was about 24 °C, and vapor pressure deficit was about 1.7 kPa. The air was circulated by a fan blowing across the drying table below the cylinder lips.

Water loss was determined by weighing daily for at least 10 d and less frequently thereafter for a total of at least 24 d of drying. Weighing was finished before the heat lamps came on. The water column loss was measured by refilling to a point gauge level.

Following the second drying cycle, crust strength was measured 15 times for each core with a penetrometer (John Chatillon and Sons, New York, Model no. 719-40)[1]. The average crust strength for each core was analyzed. All residues were removed from the soil cores, oven-dried, and weighed. The soil was removed from the cylinders in layers, using a piston to push the soil from the cylinder. Volumetric water content and bulk density were determined for layers from 0- to 10-mm, 10- to 20-mm, 20-mm layers from 20 to 200 mm, and 50-mm layers from 200 to 400mm.

The drying curves for each core for each cycle were analyzed separately to determine the rate of Stage 1 E relative to the free water E rate (RATIO) and the soil E parameters, U and C. The end of Stage 1 E was determined by identifying a drop in RATIO from its initial level. Cumulative E at the end of Stage 1 E was U. The Stage 2 E constant (C) was determined for each core as the slope of the linear regression of Stage 2 cumulative E on $d^{1/2}$. Each regression was significant at $p < 0.001$ and the r^2 for each regression exceeded 0.97, indicating that the linear model fit the data well.

The experimental design was a split plot design with the cycle treatment representing a repeated measure over time. Within each cycle, the soil cores were treated in a completely randomized manner in their arrangement under the rainfall simulator and on the drying table. Analysis of the soil core characteristics was treated as a completely randomized design with three replications.

Experiment 2—Field Microlysimeters

Effects of tillage-induced soil physical conditions on E rate were evaluated using the microlysimeter technique reported by Boast and Robertson (1982). Tillage treatments were no-till (N), sweep tillage (S), and moldboard plowing plus disking (M/D). The M/D treatment was used because an existing rainfall simulation experiment did not include a simple disk treatment, such as had been used in Exp. 1. All residues were removed from plots following tillage. Each plot was sprinkled on two occasions with a rainfall simulator at 50 mm h^{-1} until runoff occurred. Plots were covered with plastic tarps when they were not under the rainfall simulator until the initiation of the drying experiment. An initial drying cycle (13 to 14 July 1987) was interrupted by a high intensity, 25-mm rain on 14 July. The plots were covered from 15 to 20 July, when another drying cycle was started. Measurements were made 20 to 31 July during a period of no rainfall and high evaporative conditions.

The microlysimeters were constructed of aluminum pipe 82 mm in diam. and 150 mm deep with a sharpened bottom edge. Microlysimeter installation and weighing took place at dawn. Each microlysimeter was pushed vertically into the ground and removed from the hole with as little disturbance as possible. The cylinder was cleaned and the bottom sealed with aluminum foil. Each core was weighed to 0.1 g (0.02-mm water equivalent), wrapped in a plastic bag, and returned to the original hole within 30 min. The soil surface was smoothed around the core, and the plastic was trimmed at the surface. The next day, the microlysimeter was removed for weighing. Each set of cores was used for 24-, 48-, or 72-h periods, depending on the daily rate of drying. As the rate of drying decreased, cores could be used for a longer period of time without risking a deviation between the water content of the isolated soil core from the field around it. Seven sets of cores were used, with initial weights taken on Day 1, 2, 3, 4, 6, 9, and 12. Two microlysimeters were installed per plot for each set, for eight E measurements per treatment per day. Each day's measurements took from 45 to 90 min and a crew of two to four people, depending if new cores had to be installed.

Bulk density of the 0- to 150-mm layer was determined before and after the E measurements. The gravimetric water content of the soil layer was also determined following the measurements.

The experimental design was a randomized block with four blocks. Two cores were installed per plot. Blocking was used to isolate the possible effect of the length of time be-

[1] Mention of a trade name or product does not constitute a recommendation or endorsement for use by the USDA nor does it imply registration under FIFRA as amended.

tween the end of sprinkling and the beginning of the E measurements. As in Exp. 1, each replication was analyzed separately to determine the slope (*C*) of the linear regression of Stage 2 cumulative E on $d^{1/2}$. The analysis of variance was used to determine treatment and blocking effects on the slope of Stage 2 E and on soil properties.

Experiment 3—Laboratory Residue Placement Experiment

The effect of residues on E was analyzed using data published by Unger and Parker (1976) and related unpublished data (P.W. Unger, 1987, personal communication). In brief, sieved soil was packed to a density of 1.3 Mg m^{-3} and a depth of 56 mm into 102-mm diam., 61-mm deep columns. The columns were wetted to −33 kPa water potential, covered, and allowed to equilibrate for 3 d. Cut sorghum and cotton residues were placed on the surface at the rates of 200, 400, 800, 1600, and 3200 g m^{-2}. Wheat residues were placed on the surface at the rates 200, 400, and 800 g m^{-2}. Residues were cut into 50- to 70-mm lengths and each residue treatment was replicated twice. The soils were dried at water E rates from 6.6 to 12.9 mm day^{-1} as described by Unger and Parker (1976) and in a similar manner to that described in Exp. 1. Measurement of the residue depth, the density of the residues, and additional experimental details are described in Unger and Parker (1976).

Evaporation from bare soil (0 g m^{-2} residue) was used to normalize the E from the different crop residue treatments. The initial ratio of the residue covered E rate to the bare soil E rate was used to define the relative Stage 1 E (RATIO). The cumulative E at the time when RATIO began to drop from its initial value was set to *U*. For each core, the Stage 2 E curve was analyzed by regression to determine the slope (*C*) of cumulative stage 2 E on $d^{1/2}$. All of the regressions were significant at $p < 0.001$ and had $r^2 > 0.90$, again indicating that the linear model fit the data well, as in Exp. 1.

Because the data used from Unger and Parker (1976) were treatment means, no replications of treatments were available. An analysis of variance of the treatment effects on E parameters was therefore not possible. However, correlation analysis of residue amount and type and the free water E rate with *C*, *U*, and RATIO was made. The effect of residue on the relative Stage 1 E (RATIO) rate was analyzed by regression technique.

RESULTS

Experiment 1

Tillage treatments affected the soil drying curves (Tables 1 and 2) in two ways: (i) the relative Stage 1 E rates were 0.93, 0.71, and 0.58 for D, S, and N treatments, respectively; and (ii) the slopes of the Stage 2 E curves (*C*) were 5.6, 8.2, and 7.8 mm $d^{-1/2}$ for D, S, and N treatments. Cumulative Stage 1 E (*U*) was not significantly affected by tillage.

Crust strength and the residue amount were extremely variable within treatments and therefore conclusions to be drawn from these measurements must be limited. Tillage treatments did not affect crust strength significantly (data not shown), though the D cores had the highest mean crust strength. Higher water content in the surface 20 mm in the D cores compared to the N and S cores ($p \leq 0.06$, data not shown) could indicate impedance of Stage 2 E by the surface crust. Bulk density from 80 to 140 mm was significantly higher ($p \leq 0.05$, data not shown) in the D cores and could have been related to impeded flow to the surface as the soil dried, as indicated by the lower slope of the Stage 2 E curve (Table 2). The S cores had the highest residue level (significantly higher than D cores at $p \leq 0.05$, data not shown) because of build-up of loose residues ahead of the shank as it was pulled through the soil. The convention of sampling centered on a bed, to avoid the risk of sampling in a tractor tire track, probably led to a biased sampling of the residue amount in the S plots.

The correlation between the E parameters and the soil core characteristics are shown in Table 3. Residue amount was positively correlated with *C* and negatively correlated with *U*. Surprisingly, residue amount was not significantly correlated with the relative Stage 1 E rate (RATIO), possibly because some of the cores that had the highest residue amounts had clusters of matted residues covering part of the surface and had considerable portions of the surface exposed. Crust strength was not significantly correlated with the E parameters but negative correlations between the bulk density in the layers from 80 to 140 mm with the E constants indicates that the tillage effects on the soil characteristics may be important in describing E processes.

Table 1. Analysis of variance for the rate of Stage 1 evaporation relative to that of water (RATIO), and soil drying parameters, *U* and *C*, as affected by tillage and drying cycle in Exp. 1.

		Evaporation parameters		
Source	df	RATIO	*U*	*C*
		F values		
Tillage (T)†	2	5.60*	0.66	14.37**
Cycle (C)‡	1	1.76	0.11	4.23
T × C‡	2	0.88	0.17	2.40

*,** Significant at $p \leq 0.05$ and 0.01, respectively.
† Error term for T effect is Rep(T).
‡ Error term for C and T × C effects is T × C × Rep(T).

Table 2. Tillage effects on the rate of Stage 1 evaporation relative to that of water (RATIO) and on soil drying parameters, *U* and *C* in Exp. 1.

	Evaporation parameters		
Tillage	RATIO	*U*	*C*
		mm	mm $d^{-1/2}$
Disk	0.93a*	13.7a	5.6a**
Sweep	0.71ab	9.9a	8.2b
No-till	0.58b	9.9a	7.8b

*,** Values within columns followed by the same letter are not significantly different at $p \leq 0.05$ and $p \leq 0.01$, respectively, by the Tukey's studentized range test.

Table 3. Correlation of the characteristics of the soils in the cores with soil evaporation parameters, in Exp. 1.

	Evaporation parameters		
Soil core† characteristics	RATIO	*U*	*C*
		r	
Residue	NS	−0.51*	0.48*
Crust	NS	NS	NS
θ_{20}	NS	NS	0.56*
θ_{40}	0.50*	NS	NS
ρ_{20}	NS	NS	NS
ρ_{80}	0.54*	NS	−0.51*
ρ_{100}	0.55*	NS	−0.57*
ρ_{120}	0.52*	NS	−0.60*

* Significant correlation at $p \leq 0.05$. NS = no significant correlation.
† Soil characteristics are amount of crop residue on the surface (g m^{-2}), crust strength (MPa), soil-water content in layers from 20- to 40-mm (θ_{20}) and from 40- to 60-mm depth (θ_{40}), and bulk density in layers from 20 to 40 mm (ρ_{20}), 80 to 100 mm (ρ_{80}), 100 to 120 mm (ρ_{100}), and 120 to 140 mm (ρ_{120}).

Table 4. Analysis of variance for the post-drying soil-water content (θ), and pre- and post-rainfall bulk density (ρ_{pre} and ρ_{post}, respectively) and the slope of the Stage 2 drying curve (C) as affected by tillage treatments and blocks in Exp. 2.

Source	df	Soil characteristics θ	ρ_{pre}	ρ_{post}	C
		F ratio			
Tillage (T)	2	0.4	19.4***	13.2***	0.8
Block (B)	3	6.7***	1.5	5.8**	13.0***

*,**,*** Significant at $p \leq 0.05$, 0.01, and 0.001, respectively.

Table 5. Tillage effects on the post-drying soil-water content (θ), the pre- and post-rainfall bulk density (ρ_{pre} and ρ_{post}, respectively), and the slope of the Stage 2 drying curve (C) in Exp. 2.

Tillage	Soil Characteristics θ	ρ_{pre}	ρ_{post}	C
		Mg m^{-3}	Mg m^{-3}	mm d$^{-1/2}$
Moldboard/disk	0.18a†	1.13a	1.16a	5.37a
Sweep	0.18a	1.17a	1.21a	5.17a
No-till	0.17a	1.39b	1.37b	5.58a

† Values within columns followed by the same letter are not significantly different at $p \leq 0.05$ by the Tukey's studentized range test.

In this experiment, both residue and soil physical properties seemed to be related to the E responses to tillage. Examination of the soil-related tillage effects separately from the residue effects was needed.

Experiment 2

In Exp. 2, where all surface residues were removed, the slope (C) of the regression of cumulative Stage 2 E against days$^{1/2}$ of drying was not significantly affected by tillage (Table 4 and 5) nor were daily or cumulative E rates significantly affected (data not shown). There was a significant ($p \leq 0.05$) blocking effect on E but no block by tillage interaction. Even though tillage treatments resulted in surface bulk density differences (Tables 4 and 5), the differences could not be related to E rates nor to C. This indicated that the tillage-induced differences in soil physical condition were not major factors controlling E from bare soil in this experiment.

Table 6. Correlation coefficients of evaporation parameters with free water E and residue treatments in Exp. 3.

Crop Treatment	Evaporation parameters RATIO	U	C
	r	r	r
Pooled n = 39			
Water E, mm d^{-1}	NS	NS	NS
Residue, g m^{-2}	−0.69†	NS	NS
Residue, m^3 m^{-2}	−0.79†	−0.40*	−0.49**
Cotton n = 18			
Water E, mm d^{-1}	NS	NS	NS
Residue, g m^{-2}	−0.92†	NS	NS
Sorghum n = 19			
Water E, mm d^{-1}	NS	NS	NS
Residue, g m^{-2}	−0.80†	−0.45*	−0.66**
Wheat n = 10			
Water E, mm d^{-1}	NS	NS	NS
Residue, g m^{-2}	−0.95†	−0.70*	NS

*,**,† Significant at $p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.0001$, respectively. NS = not significant at $p \leq 0.05$.

Experiment 3

Residues applied in different quantities to packed soil columns had a strong effect on E. The correlation coefficients of E parameters to residue and free water E treatments are shown in Table 6. The strongest correlations in the experiments were between the residue treatments and the relative Stage 1 E rate. There were weaker and less consistent correlations between residue treatments and other E parameters. The free water E rate was not significantly correlated with any of the E parameters. The data lent itself to further investigation of the relationship between residues and Stage 1 E.

A pronounced, crop-specific effect of residue amount (g m^{-2}) on the relative Stage 1 E rate is shown in Fig. 1. Residue treatments reduced the energy reaching the

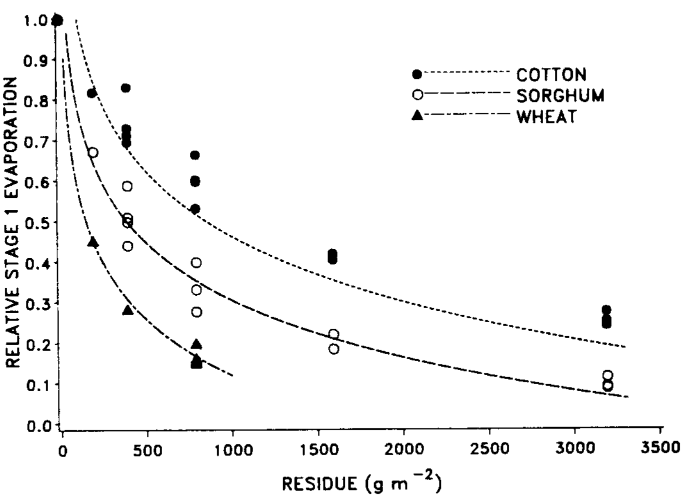

Fig. 1. Effect of residue amount (g m^{-2}) on relative Stage 1 E. Equations which describe the curves are:

Cotton: $y = 2.07 - 0.223 (\ln x)$ $r^2 = 0.95, n = 15$
Sorghum: $y = 1.72 - 0.205 (\ln x)$ $r^2 = 0.93, n = 15$
Wheat: $y = 1.50 - 0.200 (\ln x)$ $r^2 = 0.96, n = 6.$

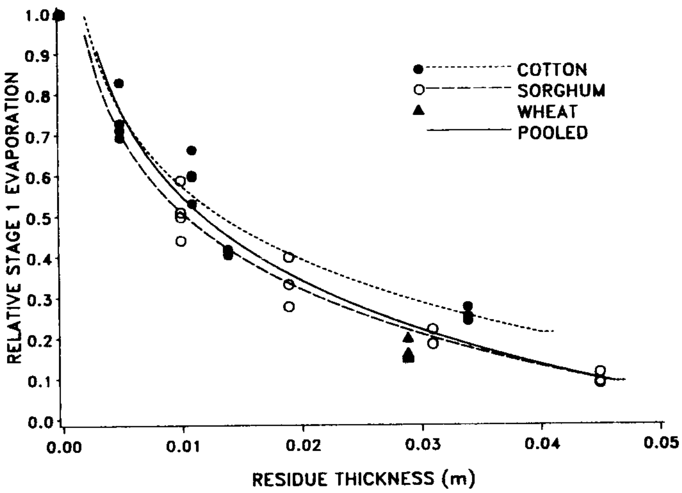

Fig. 2. Effect of residue thickness (m) on relative Stage 1 E. Equations that describe the curves are:

Cotton: $y = -0.63 - 0.261 (\ln x)$ $r^2 = 0.90, n = 14$
Sorghum: $y = -0.75 - 0.273 (\ln x)$ $r^2 = 0.93, n = 14$
Pooled: $y = -0.83 - 0.299 (\ln x)$ $r^2 = 0.91, n = 32.$

evaporating surface, as indicated by very low initial relative rates of E under high levels of residue. The response was very similar to results reported by Bond and Willis (1970) for wheat residue. Residue thickness was available for part of the data (Unger and Parker, 1976) and when the initial E rate was plotted against thickness of the residue layer (Fig. 2) the effect of the different crop types was very similar. Residue thickness, however, is seldom measured so the quantity of residues were normalized to a depth term ($m^3\ m^{-2}$) by dividing the residue amount (g m^{-2} by the crop-specific density (Mg m^{-3}) of the residue. While this depth is much smaller than the measured thickness (because the solid matter in the residue is assumed to be uniformly distributed flat on the soil surface) the different crop residues were still similarly effective in controlling the relative Stage 1 E rate (Fig. 3). With the data for all the crops fit to a single relationship, the equation that describes the residue effect on relative Stage 1 E is

$$y = -0.99 - 0.236\ (\ln x) \quad (n = 36,\ r^2 = 0.87) \quad [2]$$

where y is the relative Stage 1 E and x is the amount of residue ($m^3\ m^{-2}$). Equation [2] might provide a first estimate of the effect of crop residues other than cotton, sorghum, and wheat on E. It is important to note that Eq. [2] and the equations presented in Fig. 1 to 3 must be tested for the upper limit of 1.0. As residue levels approach zero, the equations predict relative E >1. The quantity of residue at which the equation fails depends on the residue density and is 37, 57, and 107 g m^2 for wheat, sorghum, and cotton, respectively, in Eq. [2].

DISCUSSION

Experiment 1 indicated that tillage treatments affected E and both residue and soil property effects seemed to be related to E. In a subsequent study (Exp. 2), where residues were removed from the surface, no significant tillage effects on E could be detected, leaving unanswered the question of whether tillage-induced changes in soil physical properties affects E. Tillage-related soil physical properties may have relatively subtle effects of E that are difficult to quantify. It seems quite clear from Exp. 3, however, that residues limit the energy reaching the surface that limits the relative rate of Stage 1 E in a simple logarithmic function.

To illustrate application of this relationship to the analysis of residue effects of the soil-water balance, a simple simulation example is presented. A simulation of the fallow-period water balance was conducted using the CERES model (Jones and Kinery, 1986), which uses the Ritchie (1972) soil-water balance model. Climatic data (maximum and minimum temperature, solar radiation, daily windrun, and average daily vapor pressure deficit) from the Bushland, TX, weather station from 1958 to 1986 were used to calculate the potential E rate from a bare soil. A fallow period following wheat harvest was initiated on 1 July of each year and terminated the following 1 June at the assumed time of sorghum planting. Initial available soil water (53 mm in 1.8 m) was set equal to 25% of plant available soil water. The soil constants (U and C) were 9.9 mm and 7.8 mm d^{-1}, respectively, which were the N values from Exp. 1. The published version of the model (Jones and Kinery, 1986) was changed by incorporating Eq. [2] to reduce the potential E at the soil surface as a function of residues. This assumes that effects of residues on other water balance processes (e.g., infiltration, or Stage 2 E parameters C and U) are not important and thus is a conservative estimate of the effects of residues on the soil-water balance. It also assumes that residues in the field have a similar effect on E as chopped, uniformly applied residues on soil cores.

The simulated probability distribution of soil water at the end of the fallow period as affected by residue (Fig. 4) show that 137, 153, and 182 mm of water would be stored at planting at the 50% probability level, with 100, 400, and 800 g m^{-2} of residue, respectively. The additional stored soil water can be very

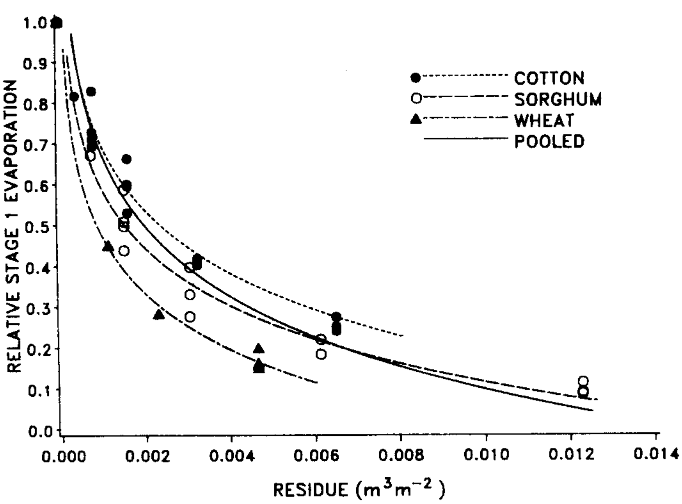

Fig. 3. Effect of residue ($m^3\ m^{-2}$) on relative Stage 1 E, assuming a specific gravity of 0.17, 0.26, and 0.49 Mg m^{-3} for wheat, sorghum, and cotton, respectively (Unger and Parker, 1976). Equations that describe the curves are:

Cotton:	$y = -0.85 - 0.223\ (\ln x)$	$r^2 = 0.95, n = 15$
Sorghum:	$y = -0.83 - 0.205\ (\ln x)$	$r^2 = 0.93, n = 15$
Wheat:	$y = -0.91 - 0.200\ (\ln x)$	$r^2 = 0.96, n = 6$
Pooled:	$y = -0.99 - 0.236\ (\ln x)$	$r^2 = 0.87, n = 36.$

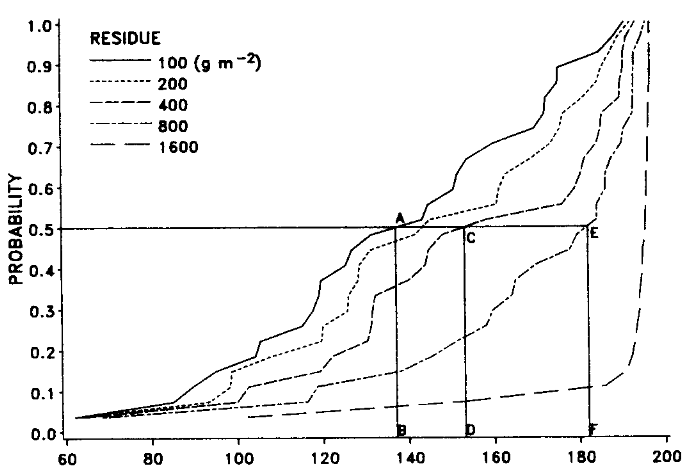

Fig. 4. Cumulative probability of available water content at planting in the 0- to 1.8-m soil depth as affected by differential crop residues during simulated fallow at Bushland, TX, 1958–1986. Lines AB, CD, and EF show soil water available at planting at the 50% probability level for 100, 400, and 800 g m^{-2}, respectively.

important in determining dryland crop yields because erratic and limited rainfall in this region often results in yield-limiting stress. Figure 4 displays characteristics consistent with field experiments described by Unger (1978) and Unger and Wiese (1979) including: (i) during very wet years or very dry years, residue amount has little effect on soil-water storage; and (ii) during average years, high residues (800 g m^{-2}) result in about 50 mm of additional soil-water storage during an 48-wk fallow period compared to low residue levels (100 to 200 g m^{-2}). With extremely high residue levels (1600 g m^{-2}), the soil-water profile is filled to maximum water holding capacity in most years. It is not practical, however, to produce such high levels of residues in field crops, and farming operations would likely be impeded. The specific outcome of this simulation is applicable only to locations in the semiarid Southern High Plains on sites with relatively low slopes and high water holding capacity soils, but simulations for other climatic regions or soil types could easily be conducted.

It is encouraging that a simple modification of the potential E calculation in a soil-water balance model produces such plausible results. While this concept had been proposed in previous studies (Bond and Willis, 1970; Van Doren and Allmaras, 1978), it had not been incorporated into a model that operates on a daily time scale with limited input requirements for soil and residue properties. Incorporating the effect of residues on E into crop-soil-climate models is essential before conducting analyses of dryland cropping systems, where the water balance between crops has a critical effect on potential crop yields. Steiner (1989) tested simulated fallow period water storage using this approach against measurements from field experiments at Bushland and presented a more detailed discussion of the application of this type of simulation to decision-making relating to fallow period management.

ACKNOWLEDGMENTS

The author appreciates the cooperation of Dr. Paul Unger, who provided unpublished evaporation data and made his rainfall simulation plots available for the evaporation study, and the technical support of Debbie Stark, Larry Fulton, Robert Bowling, and others. Reviewer comments were very helpful in preparing this manuscript for publication.

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