AGRONOMIC MODELS

Comparison of Residue Decomposition Models Used in Erosion Prediction

Harry H. Schomberg* and Jean L. Steiner

ABSTRACT

Crop residues protect soil from water and wind erosion. How long the residues remain effective depends on their decomposition rate. The crop residue decomposition submodels developed for the Revised Wind Erosion Equation (RWEQ) and Revised Universal Soil Loss Equation (RUSLE), which are used to determine the effectiveness of conservation practices, use different approaches to account for water and temperature effects on decomposition. Because of these differences, residue losses may not agree between the two models for a given location. We compared the climatic indices used in RWEQ and RUSLE to determine the similarity of results for simulated climatic scenarios, as well as for field data. Simulated climatic regimes were used to evaluate the relative responsiveness of the temperature and water functions. The two models estimated different numbers of decomposition days (DD) when water and temperature were not limiting. RUSLE usually predicted more DDs than RWEQ. Under water-limiting conditions, the estimation of DD was similar for the two models. In comparisons with field decomposition data, mass loss predictions by RWEQ were as good as or better than those by RUSLE for locations in Texas, Oregon, and Georgia. RUSLE overpredicted decomposition by 20 to 50% when residues were irrigated. RWEQ underpredicted decomposition by 20 to 50% in the Pacific Northwest. Interactions between the climatic indices (CF) and decomposition coefficients influenced the differences between measured and predicted values. Differences in the CF were related to the method of calculating the water coefficient (WC) and interpretation of the interaction between the temperature coefficient and WC. The models could be improved by developing water and temperature functions that give results closer to those produced with daily time-step functions.

Crop residues provide a protective barrier for soils against erosion by both wind and water. The effectiveness of residues in controlling soil erosion is reflected in the inclusion of residue management practices in more than 75% of conservation plans developed for Farm Program compliance (Schertz and Bushnell, 1993). In the future, evaluation of conservation plans will be made using water and wind erosion prediction technology developed by the USDA-ARS (Foster, 1991; Hagen, 1991). Estimating soil loss requires simulation of the processes affecting erodibility, including the presence of crop residues. Because the erosion protection afforded by residues diminishes as they decompose, erosion models must accurately estimate residue decomposition under field conditions. Modeling changes in crop residue amounts and orientation is therefore an integral component of soil erosion modeling.

The Revised Universal Soil Loss Equation (RUSLE) and the Revised Wind Erosion Equation (RWEQ) were developed to calculate and predict soil loss due to water and wind, respectively, using monthly climate data and empirical formulas that consider the effects of soil, crop, and management practices (Foster, 1991; Fryrear et al., 1994). In each model, the residue decomposition submodels provide information on changes in residue biomass and surface cover. Decomposition is modeled based on climate and residue chemical characteristics as controlling factors. Crop-specific decomposition coefficients account for differences in chemical and physical properties of the residues. Temperature and water functions relate climatic conditions in the field to optimum conditions in the laboratory. Climate functions lead to a decomposition day (DD) concept, much like a growing degree day, where optimum conditions produce 1 DD in a 24-h period, while less than ideal conditions produce a fraction of a DD.

The RWEQ decomposition submodel ($RWEQ_{DEC}$) uses monthly weather data as input and is similar to one developed for the Wind Erosion Prediction System (WEPS) (Steiner et al., 1995; Hagen, 1991). WEPS is a daily time-step model, but erosion predictions in RWEQ are made for each half-month. The semimonthly time step is variable in length (14, 15, or 16 d, depending on the month). Although RUSLE also uses a semimonthly time step, the decomposition model $RUSLE_{DEC}$ uses different assumptions about climatic controls than those in $RWEQ_{DEC}$ and therefore has the potential to produce different results.

The use of RUSLE and RWEQ for erosion prediction and development of conservation plans requires a degree of similarity, which should include similar predictions of decomposition for the same location. We compared the two decomposition submodels for a range of climatic conditions to identify climatic conditions where disagreement might occur and explored the underlying reasons. Surface residue losses were compared for various climatic conditions, using both simulated weather scenarios and measured results from field decomposi-

USDA-ARS, Southern Piedmont Conservation Res. Ctr., 1420 Experiment Station Rd., Watkinsville, GA 30677-2373. Received 19 Aug. 1996. *Corresponding author (hschomberg@ag.gov).

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Abbreviations: A, derived coefficient for calculating the temperature coefficient TC; CF, climatic factor; CF_{RUSLE}, climatic factor for RUSLE; CF_{RWEQ}, climatic factor for RWEQ; d, index of agreement; DD, decomposition days; k, decomposition coefficient; M_t, mass at time t; M_y, mass from the previous time; MDIF, mean difference; Q_{10}, ratio of constant rates measured at temperatures differing by 10°C; RMSE, root mean square error; RUSLE, Revised Universal Soil Loss Equation; $RUSLE_{DEC}$, Revised Universal Soil Loss Equation decomposition model; RWEQ, Revised Wind Erosion Equation; $RWEQ_{DEC}$, Revised Wind Erosion Equation decomposition model; TC, temperature coefficient; T_i, air temperature for the current period; T_{opt}, optimum temperature for decomposition; TS, time step; WC, water coefficient; WC_{RUSLE}, water coefficient for RUSLE; WC_{RWEQ}, water coefficient for RWEQ; WEPS, Wind Erosion Prediction System.

tion studies. Our objectives were to determine the sensitivity of the models to climatic conditions and to evaluate decomposition predictions against measured data for locations in the USA.

THEORY

Description of Models

The models used in this evaluation were RUSLE version 1.04 and RWEQ version 5.01. Both models predict annual erosion for a location based on combinations of factors for soil roughness, climatic conditions, soil erodibility, and management. Both RUSLE and RWEQ are improvements over the original erosion equations, USLE (Universal Soil Loss Equation) and WEQ (Wind Erosion Equation), which combined similar indices to estimate annual soil loss. The factor relationships in RUSLE and RWEQ have been improved over those in USLE and WEQ with either updated data or development of new functions based on modern erosion theory.

RUSLE and RWEQ were developed to use monthly data, because daily data would not be available for many of the locations where the models would be applied. Periodic erosion estimates are generated for a half-month period (semimonthly). The semimonthly time step allows for identification of soil condition, management, and climate interactions that may be important for reducing erosion potential. Semimonthly data are created by splitting the monthly weather input data such as rain and number of rain days. In RUSLE, air temperature for each half-month is adjusted based on the previous and following month's air temperatures; no adjustment is made in RWEQ.

Decomposition is calculated in both models using a first-order exponential mass loss equation:

$$M_t = M_y \times \exp(-k \times \mathrm{CF} \times \mathrm{TS}) \qquad [1]$$

where M_t is the quantity of biomass (kg m^{-2}) in a residue pool for the current time step, M_y is the quantity of biomass (kg m^{-2}) from the previous time step, k is a decomposition coefficient (d^{-1}) that is specific for each crop, CF is the climatic factor (i.e., a climate index) based on air temperature and water availability, and TS is the time-step length for the accounting period. The default time step is equal to the number of days in the semimonthly period for RUSLE$_{\mathrm{DEC}}$ and RWEQ$_{\mathrm{DEC}}$, but may change due to tillage operations occurring during the period.

The climatic indices attempt to account for climatic influences on decomposition using air temperature and rain data. The CF represents average decomposition conditions for the period. In RUSLE$_{\mathrm{DEC}}$, the CF is calculated as the minimum of the temperature coefficient (TC) or the water coefficient (WC):

$$\mathrm{CF}_{\mathrm{RUSLE}} = \min\,(\mathrm{TC}_{\mathrm{RUSLE}}, \mathrm{WC}_{\mathrm{RUSLE}}) \qquad [2]$$

In RWEQ$_{\mathrm{DEC}}$, the CF is calculated as the product of the two coefficients:

$$\mathrm{CF}_{\mathrm{RWEQ}} = \mathrm{TC}_{\mathrm{RWEQ}} \times \mathrm{WC}_{\mathrm{RWEQ}} \qquad [3]$$

This approach assumes that decomposition for the period is regulated by temperature on days with rain and that water is the limiting factor on other days.

The temperature coefficient equation is a modification of one used by Stroo et al. (1989) in modeling wheat (*Triticum aestivum* L.) residue decomposition. The TC value is restrained between 0 and 1, to indicate relative temperature effects on decomposition. The TC is calculated for both models as follows:

$$\mathrm{TC} = \frac{2 \times (T_i - A)^2 \times (T_{\mathrm{opt}} - A)^2 - (T_i - A)^4}{(T_{\mathrm{opt}} - A)^4} \qquad [4]$$

where T_i is the air temperature (°C) for the current period, T_{opt} is the optimum air temperature for decomposition (°C) and determines where TC = 1, and A indicates the lower limit for microbial activity and the point where TC = 0. The value of A is equal to 0°C in RWEQ$_{\mathrm{DEC}}$ and −7.8°C in RUSLE$_{\mathrm{DEC}}$; both models use a T_{opt} value of 32°C. In RWEQ$_{\mathrm{DEC}}$, TC values are calculated for the maximum and minimum air temperatures and averaged to determine the period TC. In RUSLE$_{\mathrm{DEC}}$, TC is calculated after averaging the maximum and minimum air temperatures.

Calculation of the water coefficient WC involves either the amount of rain (in RUSLE$_{\mathrm{DEC}}$) or the number of wetting events (RWEQ$_{\mathrm{DEC}}$). (More specifically, wetting events are counted as rain days: the number of days with at least one wetting event.) Both models restrain the value of WC between 0 and 1. The WC in RWEQ$_{\mathrm{DEC}}$ is calculated from the number of rain days in the period as follows:

$$\mathrm{WC}_{\mathrm{RWEQ}} = \frac{\text{rain days}}{\text{days}} \times 1.25 \qquad [5]$$

The number of rain days in a month was chosen because residues on the soil surface are subject to periods of wetting and drying, depending on the frequency and amount of rain. This also assumes that, on each day with rain, residues are sufficiently wet for optimum decomposition (given optimum temperature conditions). In developing RWEQ$_{\mathrm{DEC}}$, simulations for several locations in the Great Plains indicated that a multiplier of 1.25 is needed to produce similar DDs per period as in WEPS (Steiner and Schomberg, unpublished data, 1993). Previous results showed that residues remain moist longer than 1 d (Schreiber, 1985; Savabi and Stott, 1995), indicating that residues retain a small amount of water and the rate of evaporation is affected by soil water content near the surface. The multiplier helps account for a short drying period.

The WC for RUSLE$_{\mathrm{DEC}}$ is calculated based on the amount of rain (mm) in the period, as follows:

$$\mathrm{WC}_{\mathrm{RUSLE}} = \frac{\text{rain}}{66} \qquad [6]$$

The value of 66 was determined during calibration of RUSLE and indicates the optimum amount of rain during the semimonthly period (USDA, 1996). If the amount is greater than 66 mm, then WC is set to 1.

Simulations

Weather Scenarios

Initial evaluations of the temperature and water coefficients (TC and WC) were performed independently, to avoid confounding of the two effects. Several temperature and water regimes were considered. Evaluations were made using artificial climate scenarios that simulate a well defined spring, summer, fall, and winter progression of temperatures (Table 1). Responses of the models to the weather scenarios were determined by comparing the number of decomposition days accumulated for the simulation and by comparing the pattern of decomposition day accumulation. The variable CDD (cumulative decomposition days) is the summation of DD.

Differences due to TC were evaluated using three conditions of maximum and minimum air temperatures: (i) both

Table 1. Air temperatures and precipitation used in the ±10°C simulated climate scenarios. Various combinations of air temperatures and wetting events were used to determine the effectiveness of the climatic indices. Other temperature scenarios used the same monthly mean air temperature with ±0 and ±5°C amplitude about the mean.

	Air temperature			Uniform		Summer		Winter	
Month	Max	Min	Avg	Precip.	Events	Precip.	Events	Precip.	Events
	°C			mm	no.	mm	no.	mm	no.
Jan.	15	−5	5	100	10	50	5	200	20
Feb.	20	0	10	100	10	50	5	200	20
Mar.	25	5	15	100	10	50	5	50	5
Apr.	30	10	20	100	10	50	5	50	5
May	35	15	25	100	10	200	20	50	5
June	40	20	30	100	10	200	20	50	5
July	40	20	30	100	10	200	20	50	5
Aug.	35	15	25	100	10	200	20	50	5
Sept.	30	10	20	100	10	50	5	50	5
Oct.	25	5	15	100	10	50	5	50	5
Nov.	20	0	10	100	10	50	5	200	20
Dec.	15	−5	5	100	10	50	5	200	20

maximum and minimum set to the monthly average air temperature, (ii) air temperatures at the monthly average ± 5°C, and (iii) air temperatures at the monthly average ± 10°C. The temperature functions were also compared for their effects on the accumulation of decomposition days under wet (100 mm mo^{-1}) and dry (25 mm mo^{-1}) water regimes with uniform water distribution through the year. To isolate differences between TC calculations in both models, for this part of the evaluation both WC and CF were estimated as described for $RUSLE_{DEC}$.

For evaluating calculation of WC, we used water regimes having 25, 50, and 100 mm of rain per month occurring as 2, 5, and 10 rain-day events per month. These water regimes were chosen to represent semiarid, subhumid, and humid conditions. Both the amount of rain and the number of rain days are needed, because of the different WC functions in the two models. Air temperatures of monthly mean values ± 5°C were used in the evaluation of WC (Table 1). The TC values were calculated for both models as described for $RWEQ_{DEC}$, using maximum and minimum monthly air temperature values, and the calculation of CF was as described for each model. The effect of rain distribution through the year on decomposition prediction was evaluated using uniform, summer, or winter rain patterns (Table 1).

Additionally, the models were evaluated against measured residue mass loss data from Bushland, TX; Pullman, WA; Pendleton, OR; and Griffin, GA. These locations represent a range of decomposition conditions and data were available for decomposition of wheat from each location. Because $RWEQ_{DEC}$ and $RUSLE_{DEC}$ run on semimonthly time steps using monthly weather data as input, measured daily weather data from the field studies were averaged for 30-d periods and simulations were conducted with 15-d time steps. When field observations occurred on a date within the 15-d time step, calculations of mass remaining for that date were estimated by interpolation. Model predictions were evaluated using both graphical and statistical analysis procedures. The mean difference between measured and calculated values, root mean square error, and lack of fit tests were used for statistical evaluations of the models (Addiscott and Whitmore, 1987; Whitmore, 1991). Additionally, an index of agreement (d) as described by Willmott (1981) was used. The index of agreement is scaled from 0 to 1, with 1 indicating perfect agreement between modeled and measured data. Data were analyzed using the Statistical Analysis System (SAS Inst., 1989). The default decomposition coefficients (k) used for alfalfa (*Medicago sativa* L.), corn (*Zea mays* L.), sorghum [*Sorghum bicolor* (L.) Moench], soybean [*Glycine max* (L.) Merr.], and wheat in RWEQ were 0.053, 0.010, 0.010, 0.030, and 0.013, respectively. In RUSLE, alfalfa, corn, sorghum, soybean, and wheat k-values were 0.020, 0.016, 0.016, 0.025, and 0.008, respectively. Additionally, RUSLE sets the coefficient to 0.017 for wheat in the Pacific Northwest.

Field Data

Decomposition of residues in field environments was measured by determining the mass loss between sampling periods. For most locations, residues were collected at harvest and then placed in mesh bags made from fiberglass window screen material. The number of bags placed in the field initially was large enough to allow an adequate number to be removed at each sampling date. At Pullman, WA, the residue was collected as grab samples. Mass of the field-sampled residue was corrected for accumulated soil using ash content of a subsample.

Bushland, TX (1991). Decomposition of alfalfa, grain sorghum, and winter wheat residues in fiberglass mesh bags was determined at Bushland, TX, from May 1990 to May 1991 (Schomberg et al., 1994). Residues were placed on the soil surface and a line-source sprinkler system provided five water regimes (336, 287, 166, 60, and 5 mm yr^{-1}, with rain contributing an additional 305 mm). Rain, including irrigation, and air temperature for the highest and lowest irrigation treatments were used for the evaluations.

Bushland, TX (1992). Schomberg and Steiner (1997) evaluated decomposition of alfalfa, corn, sorghum, spring wheat, and winter wheat residues at Bushland, TX, from July 1991 to August 1992. Residues in fiberglass mesh bags were placed on the soil surface of no-till small-grain residue plots during the fallow period. Three flood irrigation treatments were used during the decomposition period. Full irrigation received approximately 50 mm water applied every 7 to 12 d during the fall, spring, and summer months; the second irrigation treatment consisted of irrigating on alternate dates, in contrast to the full irrigation treatment; the third treatment was not irrigated and is designated dryland. The study is further described in Steiner et al. (1994).

Pullman, WA. Stott et al. (1990) presented data on decomposition of wheat residue at Pullman, WA, for 1983, 1984, and 1985. Grab samples were collected from random sites within no-tillage wheat residue plots periodically during the year following wheat harvest.

Pendleton, OR. Douglas et al. (1980) placed wheat straw residue containing 0.19, 0.49, and 0.78% N in mesh bags on the soil surface and suspended above the soil surface on a wooden frame at Pendleton, OR. Mass loss was monitored from July 1976 to November 1978. In our evaluation, we used

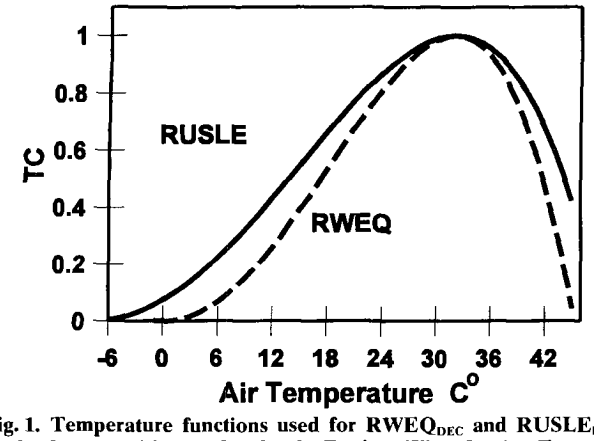

Fig. 1. Temperature functions used for $RWEQ_{DEC}$ and $RUSLE_{DEC}$, the decomposition models for the Revised Wind Erosion Equation and the Revised Universal Soil Loss Equation. Differing values of the coefficient *A* in the two models result in the different lines.

only the data for the surface-placed wheat residue containing 0.78% N.

Griffin, GA. Decomposition of wheat and soybean residue in a double crop, no-till system near Griffin, GA, was determined by Ford (1991). Residues were collected at harvest and placed on the soil surface in fiberglass mesh bags following planting of the subsequent crop. Samples were collected from the plots after 1, 2, 4, 8, and 16 wk. Wheat residues were in the field from 22 June 1988 to 14 Oct. 1988 during soybean growth. Soybean residues were in the field from 11 Nov. 1988 to 12 Mar. 1989 during growth of crimson clover (*Trifolium incarnatum* L.) and rye (*Secale cereale* L.) cover crops.

RESULTS AND DISCUSSION

Evaluation of the Temperature Coefficient TC

Even though $RUSLE_{DEC}$ and $RWEQ_{DEC}$ use the same function (Eq. [4]) for calculation of the temperature coefficient TC, the use of different *A*-values (−7.8 vs. 0) in the calculation affects the shape of the temperature function and the range over which decomposition occurs (Fig. 1). Use of average vs. maximum and minimum air temperatures to calculate TC creates further differences, particularly for extreme temperature periods. $RWEQ_{DEC}$ calculates a TC value for the minimum and maximum air temperatures before averaging. Both the minimum and maximum air temperatures must be near 30°C to produce a TC value near 1. $RUSLE_{DEC}$ uses average air temperature, which results in minimum and maximum air temperatures as different as 22 and 38°C giving a TC value of 1. As an example, using data from Table 1, in $RWEQ_{DEC}$ TC for June is 0.65 (TC at 40°C = 0.68; TC at 20°C = 0.63), while the value for $RUSLE_{DEC}$ is 0.99. A smaller difference is apparent at the low air temperature minimum in December, where the TC value for $RUSLE_{DEC}$ is 0.168 and for $RWEQ_{DEC}$ is 0.196.

A comparison of TC for a wet and a dry water regime is presented in Fig. 2. Under the wet regime, DDs accumulated at a faster rate in $RUSLE_{DEC}$, except for Months 1, 2, 11, and 12. The number of DDs accumulated in $RWEQ_{DEC}$ was limited by TC for the entire year, since the line for TC is below that of WC; in $RUSLE_{DEC}$, WC controlled estimation of DD only during the summer period. In the dry scenario, where WC was always the limiting factor, differences between the temperature functions were minimal, and both models calculated the same number of cumulative DDs (Fig. 2).

Seasonal rain distribution further illustrates how differences in the calculation of TC interacts with WC to accentuate differences in the estimation of DD by the two models (Fig. 3). For the winter rain regime (Fig. 3), both models predict a similar number of DDs; this is comparable to previous results, where water limited decomposition in the dry regime through the year (Fig. 2). In the winter scenario, patterns of air temperature and water availability were discordant, resulting in a

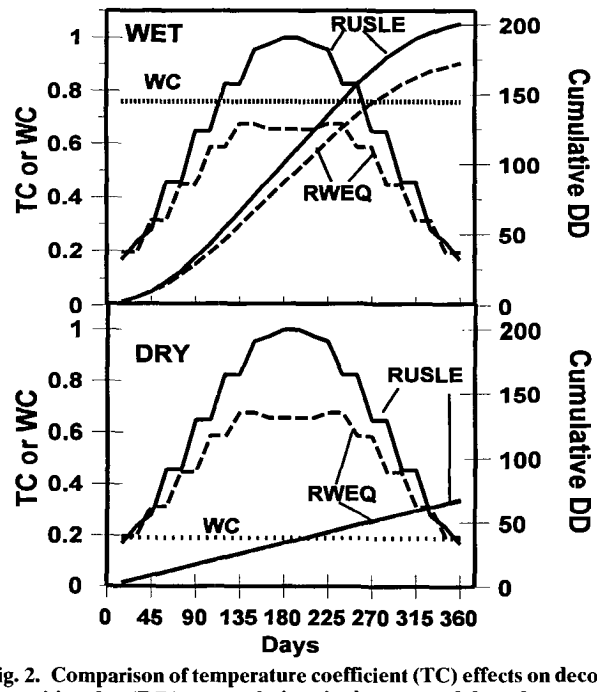

Fig. 2. Comparison of temperature coefficient (TC) effects on decomposition day (DD) accumulations in the two models under wet and dry water scenarios, using 15-d semimonthly time steps. WC, water coefficient. The number of DDs accumulated faster for $RUSLE_{DEC}$ than for $RWEQ_{DEC}$.

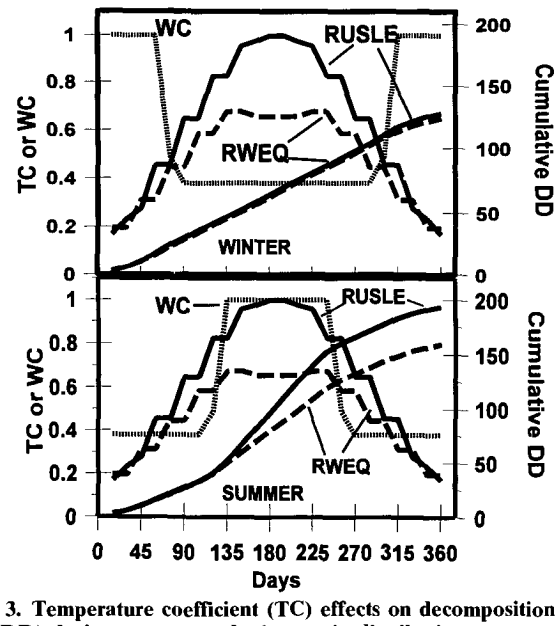

Fig. 3. Temperature coefficient (TC) effects on decomposition days (DD) during summer and winter rain distribution patterns. WC, water coefficient. Modeled values vary for the summer rain pattern, but are similar for the winter pattern.

small number of DDs. Accumulation of DDs was limited by TC during the wet, cold months and by WC during the dry, warm months, indicating that decomposition in this environment will be slow due to limited climatic resources. The rapid increase in DDs in the summer rain scenario illustrates the combined effects of warm temperatures and adequate water availability on decomposition. Both models exhibit the seasonality of the summer rain regime; however, the $RUSLE_{DEC}$ climatic function generates more DDs than the function in $RWEQ_{DEC}$ and could potentially predict greater decomposition.

Evaluation of the Water Coefficient WC

Some important differences between the two models for use of rain in calculations of the climatic index CF are illustrated in Fig. 4. Uniform rain distributions are compared in Fig. 4, where 50 mm or 5 events per 15 d represents a wet regime and 12.5 mm or 1 event per 15 d represents a dry regime. In $RUSLE_{DEC}$, WC is a function of the amount of rain; therefore, changing the number of events has no effect on model response. In $RWEQ_{DEC}$, WC is a function of the number of rain days; therefore, the amount of rain has no effect on model response. Surprisingly, the number of DDs predicted by $RUSLE_{DEC}$ for the dry regime was equal to the number predicted by $RWEQ_{DEC}$ for the wet regime.

Water regime effects are further examined in Fig. 5, using a wet regime with the uniform, winter, or summer rain distributions from Table 1. For the summer and uniform distributions, both models show similar patterns of DD accumulation, but a somewhat contrasting pattern was observed between the models for the winter regime. Overall, $RUSLE_{DEC}$ accumulates more DDs and at a faster rate than $RWEQ_{DEC}$ for all three weather scenarios. Although some of the difference may be related to the number of days (10 d mo^{-1}) or amount of rain (100 mm mo^{-1}) chosen to represent a wet regime, these results indicate that differences between the models will depend on the distribution and quantity of rain.

Measured vs. Predicted Biomass Loss

It is difficult to determine the best approach for modeling residue decomposition based only on the evaluation of climatic factors. The climatic factor analysis indicates that the two models accumulate decomposition units at different rates, which can lead to different mass loss estimates. Prediction of decomposition with Eq. [1] depends on a time component (in this case, DD) and a crop-specific decomposition rate (k). Model comparisons were further evaluated using field studies on crop residue decomposition from Texas, Washington, Oregon, and Georgia. Wheat residue was used in each study, which allows for comparison of model performance among locations.

Bushland, TX (1991). Differences in decomposition predictions between the models were not consistent across crops for the 1991 Bushland study (Table 2). The accuracy of the predictions for the three residues and two irrigation regimes can be evaluated with the statistics in Table 2. Predicted and measured mass loss for wheat residue at Bushland are presented in Fig. 6. Mass loss predictions by $RUSLE_{DEC}$ for all three crops were about 10% better for the low irrigation treatment than for the high irrigation treatment, as indicated by the d-values (Table 2). Mass loss predictions by $RWEQ_{DEC}$ were variable across the high and low irrigation treatments. The d-values in Table 2 indicate that $RWEQ_{DEC}$ predictions were best for wheat and alfalfa in the low irrigation treatment, but were best for sorghum in the high irrigation treatment. The variable results from the two irrigation treatments for $RWEQ_{DEC}$ probably is the result of the default k-value for sorghum and the

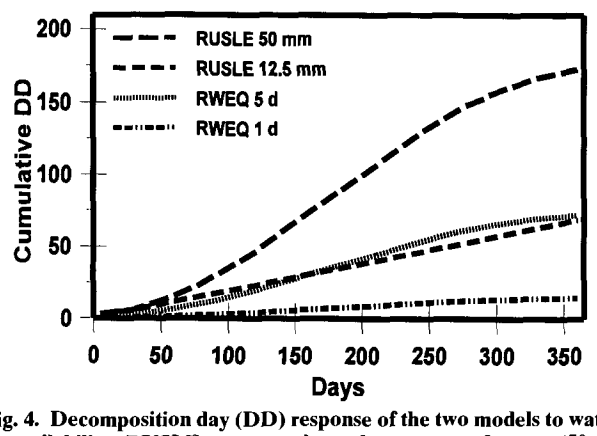

Fig. 4. Decomposition day (DD) response of the two models to water availability. $RUSLE_{DEC}$ responds to the amount of water (50 vs. 12.5 mm in 15 d), while $RWEQ_{DEC}$ responds to the number of rain-day events (5 vs. 1 d with rain in 15 d).

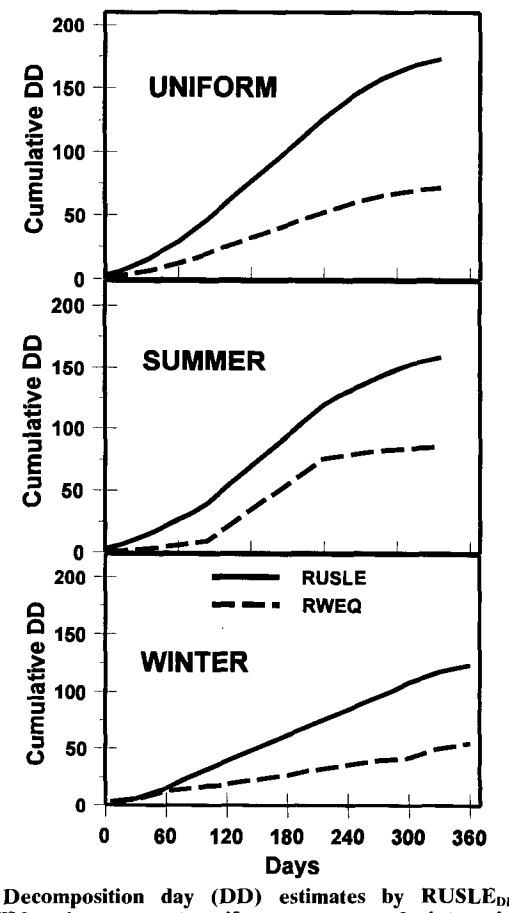

Fig. 5. Decomposition day (DD) estimates by $RUSLE_{DEC}$ and $RWEQ_{DEC}$ in response to uniform, summer, and winter rain distributions.

Table 2. Statistics for decomposition values predicted with the $RUSLE_{DEC}$ and $RWEQ_{DEC}$ models vs. measured data from a field study at Bushland, TX (1991).

Crop and moisture regime†	MDIF‡	SE (±)	R	RMSE	MLOFIT	F§	d
$RUSLE_{DEC}$							
Alfalfa 1	15.3	0.6	0.99	15.5	619	103.8	0.88
Alfalfa 5	−1.7	1.1	0.98	5.0	33	1.7NS	0.99
Sorghum 1	40.7	2.3	0.87	42.0	4565	109.4	0.53
Sorghum 5	27.8	3.2	0.83	31.2	2486	60.5	0.63
Wheat 1	20.2	1.6	0.92	21.3	1122	23.2	0.74
Wheat 5	9.1	1.3	0.92	10.9	270	10.2	0.84
$RWEQ_{DEC}$							
Alfalfa 1	−21.6	1.1	0.98	22.2	1287	215.5	0.77
Alfalfa 5	−14.3	2.3	0.98	17.6	788	39.7	0.85
Sorghum 1	4.3	1.8	0.91	9.2	156	3.7	0.92
Sorghum 5	15.8	1.8	0.82	17.8	763	18.6	0.69
Wheat 1	−8.6	2.2	0.93	13.1	370	7.6	0.78
Wheat 5	0.5	1.2	0.91	5.4	33	1.2NS	0.92

† Irrigation treatments: 1, wet; 5, dryland.
‡ MDIF, mean difference; SE, standard error of MDIF; R, correlation coefficient; RMSE, root mean square error; MLOFIT, mean square due to lack of fit; F, lack of fit F-ratio; d, index of agreement.
§ F-values were significant at $P < 0.05$ (except as noted by NS).

interaction with WC. Overprediction of sorghum decomposition by $RUSLE_{DEC}$ at both irrigation levels, indicated by the positive MDIF, was most likely due to the k-value used in Eq. [1], because the measured pattern of mass loss was followed closely in the simulation (R = 0.87 and 0.83). Variations in residue quality can affect the rate of decomposition, causing deviation from model predictions made using default decomposition coefficients.

Bushland, TX (1992). Differences among the water regimes at Bushland in 1992 were not significant, so comparisons were made with combined data (Table 3). The mass loss predictions were closer to the measured values for $RWEQ_{DEC}$ than for $RUSLE_{DEC}$ for all the residues except alfalfa, as indicated by the smaller MDIF and RMSE (Table 3). Predictions of mass loss from alfalfa were similar for the models, as indicated by close agreement for the MDIF, RMSE and d-values. In most cases, the measured mass loss was simulated closely by $RWEQ_{DEC}$, with some small underprediction or overprediction depending on the crop. On the other hand, $RUSLE_{DEC}$ generally overpredicted mass loss. In the original analysis against the individual irrigation treatments, predictions by $RUSLE_{DEC}$ improved as treatments became drier from the full irrigation to the dryland treatment (data not shown). The water function in $RUSLE_{DEC}$ is based on the amount of water applied and may have overcredited the WC value for the surface irrigation used in this study. Figure 7 shows the response of the two models for prediction of winter wheat residue in the full irrigation treatment.

Pullman, WA. Mass remaining of wheat residue was seriously overpredicted by RWEQ for the three years (Fig. 8). The predictions by $RUSLE_{DEC}$ were good; however, an alternate coefficient is used in RUSLE for the Pacific Northwest. Mass loss was closely simulated by $RUSLE_{DEC}$, as indicated by the small RMSE and large d-values (Table 4). Not enough data were available for a lack of fit test, but other indicators are presented in Table 4. $RWEQ_{DEC}$ overpredicted mass remaining (negative MDIF) with a relative accuracy of 50%, as indicated by the d-values. Deviations of predicted from measured data were greater for $RWEQ_{DEC}$ than for $RUSLE_{DEC}$, as shown by the MDIF and d-values. Predic-

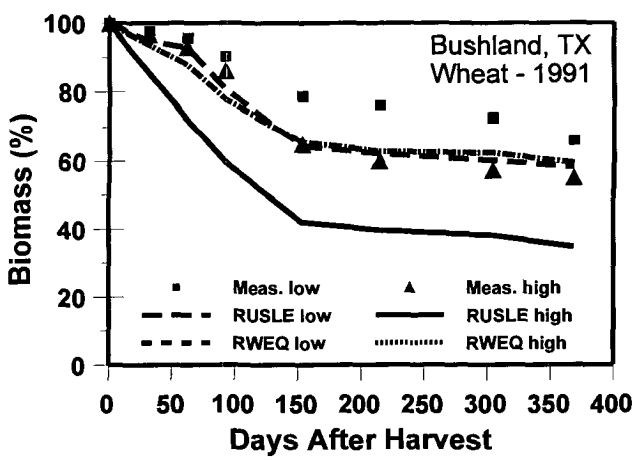

Fig. 6. Measured and predicted wheat residue mass loss in low and high irrigation treatments at Bushland, TX (data from Schomberg et al., 1994). The $RWEQ_{DEC}$ lines for the low and high irrigation treatments are the same, because the model responds to the number of rain days, not the amount of water.

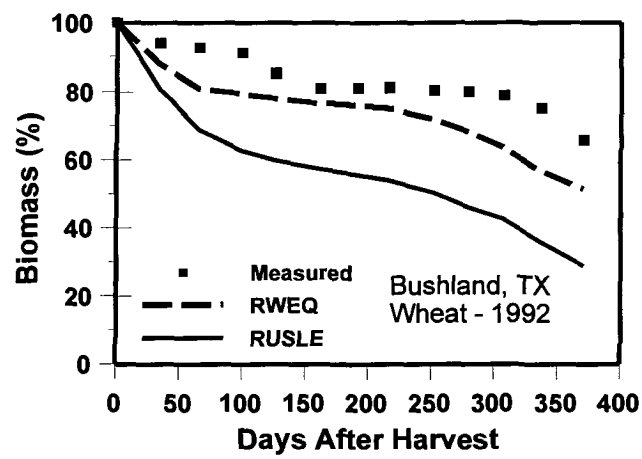

Fig. 7. Measured and predicted wheat residue mass loss in the high irrigation treatment at Bushland, TX (data from Schomberg and Steiner, 1997).

Table 3. Statistics for decomposition values predicted with the $RUSLE_{DEC}$ and $RWEQ_{DEC}$ models vs. measured data from a field study at Bushland, TX (1992).

Crop†	MDIF‡	SE (±)	R	RMSE	MLOFIT	F§	d
$RUSLE_{DEC}$							
Alfalfa	10.2	1.2	0.82	15.7	2 048	88.8	0.71
Corn	31.9	1.4	0.67	34.9	10 698	328.2	0.39
Sorghum	26.1	1.2	0.79	28.8	7 248	257.1	0.49
Spring wheat	10.8	1.1	0.69	15.5	1 789	39.8	0.68
Winter wheat	19.8	1.1	0.66	23.0	4 425	126.1	0.50
$RWEQ_{DEC}$							
Alfalfa	9.7	0.8	0.85	12.9	1 316	57.1	0.75
Corn	−7.8	0.6	0.75	10.2	680	20.8	0.73
Sorghum	−13.7	0.6	0.84	14.8	1 758	62.3	0.63
Spring wheat	−2.5	0.7	0.74	7.7	167	3.7	0.85
Winter wheat	6.5	0.7	0.72	9.7	561	16.0	0.76

† Data combined across three irrigation treatments.
‡ MDIF, mean difference; SE, standard error of MDIF; R, correlation coefficient; RMSE, root mean square error; MLOFIT, mean square due to lack of fit; F, lack of fit F-ratio; d, index of agreement.
§ F-values were significant at $P < 0.01$.

tion of slower decomposition by $RWEQ_{DEC}$ at this location may be related to the type of wheat, or to greater microbial activity during cool periods than is predicted. The prediction of slower decomposition may also be due to the use of air temperature, which would be lower than soil surface temperatures during periods of snow cover. Also the models may not be adequately responsive for low temperatures. Kirschbaum (1995) found a greater sensitivity of decomposition to temperature changes at cold temperatures than at warmer temperatures, as illustrated by changes in Q_{10} from near 8 at 0°C to 4.5 at 10°C and to 2.5 at 20°C. Therefore, decomposition at low temperatures may change at a greater rate than is simulated by the relationship used in $RUSLE_{DEC}$ and $RWEQ_{DEC}$ for cold environments.

Pendleton, OR. Mass loss predictions by the two models were similar for wheat at the Pendleton location (Fig. 9). For this location, k was set equal to the standard value (0.008) for $RUSLE_{DEC}$. There were not enough data to evaluate the models with a lack of fit test, but other data are presented in Table 4. The analysis indicates a smaller MDIF and larger d-value for $RWEQ_{DEC}$, but both models overpredicted decomposition at the end of the study (Fig. 9).

Griffin, GA. Predictions of mass loss at Griffin, GA, were affected by season and crop (Table 4). Predictions of soybean mass loss were about 30% better with $RUSLE_{DEC}$ than with $RWEQ_{DEC}$ (d-value, Table 4). The poor prediction of soybean mass loss by $RWEQ_{DEC}$ was probably due to the default k-value, since the pattern of mass loss was closely simulated. The underprediction (negative MDIF) may also have been due to underprediction of DD during the winter period. During this time, rain exceeds soil water evaporation and the soybean residues probably remained wet for periods longer than those estimated in $RWEQ_{DEC}$. Both $RWEQ_{DEC}$ and $RUSLE_{DEC}$ accurately predicted wheat mass loss (Table 4; Fig. 10). Comparisons of the d-value, MDIF, and RMSE indicate close agreement between the two models for wheat at this location.

Differences between model predictions and between predicted and measured data for the field studies can be attributed to three main factors. They are (i) the climatic indices used in calculation of DD, (ii) the decomposition coefficients, and (iii) variability of mass loss data for residues collected in field studies. Estimation of WC probably has the greatest influence on predictions, because using monthly data limits the simulation of residue wetting and drying dynamics. The use of average

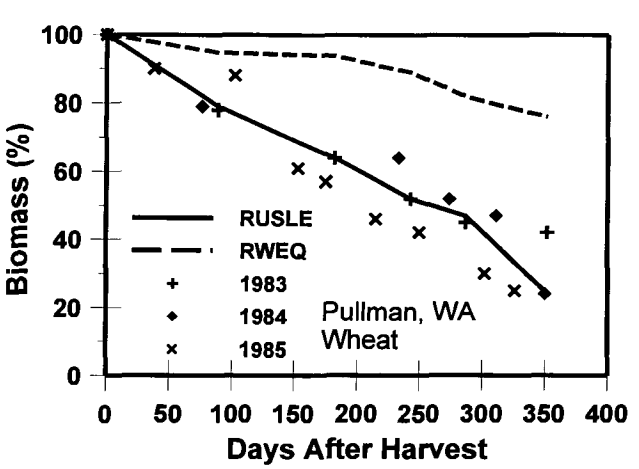

Fig. 8. Measured and predicted wheat residue mass loss at Pullman, WA, for 3 yr (data from Stott et al., 1990).

Table 4. Statistics for decomposition values predicted with the $RUSLE_{DEC}$ and $RWEQ_{DEC}$ models vs. measured data from field studies at Pullman, WA (3 yr), Pendleton, OR, and Griffin, GA.

Model†	MDIF‡	SE (±)	R	RMSE	d
Pullman, WA: Wheat					
RUSLE, 1983	−1.2	2.6	0.96	5.8	0.97
RWEQ, 1983	−33.8	5.9	0.95	35.8	0.48
RUSLE, 1984	−3.3	3.9	0.93	8.4	0.93
RWEQ, 1984	−31.1	6.5	0.96	33.7	0.49
RUSLE, 1985	−6.1	3.2	0.97	9.3	0.92
RWEQ, 1985	−34.7	6.3	0.94	38.6	0.52
Pendleton, OR: Wheat					
RUSLE	8.69	4.4	0.99	12.4	0.88
RWEQ	3.92	2.9	0.98	7.0	0.95
Griffin, GA: Soybean					
RUSLE	−2.3	3.6	0.92	8.6	0.94
RWEQ	−17.7	5.3	0.94	21.3	0.60
Griffin, GA: Wheat					
RUSLE	6.9	1.8	0.96	8.1	0.91
RWEQ	4.7	1.4	0.98	5.6	0.96

† RUSLE, Revised Universal Soil Loss Equation; RWEQ, Revised Wind Erosion Equation.
‡ MDIF, mean difference; SE, standard error of MDIF; R, correlation coefficient; RMSE, root mean square error; d, index of agreement.

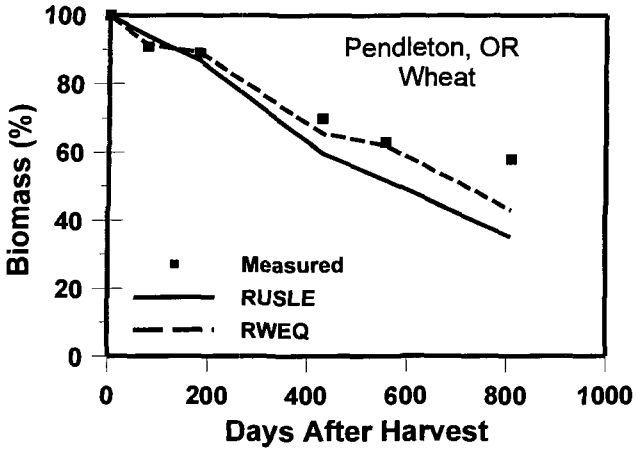

Fig. 9. Measured and predicted biomass loss from winter wheat at Pendleton, OR (data from Douglas et al., 1980).

monthly data eliminates the amount-per-event rain information that could be used to improve the WC function. The effect of WC on decomposition is most notable for the irrigation studies from Bushland, TX. The *k*-values in $RWEQ_{DEC}$ and $RUSLE_{DEC}$ were determined from data in the literature. However, there is a shortage of information on decomposition of mature crop residues under field or laboratory conditions for developing values of DD and *k*. Additionally, the variability in mass loss measurements from field studies affects the accuracy of the *k*-values. Mass loss varied 20 to 30% at Bushland, TX, but only 10 to 15% at Melfort, SK (Schomberg et al., 1996). Data on residue decomposed to <50% are difficult to collect, because the residues become fragile and soil contamination increases with time. These problems may be responsible for some of the differences between measured and predicted values. The combination of these factors will limit the accuracy of mass loss predictions with these models.

CONCLUSIONS

Our comparisons of $RWEQ_{DEC}$ and $RUSLE_{DEC}$ point to a number of environments and situations where models performance will differ. However, choosing between the models may not be the best solution. The models perform adequately for most situations, considering the large time step used in RUSLE and RWEQ. There is an obvious need to improve the water coefficient in both models. The artificial weather scenarios showed the greatest differences between the models due to WC. This was also a factor in differences between predicted and measured data for the field studies where irrigation was a treatment. A limiting factor in the WC calculation is the use of monthly weather data, which eliminates the per-event information available with daily weather data. An index that incorporates both rain amount and number of rain days should be an improvement.

A joint project between the RUSLE and RWEQ modeling teams was initiated in 1995 to address differences between the two models. Emphasis is being placed on common environmental scaling factors, which will allow use of the same decomposition coefficients in both models. The team has recently developed a method for calculating the temperature coefficient to produce values closer to those calculated with a daily time step. Continued teamwork should produce more robust decomposition and erosion predictions.

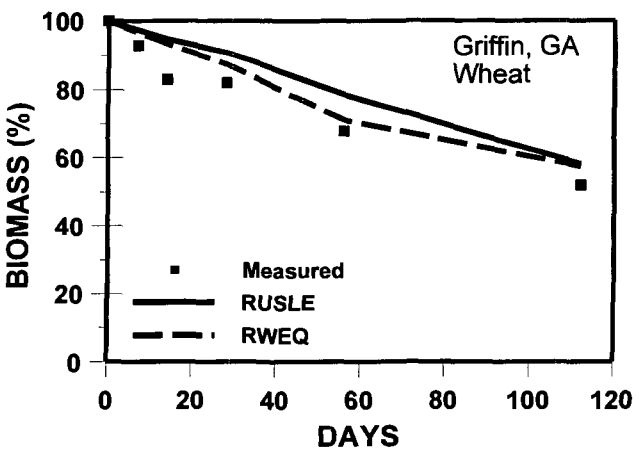

Fig. 10. Measured and predicted mass loss from wheat residue at Griffin, GA (data from Ford, 1991).

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