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Climatic Influence on Residue Decomposition Prediction in the Wind Erosion Prediction System

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With 8 Figures

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Summary

The effectiveness of crop residues to protect the soil surface and reduce soil erosion decreases as residues decompose. The rate of residue decomposition is directly related to the temperature and moisture regimes of the residues. Predicting changes in residue mass, orientation, and soil cover requires the use of functions that relate changes in decomposition rates to changes in the temperature and water regimes. Temperature and water functions used in the residue decomposition submodel of the Wind Erosion Prediction System (WEPS) were evaluated for their effects on predictions of residue decomposition. A precipitation function (PC) was found to produce relatively more accurate estimates of decomposition than a near surface soil water content function (SWC) for describing water regime effects. The estimated accuracies of the two functions were similar when bias in the estimation was considered. Predictions made with PC had estimated accuracies of ±11.4, 14.5, 13.5% for alfalfa, sorghum and wheat, respectively, while those made with SWC had estimated accuracies of ±13.8, 16.2, and 16.9%, respectively. Three temperature functions were compared for use in predicting residue decomposition over a range of locations and crops. There was little difference between the temperature functions over all the locations but, for several locations, one function overpredicted decomposition more often than the other two functions. Accuracies ranged from ±4 to ±51% of the observed values. The highest values were obtained at one location, and all three temperature functions produced similar high values. Over most of the data, estimated accuracies were generally between ±15 and ±25%. The prediction intervals were similar to those observed for decomposition of surface-placed residues. This evaluation indicates that the temperature and water functions used in the WEPS decomposition submodel will give reasonable estimates of mass loss from surface residues using easy-to-obtain weather data.

1. Introduction

Residue management is critical to soil and water conservation because residues remaining on the soil surface directly influence soil temperature, water infiltration, erosion, runoff, and evaporation. The goal of residue management is to maintain sufficient residue on the surface to minimize soil erosion while providing conditions for optimum crop growth. Conservation programs focusing on limiting soil loss from agricultural land have increased the use of reduced tillage systems and reliance on crop residue for controlling soil erosion. However, decomposition of residue alters its effectiveness. Predicting these changes requires an understanding of how climatic factors interact in controlling rates of residue decomposition.

New water and wind erosion prediction technology is under development by the Agriculture Research Service (ARS) of the United States Department of Agriculture to predict soil loss from agricultural areas on a daily basis (Foster, 1991; Hagen, 1991). The Wind Erosion Prediction System (WEPS) is composed of several submodels that describe soil, crop, atmospheric, and erosion processes (Hagen, 1991). The residue decomposition submodel of WEPS provides information on changes in orientation, biomass, and surface cover from residues. Submodel development focused on improving predictions of standing and surface residue losses using components of existing decomposition models (Steiner et al., 1994).

Temperature and water functions have been used frequently in models of soil biological activity to relate relative rates of microbial activity (decomposition) in the field to those under controlled conditions (Stroo et al., 1989; Van Veen and Frissel, 1981). Steiner et al. (1994) used decomposition days, based on the minimum of a temperature or water function, for predicting changes in orientation of standing residues. We have used the same functions in the residue decomposition submodel for prediction of biomass loss from standing, surface, and buried residues. This study was undertaken to evaluate the appropriateness of these functions over a range of conditions to determine if predictions are acceptable. We evaluated the water- and temperature-based functions for their effect on prediction of decomposition of several crops under various conditions.

2. Materials and Methods

The residue decomposition submodel of WEPS predicts biomass loss with a first order decay equation,

$$M_t = M_0 \exp(-k * \mathrm{CDD}), \tag{1}$$

where M_t, mass (kg) remaining at time t, is predicted based on M_0, the initial mass (kg), cumulative decomposition days (CDD), and k, a crop specific decomposition rate coefficient (DD^{-1}) Decomposition days (DD) are accumulated as the minimum of a temperature or water function for each day,

$$\mathrm{DD} = \min(\mathrm{TC}, \mathrm{WC}), \tag{2}$$

where TC is the temperature coefficient and WC is the water coefficient used to describe microbial activity on relative scales of 0 to 1. By constraining the temperature and water coefficients from 0 to 1, with 1 indicating optimum conditions for microbial activity and 0 indicating no microbial activity, decomposition days relate decomposition in the field to an equivalent period under controlled conditions (Stroo et al., 1989; Stott et al., 1988; Steiner et al., 1994).

2.1 *Water Function Evaluation*

We compared the use of a precipitation-based index and a soil water content-based index for estimating WC, the function relating water availability to decomposition of surface residues. The precipitation-based index (PC) was taken from the Water Erosion Prediction Project version 91.5 (Arnold et al., 1991) and was developed based on the assumption that 4 mm of rainfall is required to fully wet residues on the soil surface and that greater amounts move through the residue to the soil surface (Stott et al., 1988; Schreiber, 1987; Savabi and Stott, 1995). Estimation of PC was as follows,

$$\mathrm{PC} = \mathrm{rain}/4, \quad \text{if rain } \leqslant 4 \tag{3}$$

$$\mathrm{PC} = 1, \quad \text{if rain } > 4 \tag{4}$$

where rain is the precipitation depth in mm from rain, snow, or other forms of precipitation, with 4 mm considered to saturate the surface residues. PC is constrained to 1 when rain is greater than 4 mm. The WC is then set equal to PC. A residual water effect on decomposition is estimated by decrementing WC by a lag factor (PPTLAG) that accounts for gradual drying of residues following a rain. Heilman et al. (1992) showed that the water content of wheat residue on the soil surface decreased by approximately 50% each day following irrigation. To approximate this effect, each precipitation event is allowed to influence the water coefficient (WC) over several days, as follows:

$$\mathrm{WC}_t = \mathrm{PC}_{t-1} * \mathrm{PPTLAG} + \mathrm{PC}_t, \tag{5}$$

where PC from the previous day, $t-1$, is multiplied by PPTLAG and is added to the PC value calculated for the current day, t, with WC_t constrained between 0 and 1. The value for PPTLAG was set to 0.5 based on the data of Heilman et al. (1992). Steiner et al. (1994) used the PC index and precipitation lag in the development of a method to predict persistence of standing residues.

A second water coefficient based on the water content of the near surface soil water content was also considered for relating water availability to residue decomposition. Our assumption in using this index was that the residue water content should be in close equilibrium with the soil surface water content. The soil water coefficient (SWC) was calculated as follows:

$$SWC = \Theta_{0-5}/\Theta_{opt}, \quad (6)$$

where Θ_{0-5} was the soil water content for the 0–5 mm soil depth and Θ_{opt} is the optimum soil water content for microbial activity (−30 kPa).

The two methods for determining WC were compared to determine if the more easily determined PC function was adequate for prediction of surface residue decomposition. Decomposition data for alfalfa (*Medicago sativa* L.), grain sorghum [*Sorghum bicolor* (L.) Moench], and winter wheat (*Triticum aestivum* L.) residues in fiberglass mesh bags were used for the comparison (Schomberg et al., 1994). Residues were in the field from May 1990 to May 1991 on the surface of a Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll) at Bushland, TX. A line-source sprinkler system provided five irrigation water regimes (336, 287, 166, 60, and 5 mm yr^{-1}) and precipitation contributed an additional 305 mm of water to each plot. Dry weights were reported on an ash-free basis to account for soil remaining after cleaning of the residues.

Daily soil water content for bare soil conditions was estimated using ENWATBAL (Evett and Lascano, 1993), a mechanistic one-dimensional model of evapotranspiration. Estimates were made for each of the water regimes using 30 min measurements of wind speed, air temperature, dew point temperature, relative humidity, global radiation, barometric pressure and precipitation collected from a weather station approximately 2 km from the decomposition study. The bare soil model was used because conditions of the experiment closely resembled those of a bare soil (less than 30% ground cover). The ENWATBAL soil water content predictions were significantly correlated with gravimetric soil samples taken frequently at 0–2.5 and 11–13 cm depths during the experiment. Additionally, ENWATBAL was validated for conditions at Bushland, TX, against data from large weighing lysimeters and was considered to give reliable estimates of the soil profile water content near the surface.

In the water function evaluation, the temperature function of Steiner et al. (1994), described in the following section, was used. Optimum temperature for microbial activity was considered to be 33 °C.

2.2 *Temperature Function Evaluation*

Three functions for calculating the temperature coefficient (TC) were compared for determining decomposition days (Fig. 1). The first function was developed by Stroo et al. (1989) for use in a model to predict decomposition of wheat residues. The value is calculated as follows:

$$TC = 1.32 * \frac{2*(T-A)^2*(T_{opt}-A)^2 - (T-A)^4}{(T_{opt}-A)^4}, \quad (7)$$

where T is the average daily temperature (°C), T_{opt} is the optimum temperature for microbial activity (33 °C), and A is the minimum temperature (−6.1 °C). Optimum conditions for decomposition are considered to occur between 22 and 41 °C. The second function evaluated was a modification of the Stroo et al. (1989) function used by Steiner et al. (1994) to predict changes in small grain residue orientation from standing to flat. They set the A value to 0 to eliminate prediction of microbial activity below 0 °C and dropped the multiplication factor of 1.32. For both the Stroo and Steiner functions TC is set equal to 0 when temperatures are below A. The function of van Veen and Frissel (1981) was also considered since it had been used to model organic C dynamics in grassland soils (van Veen and Paul, 1981). The

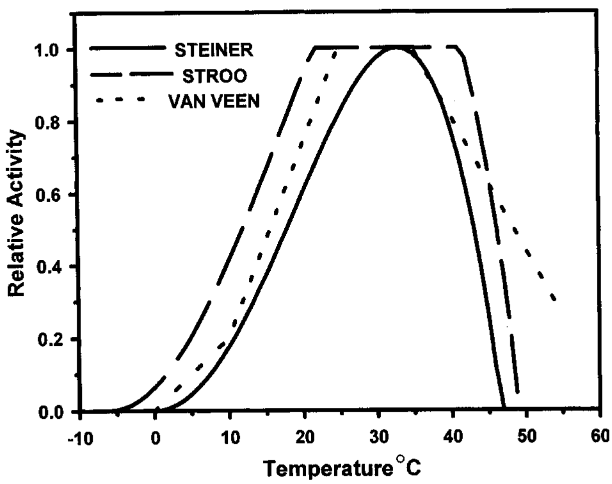


Fig. 1. Temperature functions compared for calculating decomposition days

function was estimated as follows:

$$TC = 0 \quad \text{if } T < 0\,^\circ C, \tag{8}$$

$$TC = 0.02 * T \quad \text{if } 0\,^\circ C < T < 10\,^\circ C, \tag{9}$$

$$TC = -0.33 + 0.053 * T \quad \text{if } 10\,^\circ C < T < 25\,^\circ C, \tag{10}$$

$$TC = 1 \quad \text{if } 25\,^\circ C < T < 35\,^\circ C, \tag{11}$$

$$TC = 2.3 - 0.037\,T \quad \text{if } 35\,^\circ C < T < 62\,^\circ C. \tag{12}$$

The three functions were constrained to remain between 0 and 1. Predictions of biomass loss using the three temperature functions were evaluated with data sets from Bushland, TX (Schomberg and Steiner, 1992), Pendleton, OR (Douglas, et al., 1980), Delta Junction, AK (Cochran, 1991), West Lafayette, IN, Bushland, TX, and Pullman, WA, (Stott et al., 1990), and Melfort, Saskatchewan, Canada (Moulin and Beckie, 1994).

The precipitation coefficient, PC, was used as the water coefficient in the evaluation of the temperature functions. To reduce bias from the water coefficient, the lag factor in the water coefficient calculation, PPTLAG, was optimized for each of the temperature functions since calculation of DDs is based on both the water function and the temperature functions. The optimization was made with data used in the water function evaluation above (Schomberg et al., 1994). The PPTLAG coefficient was varied over several simulations with each temperature function and optimum values were determined after fitting quadratic equations for estimated accuracy versus PPTLAG. Values of PPTLAG that resulted in the best estimated accuracy were 0.23, 0.40, and 0.30, for the Stroo, Steiner, and van Veen functions, respectively.

2.3 Analysis of Model Predictions

Model predictions were evaluated using graphical analysis (qualitative) and statistical procedures. A Chi square (χ^2) goodness of fit test was used to determine if predicted and observed populations were significantly different (Ostel and Mensing, 1975). The χ^2 was calculated as,

$$\chi^2 = \sum \frac{(y_i - x_i)^2}{x_i} \tag{13}$$

where y_i represents the i-th observed value and x_i is the i-th predicted value. We considered the observed and predicted populations to be different when the calculated χ^2 was greater than the tabular χ^2 ($\alpha = 0.05$, $n - 3$). To estimate a relative degree of difference between observed and predicted values an "estimated model accuracy" (EA) was determined using the χ^2 procedure of Freese (1960). The "estimated model accuracy" was calculated as follows,

$$EA = \sqrt{\frac{Z^2}{\chi^2} \sum (y_i - x_i)^2} \tag{14}$$

where Z is the tabular value of the standard normal deviate corresponding to the two tailed probability at an α level of 0.05 ($Z = 1.96$). Data analysis was performed using the Statistical Analysis System (SAS Inst. Inc., 1989) PROBCHI and CHINV functions.

3. Results

3.1 Water Function Evaluation

Decomposition predictions made with PC were compared to predictions made with SWC for decomposition of alfalfa, grain sorghum and wheat residues. The χ^2 test indicated that predicted biomass remaining was not significantly different from observed values for sorghum or wheat residue but were different for alfalfa when using PC (Table 1). Predictions using SWC were significantly different from observed values for all three crops. Combined analysis for all the data indicated that the two water coefficients predicted values that were significantly different than the observed values; however, using PC the probability value was 0.05. The EA intervals indicated that PC gave the best predictions of decomposition (Table 1). Residual plots (observed-predicted vs time) for SWC indicated increasing over-predic-

Table 1. *Comparison of a Precipitation-based Index (PC) Versus a Soil Water Index (SWC) to Calculate Decomposition Days for Use in Predicting Residue Decomposition*†

Crop	n	χ^2		P		Accuracy $\pm$%	
		PC	SWC	PC	SWC	PC	SWC
Alfalfa	120	184	564	0	0	11.7	13.8
Sorghum	120	113	156	0.57	0	14.5	16.2
Wheat	120	104	187	0.80	0	13.5	16.9
Total	360	402	906	0.05	0	13.8	16.4

† χ^2 is the estimated χ^2 value from Eq. 13.
P is the significance level for the χ^2 test.
Accuracy is estimated as in Eq. 14.

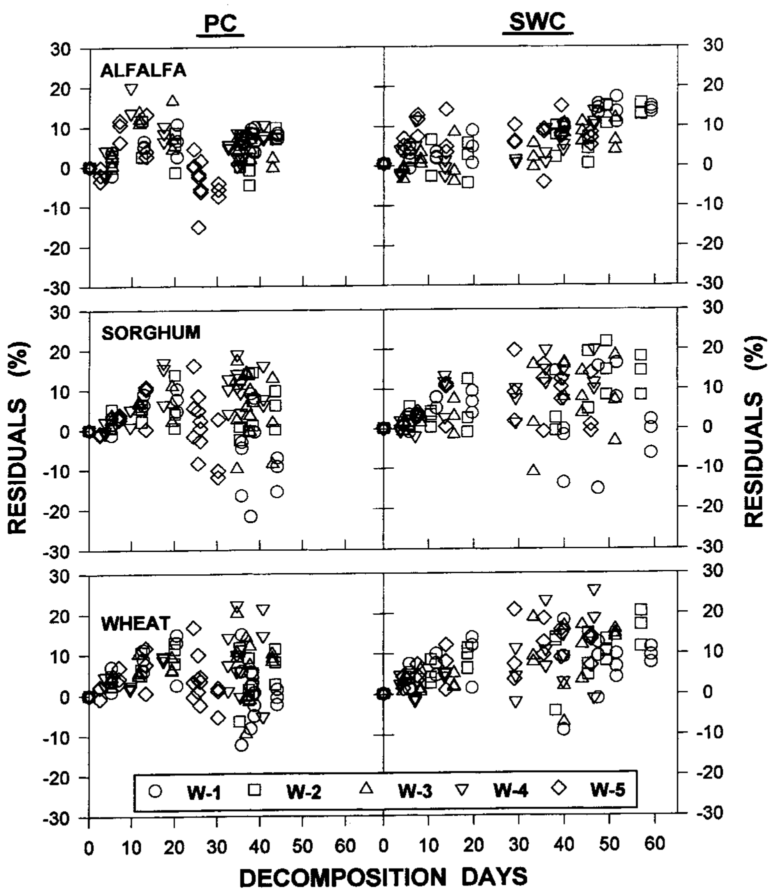
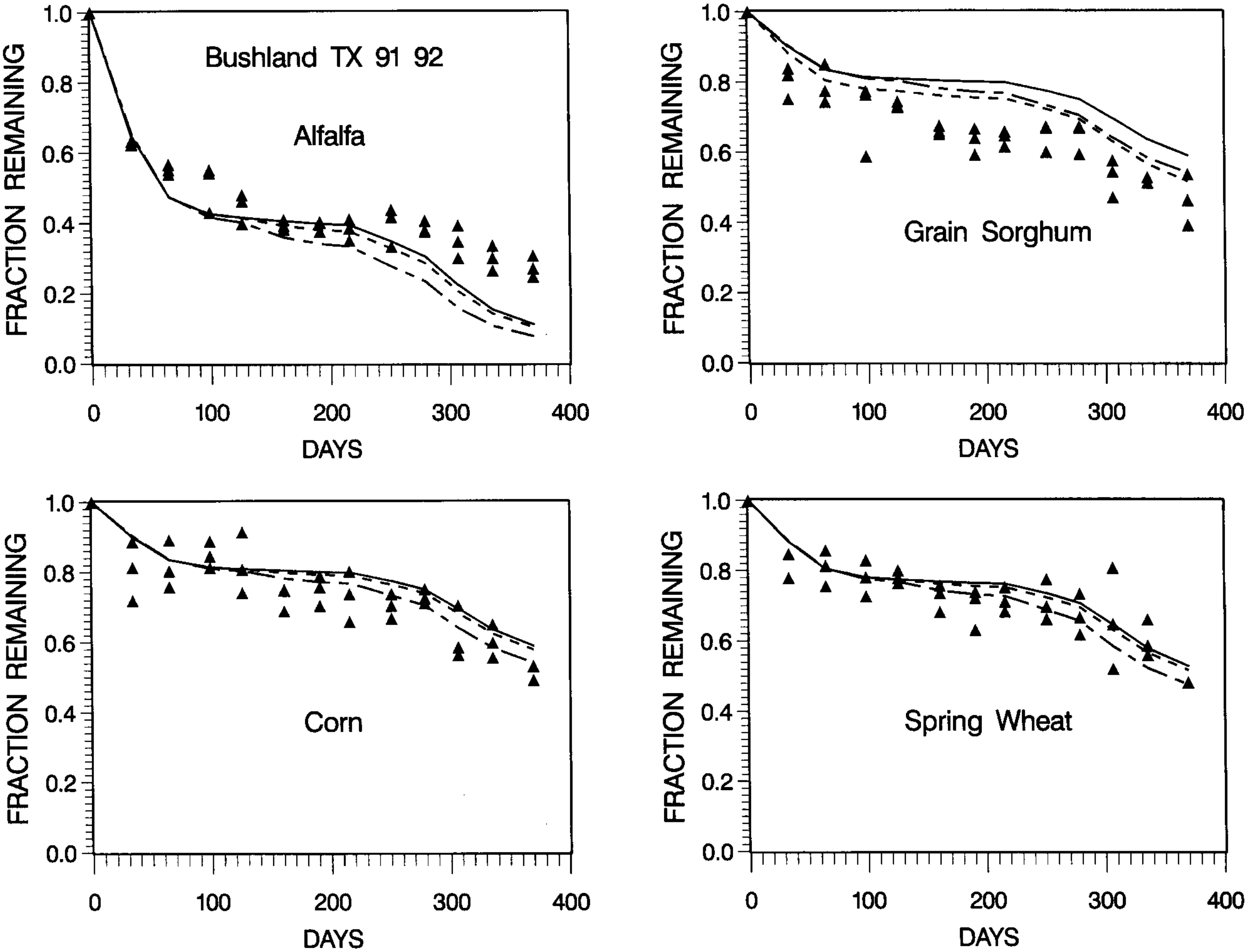


Fig. 2. Residuals (observed-predicted) versus time for residue decomposition estimates using a precipitation based water index (PC) or a soil water based index (SWC). W1 through W5 represent five water regimes from wet (W1) to dry (W5). Data from Schomberg et al., 1994

tion with time for all three residues (Fig. 2). Variation in the residuals for specific sample dates tended to be greater for PC than that for SWC. Variation in the residuals was also greater for wheat and sorghum than for alfalfa which is attributed to the faster rate of decomposition of the alfalfa and accumulation of less soil within the alfalfa residue. Additionally, increases in variation over time were probably due to the heterogeneous nature of the residues and loss of residue smaller than the bag mesh size during handling, which may have increased as material became more fragile with age. When the two indices were combined in the model by taking the maximum of PC or SWC each day, the predicted decomposition was greater than with either index alone and had an EA of around $\pm 25\%$ (data not shown).

Prediction accuracy is affected by bias (consistent deviation from the observed values) and/or lack of precision (inconsistent deviation) and both of these factors influence the EA calculation. A measure of the bias in the prediction can be made by fitting a linear regression between observed and predicted values and using the residual sum of squares in the accuracy calculation (Freese, 1960). When the data for PC and SWC were compared based on an assumption of unbiased estimates the overall accuracy for both was $\pm 7\%$ or less (data not shown). The SWC function had the best adjusted EA, but the difference between SWC and PC was within 1% for the three crops. Although the unbiased EA does not indicate where the bias is from, inspection of the residual plots indicates that the decomposition coefficients may have contributed to the inexact predictions particularly for SWC. The SWC function should provide the best estimation of water influences on residue decomposition because it is physically based. It should especially provide greater detail when water effects are related to high humidity, melting snow, or wetting by dew.

The PC index appears to provide a simple index of water effects on surface residue decomposition that would be satisfactory for modeling surface residue decomposition where the primary water influence is precipitation, computation time is



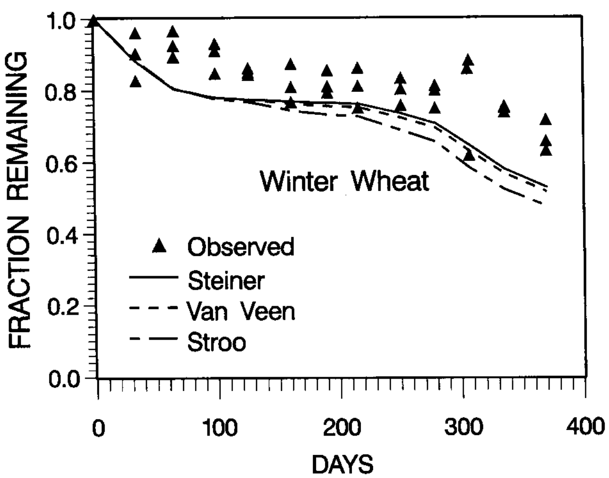


Fig. 3. Comparison of three temperature functions for use in predicting decomposition of alfalfa, corn, sorghum, spring wheat and winter wheat residue at Bushland, TX. Symbols represent measured values from Schomberg and Steiner (1992)

critical, and input data are limited. An improvement in the index might be achieved by relating amount of rainfall needed to wet the residue to the amount of residue present. Data from Schreiber (1985) indicates that the amount of water intercepted by wheat residue before runoff begins increases from 0.4 to 1.5 mm as residue loading rates increase from 2,000 to 12,000 kg ha^{-1}. Similar data from Savabi and Stott (1995) indicate the maximum interception of rainfall occurs near 8,000 kg ha^{-1} for wheat and interception by corn and soybean residues increases over the rates used in their study. The maximum interception was less than 3 mm rainfall for all three residues even with high rates of residue loading. The 4 mm used for the PC index therefore implies some wetting of the soil surface even under high residue loading rates. Soil surface wetting is necessary for residual microbial activity following a rainfall event and is included in the model within the antecedent moisture routine. Additional interception probably occurs as rain is absorbed within the residues. Estimation of residue water content and evaporative loss would be the best method for relating decomposition to residue water content. This could be achieved using methods similar to those developed in the atmosphere-residue-soil water model of Bristow et al. (1986). More data would be required for model validation and implementation but the relationship would be physically based and more robust.

3.2 Temperature Function Evaluation

Three functions for describing temperature effects on residue decomposition were compared. The functions were Stroo et al. (1989), Steiner et al. (1994), and van Veen and Frissel (1981) and are referred to in the text as the Stroo, Steiner, and van Veen functions, respectively.

Schomberg and Steiner (1992) followed decomposition of surface-placed bags of alfalfa, corn (*Zea mays* L.), sorghum, spring wheat, and winter wheat residues in no-till small grain residue plots with and without irrigation during a fallow period at Bushland, TX, from July 1991 to August 1991. The bags were placed in the high density residue plots described by Steiner et al. (1994). Prediction of decomposition was not influenced by the water treatments and only the irrigated data are presented in Fig. 3, but all of the data were used in the analysis. Observed decomposition of spring wheat was not different from predicted values with each of the three temperature functions (Table 2). Agreement between predicted and observed decomposition rates for the other residues depended on the temperature function. Predicted and observed values were not significantly different for corn when using the Stroo function but were significantly different with the Steiner and van Veen functions. Observed decomposition was closely reflected in the predicted rate of decomposition for the other residues but there were differences usually due to inaccurate prediction during early or late periods depending on the residue. Underprediction of sorghum residue decomposition was probably related to the maturity of the residue. The sorghum residues were harvested just prior to physiological maturity and had a narrower C:N ratio than the residues used in 1990–1991 study of Schomberg et al. (1994). It is well known that decomposition rates are sensitive to the chemical composition of the plant material (Stott and Martin, 1989). Greater accuracy might be obtained by determining decomposition coefficients based on residue quality factors like C:N ratios or C:lignin ratios.

Douglas et al. (1980) placed bagged wheat straw residue containing 0.19, 0.49 and 0.78% N, on the above the soil surface and monitored mass loss at Pendleton, OR, from July 1976 to November 1978. Our evaluation used the data for the wheat residue containing 0.78% N. Decomposition of wheat residue on the surface was predicted accurately with both the Steiner and van Veen temperature functions (Table 2 and Fig. 4). The Steiner function also resulted in adequate prediction of aboveground residue decomposition. The good fit of the aboveground data is somewhat surprising since no additional adjustment was made to the water coefficient for predicting decomposition of aboveground residues. Standing residues decompose slower than surface residues because standing residues dry faster following a rain and soil water content near the surface can contribute to the water content of surface residues (Douglas et al., 1980). An improvement in prediction of standing residue decomposition might be made if PPTLAG values were determined separately for standing and surface residues. However, the results of Douglas et al. (1980) do not indicate a large difference in rates of decomposition between residues on or above the soil surface in this environment.

Stott et al. (1990) presented data on decomposition of wheat residue at Pullman, WA, for 1983, 1984, and 1985; Bushland, TX, for 1985; and West Lafayette, IN, for 1985. Grab samples were collected from random sites within wheat residue plots at all locations. Residue decomposition at Pullman, WA, was underpredicted with the three temperature functions for all three years. The best prediction was for 1983 (Table 2 and Fig. 5). Similar underprediction occurred for the other

Table 2. *Comparison of Decomposition Predictions Using Three Temperature Functions for Calculating Decomposition Days*

Location crop	n	Stroo			Steiner			van Veen		
		χ^2	P	EA ± %	χ^2	P	EA ± %	χ^2	P	EA ± %
Bushland TX[1]										
alfalfa	116	796	0.00	20	332	0.00	14	401	0.00	15
corn	117	108	0.64	15	149	0.02	18	137	0.07	17
sorghum	117	227	0.00	22	311	0.00	26	183	0.00	19
s wheat	116	109	0.61	14	91	0.93	14	85	0.97	13
w wheat	116	236	0.00	20	124	0.21	15	141	0.04	16
Pendleton OR[2]										
wheat standing	6	43	0.00	24	7	0.06	11	13	0.00	15
surface	6	22	0.00	16	2	0.60	5	4	0.25	8
Pullman WA[3]										
wheat 1983	6	39	0.00	28	77	0.00	43	64	0.00	39
1984	6	52	0.00	34	81	0.00	45	71	0.00	41
1985	9	105	0.00	43	130	0.00	38	137	0.00	51
Bushland TX[3]										
wheat	5	26	0.00	24	28	0.00	9	30	0.00	10
W. Lafayette IN[3]										
wheat	5	16	0.00	15	19	0.00	7	20	0.00	8
Delta AK[4]										
barley leaves	10	22	0.00	18	37	0.00	25	34	0.00	24
stems	10	3	0.84	7	1	0.99	4	1	0.99	4
Melfort SK[5]										
alfalfa	30	80	0.00	20	86	0.00	25	74	0.00	23
barley	32	52	0.00	19	86	0.00	15	77	0.00	23
wheat	30	21	0.78	12	9	0.00	8	10	0.99	8
Summary Total	737	1885	0.00	17.8	1570	0.0	17.6	1589	0.0	17.8

[1] Schomberg and Steiner, 1992. [2] Stott et al., 1986. [3] Douglas et al., 1980. [4] Cochran, 1992. [5] Moulin and Beckie, 1994.

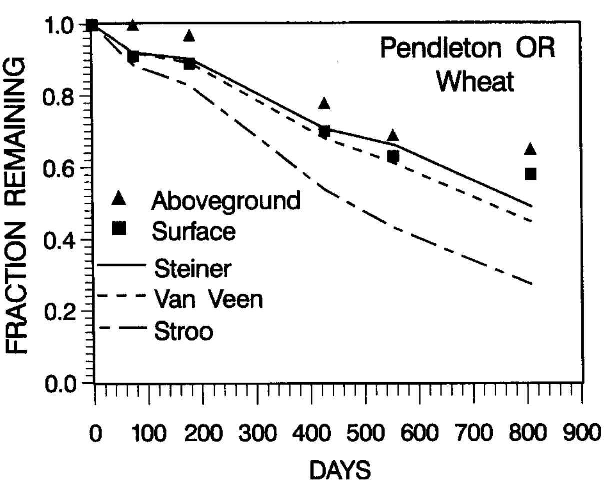


Fig. 4. Comparison of three temperature functions for use in predicting decomposition of wheat above ground and on the surface at Pendleton, OR. Symbols represent measured values from Douglas et al. (1980)

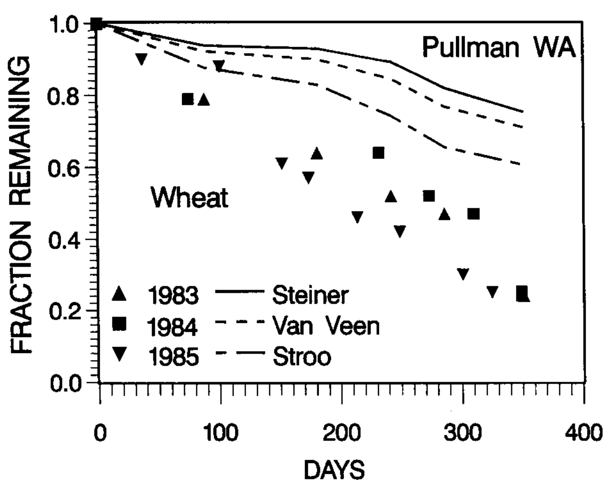


Fig. 5. Comparison of three temperature functions for use in predicting decomposition of wheat residue on the surface at Pullman, WA. Symbols represent measured values from Stott et al. (1990)

two years (prediction lines not shown). The models predicted very little decomposition for this location for any of the three years. Maximum predicted biomass loss was only 30% with the Stroo temperature function while the actual residue loss was closer to 70%. An improvement in prediction in this environment might be achieved if WC was based on ET or was constrained to remain at 1 during the cool wet winter period. This might increase simulated mass loss during the winter periods when temperatures warm slightly and the residues remain wet from previous periods of precipitation.

Differences between the mass loss at Pullman, WA, and Pendleton, OR, are surprising since the climatic regimes of the two locations are similar. However, the studies were conducted using two different residue sampling procedures; bagged residues at Pendleton and grab samples at Pullman, WA. Other modelers have used these data sets for the evaluation of predictions of residue decomposition with mixed results. Predictions of wheat straw mass loss in the Pacific Northwest by Stroo et al. (1989) were very close to observed values for residues held on the surface as straw bundles (Collins et al., 1990), were poor for data from Pendleton (C. L. Douglas, unpublished data) and were mixed for data of Stott et al. (1990). Douglas and Rickman (1992) used the published (Douglas et al., 1980) and unpublished data (local cite) from Pendleton to develop their residue decomposition model. Their predictions for mass loss at Pullman were poor when compared to the grab samples of Stott et al. (1990) but were satisfactory when compared to the data of Collins et al. (1990) where wheat residues were held on the surface by nylon string. Decomposition studies using mesh bags have been criticized because the bags alter the environment of the residues compared to that of unconfined residues. Concerns have been raised about the exclusion of predatory and saprophagous arthropods and interference with fungal activity (Hagvar and Kjondal, 1981; Seastedt, 1984; St. John, 1980). Mesh size can be used to physically exclude groups of soil organisms from contributing to fragmentation of residues and thus the rate of decomposition. House and Stinner (1987) found decomposition was not influenced by bag mesh size (.05, .2, 1.0, 10 mm) for rye (*Secale cerale* L.), crimson clover (*Trifolium incarnatum* L.), and hairy vetch (*Vicia villosa* Roth) residues placed on the soil surface and partially covered by additional residue. They concluded that microarthropod comminution of crop residues was minimal in their cropping system in North Carolina. Residues within large-mesh bags had slightly more mass than those in small-mesh bags after 3 to 4 months. However, this trend was not statistically significant and may have been related to moisture differences between mesh sizes, because large-mesh bags were drier than small-mesh bags following rainfall. There were no differences under dry-field conditions. They also found that soil contamination increased with mesh size. In the two studies from Bushland, mesh size was 1 mm and did not exclude a significant portion of the soil mesofauna since many microarthropods were present in the residue bags when sampled. Soil contamination was present within the residues but was corrected for by adjusting the weights based on ash content. We also found that the temperature of the bagged residues was not different from that of unconfined residues on the soil surface during the course of the two studies. This would indicate that the water regime of the bagged residues was similar to that of unconfined residues. Mesh bags were used in our studies at Bushland to reduce variability during the recovery process and because of the windey conditions (average wind speed of 4.4 m s^{-1} at 2 m height). Grab samples may also result in poor estimation of mass loss where residue distribution by harvesting equipment is uneven or where the possibility exists for residue redistribution by wind and animals. Also, collection of grab samples is more difficult as the residues age and become more fragile. Stott et al. (1990) point out that physical fragmentation of residues contributed to observed losses particularly for later harvests where some fragments were so small that they were difficult to recover from the soil. Stroo et al. (1989) also pointed out that wind probably removed residues from the relatively small plots and losses were probably greater in the summer when residues were dry. Their predicted results agreed most closely for plots with the most total residue. Mass loss measurements may reflect both biological and physical mechanisms depending on the methods used to collect the data. Method of data collection effects should be considered during data interpretation.

Biomass loss at West Lafayette, IN (Stott et al., 1990) was adequately predicted with the Steiner

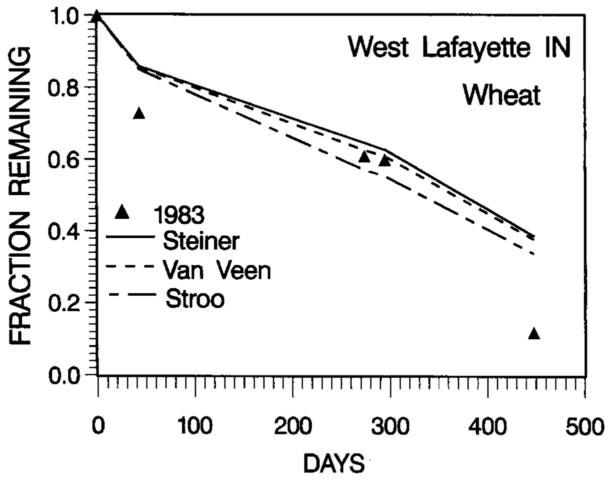


Fig. 6. Comparison of three temperature functions for use in predicting decomposition of wheat residue on the surface at West Lafayette, IN. Symbols represent measured values from Stott et al. (1990)

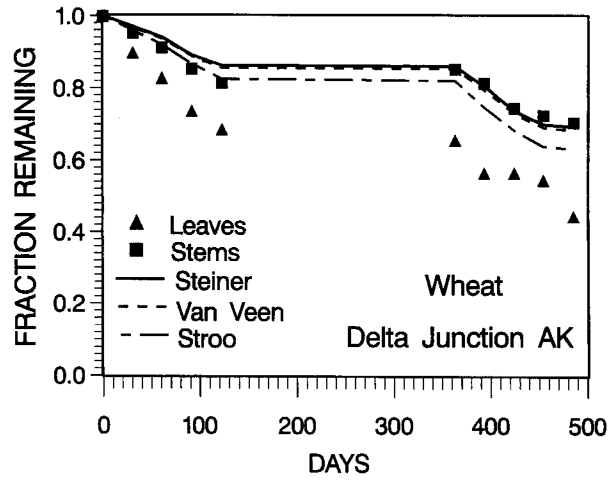
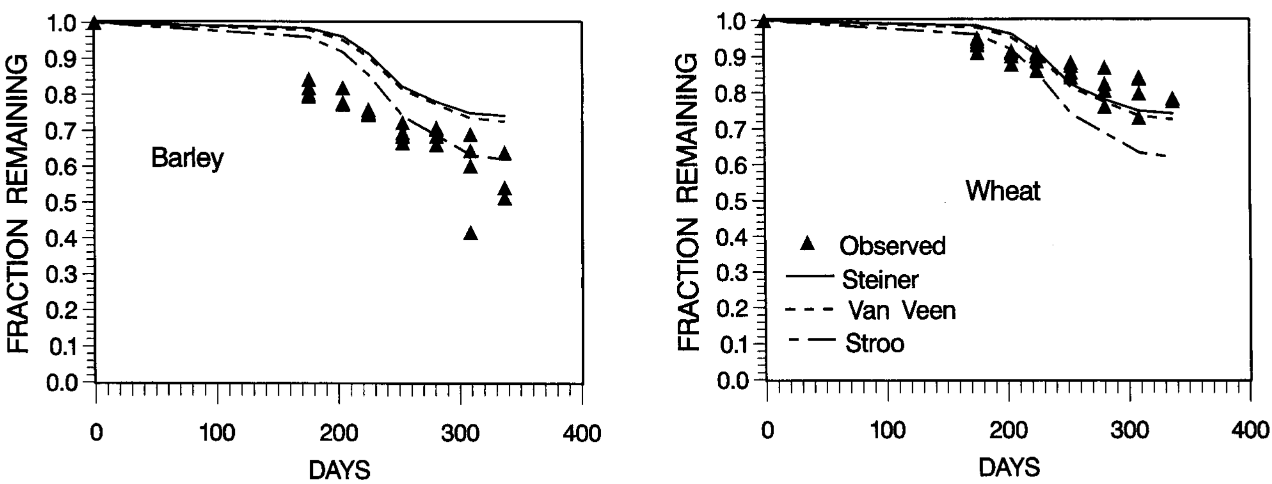


Fig. 7. Comparison of three temperature functions for use in predicting decomposition of barley leaf and stem residues on the surface near Delta Junction, AK. Symbols represent measured values from Cochran (1991)



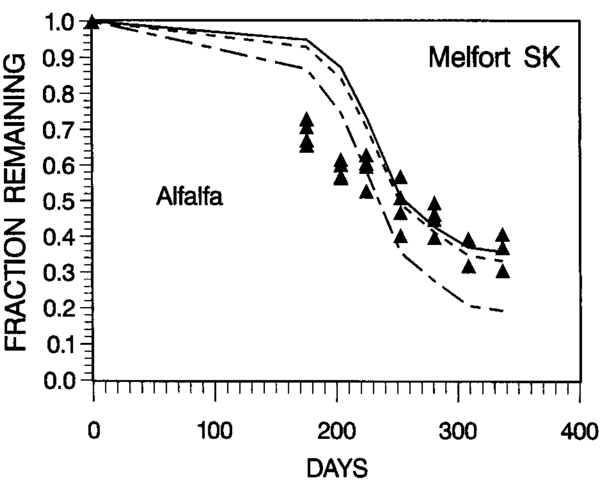


Fig. 8. Comparison of three temperature functions for use in predicting decomposition of alfalfa, barley, and wheat residue on the surface at Melfort, Saskatchewan, Canada. Symbols represent measured values from Moulin and Beckie (1994)

and van Veen functions until the last sample date while predictions with the Stroo function were not as good (Fig. 6) (Table 2). Predictions of mass loss at Bushland, TX (Stott et al., 1990) were not as good but were similar to those for West Lafayette (data not shown). At both locations, there was a divergence from the observed values for the last sample date. At West Lafayette, the last sample was collected after corn planting and a significant reduction of surface residues probably occurred during planting. If the last sample date is deleted, predictions with the three functions are not significantly different from the observed values. The decline in biomass at Bushland at the last sampling date may have also resulted from burial of residues during the planting of a subsequent crop. The use of grab samples may have contributed to the underprediction of residue decomposition.

Cochran (1991) evaluated decomposition of barely leaves and stems in bags on the soil surface near Delta Junction, AK. The soil was frozen from early October until May, so the simulation was made with no decomposition occurring during this period. Prediction of biomass loss from stems with the Steiner and van Veen temperature functions produced accurate results over the two year period (Fig. 7 and Table 2). Prediction of leaf decomposition was poor because it was made with the same decomposition coefficient used for the stems. Differences between plant components in rates of decomposition can be attributed to differences in structural components and C:N ratios. Cochran (1991) indicated decomposition rate differences between stems and leaves were related to their lignin content since addition of N to the plant material did not stimulate CO_2 evolution in a laboratory study.

Moulin and Beckie (1994) measured decomposition of bagged residues of alfalfa, barley, and wheat on the soil surface at Melfort, Saskatchewan, Canada from November, 1991, through October, 1992. Prediction of wheat decomposition was good with each of the three temperature functions. The Steiner function gave the best prediction. Decomposition of barley was underpredicted with the three temperature functions; however, the general pattern of mass loss was similar for the observed and predicted values. Decomposition of alfalfa was underpredicted initially but improved near the end. A similar pattern of initial underprediction was observed for all three residues. The pattern was more exaggerated for alfalfa and may have been the result of decomposition or loss of soluble material during snow cover.

4. Conclusion

Development of the WEPS residue decomposition submodel is an ongoing project and the results of this study will be used to make several changes and improvements in the functioning of the submodel. Good estimations of crop residue mass loss were obtained with simple functions relating climatic conditions to those for optimum rates of residue decomposition. Prediction of decomposition using the three temperature functions resulted in similar results across a range of environments. The Stroo function predicted faster residue decomposition than did the Steiner or van Veen functions. Based on the overall χ^2 and EA, the Steiner function gave the best predictions; however, the differences between the functions were small, particularly between the Steiner and van Veen functions. Predictions of residue decomposition were generally within 15 to 25% of the observed mass loss values. Variability present in the two sets of observed data from Bushland was generally as great or greater than this, while variability in the data from Melfort ranged from 5 to 15%. Since the variability of the observed data was similar to that of the predictions, it appears that the model accuracy is reasonable for a range of environments. A possible reason for differences in variability between the two locations could be a greater contribution of insects to the decomposition process at Bushland. Although these residues were bagged, a considerable amount of mesofauna was observed inside the bags at sampling (mostly *Annelida, Chilopoda, Collemboda, Diplopoda*).

The results from several locations indicate possible further improvements that can be made to the model. Soil temperature might be a better indication of temperature effects on surface residues and could be used for calculating the temperature function. The Melfort study and possibly the Pullman study indicate that a greater amount of decomposition occurs under snow cover than the model predicts. Future work will focus on developing relationships within the soil hydrology submodel of WEPS to predict the water content of the residues on the soil surface. This should improve predictions under snow melt and thus better reflect the water regime of the residues in the spring. Although not investigated in this study, the effect of high humidity may also result in underprediction of decomposition and may need to be addressed as part of the water coefficient. Estimation of decomposition constants based on crop N content or yield could improve model predictions by more closely relating decomposition to plant composition. Overall the model provides a simple means for determining residue decomposition rates over a range of environments with relatively good results.

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