Predicting Crop Residue Decomposition and Cover for Wind Erosion Simulation

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Introduction

Improved crop residue management can provide efficient and cost-effective practices to address land resource issues relating to soil conservation, water quality, sustainability, and enhanced nutrient cycling (Unger, 1994; Steiner, 1994). A recent survey of U.S.A. tillage practices by the Conservation Technology Information Center (1994) indicated that 35% of cropland is managed with conservation tillage, compared to 25.6% in 1989. National farm policy, which now links eligibility for farm support programs to development and implementation of conservation plans for highly erodible land, has been a factor in the transition to reduced tillage. More than 75% of farmers' conservation plans developed under these policies use improved crop residue management to meet conservation goals. Therefore, erosion prediction technologies developed to meet needs of the USDA-Natural Resources Conservation Service and of others must realistically address changes in surface crop residue amount and distribution with time.

In areas where erosion is primarily by water, the required amount of residue has been based on percent soil cover (e.g., 30% residue cover remaining after planting the subsequent crop). The percent of soil covered by crop residue influences both the effect of raindrop impact on soil surface properties (aggregation, crusting, etc.) and surface aerodynamic properties (Hagen et al., 1995; Morrison et al., 1984). Bilbro and Fryrear (1995) showed that vertical residues are much more effective that flat surface cover in controlling soil loss by wind. Also, standing residues persist longer than flat residues that are in close contact with the soil (Tanaka, 1986). In the late 1980s we initiated research to develop a residue decomposition model that would be applicable to diverse on-farm conditions and suitable for implementation in Natural Resource Conservation Service field offices nationwide. The model equations and parameters for various crops are given in the WEPS documentation (Steiner et al., 1995). The objective of this paper is to describe basic principles and performance of the residue decomposition model developed for WEPS.

Model Description

Climate indices Crop residues are simulated in three pools: standing, flat, and sub-surface as shown in Figure 1. Mass loss from residues and standing stem number decline is estimated for various climates using temperature and precipitation or soil moisture data. We developed a scale, decomposition days (DD), that accumulates with time and incorporates temperature and moisture as driving variables (Steiner et al., 1994; Schomberg et al., 1996).

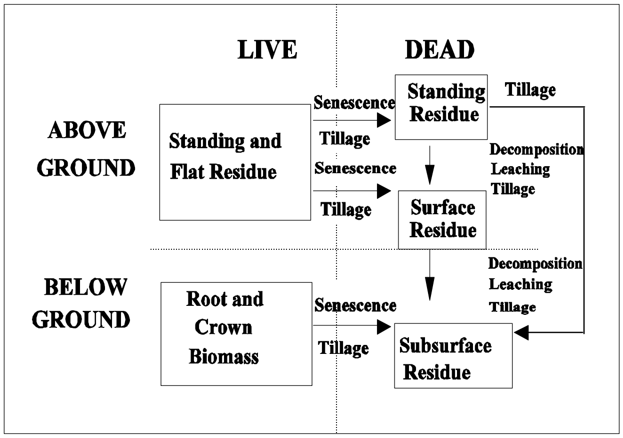

Figure 1. Biomass distribution and transfer between residue pools in decomposition submodel (from Steiner et al., 1995).

For each calendar day, daily mean temperature and moisture indices relate expected decomposition to that which would occur under "optimum" laboratory conditions. Optimum moisture and temperature conditions result in the accumulation of 1 decomposition day for each day of the simulation. The minimum of daily moisture and temperature functions is used to accumulate a fraction of a DD. Estimated daily DD range from 0 (for very cold or dry conditions) to near 1 (for warm and moist conditions).

Variables used to calculate DDs for each residue pool are given in Table 1. For surface residues, precipitation $4 mm is assumed to wet the residue and soil surface to provide optimum conditions. Precipitation less than 4 mm results in an index proportionally less than 1. The effect of precipitation decreases by 50% per day. For subsurface residues, the moisture function is optimum at field capacity and declines linearly below field capacity. The optimum temperature for decomposition is 32EC and the coefficient declines above and below that temperature. Since the daily average temperature is rarely 32EC, field DD are almost always below 1. Accumulation of DD differs by season and climatic region.

Table 1. Environmental inputs to calculate Decomposition Days

Residue Pool	**Temperature** (EC)	**Moisture**
Standing	Air	Precipitation (mm)
Flat	Air	Precipitation (mm)
Sub-surface	Soil	Soil water content (m^{3} —^{3})

Mass loss Initial residue mass is estimated from yield (Table 2). Actual residue amounts vary depending on management, growing season, and crop variety, so it may be preferable to measure initial residue mass if possible. Harvesting equipment and techniques influence height and distribution of surface residues. The user determines harvest height and the model partitions residues to standing or flat pools proportionally based on crop height relative to cutting height.

We simulate decomposition using a first order decay equation and assume that the decomposition rate constant depends primarily on residue quality. Since residue decomposition may require considerable time and since some cropping systems leave little or no time between crops, residue biomass from sequential harvests are accounted for in separate data pools for the most recently harvested crop, the penultimate crop, and aged organic material from earlier crops.

Table 2. Functions for estimating residue mass (RES) from economic yield (Y)

Crop	Above-ground Dry Matter Mg/ha	Residue Mg/ha
Corn	$ADM^{\S} = (1.51Y^{\P}) + 3.7$	RES = ADM - Y
Grain Sorghum	$ADM = (2.13Y) + 1.1$	RES = ADM - Y
Small Grains	$ADM = (2.56Y) + 0.4$	RES = ADM - Y
Sunflower	$ADM = 3.59Y$	RES = ADM - Y
Cotton	$ADM = 9.26LY^{\dagger}$	$Takeoff_{\mathbf{strip}} = 4.5\ LY$ $Takeoff_{pick} = 3.2\ LY$ RES = ADM - Takeoff

§ Above-ground plant dry matter before harvest.

¶ Adjust yield to 13% moisture for corn and sorghum, 12% for small grains, and 9% for sunflower.

† Lint yield (Mg /ha)

Standing stem number Standing residues provide a vertical surface area that directly reduces wind speed and reduces soil erosion. To represent this effect, stem area index (SAI) was developed by Bilbro and Fryrear (1994) based on stem diameter, stem height, and number of stems per unit land area. A daily estimate of standing stem number is required in the erosion submodel to calculate SAI. Steiner et al. (1994) developed equations to predict the decline in standing stem fraction (the fraction of standing stems relative to initial stem number following harvest in no-till systems) using a first order decay function similar to the mass loss equation, but with a threshold number of DDs required before standing stems start to fall. Transfer of biomass from the standing to flat pools is calculated from the change in stem number.

Mass:cover relationship Surface cover is provided primarily by flat residue and is calculated using the method of Gregory (1982). The relationship of residue mass to cover has been described for many crops (Figure 2) and varies depending on the density of the material, stem and leaf fractions, and other crop specific properties. While this simple relationship is widely used, several factors affect the accuracy. Relationships have often been developed using freshly cut residues and sometimes only include part of the plant material (e.g., stems of small grains). Often, residues have been randomly distributed rather than being measured in natural distributions found in the field. The change in percent cover during decomposition is not well

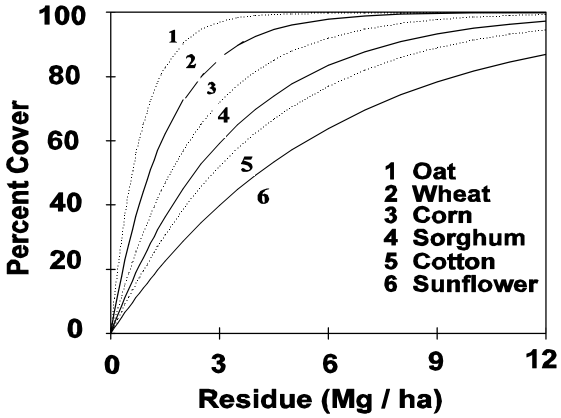

Figure 2. Relationship of residue mass to soil cover for several crops (from Steiner et al., 1994b).

understood. The relationship plateaus at high residue mass, so considerable mass loss may occur before cover decreases significantly. If residue level following harvest is low, mass loss will be associated with loss of cover. For residues with a high proportion of leaf material, cover may decline following harvest with little loss in mass because leaf material decomposes rapidly and is light compared to stem material. Soluble carbohydrates, which comprise as much as 20% of the mass at harvest, can leach out with little change in cover.

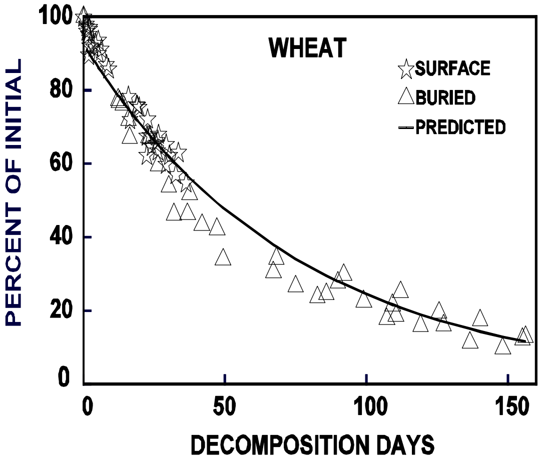

Figure 3. Decomposition of wheat residue related to field decomposition days for surface and subsurface conditions. Line is based on independent (Collins, et al., 1990) laboratory data (Schomberg, unpublished data)

Model Evaluation

Climate indices Schomberg et al. (1996) showed that a precipitation-based moisture index was as effective as an index using precipitation and soil water content data for predicting flat surface residue mass loss. Since precipitation is much easier to obtain than soil water content, this makes it easier to compile data sets for decomposition studies. Several published temperature functions were compared and found to provide similar predictions of mass loss, except at one location. The simple weather parameters in the decomposition model provided satisfactory predictions of decomposition compared to field measurements of mass loss from several crops at several North American locations. Two northern sites (Melfort, Saskatchewan and Pullman, WA) indicated greater decomposition may occur under snow than is predicted in this model.

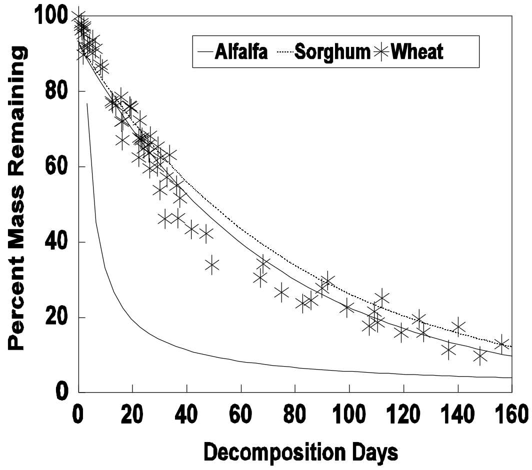

Figure 4. Decomposition of alfalfa, sorghum, and wheat residue related to decomposition days for surface and subsurface conditions (Schomberg, unpublished).

Mass loss

Winter wheat mass loss prediction based on laboratory decomposition under optimum conditions (Collins et al., 1990) was compared to mass loss of surface and subsurface winter wheat residues under field conditions (Figure 3). Decomposition days for field data were calculated from air temperature and precipitation data for surface residues and from soil temperature and soil water content for buried residues. For the "predicted line," each calendar day was equated to a full decomposition day to represent optimal decomposition conditions in the laboratory. It took almost a year to accumulate about 40 decomposition days for surface residues and about 160 decomposition days for buried residues. The consistency of the field and laboratory data indicates that major environmental factors are captured by the DD index. Figure 4 shows surface and subsurface mass loss for alfalfa, sorghum, and wheat, indicating the importance of residue type in controlling decomposition rates.

Standing stem number

Figure 5 shows the decline in standing stems for winter wheat at Bushland, TX. Similar data collected for other small grains in the experiment indicated differences in the threshold DDs required to decompose the stem base and also differences in the rate coefficients (Figure 6). Measured values from North Dakota, Oregon, and independent studies at Bushland, TX, indicated that predicted values based on parameters derived from Bushland data tested provided reasonable predictions of stem number decline (Figure 7). However, the threshold DD effect was not pronounced at the other locations, indicating the need to consider other climatic forces that may be important.

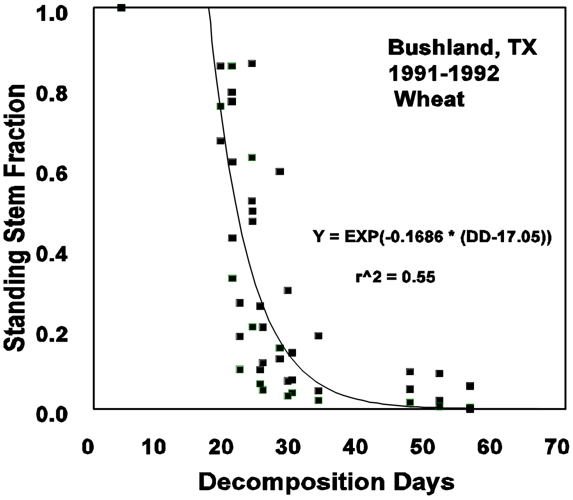

Figure 5. Decline of standing stems of no-till wheat as related to field decomposition days (Steiner et al., 1994a).

Mass cover relationship

Data collected at Bushland, TX, were used to examine mass:cover relationships of winter wheat. Contrary to assumptions in the WEPS model and most published values, the data indicated that freshly harvested residues provided less cover than the same mass of aged residues (Figure 8). The relationship between mass and cover was better if only flat mass was

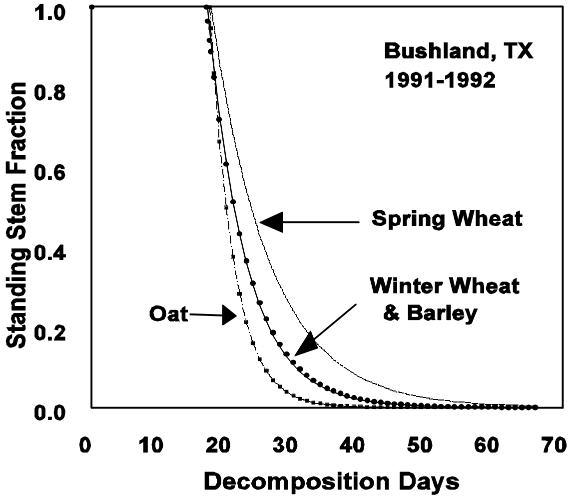

Figure 6. Decline of standing stems of four no-till small grains (Steiner et al., 1994a)

Future research needs

The decomposition model follows simple principles and uses easily available data to predict residue decomposition in field environments. For implementation of the model in NRCS field offices, considerable effort is required to populate data bases with default coefficient values for diverse crops and cropping systems. This would allow the model to be run with minimal input from the user. When possible, it would be desirable to develop equations to estimate coefficient values based on simple laboratory procedures (e.g., Schomberg and Steiner, 1997) or standard residue quality parameters, to reduce the cost of adding new crops or modifying coefficients for specific genotypes of a crop. In addition, remote sensing and other new technologies (Daughtry et al., 1996) are needed to provide better and more cost-effective ground truth when erosion predictions are implemented in an operational mode.

Standing stem number is a very important parameter in WEPS, but few data are published in the literature about persistence of standing residues. Additional data are particularly needed for different types of crops than small grains. Prediction of standing stem number might be improved by adding a variable to represent forces that cause stems to fall. The current DD index only considers the resistance of stems to falling as they decompose.

The model would be more accurate in predicting soil cover from mass over a wider range of conditions if changes in the residue properties as residues decompose were considered. However, few data are available in the literature to derive such relationships and field measurements of surface cover are inherently variable, making it difficult to derive generalized equations.

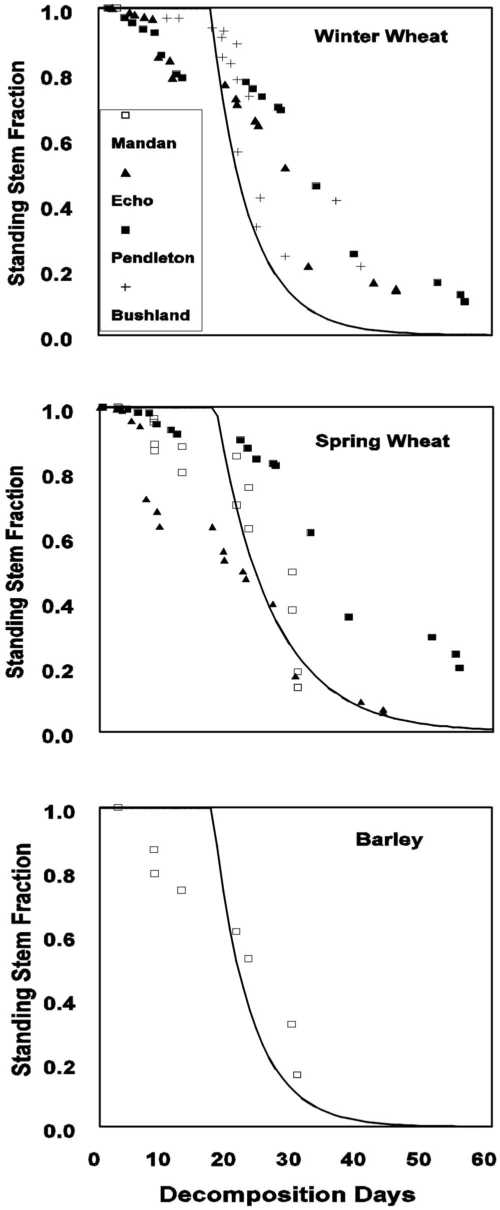

Figure 7. Evaluation of predicted standing stem decline of small grains compared to field measurements (Steiner et al., 19941).

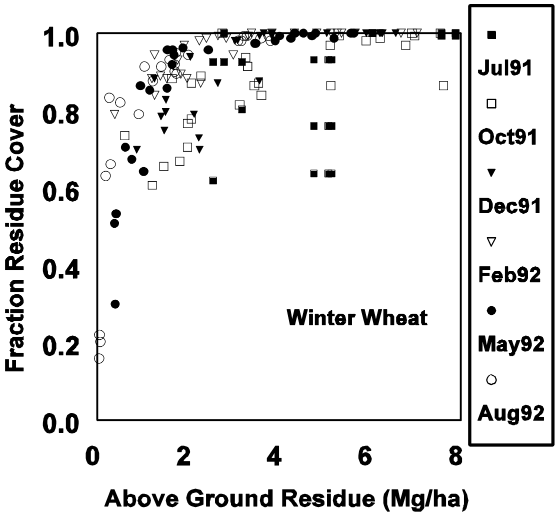

Figure 8. Relationship of soil cover to total above-ground wheat residue biomass through the decomposition period (Steiner, unpublished).

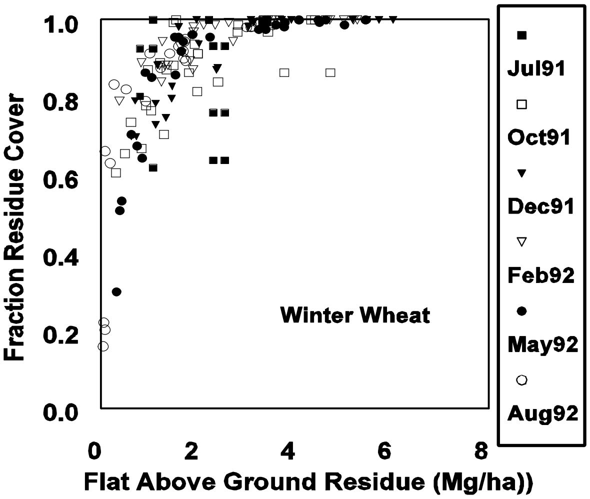

Figure 9. Relationship of soil cover to flat above-ground wheat residue through the decomposition period (Steiner, unpublished).

Acknowledgments

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References

Bilbro, J. D. and D. W. Fryrear. 1994. Wind erosion losses as related to plant silhouette and soil cover. Agron. J. 86:550-553.

Collins, H. P., L. F. Elliott, R. W. Rickman, D. F. Bezdicek, and R. I. Papendick. 1990. Decomposition and interactions among wheat residue components. Soil Sci. Soc. Am. J. 54:780-785.

Conservation Technology Information Center. 1994. National Crop Residue Management Survey. 1220 Potter Drive, Rm 170, West Lafayette, IN 47906-1383.

Daughtry, C.S.T., J. E. McMurtry, III, E. W. Chapelle, W. J. Hunter, and J. L. Steiner. 1996. Measuring crop residue cover using remote sensing techniques. Theor. Appl. Climatology. 54:17-26

Gregory, J. M. 1982. Soil cover prediction with various amounts and types of crop residue. Trans. Am. Soc. Agric. Engin. 25:1333-1337.

Hagen, L. J., L. E. Wagner, and J. Tatarko. 1995. Wind Erosion Prediction System (WEPS). Technical Documentation. Beta Release 95-08. USDA, Agricultural Research Service, Wind Erosion Research Unit, Throckmorton Hall, Manhattan, Kansas, 66506.

Morrison, J. E., Jr., T. J. Gerik, and L. A. Bartek. 1984. Raindrop view of soil and residue. Am. Soc. Agric. Eng. Paper No. 84-2042.

Schomberg, H. H. and J. L. Steiner. 1997. Comparison of decomposition models used in erosion prediction. Agron. J. 89: (in press).

Schomberg, H. H. and J. L. Steiner. 1997. Estimating crop residue decomposition coefficients using substrate-induced respiration. Soil Biol. Biochem. 60:1-9.

Schomberg, H. H., J. L. Steiner, S. R. Evett, and A. P. Moulin. 1996. Climatic influences on residue decomposition prediction in the Wind Erosion Prediction System. Theor. Appl. Climatology. 54:5-16.

Steiner, J. L. 1994. Crop residue effects on water conservation. pp. 41-76, In P. W. Unger (ed.) Managing Agricultural Residues. Lewis Publ., Boca Raton, FL.

Steiner, J. L., H. H. Schomberg, C. L. Douglas Jr., and A. L. Black. 1994. Standing stem persistence in no-tillage small grain fields. Agron. J. 86:76-81.

Steiner, J. L., H. H. Schomberg, and J. E Morrison. 1994. Measuring surface residue and calculating losses from decomposition and redistribution. pp. 21-29 In W. C. Moldenhauer (Managing Ed.) and B. A. Stewart (Regional Ed.) Crop Residue Management to Reduce Erosion and Improve Soil Quality: Southern Great Plains. USDA-ARS Conservation Research Report No. 37.

Steiner, J. L., H. H. Schomberg, and P. W. Unger. 1995. Residue Decomposition Submodel. pp. D1-D12, In L. J. Hagen, L. E. Wagner, and J. Tatarko. 1995. Wind Erosion Prediction System (WEPS). Technical Documentation. Beta Release 95-08. USDA, Agricultural Research Service, Wind Erosion Research Unit, Throckmorton Hall, Manhattan, Kansas, 66506.

Tanaka, D. 1986. Wheat residue loss for chemical and stubble-mulch fallow. Soil Sci. Soc. Am. J. 53:228-232.

Unger, P. W. [ed.]. 1994. Managing Agricultural Residues. Lewis Publ., Boca Raton, Florida.