Decomposition of Surface Crop Residues in Long-Term Studies of Dryland Agroecosystems

Liwang Ma, Gary A. Peterson, Lajpat R. Ahuja,* Lucretia Sherrod, Marvin J. Shaffer, and Kenneth W. Rojas

ABSTRACT

Decomposition of surface crop residues is important for agricultural management, especially under conservation tillage. The objective of this study was to test several models for describing crop residue decomposition under three eastern Colorado dryland agroecosystems at Sterling, Stratton, and Walsh with a yearly mean air temperature of 9.7, 10.4, and 12.0°C, respectively. At each site, a soil toposequence common to its geographic region was chosen to include a summit, a sideslope, and a toeslope position, and several crop rotations were practiced under no-till conditions. Grab samples were taken at planting and before harvesting for surface residue measurement since 1985. Simulation results showed that the Douglas–Rickman model described surface crop residue decomposition better than the Gregory model during a 13-year period, based on a normalized objective function (NOF). Our fitted decomposition rate coefficients using the Douglas–Rickman model matched those originally published. The Douglas–Rickman model, which uses a first-order decay with respect to degree-days, was further evaluated against two other first-order decay models: one using a first-order decay equation with respect to decomposition-days and the other assuming a first-order decay with respect to time (d). Although the three approaches performed equally well in terms of NOF values ($P = 0.354$), fitted decomposition rate coefficients were significantly different ($P < 0.012$) among the three experiment sites when models based on decomposition-days or on time (in days) were used. Therefore, the Douglas–Rickman model may be more applicable for describing long-term crop residue decomposition because of its consistency in model parameters among experimental sites and simplicity in modeling approach.

Managing crop residues has been a focus of study for many years because of their multiple roles in sustainable agriculture (Unger, 1994). Correct estimation of surface residues under various agricultural systems and at different times of the year is a prerequisite for developing better residue management practices. As a result, numerous studies have been conducted to understand the decomposition of crop residues under laboratory and field conditions. In a field study with wheat (*Triticum aestivum* L.) residues in fiberglass cloth bags, Douglas et al. (1980) found that residue decomposition was greatest when buried in the soil and the least when placed above the soil surface. Similar results were reported by Ghidey and Alberts (1993) and Brown and Dickey (1970). Stott et al. (1990) monitored surface residue losses by taking grab samples from no-till experiment sites, and found that 35 to 42% of residue weight was lost in 30 wk. Collins et al. (1990a) exposed wheat straw bundles in the field, to avoid relocation of crop residue under windy weather conditions. Straw samples were then taken periodically from those bundles and analyzed in the laboratory for C mineralization rates (decomposability). They found that straw decomposability was highest for samples taken at harvest and showed no differences among samples taken after 94 d of field exposure.

Residue decomposition depends mainly on air temperature and soil moisture (Douglas and Rickman, 1992; Stott et al., 1990; Steiner et al., 1994; Ghidey and Alberts, 1993). Although the C/N ratio and N content have been used to describe residue decomposition (Douglas and Rickman, 1992; Ghidey and Alberts, 1993), these are not always related to decomposition rate (Smith and Peckenpaugh, 1986; Reinertsen et al., 1984; Collins et al., 1990a,b). Reinertsen et al. (1984) concluded that early-stage residue decomposition was largely dependent on the size of water-soluble C pool and an intermediately available C pool. This finding is in agreement with a recent study by Gilmour et al. (1998), who found that only initial (0–2 wk) decomposition was related to crop residue organic N and C/N ratio.

Several models have been proposed to quantify residue weight loss under various environmental conditions. Douglas and Rickman (1992) assumed a first-order decay of crop residues in the field based on cumulative degree-days, and the rate constant was related to residue initial N content and average moisture condition. Their model was developed from decomposition data collected near Pendleton, OR, and was used to calculate residue decomposition from locations in seven other states regardless of residue type and weather condition. They found that a two-stage decomposition model was better for buried residues and a one stage decomposition model for aboveground and surface residues. Gregory et al. (1985) developed a mathematical model based on residue structure, rain, and air temperature. The resulting equation was second-order with respect to degree-days. Ghidey and Alberts (1993) and Ghidey et al. (1985) were able to calculate residue losses from fiberglass bags under field conditions using the approach of Gregory et al. (1985).

Stroo et al. (1989) and Steiner et al. (1994) developed a decomposition-days concept, wherein residue decomposition is limited by the less favorable of the two factors, soil moisture or temperature. Steiner et al. (1994) used an overall first-order decay equation for standing residue decomposition, whereas Stroo et al. (1989) applied a first-order equation for each residue component

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Abbreviations: DCD, decomposition days [model]; DGD, degree-days; MC, moisture coefficient; MDR, multiple decomposition rate; NOF, normalized objective function; ODR, one decomposition rate; TC, [air] temperature coefficient; TID, time in days [model].

(straw, leaves, and chaff) in a laboratory study. Such a decomposition-day approach was further tested by Schomberg and Steiner (1997) under various assumptions and environmental conditions. Voroney et al. (1989) and Collins et al. (1990b) assumed the decay rates as a function of time only, without consideration of environmental factors and residue characteristics. Voroney et al. (1989) assumed a two-stage decay of crop residues to account for the rapid initial decomposition rate. Collins et al. (1990b), on the other hand, found that a single-term equation was better than a multiple-term model in describing cumulative decomposition of crop residues under laboratory conditions. Gilmour et al. (1998) concluded that a one-rate decomposition model is suitable for long-term studies, while a two-stage decomposition model is better for describing short-term experiment results.

Note that the experimental period was relatively short in most of these studies, and that the models were used to describe single-load residue losses without new addition of residues during the decomposition period. In this study, we measured crop residues under different no-till crop rotations during a 13-year experiment at three locations in eastern Colorado, as part of a sustainable dryland agroecosystem management project to study extensive crop coverage on water use efficiency (Peterson et al., 1993, 1998). New crop residue was added into the soil system at each harvesting. Since crop residue has a significant effect on reducing water evaporation, the ability to predict the amount of crop residues on the soil surface is desirable. Currently, models have been developed for calculating residue decomposition under field conditions, but have not been tested in long-term studies with multiple residue inputs as is the case in this experiment. Therefore, the objectives were to evaluate various models in the literature and to find the best applicable model for describing multiple-year residue decomposition in dryland no-till agricultural systems.

MATERIALS AND METHODS

The experiment was initiated in 1985 and (at the time of this publication) is still in progress (Peterson et al., 1993, 1998). Three study sites were established at Sterling (40°22′ N, 103°8′ W), Stratton (39°11′ N, 102°16′ W), and Walsh (37°14′ N, 102°10′ W) in eastern Colorado with crop-season open pan evaporation of 1000, 1400, and 1900 mm, respectively (Wood et al., 1991). Each location has a soil toposequence common to the geographic region in which it is located, including a distinct summit, sideslope, and toeslope. Soil classification and texture are shown in Table 1 for each experiment site and slope position. Measured average daily air temperature for the 13 years was 9.8, 10.4, and 12.0°C for Sterling, Stratton, and Walsh, respectively. Corresponding measured average yearly precipitation for the three sites was 470, 430, and 440 mm. Daily air temperature and precipitation were recorded by an on-site weather station.

The experiment fields were moldboard plowed prior to 1985, and then initiated with no-till (Wood et al., 1990). Cropping systems are described in Table 2. The crops tested were wheat (*Triticum aestivum* L.), corn (*Zea mays* L.), proso millet (*Panicum miliaceum* L.), sorghum [*Sorghum bicolor* (L.) Moench], hay millet [*Setaria italica* (L.) P. Beauv.], sunflower (*Helianthus annuus* L.), and the intraspecific cross of sorghum and sudangrass [*Sorghum bicolor* (L.) Moench] known commercially as sudex. Crop rotation treatments at the Sterling site were initially wheat–fallow, wheat–corn–fallow, and wheat–corn–proso millet–fallow. The initial rotation treatments at Stratton and Walsh were wheat–fallow, wheat–sorghum–fallow, and wheat–sorghum–proso millet–fallow. At Stratton, the sorghum crop failed in 1990 and was then replaced by corn. Proso millet was replaced by forage sorghum at Walsh in 1991 and by grain sorghum in 1993. Starting in 1994, sunflower replaced proso millet at Sterling and Stratton. An opportunity cropping system was also tested at each site to maximize soil water usage by planting a crop every year (Table 2). Each cropping system was replicated twice in a randomized complete block design. All phases of each cropping system were present in each replication each year (Table 2). Fertilizer for each crop was applied based on soil tests. One half of each experimental unit was fertilized with P (9.5 kg ha^{-1}) and the other half received no P to study the possible effects of P on crop yield (Peterson et al., 1998).

Surface residues were measured by collecting 1-m^2 grab samples at the beginning of the experiment for all the locations and slopes and later at planting and before harvest of each crop. One sample was taken for each duplicate and treatment plot, and was stripped and oven-dried in the laboratory. Grain yield and crop residue returned to the soil after each crop were also measured. Grain and crop residue N contents were determined colorimetrically using a micro-Kjeldahl procedure following a block digestion (Adamski, 1976).

MODEL DESCRIPTION

There are two models that use the degree-days concept and consider the effects of air temperature, soil moisture, and nitrogen content of crop residues on decomposition rate. Douglas and Rickman (1992) assumed a first-order decay with

Table 1. Soil characterization and initial crop residue properties for study sites at Sterling, Stratton, and Walsh in eastern Colorado. Data were collected in the fall of 1985.

Slope position	Soil classification	Soil texture	Initial crop residue Mass	Initial crop residue N
			kg ha^{-1}	g kg^{-1}
Sterling				
summit	fine, smectitic, mesic Aridic Paleustolls	loam	4420	4.52
sideslope	fine, smectitic, mesic Aridic Paleustolls	loam	3140	3.18
toeslope	fine, smectitic, mesic Pachic Argiustolls	loam	8210	4.87
Stratton				
summit	fine-silty, mixed, mesic Aridic Argiustolls	clay loam	720	4.17
sideslope	fine-silty, mixed (calcareous) Ustic Torriorthents	loam	970	3.09
toeslope	fine-silty, mixed, mesic Pachic Argiustolls	loam	2190	9.13
Walsh				
summit	fine, smectitic, mesic, Ustollic Haplargids	loamy sand	1230	6.50
sideslope	fine, smectitic, mesic, Ustollic Haplargids	sandy loam	960	6.25
toeslope	fine, smectitic, mesic, Ustollic Paleargids	sandy clay loam	1630	7.36

Table 2. First crop in 1985–1986 and crop rotation treatments at Sterling, Stratton, and Walsh in Colorado.

Treatment	Sterling		Stratton and Walsh	
no.	First crop	Crop rotations	First crop	Crop rotations
1	wheat	wheat–fallow	wheat	wheat–fallow
2	fallow	wheat–fallow	fallow	wheat–fallow
3	wheat	wheat–corn–fallow	wheat	wheat–sorghum–fallow
4	corn	wheat–corn–fallow	sorghum	wheat–sorghum–fallow
5	fallow	wheat–corn–fallow	fallow	wheat–sorghum–fallow
6	wheat	wheat–corn–proso millet–fallow	wheat	wheat–sorghum–proso millet–fallow
7	corn	wheat–corn–proso millet–fallow	sorghum	wheat–sorghum–proso millet–fallow
8	proso millet	wheat–corn–proso millet–fallow	proso millet	wheat–sorghum–proso millet–fallow
9	fallow	wheat–corn–proso millet–fallow	fallow	wheat–sorghum–proso millet–fallow
10	†	opportunity cropping system†	†	opportunity cropping system†

† The cropping history for the opportunity cropping system from 1985 to 1996 is wheat–wheat–corn–corn–hay millet–wheat–corn–hay millet–corn–sunflower–wheat–corn at Sterling, fallow–wheat–sorghum–sorghum–hay millet–wheat–corn–hay millet–corn–sunflower–wheat–corn at Stratton, and sorghum–sorghum–proso millet–sudex–sorghum–sunflower–wheat–corn–fallow–wheat–wheat–fallow at Walsh.

respect to degree-days, such as

$$M_t = M_{t-1}(1 - K_d \mathrm{DGD}_t) \quad [1]$$

where M_t and M_{t-1} are residue mass at current and previous day (kg ha^{-1}); DGD$_t$ is the degree-days for the current day, which is taken as the average temperature above 0°C of that day; and K_d is a first-order decomposition constant (1/DGD). K_d is written as

$$K_d = k f_N f_w \quad [2]$$

where f_N and f_w are factors accounting for initial crop residue N and soil moisture effects, and k is a rate coefficient (1/DGD). Douglas and Rickman (1992) provided a regression equation ($r^2 = 0.88$) for f_N as

$$f_N = 0.570 + 0.126\,[N] \quad [3]$$

where $[N]$ is initial N concentration of the residue (g N kg^{-1}). Discrete values were used for f_w such that $f_w = 1.0$ for buried residue in a fallowed field, $f_w = 0.8$ for buried residue in a cropped field, $f_w = 0.3$ for surface residue in a fallowed field, and $f_w = 0.2$ for surface residue in a cropped field. This model will be referred to as the Douglas–Rickman model.

The model of Gregory et al. (1985), referred to as Gregory model hereafter, uses the C/N ratio and a moisture factor to calculate weighted degree-days. Residue decomposition is second-order with respect to the weighted degree-days (Gregory et al., 1985; Ghidey and Alberts, 1993):

$$M_t = M_{t-1}(1 - \alpha\tau)^2 \quad [4]$$

where α is a lumped rate coefficient; and τ is weighted degree-days. The τ is calculated as

$$\tau = \frac{T a_m}{\mathrm{CNR}} \quad [5]$$

where T is the average daily air temperature (°C), CNR is the C/N ratio of the residue at senescence, and a_m is an antecedent moisture index (m). This index is calculated as

$$a_m = \sum_{i=1}^{5} \frac{P_i}{i} \quad [6]$$

where P_i is precipitation depth on a given day (m), and i is day number (with the current day being 1, the previous day being 2, and so on). An antecedent moisture index > 0.01 is set to 0.01 to reduce the percent decomposition of surface residue during high precipitation periods. The C/N ratio required by the Gregory model is estimated from measured initial N content and residue mass by assuming a 40% C content in the residue at harvest (Hanson et al., 1988; Collins et al., 1990a; Ghidey et al., 1985; Smith and Peckenpaugh, 1986).

Two other first-order decay models were also used to quantify crop residue losses. One assumed a first-order decay with respect to time (d) (Schomberg et al., 1994; Collins et al., 1990b) and the other used a decomposition-days concept which takes the minimum of air temperature and soil moisture effective coefficients. The air temperature coefficient (TC) is calculated (Steiner et al., 1994) as

$$\mathrm{TC} = \frac{2T^2(T_{opt})^2 - T^4}{(T_{opt})^4} \quad [7]$$

where $T_{opt} = 32$°C; and T is air temperature (°C). The moisture coefficient (MC) is defined (Steiner et al., 1994) as

$$\mathrm{MC}_t = 0.5\mathrm{MC}_{t-1} + \mathrm{PC}_t \quad [8]$$

where MC$_t$ and MC$_{t-1}$ are the moisture coefficients for the current and previous days; and PC$_t$ is the precipitation coefficient of the current day. PC$_t$ is calculated as

$$\mathrm{PC}_t = 1.0, \quad P_t \geq 4$$
$$\mathrm{PC}_t = P_t/4, \quad P_t < 4 \quad [9]$$

where P_t is the current day's precipitation in millimeters. Bounds of 0 and 1 were set for TC and MC. The decomposition-days for a single day were then calculated by taking the minimum value of MC and TC.

Model efficiency was quantified with a normalized objective function (NOF) that is similar to coefficient of variation (CV) (Costa et al., 1994; Ma et al., 1998).

$$\mathrm{NOF} = \frac{\mathrm{RMSE}}{\mu_{obs}} \quad [10]$$

where RMSE is the root mean square error and μ_{obs} is the mean of the observed (measured) values. NOF should be interpreted as a relative value for comparing model performance. NOF = 0 indicates a perfect match between experiment and modeling results. NOF < 1 may be interpreted as simulation error of less than one standard derivation around the experimental mean. NOF = CV suggests that the deviation of model simulation from experimental data (mean value) is the same as the deviation of the experiment measurement from its mean.

Crop rotations were treated as replicates rather than independent factors for ANOVA analysis for the following reasons. First, crop rotation was different from year to year and from experiment site to experiment site. There was no consistent experimental design for crop rotation. Second, crop rotation was considered in the model simulation by the amount and N content of crop residues returned to the soil surface. Third, the models consider only soil moisture (rain), air temperature, and N concentration. Crop rotation should have little effect on model simulation results as long as the right amount of crop residue and its N content were considered in

Table 3. Coefficients of variation (CV) of experimental measurement and normalized objective function (NOF) values for simulated results under the Douglas–Rickman model (DRM) and Gregory model (GM), with assumptions of either one decomposition rate (ODR) or multiple rates (MDR). Results are for the sideslope position at the Sterling site in Colorado.

		NOF with average crop residue input				NOF with adjusted crop residue input			
		DRM		GM		DRM		GM	
Treatment no.†	CV	ODR	MDR	ODR	MDR	ODR	MDR	ODR	MDR
1	0.32	0.25	0.27	0.22	0.23	0.15	0.18	0.18	0.20
2	0.42	0.31	0.32	0.31	0.33	0.25	0.26	0.20	0.23
3	0.32	0.22	0.24	0.25	0.24	0.20	0.20	0.23	0.22
4	0.39	0.29	0.31	0.30	0.32	0.26	0.27	0.26	0.27
5	0.41	0.32	0.34	0.33	0.35	0.25	0.26	0.25	0.27
6	0.34	0.29	0.29	0.33	0.32	0.27	0.27	0.29	0.29
7	0.36	0.22	0.22	0.21	0.19	0.19	0.23	0.18	0.23
8	0.46	0.23	0.26	0.24	0.29	0.21	0.24	0.22	0.26
9	0.25	0.21	0.20	0.26	0.24	0.15	0.15	0.18	0.16
10	0.39	0.26	0.27	0.33	0.31	0.24	0.29	0.28	0.34
Avg.	0.37	0.26	0.27	0.28	0.28	0.22	0.23	0.23	0.25

† Treatments are as described in Table 2.

the model. Lastly, we are seeking a model that can simulate residue decomposition for all crop rotations.

RESULTS AND DISCUSSION

Crop yields between the P and no-P fertilized halves of each experimental unit were not significantly different as indicated by a paired *t*-test ($P > 0.08$). Therefore, measurements from both P and no-P fertilized sides of each plot were pooled. Surface residues were measured in fall of 1985 to provide an initial estimation of residue mass in the system (Table 1). The Douglas–Rickman model (Douglas and Rickman, 1992) and the Gregory model (Gregory et al., 1985) model were first used to simulate crop residue decomposition in this study because both models were based on degree-days. Since both models were developed for a single-load residue decomposition event, two assumptions were made for the interaction between newly added crop residues and old surface residues during multiple-year decomposition. First, we assumed that all the residues had the same decay rate as newly added crop residue. This is called the one-decomposition-rate assumption (ODR). Second, surface residues of different origins decompose independently, which we called multiple-decomposition-rate assumption (MDR). Therefore, a separate rate coefficient is calculated for each addition (load) of crop residue based on its initial N concentration, and residue of different origins were modeled independently. Although both assumptions are extremes of the real world, they are reasonable based on our current understanding of crop residue dynamics. In addition, initial residue N concentration or C/N ratio may not be the best indicator of long-term crop residue decomposition (Collins et al., 1990a,b; Reinertsen et al., 1984; Smith and Peckenpaugh, 1986; Gilmour et al., 1998).

To compare the Douglas–Rickman model with the Gregory model, we chose to fit the rate coefficients under the ODR and MDR assumptions. Rate coefficients (k or α) of both models were optimized using the 13-year residue measurements for each crop rotation and each slope position at Sterling, Stratton, and Walsh. An example of the goodness-of-fit in terms of NOF is shown in Table 3 for the sideslope position at the Sterling site. Similar results were obtained for other positions and sites (Stratton and Walsh). As shown in Table 3, NOF values for each crop rotation were similar to their experimental CV values, which suggests that the deviation of model simulation from experimental mean is similar to experimental error. The Douglas–Rickman model better described residue decomposition than Gregory model ($P = 0.039$). No significant differences were found between the one-decomposition-rate and multiple-decomposition-rate assumptions for either the Douglas–Rickman ($P = 0.949$) or the Gregory model ($P = 0.603$). Although there was no significant difference in model simulations among slope positions ($P = 0.158$), both models were better in describing residue decomposition at Sterling and Stratton than at Walsh ($P < 0.001$).

To account for variability in crop biomass measurement, the models were further fitted to measured surface residues by allowing the amount of crop residue input (biomass returned to the soil surface) at each harvest time to vary within one standard error of its experimental mean, rather than using the mean value, to minimize RMSEs. Such an adjustment was considered necessary to maximize the predictability of the models, because the average coefficient of variation (CV) in biomass measurement was 20% with maximum CV of 113%, and because the locations for biomass measurement may be different from those for surface residue sampling. Goodness-of-fit, in terms of NOF after adjusting yearly crop residue input, is shown in Table 3 for the sideslope at the Sterling site. Accounting for variability in crop biomass measurements significantly reduced NOF values for both models ($P < 0.001$). Again, the Douglas–Rickman model performed better than the Gregory model ($P = 0.046$). Both models provided better descriptions of residue decomposition at Sterling and Stratton than at Walsh ($P < 0.001$), however, and model performance was not affected by slope position ($P = 0.198$ to 0.552).

Figure 1 shows fitted k-values (Eq. [2]) and Fig. 2 shows fitted α-values (Eq. [4]) for all experiment sites, slope positions, and crop rotations after adjusting the amount of crop residue input. It is interesting that fitted

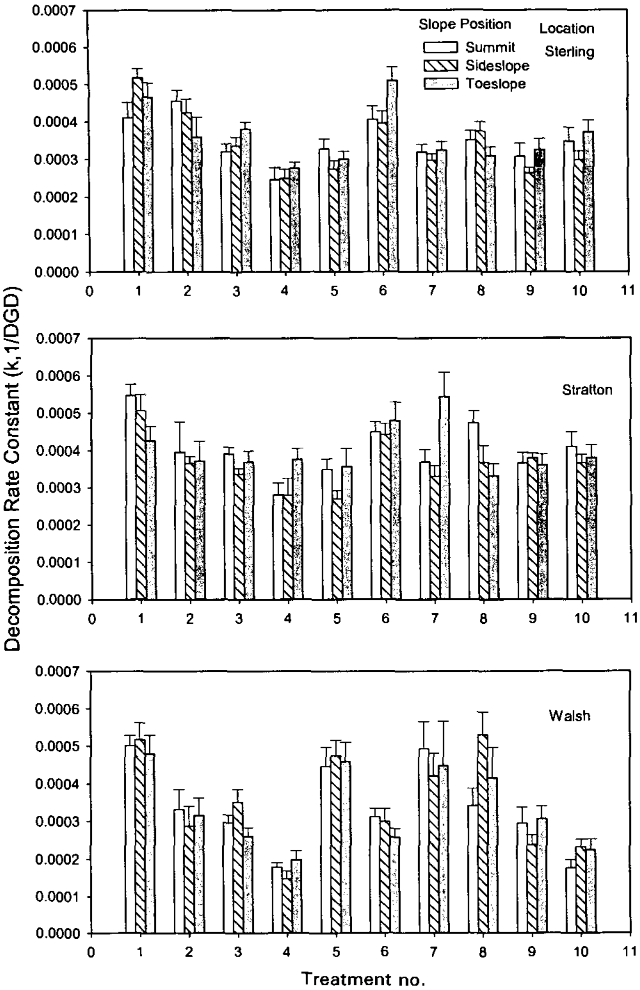

Fig. 1. Fitted residue decomposition rate coefficients (*k*) for the Douglas–Rickman model across all experiment sites, slope positions, and crop rotations under the one-decomposition-rate assumption. DGD, degree-days. See Table 2 for treatment numbers.

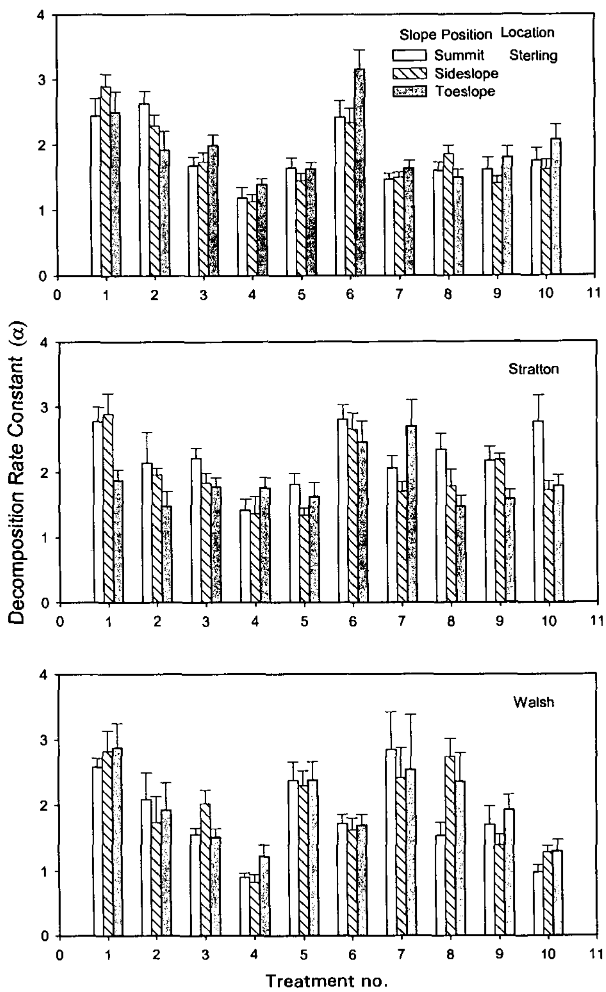

Fig. 2. Fitted residue decomposition rate coefficients (α) for the Gregory model across all experiment sites, slope positions, and crop rotations under the one-decomposition-rate assumption. See Table 2 for treatment numbers.

k- and α-values were not significantly different from those obtained with an average crop residue input. Therefore, the rate coefficients were not affected by initial amount of crop residues. Also, k and α showed the same trends among treatments (Fig. 1 and 2), and they were not significantly affected by slope position ($P = 0.439$). The average k-values from the Douglas–Rickman model for Sterling, Stratton, and Walsh were 0.000352, 0.000389, and 0.000341 1/DGD, respectively. No significant difference was found in residue decomposition rates for the three sites ($P = 0.097$). Average k-value across all the sites was 0.000361 1/DGD, with a standard error of 0.0000883 1/DGD, which is essentially the same as the k-value of 0.00040 1/DGD obtained by Douglas and Rickman (1992). Average α-values of the Gregory model were 1.978, 1.895, and 1.933 for the Sterling, Stratton, and Walsh sites, respectively. Again, there was no significant difference among sites ($P = 0.567$) or slope positions ($P = 0.833$). These α-values were much higher than the 0.3 to 0.8 for surface residues reported by Ghidey and Alberts (1993), and may have resulted from higher crop residue C/N ratios measured in our experiment. Ghidey and Alberts (1993) measured C/N ratios for wheat, corn, and sorghum were 74, 29, and 21, respectively, while our estimated C/N ratios from measured N contents were 81, 61, and 53, respectively. Large C/N ratios tend to increase the fitted α-values.

Figure 3 shows examples of experiment measurements, simulated residue amounts remaining at each sampling time using the Douglas–Rickman model (under the one-decomposition-rate assumption) with adjusted crop residue input, and 95% confidence intervals of simulated results. Generally, the simulation results correctly reflected the trend in residue mass change during the 13 years of the experiment. A majority of the experiment measurements falls into the 95% confidence intervals. Even though only one model parameter was used to describe crop residue decomposition, the model was quite adequate, especially for residue management purposes.

Although the Douglas–Rickman model fits the experiment results better than the Gregory model, a better evaluation of the models would be to compare their

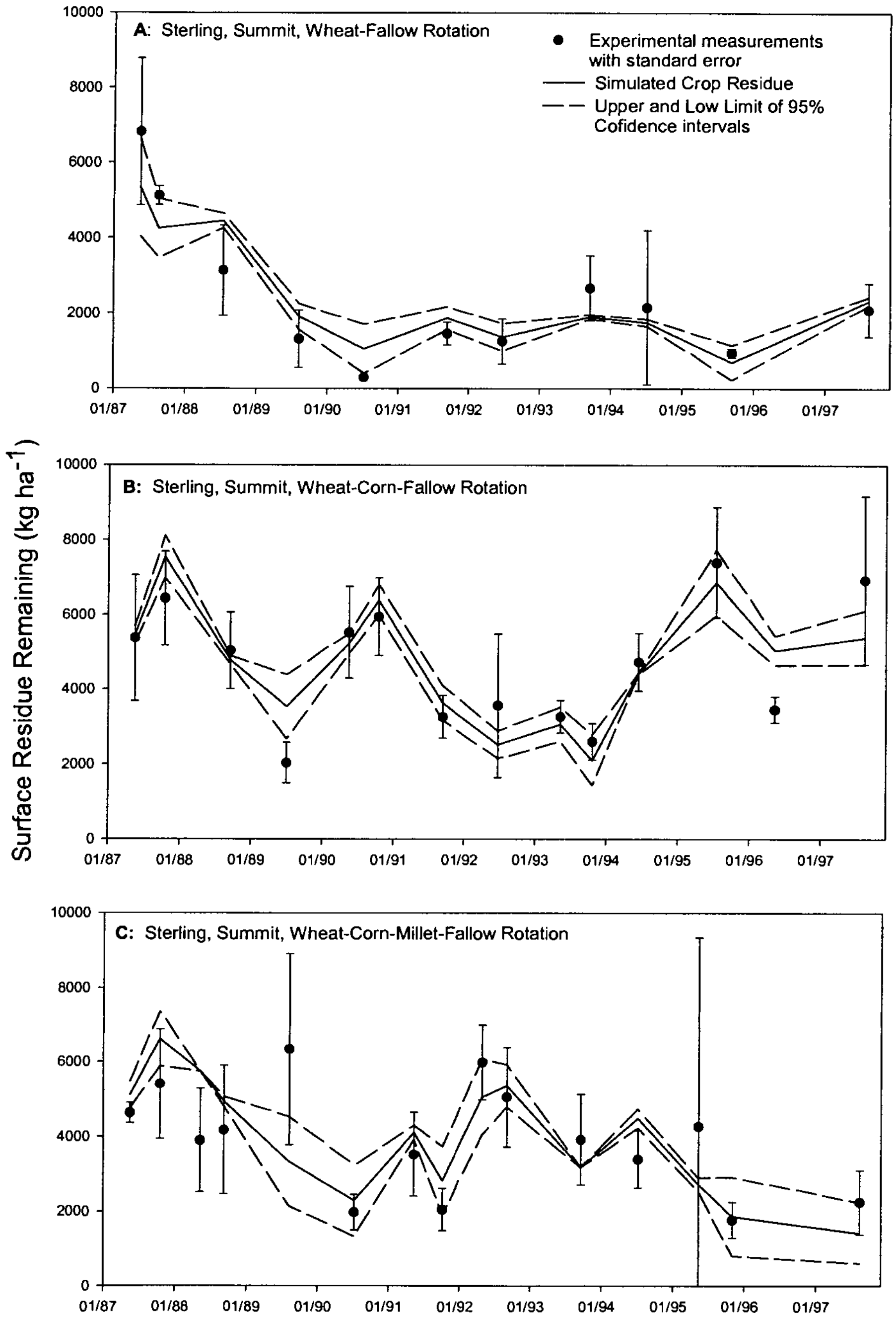

Fig. 3. Simulated crop surface residue under three rotations for the summit position at Sterling (Jan. 1987 to Jan. 1997), using the Douglas–Rickman model with adjusted crop residue input.

ability to calculate residue mass at all sites using one rate coefficient. To do so, we averaged all fitted rate coefficients for each model, and then used this average value to calculate crop decomposition for all experiment sites, slope positions, and crop rotations. Calculated NOF values were significantly higher than the fitted ones ($P < 0.001$), but model-calculated crop surface residues were still quite adequate, considering the large variations in residue measurements (Fig. 4). The difference between the Douglas–Rickman model and the Gregory model became marginal ($P = 0.092$), suggesting that both models performed the same in terms of model prediction. However, the average rate coefficient of the Douglas–Rickman model came close to the value originally given by the authors (Douglas and Rickman, 1992), whereas the average value for the Gregory model was three to seven times higher than those reported in the literature (Ghidey and Alberts, 1993).

So far, we have evaluated two models developed from the degree-days concept. To answer the question of how effective the degree-days models are, in comparison with models derived from decomposition-days (DCD) and time-in-days (TID), the Douglas–Rickman model was further compared with DCD- and TID-based models. Decomposition-days model was adopted from

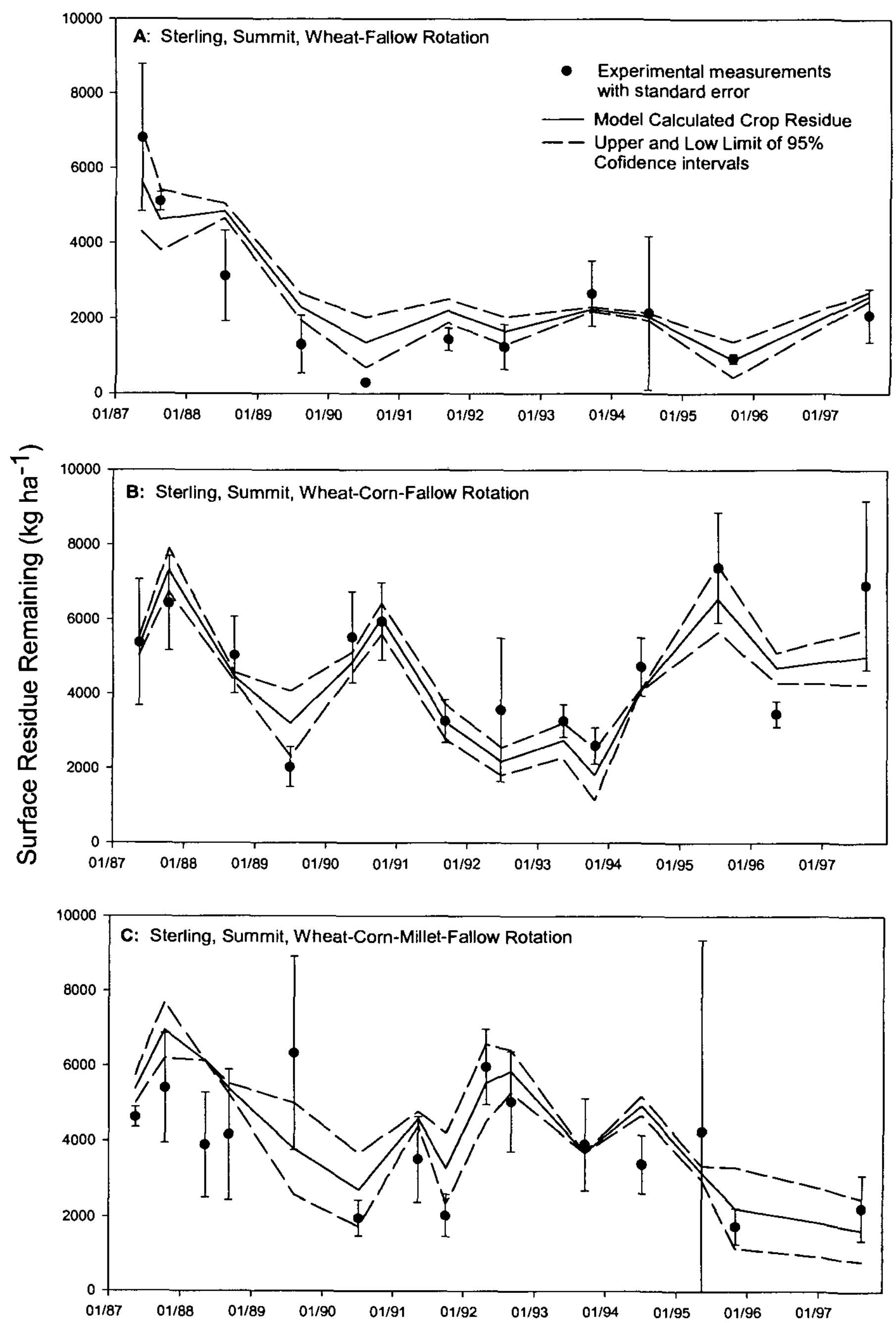

Fig. 4. Model calculation of surface residue under three rotations for the summit position at Sterling (Jan. 1987 to Jan. 1997), using the Douglas–Rickman model with an average rate constant of 0.000361 1/DGD, where DGD is degree-days.

Steiner et al. (1994), and the time-in-days model was a simple first-order decay equation with respect to time (days) (Schomberg et al., 1994). Again, we use the one-decomposition-rate assumption for multiple-year model simulation, and crop residue inputs were adjusted as needed rather than using their average values. Accumulated degree-days were the highest at Walsh and lowest at Sterling because of high air temperature at Walsh, while accumulated decomposition-days were the highest at Sterling and lowest at Walsh (data not shown). Such an inverse relationship indicates that water stress (represented by the moisture coefficient, MC) was often the limiting factor in the decomposition-days calculation under dryland agricultural systems.

Table 4 shows the NOF values of the three models for describing residue decomposition at the Sterling site. Analysis of variance (ANOVA) with site and slope position as main factors indicated no significant differences in performance among models ($P = 0.354$). All the models provided better descriptions for residue decomposition at Sterling and Stratton than at Walsh ($P < 0.001$). Model performance in terms of NOF was not affected by slope position when a two-way ANOVA analysis was conducted for each model ($P = 0.198$ to

Table 4. Coefficients of variation (CV) of experimental measurement and normalized objective function (NOF) values of simulated results under the Douglas–Rickman model (DRM), the decomposition-days model (DCD), and the time-in-days model (TID), with the one-decomposition-rate assumption. Results are for the Sterling site in Colorado.

Treatment no.†	Summit				Sideslope				Toeslope			
	CV	DRM	DCD	TID	CV	DRM	DCD	TID	CV	DRM	DCD	TID
1	0.33	0.31	0.35	0.39	0.32	0.15	0.30	0.31	0.24	0.27	0.32	0.20
2	0.31	0.19	0.16	0.19	0.42	0.25	0.26	0.29	0.39	0.42	0.44	0.44
3	0.23	0.19	0.22	0.19	0.32	0.20	0.20	0.22	0.31	0.16	0.18	0.16
4	0.25	0.38	0.42	0.40	0.39	0.26	0.30	0.30	0.28	0.16	0.20	0.20
5	0.25	0.28	0.33	0.34	0.41	0.25	0.27	0.26	0.30	0.23	0.27	0.27
6	0.35	0.31	0.28	0.30	0.34	0.27	0.24	0.26	0.25	0.24	0.24	0.21
7	0.29	0.21	0.22	0.27	0.36	0.19	0.19	0.20	0.26	0.23	0.27	0.26
8	0.40	0.24	0.28	0.25	0.46	0.21	0.29	0.28	0.27	0.23	0.31	0.25
9	0.31	0.31	0.32	0.34	0.25	0.15	0.14	0.15	0.31	0.24	0.24	0.25
10	0.20	0.29	0.27	0.29	0.39	0.24	0.27	0.26	0.22	0.26	0.23	0.22
Avg.	0.29	0.27	0.28	0.30	0.37	0.22	0.24	0.25	0.28	0.24	0.27	0.25

† Treatments are as described in Table 2.

0.672). However, rate coefficients were significantly different among experiment sites for the decomposition-days (DCD) ($P < 0.001$) and time-in-days (TID) models ($P = 0.012$), although differences in rate coefficients among sites were virtually nonexistent for the Douglas–Rickman model ($P = 0.097$).

CONCLUSION

This study examined four models for describing surface residue decomposition under different crop rotation systems. Results showed that the Douglas–Rickman model may be used to calculate crop residue decomposition in eastern Colorado. In addition, an average rate coefficient may be sufficient for all three experiment sites, given the large variability among crops and years. As Gilmour et al. (1998) had concluded, use of mean estimates of rate coefficients is warranted until the variability of each rate coefficient among crops and years can be explained.

On comparing the Douglas–Rickman model with the DCD and TID models, rate coefficients of the latter two models were significantly different among experiment sites. Such a difference may result in misinterpretation of experiment results. For example, based on DCD simulations, surface residues disappeared fastest at Walsh and slowest at Sterling, while the TID model indicated similar decomposition rates at Stratton and Walsh and lower rates at Sterling. No significant difference in decomposition rates was inferred from the Douglas–Rickman model simulations.

Soil moisture effect on residue decomposition was estimated from rain or crop coverage mainly because of the unavailability of soil moisture measurements in general. The soil moisture factor described by Stroo et al. (1989) may be more appropriate for more rigorous comparison of residue decomposition among the experiment sites and slope positions, especially when crop residue decomposition is simulated within process-based agricultural system models such as the Root Zone Water Quality Model (RZWQM) (Ma et al., 1998; Ahuja et al., 1999; RZWQM, 1999) where daily soil moisture content can be provided by the water transport module.

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REFERENCES

Adamski, J.M. 1976. Simplified Kjeldahl determination of sea water by a semi-automated digestion method. Anal. Chem. 48:1194–1197.

Ahuja, L.R., K.W. Rojas, J.D. Hanson, M.J. Shaffer, and L. Ma (ed.) 1999. Root Zone Water Quality Model: Modeling management effects on water quality and crop production. Water Resources Publ., Highlands Ranch, CO.

Brown, P.L., and D.D. Dickey. 1970. Losses of wheat straw residue under simulated field conditions. Soil Sci. Soc. Am. Proc. 34: 118–212.

Collins, H.P., L.F. Elliott, and R.I. Papendick. 1990a. Wheat straw decomposition and changes in decomposability during field exposure. Soil Sci. Soc. Am. J. 54:1013–1016.

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

Costa, J.L., R.E. Knighton, and L. Prunty. 1994. Model comparison of unsaturated steady-state solute transport in a field plot. Soil Sci. Soc. Am. J. 58:1277–1287.

Douglas, C.L., Jr., R.R. Allmaras, P.E. Rasmussen, R.E. Ramig, and N.C. Roager, Jr. 1980. Wheat straw composition and placement effects on decomposition in dryland agriculture of the Pacific Northwest. Soil Sci. Soc. Am. J. 44:833–837.

Douglas, C.L., Jr., and R.W. Rickman. 1992. Estimating crop residue decomposition from air temperature, initial nitrogen content, and residue placement. Soil Sci. Soc. Am. J. 56:272–278.

Ghidey, F., and E.E. Alberts. 1993. Residue type and placement effects on decomposition: Field study and model evaluation. Trans. ASAE 36:1611–1617.

Ghidey, F., J.M. Gregory, T.R. McCarty, and E.E. Alberts. 1985. Residue decay evaluation and prediction. Trans. ASAE 28: 102–105.

Gilmour, J.T., A. Mauromoustakos, P.M. Gale, and R.J. Norman. 1998. Kinetics of crop residue decomposition: Variability among crops and years. Soil Sci. Soc. Am. J. 62:750–755.

Gregory, J.M., T.R. McCarty, F. Ghidey, and E.E. Alberts. 1985. Derivation and evaluation of a residue decay equation. Trans. ASAE 28:98–101.

Hanson, J.D., J.W. Skiles, and W.J. Parton. 1988. A multi-species model for rangeland plant communities. Ecol. Modell. 44:89–123.

Ma, L., H.D. Scott, M.J. Shaffer, and L.R. Ahuja. 1998. RZWQM simulations of water and nitrate movement in a manured tall fescue field. Soil Sci. 163:259–270.

Peterson, G.A., D.G. Westfall, and C.V. Cole. 1993. Agroecosystem approach to soil and crop management research. Soil Sci. Soc. Am. J. 57:1354–1360.

Peterson, G.A., D.G. Westfall, L. Sherrod, D. Poss, K. Larson, D.L. Thompson, and L.R. Ahuja. 1998. Sustainable dryland agroecosystem management. Colo. Agric. Exp. Stn. Tech. Bull. TB98-1. Colorado State Univ., Fort Collins.

Reinertsen, S.A., L.F. Elliott, V.L. Cochran, and G.S. Campbell. 1984. Role of available carbon and nitrogen in determining the rate of wheat straw decomposition. Soil Biol. Biochem. 16:459–464.

RZWQM. 1999. Root Zone Water Quality Model [Online]. Updated information available at http://www.gpsr.colostate.edu/GPSR/products/rzwqm.htm (verified 17 Apr. 1999).

Schomberg, H.H., and J.L. Steiner. 1997. Comparison of residue decomposition models used in erosion prediction. Agron. J. 89: 911–919.

Schomberg, H.H., J.L. Steiner, and P.W. Unger. 1994. Decomposition and nitrogen dynamics of crop residues: Residue quality and water effects. Soil Sci. Soc. Am. J. 58:371–381.

Smith, J.H., and R.E. Peckenpaugh. 1986. Straw decomposition in irrigated soil: Comparison of twenty-three cereal straws. Soil Sci. Soc. Am. J. 50:928–932.

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.

Stott, D.E., H.F. Stroo, L.F. Elliott, R.I. Papendick, and P.W. Unger. 1990. Wheat residue loss from fields under no-till management. Soil Sci. Soc. Am. J. 54:92–98.

Stroo, H.F., K.L. Bristow, L.F. Elliott, R.I. Papendick, and G.S. Campbell. 1989. Predicting rates of wheat residue decomposition. Soil Sci. Soc. Am. J. 53:91–99.

Unger, P.W. (ed.) 1994. Managing agricultural residues. Lewis Publ., Boca Raton, FL.

Voroney, R.P., E.A. Paul, and D.W. Anderson. 1989. Decomposition of wheat straw and stabilization of microbial products. Can. J. Soil Sci. 69:63–77.

Wood, C.W., G.A. Peterson, D.G. Westfall, C.V. Cole, and W.O. Willis. 1991. Nitrogen balance and biomass production of newly established no-till dryland agroecosystems. Agron. J. 83:519–526.

Wood, C.W., D.G. Westfall, G.A. Peterson, and I.C. Burke. 1990. Impacts of cropping intensity on carbon and nitrogen mineralization under no-till dryland agroecosystems. Agron. J. 82:1115–1120