Residue Decay Evaluation and Prediction

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ABSTRACT

RESIDUE decay prediction is essential for designing effective crop residue management systems. The decomposition of soybean, corn, sunflower and wheat residues was studied under field conditions. After 10 months exposure, residue mass losses were 74, 71, 61, and 36% for soybean, corn, sunflower and wheat residues, respectively. Temperature, moisture, and the initial carbon/nitrogen ratio of the residue were important factors that affected decomposition. The experimental data were also used to check and verify a theoretically derived residue decay model.

INTRODUCTION

Crop residue is useful for erosion control, maintaining soil productivity, and improving soil physical properties. Poor residue management increases soil erosion, plant nutrient losses, and decreases soil productivity. In order to design effective crop residue management systems, it is necessary to determine the amount of residue that is left on the soil throughout the year.

Crop residue decomposition is affected by temperature, moisture, areation, pH, available nutrients, carbon/nitrogen (C/N) ratio, lignin content, and age and size of material (Parr and Papendick, 1978). However, experimental data available in the literature indicate that temperature, moisture, C/N ratio, and location on or within the soil profile are the most important factors (Reddy et al., 1980). Previous researchers have selected certain factors such as temperature, moisture or placement in the soil profile and investigated their individual effects on residue decomposition for particular crops (Waksman and Gerretsen, 1931; Pal and Broadbent, 1975; Parker, 1962; Brown and Dicky, 1970).

Decomposition rates of soybean, corn, sunflower and wheat residues under field conditions are presented in this paper. A residue decay model developed by Gregory et al. (1985) is also verified.

EXPERIMENTAL DESIGN AND PROCEDURE

Residue decay was studied for four crops at Fleetwood Farm, located approximately 13 km southeast of Columbia, MO. Approximately 25 g of soybean, corn, sunflower and wheat residues were placed in 20 x 40 cm fiberglass cloth bags. A total of 60 samples for twelve month's study were prepared for each residue type. All samples were oven dried at 105 °C for 24 h to obtain their initial oven dry weights. On January 30, 1981, the samples were taken to the field and randomly placed on the surface of a silt loam soil in five rows. The ends of the bags were fastened to the soil to prevent their removal by wind. At monthly intervals five samples from each residue type were removed and mass loss was measured.

Residue bags were contaminated with soil particles after commencement of intense rains in March. This contamination caused final weights of the residue bags to be greater than the initial weights. Corrections were made for the addition of soil by analyzing the decay on an ash-free basis. The procedure described by Parker (1962) was followed in the ash percentage determination.

Temperature and precipitation data were collected from the Columbia Regional Airport located approximately seven kilometers from the site. Monthly values of temperature and rainfall are given in Table 1.

The carbon and total nitrogen percentages of the residues were determined by procedures described by Mebius (1960) and Nelson and Sommers (1972), respectively. Mean C/N ratios for soybean, corn, sunflower and wheat were 30.8, 27.8, 39.2 and 107.0 respectively. All residue types contained 38% carbon. Therefore, the C/N ratios varied among the different residue types because of a variable nitrogen percentage. The C/N ratio of corn was low because drought conditions eliminated grainfill and translocation of nitrogen from the stalk to the grain.

Analysis of variance of the data was performed using procedures described by Goodnight (1982). The least significant difference (LSD) was calculated from the error mean square (Snedecor and Cochran, 1980) and used to compare all simple treatment means.

TREATMENT RESULTS

Results from the ANOVA of our data showed that residue type, month, and the interaction term were all highly significant ($P < 0.01$). Because the residue type by month interaction was highly significant, the ensuing discussion explains the difference in residue decomposition among the four residue types over the 10 month study.

Simple treatment means and the results of the least significant difference (LSD) comparisons are shown in Table 1.

By the end of the study, there was no significant difference in the percentage of residue remaining for soybean and corn. However, differences in decomposition rates occurred during the study period. Soybean residue decomposed rapidly during the first

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TABLE 1. RESIDUE REMAINING, MEAN MONTHLY TEMPERATURE AND MONTHLY PRECIPITATION DATA FROM JANUARY 30, 1981 THROUGH NOVEMBER 30, 1981.

Month	Mean monthly temp., °C	Monthly precip., mm	Percent residue remaining			
			Soybean residue	Corn residue	Sunflower residue	Wheat residue
February	0.8	28	89.8 BCD*	92.1 ABC	92.2 ABC	96.5 A
March	6.9	34	87.3 DC	90.0 BCD	89.3 BCD	94.4 AB
April	16.1	139	77.7 E	92.3 ABC	85.3 D	97.9 A
May	15.1	196	71.4 FG	77.7 E	91.8 ABC	93.4 ABC
June	23.6	204	47.5 KL	71.0 FG	74.1 EF	87.9 DC
July	26.6	308	35.8 M	48.1 K	55.3 J	69.9 FGH
August	23.8	63	27.2 N	41.4 LM	60.5 IJ	73.8 EFG
September	20.2	17	29.5 N	40.6 M	58.2 IJ	67.8 GH
October	12.8	102	27.4 N	24.6 N	37.2 M	59.2 IJ
November	8.2	91	25.9 N	28.8 N	38.5 M	63.9 HI

*Numbers followed by different letters are significantly ($P<0.05$) different. All values are directly comparable.

seven months of the study. Little decomposition occurred during the remaining three months of the study, because most of the easily decomposing compounds were gone. In contrast, corn residue decomposed at a slower rate for the first seven months. By August 41.4% of the residue remained. An additional 12.6% of the residue was lost during September, October and November.

About 38.5% of sunflower residue remained at the end of the study, which was significantly ($P < 0.05$) higher than either soybean or corn. Decomposition proceeded slowly until May. In June, almost one-fourth of the total mass was lost; and by the end of July about 45% was decomposed. In August and September, decomposition was quite slow due to dry weather; but increased again in October.

Decomposition was noticeably slower for wheat residue from February until June. Decomposition was rapid in July. By the end of the study about 64% of the total residue mass remained which is significantly higher than the other residue types.

A linear relationship with an R^2 value of 0.95 was obtained between the C/N ratio and the residue remaining at the end of the study. Soybean and corn residues with C/N ratios of 30.8 and 27.8, respectively decomposed more rapidly than wheat residue with a C/N ratio of 107. Therefore, under similar environmental conditions residues with low C/N ratios decompose faster than residues with high ratios.

RESIDUE DECAY MODEL

Experimental evidence indicates that residue decomposition follows first order kinetics described by the following equation:

$$\frac{M}{M_0} = e^{-kt} \qquad [1]$$

where

M_0 = original mass of residue
M = amount of residue at time t
t = time in days
k = first order rate constant.

The above equation doesn't take into account important variables such as temperature, moisture and C/N ratio. Recent models developed by Gilmour et al. (1977) and Reddy et al. (1980) take into account the aforementioned variables. Basically, Gilmour and Reddy's models assumed decomposition to follow first order kinetics. However, the kinetic rate constant, k, was adjusted for changes in temperature, moisture, C/N ratio and method of application. These models are difficult and complicated to apply. Gregory et al. (1985) developed a simple residue decay equation.

The equation was derived based on change in surface area and is given by:

$$\left(\frac{M}{M_0}\right)^{1/2} = 1 - \frac{u\tau}{R_0} \qquad [2]$$

where,

M = present mass of residue
M_0 = initial mass of residue
u = a constant
R_0 = radius of one stem
τ = a weighted time variable adjusted for temperature, moisture and the initial C/N ratio.

The variable, τ, is calculated with the following equation:

$$\tau = \frac{TtA_m}{C/N} \qquad [3]$$

where,

t = time, days
T = temperature (°C above zero)
C/N = initial C/N ratio
A_m = moisture index, mm.

The moisture index, A_m, is estimated using equation [4] as reported by Ligon and Johnson (1960). The time interval was modified from 10 days to 5 days based on the rationale that changes in the index after five days are small compared with the first five days.

$$A_m = \sum_{i=1}^{i=5} \frac{I_i}{i} \qquad [4]$$

where,

I_i = depth of rainfall on a given day, mm
i = the day number with the present day being 1, the previous day being 2, etc.

Equation [4] was modified when used for surface residue. If the residue were initially wet and rainfall exactly matched evaporation rate, then the residue would be maintained at the maximum wetness. Any rainall amount greater than the evaporation rate would not increase the wetness and thus should not increase decay

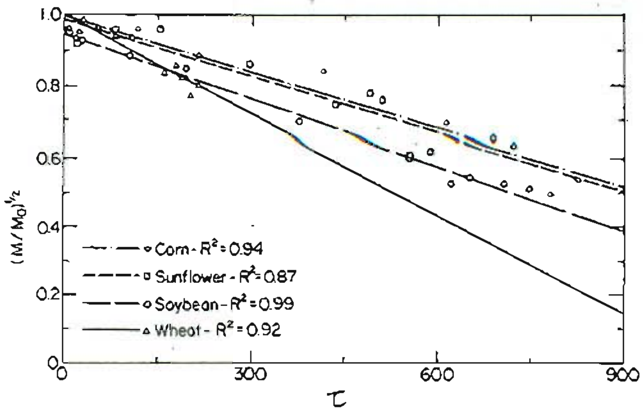

Fig. 1—Scatter diagram of data and the results obtained with linear regression for the prediction equation.

rate. The moisture index, A_m, computed based on the rainfall equal to the evaporation rate, should represent a reasonable upper limit for surface residue where moisture storage is minimum. Gregory et al. (1985) assumed that the average potential evaporation rate was 4 or 5 mm per day. If rainfall exactly replaces the evaporation amount, then A_m would be 9.1 mm and 11.4 mm for the 4 mm and 5 mm rainfalls per day, respectively. Based on these estimates an average A_m value of 10 mm was used as the upper limit for the moisture index.

MODEL EVALUATION

The residue decay model given in equation [2] was checked using the measured data. Since the residue samples contained both stem and leaf materials, R_o could not be measured directly. The constant u and R_o were lumped together and treated as a constant for a given residue type. Ghidey (1982) described the computational methods of the various parameters. The equation was treated as a linear regression model. The square root of the ratio of the residue remaining to the original mass of residue $[M/M_o]^{1/2}$, was the dependent variable; while the factor τ was the independent variable of the model. A scatter diagram with linear regression lines is shown in Fig. 1. The intercept, slope (u/R_o) and R^2 values obtained for the model are given in Table 2.

Generally the model explained the measured results well. The coefficients of determination, R^2, obtained were all close to one and significant at the 99% probability level in all cases. The intercept values were also close to the theoretical value of one. Soybeans had the lowest intercept value and can be explained by the fragile nature of the soybean leaves in the sample. It was noticed that small fragments of soybean leaves fell from the sample bags during transport to the field. While a relatively small amount was lost in this way, it would affect all soybean samples and could account for the lower intercept. The first rain in the field could also have provided mechanical action to further accelerate the loss of fine leaf particles.

TABLE 2. R^2 VALUES AND THE EQUATIONS OBTAINED FROM THE RESIDUE DECAY MODEL FOR SOYBEAN, CORN, SUNFLOWER AND WHEAT RESIDUES.

Crop Residue Type	Equation	R^2
Soybean	$\left(\frac{M}{M_o}\right)^{1/2} = 0.947 - 0.000623\,(\tau)$	0.99
Corn	$\left(\frac{M}{M_o}\right)^{1/2} = 0.998 - 0.000536\,(\tau)$	0.94
Sunflower	$\left(\frac{M}{M_o}\right)^{1/2} = 0.985 - 0.000539\,(\tau)$	0.87
Wheat	$\left(\frac{M}{M_o}\right)^{1/2} = 1.000 - 0.000955\,(\tau)$	0.92

Because it takes initial radius into consideration, the value of u/R_o is not the same for different crop residue types. Residues with smaller R_o are expected to have greater u/R_o values than residues with larger R_o. Values for u/R_o in the above equations agree with this statement. The u/R_o values for corn and sunflower are almost equal. The stem size is also similar for these two plants. The u/R_o value for wheat was larger than the other residue types and may be due to the hollow nature of wheat straw (more surface area per mass).

According to the model, the value of the constant, u, must be the same for all crop residue types. However, u has not been evaluated because the initial radius of the residue was not measured. For further verification of the equation, the value of u must be checked to evaluate if it is the same for different residue types. Nevertheless, because of the good fit of the model to the data (R^2 values of 0.87 to 0.99), the residue decay equation stated in equation [2] is considered to be adequate for prediction of residue decay for soybean, corn, sunflower and wheat.

APPLICATION OF RESIDUE DECAY MODEL FOR FIELD CONDITIONS

A computer program was written to evaluate the C factor in the Universal Soil Loss Equation. The program estimates the residue amount at harvest time, residue decay rate, fraction of residue cover, fraction of green cover, period C-factor, period soil loss rate and annual C-factor. The residue decay model in equation [2] was used in the program to estimate the residue decay rate.

When the equations given in Table 1 were used directly, the computer program predicted a relatively slow decay of residue causing a buildup of residue from one year to another. The data of Parker (1962) was analyzed and a u/R_o value 2.2 times larger than 0.000536 for corn was obtained. This value gave good results in the program. The values of u/R_o for soybean, corn, sunflower and wheat were thus adjusted by a factor of 2.2. The experimental procedure of placing residue in bags on hard, untilled surface did not provide the soil contact normally experienced with surface residue which may explain why the u/R_o value had to be adjusted. C-factors obtained with the computer model using the larger adjusted u/R_o values closely match the C-factors used by the University of Missouri Extension Department for northern Missouri (Steichen, 1976). Based on this comparison, the u/R_o values given in Table 2 should be multiplied by a factor of 2.2 when predicting residue decay in the field.

SUMMARY AND CONCLUSIONS

The decomposition of soybean, corn, sunflower, and wheat residues was studied under field conditions at the University of Missouri-Columbia. The effects of temperature, moisture and initial carbon/nitrogen ratio of the residue were evaluated. The study showed that high temperature and moisture result in rapid decomposition rates. Decomposition was also affected by the initial carbon/nitrogen ratio of crop residue. In the same environment, residues with low carbon/nitrogen ratios decomposed more rapidly than residues with higher carbon/nitrogen ratios. Wheat residue with a high ratio (107.0) decomposed at a significantly ($P < 0.05$) lower rate than soybean (30.8) and corn (27.8) residues. A residue decay equation developed by Gregory et al. (1985) was also evaluated using the measured data. The equation was determined to be an adequate residue decay model.

References

1. Brown, P. L. and D. T. Dickey. 1970. Losses of wheat straw residue under simulated conditions. Soil Sci. Soc. Am. Proc. 34:118-121.

2. Ghidey, F. 1982. Developing crop residue model to evaluate the C-factor in the Universal Soil Loss Equation. Unpublished Master's thesis. University of Missouri-Columbia.

3. Gilmour, C. M., E. F. Broadbent and S. M. Beck. 1977. Effects of waste application on soil carbon and nitrogen cycles. pp. 173-194. In: L. F. Elliot and F. J. Stevenson (ed.) Soils for management of organic waste and waste matters. Soil Sci. Soc. of Am., Madison. WI.

4. Goodnight, J. H. 1982. ANOVA p. 119-137. In A. A. Ray (ed.) SAS User's Guide: Statistics, 1982. SAS Institute, Cary, NC.

5. Gregory, J. M., T. R. McCarty, F. Ghidey and E. E. Alberts. 1985. Derivation and evaluation of a residue decay equation. TRANSACTIONS of the ASAE 28(1):this issue.

6. Ligon, J. T. and H. P. Johnson. 1960. Infiltration Capacities of Fayette Silt Loam from Analysis of Hydrologic Data. TRANSACTIONS of the ASAE 3(1):36, 37.

7. Mebius, L. J. 1960. A rapid method for determination of carbon in soil. Analytica. chemical. ACTA. 22:120-124.

8. Nelson, D. W. and L. E. Sommers. 1973. Determination of total nitrogen in plant material. Agron. J. 65:109-111.

9. Pal, D. and F. E. Broadbent. 1975. Influence of moisture on rice straw decomposition in soils. Soil Sci. Soc. Am. Proc. 39:59-63.

10. Parker, D. T. 1962. Decomposition in the field of buried and surface applied cornstalk residues. Soil Sci. Soc. Am. Proc. 26:559-562.

11. Parr, J. F. and R. I. Papendeck. 1978. Factors affecting the decomposition of crop residues by microorganisms. pp. 101-129. In: W. R. Oschwald (ed.) Crop residue management systems. Am. Soc. Agron., Madison. Wisconsin.

12. Reddy, K. R., R. Khaleel and M. R. Overcash. 1980. Carbon transformation in the land areas receiving organic wastes in relation to nonpoint source pollution. A conceptual model. J. Environ. Qual. 9:434-442.

13. Snedecor, G. W. and W. G. Cochran. 1980. Statistical Methods. Seventh edition. The Iowa State University Press, Ames, IA.

14. Steichen, J. M. 1976. Estimating Soil losses in Northern Missouri. Science and Technology Guide. Published by University of Missouri-Columbia, Extension Division.

15. Waksman, S. A. and F. C. Gerretsen. 1931. Influence of temperature and moisture upon nature and extent of decomposition of plant residues by microorganisms. Ecology, 12:33.