DIVISION S-6—SOIL & WATER MANAGEMENT & CONSERVATION

Nutrient Dynamics of Crop Residues Decomposing on a Fallow No-Till Soil Surface

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ABSTRACT

Conservation practices retain crop residues on the soil surface that affect nutrient distribution in time and space. We hypothesized that nutrient mineralization from surface residues may not be correlated to mass loss but may depend on crop type and water availability. Frequent, moderate, and no irrigation were used to evaluate water effects on N, P, K, and mass dynamics of alfalfa (*Medicago sativa* L.), corn (*Zea mays* L.), grain sorghum [*Sorghum bicolor* (L.) Moench], spring and winter wheat (*Triticum aestivum* L.). Residues (20 g) in 10 by 10 cm, 1-mm mesh bags were placed on a Pullman clay loam (fine, mixed, thermic Torrertic Paleustolls) at Bushland, TX, in August 1991 and collected monthly until August 1992. Water regime did not influence mass, N, or P dynamics but did affect K. Mass declined exponentially with decomposition coefficients ($-r$) of 4.4, 1.5, 2.0, 1.7, and 1.1 g kg^{-1} d^{-1} for the five crop residues listed above, respectively. Potassium loss was first order with $-r$ ranging from 29.3 to 4.4 g kg^{-1} initial K d^{-1}, depending on crop and water. Averaged across water regimes, $-r$ equaled 25, 9, 8, 12, and 7 g kg^{-1} initial K d^{-1} for the respective crops. The water effect indicated 150-mm water removed 500 g kg^{-1} initial K from residues. Residue N declined from 38.7 to 16.0, 10.9 to 5.1, 12.2 to 6.4, 9.5 to 4.5, and from 7.6 to 3.4 g kg^{-1} during the first 34 d for the respective crop residues, after which nonlegume residues accumulated N (0.21 to 0.96 g kg^{-1} initial N d^{-1}), while alfalfa lost N (−0.37 g kg^{-1} initial N d^{-1}). Corn and winter wheat residue P increased from 0.7 to 1.2 and 0.5 to 1.0 g P kg^{-1}, respectively, during the first 34 d, after which all residues lost P (−1.4, −2.1, −1.3, −2.0, and −2.8 g kg^{-1} initial P d^{-1}, respectively). Nutrient dynamics were not directly related to mass loss. Water regime effects were small, so nutrient availability from residues should be similar in irrigated and dryland systems in the southern High Plains.

RESIDUE MANAGEMENT has become an important component of conservation tillage systems because surface residues help reduce water loss and soil erosion. Distribution of nutrients within the soil profile is altered in reduced tillage systems when compared with conventional tillage systems (Hargrove, 1985; Unger, 1991). Stratification of nutrients within the soil profile of no-till systems may positively affect crop production and result in beneficial changes in soil physical properties (Bruce et al., 1995). Because surface residues decompose slower than incorporated residues (Douglas et al., 1980), there is a stratification of nutrients across time as well as space. Uneven distribution of residues by mechanical harvesters had a detrimental effect on nutrient availability to subsequent crops that was equivalent to poor distribution of fertilizer inputs (Douglas et al., 1992). Nutrient release from residues may play an equally important role in crop productivity through the effects of timing on nutrient availability.

Several factors affect residue decomposition with the most important in agricultural systems being water, temperature, and residue properties such as N, cellulose, and lignin contents. The water regime of surface-placed residues is much different than that of incorporated residues (Douglas et al., 1980; Schomberg et al., 1994). Surface residues are subject to more frequent and extreme wetting and drying events than incorporated residues, which may alter the pattern and degree of residue decomposition (Franzluebbers et al., 1994). Wetting events can result in significant losses of soluble components from surface residues. Mass and nutrient losses ≤25% have been observed from surface residues during the first 30 d in the field (Douglas et al., 1980; Christensen, 1986; Collins et al., 1990). Decomposition rates usually decrease after initial losses of soluble C and other components (Christensen, 1985; Collins et al., 1990) because soluble carbohydrates serve as energy sources for the subsequent breakdown of more complex celluloses and lignins (Reinertsen et al., 1984).

Most studies of residue dynamics have focused on changes in N and C, while only a few have evaluated changes in P (McLaughlin et al., 1988a, b, and c; Berg and McClaugherty, 1989; Sharpley and Smith, 1989; Buchanan and King, 1993) or K (Christensen, 1986) of decomposing residues. None of these studies evaluated multiple crop species decomposing under irrigated and nonirrigated field conditions or in an environment similar to that of the southern High Plains. Understanding water regime effects on surface-residue nutrient losses and residue decomposition is important when evaluating productivity of conservation tillage systems. This is especially true for the southern High Plains where under dryland conditions, crop and residue production is water-limited, but with irrigation nutrient availability becomes more important. Our objective was to evaluate water regime and crop effects on nutrient dynamics of surface residues.

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Abbreviations: $-r$, exponential decay coefficient; W1, water regime that received 50 mm of irrigation at 7- to 21-d intervals during the spring and summer; W2, water regime that received 50 mm of irrigation every other time W1 received irrigation; W3, water regime that was not irrigated.

MATERIALS AND METHODS

Field Procedures

Mass loss and nutrient dynamics of five crop residues were determined monthly from September 1991 to August 1992. The study was conducted on a Pullman clay loam at the USDA-ARS Conservation and Production Research Laboratory, Bushland, TX. Corn, grain sorghum, winter and spring wheat stem and leaf material were collected from conventional tillage research areas that were irrigated and had adequate fertility and good weed control. Alfalfa that was near full bloom was harvested from a hay production area during the first week of July 1991. The alfalfa was not mature residue, so it is considered different from the other crop materials. Corn residue was collected from irrigated plots following grain harvest during fall of 1990. Corn grain yield was 8400 kg ha^{-1}. Grain sorghum residue was collected from irrigated plots after grain fill in fall of 1990. Grain sorghum yield was 7280 kg ha^{-1}. Spring and winter wheat residues were collected from irrigated plots 1 wk prior to harvest in June 1991. Spring wheat yield was 2420 kg ha^{-1} and winter wheat yield was 3450 kg ha^{-1}.

Residues were dried 3 to 5 d at 55 to 60°C at the time of collection and again for 1 d at 55°C prior to processing. Residues were chopped into 6- to 9-cm lengths and weighed (20 g) into 10 by 10 cm, 1-mm mesh gray polypropylene bags. Nonlegume residues consisted of a mixture of leaf and stem material at a ratio of 1 to 2, while alfalfa was used as whole clusters of leaves and stems.

Residues were placed within three water regime treatments of a larger experiment evaluating changes in standing residue, surface cover, and mass to cover relationships for small grains (Steiner et al., 1994). The three water regimes were established on 12 by 22 m plots as follows: W1 received 50 mm irrigation at 7- to 21-d intervals during the spring and summer, W2 received 50 mm irrigation every other time W1 received irrigation, and W3 was not irrigated. Irrigation was applied as overland flow from 30-cm gated pipe. The N content of the water was usually less than 1.5 μg mL^{-1} (A.D. Schneider, 1998, personal communication). There were three replications of each water regime.

Bags of each crop residue were placed on the soil surface between rows of standing winter wheat residue on 31 July 1991. Enough bags were placed in the plots so that one bag of each residue could be removed from each treatment-replication at ≈30-d intervals. Soil samples to 25 mm were collected from the areas where the residues were placed on 31 July 1991 for chemical characterization.

Air temperatures inside the mesh bags and in the wheat residue layer adjacent to the bags were measured at 15-min intervals with thermocouples and a data logger. Average daily temperatures inside the residue bags and within the adjacent wheat residue were usually within ±0.5°C and never varied more than ±2°C (data not shown).

Mass Loss

Mass remaining at each sampling date was estimated from the moist weight of residues, moisture content of a subsample dried for 24 h at 55°C, and subsample ash content after ashing in a muffle furnace at 475°C for 4 h. Ash content was used to adjust weights for any soil adhering to residues. This procedure was used because microbial activity was also measured on residues (Schomberg and Steiner, 1997). Mass loss is expressed as ash-free dry matter remaining (g kg^{-1}), estimated as described by Christensen (1985). Mass loss data were previously reported with microbial activity data (Schomberg and Steiner, 1997).

Table 1. Initial nutrient and ash content of the soil and crop residues.

Material	C†	N	P	K	Ash
	g kg^{-1}				
Soil	7.9	0.68	0.01	0.62	975.5
Alfalfa	nd	38.78	2.36	25.74	63.7
Corn	nd	10.98	0.73	11.35	59.9
Grain sorghum	nd	12.24	1.07	19.95	90.4
Spring wheat	nd	9.57	1.05	14.89	78.8
Winter wheat	nd	7.65	0.45	4.04	53.1

† C content determined for soils only; nd indicates not determined.

Nutrient Analysis

Nitrogen, phosphorous, and potassium were determined on oven-dried (55°C for 48 h) residues ground to pass a 1-mm sieve. Total N and P were determined in Kjeldahl digests (Nelson and Sommers, 1973; Olsen and Sommers, 1982) on a Technicon[1] Autoanalyzer AAII (Technicon Inc., 1977). Potassium was determined on the ashed subsample (see above). After ashing, 1 mL of HNO_3 was added to the ash and then diluted with H_2O. Potassium was determined by atomic absorption spectroscopy (Isaac and Johnson, 1975) on a Perkin Elmer Model 303 (Perkin Elmer, Norwalk, CT). Soil samples (25 mm depth) collected at the beginning of the study were analyzed for N, P, and K in the same manner as the residues. Soil C was determined by the Walkley-Black method (Nelson and Sommers, 1982). Soil nutrient and ash contents were used to correct residue nutrient contents following the procedure described by Christensen (1985).

Corrected nutrient content, $Z_{corrected}$ (Z is N, P, or K), was calculated using the following series of equations. First, the contribution of soil to the sample ash content was calculated by correcting for ash remaining from the initial residue material (Eq. [1]).

$$g\ ash_{from\ soil} = g\ ash_{from\ sample} - [g\ ash_{from\ initial\ residue} \times (1 - g\ ash_{from\ sample}/g\ sample)] \quad [1]$$

Nutrient content of soil from Table 1 was used in Eq. [2] to calculate the quantity of nutrient attributable to soil (Z_{soil}).

$$g\ Z_{soil} = (g\ Z\ g^{-1}\ soil)_{initial} \times g\ ash_{from\ soil} \quad [2]$$

Corrected residue nutrient content was calculated by subtracting Z_{soil} from the uncorrected sample nutrient content.

$$g\ Z_{corrected} = g\ Z_{total\ sample} - g\ Z_{soil} \quad [3]$$

Nutrient content remaining was calculated as g $Z_{corrected}$ kg^{-1} Z in initial residue.

Statistical Analysis

Crop, water, and time effects on residue properties were analyzed with the Statistical Analysis System (SAS Institute, 1988 and 1989) using repeated measures, linear and non-linear regression, and analysis of variance. Repeated measures analysis was used to evaluate nutrient and mass changes over time because measurements taken close together in space or time may be more highly correlated than measurements taken far apart, and certain conditions must be met by the correlations between these measurements for standard univariate F tests to be valid (Littell, 1989). Evaluation is made as a sphericity test using the REPEATED option in the GLM procedure of the Statistical Analysis System (SAS Institute, 1989). A significant sphericity test indicates a correlation among observations is present and univariate analysis is not appropriate without certain adjustments. A highly significant sphericity

[1] The mention of trade or manufacture names is made for information only and does not imply an endorsement, recommendation, or exclusion by the USDA-Agricultural Research Service.

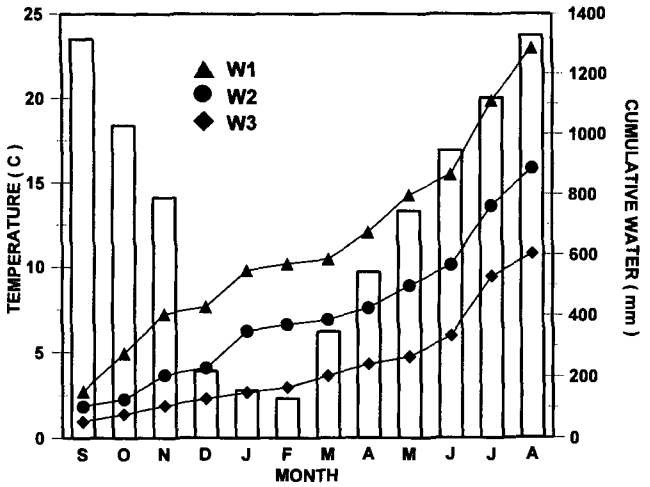

Fig. 1. Cumulative rain and irrigation (lines) for the three water regimes and mean air temperature (bars) for each period. W1 was frequently irrigated; W2 was irrigated at half the frequency of W1; and W3 was not irrigated.

test ($P < 0.01$) indicates adjustments should not be made and multivariate analysis is recommended (Littell, 1989). The sphericity test is not relevant to validity of univariate analysis of other treatments (in this case crop and water regime).

When time effects were significant, relationships were developed to describe change in nutrient content or residue mass using linear or nonlinear regression. Choice of linear or nonlinear regression is described in the text. Linear relationships were evaluated using the REG procedure in SAS/STAT (SAS Institute, 1989), while first order rate decay coefficients were estimated for nonlinear relationships using the MODEL procedure in SAS/ETS (SAS Institute, 1988). All linear and nonlinear relationships were determined using the individual data. The first order decay equation is,

$$X_t = X_0 \times \exp(-r \times t) \quad [4]$$

where X_t is mass (g kg^{-1} initial residue) or nutrient (g kg^{-1} initial nutrient in residue) remaining at time t (d), X_0 is initial quantity of X, and $-r$ is the decay coefficient (d^{-1}). Differences among coefficients were compared by subjecting estimated $-r$ to analysis of variance in the ANOVA procedure of SAS/STAT (SAS Institute, 1989; Littell, 1989).

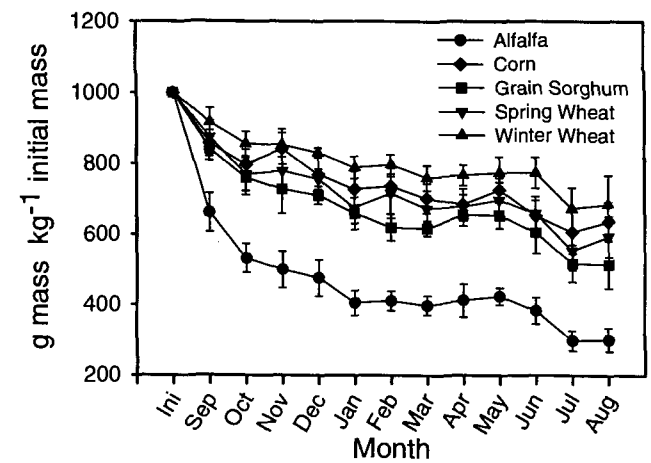

Fig. 2. Mass loss of five crop residues decomposing on the soil surface. Each point represents the mean averaged over water regime and replication (n = 9). Bars represent the standard deviation of the mean value.

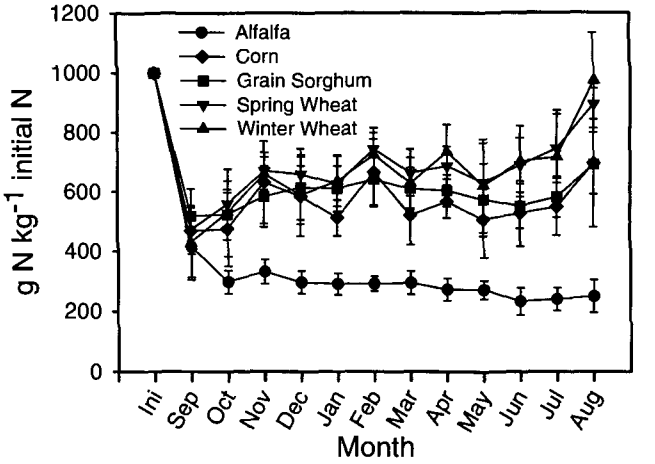

Fig. 3. Change in N content of five crop residues decomposing on the soil surface. Each point represents the mean averaged over water regime and replication (n = 9). Bars represent the standard deviation of the mean value.

RESULTS

Initial nutrient and ash contents of residues and soil are presented in Table 1. Nitrogen content of alfalfa was greater than other residues because it was collected prior to full maturity. Soil ash content indicates an accumulation of partially decomposed residues near the surface from prior conservation tillage. Accumulation of water (rain + irrigation) for each treatment and average air temperature for periods between sampling are presented in Fig 1.

Changes in residue mass, N, P, and K are presented as a fraction of initial quantity remaining (g kg^{-1}) in Fig. 2 through 5. Both physical and biological mechanisms were responsible for noted changes in mass and nutrient concentrations. Physical losses occur through leaching and comminution of residues by soil fauna. Biological changes primarily result from microbial activity. Separation of microbial biomass from the decomposing residues was not possible, so measured values represent nutrient contents of residue and associated microbial biomass. The sphericity test in Table 2 indicated highly significant correlation among measure-

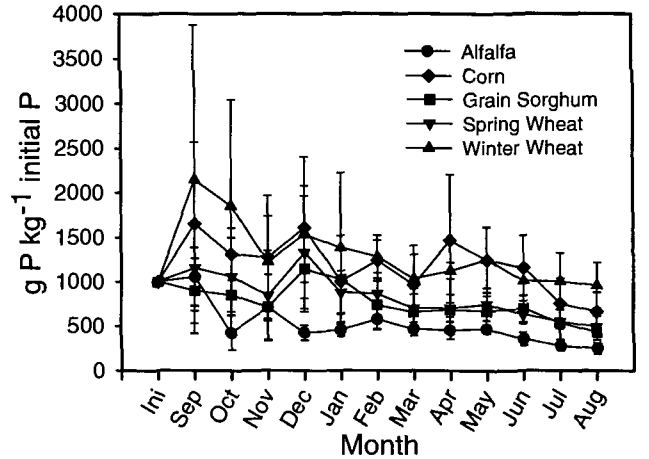

Fig. 4. Change in P content of five crop residues decomposing on the soil surface. Each point represents the mean averaged over water regime and replication (n = 9). Bars represent the standard deviation of the mean value.

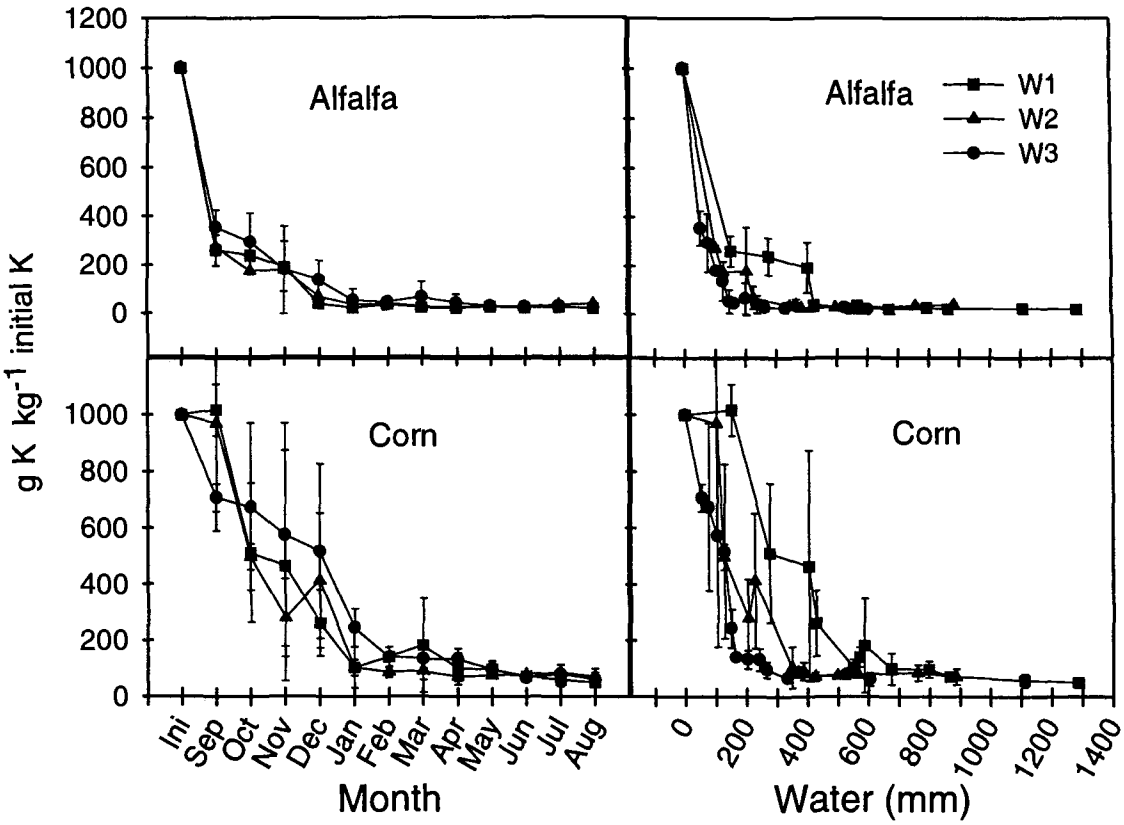

Fig. 5. Change in K content of alfalfa and corn residues decomposing on the soil surface in three water regimes. Means for each replication are plotted against time and cumulative water. Each point represents the mean averaged over replications (n = 3). Bars represent the standard deviation of the mean value. W1 was frequently irrigated; W2 was irrigated at half the frequency of W1; and W3 was not irrigated.

ments taken over time for biomass, N, P, and K. Therefore, multivariate analyses were used for evaluating time and time interactions with crop and water regime. Changes in mass, N, P, and K differed among crops, as indicated by significant time and crop interactions. Only K had a significant time and water interaction, and there were no significant water by crop or three way interactions. Figures 2 through 4 show mean mass, N, and P remaining for each crop, averaged across water regimes, while Fig. 5 illustrates K remaining for alfalfa and corn for each water regime. Time by crop and time by water interactions were further evaluated by nonlinear and linear analyses.

Table 2. Repeated measures analysis for crop, water, and time effects on nutrient and mass changes in crop residues.

Effect	Biomass	N	P	K
		$P > F$		
Crop†	0.0001	0.0001	0.0001	0.0001
Water	0.30	0.087	0.63	0.0013
Crop by water	0.17	0.69	0.92	0.35
Error A‡	0.0026	0.0151	0.2472	0.032
Time§	0.0001	0.0001	0.0001	0.0001
Time by crop	0.0001	0.0004	0.0014	0.0001
Time by water	0.1900	0.42	0.08	0.0017
Time–crop–water	0.75	0.49	0.81	0.1194
Error B‡	0.0018	0.0079	0.2106	0.0163
Sphericity	0.0001	0.0001	0.0001	0.0001

† Crop, water, and crop by water effects are from the repeated-measures univariate analysis.
‡ Errors A and B are the mean square errors from the repeated-measures univariate analysis.
§ Time and time interaction effects are the Wilk's λ results from the repeated-measures multivariate analysis that used error values derived from the error sums of squares and cross products.

Mass Loss

Mass changes in time were evaluated with nonlinear regression because losses appeared to follow first order decay kinetics (Fig. 2). Since no water effects were significant, as indicated by repeated measures analysis, decay coefficients were determined for each crop using each crop–water replication combination, thereby giving nine coefficients for evaluating differences in mass loss. Coefficients were similar across water regimes for each crop, which supports the repeated measures analysis that indicated no water regime effects on mass loss (data not shown). Rate of mass loss for alfalfa was greater than for nonlegume residues (Table 3). Among the nonlegume residues, mass loss coefficients tended to increase with initial N content. The difference in decomposition between spring and winter wheats should be noted, since they were grown in the same area with similar fertility and irrigation and were harvested at the same time, but N content of spring wheat was 25% greater than winter wheat, indicating differences in retention of N within stem and leaf residues. Douglas et al. (1980) showed that decomposition of wheat residues increased as N content of residues increased, but their study focused on wheat residues grown under different fertility conditions. Our results support those of Smith and Douglas (1970) and Brown and Dickey (1970), who

Table 3. Exponential coefficients estimated for mass and K loss of five crop residues decomposing on the soil surface at Bushland, TX.

	Mass		K					
			W1		W2		W3	
	$-r$†	STD‡	$-r$	STD	$-r$	STD	$-r$	STD
Alfalfa	4.4	0.24	28.6	7.3	29.3	4.8	20.9	2.3
Corn	1.5	0.12	9.5	3.0	10.3	2.6	7.7	1.3
Grain sorghum	2.0	0.12	7.5	1.9	8.5	1.9	7.0	1.6
Spring wheat	1.7	0.14	13.7	3.5	19.0	6.0	9.8	4.2
Winter wheat	1.1	0.10	7.9	2.7	7.8	0.7	4.4	0.3
LSD§ α = 0.05	0.1				5.6¶			

† $-r$ = Mean rate decay coefficient determined for Eq. 4 where time is days in the field. Coefficients were calculated for each crop using each crop water replication combination and then averaged (n = 9 for mass and n = 3 for K).
‡ STD is the standard deviation of the $-r$ mean.
§ LSD is the least significant difference.
¶ LSD for comparison of K among all water and crop combinations.

showed that differences in nutrient retention between similar crops result in different decomposition rates.

Nitrogen

Change in N content was different for the five crops (Fig. 3). Since the repeated measures analysis indicated no water effects for N, regressions were determined for each crop using data from all three water regimes (Table 4). Nitrogen content of all residues declined nearly 50% during the first 34 d in the field (Fig. 3). This large loss of N probably was associated with leaching. We did not measure water soluble N content of initial residues, but significant losses of soluble components have been noted by Christensen (1985 and 1986) and Schreiber (1985). Nearly 60% of the N in alfalfa was lost during the first 34 d. Initial N concentration was not included in regressions because of the significant early losses that we attribute to soluble components. Regressions were determined for September through August because changes in nutrient content during the first 34 d were the result of processes not captured by our sampling interval, and because comparison among residues is simpler for the major portion of time residues were in the field. After 34 d N continued to be lost from alfalfa residues, while N accumulated in other residues, as indicated by the positive slopes of regression lines in Table 4. Slopes were significantly greater than zero (Table 4). Although regressions were significant, they explained only a small portion of the change in N content of residues, probably because of initial variability. Slopes of regressions for nonlegumes tended to increase with decreasing initial N content, which indicated N was being immobilized to a greater extent by microorganisms in lower-N residues. Corn and grain sorghum had similar slopes, as did the two wheat residues. Final N content of residues expressed as g N kg^{-1} residue-remaining were 6, 12, 16, 15 and 11 for alfalfa, corn, grain sorghum, spring and winter wheat, respectively.

Phosphorus

Change in P concentration was significantly different among different crop residues (Table 4). Like the results with N, there were no significant water effects for P, so

Table 4. Linear regression coefficients for change in N and P concentrations of five crop residues estimated against time in the field.†

Crop/Nutrient	Intercept	SE-int.‡	Slope	SE-slope	$P > \|T\|$§	R^2¶	RMSE#
N							
Alfalfa	365	11	−0.37	0.05	0.0001	0.34	52
Corn	492	23	0.29	0.10	0.0054	0.07	108
Grain sorghum	548	22	0.21	0.10	0.0345	0.03	104
Spring wheat	519	21	0.74	0.10	0.0001	0.36	103
Winter wheat	471	29	0.96	0.13	0.0001	0.36	134
P							
Alfalfa	786	42	−1.43	0.18	0.0001	0.37	195
Corn	1613	114	−2.07	0.50	0.0001	0.14	537
Grain sorghum	1021	69	−1.29	0.31	0.0001	0.14	325
Spring wheat	1229	74	−1.95	0.33	0.0001	0.25	350
Winter wheat	1888	15	−2.82	0.66	0.0001	0.15	699

† The regression equation was Nutrient remaining (g kg^{-1}) = intercept + slope × days. All data were used to determine the regression equation parameters.
‡ SE is the standard error of the coefficient; int is the intercept.
§ $P > |T|$ indicates the possibility that the slope is different from 0.
¶ R^2 is the adjusted R square.
# RMSE is the root mean square error.

regressions were determined for each crop using data from all three water regimes. There was a general loss of P from all residues, particularly after the first sampling date (Fig. 4). The initial P concentration was not used in regressions for comparing residues because of apparent immobilization of P by microbial biomass associated with corn and winter wheat residues. Of the five residues, only corn and winter wheat had significant changes in P content between initial and September samplings (t-test, data not shown). Apparently, the amount of P available in these two residues was below the amount required by microorganisms involved in decomposition, so P was taken up from the soil. The amount of P was near 1.0 g P kg^{-1} of residue for corn and winter wheat in September, which is similar to initial P levels in other residues (Table 1). Changes in P content varied among residues and showed greater variability between sampling dates than other nutrients (Fig. 4 and Table 4). Some of this variability was probably associated with soil accumulation on and in the residues. Differences in accumulation of fine organic material or soil particles could have differentially affected P measurements. This effect would not be accounted for by the general correction for soil P and ash.

The rate of P loss was similar for alfalfa and grain sorghum and for corn and spring wheat. Winter wheat had the fastest rate of P loss, as indicated by regression slopes (Table 4). As with N, regressions explained only a small amount of the variability in P loss.

Potassium

Potassium losses were influenced by both crop and water interactions with time (Table 2). Data for alfalfa and corn in Fig. 5 are representative of changes observed for other crops. Loss of K from residues declined exponentially, so rate loss coefficients were determined using Eq. [4] for each crop–water combination (Table 3). Potassium losses were rapid between initial field placement and sampling in January. Rate loss coefficients indicated

faster K loss by alfalfa residue than by other residues (Table 3). Faster loss of K from alfalfa was probably related to immaturity of the plant material. The rate of K loss was greater for spring wheat than for winter wheat and grain sorghum. Winter wheat appeared to retain more K at latter sampling dates than other residues (Fig. 5). When evaluating K losses among water regimes, coefficients were greater for irrigated (W1 and W2) than for nonirrigated residues (W3) (Table 3 and Fig. 5). Differences in cumulative water among water regimes (Fig. 1) explain some of the results. For an accumulation of 250-mm water, W1 required 2 mo, W2 required 5 mo, and W3 required 10 mo. Rate loss values averaged across crops indicate similar loss rates for W1 and W2 (13.4 and 14.9 g kg^{-1} d^{-1}) and a slower rate for W3 (9.9 g kg^{-1} d^{-1}). There was a trend for residues from W2 to have lower K contents at the first three sampling dates, but the differences were small. The slightly slower rate for W1 compared to W2 is surprising since it received more irrigations and total water. These small differences may be related to frequency of residue wetting and drying since residues in W1 were occasionally rewetted prior to complete drying of the soil surface. Residues in W3 experienced less frequent wetting and drying than those in W2.

An additional confounding factor for water regime effects is illustrated in Fig. 5 where K loss is plotted against cumulative water. Potassium loss was less per unit of water applied in the more frequently irrigated treatment (W1). Similar differences among water regimes were observed for all crops. In our calculations of cumulative water we gave credit for the full amount of water applied in W1, but the effectiveness was probably less, a result that is also indicated in the data of Schreiber (1985). From the data for W2 and W3 in Fig. 5 it appears that ≈150 mm of water reduces K content of residues by 50 percent.

DISCUSSION

Mineral N loss from residues during the first 34 d were similar to results observed by Christensen (1986) and is probably due to leaching. Subsequent N increases in nonlegume residues indicate the microbial community was immobilizing N from soil. Nitrogen contributions from irrigation water were not apparent since there was no difference in N concentration among water regimes. Nitrogen content of the irrigation water was less than 1.5 μg mL^{-1} N as NO_3^-, which would have contributed ≈1.02 g N m^2 to W1 plots for the entire year. Holland and Coleman (1987) found an increase in N content of surface and buried wheat straw residues over a 425-d period. They attributed N accumulation in surface residues to an abundance of fungal decomposers and hypothesized that hyphal bridges between soil and straw allowed use of soil N and residue C during decomposition. Microbial biomass levels near the soil surface have been related to greater immobilization of fertilizer N in no-tillage systems compared with conventional or shallow tillage practices (Wagger et al., 1985; Carter, 1992; Beare et al., 1992). Some N accumulation in residues may have occurred by biological N_2 fixation (Roper, 1985), sorption of fixed N gases from the atmosphere, deposition from rain or soil, or movement of N to the soil surface with water (Parker et al., 1957). Although we did not observe net immobilization in this study, previous studies at this location indicate that microbial immobilization of N in surface-placed nonlegume residues can range from 10 to 15 kg N ha^{-1} after 1 yr (Schomberg et al., 1994).

In a wheat–sorghum–fallow cropping system, most of this N would be immobilized during fallow periods. Immobilization of soil N within surface residues may eventually have a positive influence on subsequent crop growth because N remains in the root zone for later net mineralization. Wagger et al. (1985) found that 12 to 15% of wheat and 12 to 33% of grain sorghum residue-N was mineralized from incorporated residues after one cropping season in Kansas. Slow mineralization was beneficial because the subsequent wheat and sorghum recovered 79 and 82% of the mineralized N, respectively. Our results indicate that leaving residues on the surface affects N mineralization–immobilization similarly under both dryland and irrigated conditions. However, immobilizing N during non-cropped periods may be more important with irrigation, because N demand of irrigated crops is greater than that of dryland crops.

Phosphorous measurements for the nonlegumes indicated a steady decline through time that appeared to be related to microbial degradation. In contrast, loss of P from alfalfa was very rapid during the early phase of decomposition. Others have found that loss of P may not be equated with mass loss because inorganic P present in residues is susceptible to leaching loss (McLaughlin et al., 1988c; Sharpley and Smith, 1989; Buchanan and King, 1993). Sharpley and Smith (1989) found that inorganic P leaching was greater from soils with surface residues than from soils with incorporated residues, while the opposite trend was observed for organic P. Immobilization of P during the initial incubation period was apparent for both residue placements. Buchanan and King (1993) observed exponential rates of P loss from corn, wheat, and soybean residues on the surface in no-till systems. Losses of P and C were not highly correlated, as indicated by variable C to P ratios. Using mass as an indicator of C loss in our study, losses of mass and P were also not parallel, which indicates that some retention of P by microbial biomass may have been occurring. Rapid assimilation of P by microbial biomass reduces concentrations of inorganic P within the rooting zone (McLaughlin et al., 1988c). The same type of immobilization probably occurs within surface residues because of microbial demand. Loss of P from surface and incorporated residues is modified by type of residue, soil infiltration capacity, and soil P status (Sharpley and Smith, 1989).

Loss of K was rapid and most likely due to leaching. Rapid losses from fresh residues would be expected because K is not associated with structural components of plants (Marschner, 1995). Potassium was the only nutrient affected by water regime and appeared to increase with wetting and drying, but further study is

needed to determine the full extent of this effect. Because of the rapid loss, residue placement may have little effect on K availability to subsequent crops.

We have not accounted for subsequent nutrient losses from the rooting zone, nor for plant uptake of nutrients released during residue decomposition; however, it is obvious from the patterns of nutrient dynamics that productivity of subsequent crops can be affected. Water regime effects on mass, N, and P dynamics were minimal in this study, which is somewhat surprising. Differences in mass, N, and P dynamics were more a function of residue type, which is related to the chemical characteristics of the residues. The dynamics of K were influenced by both water and crop, indicating that both physical and chemical mechanisms were involved. The nonstructural role of K in plants leads to its rapid loss by leaching and water regime impacts. Differences among crops probably resulted from differences in K uptake and plant morphology. Changes in residue nutrient dynamics can have a direct impact on crop production in reduced tillage systems. Availability of nutrients to succeeding crops depends on the rate of release of nutrients from previous crop residues. Our results indicate that nutrient release dynamics are more complex than direct correlations to changes in residue mass.

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