Crop Residues

Chemical Composition of Residue from Cereal Crops and Cultivars in Dryland Ecosystems

T. L. Stubbs,* A. C. Kennedy, P. E. Reisenauer, and J. W. Burns

ABSTRACT

Cropping systems in the dryland farming region of eastern Washington State are dominated by winter and spring wheat (*Triticum aestivum* L.) and spring barley (*Hordeum vulgare* L.). Excessive levels of residue may be an obstacle in the adoption of conservation farming systems. Decomposition of cereal crop residues is associated with fiber and nutrient content, and growers have observed differences in decomposition among cultivars; however, little information exists on their residue characteristics. Cultivars of spring barley (SB), spring wheat (SW), and winter wheat (WW) grown at four locations over two crop years were analyzed for neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), C, and N contents, and winter wheat decomposition was tested in a laboratory incubation study. Acid detergent lignin was highest in spring barley (9.9%), and least in winter wheat (9.2%) and hard white spring wheat (9.5%). Fiber components and nutrient content varied by location, precipitation zone, and cultivar. Residue in the drier year of the study had lower NDF, ADF, ADL, C, and C/N ratio. Foot rot (*Fusarium* spp.)–resistant winter wheat cultivars had higher NDF, ADF, and ADL than susceptible cultivars. Laboratory incubation studies showed decomposition of winter wheat straw in soil was correlated with ADF (R^2 > 0.66, P = 0.002) and total N (R^2 > 0.67, P = 0.04). Fiber and nutrient characteristics of residue from wheat and barley cultivars currently produced in the Pacific Northwest can be used to predict residue decomposition in cropping systems that conserve soil and water, and enhance build-up of organic matter.

The rolling hills of the Palouse region of eastern Washington State, and the lands of the Columbia Plateau of central Washington State make up one of the most productive dryland cropping regions of the world; however, soils in this region are extremely susceptible to wind erosion because of low rainfall (<450 mm annual precipitation), and water erosion (>450 mm annual precipitation) due to steep terrain, winter precipitation, runoff from frozen soils, and fall tillage (Horning et al., 1998). Erosion in this region ranges between 200 and 450 t soil ha^{-1} (Papendick et al., 1985). Adoption of no-till (direct seed) farming in the Palouse has not kept pace with other parts of the United States and the world, partly because of the topography, difficulties with residue management and seedling emergence, and cost and availability of specialized equipment. Conversely, in the lower rainfall areas too little crop residue is produced to conserve moisture for no-till seeding, and residue is needed that decomposes slowly to provide cover for protection from wind erosion and to conserve moisture. Although soil erosion has prompted many growers in the region to adopt conservation farming practices such as no-till and minimum tillage, residue management is still a major concern. Excessive residue levels can slow planting, reduce the rate of soil warming in the spring, reduce soil to seed contact, hinder seed germination, and inhibit seedling emergence, all of which may lead to reduced grain yields in direct seed systems (Rasmussen et al., 1997). Large amounts of residue are produced in the high rainfall region (450–500 mm annual precipitation) of eastern Washington where annual cropping with rotations of small grains and legumes is practiced. In the low rainfall zone (150–300 mm annual precipitation) where a winter wheat-summer fallow system is followed, too little residue may be present to conserve moisture and prevent soil erosion.

There is no single indicator of straw quality that can predict residue decomposition in soil (Giller and Cadisch, 1997; Kumar and Goh, 2000). The structural components of residue, C and N content, and C/N ratio are known to be indicators of residue decomposition and N mineralization (Baggie et al., 2004; Goh and Tutuna, 2004). High hemicellulose is linked to rapid decomposition and high lignin content, high C/N ratio, and low total N are associated with slower breakdown (Wagner and Wolf, 1998). Cereal crops (Smith and Peckenpaugh, 1986) and crop cultivars (Chalaux et al., 1995) vary in their composition and residue decomposition rates. Information is available on decomposition of wheat and barley straw in general, both in conventional and no-till systems (Douglas et al., 1980; Henriksen and Breland, 2002). Growers have observed differences in residue decomposition in their own fields; however, little is known about the straw quality differences among the wheat and barley cultivars produced under varying conditions in

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Abbreviations: SB, spring barley; SW, spring wheat; WW, winter wheat; NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin.

eastern Washington. Dryland foot rot caused by *Fusarium* spp. causes economically significant winter wheat yield loss in crop producing regions (Paulitz, 2006), and researchers and growers alike are interested in the relationships among cultivar residue characteristics and foot rot susceptibility.

Knowledge of decomposition characteristics would aid growers in planning rotations for reduced tillage cropping systems. This information is needed to better understand organic matter dynamics and nutrient cycling, especially under no-till systems. The objective of this study was to characterize multiple cereal cultivars from several locations over 2 yr by the fiber and nutrient components of the residue, and to relate the residue characteristics of winter wheat to decomposition in soil in a laboratory incubation study.

MATERIALS AND METHODS

Sample Collection and Preparation

Residues of 17 cultivars of winter wheat (WW), 16 cultivars of spring wheat (SW), and 9 cultivars of spring barley (SB) were sampled after harvest in 2003 and 2004 from the Washington State University Cooperative Extension Variety Testing Nurseries at Ritzville (282 mm average annual precipitation), Dusty (406 mm), Dayton (498 mm), and Pullman (521 mm), WA, to represent different climatic zones (Table 1). The experimental design was a split split-plot, completely randomized with location as the main plot and time as the subplot. Cultivars were chosen for testing based on their level of production in the Pacific Northwest, and some winter wheat cultivars were selected based on their resistance to dryland foot rot disease caused by *Fusarium* spp. Individual plot size was 1.2 by 3.7 m. Residue was removed at ground level at the time of grain harvest. Management was standard for each location using either conventional or direct seed tillage practices, the fertility program of each grower-cooperator, and seeding rates based on soil test results and yield goals. Planting dates for SB and SW were mid-March to mid-April, and mid-September to early October for WW. Harvest took place during late July to early August for all of the crops.

Residue Partitioning

Plant residue was initially separated into leaves, nodes, and internode portions to determine the most appropriate plant part(s) to use in these studies. Several cultivars were used to determine the most consistent portions. The analyses below were used on the individual plant components before the analysis of the full set of samples.

Fiber, Carbon, and Nitrogen Analyses

Residue samples were oven-dried at 60°C and ground to pass through a 1-mm sieve using a Wiley mill (Thomas Scientific, Swedesboro, NJ). For consistency, only the internode portion of the plant was used in all experiments. Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) contents were determined using the VanSoest et al. (1991) procedure modified by using the ANKOM automated system using filter bags (ANKOM Technology Corp., Fairport, NY). Neutral detergent fiber includes hemicellulose, cellulose, and lignin, which are the insoluble cell wall components. Acid detergent fiber consists of the cellulose and lignin portions, with hemicellulose removed. Acid detergent lignin is the portion remaining after cellulose is removed. Ground straw samples were analyzed using a LECO CNS-2000 Elemental Analyzer (LECO Corp., St. Joseph, MI) to determine total C and N.

Incubation Study

Internode straw from six winter wheat cultivars (‘Basin’, ‘Madsen’, ‘Eltan’, ‘Cashup’, ‘Rely’, ‘Tres’) and spring wheat (‘Alpowa’, ‘ID377S’, ‘Scarlet’, ‘Wawawai’, ‘West Bred 926’) from Pullman and Dusty, WA, were cut into 5-cm sections. Residue was oven-dried and weighed in sets of 10 straw sections. Straw sections were placed in 10- by 10-cm resealable bags containing equal quantities of moist (15% water content) Ritzville silt loam (coarse-silty, mixed, mesic Andic Aridic Haplustoll) soil so that straw was surrounded by soil, and incubated at 25°C. At 4-wk intervals for 16 wk, three bags for each cultivar were removed and sampled. Loose soil was removed from each straw section, and straw was washed three times by gently shaking in water to remove soil. Straw sections were oven-dried, weighed, and the percentage of straw mass lost through decomposition was calculated.

Grower Survey

Grower perception as to the decomposability of various cultivars was assessed using a questionnaire distributed at several grower meetings. Fifty-six growers responded to the questionnaire; indicated the cultivars with which they were familiar; and ranked them as to their over-winter decomposition.

Statistical Analysis

Differences in fiber content, C, and N among cultivars were determined by ANOVA using Fisher’s protected least significant difference (SAS Institute, 2007). The relationships

Table 1. Location information for spring barley (SB), spring wheat (SW), and winter wheat (WW) production sites in eastern Washington in 2003 and 2004. Straw samples from each site were analyzed for fiber, C, and N contents.

Location	Soil type	Crop type	Elevation	2003 crop year precipitation	2004 crop year precipitation
			m	mm	
Pullman	Palouse silt loam	SB, SW	780	325†	353
Pullman	Palouse silt loam	WW	760	474	511
Dayton	Athena silt loam	SB, SW	500	263	364
Dayton	Athena silt loam	WW	560	408	450
Dusty	Onyx silt loam	SB, SW	500	341	334
Dusty	Onyx silt loam	WW	490	341	391
Ritzville	Walla Walla silt loam	SB, SW	580	210	200
Ritzville	Walla Walla silt loam	WW	580	278	282

† For SB and SW, includes available moisture at seeding time + moisture received during growing season.

Table 2. Results from ANOVA for spring barley, spring wheat, and winter wheat by cultivar, location, and year, for straw samples collected from field trials in eastern Washington.†

		Spring barley							Spring wheat							Winter wheat					
Source	df	NDF	ADF	ADL	C	N	C/N	df	NDF	ADF	ADL	C	N	C/N	df	NDF	ADF	ADL	C	N	C/N
Cultivar (C)	8	***	***	***	NS‡	**	*	15	***	***	***	NS	***	***	16	***	***	***	NS	NS	*
Location (L)	3	***	***	***	***	***	***	3	***	***	***	***	***	***	3	***	***	***	***	***	***
Year (Y)	1	*	***	***	***	NS	***	1	***	***	***	NS	***	***	1	**	NS	***	NS	***	***
L × Y	3	***	***	***	***	***	***	3	***	***	***	***	***	***	3	***	***	***	***	***	***
C × L	24	*	NS	NS	NS	NS	NS	45	NS	NS	NS	NS	**	**	48	NS	NS	NS	NS	NS	NS
C × Y	8	NS	NS	NS	NS	***	***	15	NS	NS	***	NS	NS	NS	16	NS	**	*	**	NS	NS
C × L × Y	24	NS	NS	NS	NS	NS	NS	45	*	**	*	NS	NS	**	48	***	***	*	NS	NS	NS

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

† NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin.

‡ NS = not significant.

between residue decomposition in the incubation study to fiber composition and nutrient content were determined through simple regression analysis (Steel et al., 1997). Pearson correlation coefficients were calculated to determine the relationships among fiber and nutrients in the straw and straw decomposition. All analyses were conducted using SAS 9.1 (SAS Institute, 2007).

RESULTS

The initial analysis of plant residue components indicated that the internode portions of the stalk had the greatest mass, had the most consistent nutrient content, and were the easiest to obtain from mixed residue when compared with the nodal area and leaves. In a separate, smaller study comparing the fiber, C, and N values of the upper and lower internode of wheat and barley, we found that the N values for the internode areas of the whole stalk ranged from 0.35 to 0.57%. The N values from the lower portion of the stalk were 0.27% compared with 0.58% for the upper portion. The C values were not different between the two portions (45.7% upper; 47.1% lower). The lower internode portions of the stalks were used for all subsequent analyses.

Straw composition varied with crop type. Overall, spring barley had the lowest NDF (83.8%), ADF (56.0%), and C/N (238.8) values of the three crop types, and the highest ADL (9.9%) and C (48.1%). Winter wheat had the lowest ADL (9.2%) compared with 9.9% for SB, and the highest C/N ratio (389.8) compared with 238.8 for SB. Spring wheat values of NDF (84.2%), ADF (57.1%), ADL (9.5%), C (47.6%), N (0.21%), and C/N (287.2) fell between SB and WW.

The ANOVA results for fiber, C, and N analyses by cultivar, year, location, and interactions among treatments are shown in Table 2. Straw composition varied with cultivar, year, and location. For each of the three cereal crops tested there were significant cultivar and location differences for all fiber components and C/N. Carbon differed by location as well. Year was significant for all variables, for all crops, except N for SB; C for SW; and ADF and C for WW. There were few interactions among treatments, except location × year. Cultivar × year interactions were present for N and C/N for SB; ADL for SW; and ADF and ADL for WW. Cultivar × location × year interactions were evident for NDF, ADF, and ADL for SW, and C/N, NDF, ADF, and ADL for WW. These interactions were generally due to specific cultivars within each crop.

Straw composition varied with crop type, year, and location (Fig. 1 and Table 3), and is linked to annual precipitation (Table 1). The year that was drier overall (2003) produced spring barley, spring wheat, and winter wheat straw that was lower in NDF. Spring crop straw also had lower ADF and ADL contents in 2003. Spring barley had lower C (47.8%), and a higher C/N ratio (285.5) in 2003 compared with 2004 (48.4%

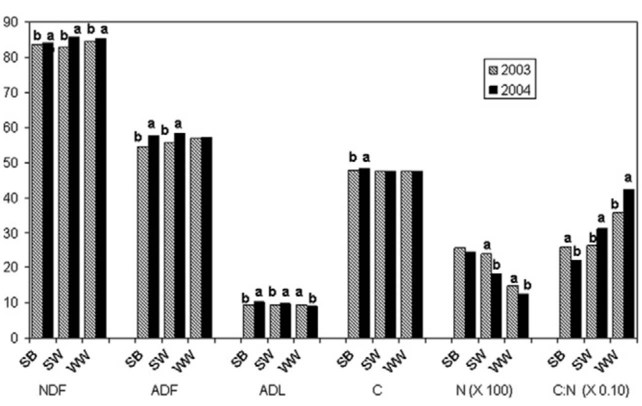

Fig. 1. Results of fiber, C, and N analysis of spring barley, spring wheat, and winter wheat straw samples collected from nursery trials in eastern Washington in 2003 and 2004. Values within the same group for each crop type followed by the same letter are not significantly different at the 0.05 probability level.

Table 3. Results of fiber, C, and N analysis of spring barley, spring wheat, and winter wheat straw samples collected from nursery trials in eastern Washington. Values within the same column for each crop type followed by the same letter are not significantly different at the 0.05 probability level.†

Location	NDF	ADF	ADL	C	N	C/N
			%			
			Spring barley			
Pullman	85.8a	59.1a	10.7a	48.3b	0.184c	290.8a
Dayton	85.1b	55.5c	9.5c	48.7a	0.195c	291.9a
Dusty	82.5c	56.1b	10.0b	47.7c	0.280b	196.0b
Ritzville	81.9d	53.5d	9.4c	47.9c	0.338a	176.6b
			Spring wheat			
Pullman	86.0a	59.5a	9.5b	47.4c	0.143c	361.6a
Dayton	85.5b	58.0b	9.4b	47.3c	0.247a	234.3c
Dusty	82.8c	55.7c	9.2c	48.2a	0.203b	326.7b
Ritzville	82.6c	55.3d	10.1a	47.6b	0.254a	226.2c
			Winter wheat			
Pullman	85.7a	57.9a	9.2b	47.0c	0.124c	423.8a
Dayton	85.0b	57.1b	9.2b	47.8b	0.135b	383.7b
Dusty	84.1c	55.8c	9.4a	47.8b	0.146a	346.6c
Ritzville	84.7b	57.5b	9.0c	47.9a	0.139b	405.2ab

† NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin.

Table 4. Pearson correlation coefficients of spring wheat (SW) and winter wheat (WW) decomposition, fiber and nutrient composition, and precipitation. Straw samples from each site were analyzed for fiber, C, and N contents.

	Decomposition								
	Week 4	Week 8	Week 12	Week 16	ADF	ADL	C	N	C/N
Decomposition Week 8	0.749*								
Decomposition Week 12	0.621*	0.696*							
Decomposition Week 16	0.580*	0.587*	0.536*						
ADF	–0.586*	–0.662*	–0.403*	–0.497*					
ADL	–0.600*	–0.630*	–0.307*	–0.400*	0.439*				
Carbon	0.108	0.243	0.245	0.378	0.041	0.199*			
Nitrogen	0.254	0.208	0.206	0.277*	–0.320*	0.045	–0.115*		
C/N	–0.332*	–0.290*	–0.302*	–0.379*	0.163*	–0.156*	0.089*	–0.793*	
Precipitation	–0.581*	–0.621*	–0.658*	–0.485*	0.329*	0.233	–0.444*	–0.577*	0.648*

* Significant at the 0.05 probability level.

C, 219.2 C/N). Spring wheat values for carbon did not differ significantly between the 2 yr; however, N was higher (0.24%) and C/N was lower (264.3) in 2003 compared with 0.18% N and 310.1 C/N in 2004. Winter wheat had lower NDF and C/N in 2003 compared with 2004. For 2003 and 2004 combined, WW had the highest values for NDF and C/N. Winter wheat was lowest in ADL and N; WW and SW had similar ADF and C.

The five different locations were spread across eastern Washington State and had different precipitation, elevation, and soil type (Table 1). Straw composition varied with location (Table 3). Mean values over 2003 and 2004 for NDF and ADF were highest for the Pullman location (highest precipitation). All three crops at the highest rainfall site, Pullman, had the highest NDF, ADF, C/N, and lowest N. Crops at the other three locations showed indications for more rapid decomposition. Samples from Ritzville with an annual precipitation of 282 mm, and Dusty with an annual precipitation of 406 mm had low NDF (about 83%) and ADF (about 56%). Dayton, with an annual precipitation of 498 mm had samples with the lowest lignin (9.3%) of all the sites and lower C/N (about 310) compared to Pullman where the average C/N was 378.

The potential rate of laboratory decomposition and fiber and nutrients showed several relationships. The ADF and ADL were negatively correlated to the laboratory decomposition at each sampling period (Table 4). Interestingly, C showed influence on decomposition and correlated only with Week 16 decomposition and ADL. On the other hand, N was correlated with Week 16 decomposition, ADF, and C. The C/N ratio was negatively correlated with decomposition parameters except for ADF and C, which were positively correlated to C/N. Precipitation correlated with decomposition, ADF, C, N, and C/N. Precipitation positively influenced ADL, ADF, and C/N and was negatively correlated to each decomposition sampling and to C and N.

The ADF, ADL, C, N, and C/N values for each cultivar varied with year, but the relative ranking of the cultivars within each variable were consistent and did not change with year or location. Spring barley cultivars differed for all characteristics (Table 5); however, it was difficult to draw obvious conclusions among barley cultivars for the quality traits tested. 'Morex', the only 6-row feed barley included in the study, had the lowest NDF (82.1%) and ADF (53.6%), and was nearly the lowest in ADL (9.4%). The 2-row cultivar 'Radiant' had the highest ADL (10.6%) and C/N (258) of the cultivars tested. The cultivar × location interaction for spring barley NDF levels were due to the differences in 'Camas', 'Morex', and 'Xena' between the high and low precipitation sites. The cultivar × year interaction seen for N was due to decreases in 'Camas' and 'Xena' N values in the second year, whereas the N for all other cultivars did not vary. The cultivar × year interaction for C/N was due to a decrease in C/N in all but two cultivars ('Camas' and 'Bob') in the second year.

Spring wheat straw composition varied with market class (Table 6). Spring wheat ADL values ranged from 9.7% for hard red and soft white, to 9.2% for hard white (Table 6). Carbon/N of the spring wheat cultivars separated by market class in the order soft white > hard white > hard red (Table 6). Soft white wheat residue contained the highest amounts of NDF, ADF, and C, as well as the highest C/N ratio of the SW types. The soft white cultivar 'Nick' had, or was among the highest in NDF, ADF, C, and C/N, and low N (Table 6). 'Wawawai' had low N, and high C/N. In contrast, the hard white cultivar 'Macon' had low ADF and ADL.

Winter wheat cultivars differed from one another in each of the fiber traits (Table 7). Cultivars which ranked in the top four for at least two of the indicators of rapid decomposition were 'Coda', 'Eltan', and 'Stephens' (Table 7). Each of those cultivars had some combination of low NDF, ADF, and ADL. 'Bruehl', 'Finch', and 'Madsen' all had some combination of high NDF, ADF, or ADL. 'Stephens' had the highest C/N ratio; however, it had none of the other indicators for slow decomposition, which reinforces the need to test for more than one residue characteristic. The cultivar × year interactions seen for NDF, ADF, ADL, and C were due to differences among cultivars at the Dayton and Dusty sites. On average, foot rot–resistant cultivars had higher NDF, ADF, and ADL than foot

Table 5. Fiber, C, and N analysis results for spring barley cultivars averaged over four locations and 2 yr (2003 and 2004). Values within the same column followed by the same letter are not significantly different at the 0.05 probability level.†

Spring barley cultivar	Spring barley straw composition					
	NDF	ADF	ADL	C	N	C/N
	%					
AC Metcalfe	84.4a	56.2b	10.2bc	48.4a	0.227b	248.1a
Baronesse	84.3a	56.9ab	9.5e	48.1ab	0.232b	254.4a
Bob	83.7a	56.0b	9.7e	48.0b	0.236b	243.9a
Camas	83.5a	56.3ab	10.1cd	48.2ab	0.322a	187.4b
Farmington	84.0a	55.4b	9.3e	48.1ab	0.238b	244.8a
Harrington	84.3a	56.7ab	10.5ab	48.2ab	0.235b	256.6a
Morex	82.1b	53.6c	9.4e	47.9b	0.273ab	233.6a
Radiant	84.4a	57.8a	10.6a	48.2ab	0.225b	258.0a
Xena	83.6a	55.4b	9.7de	48.1ab	0.254b	222.6ab

† NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin.

Table 6. Fiber, C, and N analysis results for spring wheat cultivars averaged over four locations and 2 yr (2003 and 2004) and means across market class. Values within the same column followed by the same lower case letter or within the row of means with the same capital letter are not significantly different at the 0.05 probability level.

Spring wheat cultivar	Spring wheat straw composition					
	NDF†	ADF	ADL	C	N	C/N
	%					
			Soft white/club			
Alpowa	83.7cd	56.2def	9.4efg	47.7abcd	0.202bcd	348.9a
Eden	83.6cd	57.5bcd	9.7bcde	47.9ab	0.192bcd	326.6ab
Nick	86.9a	59.5a	9.6cdef	48.0a	0.159d	360.8a
Wawawai	84.9bc	58.7ab	9.9abc	47.8abc	0.164d	353.5a
Zak	84.2bcd	57.4bcd	9.7bcde	47.8abc	0.229abc	277.1bcd
Soft white/club mean	84.6A	57.8A	9.7A	47.8A	0.189B	333.4A
			Hard white			
Blanca Grande	84.3bc	57.1cde	9.3fgh	47.5bcd	0.192cd	319.2ab
ID377S	84.2bc	56.3def	9.0hi	47.7abcd	0.223abc	278.1bcd
Lolo	84.5bc	56.6cde	9.1ghi	47.5abcd	0.255a	265.6bcd
Macon	83.7cd	55.2f	8.8i	47.7abcd	0.194bcd	310.2abc
Plata	84.8bc	57.8bc	9.5def	47.6abcd	0.200bcd	317.3ab
Hard white mean	84.3AB	56.6B	9.2B	47.6B	0.213A	297.0B
			Hard red			
Hank	83.5cd	56.1def	9.4ef	47.6abcd	0.224abc	249.1cd
Hollis	84.1bcd	57.4bcd	10.2a	47.7abc	0.227abc	241.2d
Jefferson	85.5ab	58.0bc	9.9ab	47.7abcd	0.197bcd	277.6bcd
Scarlet	83.5cd	57.0cde	9.7bcde	47.5bcd	0.259a	215.8d
Tara 2002	82.6d	55.9ef	9.4ef	47.4cd	0.231abc	230.7d
WPB 926	84.0bcd	57.0cde	9.7bcd	47.2d	0.244ab	223.5d
Hard red mean	83.9B	56.9B	9.7A	47.5B	0.230A	240.1C

† NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL = acid detergent lignin.

rot susceptible cultivars (Table 7). Resistant and susceptible cultivars were not different in C; however, susceptible cultivars had higher N and lower C/N than foot rot–resistant cultivars.

Incubation studies of winter wheat collected from Dusty and Pullman showed differences in rate of decomposition among cultivars, and those differences were compared with ADF (Fig. 2a; $F = 11.4$, $P = 0.02$), total N (Fig. 2b; $F = 4.21$, $P = 0.06$), and carbon ($F = 4.95$; $P = 0.01$). Both ADF and total N were good predictors of decomposition based on the results of the regression analyses, with R^2 values ranging from 0.66 to 0.89. Percent ADF was best correlated with decomposition after 8 wk of incubation (Fig. 2a; $R^2 = 0.89$, $P = 0.001$). Carbon/N also showed the highest correlation after 8 wk, with an R^2 value of 0.84 (Fig. 2b). Carbon/N ($R^2 = 0.63$; $P = 0.05$) also was correlated with amount of decomposition at Week 16, where lower C/N ratios indicated higher decomposition.

To determine grower perception of decomposition, we took an informal survey of several growers and asked them to rank the 42 cultivars used in this study for their speed of decomposition in the field. Growers chose Eltan, Coda, and Stephens as those cultivars that seem to disappear the most quickly from the field, while Madsen, Wawawai, and Finch appear to growers to maintain structure in their soils the longest. We then compared grower responses to expected decomposition based on data from the laboratory analyses. Of the 21 cultivars with which growers had experience, we found that their perceptions of decomposition rate matched the component analyses for 14 of the cultivars ($F = 3.26$; $P = 0.005$). Of the seven cultivars in

Table 7. Fiber, C, and N analysis results for winter wheat cultivars averaged over four locations and 2 yr (2003 and 2004). Values within the same column followed by the same letter are not significantly different at the 0.05 probability level.

Winter wheat cultivar	Foot rot response‡	Winter wheat straw composition†					
		NDF	ADF	ADL	C	N	C/N
		%					
Bruehl	S	85.9ab	58.4a	9.6ab	47.7a	0.129abcd	418.3abc
Brundage	MS	85.3abcde	58.3ab	9.1fgh	47.6abc	0.138abcd	380.8abcde
Cashup	S	85.7abc	57.5abc	9.3def	47.6abc	0.146ab	341.5e
Chukar	R	85.6abcd	57.4bcd	9.3cde	47.7ab	0.124cd	401.8abcd
Coda	R	83.7f	56.2ef	8.7i	47.7ab	0.132abcd	407.0abcd
Edwin	MS	85.2abcde	57.0cde	9.3def	47.7ab	0.124d	410.9abcd
Eltan	S	81.9g	53.8g	9.0gh	47.5bc	0.139abcd	392.2abcde
Finch	R	86.0a	58.4ab	9.8a	47.6abc	0.139abcd	375.8bcde
Lambert	MS	85.3abcde	56.5def	8.9hi	47.4c	0.145ab	374.5bcde
Madsen	R	85.5abcd	58.5a	9.4cd	47.6abc	0.127bcd	424.8ab
Mohler	R	85.0abcde	57.4bcd	9.2efg	47.7a	0.142abc	368.1cde
Rely	S	84.3ef	56.6cde	9.2defg	47.8a	0.148a	358.3de
Rod	S	84.3ef	56.6cde	9.5bc	47.7abc	0.145ab	363.2cde
Simon	–	84.6cdef	57.1cde	9.0gh	47.5abc	0.130abcd	410.2abcd
Stephens	S	84.5def	55.6f	8.8i	47.5bc	0.125cd	433.2a
Tubbs	R	85.2abcde	57.7abc	9.1fgh	47.5abc	0.139abcd	378.7abcde
WA7933	–	84.8bcdef	57.5abc	9.3def	47.6abc	0.141abcd	387.6abcde

† NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin.

‡ Foot rot response: S, susceptible; MS, moderately susceptible; R, resistant.

which grower assessment and analytical information did not correlate, we found that the lab analyses equally either over- or underestimated the potential decomposition rate compared with grower perception. Winter wheat cultivars had a greater number of matches between grower perception and lab results than spring wheat or spring barley. Observed winter wheat decomposition was well correlated with ADF ($F = 13.49$; $P = 0.002$) and ADL ($F = 19$; $P = 0.001$).

DISCUSSION

To have a consistent sample to analyze, only the internode portion of the stalk was used for these studies. The C/N ratios of the internode portions were 39% higher for the lower portions, compared with the internodes for the entire plant, which explains the elevated C/N ratios overall. It is documented that plant parts differ in their fiber content and rate of decomposition (Quemada and Cabrera, 1995; Palm and Rowland, 1997). The structural components of straw are found in different proportions depending on crop species (Goh and Tutuna, 2004; Hadas et al., 2004), and likewise, different portions of straw (soluble carbohydrates, cellulose, lignin) break down at different rates, affecting the availability of C and N as residue decomposes (Hadas et al., 2004).

The residue N values in this study are much lower, and C/N values much higher than would be expected for wheat and barley residue. Residue from the WSU Variety Testing nurseries typically has low N content because of the minimal rates of N fertilization in those trials (P. Reisenauer, personal communication, 2008). The residue for these studies was collected post-harvest and it included only the lower portion of the plant, which had a higher C/N ratio than the entire plant. The relative relationships among crop types, years, and locations, however, were the same throughout all the plant parts.

As expected, we found that SB, SW, and WW differed from one another in fiber, C, and N content. Other researchers have also observed differences in fiber contents among crop types. Sheaffer et al. (1994) determined that semidwarf and conventional height barley differ in their fiber contents, with semidwarf containing lower ADF and ADL contents. Smith and Peckenpaugh (1986) found that cereal crop residue of different genera decomposed at different rates, and that the same patterns of N loss did not occur between barley and wheat. Winter wheat is the most widely grown crop in eastern Washington; however, large amounts of residue and slow decomposition impede no-till seeding. Knowledge of residue composition may aid in designing rotations that incorporate more rapidly decomposing crops and cultivars while maintaining economic feasibility. The large amounts of winter wheat straw produced could be harvested for other uses, such as ethanol production, as long as enough residue is present to prevent soil erosion and maintain soil quality for future crop production.

We found that ADL content overall was lower in 2003 (9.4%), the drier year of the study, compared with 2004 (9.7%), as was ADF content (55.7% in 2003, 57.8% in 2004). This is similar to results obtained by Soon and Arshad (2002), who tested residue composition in both years of their studies and found that canola (*Brassica napus* L.), pea (*Pisum sativum* L.), and wheat residues had lower lignin, and pea had lower C/N in the drier year of the study. Carbon/N values in our studies

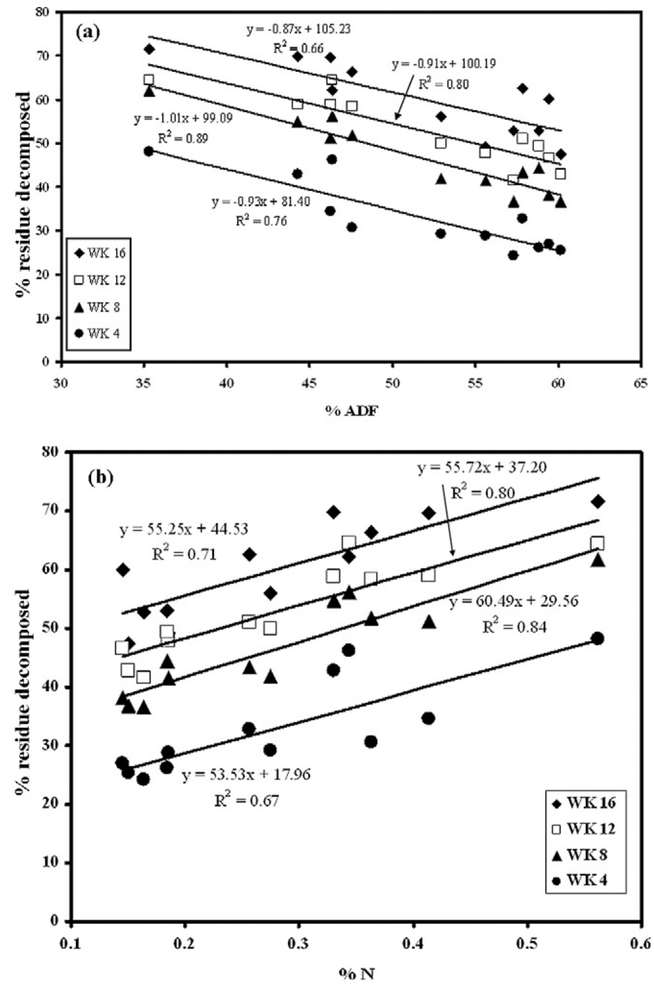

Fig. 2. Correlation of Pullman and Dusty, WA, winter wheat residue decomposition with (a) percentage acid detergent fiber (ADF) and (b) percentage total N after 16-wk incubation of six cultivars from each location. Straw decomposition was calculated as percentage of mass lost.

were 25 units lower in 2003 compared with 2004. Overall, straw grown in 2004 had higher values for ADF and ADL; therefore, we predict slower straw decomposition for 2004 than 2003. Rao (1989) also found that increased spring precipitation was linked to higher wheat straw ADF content, possibly due to leaching of soluble compounds from straw. Cereal straw quality is affected not only by precipitation (Rao, 1989; Rao and Dao, 1994), but also by production location (Rao, 1989; Chalaux et al., 1995), air temperature (Rao and Dao, 1994), and crop management strategy (Collins et al., 1990; Chalaux et al., 1995). This makes drawing conclusions about cultivar decomposition by using only one location and 1 yr difficult if not impossible. Evaluation of residue quality and decomposition needs to be tested on multiple cultivars, locations, and years.

The differences in fiber characteristics among wheat and barley cultivars in this study are similar to other data that show residue quality differences among cultivars of wheat (Chalaux et al., 1995; Rao and Dao, 1994), as well as among cultivars of other crops such as Eastern gamagrass (*Tripsacum dactyloides* L.) (Bidlack et al., 1999), pea for silage (Mustafa et al., 2002), timothy (*Phleum pretense* L.) (Claessens et al., 2004), and forage cultivars of sorghum spp. [*Sorghum bicolor* (L.) Moench] (Moyer et al., 2004). Researchers in

Washington State found that winter wheat cultivars differed in their suitability for paper production based on differences in fiber length between an irrigated site and a dryland site (McKean and Jacobs, 1997).

Winter wheat decomposition in these studies was correlated with ADF ($F = 13.49$; $P = 0.002$), lignin ($F = 51.6$; $P = 0.0001$), total N ($F = 5.17$; $P = 0.005$), and C/N ($F = 2.15$; $F = 0.05$); however, the characteristics to predict decomposition potential differed among individual cultivars. Overall, total N was the most reliable predictor of decomposition for winter wheat. This result is similar to that of Douglas et al. (1980) for buried wheat straw in the field. Spring wheat was similar to winter wheat with decomposition correlated with ADF, ADL, and N, and is not presented here.

Our initial hypothesis was that fiber content would dictate decomposition, with high NDF, ADF, ADL, C/N, and low N indicative of slow decomposition. Along these lines, residue with low NDF, ADF, ADL, C/N, and high N would decompose at a faster rate. The crops grown at Pullman, the highest rainfall site compared with the other locations, had the highest NDF, ADF, C/N, and lowest N, all indicators of slow decomposing straw. The hard white spring wheat cultivar 'Macon' had the indicators for rapid decomposition with low ADF and ADL. Winter wheat cultivars having characteristics of slower decomposition were 'Bruehl', 'Finch', and 'Madsen', all of which had some combination of high NDF, ADF, or ADL, which translated into higher lignin, hemicellulose, and cellulose. The cultivar 'Stephens' had the highest C/N ratio; however, it had none of the other indicators for slow decomposition. This and other anomalies with several cultivars and their decomposition potential reinforce the need to test for more than one residue characteristic.

Foot rot–resistant winter wheat cultivars had higher NDF, ADF, and ADL contents, and higher C/N than foot rot–susceptible cultivars. Differences in fiber characteristics among foot rot–resistant and susceptible cultivars have also been shown in other plant species. In smooth bromegrass (*Bromus inermis* Leyss.), high lignin may confer increased resistance to rust (*Puccinia coronata* Corda) (Delgado et al., 2002). Fiber content and C/N, may be a predictor of disease ranking, and may be another tool to aid cereal breeders in selecting for disease resistance.

An understanding of residue decomposition patterns, gained by knowing fiber content of crop cultivars, will aid growers in determining fertility requirements and planning annual crop rotations for high rainfall regions where residue is excessive, or for low rainfall zones where residue levels may be inadequate to prevent soil erosion. This information may also determine the mineralization and immobilization of nutrients as affected by fiber component and nutrient composition of crop residue. Cereal cultivars produced in the Pacific Northwest may be characterized for their suitability in ethanol production, paper and strawboard production, and as a substrate for mushroom production. Additionally, this information on fiber characteristics can be used when selecting for disease resistance. Multiple fiber and nutrient characteristics are needed to best predict the decomposition potential of cereal cultivars in dryland agriculture.

CONCLUSION

Cereal crop cultivars varied in their NDF, ADF, ADL, lignin, total N, and C/N ratio. Of those 42 cultivars tested here, 14% had definite characteristics for slow residue decomposition and another 14% were considered to have rapid decomposition potential. Other cultivars had some indication of either being rapidly or slowly decomposed, whereas the rest fell into the intermediate range for these characteristics. Fiber and nutrient content of cereal residues correlated with residue potential for decomposition. Specifically, decomposition is negatively correlated to ADF and positively correlated to N. These analyses have practical application for growers interested in residue decomposition when making cultivar selection. Other factors such as residue tannin content, soil × plant interactions, and precipitation zones also may need to be considered to improve the prediction of residue decomposition. The analyses used here may have application for testing decomposition potential before a cultivar's release, and this information along with other cultivar traits may be used by growers when making planting decisions.

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