Review: The composition and availability of straw and chaff from small grain cereals for beef cattle in western Canada

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McCartney, D. H., Block, H. C., Dubeski, P. L. and Ohama, A. J. 2006. **Review: The composition and availability of straw and chaff from small grain cereals for beef cattle in western Canada.** Can. J. Anim. Sci. **86**: 443–455. Small cereal grain residues are heterogeneous feeds consisting of several botanical fractions: chaff, grain, leaf blade, leaf sheath, internode and node. These parts vary in composition, digestibility, resistance to comminution, intake potential and energy availability. Large differences in the nutritional quality of straw and chaff may occur from year to year and between locations due to effects of environmental conditions on botanical composition and cell anatomy. Stage of maturity, harvest method and weathering will influence composition and quality of the most nutritious parts of cereal residues, the leaf and chaff. In addition, cultivars and species differ in the proportion, anatomy and digestibility of botanical fractions. As a result, the quality of crop residues is highly variable with an economic value that is difficult to accurately assess.

Cereal straw and chaff are of low economic value as they are low in nutritive value, where nutritive value is the product of nutrient intake, digestibility, and efficiency of use. However, due to availability, cereal crop residues have the potential to be a substantial feed resource for beef cows. Previous reviews have not focused on straw and chaff nutrition research relevant to use by beef cattle in western Canada. This review includes discussions on yield and nutritive value with a focus on identifying information deficiencies, including the lack of detailed production statistics for determining residue yields on a regional bases and the need for more detailed nutrient composition to update regional feed data bases for western Canada.

Key words: Straw, chaff, nutrient quality, beef cattle

McCartney, D. H., Block, H. C., Dubeski, P. L. et Ohama, A. J. 2006. **Composition et disponibilité de la paille et de la balle des petites céréales pour l'engraissement des bovins de boucherie dans l'ouest du Canada : un survol**. Can. J. Anim. Sci. **86**: 443–455. Les résidus des petites céréales constituent un aliment du bétail hétérogène dans lequel on retrouve plusieurs fractions botaniques : balle, grain, feuilles, gaine des feuilles, entre-nœuds et nœuds. La composition, la digestibilité, la résistance à la fragmentation, l'ingestion potentielle et la quantité d'énergie de ces fractions varient. La qualité nutritive de la paille et de la balle connaît d'importants écarts d'une année et d'un endroit à l'autre à cause des effets de l'environnement sur la composition botanique des résidus et l'anatomie des cellules. Le stade de maturité, la méthode de récolte et les intempéries influeront sur la composition et la qualité des feuilles et de la balle, les parties les plus nourrissantes des résidus céréaliers. Par ailleurs, la proportion, l'anatomie et la digestibilité des cultivars et des espèces varient dans les fractions botaniques. C'est pourquoi la qualité des résidus fluctue considérablement et il est difficile d'en évaluer avec précision la valeur économique. La paille et la balle des céréales n'ont guère de valeur en raison de leur piètre qualité nutritive, celle-ci correspondant au résultat de l'ingestion, de la digestibilité et de l'assimilation des nutriments. Toutefois, à cause de leur disponibilité, ces résidus pourraient devenir une importante source d'aliments pour les vaches de boucherie. Les survols antérieurs se sont peu attardés à la recherche sur la nutrition de la paille et de la balle susceptible d'intéresser les éleveurs de bovins de boucherie de l'ouest du Canada. Le présent article examine le rendement et la valeur nutritive de ces résidus en insistant sur les lacunes actuelles au niveau de l'information, notamment l'absence de statistiques détaillées sur la production qui permettraient d'établir le rendement en résidus par région et la nécessité d'une meilleure analyse de la composition des éléments nutritifs en vue d'actualiser les bases de données sur les provendes dans l'ouest du Canada.

Mots clés: Paille, balle, qualité nutritive, bovins de boucherie

Abbreviations: ADF, acid detergent fibre; **CP**, crude protein; **DM**, dry matter; **IVOMD**, in vitro organic matter digestibility; **HI,** harvest index; **KMC**, kernel moisture content; **NDF**, neutral detergent fibre; **TDN**, total digestible nutrients

The cost of wintering beef cows in western Canada is the single most important cost of beef production and accounts for 60–65% of the total cost of production in a cow-calf operation (Kaliel and Kotowich 2002). The residues from the large acreages of cereal crops grown in western Canada (Table 1) are potential sources of feed for the maintenance of beef cows. This low-cost feed resource can be utilized to help lower winter feeding costs for the beef herd. Approximately half of the above-ground dry matter of cereal crops consists of straw and chaff. Cereal straw, the stem and leaf residue remaining after the grain is harvested (Fig. 1), and chaff, the parts of the spike left after the grain is harvested, can provide approximately 50–60% of the winter dry matter (DM) feed for the beef cow. Additional energy and protein must be provided to the beef cow to meet nutrient requirements and prevent impaction [Weisenburger et al. 1976; Weisenburger and Mathison 1977; Mathison et al. 1981; National Research Council (NRC) 1971, 2000, 2001].

Today, several reviews or summaries of straw-based research from the United States and Europe can be found (Anderson 1978; Staniforth 1979; Reid and Klopfenstein 1983; Sundstøl and Owen 1984; Givens 1987; Males 1987; Capper 1988; Reed et al. 1988; Flachowsky et al. 1999); however, none are specific to the Saskatchewan and Alberta research studies on this topic.

Given the lack of recent articles focusing on the limitations and potential for feeding cereal straw and chaff to beef cattle in western Canada, this paper attempts to summarize research on cereal crop residue, yield, composition and nutritional quality under western Canadian conditions.

Morphological Composition of Cereal Residue

Cereal straw consists of the senesced leaves (sheath and blade) and stems (node and internode) material remaining after grain harvesting and contains approximately two-thirds stem and one-third leaf [56% internodes, 7–8% nodes, 23% leaf sheaths, 14% leaf blades (Ohlde et al. 1992)]. Straw can also contain 0.1–0.2% thin kernels of grain (Staniforth 1979). Cereal crop chaff consists of smaller particles than straw and contains glumes, hulls, parts of heads, short straw, leaf materials, weed seeds, and whole or cracked kernels separated from harvested grain (Anonymous 1984; Anonymous 1987; Ensminger et al. 1990). Chaff is not a consistent material, and varies with the type of crop, weather, moisture content and quality of combining (Anonymous 1984). Since the majority of this material is discharged from conventional combines and falls to the ground ahead of the straw, specialized collection and handling methods are required to harvest chaff. The proportion of chaff that can be retained in straw is highly variable, and ranges from about 1 to 21% depending on species and variety and harvesting system (Ernst et al. 1960; Thiago and Kellaway 1982; Flachowsky et al. 1991).

The botanical composition of a cereal residue (leaf, stem, chaff, grain) and the presence of any contaminants (weeds, weed seeds, soil) determine the nutritional quality of this crop by-product. The amount, nutrient composition, degradability and physical traits of these fractions affect digestibility, palatability and intake of cereal residues. Comparative information on nutrient concentrations of different types of cereal straw and chaff are summarized from all available data from provincial feed laboratories in western Canada (Tables 2 through 5).

Composition of botanical fractions in cereal residues was investigated by Thiago and Kellaway (1982), Kernan et al. (1984), Ramanzin et al. (1986), Shand et al. (1988), Flachowsky et al. (1991) and Ohlde et al. (1992). Kernan et al. (1984) found that grain accounted for 390 g kg^{-1} DM of the total components in six different wheat (*Triticum aestivum* L.) cultivars, while the chaff accounted for 170 g kg^{-1} DM, leaf 180 g kg^{-1} DM and stem accounted for 260 g kg^{-1} DM. In addition, the substantial variability in the proportions of the botanical components and nutritional quality associated with straw from different grain species and cultivar is evidenced by Theander and Åman (1984), Shand et al. (1988), Capper et al. (1992) and Ohlde et al. (1992) (Table 6). In general, barley (*Hordeum vulgare* L.) and oat (*Avena sativa* L.) straws contain more leaves than spring or winter wheat (*Triticum aestivum* L.) or rye (*Secale cereale* L.) straws (Theander and Åman 1984; Flachowsky et al. 1991). The variation in these morphological components is the cause of much of the variation in cereal straw and chaff characteristics.

Estimation of Straw and Chaff Yields

Harvest index (HI) is the proportion of grain yield to total above-ground biomass of a cereal crop. Harvest index allows for estimation of total straw, chaff and stubble yield from grain yield data. The proportion of total residue (including straw, stubble, and chaff) in the total above-ground biomass is typically 620 g kg^{-1} (HI = 380g kg^{-1}) for wheat (Anonymous 2000), but can range from 800 to 500 g kg^{-1} (HI = 200 to 500 g kg^{-1}). Aase and Siddoway (1981) found that the total yield of straw plus chaff from spring wheat equaled grain production under a wide range of grain yields. In contrast, Kernan et al. (1984) found HI of 391 g kg^{-1} in six wheat cultivars. Additionally, in Saskatchewan HI is typically 400 to 450 g kg^{-1} for wheat, 450 to 500 g kg^{-1} for oat, and 500 to 550 g kg^{-1} for barley; although, depending on the cultivar, wheat can be greater than 500 g kg^{-1}, and barley greater than 600 g kg^{-1} (B. Rossnagel, personal communication, University of Saskatchewan, Saskatoon, SK).

Present day cultivars of wheat and barley tend to be shorter, earlier-maturing, higher-yielding, and produce a higher proportion of grain relative to straw than the older cultivars (Capper 1988). In the 1960s and 1970s, dwarfing genes were introduced into wheat and barley in hopes of improving lodging resistance. Many dwarf and semi-dwarf cultivars are more resistant to lodging than traditional cultivars especially under high input productions systems such as heavy fertilizer or manure applications and irrigation (Travis et al. 1996). Straw yield was not directly correlated with cultivar height, although some shorter cultivars had low straw yields, especially under drought conditions.

Based on a report by the Cochrane Group (Anonymous 1994), Stumborg and Townley-Smith (2004) presented data indicating that HI is related to soil type with HI on brown

Table 1. Estimated seeded hectares in grain crops in the prairie provinces 2001–2005[z]

Type of crop	2001	2002	2003	2004	2005
All wheat	10 570 200	10 286 600	10 114 300	9 934 600	9 622 100
Oats	1 724 000	2 185 300	2 055 800	1 780 600	1 626 900
Barley	4 318 100	4 734 900	4 694 400	4 358 500	4 127 800
All rye	131 600	117 300	204 300	236 700	190 200
Mixed grains	234 700	159 900	129 500	121 400	109 200

[z] Source: Statistics Canada (2006).

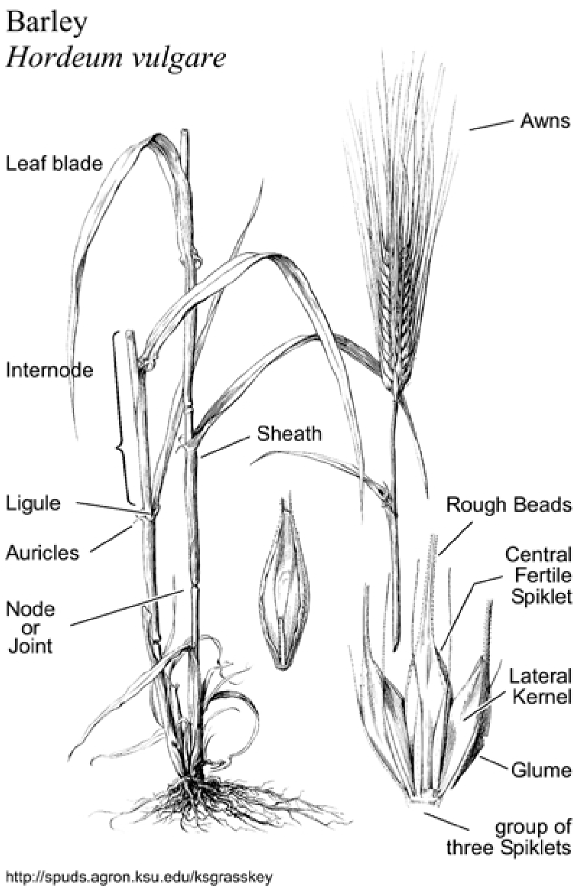

Fig. 1. Parts of a cereal plant.

soils of 380 g kg^{-1} for barley and 430 g kg^{-1} for wheat, on dark brown soils of 430 g kg^{-1} for barley and 500 g kg^{-1} for wheat, and on black soils of 500 g kg^{-1} for barley and 600 g kg^{-1} for wheat. Based on a 25–yr data set, Stumborg and Townley-Smith (2004) determined that under a moisture deficit of 200 mm and using regression analysis the proportion of total residue in the above-ground biomass was 480 g kg^{-1} for barley and 550 g kg^{-1} for wheat (HI = 520 g kg^{-1} and 450 g kg^{-1}, respectively). However, for barley the proportion of residue decreased by 8 g kg^{-1} with each 10 cm increase in moisture deficit, while for wheat it decreased by 10 g kg^{-1}. Additionally, the impact of moisture deficit appears to be modified by timing. Spratt and Gasser (1970) found that with drought at tillering, stems were shorter and thinner and leaves were smaller causing a decrease in straw:grain ratio; while with drought at later stages of growth, kernel size and numbers were decreased causing an increase in the straw:grain ratio. Wheat chaff:grain yields at 200 g kg^{-1} were unaffected by soil moisture deficit (L. Townley-Smith, personal communication, Prairie Farm Rehabilitation Administration, Regina, SK).

De la Llata and Swingle (1979) and Coxworth et al. (1980) found that one-third of spring wheat residue was chaff; however, much of this chaff was lost at harvest unless specialized mechanical chaff collecting equipment was used. In a summary of spring wheat by Stumborg and Townley-Smith (1997), chaff yield represented 170 to 200 g kg^{-1} of total residue for six tall, awnless wheat cultivars, and 230 to 260 g kg^{-1} of total residue for two semi-dwarf, awned cultivars. They indicated that short crops produce more chaff due to an increase in the proportion of short straws dropping on to the sieves, and more chaff was collected when dry combining conditions aided in crop fractionation. The data presented by Stumborg and Townley-Smith (2004) also indicated that chaff yield was related to combining method with 130 g kg^{-1} of barley and 150 g kg^{-1} of wheat residue as chaff with conventional combining, and 200 g kg^{-1} of barley and 250 g kg^{-1} of wheat residue as chaff with more aggressive rotary combining. Stumborg and Townley-Smith (1997) estimated that weight of chaff recovered was 150 g kg^{-1} of grain for barley and 170 g kg^{-1} of grain for wheat. The larger recovering for wheat than barley is expected due to the retention of the hull on barley.

Chaff collecting systems have been evaluated by Stumborg and Craig (1989), Olfert et al. (1991), Lischynski et al. (1992), the Prairie Agricultural Machinery Institute (1998) and Stumborg and Townley-Smith (2004). Despite limited commercial availability of chaff collecting equipment such as the Redekop Chaff-O-Matic Chaff Saver (Saskatoon, SK) and the McLeod Harvest System (Winnipeg, MB), all chaff material produced is potentially harvestable, whereas harvestable straw will vary with cutting height. Retaining residue on the field can aid in increasing soil nutrients, preventing soil erosion, and increasing moisture retention. Gale and Cambardella (2000) concluded that root biomass was the primary contributor to soil carbon under no-till conditions, indicating that residue removal should have limited impact on soil nutrients provided adequate fertilizer is supplied. Stumborg and Townley-Smith (2004) suggest that retaining 0.75 t ha^{-1} of residue, corresponding to a swathing height of 15 cm, should be adequate to prevent soil erosion with no-till crop production, yet

Table 2. Analyzed composition of cereal straws in Alberta 1984–1994 on a dry matter basis [z]

	Six-row barley		Two-row barley		Oats		Wheat		Rye	
	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD	*n*
Moisture (%)	10.7 ± 2.6	306	10.2 ± 2.6	71	10.4 ± 2.9	246	9.9 ± 2.8	120	8.4 ± 2.0	8
Protein (%)	5.4 ± 2.5	282	5.1 ± 1.9	70	4.8 ± 2.4	215	4.3 ± 1.8	115	6.7 ± 3.5	8
ADF (%)	44.4 ± 9.1	281	44.0 ± 5.3	69	44.0 ± 10.8	212	47.1 ± 7.4	117	42.4 ± 5.7	8
NDF (%)	–	0	–	0	–	0	74.4 ± 2.5	4	–	0
Calcium (%)	0.43 ± 0.17	279	0.43 ± 0.14	70	0.33 ± 0.17	215	0.31 ± 0.12	114	0.41 ± 0.17	8
Phosphorus (%)	0.09 ± 0.06	282	0.09 ± 0.06	70	0.10 ± 0.06	215	0.07 ± 0.05	115	0.13 ± 0.04	8
Potassium (%)	1.52 ± 0.64	35	1.36 ± 0.25	8	1.80 ± 0.61	36	1.39 ± 0.50	19	1.22 ± 0.41	2
Magnesium (%)	0.13 ± 0.04	36	0.13 ± 0.04	8	0.15 ± 0.07	36	0.12 ± 0.05	19	0.14 ± 0.06	2
Sodium (mg kg^{-1})	1619 ± 1513	30	1153 ± 1111	7	2732 ± 2622	29	546 ± 1070	19	–	1
Sulphur (%)	0.15 ± 0.05	24	0.15 ± 0.02	6	0.14 ± 0.04	25	0.14 ± 0.05	17	0.15	1
Iron (mg kg^{-1})	147 ± 189	30	250 ± 328	7	99 ± 58	35	139 ± 103	19	54 ± 21	2
Copper (mg kg^{-1})	3.7 ± 4.6	40	3.0 ± 0.9	8	3.4 ± 1.9	37	9.1 ± 27.6	19	3.3 ± 0.1	2
Manganese (mg kg^{-1})	30 ± 20	38	37 ± 20	8	48 ± 33	38	35 ± 16	19	18 ± 8	2
Zinc (mg kg^{-1})	15 ± 13	40	12 ± 4	8	15 ± 11	37	16 ± 35	19	12 ± 5	2
Selenium (mg kg^{-1})	0.16 ± 0.16	49	0.20 ± 0.20	9	0.08 ± 0.10	38	0.23 ± 0.27	28	0.13	1
Molybdenum (mg kg^{-1})	0.9 ± 1.3	17	0.3 ± 0.4	2	1.9 ± 1.5	20	1.0 ± 1.1	6	0.6 ± 0.3	2
Cobalt (mg kg^{-1})	1.0 ± 1.2	14	0.4 ± 0.0	2	1.3 ± 1.4	16	0.8 ± 1.2	6	0.5	1

[z]Alberta Agriculture, Food and Rural Development, Soil and Feed Test Laboratory data base.

Table 3. Nutrient composition of cereal straws tested at Saskatchewan Feed Test Laboratory, average of years 1974–1982, 1986, and 1990

	Wheat		Oat		Barley	
Item (DM basis)	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD	*n*
Protein (%)	5.31 ± 2.07	312	5.86 ± 1.87	253	6.24 ± 2.44	371
ADF (%)	53.97 ± 3.6	312	47.63 ± 4.26	253	48.71 ± 4.54	371
Calcium (%)	0.23 ± 0.06	312	0.29 ± 0.08	253	0.32 ± 0.08	371
Phosphorus (%)	0.09 ± 0.04	312	0.12 ± 0.06	253	0.12 ± 0.07	371
TDN (%)	44.0 ± 5.25	11	46.71 ± 4.8	12	46.55 ± 4.1	35

Table 4. Analyzed composition of cereal chaffs in Alberta between 1984 and 1994 on a dry matter basis [z]

	Two-row barley		Six-row barley		Wheat		Oats	
Item (DM basis)	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD	*n*
Moisture (%)	9.3 ± 1.4	2	12.5 ± 3.7	19	10.6 ± 4.2	22	11.7 ± 3.7	6
Protein (%)	8.0 ± 2.3	2	7.2 ± 2.3	19	6.1 ± 2.4	21	7.5 ± 3.6	6
ADF (%)	32.3 ± 4.0	2	34.8 ± 10.3	19	39.5 ± 10.6	22	30.2 ± 15.8	6
NDF (%)			–	0	–	0		
Calcium (%)	0.45 ± 0.06	2	0.51 ± 0.18	19	0.26 ± 0.12	19	0.37 ± 0.13	5
Phosphorus (%)	0.11 ± 0.03	2	0.14 ± 0.05	19	0.09 ± 0.06	21	0.11 ± 0.05	6
Potassium (%)			0.98 ± 0.26	3	0.70 ± 0.52	2		
Magnesium (%)			0.19 ± 0.07	3	0.13 ± 0.08	2		
Sodium (mg kg^{-1})			164 ± 284	3	–	2		
Sulphur (%)			0.12	1	–	0		
Iron (mg kg^{-1})			585 ± 476	2	144 ± 8	2		
Copper (mg kg^{-1})			4.0 ± 2.0	3	4.4 ± 1.6	3		
Manganese (mg kg^{-1})			48 ± 13	3	32 ± 11	3		
Zinc (mg kg^{-1})			37 ± 24	3	14 ± 7	3		
Selenium (mg kg^{-1})	0.09	1	0.15 ± 0.05	3	0.11 ± 0.01	2		
Molybdenum (mg kg^{-1})			1.3 ± 1.4	3	2.7 ± 0.3	2		
Cobalt (mg kg^{-1})			4.7 ± 6.3	2	2.3 ± 0.5	2		

[z] Alberta Agriculture, Food and Rural Development, Soil and Feed Test Laboratory data base.

increasing retained residue to a 25 cm swathing height equivalent may aid in moisture retention. Based on their summary of six tall, awnless spring wheat cultivars and two semi-dwarf, awned spring wheat cultivars, a 15-cm swathing height allowed for harvest of approximately 800 g kg^{-1} of total straw. However, Boyden et al. (2001) reported that straw recovered in bales represented only 400 to 500 g kg^{-1} of total straw grown. For hard red spring and Canadian prairie spring wheat cultivars, only 770 and 660 g kg^{-1}, respectively, of material discharged from the combine was captured as baled straw (Boyden et al. 2001). Additional estimates of harvestable straw yield for the cereal grain species grown in western Canada and harvesting methods are presented in Table 7.

Table 5. Analyzed composition of cereal chaffs in NE Alberta in 1996 and 1997[z]

	Wheat Chaff		Wheat Chaff + Straw[y]		Barley Chaff		Barley Chaff + Straw[y]		Oat Chaff	
Item (DM basis)	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SC	*n*	Mean ± SD	*n*
Dry matter (%)	91.1 ± 4.6	53	90.0 ± 4.4	21	88.8 ± 4.0	51	88.5 ± 3.6	28	87.4 ± 7.2	17
Protein (%)	4.6 ± 1.7	53	4.10 ± 1.5	21	6.5 ± 2.3	51	5.0 ± 1.8	28	7.2 ± 2.2	17
ADF (%)	51.5 ± 5.5	53	53.6 ± 4.2	21	42.8 ± 5.5	51	49.6 ± 5.1	28	42.6 ± 4.6	17
Calcium (%)	0.24 ± 0.11	53	0.82 ± 0.09	21	0.52 ± 0.27	51	0.45 ± 0.18	28	0.71 ± 0.45	17
Phosphorus (%)	0.08 ± 0.04	53	0.08 ± 0.04	21	0.13 ± 0.06	51	0.11 ± 0.05	28	0.14 ± 0.06	17
Magnesium (%)	0.12 ± 0.05	53	0.10 ± 0.03	21	0.17 ± 0.05	51	0.45 ± 0.06	28	0.23 ± 0.05	17

[z]Alberta Agriculture, Food and Rural Development, Soil and Feed Test Laboratory data base.
[y]During the combining process, a chaff cyclone was used to drop chaff on top of straw immediately before baling in an attempt to retain chaff, but significant chaff loss might have occurred.

Table 6. Morphological components of straw and chaff

Source and cereal grain species	DM proportions of whole plant (g kg^{-1})				
	Internodes	Nodes	Leaves		Chaff
Shand et al. (1988), oat	550–600	60–80	290–330		30–80
Shand et al. (1988), wheat	440–510	50–80	280–370		80–180
	Internodes	Nodes	Leaf sheaths	Leaf blades	
Ohlde et al. (1992), barley, oat, rye, triticale, durum, spring and winter wheat	450–670	80–90	170–330	10–180	
	Internodes and nodes		Leaf sheath	Leaf blades	
Capper et al. (1992), barley	540–610		230–310	100–170	
	Internodes and nodes	Nodes			Chaff
Theander and Åman (1984), barley, oat, rice, rye, wheat	400–800	40–80			20–100
	Stem		Leaves		Chaff
Kernan et al. (1984), wheat	260		180		170

It is extremely difficult to estimate the amount of small grain cereal crop residue available to cattle producers in western Canada. While crude, the estimation methods previously described are necessary due to the lack of detailed agricultural statistics quantifying the production of cereal straw and chaff. This may be attributed to the regional nature and the low economic value associated with these crop residues. Although cumbersome, the amount of straw chaff and stubble can be estimated from the HI of the particular cereal crop. Wood and Layzell (2003) have estimated that Canada produces 22.5 Mt DM of wheat, barley and oat residue each year. This was based a HI of 430 g kg^{-1} for wheat and 500 g kg^{-1} for all other cereal grains. This figure assumes that only 70% of the sustainable residues (residue remaining after minimal residues requirements are met for sustaining cereal crop lands) is available due to difficulties during recovery or bailing. If only 10% of this residue is actually fed to cows at an assumed DM intake of 5 kg straw per head at a value of \$40 t^{-1} plus transportation for a 200-d winter feeding period, it could equate to feeding 2.2 million beef cows at an economic value of \$88 000 000.

In some areas farmers do not feed straw and chaff residue due to cost compared with hay. Depending upon the rainfall during the growing season, hay is often cheaper to purchase than straw. This can be due to a surplus of hay in the area, a general lack of cereal straw in the area, higher field costs for straw and chaff due to higher fertilizer costs associated with the cereal crop, and ever increasing costs of transportation due to increasing fuel prices. However, there is a possibility of wintering more cows on straw and chaff at a lower cost by leaving the cereal crop residue in the fields and hauling the hay and grain supplementation to the field rather that hauling the straw and chaff to the cows.

In recognition of the biomass potential of cereal residues as an industrial fibre source or fuel ethanol substrate, a geographic information system intended to guide industrial development that uses many of these estimation methods is in progress (L. Townley-Smith, personal communication, Prairie Farm Rehabilitation Administration, Regina, SK). However, this system is currently focused on large-scale wheat and barley resources with little information on specific cultivars or other cereal crops such as oat or fall rye, and has limited functionality for individual producers. It is difficult to state the importance of cereal straw and chaff on the basis of the quantity produced without better estimates of production, and although the economic focus for cereal crop production is on grain production, this should not exclude more precise quantification of straw and chaff yields. These are issues that can and should be addressed.

Table 7. Straw yield as a fraction of grain yield[z]

Crop	Method of harvest	Type of combine: Conventional	Type of combine: Rotary/Intensive separation
Wheat	Swath (8″ stubble)	0.72	0.57
	Straight combine (12″ stubble)	0.56	0.44
Oats/Barley	Swath (8″ stubble)	0.54	0.43
	Straight combine (12″ stubble)	0.42	0.33
Rye/Flax	Swath (8″ stubble)	0.65	0.52
	Straight combine (12″ stubble)	0.50	0.40

[z]Data from Tony Kaminski, personal communication, Saskatchewan Research Council, Saskatoon, SK.
[y]Barley, oats and rye typically yield less straw per unit of grain than wheat does. Relative to wheat, straw:grain ratios were lower for barley, oats and rye (0.85, 0.75, and 0.90, respectively). With barley straw being relatively weak and breaking more than wheat straw during harvest, the straw:grain ratio for barley is close to that of wheat (0.75).

Table 8. Estimate of organic matter digestibility or dry matter degradability of straw components

	Nodes	Leaf	Chaff	Source
		($g\ kg^{-1}$)		
Stem				
267–368		478–552	377–506	Kernan[z] et al. (1984) (spring wheat)
Internodes				
271	495	501	679	Shand[y] et al. (1988) (oat)
330	514	615	404	Shand[y] et al. (1988) (spring wheat)
400	480	660	680	Flachowsky[x] et al. (1991)
320	370	470	430	Flachowsky[w] et al. (1991)

[z]In vitro digestibility.
[y]In vivo degradability.
[x]Oat, spring barley in vivo degradability.
[w]Winter barley, winter rye, winter wheat, triticale in vivo degradability.

Nutrient Composition of Straw and Chaff

Grain varieties have been developed for grain production and lodging resistance. As a result, straw is highly lignified and has limited rumen degradability. Theander and Åman (1984) and Akin (1989) have described the various structural layers of straw internodes that restrict microbial degradation of the internodes. This arrangement of resistant material can result in rigid residues with intact physical structures after microbial degradation. The separation of lignified tissues in leaves is less restrictive to microbial degradation (Akin 1989).

Nutritional composition summaries of the morphological components are not readily available for straw and chaff. The reports that are available indicate the impact on nutrient composition that can result from changes in leaf to stem ratios in straw and the inclusion of chaff. Kernan et al. (1984) evaluated wheat cultivars in two different trials and reported average crude protein (CP) content from each trial for stems of 26 and 29 $g\ kg^{-1}$ DM, leaves 53 and 62 $g\ kg^{-1}$ DM, and chaff 43 and 74 $g\ kg^{-1}$ DM. The stems were the largest botanical fraction (420 $g\ kg^{-1}$ DM), and were less digestible than leaf and chaff with the average in vitro digestibility in the two trials of 294 and 319 $g\ kg^{-1}$ for stems. The leaves and chaff made up 340 $g\ kg^{-1}$ and 240 $g\ kg^{-1}$ of the botanical fraction and the average in vitro digestibility in the two trials were 496 and 513 $g\ kg^{-1}$ for leaves, and 432 and 468 $g\ kg^{-1}$ for chaff. Kernan et al. (1984) concluded that chaff and the leaf components had a higher feed value than stems. This was also confirmed by Ramanzin et al. (1986), Shand et al. (1988), Flachowsky et al. (1991) and Thomson et al. (1993). Results of analyses on chaffs from Canada and the northern US states are limited and are summarized in Table 8. These results demonstrate large variability in estimates of organic matter digestibility, and dry matter degradability of chaff, similar to that observed for other straw components.

Ohlde et al. (1992) found more variability in composition and digestibility of stems compared with leaves among cereal species and cultivars. The amount and quality of stems accounts for most of the variability in straw digestibility, and through differences in resistance to grinding, stems may have even larger effects on intake independent of digestibility. Stems can vary greatly in shear force even when the straws have the same digestibility. Ohlde et al. (1992) found shear stress of the first (uppermost) and fourth internodes were 146 and 426 $N\ mm^{-1}$, respectively, for spring barley straw compared with 501 and 577 $N\ mm^{-1}$, respectively, for triticale (X *Triticosecale* Wittmack L.) straw. The *in vitro* digestible cell wall content of the first and fourth internodes of these two straws was 497 $g\ kg^{-1}$ and 228 $g\ kg^{-1}$ for barley, and 510 $g\ kg^{-1}$ and 201 $g\ kg^{-1}$ for triticale. Similar gradients in shear force of nodes occurred as well, but the authors suggested that while shear stress may allow ranking of the crushing force resistance of nodes, it might not reflect the compression power required by an animal to crush an internode. Ohlde et al. (1992) observed that most of the feed refusals in straw feeding trials consist of straw stem sections a few centimeters above and below a node. They suggested that nodes may have a large impact on straw stem intake or refusal, and ease of comminution, because these plant parts were tough and animals do not like to chew them.

In studies by Kernan et al. (1984) differences observed in the organic matter in vitro digestibility of leaf and stem fractions of wheat straw contributed more to digestibility than the actual proportions of leaf to stem fractions in the straw. Ramanzin et al. (1986) observed the same relation for dry matter degradability of barley straw. Leaves had the highest degradability values, followed by chaff, nodes and internodes. However, Capper et al. (1989) argued that with a larger range of values, the stem to leaf ratio becomes a major contributor to variation in digestibility. Plant height was positively related to the content of cell wall components (Capper et al. 1989; Mathison et al. 1999) and negatively related to microbial degradation in the rumen (Colucci et al. 1992; Mathison et al. 1999). Degradation is closely related to the distribution of cell types (parenchyma, epidermis, and sclerenchyma cells) within leaf and stem, and the thickness of the walls of specific cell types (Goto et al. 1991).

Capper (1988) suggested that high rainfall produces taller plants, and thereby more stem (straw) with less leaf material. Rao (1989) found that increased precipitation increased height and diameter of stems for winter wheat cultivars, resulting in a higher proportion of stem material with overall lower digestibility. However, there appears to be a trade-off with plants that have more moisture prior to spike initiation setting more leaves per stem. Therefore, time of precipitation can influence the proportions of leaf, stem and heads, with early season precipitation promoting leaf, mid season promoting stem and late season promoting heads.

Awns or beards are photosynthetic organs of the spike found in most cultivars of barley, and in some cultivars of triticale, fall rye and wheat. At maturity, awns have lower feed value than other components of chaff. Kernan et al. (1990) isolated awns from a rough-awned cultivar of winter wheat (Norwin) and found that they contained 24 g kg^{-1} CP, 89 g kg^{-1} ash, and had lower in vitro organic matter digestibility (IVOMD) of 447 g kg^{-1} than wheat at 507 g kg^{-1} or barley chaff at 582 g kg^{-1}. Mathison et al. (1999) showed that barley genotypes with smooth awns had higher rates of degradation, but contained less of the slowly degraded fraction than straw with rough awns when straws of medium straw length were compared. In addition, Mathison et al. (1999) found no comprehensive data in the literature in which the effects of awn on ruminal degradability characteristics of barley straw have been compared. However, the presence of awns can cause injury to eyes and mouth of beef cattle (Harlan 1920; Anderson 1978).

The morphological components of straw and chaff, and the presence of contaminants including weeds, weed seeds, and soil differ in relative proportion, nutrient composition, and nutritive value. Their role in determining the nutrient composition and nutritive value of cereal straw and chaff makes definition and characterization of cereal straw and chaff composition important. One possible solution to determining the composition of straw and chaff might be the use of near infrared reflectance spectroscopy. Smart et al. (2004) found near infrared reflectance spectroscopy could explain 73 to 84% of the variation in the proportion of leaf to stem in several grasses. If this technology could be successfully applied to cereal straws and chaffs it would help quantify the wide variation in nutrient composition of straw and chaff associated with the proportion of morphological components in the residue.

Cereal Straw and Chaff in Ration Formulation

When formulating rations based on straw or chaff, it is important to have detailed descriptions of nutrient composition to permit accurate provision of nutritionally adequate diets while avoiding costly oversupply of nutrients. As a feed characterized by high fibre, low protein, and low fat content (NRC 1983, 2001) detailed information on the fibre components of straw that contribute to meeting the animal's nutrient requirements is important. The potential inclusion in chaff of non-fibre carbohydrate from weed seed or unthreshed grain calls for additional non-fibre carbohydrate analysis. Unfortunately, few samples from provincial feed laboratories in western Canada have analyses proceeding beyond CP, acid detergent fibre (ADF), calcium, and phosphorus (Tables 2 through 5). In addition, detailed nutrient composition information of cereal chaff is either limited in terms of cereal species and nutrients described (Morrison 1961; NRC 1971; Ensminger et al. 1990) or unavailable (Van Soest 1994; NRC 2000, 2001). Energy content of straw-based diets is often estimated using ADF values. These straw-based diets usually require supplemental protein and energy, calcium and phosphorus to meet cattle nutrient requirements. With very limited detailed nutritional analysis of straw and chaff, more detailed nutritional analysis on a regional basis is required in order to have a more accurate assessment of the nutrient value of the feed. The closure of the provincial government feed testing laboratories and subsequent dependence on private and confidential commercial laboratories has made obtaining detailed summaries of straw and chaff analysis on a regional basis more difficult.

Recent attention has been directed to the relatively high potassium content of cereal based feeds. Observations in western Saskatchewan (Doig 2002) and evaluations at the University of Saskatchewan have implicated elevated dietary potassium as a factor in the development of tetany in 50 beef cow herds fed green feed based diets (Walker 2003). This effect is presumably due to the effect of potassium in disrupting dietary cation-anion balance (Byers 1993; Oetzel 1993) and causing milk fever (Walker 2003). Although these cattle were not directly fed straw chaff diets, the high levels of potassium as seen in Tables 2 and 4 suggest that this could also be an issue. Fortunately, tetany is avoidable through supplementation of calcium, magnesium, and management of dietary cation-anion balance. The problems of tetany and other mineral imbalances such as low levels of calcium, phosphorus, copper, manganese and zinc confirm the need for additional mineral analysis information on straw and chaff.

The provincial laboratory composition summaries of historical data (Tables 2 through 5), indicate substantial variability in nutrient content of cereal straw and chaff feedstuffs. Even when focusing only on feedstuffs within a cereal species with a minimum of 20 samples, and the common analyses of CP, calcium, and phosphorus, standard deviations frequently exceed 30% of the average. Despite lower relative variation in ADF content, absolute standard deviations of 50 to 100 g kg^{-1} of DM were still common. In order to make better use of straw and chaff in beef cattle rations it is essential to have access to accurate chemical analysis of the nutrient content of these feedstuffs.

Factors Affecting Quality

Chaff Quality

There is limited research on cereal chaff. This could be due to its limited use as a feed resource due to the difficulties of collecting and moving this very bulky crop by-product. Chaff from conventional harvesting systems has a low bulk density that varies with cereal species and harvesting conditions and this is a limitation to transport this by-product economically. Within species, bulk density is closely and positively related to feeding value. In Saskatchewan, Coxworth et al. (1981a) reported average densities of 35, 56, and 64 kg m^{-3} for barley, wheat, and oat chaffs, respectively. Straw content of chaff had little effect on density. Farm-collected chaff samples varied greatly in bulk density and feeding value, with the highest bulk density chaff having the highest feed value due to the inclusion of grain and weed seeds.

Species of the cereal crop is one source of variation in the nutrient content of cereal chaffs. White and Bergman (1985) found higher CP content in barley chaff at 41 g kg^{-1}, while oat chaff was only 26 g kg^{-1} and winter wheat chaff was 17 g kg^{-1}. Furthermore, the CP content of chaff was correlated to the CP content of the grain. Within species, cultivar has been found to be a major source of nutrient variability for wheat and barley chaff (Coxworth et al. 1981b; Kernan et al. 1984; Kernan et al. 1991) and barley, oat, and spring and winter wheat chaff (Erickson et al. 1982; White and Bergman 1985). Chaff IVOMD ranged from 487 to 627 g kg^{-1} for eight barley cultivars, and from 478 to 545g kg^{-1} for eight spring wheat cultivars (Kernan et al. 1991). Additional studies have been summarized in Table 9. Unfortunately, other sources of variation in nutrient composition of chaff are not well documented.

Cereal Genotype Effects

Straw quality is an important characteristic that may be improved through selection without compromising grain production. Straw quality is not correlated with yield and quality of grain (Erickson et al. 1982; Tuah et al. 1986; Capper 1989; Shand et al. 1988; Ramanzin et al. 1991; Colucci et al. 1992). Cultivars of barley, wheat or oats with similar agronomic characteristics may differ markedly in straw morphology (Kernan et al. 1984; Capper 1988), chemical composition (Kernan et al. 1979; Erickson et al. 1982; Narasimhalu et al. 1998), and rumen degradation and *in vitro* digestibility (Ramanzin et al. 1986; Tuah et al. 1986; Reed et al. 1988; Shand et al. 1988; Ørskov et al. 1990; Colucci et al. 1992). Differences in nutritive value among varieties generally are consistent from year to year (Ørskov et al. 1990).

Cultivars with improved straw degradability may have higher proportions of leaf (Ramanzin et al. 1986; Capper 1988; Goto et al. 1991) and higher microbial degradation of leaf and stem fractions in the rumen (Kernan et al. 1984; Ramanzin et al. 1991; Goto et al. 1991). However, genetic differences in digestibility or microbial degradation of leaf and stem fractions contributed far more to feeding value than the proportions of leaf and stem in studies by Kernan et al. (1984) and Ramanzin et al. (1991).

Dwarf and semi-dwarf cultivars have shorter internodes and contain higher proportions of leaf blade and lower proportions of stem than taller cultivars (Capper 1988). As leaf is consistently more digestible than stem in temperate cereal crops, dwarf cultivars are associated with improved quality. Dwarfing genes may cause a reduction in internode elongation or they may result in fewer internodes being produced and thereby a concomitant lower number of leaves. Since plant height is related to the cell wall components, genetic differences in plant height and the related effects on straw quality may not be expressed under poor growing conditions such as drought (Capper 1988).

Much of the barley grain used as feed in western Canada is obtained from two-row barley malting cultivars. Two-row barley straw is slightly higher in quality than six-row barley straw as it contained less ADF, similar or less neutral detergent fibre (NDF), and similar or greater CP than six-row cultivars (Thorlacius 1978; Erickson et al. 1982; Mathison et al. 1999). Mathison et al. (1999) compared two-row cultivars with six-row cultivars of similar straw length and found that two-row cultivars contained more CP (44 vs. 37 g kg^{-1}) and less ADF (455 vs. 484 g kg^{-1}), NDF (752 vs. 776 g kg^{-1}), cellulose (394 vs. 415 g kg^{-1}), and lignin (61 vs. 69 g kg^{-1}). McCartney and Okine (2002) found small differences between two-row and six-row barley straw with respect to NDF disappearance, but the differences were too small to be of great benefit in terms of evaluation of barley straw for feeding beef cattle.

Effective microbial degradation was 5% higher (Mathison et al. 1999) and IVOMD was greater (429 g kg^{-1} vs. 413 g kg^{-1}; Erickson et al. 1982) for the straw from two-row cultivars compared with six-row cultivars. Thorlacius (1978) found that the straw from two-row cultivars tended to have 10% greater dry matter degradation than six-row barley cultivars. Two-row barley may produce straw with somewhat higher quality than six-row barley, but variability is far greater among cultivars within each type than between the two types. A summary of *in vitro* organic matter digestibility of various straw types can be found in Table 10. Limited research information is available on straw from hulless barley. Mathison et al. (1999) found that hulless barley plants contained more leaf material (443 g kg^{-1} vs. 416 g kg^{-1}) than hulled cultivars, but the hulless barley cultivars they studied were semi-dwarf types, while there was a range of heights in the hulled cultivars. The straw from hulless barley has minor differences in composition compared with hulled cultivars (Narasimhalu et al. 1998; Mathison et al. 1999). The straw from hulless barley was similar to hulled barley when straws of similar length were compared. However, the straw from hulless barley contained more NDF than the straw from hulled barley (Mathison et al. 1999). Many of the six-rowed hulless cultivars available in western Canada are semi-dwarf in nature and comparisons with hulled cultivars are confounded by this difference.

McLeod et al. (1997) has reported lower quality in straw from winter rye, wheat, and triticale cultivars as they contained more NDF, ADF, cellulose and lignin, and had less crude protein, and IVOMD than spring barley, wheat, triticale or oat cultivars.

From the current research (Kernan et al. 1979; Erickson et al. 1982; Shand et al. 1988; Ørskov et al. 1990; Mathison et al. 1999) we can conclude that there is a significant difference in nutritional quality between cereal cultivars and that it would be useful to direct future efforts to genetic improvement of the nutritional value of straw for ruminant animals. It should also be possible to select varieties of barley, wheat and oat straws more suitable for feeding without sacrificing yields of grain. Research has shown that the estimated feeding value of straw is influenced by year and the local growing conditions. In addition, two-row barley straw is more digestible than the six-row cultivars and straw from shorter cultivars is more digestible than straw from taller cultivars.

Table 9. Nutritional quality and digestibility of cereal chaff residues

Cereal grain species	*n*	CP(%)	Ash(%)	ADF(%)	NDF(%)	Lignin (%)	IVOMD (g kg^{-1})	Source
Spring barley	6	7.3	10.6	–	–	–	582 (485–627)	Kernan et al. (1981)
Spring barley, year 1	22	8.5	17.5	–	–	–	428 ± 15 (376–474)	White and Bergman (1985)
Spring barley, year 2	22	7.7	15.0	–	–	–	516 ± 12 (460–575)	White and Bergman (1985)
Spring oats, year 1	17	7.9	18.7	–	–	–	461 ± 10 (415–491)	White and Bergman (1985)
Spring oats, year 2	17	6.1	18.3	–	–	–	538 ± 7 (519–557)	White and Bergman (1985)
Spring wheat	8	5.4	10.2	–	–	–	507 (478–545)	Kernan et al. (1981)
Spring wheat, year 1	19	6.2	19.9	–	–	–	353 ± 9 (293–417)	White and Bergman (1985)
Spring wheat, year 2	19	3.7	16.3	–	–	–	403 ± 14 (322–480)	White and Bergman (1985)
Spring wheat	1	5.7	–	48.3	77.0	6.6	363	Mann et al. (1988)
Spring wheat, Neepawa	4	6.0	–	50.5	–	–	453	Kernan et al. (1981)
Spring wheat, Katepwa	1	5.5	–	43.8	67.7	–	361	Kernan et al. (1991)
Spring wheat, Wakooma	1	4.6	–	41.4	63.5	–	466	Kernan et al. (1991)
Winter wheat, year 1	16	3.6	12.2	–	–	–	493 ± 8 (461–547)	White and Bergman (1985)
Winter. wheat, year 2	16	3.8	10.9	–	–	–	426 ± 8 (393–474)	White and Bergman, (1985)
Winter wheat awns, Norwin	1	2.4	8.9	–	–	–	447	Kernan et al. (1981)

Table 10. In vitro organic matter digestibility of cereal straw and chaff

Type and source	Barley					Canary	Oat	Fall rye	Triticale	Wheat				
											Spring			
	2-row			6-row						Durum	Standard	Semi-dwarf	Solid stem	Winter
Cereal straw														
Kernan et al. (1979)			377				398				367			
Coxworth et al. (1981c)			480						380		370			
White et al. (1981)										370	331	408	403	
Mann et al. (1988)											410			
Colucci et al. (1992)			487				540							357
White et al. (1981)			436				450							405
McCartney (1988)	459			464		433	356	396			342			
Mir et al. (1988)			423			337					342			486
Cereal chaff	Feed	Malt		Feed	Malt									
White and Bergman (1985)	478	470		480	466		500			361	339	405	361	460

Harvesting and Weather Condition Effects

During mechanical harvest, changes in residual stubble height and loss of leaf blade material further exacerbate variation in the morphological composition of cereal straw. Loss of leaf material from straw during drying and harvest may be reduced by harvesting prior to complete maturity. During maturation cereal species differ in the rate at which digestibility declines (Cherney and Marten 1982; Khorasani et al. 1997). Advancing or delaying harvest time by only 1 or 2 wk had a large impact on decreasing straw digestibility, crude protein content and yield (Acock et al. 1978; Manley and Wood 1978; Kernan et al. 1993).

The stage of maturity at harvest influences straw quality by affecting botanical composition, the extent of lignification, the amount of nutrient translocation from straw to grain during maturation, and retention of leaf and chaff during drying and harvesting. In cereal crops, the translocation of nutrients to the grain stops at the physiological maturity of 350 g kg^{-1} moisture content in the grain or kernel moisture content (KMC). *In vitro* organic matter digestibility content of straw from wheat varieties varied from 445 g kg^{-1} for samples taken at 1 wk before normal grain harvest, to 383 at harvest (150–200 g kg^{-1} KMC), and 350 g kg^{-1} for 1 wk after harvest (Acock et al. 1978). Manley and Wood (1978) found the changes in cell wall content and digestibility of most plant components were large during a 14 d period preceding harvest (150–200 g kg^{-1} KMC). The ADF content of the internodes, nodes, and leaves increased by 100 g kg^{-1} during the final 14 d before physiological maturity. Chaff and awn quality deteriorated during a 3 wk period prior to harvest; with ADF content of chaff increasing by approximately 50 g kg^{-1} DM. The IVOMD fell 100 to 130 g kg^{-1} for both wheat chaff and awns in barley.

Desiccant treatment of cereal crops to speed drying time and control weeds has become increasingly common, but effects on straw quality are unknown. Desiccants may improve quality in short-season areas by allowing earlier harvest, but by accelerating senescence, desiccant treatment may exacerbate leaf loss if harvesting is delayed. This management technique requires detailed research as to the effects on nutrient quality of straw.

Kernan et al. (1993) found that harvest method (direct combining vs. swathing) did not markedly affect nutritive value of straw when barley straw was direct combined or swathed at the same stage of maturity or kernel moisture content. However, the Prairie Agricultural Machinery

Institute (1998) has shown that the type of combine influences residue yield and quality. The mechanical damage to straw was more extensive when cereals were threshed using a rotary combine compared with a conventional combine and resulted in less collectable straw and chaff. In addition, the straw bales from fields harvested by a rotary combine often broke apart during transport.

Stubble height affects straw quality because the lower parts of the plant, especially stems, have lower digestibility than tissues at the top of the plant (Ohlde et al. 1992). Harvesting by direct combining at 25.4 cm vs. 7.5 cm stubble height increased crude protein and IVOMD of barley straw (Kernan et al. 1993). Similarly, barley harvested at 20 cm produced straw with higher nutritive value than barley harvested at ground level (Capper et al. 1989). However, greater stubble height decreased total straw yield.

Cutforth and McConkey (1997) found increased grain yields and water use efficiency when spring wheat was seeded in the Brown soil zone of Saskatchewan directly into standing stubble that was 30 cm tall, compared with short stubble of 15 cm or cultivated cereal stubble. This increase was related to the altered microclimate and decrease in potential evaporation. There was a tendency for spring wheat grown on tall stubble to produce more dry matter and more leaf area. In another study in the Black soil zone, the impact of stubble management on crop yield was highly variable and was affected by temporal variability of precipitation (A. Moulin personal communication, Brandon Research Centre, Brandon, MB).

Straw from lodged crops is more likely to be cut closer to the ground, be affected by fungal disease, and be contaminated with soil and dust. Lodged crops tend to have heavier stem and leaf growth, and may be mixed with weeds and secondary cereal growth, which will have a variable effect on nutritional quality of the straw (Staniforth 1979).

Kjos et al. (1987) showed that weathering wheat, oat, and barley straw for 1 mo after grain harvest before baling increased NDF by 80 g kg^{-1}, ADF by 140 g kg^{-1}, and lignin by 49 g kg^{-1} compared with straw from the same fields baled at harvest, although CP was not altered. Microbial degradation of straw was minimal when straw moisture was under 15% (Staniforth 1979). However, at higher moisture concentrations, fungal and microbial utilization of cellulose and hemicellulose resulted in substantial DM loss.

Elevated moisture content of straw and chaff when baled or collected can cause microbial or fungal growth in the feed. This is an additional issue with use of weathered straw apart from the changes in chemical constituents normally contributing to nutritive value. Fungi-associated risks to cattle include mycotic abortion, haemorrhagic disease, aspergillosis, and fungal toxicosis when moldy straw is used as feed or bedding (Lacey 1979; Scudamore and Livesey 1998). Mycotoxins from feeding moldy straw to cattle induced liver damage and was presumably responsible for secondary photosensitization of non-pigmented areas of the body, resulting in conjunctivitis or ulcerative keratitis of the eyes, and lesions around the eyes and on the muzzle, underside of the jaw, teats, and limbs (Bagley et al. 1983). Cattle usually recovered within 2 to 4 wk after removal from the straw diet, but symptoms could re-occur later on green spring pasture as liver damage inhibits removal of porphyrins from circulation. Ribble et al. (1993) has reported an outbreak of congenital spinal stenosis (birth defects affecting skull and spine) in calves, and alopecia with 0–25% mortality in dams, associated with feeding moldy cereal straw to four beef herds in Saskatchewan.

Drought will often prematurely terminate growth resulting in less secondary cell wall formation and less translocation of nutrients to the developing grain. Drought increased CP of barley straw from 37 to 74 g kg^{-1} DM and decreased crude fibre from 490 to 410 g kg^{-1} DM compared with similar barley on irrigated plots (Coxworth et al. 1980). Erickson et al. (1982) reported a significant increase in ADF from 421 to 511 g kg^{-1}, whereas hemicellulose was lowered from 29 to 23 g kg^{-1} with irrigated barley compared to dryland production.

Drought effects on straw composition are exacerbated by high rates of N fertilization, which increases soil moisture use by plants (Campbell and Paul 1977). Various reports on the effects of N fertilizer have shown either no improvement or only slight increases in straw CP with higher N rates (Gately 1976; Campbell and Paul 1977; Campbell et al. 1977; Hogg and Halstead 1977; Coxworth et al. 1980, 1981c; Eriksson 1981). Kernan et al. (1984) found that increasing N fertilizer from 0 to 224 kg N ha^{-1} increased the CP content of leaf material from 35 to 47 g kg^{-1} DM and chaff material from 36 to 52 g kg^{-1} DM. However, when Coxworth et al. (1980) applied heavy amounts of manure to irrigated land for 2 successive years, unacceptably high crop nitrate concentrations, ≥ 15 g kg^{-1} as KNO_3, resulted.

Future Needs

The feeding value of straw differs among cereal species reflecting differences in proportion of leaves and stems (Flachowsky et al. 1991), and in the nutrient composition and microbial degradation in the rumen of those fractions (Ohlde et al. 1992). Although differences within species can be greater than those between species, oat and barley straws generally have a higher nutritive value than wheat straw, and oat straw is similar or superior to barley straw (Kernan et al. 1979; Colucci et al. 1992). Furthermore, differences in nutritive value among varieties are generally consistent from year to year (Ørskov et al. 1990). Chaff has higher nutritive value than straw due to the presence of seed, head parts and broken grain (Coxworth et al. 1981b). The variation in nutritive value of cereal straw and chaff indicates an advantage in characterizing the nutritive value of these feeds.

Provincial composition summaries (Tables 2 through 5) represent a larger data base of straw samples than are available with more detailed summaries (Mathison et al. 1999; NRC 2000, 2001). However, they are quite limited in terms of nutrients analyzed and sources of variation explained. These summaries are typical of the information requested by, and available to, cattle producers, and actually have some nutrient composition information on chaff. What is needed is a data set on nutrient contents of straw and chaff that: (1) is large enough to reflect the expected range in nutrient composition of western Canadian straw and chaff; (2) has enough detailed analysis to allow use in more mechanistic nutrient models for microbial growth and rumen degradation of feeds; and (3) partitions the analysis summaries according to major sources of variation. Development of such a data base would enable better characterization of the nutritive value of straw and chaff feedstuffs, and allow for the education of cattle producers on the benefits of this improved characterization.

In the past, excess cereal crop residue often was burned in western Canada because it appeared to have little value. Given the proper attention and treatment, higher-quality cereal grain residues can provide a low-cost feedstuff for wintering beef cattle, whereas lower-quality plant residues remain suitable for bedding.

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