FORAGES

Barley, Oat, and Cereal–Pea Mixtures as Dryland Forages in the Northern Great Plains

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ABSTRACT

Oat (*Avena* spp.) is a popular cereal forage in cool semiarid regions. Barley (*Hordeum vulgare* L.) has produced equal or greater amounts of superior quality forage in subhumid regions. The importance of cereal crop, cultivar, and plant part on forage production was determined in low-soil-N environments in southwestern North Dakota. Barley and oat cultivars, along with intercrops of pea (*Pisum sativum* L. subsp. *sativum*) with barley and oat, were compared for forage yield and quality over 2 yr. Forage dry matter (DM) yield averaged 3.84 Mg ha^{-1} for oat compared with 2.91 Mg ha^{-1} for barley while crude protein (CP) concentration of oat forage averaged 61 g kg^{-1} compared with 90 g kg^{-1} for barley ($P < 0.05$). No difference in forage N yield occurred between barley and oat. Acid detergent fiber and neutral detergent fiber concentrations averaged 39 and 41 g kg^{-1} lower, respectively, for barley compared with oat forage while Ca and P concentrations were higher for barley forage. Cultivar selection within each crop species generally did not affect forage yield or quality. The relative contributions of stem, inflorescence, leaf blade, and leaf sheath to forage yield were similar between cereal species and averaged 20, 44, 14, and 22%, respectively. Intercropping with pea increased forage and N yield. These results suggest that forage yield is reduced but quality is enhanced when oat is replaced with barley in low-soil-N, unfertilized environments. Furthermore, the results indicate that forage yield and quality can be enhanced by intercropping barley or oat with pea.

Cereals are popular annual forages in the Northern Great Plains and were harvested for forage from 0.25 million ha across Montana, North Dakota, and South Dakota in 1997 (USDA Natl. Agric. Stat. Serv., 1999). Oat is the most popular cool-season cereal species grown for forage in the Great Plains region, particularly in northern tier states. Oat comprised approximately 80% of the cereal area devoted to hay production in 1997 in North Dakota, approximately 90% of cereal in South Dakota, and almost 50% in Montana (E. Stabenow, personal communication, 2000). The remaining area consisted of barley (14%) and other [rye (*Secale cereale* L.) and wheat (*Triticum aestivum* L. emend. Thell.)] cereal crops.

Previous work in subhumid regions indicates that barley produces higher quality forage than oat. Barley had greater nutritive value than oat, triticale (×*Triticosecale* Wittmack), and wheat in Minnesota (Cherney and Marten, 1982a). Barley forage was highest in digestible DM and lowest in acid detergent fiber (ADF) concentrations. Crude protein concentration was 16 g kg^{-1} greater in barley forage than in oat forage.

The superior quality of barley forage compared with oat and other cereal forages may result from a greater proportion of DM occurring as inflorescence in barley. More than 25% of barley forage DM consisted of inflorescence compared with 20% for oat, triticale, and wheat forage across six maturity stages in subhumid regions (Cherney and Marten, 1982b). The inflorescence was more digestible and nutritious than other plant components. The leaf blade and sheath of barley also had less lignified area than oat. Similar compositional data are not available for barley and oat cultivars grown in the Northern Great Plains.

The CP concentrations of barley and barley–pea forage were superior to those of oat and oat–pea forage in a study at Dickinson, ND (Carr et al., 1998). Additional cereal forage quality data have been compared in subhumid regions (Cherney and Marten, 1982b) but not in the Northern Great Plains. Factors in addition to CP concentration are important in determining the nutritive and economic value of forage. Energy, digestibility, and mineral concentrations are required for comparisons between barley and oat grown in the region.

Barley forage yield has been equal or superior to forage yield of oat in subhumid regions, whether grown alone (Cherney and Marten, 1982a) or with pea as a companion crop for alfalfa (*Medicago sativa* L.) establishment (Chapko et al., 1991). Barley forage yield has been inconsistent compared with oat in the Northern Great Plains. 'Dumont' and 'Magnum' oat were superior to 'Bowman' and 'Horsford' barley for yield when the cultivars were grown alone and in combination with field pea in 1993 and 1994 at Dickinson, ND (Carr et al., 1998). However, differences in yield between Chopper, Haybet, and B 7518 barley cultivars and Dumont oat were not detected in a subsequent study (Carr, unpublished data, 1996). These data suggest that cultivar selection may impact barley forage yield in semiarid regions. Comparison of a diverse group of barley and oat cultivars may be justified to verify these results since only a few cultivars were compared.

Intercropping pea with cereal crops is practiced to enhance forage CP concentration compared with cereal sole cropping. For example, forage CP concentration was enhanced by intercropping pea with oat compared

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Abbreviations: ADF, acid detergent fiber; CP, crude protein; DM, dry matter; NDF, neutral detergent fiber; TDN, total digestible nutrient(s).

with an oat sole crop in Minnesota (Robinson, 1960). Similarly, CP concentration was superior for oat–pea and barley–pea forage compared with forage produced by a cereal sole crop in the Northern Great Plains, but only in an environment with less than 35 kg N ha^{-1} in the 0- to 60-cm soil surface depth at seeding (Carr et al., 1998). No differences were observed between forage produced by oat–pea or barley–pea intercrops and a cereal sole crop in environments with more than 55 kg N ha^{-1} in surface soil depths. Additional research is needed to verify the impact of intercropping on forage CP concentration that occurred in the single low-N environment included in the study by Carr et al. (1998).

The impact of intercropping pea with cereal crops on forage DM yield has been inconsistent. Intercropping pea with oat enhanced yield of haylage compared with an oat sole crop in Minnesota (Robinson, 1960). Similarly, forage DM yield was greater when a barley–pea mixture was used as a nurse crop for alfalfa compared with a barley sole crop in Wisconsin (Chapko et al., 1991). Conversely, intercropping pea with barley and oat reduced forage DM yield when the cereal component was seeded at 50% of the sole crop rate in western North Dakota (Carr et al., 1998). Forage DM yield was unaffected by intercropping when the cereal component was seeded at a sole crop or heavier rate or when the pea component was seeded at rates ranging from 50 to 200% of the sole crop rate. Results of the study by Carr et al. (1998) suggest that the cereal component should be seeded at a sole crop or heavier rate if the goal of intercropping is maintenance of forage DM yield compared with a cereal sole crop in the Northern Great Plains

Our objectives were to determine in a low-soil-N environment in the Northern Great Plains: (i) if forage yield and quality of barley were superior to oat; (ii) the effect of cultivar selection on forage yield and quality; (iii) the relative contribution of stem, inflorescence, leaf blade, and leaf sheath to yield; and (iv) the effect of intercropping with field pea on forage yield and quality.

Table 1. Harvest dates corresponding to mid-milk to early soft dough growth stages (Zadoks Growth Stages 75 to 83) for barley, oat, and pea cultivars during 1999 and 2000 at Dickinson, ND.

Crop(s) and type	Cultivar	1999	2000
Barley			
Grain			
Six row	Foster	13 July	7 July
	Robust	13 July	7 July
	Stander	13 July	7 July
Two row	Conlon	13 July	7 July
	Logan	13 July	7 July
	Stark	13 July	7 July
Forage	Haybet	13 July	7 July
	Horsford	13 July	8 July
	Westford	13 July	14 July
Oat			
Grain	Paul	21 July	27 July
	Triple Crown	21 July	27 July
	Whitestone	21 July	20 July
Forage	Celsia	21 July	27 July
	Mammoth	21 July	27 July
Pea	Trapper	21 July	21 July
Intercrops			
Barley–pea	Robust–Arvika	13 July	7 July
	Robust–Trapper	13 July	7 July
Oat–pea	Whitestone–Arvika	21 July	20 July
	Whitestone–Trapper	21 July	20 July

MATERIALS AND METHODS

Field experiments were conducted under dryland management during 1999 and 2000 at Dickinson, ND (46°53′ N, 102°49′ W; 760 m elevation). The experiments were located on a Farnuf loam (fine-loamy, mixed Typic Argiustolls) in fields where foxtail millet [*Setaria italica* (L.) P. Beauv.] was grown the previous year. Low amounts of less than 15 kg N ha^{-1} as nitrate occurred in the 0- to 60-cm soil depth, but moderate amounts, or approximately 20 kg P ha^{-1}, occurred in the 0- to 15-cm soil depth before establishing the field experiments in both years. Nitrogen and P fertilizers were not applied to reflect the common practice of forgoing fertilizer applications when growing cool-season annual forages in the region. Soils were not evaluated for K status since soils have high natural K content at Dickinson and K fertilizers are not applied to cereal forage crops. Similarly, soils were not evaluated for pH and organic matter status during the study but historically are slightly acidic with organic matter content of approximately 25 to 30 g kg^{-1} at the 0- to 15-cm soil surface (Carr et al., 1998).

Nine barley, five oat, and one pea cultivar, along with two barley–pea and two oat–pea intercrops, were included in the study. The barley cultivars included three grown for forage (Haybet, Horsford, and Westford), three two-rowed cultivars developed for grain production (Conlon, Logan, and Stark), and three six-rowed cultivars developed for grain production (Foster, Robust, and Stander). The oat cultivars included two grown for forage (Celsia and Mammoth) and one hull-less cultivar (Paul) along with two hulled cultivars (Triple Crown and Whitestone) developed for grain production. The long-vined pea cultivars Trapper and Arvika each were intercropped with Robust barley and Whitestone oat. In addition, Trapper pea was grown alone.

The cultivar sole crop and intercrop treatments were established in rows spaced 20 cm apart within 1.8- by 8-m plots in a no-tillage seedbed using a small-plot seeder with cropmaker openers (Acra-Planter,[1] Garden City, KS). Oat and barley were sown alone at a rate of 296 viable kernels m^{-2} and at 148 viable kernels m^{-2} when intercropped with pea. Pea was sown at 80 live seed m^{-2} in a sole crop and intercropped at 46 viable seed m^{-2}. Seeding rates used for barley, oat, and pea sole crops reflected rates used commercially in the region. Seeding rates for intercrops reflected a slight modification of the rates used to maintain forage DM yield and enhance forage CP concentration compared with a cereal sole crop in previous research at Dickinson (Carr et al., 1998). The plots were arranged in a randomized complete block, with treatments replicated four times.

Daily precipitation and temperature were recorded at a National Oceanographic and Atmospheric Administration weather service station 1 km from the field experiments. The depth of moist soil was determined using a soil moisture probe as described by Brown et al. (1985) before establishing the treatments on 30 Apr. 1999 and 26 Apr. 2000.

Forage yield was determined by harvesting the center three rows of each nine-row plot to a 6-cm stubble height with a forage plot harvester (Swift Machine and Welding Ltd.,[1] Swift Current, SK) in early to late July (Table 1), when a cereal crop cultivar was in the mid-milk to early soft dough stages

[1]Mention of a proprietary product name is for identification purposes only and does not imply endorsement or warranty to the exclusion of other products.

of development (Zadoks Growth Stages 75 to 84; Zadoks et al., 1974), and a fresh weight was recorded. Pea in sole crop plots was harvested at first pod set (Pea Growth Stage 204; Knott, 1987) and at first open flower to pod fill growth stages (Pea Growth Stages 203 to 207) in intercrops, depending on when the cereal crop was in the mid-milk to early soft stages of development. A subsample of approximately 450 g was selected randomly from the harvested portion of each plot and dried at 50°C for approximately 72 h until a constant weight was attained. Forage yield was expressed on a dry weight basis.

Forage analyses were performed by a commercial laboratory (Chemical Services Laboratory,[1] Jeffersonville, IN) on the subsample used for determination of DM yield from each plot in three of four blocks in both years. Forage CP, ADF, ether extract (fat), ash, P, and Ca concentrations were determined by standard procedures (AOAC, 1990). Neutral detergent fiber (NDF) concentration was determined using recommended procedures (NFTA, 2002). Total digestible nutrient (TDN) concentration was reported by commercial laboratory using the following relationship: TDN = $(-1.2910 \times \text{ADF}) + 101.35$. Forage N yield was determined as N yield × FY, where FY is forage yield.

Cereal plants in sole crop plots and cereal and pea plants in intercropped plots were clipped by hand in a 0.6-m length of row (0.12-m^2 area) from an interior row bordering the harvested area in each plot. The clipped plants were placed in a burlap bag and transported to a refrigeration unit where a temperature of 4°C was maintained for short-term storage. Plants were removed from the refrigeration unit and then separated manually into stem, inflorescence (including peduncle), leaf blade, and leaf sheath fractions. Plant fractions were dried at 50°C until a constant weight was attained, and the relative contribution of each component to plant DM was calculated.

Data were analyzed across both years by the GLM procedure from SAS (SAS Inst., 1985). Cultivar and intercrop treatments were considered fixed effects. Years and replicates were considered random effects. Nonorthogonal contrasts were used to compare means of barley with oat treatments, forage with grain cultivar treatments, and plant fractions where *F* tests indicated significant differences ($P < 0.05$) existed between treatments. Comparisons also were made between sole crop and intercrop treatments. Years were analyzed separately for any factor when the year × treatment interaction was significant.

RESULTS AND DISCUSSION

Precipitation and Temperature

Overwinter precipitation was 187% of the 30-yr average of 123 mm in 1999, and moist soil extended to a depth of 90 cm before establishing the field experiment. Conversely, overwinter precipitation was 85% of the 30-yr average in 2000 when moist soil extended to a depth of only 46 cm. However, precipitation was only 88% of the 30-yr average of 243 mm in 1999 but 102% in 2000 during the growing season (April–July). Average temperature during the growing season was within 1°C of the 30-yr average of 15°C in both years.

Table 3. Dry matter (DM) yield, N yield, and crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), total digestible nutrients (TDN), P, and Ca concentrations of forage produced by barley, oat, pea, and cereal–pea intercrops under dryland management across 2 yr in southwestern North Dakota, USA.

	Yield		Forage quality parameter					
Forage treatment	DM	N	CP	ADF	NDF	TDN†	Ca	P
	Mg ha^{-1}	kg ha^{-1}	g kg^{-1}					
Barley	2.91	44	90	350	584	562	3.64	2.78
Oat	3.84	37	61	385	618	516	2.98	2.01
Intercrops	4.05	75	118	355	530	562	6.71	2.39
Barley–pea	3.53	76	135	344	508	579	7.00	2.80
Oat–pea	4.56	74	100	365	552	545	6.42	1.97
Pea	5.38	143	166	382	481	554	12.30	2.60
	Nonorthogonal contrasts							
Barley vs. oat	*	NS‡	*	*	*	*	*	*
Sole barley vs. intercropped oat	*	*	*	*	NS	NS	*	*
Sole oat vs. intercropped barley	NS	*	*	*	*	*	*	*
Sole pea vs. intercropped pea	*	NS	*	NS	*	NS	*	NS
Intercropped oat vs. intercropped barley	*	NS	*	NS	*	NS	NS	*

* Significant at the 0.05 probability level.
† TDN = $(-1.291 \times \text{ADF}) + 101.35$.
‡ NS, not significant.

Forage Yield

The year × treatment interaction was significant for forage DM production (Table 2). However, the interaction indicated a change in the magnitude of response and not a crossover in ranking of the treatments or treatment combinations (data not presented). As a result, mean comparisons are presented from the combined analyses across years.

Dry matter production averaged 3.84 Mg DM ha^{-1} for oat cultivars compared with 2.91 Mg ha^{-1} for barley cultivars included in this study (Table 3). Dry matter production of barley cultivars developed for grain production was 1.05 Mg DM ha^{-1} less than oat cultivars developed for grain production and 1.17 Mg ha^{-1} less than oat cultivars grown for forage (Table 4; $P < 0.05$). Differences in DM production were not detected, but significance was approached between barley cultivars grown for forage and oat cultivars grown for forage

Table 2. Mean squares† from the analyses of variance for forage and N yield, and crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), total digestible nutrients (TDN), P, and Ca concentrations of sole cereal treatments and intercrops grown in low-soil-N environments during 1999 and 2000 in southwestern North Dakota, USA.

					Forage quality parameter					
	df	DM yield	df	N yield	CP	ADF	NDF	TDN	P	Ca
Year (Y)	1	138.50*	1	34 583*	9 031*	173	28 985*	4	1.66	21.51*
Rep (R) [Y]	6	2.60	4	724	322	493	2 832	1 136	1.15	1.05
Forage treatment (FT)	19	5.3*	19	4 289*	4 951*	3 597*	11 863*	6 134*	1.19*	36.52*
Y × FT	19	1.0*	19	406*	449*	998	2 214	1 928	0.28	1.81*
Residual	114	0.3	76	189	245	1 292	1 406	2 242	0.17	0.61

* Significant at the 0.05 probability level.
† SAS statement for the *F* test for treatments was TEST H = forage treatment E = year × forage treatment.

Table 4. Dry matter (DM) yield, N yield, and crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), total digestible nutrients (TDN), P, and Ca concentrations of forage produced by barley, oat, and pea cultivars and cereal–pea intercrops across 2 yr in southwestern North Dakota.

	Yield		Forage quality parameter					
Crop species, type, and cultivar	DM	N	CP	ADF	NDF	TDN†	P	Ca
	Mg ha^{-1}	kg ha^{-1}	g kg^{-1}					
Barley								
Grain	2.74	41	91	337	565	580	2.78	3.74
Six-rowed grain	2.80	41	90	338	575	577	2.81	3.88
Foster	2.85	43	87	344	579	569	2.70	4.03
Robust	2.76	38	88	353	584	558	2.60	3.80
Stander	2.80	42	95	318	562	603	3.12	3.80
Two-rowed grain	2.69	42	92	335	557	583	2.76	3.64
Conlon	2.74	37	85	335	570	581	2.67	2.95
Logan	2.73	38	85	337	546	579	2.97	3.65
Stark	2.60	51	105	334	556	590	2.63	4.33
Forage	3.24	47	88	364	599	544	2.78	3.41
Haybet	3.53	50	83	353	609	558	2.30	3.67
Horsford	2.82	42	89	346	566	567	2.97	3.17
Westford	3.37	48	93	392	623	507	3.07	3.38
Intercrops								
Robust + Arvika pea	3.70	74	124	343	517	571	2.60	6.87
Robust + Trapper pea	3.35	79	147	345	500	586	3.00	7.13
Oat								
Grain	3.79	39	64	376	611	529	2.08	2.94
Hull-less								
Paul	3.41	41	75	367	572	540	2.18	3.02
Hulled	3.99	38	58	380	631	523	2.03	2.90
Triple Crown	3.99	40	61	367	611	539	2.08	3.10
Whitestone	3.98	36	55	393	650	507	1.98	2.70
Forage	3.91	39	57	400	629	497	1.91	3.05
Celsia	3.82	37	55	418	646	474	1.72	3.42
Mammoth	4.00	41	60	382	611	520	2.10	2.67
Intercrops								
Whitestone + Arvika pea	4.04	62	95	366	563	541	1.98	5.88
Whitestone + Trapper pea	5.07	86	106	361	541	548	1.95	6.95
				Nonorthogonal contrasts				
Barley								
Forage vs. grain	NS‡	NS	NS	*	*	*	NS	*
Two-rowed grain vs. six-rowed grain	NS	NS	NS	NS	NS	NS	NS	NS
Sole vs. intercropped	*	*	*	NS	*	NS	*	*
Forage vs. intercropped	NS	*	*	NS	*	NS	*	NS
Grain vs. intercropped	*	*	*	NS	*	NS	*	NS
Oat								
Forage vs. grain	NS	NS	NS	NS	NS	NS	NS	NS
Hull-less vs. hulled	NS	NS	NS	NS	*	NS	NS	NS
Sole vs. intercropped	*	*	*	*	*	NS	*	*
Forage vs. intercropped	*	*	*	*	*	NS	*	*
Grain vs. intercropped	*	*	*	NS	*	NS	*	NS
Crop species and cultivar type								
Forage barley vs. forage oat	NS	NS	*	*	NS	*	NS	*
Forage barley vs. grain oat	NS	NS	*	NS	NS	*	NS	NS
Grain barley vs. forage oat	*	NS	*	*	*	*	NS	*
Grain barley vs. grain oat	*	NS	*	*	*	*	*	*

* Significant at the 0.05 probability level.
† TDN = (−1.291 × ADF) + 101.35.
‡ NS = not significant at less than the 0.05 probability level.

($P = 0.05$) or developed for grain production ($P = 0.07$). Previous work in southwestern North Dakota indicated that DM production generally is lower for barley compared with oat in the Northern Great Plains in high soil N environments (Larson and Carter, 1970; Carr et al., 1998). Conversely, DM production has been equal or superior for barley compared with oat in subhumid regions (Cherney and Marten, 1982a; McElroy and Gervais, 1983; Chapko et al., 1991).

Differences in the relative contribution of stem ($P = 0.23$), inflorescence ($P = 0.11$), leaf blade ($P = 0.10$), and leaf sheath ($P = 0.69$) to forage DM yield were not indicated by the *F* test for forage treatments (data not presented). Cherney and Marten (1982b) concluded that the relative contribution of the inflorescence to DM yield was greater for barley compared with oat across six different growth stages ranging from flag leaf extension to kernel ripe stages of development (Zadoks Growth Stages 41 to 92) in Minnesota. Differences in environmental factors may explain the inconsistency in results between the two studies. Low soil N status in both years stressed cereal plants and was reflected in the relatively low forage DM yields in our study (Table 3). Forage DM yields averaged close to 8 Mg ha^{-1} in a subsequent field experiment under relatively high soil N conditions at Dickinson, and a greater proportion of forage was comprised of inflorescence for barley compared with oat (Carr, unpublished data, 2002).

The contributions of stem, inflorescence, leaf blade, and leaf sheath to DM yield were 20, 44, 14, and 22%, respectively, for barley and oat in this study. A similar composition of barley plant DM was reported in a study by Mannerkorpi and Taube (1995). Conversely, a greater proportion of barley DM consisted of stem and leaf sheath in other studies (Droushiotis and Wilman, 1987). Inconsistencies in the composition of barley forage DM reported among studies may result from differences in the timing of harvest. Barley plants were harvested at the milk and earlier stages of development in the study by Droushiotis and Wilman (1987), whereas plants were harvested at later growth stages in our study. Small changes in crop development stages can alter plant fraction composition of forage DM significantly. For example, the contribution of inflorescence to forage DM increased 18% during the relatively short time between early soft dough to early hard dough stages of development (Zadoks Growth Stages 83 to 91) in barley (Mannerkorpi and Taube, 1995). Timing of harvest as related to crop developmental stage can have a greater effect on forage composition than other management considerations (Juskiw et al., 2000b).

Intercropping oat with pea increased DM production compared with an oat sole crop, regardless of cultivar selection (Table 4). Intercropping barley with pea increased DM production compared with a barley sole crop when cultivars developed for grain production were grown in a sole crop but not when cultivars developed for forage production were grown. The pea component contributed from 40 to 50% of total DM of intercropped forage, depending on cereal crop species and cereal and pea cultivars comprising the mixture. Results of this research indicate that intercropping pea with barley and oat can enhance forage DM in low-soil-N environments. In contrast, previous research indicates that DM yield is not enhanced and may be reduced when pea is intercropped with cereals under high soil N conditions (Carr et al., 1998).

Forage DM yield was maintained by intercropping barley with pea compared with an oat sole crop ($P = 0.31$; Table 3). These results suggest that barley–pea intercrops may be substituted for a monoculture of oat without sacrificing DM yield in low-soil-N environments. The substitution of barley–pea intercrops for an oat sole crop may be advantageous when quality of intercropped forage is superior, if barley and pea are easier to obtain than oat, or if other factors favor use of the intercrop. Forage DM yield was greater for an oat–pea intercrop than barley–pea intercrops, indicating that oat–pea intercrops would be favored to barley–pea intercrops in low-soil-N environments if the goal of intercropping is to maximize forage DM yield. Similarly, previous research indicated that more DM was produced by oat–pea intercrops than barley–pea intercrops in high-soil-N environments in the Northern Great Plains (Carr et al., 1998).

Differences in DM yield were not detected between barley cultivars developed for grain or forage production ($P = 0.07$) or between two- and six-rowed grain barley types ($P = 0.71$; Table 4). Differences in DM yield also were not detected between oat cultivars developed for grain production and cultivars grown for forage ($P = 0.73$) or between hull-less and hulled grain oat cultivars ($P = 0.20$). These results suggest that cultivar selection within small-grain species may not be important in low-soil-N environments, possibly because lack of N eliminates the potential for differences in DM production between low- and high-yielding cultivars that can occur under high-soil-N conditions.

Forage Quality

Crude protein concentration averaged 90 g kg^{-1} in barley forage compared with 61 g kg^{-1} in oat (Table 3). Likewise, Cherney and Marten (1982a) and others (Carr et al., 1998) concluded that CP concentration of forage generally is greater for barley compared with oat. Crude protein concentration of barley forage was superior to oat forage in some field experiments but not others in a 3-yr study at Lacombe, AB, Canada (Juskiw et al., 2000a). However, some comparisons of CP concentration between barley and oat forage in the study by Juskiw et al. (2000a) were confounded since the cereal crops and cereal crop mixtures were harvested at different growth stages in the field experiments. The impact of growth stage differences on CP concentration of cereal forages often is greater than the impact of the crop species and cultivars compared (Cherney and Marten, 1982a; McElroy and Gervais, 1983).

Forage CP was 35 g kg^{-1} more concentrated for barley–pea intercrops compared with a barley sole crop and for oat–pea intercrops compared with an oat sole crop (Table 4). Forage CP was 74 g kg^{-1} more concentrated for barley–pea intercrops compared with a monoculture of oat and 10 g kg^{-1} more concentrated for oat–pea intercrops compared with a monoculture of barley (Table 3). Our results suggest that intercropping pea with barley or oat can enhance the CP concentration of forage compared with a sole crop of either cereal species. The results indicate that intercropping pea with barley may be preferred to an oat sole crop in low-soil-N environments since forage CP concentration is superior for the intercrop and DM yield is maintained. Similarly, intercropping pea with oat may be preferred to a barley sole crop since forage DM yield is superior for the intercrop and CP concentration can be maintained.

Nitrogen yield was similar between barley and oat in our study (Table 3), indicating that the higher concentration of CP in barley forage compensated for the lower production of DM compared with oat. Larson and Carter (1970) found that CP yield was greater for oat when oat and barley were harvested at the milk growth stage (Zadoks 73 through 78), whereas CP yield was greater for barley when both crops were harvested at the dough stage (Zadoks 83 through 87). The study by Larson and Carter (1970) indicates that the ranking of barley and oat for N yield is transitory and depends on the growth stage of crops when harvested, but additional research may be needed to justify their conclusions using modern production methods and germplasm.

Nitrogen yield was 32 kg ha^{-1} greater for barley–pea intercrops compared with a barley sole crop and 37 kg ha^{-1} greater for oat–pea intercrops compared with an oat sole crop in low-soil-N environments (Tables 3 and 4). Conversely, forage N yield was unaffected by intercropping in previous research under relatively high-soil-N conditions (Carr et al., 1998). Intercropping cereal crops with pea may be advantageous because of the biological N-fixing ability of pea under low-soil-N conditions. A recent study indicates that pea is more effective at biological N fixation than other pulses in the Northern Great Plains, contributing up to 50 kg ha^{-1} more N than lentil (*Lens culinaris* Medik.) in a loam soil (Miller et al., 2003).

Nitrogen yield was greater for barley–pea intercrops compared with an oat sole crop and for oat–pea intercrops compared with a sole crop of barley (Table 3). Hence, intercropping pea with either barley or oat enhances forage N yield compared with growing either cereal species as a sole crop. No difference in N yield was detected between barley–pea and oat–pea intercrops ($P = 0.80$), suggesting that the relatively high CP concentration of pea forage compensated for the relatively low yield of barley–pea intercrop compared with oat–pea intercrop.

Acid detergent fiber concentration averaged 35 g kg^{-1} lower for barley forage compared with oat forage in this study while NDF concentration averaged 34 g kg^{-1} lower in barley forage (Table 3). Forage ADF and NDF concentrations were lower for barley cultivars grown for forage compared with oat cultivars grown for forage and for barley cultivars developed for grain production compared with oat cultivars grown for forage. Differences in forage ADF concentration were not detected between barley cultivars grown for forage and oat cultivars developed for grain production (Table 4; $P = 0.28$), nor were differences in forage NDF concentration detected between barley cultivars grown for forage and oat cultivars grown for grain ($P = 0.11$) or for forage ($P = 0.46$). Previous research in subhumid regions indicated that ADF and NDF concentrations of forage generally were lower for barley compared with oat (Chapko et al., 1991; Cherney and Marten, 1982a). However, Brink and Marten (1986) emphasized that environmental factors can affect relative quality differences between barley and oat forage. Results of our study suggest that cultivar selection may impact the relative ranking of barley and oat for forage NDF concentration.

Intercropping pea with barley did not affect forage ADF concentration compared with a barley sole crop while forage NDF concentration was reduced by intercropping (Table 4). Likewise, intercropping pea with oat reduced the NDF concentration of forage compared with an oat sole crop. Acid detergent fiber concentration also was lower for forage produced by an oat–pea intercrop compared with a sole crop comprised of a forage cultivar but not an oat cultivar grown for grain. Differences in forage ADF concentration were not detected between barley–pea and oat–pea intercrops while NDF concentration was lower in forage produced by barley–pea intercrops than oat–pea intercrops.

Average TDN concentration was 46 g kg^{-1} higher for forage produced by barley compared with oat in this study (Table 3). Forage TDN concentration was greater for barley compared with oat cultivars grown for forage and greater for barley cultivars developed for grain production compared with either group of oat cultivars (Table 4). Differences in the TDN concentration of forage produced by barley cultivars grown for forage and oat cultivars grown for grain were not detected ($P = 0.31$). Similarly, McElroy and Gervais (1983) found that forage TDN concentration of ‘Conquest’ barley and ‘Dorval’ oat was similar in a 3-yr study. Results of our study suggest that crop species and cultivar selection can impact TDN concentration of small-grain forage. However, environment and other factors, such as the presence or absence of awns on spikelets in barley, also impact this quality trait.

Total digestible nutrients were 17 g kg^{-1} more concentrated in forage produced by barley–pea intercrops than a barley sole crop and 29 g kg^{-1} more concentrated in forage produced by oat–pea intercrops than an oat sole crop (Tables 3 and 4). These data suggest that intercropping may be a suitable strategy for enhancing the TDN concentration of forage compared with managing the cereal component as a sole crop. No differences were detected in the TDN concentration between barley–pea and oat–pea forage.

Forage P was 0.77 g kg^{-1} more concentrated for barley compared with oat (Table 3). Phosphorus was 0.70 g kg^{-1} more concentrated in barley forage when oat and barley cultivars developed for grain production were compared, but differences were not detected in forage P concentration between barley cultivars grown for forage and oat cultivars grown for forage ($P = 0.48$) or developed for grain production ($P = 0.31$). Differences also were not detected in forage P concentration between barley cultivars developed for grain production and oat cultivars grown for forage ($P = 0.12$). Results of our study suggest that cultivar selection may impact the ranking of barley and oat for forage P concentration in some environments.

Forage Ca concentration was 3.64 g kg^{-1} for barley forage compared with 2.98 g kg^{-1} for oat forage (Table 3). Similarly, McElroy and Gervais (1983) concluded that Ca was more concentrated in barley compared with oat forage when grown in a subhumid region. Calcium was 2.78 g kg^{-1} more concentrated in forage produced by a barley–pea intercrop than a monoculture of oat and 3.45 g kg^{-1} more concentrated in forage produced by an oat–pea intercrop than a monoculture of barley. There was no difference in forage Ca concentration between barley–pea and oat–pea intercrops.

Intercropping increased Ca concentration of forage compared with a sole crop of either cereal species in this study (Tables 3 and 4). The relatively high concentrations of Ca in pea forage accounted for the elevated Ca concentration of forage produced by intercrops compared with a cereal sole crop. Conversely, intercropping generally failed to affect forage P concentration compared with a cereal sole crop. Likewise, no differences in ash or fat concentrations of forage were detected between intercrops and a sole crop of either barley or oat (data not presented).

Differences in CP, P, and N yield were not detected between barley cultivars developed for grain production and cultivars developed for forage (Table 4). Forage was lower in ADF and NDF concentrations but higher in TDN concentration for barley cultivars developed for grain production compared with cultivars developed for forage. No difference in any forage quality trait was detected between two- and six-rowed barley cultivars developed for grain production. Similarly, differences in forage quality traits were not detected between oat cultivars grown for grain and cultivars developed for forage or between hull-less and hulled oat cultivars, except for forage NDF concentration. Differences in ash and fat concentrations of forage were not detected between forage produced by a sole crop of barley and oat (data not presented).

CONCLUSIONS

Our objective was to determine if forage yield and quality were superior for a diverse group of adapted barley cultivars compared with a group of oat cultivars in the Northern Great Plains. Previous research in other environments suggested that forage DM production would be superior for oat but barley would produce higher quality forage. Forage DM production was greater for oat in this study while quality of barley forage was superior. The field experiments included in our study were located in low-soil-N, unfertilized environments, but similar results were generated when barley and oat cultivars were compared in environments with relatively high-soil-N conditions conducted previously at Dickinson (Carr et al., 1998). Results of these two studies indicate that forage DM yield is greater for oat than barley under a range of soil N conditions in the Northern Great Plains, in contrast to environments in subhumid regions where barley has produced equal or greater amounts of forage compared with oat.

Forage CP concentration was superior for barley compared with oat in our study as well as previous studies in the Northern Great Plains. However, past research did not compare barley and oat forage for other quality parameters in this region. Our research suggests that P, Ca, and TDN are more concentrated in barley forage while ADF and NDF are less concentrated. Differences in forage N yield were not detected in our study or in other environments included in previous research (Carr et al., 1998), suggesting that barley may be preferred to oat if optimizing N yield while limiting DM production is an important criterion in forage selection.

Forage DM yield and CP concentrations were optimized when cultivars developed for forage rather than grain production were grown in previous research in the Northern Great Plains (Carr et al., 1998). However, cultivar selection did not affect forage DM yield and CP concentration in our study. We speculate that differences in forage DM production, CP concentration, and N yield were narrowed between cultivars because of the low-soil-N, unfertilized environments that were encountered. Results of our study support the hypothesis that cultivar selection may not be an important criterion for maximizing forage DM yield or quality in N-stressed environments though additional research may be needed to verify these results.

Differences in the percentage of forage comprised of the various plant fractions between barley and oat were not detected in our study. We are unable to explain the superior quality of barley forage compared with oat forage on the basis of plant fraction composition, as was done by researchers working in subhumid regions. Additional work is needed in the Northern Great Plains to determine if plant fraction composition of barley and oat forage is similar in environments that favor DM production. The impact of timing of harvest on plant fraction composition of forage across the range of growth development stages when barley and oat are harvested for forage should be included in the effort.

Forage DM and N yield were unaffected by intercropping under favorable soil N conditions during previous research in the Northern Great Plains. Conversely, forage DM and N yield were enhanced by intercropping in this study. The ability of pea to fix N biologically may have been an advantage in the low-soil-N environments that were encountered during our study while ability of pea to fix N biologically may have been limited in the high-soil-N environments that were encountered during previous research. Results of our study support the hypothesis that intercropping pea with barley and oat can enhance forage DM and N yield along with forage CP concentration compared with a monoculture of either cereal crop under low-soil-N conditions when N fertilizer is not applied in the Northern Great Plains.

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