Forage Nutritional Characteristics of Orchardgrass and Perennial Ryegrass at Five Irrigation Levels

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ABSTRACT

As water resources become limiting, the need to produce stable amounts of highly nutritional forage increases. An understanding of how levels of irrigation affect crude protein (CP), digestible neutral detergent fiber (dNDF), in vitro true digestibility (IVTD), and neutral detergent fiber (NDF) is critical in pasture forage management. Cultivars of orchardgrass (*Dactylis glomerata* L.) and perennial ryegrass (*Lolium perenne* L.) were established under a line-source irrigation system to evaluate the effect of five water levels (WLs) and three harvest dates on concentrations of CP, dNDF, IVTD, and NDF. Perennial ryegrass forage had higher CP, dNDF, and IVTD and lower NDF concentrations than orchardgrass at all harvest dates and within WLs. The most notable trend in nutritional value across WLs was the near linear increase in CP ranging from 175 g kg^{-1} at the wettest WL to 217 g kg^{-1} at the driest WL. Digestible NDF ranged from 709 to 757 g kg^{-1} at corresponding WLs. These trends were particularly evident later in the growing season. Orchardgrass maturity (early vs. late) had little effect on forage nutritional characteristics across WLs. Combined over WLs, tetraploid perennial ryegrass cultivars averaged higher concentrations of CP, IVTD, and dNDF and lower NDF values compared with diploid cultivars. In general, as water stress increased, forage nutritional value (i.e., CP and dNDF) increased.

Interest in maximizing productivity of irrigated pastures has escalated with the increased restrictions on grazing public lands in the western USA. Under adequate irrigation, cool-season grass pastures represent some of the most productive grazing lands throughout the West (Bateman and Keller, 1956). Increasing human population and droughty growing conditions place additional demands on available irrigation water. As a result, producers are required to use less water while trying to maintain stable amounts of highly nutritious forage. Historically, germplasm improvement in orchardgrass and forage-type perennial ryegrass has focused on forage traits, disease resistance, and agronomic adaptation to temperate areas (Balasko et al., 1995; Christie and McElroy, 1995; Jung et al., 1996; Casler et al., 2000).

Forage nutrition can be measured by the relative performance of animals when forage is fed to livestock. Animal performance is highly influenced by nutrient concentration, intake, and digestibility (Buxton et al., 1996). In the absence of feeding trials, forage nutritive value is often evaluated by measuring such characteristics as CP, NDF, acid detergent fiber, IVTD, and hemicellulose (Pavetti et al., 1994). Cell wall constituents are the major contributors to NDF (Fisher et al., 1995). Laboratory measures of NDF are correlated with voluntary intake (Casler and Vogel, 1999). Fisher et al. (1995) reported that energy is closely related to the digestibility of NDF (dNDF) in forage grasses. Grant (2002) reported that NDF digestion can range from 2 to 20% h^{-1} in dairy cows (*Bos taurus*). Oba and Allen (1999) reported that an increase in forage dNDF resulted in increased dry matter intake and milk yield. They further concluded that for every 1% unit increase in dNDF, there was a 0.18-kg increase in dry matter intake and a 0.03-kg increase in body weight in dairy cows. Selection for increased CP and in vitro dry matter digestibility in cool-season grasses has resulted in subsequent yield reductions in smooth bromegrass (*Bromus inermis* Leyss.) and reed canarygrass (*Phalaris arundinacea* L.) (Casler, 1998; Casler and Vogel, 1999).

Hall (1998) found that maximum forage nutrition was achieved when orchardgrass, smooth bromegrass, and reed canarygrass were harvested at 35- to 45-d intervals. In another study (Turner et al., 1996), increased CP and lower NDF concentrations were observed under early and frequent defoliation compared with a hay management system for festulolium [*Xfestulolium braunii* (K. Richt) A. Camus], orchardgrass, and prairie grass (*Bromus catharticus* M. Vahl). Similarly, CP in stockpiled forage of 11 cool-season grasses declined by 55% from June to September (Suleiman et al., 1999). Under the same line source, orchardgrass cultivars had higher dry matter yield and increased water use efficiency than perennial ryegrass cultivars (Jensen et al., 2001, 2002).

A line-source irrigation system was developed to evaluate plant growth under a gradient of WLs (Hanks et al., 1976). This system has been used to study the responses of cool-season grasses to controlled irrigation levels (Johnson et al., 1982; Asay and Johnson, 1990; Asay et al., 2001; Jensen et al., 2001; Waldron et al., 2002). Literature is limited regarding the effects of irrigation on forage nutritional characteristics under repeated harvesting.

Objectives of this study were to study the trends in CP, dNDF, IVTD, and NDF for nine cultivars of orchardgrass and seven of perennial ryegrass across an irrigation gradient. A secondary objective was to evaluate the effect of ploidy level in perennial ryegrass and maturity in orchardgrass on any observed differences and trends in forage nutritive value across the irrigation gradient.

USDA-ARS, Forage and Range Res. Lab., Utah State Univ., Logan, UT 84322-6300. Joint contribution of the USDA-ARS and the Utah Agric. Exp. Stn. Journal Paper no. 7468. Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the USDA or Utah State Univ. Received 13 May 2002. *Corresponding author (kevin@cc.usu.edu).

Published in Agron. J. 95:668–675 (2003).

Abbreviations: CP, crude protein; dNDF, digestible neutral detergent fiber; IVTD, in vitro true digestibility; NDF, neutral detergent fiber; NIRS, near infrared reflectance spectroscopy; WL, water level.

MATERIALS AND METHODS

Nine orchardgrass and seven perennial ryegrass cultivars (Table 1) were previously described by Jensen et al. (2001). All ryegrass cultivars were endophyte-free. The experiment was located at the Utah State University Evans Experimental Farm, which is located about 2 km south of Logan, UT (41°45′ N, 111°8′ W; 1350 m above sea level). Soil type at the site is a Nibley silty clay loam (fine, mixed, mesic Aquic Argiustolls).

Sward plots (16 by 1 m) were planted 7 May 1995 with a cone seeder at a depth of 1.3 cm. The seeding rate for each cultivar was approximately 135 seeds per linear meter of row with 15-cm row spacing. Plots were oriented perpendicular to the irrigation line and divided into five WLs (WL 1 = wettest, WL 5 = driest) on each side of the irrigation line. Each plot was 2.0 m^2 (2 by 1 m) and spaced at 2-m intervals from the line-source sprinkler. The plots were arranged as a modified strip-plot design with four replications and irrigation levels applied as nonrandom strips.

During the establishment year, plots were irrigated as needed, and 112 kg N ha^{-1} was applied as a split application during midsummer and fall. Applications of 56 kg N ha^{-1} were made before Harvest 1 and immediately after Harvests 3, 5, and 6 in 1997 and before Harvest 1 and immediately after Harvests 3, 4, and 5 in 1998. First and second harvests were conducted when forage at WLs 1 and 2 were visually estimated to be between the vegetative and elongation stage (Moore et al., 1991). At all subsequent harvests, plots were in the vegetative stage at all WLs. All plots were harvested on the same day on each of six dates in 1997, and samples for determination of forage nutritional value were collected at Harvests 2 (2 June), 4 (21 July), and 6 (23 September). Only five harvests were made in 1998, with samples for forage nutritional value obtained from Harvests 2 (15 June), 4 (18 August), and 5 (28 September). These sampling dates represent early-, mid-, and late-season harvests for each year. Averaged over years, water received by the plots was 4.2, 3.7, 3.2, 2.8, and 2.3 mm d^{-1} for WL 1 to 5, respectively.

Samples for determination of forage nutritional value were dried at 60°C (to a constant weight) in a forced-air oven, initially ground in a Wiley mill, and then finely ground in a Cyclone mill to pass through a 1-mm screen. Ground plant samples were scanned with a near infrared reflectance spectroscopy (NIRS) instrument (Model 6500, Pacific Scientific Instruments, Silver Spring, MD). Software from NIRS systems (IS-0122FS, Infrasoft International LLC, Port Matilda, PA) was used to calibrate a forage equation. Representative samples were selected from each year and harvest and used as a calibration data set for actual chemical analysis. This data set consisted of 440 samples for CP, 473 for NDF, and 441 for IVTD. Validation of the new equation was determined from a different set of samples. The r^2 values for validation of the CP determinations ranged from 0.91 to 0.98 for the six year–harvest combinations and averaged 0.90 when combined across years and harvests. Corresponding values were 0.89 to 0.98 and 0.94 for NDF and 0.80 to 0.94 and 0.85 for IVTD.

Samples used for calibration were analyzed for N using a LECO CHN-2000 Series Elemental Analyzer (LECO Corp., St. Joseph, MI). Levels of CP were determined by multiplying N × 6.25. Neutral detergent fiber and IVTD were determined using procedures described by Goering and Van Soest (1970). Analysis for NDF was made with an ANKOM-200 Fiber Analyzer (ANKOM Technol. Corp., Fairport, NY). The first stage of the IVTD procedure consisted of a 48-h in vitro fermentation in the ANKOM Daisy II incubator (ANKOM Technol. Corp., Fairport, NY). The residual dry matter was then exposed to the NDF procedure. Neutral detergent fiber digestibility values were calculated using the initial concentrations of NDF and IVTD.

Data were analyzed for species and cultivar differences within and across years and WLs using the GLM procedure with a random statement (SAS Inst., 1999). Entry, WL, and year were considered as fixed variables and replications as random variables. A valid *F* test for the main effect due to WLs was not possible because WLs were not randomized within entries (Hanks et al., 1980). However, mean squares for entry and entry × WL were tested with their first-order

Table 1. Combined means in crude protein(CP), digestible neutral detergent fiber (dNDF), neutral detergent fiber (NDF), and in vitro true digestibility (IVTD) on nine orchardgrass and seven perennial ryegrass cultivars combined over five water levels, three harvests, and 2 yr.

	CP			dNDF†			IVTD			NDF		
Cultivars	**g kg^{-1}**	**Linear‡**	**Curvilinear**	**g kg^{-1}**	**Linear**	**Curvilinear**	**g kg^{-1}**	**Linear**	**Curvilinear**	**g kg^{-1}**	**Linear**	**Curvilinear**
Orchardgrass												
Ambassador	197	96*	4	739	98**	<1	880	99*	<1	455	30*	67**
DS-8	191	85**	11**	731	67*	<1	874	36	40	467	<1	99*
Dawn	184	83**	13	723	81**	16	870	48*	45*	469	8	93**
Justus	199	90**	8*	735	90**	<1	878	38	59*	457	38	59*
Latar	191	92**	6*	742	84*	<1	880	49*	44	463	3	97**
Paiute	202	91**	5	731	99**	<1	876	89*	4	458	<1	54
Pizza	199	92**	10**	732	78	<1	879	88**	<1	447	10	90
Potomac	198	96**	3	729	79**	16	876	69**	25*	456	11	89*
Sampson	192	96**	2	732	79**	15	880	66**	30*	449	1	98*
Mean	195	94**	5**	733	97**	<1	877	87**	10*	458	3	94**
LSD (0.05)	5.8			6.0			3.9			5.9		
Perennial ryegrass												
Baramco—2x	207	91**	<1	803	94**	<1	921	72**	16	390	6	97
Bastion—4x	205	80**	10*	779	54**	19	910	21*	56**	405	4	99**
Cambridge—2x	200	93**	7	777	89**	<1	908	66*	21	409	<1	99*
Citadell—4x	197	79**	17**	786	85	11	914	6	86	399	26**	93**
Gambit—4x	211	94**	6	788	59**	12	916	10	11	391	29	85*
Moy—2x	190	83**	18	753	72**	14*	893	49**	39**	433	<1	99**
Zero_nui—2x	198	65**	25	767	<1	99*	900	29*	85**	424	50**	65**
Mean	201	89**	10**	779	75**	15*	909	25**	66**	407	9*	91**
LSD (0.05)	5.7			8.3			4.0			6.2		

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

† Neutral detergent fiber digestibility (dNDF) values were calculated using the initial concentrations of NDF and IVTD.

‡ Percent of WL sums of squares due to linear and curvilinear effects based on orthogonal polynomials with unequal spacings (Gomez and Gomez, 1984).

Table 2. Mean squares from analysis of variance for crude protein (CP), digestible neutral detergent fiber (dNDF), in vitro true digestibility (IVTD), and neutral detergent fiber (NDF) of nine orchardgrass cultivars at five water levels, three harvest dates, and 2 yr.

		Harvest dates			
Source	**df**	**Early**	**Mid**	**Late**	**Combined**
		g kg^{-1}			
			CP		
Cultivar (C)	8	7 562**	402	910**	3 258**
Water level (WL)	4	3 642 nv†	12 004 nv	8 106 nv	16 428 nv
C × WL	32	238	128	82	230
Harvest (H)	2				64 919**
C × H	16				2 316**
WL × H	8				1 624**
C × H × WL	64				98
			dNDF‡		
C	8	8 500**	3 992**	1 293**	2 478**
WL	4	3 100 nv	23 986 nv	2 099 nv	17 223 nv
C × WL	32	406	420	403	489
H	2				608 376**
C × H	16				5 671**
WL × H	8				3 311**
C × H × WL	64				367
			IVTD		
C	8	4 902**	1 338**	508**	1 047**
WL	4	918 nv	5 943 nv	1 239 nv	5 275 nv
C × WL	32	117	115	105	145
H	2				199 600**
C × H	16				2 659**
WL × H	8				756**
C × H × WL	64				92
			NDF		
C	8	15 373**	1 337**	1 796**	3 962**
WL	4	606 nv	2 525 nv	3 940 nv	4 147 nv
C × WL	32	224	87	180**	196
H	2				290 367**
C × H	16				5 877**
WL × H	8				1 204*
C × H × WL	64				142

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

† nv = no valid *F* test for water levels.

‡ Neutral detergent fiber digestibility values were calculated using the initial concentrations of NDF and IVTD.

Table 3. Mean squares from analysis of variance for crude protein (CP), digestible neutral detergent fiber (dNDF), in vitro true digestibility (IVTD), and neutral detergent fiber (NDF) of seven perennial ryegrass cultivars at five water levels, three harvest dates, and 2 yr.

		Harvest dates			
Source	**df**	**Early**	**Mid**	**Late**	**Combined**
		g kg^{-1}			
			CP		
Cultivar (C)	6	6 299**	4 310**	1 546**	4 537**
Water level (WL)	4	8 356 nv†	5 671 nv	963 nv	19 505 nv
C × WL	24	252	173	119*	288
Harvest (H)	2				27 090**
C × H	12				3 396**
WL × H	8				763**
C × H × WL	48				133
			dNDF‡		
C	8	42 479**	4 531**	7 118**	16 874**
WL	4	1 372 nv	1 567 nv	7 953 nv	8 691 nv
C × WL	32	1 028	685	490	689
H	2				285 687**
C × H	16				12 222**
WL × H	8				1 643*
C × H × WL	64				682
			IVTD		
C	6	14 500**	2 458**	2 195**	8 401**
WL	4	498 nv	387 nv	2 162 nv	2 173 nv
C × WL	24	323	229	71	211
H	2				48 535**
C × H	12				3 860**
WL × H	8				366*
C × H × WL	48				172
			NDF		
C	6	200 919**	7 029**	7 121**	22 826**
WL	4	2 071 nv	485 nv	6 579 nv	4 638 nv
C × WL	24	628	375	121*	462
H	2				238 913**
C × H	12				9 101**
WL × H	8				1 625**
C × H × WL	48				365

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

† nv = no valid *F* test for water levels.

‡ Neutral detergent fiber digestibility values were calculated using the initial concentrations of NDF and IVTD.

interactions with replications. Data from individual years were treated as repeated measures in the analysis of data combined across years.

Mean separations were made using Fisher's protected least significant difference (LSD) at the 0.05 probability level. Linear and curvilinear trends in CP, dNDF, IVTD, and NDF across WLs were evaluated using orthogonal polynomials with uneven spacings (Gomez and Gomez, 1984). Amounts of water (mm d^{-1}) received by the plots from 1 April until the harvest date were used in the computation of the coefficients.

RESULTS AND DISCUSSION

Crude Protein

Harvest

Orchardgrass had lower CP concentrations at the midseason ($P \leq 0.05$) and late-season harvests ($P \leq 0.01$) than did perennial ryegrass (data not presented). Differences among orchardgrass cultivars were significant ($P \leq 0.01$) for CP at the early- and late-season harvests (Table 2). Within harvests, early vs. late-maturing orchardgrass cultivars had no effect on CP concentrations (data not presented).

Perennial ryegrass cultivars differed ($P \leq 0.01$) for CP at the early-, mid-, and late-season harvests (Table 3). With the exception of the early-season harvest, tetraploid perennial ryegrass had higher levels of CP ($P \leq 0.01$) than did diploids (data not presented). Under irrigation, Casler (1990) reported that tetraploids had higher relative feed values at first cut but were similar at second cut compared with diploid perennial ryegrass. In general, CP concentrations in orchardgrass and perennial ryegrass declined from the early-season harvest to midseason harvest, with a subsequent increase by the late-season harvest date (Fig. 1a and 1b).

Water Levels

Within each WL, orchardgrass consistently had lower CP than perennial ryegrass; however, only at WLs 4 and 5 were these differences significant ($P \leq 0.05$; Fig. 1c). The cultivar × WL interaction was not significant ($P > 0.05$); therefore, the results are combined across WLs (Table 1) for both orchardgrass and perennial ryegrass. Significant differences in CP were found among orchardgrass cultivars within WLs (data not presented). Mean CP concentrations ranged from 175 g kg^{-1} at WL 1 in 'Dawn' to a maximum of 217 g kg^{-1} at WL 5 in 'Paiute' (data not presented). Water level had no effect on CP concentrations when comparing early vs. late (cv. Latar)-maturing orchardgrass cultivars.

Increased ($P \leq 0.01$) concentrations of CP during the late-season harvest at WLs 4 and 5 (Fig. 1a) contributed to a WL × harvest interaction ($P \leq 0.01$; Table 2). A possible cause for the increase in CP maybe a potential buildup of N levels in the soil at the drier WLs. Buxton et al. (1996) reported that CP concentration in forage is strongly influenced by available soil N. Increased CP levels in tall fescue (*Festuca arundinacea* Schreber) and perennial ryegrass were reported by Collins (1991) with increasing soil N levels. Increased CP levels were reported in maize (*Zea mays* L.) (Crasta and Cox, 1996) and alfalfa (*Medicago sativa* L.) (Halim et al., 1990; Deetz et al., 1996) when exposed to water stress. In addition, increased CP concentrations at the late-season harvest corresponded to shorter, cooler days and occasional freezing nighttime temperatures. Among orchardgrass cultivars, linear trends in CP due to WLs were significant ($P \leq 0.01$), and curvilinear trends ($P \leq 0.05$) in 'DS8', 'Justus', 'Latar', and 'Pizza' (Table 1) were attributed to a rapid increase in CP concentrations from WL 3 to WL 2, particularly at the late- and midseason harvests.

Relative differences in CP among perennial ryegrass cultivars were consistent across WLs; the WL × cultivar interaction was significant ($P < 0.05$) only at the late-season harvest (Table 3). Differences ($P \leq 0.01$) in CP were found among perennial ryegrass cultivars within WLs 2, 3, 4, and 5 (data not presented). Mean CP levels ranged from 173 g kg^{-1} at WL 2 in 'Moy' to 226 g kg^{-1} at WL 5 in 'Cambridge' (data not presented). Tetraploid perennial ryegrass had higher CP than did the diploids; however, that difference was only significant ($P \leq 0.05$) at WL 1 and WL 3 (Fig. 1d). An increase ($P \leq 0.01$) in CP during the late-season harvest (Fig. 1b) at drier WLs resulted in a WL × harvest interaction ($P \leq 0.01$; Table 3). Significant ($P \leq 0.01$) linear trends toward increased CP as irrigation declined were observed in all perennial ryegrass cultivars but were most prominent at the late-season harvest (Table 1; Fig. 1b). Curvilinear trends were observed ($P \leq 0.05$) in cultivars Citadel and Bastion (Table 1).

Digestible Neutral Detergent Fiber

Harvest

Orchardgrass had significantly lower ($P \leq 0.01$) dNDF than did perennial ryegrass (data not presented). Differences among the orchardgrass cultivars were significant ($P < 0.01$) for dNDF at the early-, mid-, and late-season harvests (Table 2). Early-season forage had significantly ($P < 0.05$) higher dNDF values than either midseason or late-season forage (Fig. 2a). When forage was maintained at the vegetative stage, there was little advantage between early and late-maturing orchardgrass cultivars across harvest dates for dNDF concentrations (data not presented).

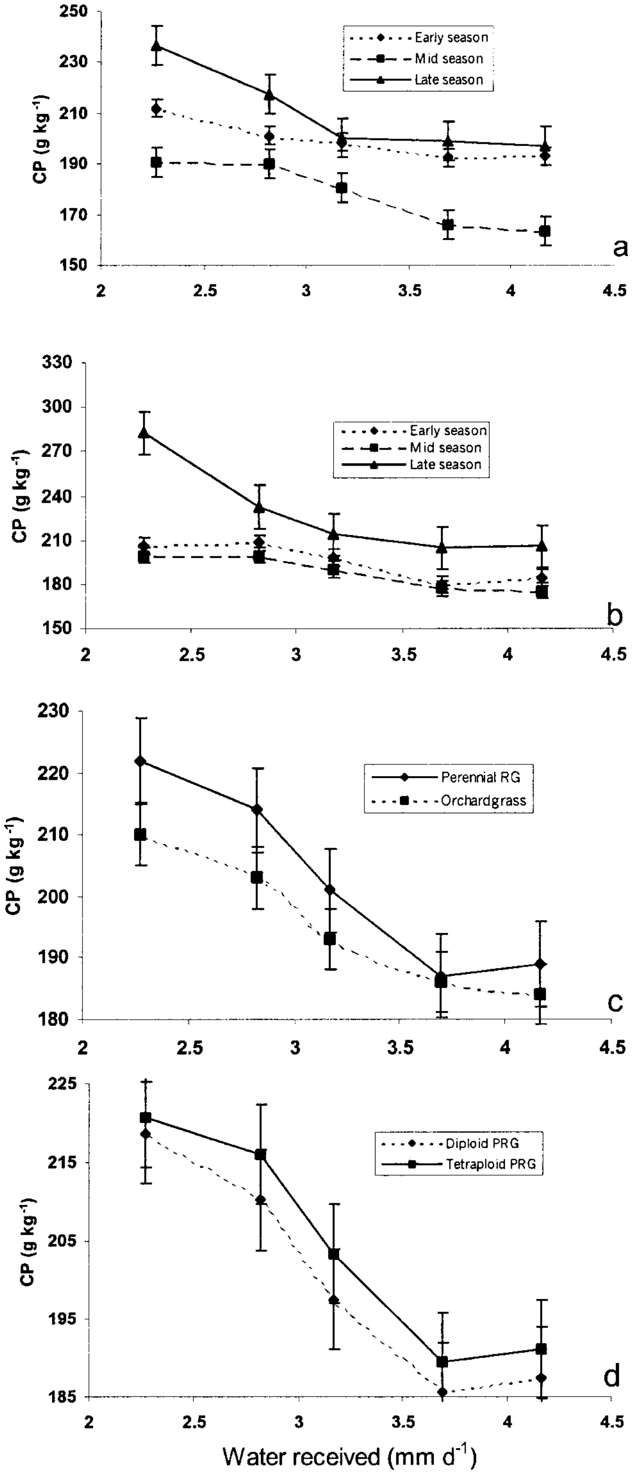

Fig. 1. Mean trends in crude protein (CP): (a) nine orchardgrass cultivars at five water levels (WLs) and three harvest dates (mid-June, July–August, late-September), (b) seven perennial ryegrass cultivars at five WLs and three harvest dates, (c) orchardgrass and perennial ryegrass (RG) across five WLs, and (d) diploid and tetraploid perennial ryegrass (PRG) across five WLs. Vertical bars indicate the standard error.

Perennial ryegrass cultivars differed ($P \leq 0.01$) for dNDF at the early-, mid-, and late-season harvests (Table 3). Forage of perennial ryegrass harvested during the early- and late-season had significantly ($P < 0.05$)

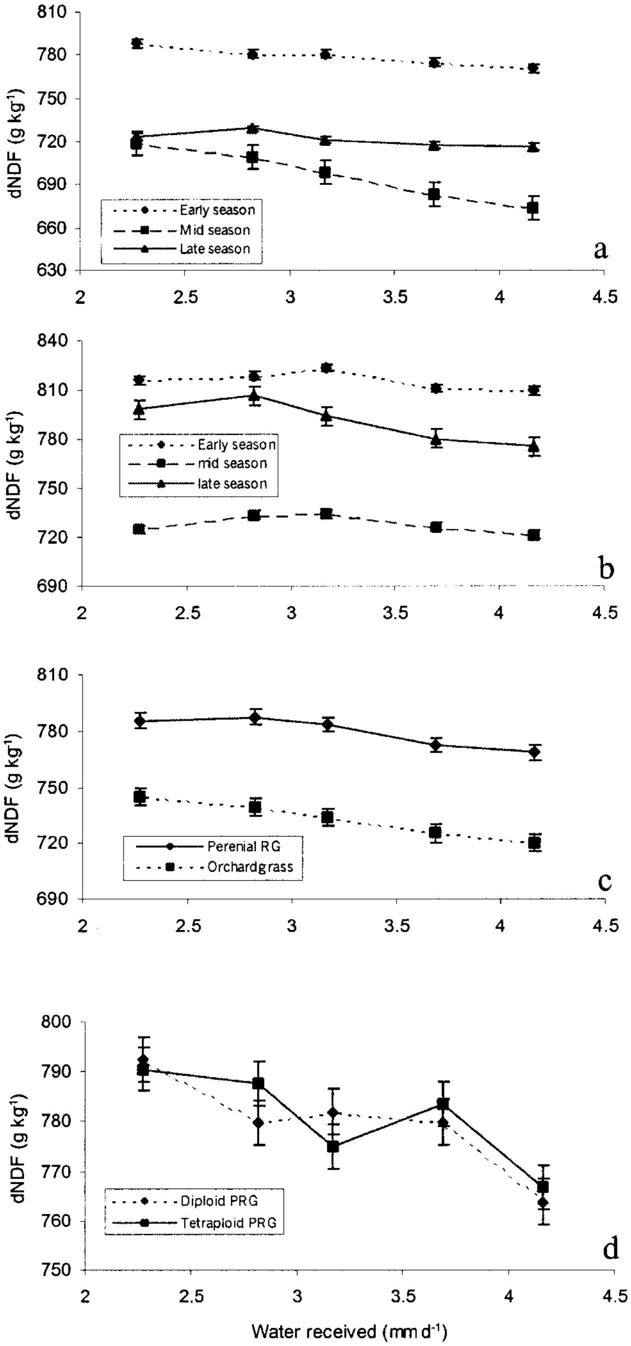

Fig. 2. Mean trends in digestible neutral detergent fiber (dNDF): (a) nine orchardgrass cultivars at five water levels (WLs) and three harvest dates (mid-June, July–August, late-September), (b) seven perennial ryegrass cultivars at five WLs and three harvest dates, (c) orchardgrass and perennial ryegrass (RG) across five WLs, and (d) diploid and tetraploid perennial ryegrass (PRG) across five WLs. Vertical bars indicate the standard error.

higher dNDF concentrations than at the midseason harvest (Fig. 2b). Tetraploid perennial ryegrass had higher levels of dNDF at midseason ($P \leq 0.01$) and late-season ($P \leq 0.05$) harvests (data not presented).

Water Levels

Averaged across WLs, orchardgrass had 733 g kg^{-1} dNDF compared with 780 g kg^{-1} dNDF in perennial ryegrass cultivars (data not presented). Within WLs, orchardgrass consistently had lower ($P \leq 0.01$) dNDF concentrations than did perennial ryegrass (Fig. 2c). Relative differences among orchardgrass cultivars for dNDF were consistent across WLs; the WL × cultivar interaction was nonsignificant (Table 2). Combined across years and within WLs, differences among cultivars for dNDF were not significant, except for WL 1 and WL 3 (data not presented), suggesting limited variation within the orchardgrass cultivars studied for dNDF. Mean dNDF concentration ranged from 709 g kg^{-1} at WL 1 in ‘Potomac’ to 757 g kg^{-1} at WL 5 in ‘Ambassador’ (data not presented). The late-maturing cultivar, Latar, had higher dNDF values than the early maturing cultivars (Table 1). However, that difference was significant only at WLs 1($P \leq 0.05$) and 4 ($P \leq 0.01$) (data not presented).

With the exception of the midseason harvest, digestible fiber concentrations tended to increase with increased water stress in orchardgrass (Fig. 2a). Linear trends ($P \leq 0.05$) for dNDF in response to WLs were observed in all orchardgrass cultivars except Pizza (Table 1).

Differences in dNDF ($P \leq 0.01$) were found among perennial ryegrass cultivars within each WL (data not presented) and in the combined analysis (Table 1). A nonsignificant cultivar × WL interaction (Table 3) indicates that differences among cultivars were consistent across WLs (Table 3). At WLs 1, 2, and 4, tetraploid perennial ryegrass cultivars had higher ($P \leq 0.05$) dNDF concentrations than did the diploids (Fig. 2d).

Within WLs, early- and late-season–harvested forage had higher dNDF ($P \leq 0.01$) than the midseason harvest (Fig. 2b). In the analysis combined across cultivars, harvests, and years, 75 and 15% (Table 1) of the sum of squares for WLs were due to linear and curvilinear effects, respectively. Changes in dNDF across WLs were relatively small (Fig. 2b).

In Vitro True Digestibility

Harvest

Orchardgrass had lower IVTD ($P \leq 0.01$) than perennial ryegrass at each harvest date (data not presented). Orchardgrass cultivars differed in IVTD ($P \leq 0.01$) at all three harvest dates (Table 2). Concentrations of IVTD declined ($P < 0.05$; Fig. 3a) from the early-season harvest to the midseason harvest, followed by a subsequent increase at the late-season harvest. The late-maturing cultivar, Latar, had lower ($P < 0.05$) IVTD values at the early-season harvest but higher ($P < 0.05$) IVTD values at the later two harvest dates (data not presented).

Perennial ryegrass cultivars differed for IVTD ($P \leq 0.01$) at each harvest date (Table 3). Trends in IVTD across harvest dates were similar to CP in perennial ryegrass (Fig. 3b), with early- and late-season–harvested forage having higher ($P < 0.05$) IVTD values. Tetraploid perennial ryegrass cultivars had higher IVTD values compared with the diploid cultivars at each harvest;

however, that difference was only significant ($P \leq 0.01$) at the midseason and late-season harvests (data not presented).

Water Levels

At each WL, orchardgrass had lower IVTD values ($P \leq 0.01$) than perennial ryegrass (Fig. 3c). A nonsignificant cultivar × WL interaction suggests that differences among orchardgrass cultivars were consistent across WLs (Table 2). Mean IVTD concentrations ranged from 864 g kg^{-1} at WL 2 in Dawn to 889 g kg^{-1} at WL 5 in Ambassador (data not presented). Early-season forage had higher IVTD values ($P \leq 0.01$) at all WLs than the midseason- and late-season–harvested forage (Fig. 3a).

As irrigation levels increased, trends toward lower IVTD values were observed, most notable at the midseason harvest (Fig. 3a). In the analysis combined across cultivars, harvests, and years, 87 and 10% (Table 1) of the sums of squares for WLs were due to linear and curvilinear effects, respectively. Linear trends ($P \leq 0.05$) for IVTD in response to WLs were observed in all orchardgrass cultivars, except DS-8 and Justus (Table 1). Constant IVTD levels from WL 5 to WL 4 followed by a subsequent decline in IVTD at increased WLs contributed to curvilinear ($P \leq 0.05$, Table 1) trends in Dawn, Justus, Potomac, and 'Sampson'.

There was a nonsignificant cultivar × WL interaction in perennial ryegrass cultivars (Table 3). Differences in IVTD ($P \leq 0.01$) were found among perennial ryegrass cultivars (Table 1). Averaged across harvests, mean IVTD concentrations ranged from 885 g kg^{-1} at WL 1 in Moy to 925 g kg^{-1} at WL 5 in 'Baramco' (data not presented). Within WLs, early- and late-season forage of perennial ryegrass had higher IVTD values ($P \leq 0.01$) than the midseason harvest (Fig. 3b). At WLs 1, 2, and 3, tetraploid perennial ryegrass had higher IVTD concentrations ($P \leq 0.05$) than diploids (Fig. 3d). In the analysis combined across cultivars, harvests, and years, 25 and 66% (Table 1) of the sums of squares for WLs were due to linear and curvilinear effects, respectively. Changes in IVTD across WLs were relatively small (Fig. 3a and 3b).

Neutral Detergent Fiber

Harvest

Orchardgrass cultivars had higher NDF ($P \leq 0.01$) than perennial ryegrass at each harvest date (data not presented). Orchardgrass cultivars differed in NDF concentrations ($P \leq 0.01$) at each harvest date (Table 2). Orchardgrass forage harvested later in the growing season had significantly ($P \leq 0.01$) lower NDF concentrations than the early- and midseason harvests (Fig. 4a). Rank changes across harvest dates resulted in a cultivar × harvest date interaction ($P \leq 0.01$) (Table 2). Most notable was the cultivar Latar (late maturing), which had high NDF values ($P \leq 0.01$) at the early-season harvest and ranked among the lowest for NDF at the late-season harvest (data not presented).

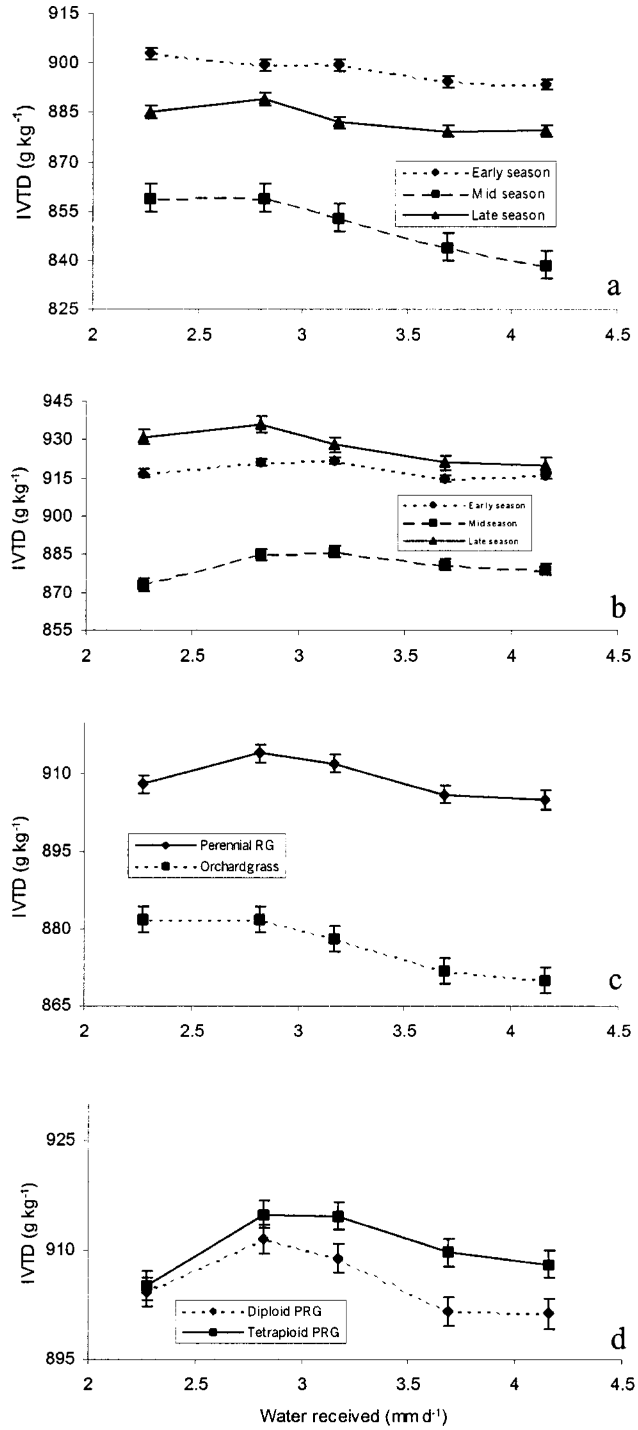

Fig. 3. Mean trends in in vitro true digestibility (IVTD): (a) nine orchardgrass cultivars at five water levels (WLs) and three harvest dates (mid-June, July–August, late-September), (b) seven perennial ryegrass cultivars at five WLs and three harvest dates, (c) orchardgrass and perennial ryegrass (RG) across five WLs, and (d) diploid and tetraploid perennial ryegrass (PRG) across five WLs. Vertical bars indicate the standard error.

Differences in NDF were significant ($P \leq 0.01$) among perennial ryegrass cultivars at all harvests (Table 3). In general, NDF concentrations were highest at the early- and midseason harvests and declined in the late-season harvest (Fig. 4b). Increased NDF concentrations at the early harvest can be attributed to stem development

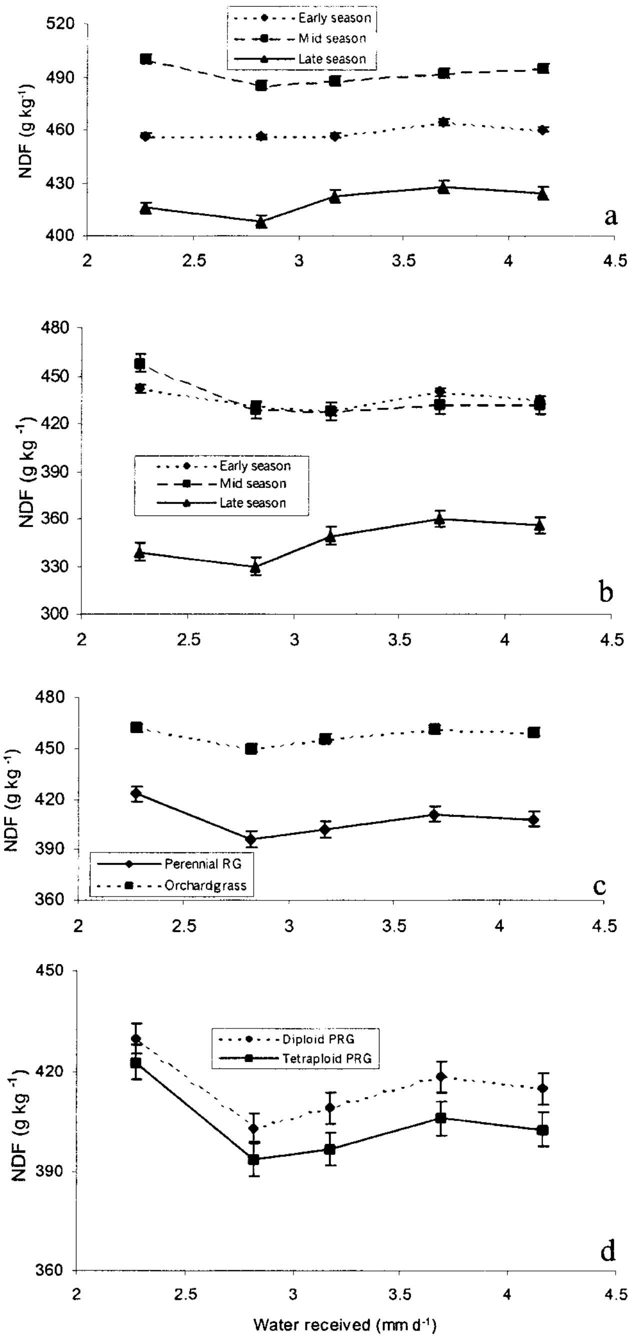

Fig. 4. Mean trends in neutral detergent fiber (NDF): (a) nine orchardgrass cultivars at five water levels (WLs) and three harvest dates (mid-June, July–August, late-September), (b) seven perennial ryegrass cultivars at five WLs and three harvest dates, (c) orchardgrass and perennial ryegrass (RG) across five WLs, and (d) diploid and tetraploid perennial ryegrass (PRG) across five WLs. Vertical bars indicate the standard error.

and increased growth rate early in the growing season. Based on visual observations, perennial ryegrass had a tendency to produce more stems and less dry matter yield (Jensen et al., 2001) during the hotter portions of the growing season than did orchardgrass (data not presented). The increase in stem production probably contributed to the increased NDF values in perennial ryegrass at the midseason harvest (Fig. 4b). Tetraploid perennial ryegrass had lower NDF concentrations ($P \leq 0.01$) than the diploids at the midseason and late-season harvests (data not presented).

Water Levels

Within each WL, orchardgrass had higher NDF levels ($P \leq 0.01$) than perennial ryegrass (Fig. 4c). Even though differences ($P \leq 0.01$) in NDF were found among orchardgrass cultivars (Table 1), no consistent trends in NDF across WLs were observed (Fig. 4a). Multiple rank changes, involving cultivars DS8, Latar, and Pizza, contributed to the significant cultivar × WL interaction ($P \leq 0.01$) at the late-season harvest (Table 2). Curvilinear responses to WL were significant ($P \leq 0.05$) in cultivars Ambassador, DS-8, Dawn, Justus, Latar, Potomac, and Sampson (Table 1).

Significant ($P \leq 0.01$) differences in NDF were found among perennial ryegrass cultivars for NDF (Table 1). There were no apparent trends observed in NDF across WLs (Fig. 4b). A rank change in cultivars Bastion and Cambridge from WL 1 to WL 5 contributed to a cultivar × WL interaction ($P \leq 0.05$) at the late-season harvest (Table 3). Tetraploid perennial ryegrass had lower NDF ($P \leq 0.05$) values at WLs 1, 2, 3, and 4 than the diploids (Fig. 4d).

Early- and midseason forage of perennial ryegrass had higher ($P \leq 0.01$) NDF values at all WLs than did the late-season harvest (Fig. 4b). Based on orthogonal polynomials, the majority of the variation within perennial ryegrass was associated with curvilinear effects (Table 1), particularly in the midseason and late-season harvests (Fig. 4b).

CONCLUSIONS

In summary, perennial ryegrass forage had higher CP, dNDF, and IVTD and lower NDF concentrations than orchardgrass at all harvest dates and within WLs. Orchardgrass cultivars Paiute, Pizza, Justus, and Potomac had the highest CP concentrations across WLs. Tetraploid perennial ryegrass cultivars Bastion, Citadell, and Gambit had better forage nutrition at each harvest and across WLs than diploid cultivars. The most notable trend in forage nutritional value across WLs was the near linear increase in CP and dNDF with decreasing levels of irrigation, particularly later in the growing season. There were no observable trends in NDF across WLs while IVTD increased slightly as irrigation levels were reduced from WL 2 to WL 5. Within WL means, orchardgrass increased from 720 to 745 g kg $^{-1}$ dNDF, representing a 3.3% increase in dNDF from WL 1 to WL 5. Based on Oba and Allen (1999), this would represent an increase in dry matter intake of 0.63 kg. A similar increase in dNDF of 2.3% was observed in perennial ryegrass from WL 1 to WL 5 on forages that were grown under water stress. Our results indicate that nutritional value of both species can be increased if grown under limited irrigation. However, the increased nutritional value associated with water stress is in most cases negated by the associated negative trend in dry matter yield with increased water stress.

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