Biomass yield and feeding value of rye, triticale, and wheat straw produced under a dual-purpose management system¹

S. Ates,^{*†‡2} G. Keles,[§] U. Demirci,[‡] S. Dogan,[‡] and H. Ben Salem^{†#}

^{*}Department of Animal and Rangeland Sciences, Oregon State University, Corvallis 97333;

[†]International Centre for Agricultural Research in the Dry Areas (ICARDA), 11195, Amman,

Jordan; [‡]Bahri Dagdas International Agricultural Research Institute, 42020, Konya, Turkey;

[§]Department of Animal Science, Faculty of Agriculture, Adnan Menderes University, 09100 Aydin, Turkey;

and [#]National Institute of Agricultural Research of Tunisia (INRAT), University of Carthage, 2049 Ariana, Tunisia

ABSTRACT: Dual-purpose management of winter cereals for grazing and grain production provides highly nutritive forage for ruminants in the spring and may positively affect straw feeding value. A 2-yr study investigated the effect of spring defoliation of triticale, wheat, and rye at the tillering and stem elongation stages on total biomass, grain yields, and straw quality. Furthermore, straws of spring-defoliated and undefoliated (control) cereal crops were evaluated for nutritional value and voluntary intake as a means of assessing the efficiency of dual-purpose management systems from the winter feeding context as well. The feeding study consisted of 9 total mixed rations (TMR), each containing 35% triticale, rye, or wheat straw obtained under 3 spring-defoliation regimens. The TMR were individually fed to fifty-four

1-yr-old Anatolian Merino ewes for 28 d. Defoliation of the crops at tillering did not affect the total biomass production or grain yields. However, biomass and grain yields were reduced ($P < 0.01$) by 55 and 52%, respectively, in crops defoliated at stem elongation. Straw of spring-defoliated cereals had less NDF and ADF concentrations ($P < 0.01$) but greater CP ($P < 0.01$), nonfiber carbohydrates ($P < 0.01$), and ME concentrations ($P < 0.01$) compared with straw from undefoliated crops. The increase in the nutritive value of straw led to greater nutrient digestion ($P < 0.01$) and intake of DM and OM of ewes ($P < 0.01$). However, sheep live weight gain did not differ among treatments ($P > 0.77$). This study indicated that straw feeding value and digestibility can be increased through spring defoliation.

Key words: digestibility, feed intake, fiber, grazing, mixed farming, sheep

© 2017 American Society of Animal Science. All rights reserved.

J. Anim. Sci. 2017.95:4893–4903

doi:10.2527/jas2017.1888

INTRODUCTION

Dryland agricultural systems in the Southern Mediterranean region typically combine cereal cropping with low-input, extensive small ruminant production. The major constraint for the livestock component of the farming system is scarcity of high-quality feedstuffs, particularly in the autumn and winter seasons.

Small grain winter cereals at the early vegetative stage offer high nutritive value forage for ruminants (Coblentz and Walgenbach, 2010) and provide live weight gains that are similar to those of concentrates (Keles et al., 2016). Grazing of immature cereal crops may also have a positive impact on the nutritive value of the regrown forage material (Francia et al., 2006; Jacobs et al., 2009; Keles et al., 2013). A battery of information on the effect of grazing immature cereal crops on the subsequent grain production and quality is available (Virgona et al., 2006; Jacobs et al., 2009; Kelman and Dove, 2009; Hussein et al., 2016). Several researchers also investigated the impact of spring defoliation of cereal forages on biomass production and nutritive value when harvested as silage or hay (de Ruiter et al., 2002; Jacobs et al., 2009; Cazzato et al., 2012; Keles et al., 2013). Despite the

¹The authors acknowledge the Australian Centre for International Agricultural Research (ACIAR) for financial support in undertaking this study. The study was conducted as part of mirror trial concept for the “Forage options for smallholder livestock in water-scarce environments of Afghanistan” project (AH/2012/021).

²Corresponding author: Serkan.ates@oregonstate.edu

Received July 5, 2017.

Accepted September 13, 2017.

central role that cereal straw plays in the crop–livestock production in Southern Mediterranean countries, there is a paucity of information regarding the impact of spring grazing on grain yield, straw quality, and animal performance under dual-purpose management. The optimized management of cereals for both spring forage grazing and summer grain and straw production may have a substantial impact on the overall farming system efficiency. Therefore, the purpose of this study was to determine and compare the feeding value (nutrient concentrations and voluntary intake) of wheat, triticale, and rye straws grown in dual-purpose management systems. The hypothesis of the current research is that spring defoliation of immature crops would improve the nutritional value and DMI of straw after harvest.

MATERIAL AND METHODS

Ewes used in the present study were cared for according to Committee of Animal Ethics at Bahri Dagdas International Agricultural Research Institute.

Site, Establishment, and Experimental Design for the Field Study

The study was conducted in the research field (37°51' N, 32°33' E, and 1,008 m above sea level) and animal research facilities at Bahri Dagdas International Agricultural Research Institute, located in Konya, Turkey, from 2013 to 2015. The field site was on an alkaline clay–loam soil with low OM.

Climate

Air temperatures and precipitation at the site during the experiment period (2013 to 2015) are presented in Fig. 1. The research farm, located in the central Anatolian highlands, has a continental climate with 322 mm long-term mean (LTM) annual precipitation and 11.6°C LTM annual air temperature. Total annual precipitation in 2013 and 2014 was lower than the LTM by 138 and 21 mm, respectively. In most cases, the mean monthly air temperature was similar to the LTM. Of note was that the mean temperature was 1.7 to 3.2°C greater than the LTM in the winter months except the mean monthly air temperature was 3.2°C colder than the LTM in December 2013.

Following cultivation and seedbed preparation, cereal grains were planted into 50- by 90-m plots using a commercial grain drill with 0.2-m row spacing on 13 November, 2013, and 14 November, 2014. Cereal grains were seeded at 195 kg/ha for wheat (*Triticum aestivum* cv. Bayraktar), 183 kg/ha for triticale (*×Triticosecale* Wittmack cv. Tatlicak), and 155 kg/ha for rye (*Secale*

Figure 1. Monthly rainfall (a) and mean daily air temperatures (b) during the experimental period (2013–2015). LTM = long-term mean (of air temperature and precipitation are for the period of 1975 through 2010).

cereale cv. Aslim). In both years, 27.4 kg/ha ammoniacal N and 70 kg P₂O₅ were applied at sowing. An additional 42.6 kg/ha nitrate was applied in spring at the tillering stage of plant growth. In both years, each plot was sprayed with an herbicide mixture of florasulam (6.25 g/L) and 2,4-dichlorophenoxyacetic acid (452.42 g/L) at the tillering stage. The experiment was performed at rainfed conditions without any supplemental irrigation.

Treatments were arranged in a split-plot design with 3 replicates. Cereal crops were the main plot factor, and defoliation times at tillering, stem elongation, and no spring defoliation (control) were the subplot factors. Dry matter yield of cereal crop subplots was determined from quadrat cuts at tillering (Zadoks 24 [Z24]) and stem elongation stages (Zadoks 31 [Z31]; Zadoks et al., 1974). Five randomly placed 0.5-m² quadrats were cut to 30 mm residual height with electric shears and immediately weighed. Subsamples were dried in a forced-air oven at 60°C for 48 h for DM determination. Following collection of the samples of both growth stages, the remainder of the subplots (50 by 30 m) was

Table 1. Formulation of experimental diets (DM basis)

Ingredient	Percent
Cereal straw	35.0
Sugar beet pulp	25.0
Barley grain	16.1
Wheat bran	20.0
Soy bean meal	3.52
Limestone	0.30
Vitamin–mineral premix ¹	0.05
Salt	0.05

¹Each kilogram contains 1,300,000 IU vitamin A, 260,000 IU vitamin D₃, 3,000 mg vitamin E, 120,000 mg niacin, 5,000 mg Mn, 5,000 mg Fe, 5,000 mg Zn, 1,000 mg Cu, 15 mg Co, 80 mg I, and 15 mg Se.

harvested. Defoliation was achieved using a forage harvester (Surum Tarım Makineleri, Konya, Turkey) at a 30-mm residual height. The defoliation management was arranged either for only grain and straw production or for cutting the cereals in spring for forage and harvesting the grain and straw produced after regrowth in summer. Crops in spring defoliation treatments (Z24 and Z31) were mown only once in both years.

Plots were sampled again at maturity for grain and straw production and quality. Whole stems inside the 5 randomly placed 0.5-m² quadrats were hand cut to approximately a 50-mm residual height. Straw production and straw quality, grain yield, grain protein concentration, and 1,000-grain weight of undefoliated and spring-defoliated cereal crops were measured for all plots. The plots were then harvested using a plot harvester to obtain the straw for the feeding trial. Cereal grains and straw were threshed using a Walter-Wintersteiger thresher (Wintersteiger AG, Ried, Austria), and their weights were recorded. Grain weights were determined by weighing 200 randomly selected seeds from each sample collected for yield determination. Nitrogen concentration was determined on whole grains using a LECO FP 528 analyzer (LECO Corp., St. Joseph, MI).

Feeding Experiment

A pen feeding experiment was performed using 54 Anatolian merino ewes (80% German Mutton Merino × 20% Native Akkaraman; 12–13 mo old and 39.7 kg ± 2.83 initial BW) for a period of 4 wk (15 January to 12 February, 2015). Ewes were randomly assigned to treatments and housed in individual pens (1.7 by 1.5 m) equipped with a feeder and a water container. Ewes were allowed to acclimatize for their pen and total mixed rations (TMR) for a 9-d period (6 January to 14 January, 2015) prior to the feeding experiment. The ewes were dewormed with ivermectin (Mectizan B; Provet, Istanbul, Turkey) and vaccinated against enterotoxemia at the start of the experiment.

Straw obtained in the second year (2014) of the field trial was used to prepare the diets. Diets were fed as a TMR based on nutritive value of wheat straw harvested from control plots that were not defoliated in spring. Straw obtained from undefoliated (control) and spring-defoliated (tillering and stem elongation stages) wheat, triticale, and rye crops was mixed with beet pulp and concentrate to obtain 9 TMR (Table 1). Diets contained the same proportion (35%) of straw. Ingredients and nutritional components of the TMR are presented in Tables 1 and 2, respectively. The TMR were prepared daily and offered ad libitum once a day (0900 h) in clean feeders. Ad libitum feeding was calculated as 20% above the feed consumed at the end of the acclimation period. Amounts of feeds distributed to ewes and individual refusals were weighed, sampled, and dried in the last 7 d of the feeding experiment. On average, refusals represented 15 ± 8% (DM basis) of TMR offered to ewes. Individual fecal grab samples from ewes were collected from the rectum, starting at the time of feed sampling at d 22 and moving ahead 2 h each day until d 28. The 7-d individual dried TMR, refusals, and fecal samples were pooled for each animal. Ewes were weighed at the beginning and the end of the trial following a 12-h fast. Average BW gains (BWG) were calculated from the change in BW between 2 consecutive live weight measurements. Gain efficiency was calculated by dividing daily BWG by daily DMI and gave the G:F.

Analytical Procedures

Samples of straw, TMR, refusals, and feces were dried to a constant weight in a forced-air oven at 55°C for a minimum of 48 h. Samples were ground to pass through a 2-mm screen (MF 10 B; IKA-Werke, USA, Staufen, Germany), and analyzed for DM (method 2001.12; AOAC, 2003), ash (method 942.05; AOAC, 2003), and ether extract (method 920.39; AOAC, 2003). The CP concentration of all samples was determined by the Kjeldahl method according to the Association of Official Analytical Chemists (1990; Gerhardt Vapodest 45s, with automated distillation and titration; C. Gerhardt GmbH & Co. KG, Königswinter, Germany). Neutral detergent fiber and ADF were assayed according to the methods described by Van Soest et al. (1991) using an Ankom^{200/220} Fiber Analyzer (ANKOM Technology Corp., Macedon, NY). The NDF was analyzed with the inclusion of a heat stable α -amylase and sodium sulfite, but both NDF and ADF were expressed inclusive of residual ash. Lignin was determined by incubation of ADF residues in diluted H₂SO₄ (1,634 g/L in 20°C) for 3 h in a Daisy Incubator (ANKOM Technology Corp.). Nonfiber carbohydrates fraction was determined as 100

Table 2. Chemical composition of straw-based diets, as a percent of DM (unless otherwise stated; $n = 6$)

Nutrient ¹	Rye			Triticale			Wheat			P_C ⁴	P_{CR} ⁵	$P_{C \times CR}$ ⁶	SEM
	Uncut	Z24 ²	Z31 ³	Uncut	Z24	Z31	Uncut	Z24	Z31				
DM	48.0	48.4	48.6	48.1	48.2	48.2	48.0	48.3	48.2	0.88	0.74	0.99	0.51
OM	94.4	94.4	94.6	93.7	94.5	93.9	94.1	93.9	94.4	0.78	0.69	0.80	0.52
CF	1.28 ^c	1.00 ^a	1.18 ^{bc}	1.25 ^{bc}	1.31 ^c	1.12 ^{ab}	1.30 ^c	1.30 ^c	1.26 ^{bc}	0.01	0.05	0.01	0.04
CP	9.6 ^a	9.9 ^{ab}	11.3 ^d	9.6 ^a	9.7 ^a	10.1 ^{ab}	10.0 ^{ab}	10.5 ^{bc}	10.8 ^{cd}	0.01	0.01	0.05	0.21
NDIN, % total N	8.8 ^c	8.5 ^c	7.5 ^b	6.8 ^a	7.3 ^{ab}	7.0 ^{ab}	7.6 ^b	7.2 ^{ab}	7.6 ^b	0.01	0.06	0.01	0.19
ADIN, % total N	4.49 ^b	4.46 ^b	4.88 ^{cd}	4.01 ^a	4.91 ^{cd}	5.19 ^d	4.74 ^{bc}	4.45 ^b	4.62 ^{bc}	0.54	0.01	0.01	0.12
NDF	58.5 ^{de}	57.5 ^{cd}	54.7 ^{ab}	60.1 ^e	57.1 ^{bcd}	55.2 ^{abc}	56.2 ^{abcd}	55.5 ^{abc}	54.3 ^a	0.01	0.01	0.36	0.82
ADF	33.4 ^d	30.6 ^{bc}	27.7 ^a	32.8 ^d	30.2 ^{bc}	28.9 ^{ab}	31.9 ^{cd}	30.2 ^{bc}	28.9 ^{ab}	0.75	0.01	0.17	0.56
ADL	4.6 ^b	4.0 ^a	4.1 ^a	5.0 ^{bc}	4.8 ^b	5.0 ^{bc}	5.4 ^c	5.2 ^c	5.3 ^c	0.01	0.05	0.64	0.15
NFC	24.6 ^{ab}	25.9 ^{bc}	27.5 ^{bc}	22.8 ^a	26.3 ^{bc}	27.5 ^{bc}	26.7 ^{bc}	26.7 ^{bc}	28.1 ^c	0.14	0.01	0.43	1.01
TDN ⁷	58.4	59.3	60.2	56.7	58.6	58.0	57.5	57.9	58.5	0.08	0.13	0.84	0.86
ME, ⁸ Mcal/kg	2.01 ^a	2.21 ^{cd}	2.32 ^e	2.04 ^{ab}	2.09 ^{ab}	2.11 ^b	2.14 ^{bc}	2.10 ^{ab}	2.27 ^{de}	0.01	0.01	0.01	0.03

^{a-c}Means within a row with different superscripts differ ($\alpha = 0.05$).

¹CF = crude fat; NFC = nonfiber carbohydrates.

²Z24 = tillering stage.

³Z31 = stem elongation stage.

⁴ P_C = cereal species (rye, triticale, wheat).

⁵ P_{CR} = cutting regimens (uncut, Z24 and Z31).

⁶ $P_{C \times CR}$ = cereal $\times$ cutting regimen.

⁷According to the NRC (2001).

⁸According to the Agricultural Food Research Council (1993).

– ash – CP – ether extract – NDF. The NDF and ADF residues were further analyzed for their CP concentration. The ME of straws and TMR were calculated according to the NRC (2001). The ME content of each diet was estimated using the following equation (AFRC, 1993): ME (MJ/kg DM) = $0.0157 \times \text{D-value (g/kg DM)}$, in which D-value (g/kg DM) is calculated as $[\text{OM intake (g)} - \text{fecal OM (g)}] / \text{DMI (kg)}$.

The JME intake (MJ/d) = ME (g/kg DM) $\times$ DMI (kg/d). The ME content of each diet and ME intake are expressed as megacalories per kilogram DM and megacalories per day, respectively. Apparent digestibility of nutrients was indirectly determined using AIA as an indigestible dietary marker, as described by Van Keulen and Young (1977). The nutrient intake, fecal output, and apparent digestibility of nutrients (in DM) were calculated as follows: nutrient intake = nutrient in feed offered – nutrient in refusal; fecal output = acid insoluble ash intake (g)/fecal acid insoluble ash (%); and apparent digestibility = $[\text{intake of nutrient (g)} - \text{fecal nutrient output (g)}] / \text{intake of nutrient (g)} \times 100$.

Statistical Analyses

Biomass yield (spring forage and summer straw), grain production, 1,000-grain weight, and grain protein concentration were analyzed by ANOVA with 3 replicates of a split-split-plot design where cereal crops were the main plot factor, cutting regimens were the subplot factor, and the year was the sub-subplot factor. Where

the ANOVA was significant, means were separated by Fisher's unprotected least significant difference at $\alpha = 0.05$. The nutritive value of the straw was analyzed by ANOVA with 3 replicates of a split-plot design where cereal crops were the main plot factor and the cutting time was the subplot factor. Nutritive value of TMR, BWG, intake, and digestibility parameters were analyzed by ANOVA based on a 3×3 factorial model that accounted for the main effects of cereal species and defoliation regimen in a complete randomized design. Where the ANOVA was significant, means were separated by Fisher's protected least significant difference at $\alpha = 0.05$. All analyses were performed using GenStat version 18 (VSN International Ltd., Rothamstead, UK).

RESULTS

Biomass and Grain Yields of Rye, Triticale, and Wheat

Significant interactions were detected for cereal $\times$ year ($P < 0.01$) and cutting regimens $\times$ year ($P < 0.05$) for spring DM production (Fig. 2). Wheat and rye had considerably greater ($P < 0.01$) DM production in 2015 than 2014, whereas DM production of triticale did not differ. Overall, rye had the greatest spring DM production, whereas triticale had the least DM production. In both years, cereals provided greater amounts of forages at stem elongation than at the tillering stage, but the difference in DM production was more profound ($P < 0.05$) in spring 2015 than in spring 2014.

Figure 2. Spring biomass (white), straw (colored), and total fodder production (white + colored) of wheat, triticale, and rye under different spring cutting regimes in 2014 (A) and in 2015 (B). Bars represent SEM ($\alpha < 0.05$) for the cereal $\times$ cutting regimen interaction. Z24 = tillering stage; Z31 = stem elongation stage. ^{a-h}Lowercase letters indicate statistical differences for total annual DM production according to Fisher's unprotected least significant difference ($\alpha = 0.05$).

Similarly, there were cereal $\times$ year ($P < 0.01$), cereal $\times$ cutting regimens ($P < 0.01$), and cutting regimens $\times$ year ($P < 0.05$) interactions for the straw production (Fig. 2). Cereals had 3,385 to 8,013 kg/ha greater ($P < 0.01$) straw production in 2015 than in 2014. Although straw production of the cereals did not differ in 2014, wheat had 68% greater ($P < 0.01$) straw production than both triticale and rye in 2015. Straw production of all 3 cereal crops did not differ in the control (uncut), but wheat had greater ($P < 0.01$) straw yield than triticale and rye when cut at the tillering stage. The reduction in straw yield was sharper for rye than for wheat and triticale when spring defoliation of cereals was delayed to the stem elongation stage. Consequently, rye had substantially less straw yield than wheat and triticale.

In 2015, total average annual DM production of all cereals was considerably greater ($P < 0.01$) than in 2014. A cereal $\times$ year interaction ($P < 0.05$) was detected for total annual DM production. Total average annual DM production of cereals did not differ in 2014, but wheat had greater ($P < 0.01$) annual DM than triticale and rye by 4,418 and 5,730 kg DM/ha, respectively, in 2015. The total average annual biomass production of triticale and rye was gradually reduced ($P < 0.01$) by cutting at the tillering and stem elongation stages, whereas the control and cutting at the tillering stage resulted in comparable total average biomass production for wheat (Fig. 2).

A significant cereal $\times$ year interaction ($P < 0.05$) was detected for grain production of cereals (Table 3). Grain production of cereal crops did not differ within cutting treatment in 2014, but wheat outyielded ($P <$

0.05) rye and triticale in 2015. Furthermore, the grain yield of rye was similar in both years, whereas triticale and wheat had greater grain production in 2015 than in 2014. In 2014, compared with the control, grain production of cereals decreased ($P < 0.01$) by 862 and 2,284 kg/ha with defoliation at the tillering and stem elongation stages, respectively. The reduction in grain production by cutting at the tillering stage tended to be less severe ($P = 0.08$) in 2015 than in 2014.

A cutting regimen $\times$ year interaction ($P < 0.01$) was detected for the 1,000-grain weight. Cutting regime did not affect 1,000-grain weight in 2014, whereas cutting at the stem elongation stage resulted in reduced 1,000-grain weight compared with the control and cutting at the tillering stage in 2015 (Table 3). There was a cereal $\times$ year interaction ($P < 0.01$) for grain protein concentration. Although the grain protein concentration of rye and triticale did not differ in 2014, triticale had a greater ($P < 0.01$) grain protein concentration than rye in 2015. Wheat had a greater protein concentration than triticale and rye in both years. Cutting at tillering resulted in an increase ($P < 0.05$) in grain protein concentration compared with the control and cutting at stem elongation.

Nutritive Value of Total Mixed Rations and Straw

Dry matter, OM, and nonfiber carbohydrate concentrations of the TMR were not affected by cereal ($P = 0.88$, $P = 0.78$, and $P = 0.08$, respectively) or cutting regimen ($P = 0.74$, $P = 0.69$, and $P = 0.18$, respectively; Table 2). Significant interactions ($P < 0.05$ and $P < 0.01$) were detected for crude fat, CP, NDIN,

Table 3. Grain yield and quality traits of wheat, triticale, and rye under different spring cutting regimens

Cereal	Cutting regimen	Grain production, kg/ha		1,000-grain weight, g		Grain protein, %	
		2014	2015	2014	2015	2014	2015
Rye	Uncut	4,251 ^{fg}	4,701 ^{ghi}	24.4 ^{ab}	28.5 ^{cdef}	10.8 ^{defg}	8.8 ^{ab}
	Z24 ¹	3,311 ^{cde}	4,257 ^{fg}	25.6 ^{abc}	26.3 ^{abcd}	11.2 ^{efgh}	8.6 ^a
	Z31 ²	1,582 ^a	1,612 ^a	24.4 ^{ab}	22.5 ^a	11.3 ^{fgh}	9.0 ^{abc}
Triticale	Uncut	4,102 ^{efg}	5,135 ^{hij}	30.5 ^{efg}	35.5 ^{hij}	10.4 ^{def}	9.9 ^{bcd}
	Z24	3,056 ^{cd}	4,451 ^{gh}	29.9 ^{defg}	31.7 ^{fgh}	11.0 ^{efgh}	9.9 ^{cd}
	Z31	2,205 ^{ab}	2,484 ^{bc}	28.0 ^{bcdef}	27.5 ^{bcde}	11.3 ^{efgh}	10.2 ^{de}
Wheat	Uncut	4,175 ^{fg}	5,578 ^j	34.6 ^{hi}	38.7 ^j	12.0 ^{hi}	11.5 ^{gh}
	Z24	3,575 ^{def}	5,451 ^{ij}	36.9 ^{ij}	39.3 ^j	12.6 ^{ij}	11.1 ^{efgh}
	Z31	1,890 ^{ab}	3,365 ^{de}	35.6 ^{hij}	33.8 ^{ghi}	13.5 ^j	11.9 ^{hi}
P_C^3			0.05		0.01		0.01
P_{CR}^4			0.01		0.01		0.05
P_Y^5			0.01		0.05		0.01
$P_{C \times CR}^6$			0.09		0.43		0.70
$P_{C \times Y}^7$			0.05		0.76		0.05
$P_{CR \times Y}^8$			0.08		0.01		0.22
$P_{C \times CR \times Y}^9$			0.88		0.98		0.96
SEM			291.8		1.42		0.37

^{a-j}Means within columns of each parameter with different superscripts significantly differ according to Fisher's unprotected least significant difference ($\alpha = 0.05$).

¹Z24 = tillering stage.

²Z31 = stem elongation stage.

³ P_C = cereal species (rye triticale, wheat).

⁴ P_{CR} = cutting regimens (uncut, Z24 and Z31).

⁵ P_Y = year (2014 and 2015).

⁶ $P_{C \times CR}$ = cereal species (rye triticale, wheat) $\times$ cutting regimens (uncut, Z24 and Z31).

⁷ $P_{C \times Y}$ = cereal species (rye triticale, wheat) $\times$ year (2014 and 2015).

⁸ $P_{CR \times Y}$ = cutting regimens (uncut, Z24 and Z31) $\times$ year (2014 and 2015).

⁹ $P_{C \times CR \times Y}$ = cereal species (rye triticale, wheat) $\times$ cutting regimens (uncut, Z24 and Z31) $\times$ year (2014 and 2015).

ADIN, and ME concentrations of TMR. The TMR that contained wheat straw had less NDF but greater ADL concentrations than those that contained triticale and rye straw. The NDF, ADF, and ADL concentrations of TMR were less ($P < 0.01$ and $P < 0.05$) when they included straw of cereals that were cut at the tillering and stem elongation stages compared with uncut cereal straw. This effect was more prominent ($P < 0.01$) with cutting at stem elongation than cutting at the tillering stage. The CP concentration of TMR did not differ from the ones that contained triticale straw regardless of the cutting regimen. However, TMR that contained rye and wheat straw had greater CP content when the cereals were cut at the stem elongation stage. The ADIN concentration of TMR with rye and triticale straw was greater at the stem elongation cutting stage than the control (uncut). However, NDIN concentration was different only in TMR that contained straw of rye that was defoliated at the stem elongation stage than that defoliated at tillering and uncut (Table 2).

Except for CP, ADL, TDN, and ME concentrations of cereal straw, interactions ($P < 0.05$) between cereal and cutting regimens were detected for nutritive value

parameters (Table 4). The CP concentration of cereal straw increased ($P < 0.01$) from an average of 3.6% for uncut cereals to 4.7% for those cut at the tillering stage. A further increase in CP concentration up to 6.1% occurred when cereal crops were cut at the stem elongation stage. Wheat and rye straw had greater ($P < 0.01$) CP concentration than triticale straw, but the average ADL concentration of wheat (7.0%) and triticale straw (6.9%) was greater ($P < 0.01$) than that of rye straw (5.9%). Similarly, calculation of the ME concentration of cereal straw increased with spring cutting compared with uncut cereal straw. Regardless of the cereal species, cutting at stem elongation resulted in the highest ME in straw. Calculation of the ME concentration of rye was greater ($P < 0.01$) than that of triticale and wheat. Straw ADL decreased ($P < 0.01$) with spring cutting, especially when cut at the stem elongation stage.

Although the ash concentration of wheat and triticale straws was not different, rye straw had the least ash ($P < 0.01$). Inconsistent effects of cutting regimen on the response of cereal straw were observed for the ash concentration. The ash concentration of wheat straw had a steady decline from 7.8% in the control to 7.0% in straw

Table 4. Nutritive value of wheat, triticale, and rye straws under different spring cutting regimens, as a percentage of DM (unless stated otherwise)

Nutrient ¹	Rye			Triticale			Wheat			P_C ⁴	P_{CR} ⁵	$P_{C \times CR}$ ⁶	SEM
	Uncut	Z24 ²	Z31 ³	Uncut	Z24	Z31	Uncut	Z24	Z31				
OM	93.6 ^c	93.2 ^{bc}	93.5 ^c	92.2 ^a	91.9 ^a	92.5 ^{ab}	92.2 ^a	93.0 ^c	93.7 ^c	0.001	0.05	0.05	0.24
Ash	6.4 ^a	6.8 ^{ab}	6.5 ^a	7.8 ^{cd}	8.1 ^d	7.5 ^{bcd}	7.8 ^d	7.0 ^{abc}	6.3 ^a	0.001	0.01	0.05	0.24
CP	3.76 ^b	5.18 ^{de}	6.59 ^f	3.30 ^a	4.24 ^c	5.48 ^e	3.61 ^{ab}	4.56 ^d	6.30 ^f	0.001	0.001	0.34	0.14
CF	0.79 ^b	0.93 ^{cd}	1.29 ^f	0.95 ^d	1.07 ^e	1.12 ^e	0.71 ^a	0.88 ^c	1.08 ^e	0.01	0.01	0.01	0.02
NDIN, % total N	32.2 ^c	23.3 ^{ab}	21.4 ^a	33.4 ^c	37.9 ^d	34.1 ^c	25.0 ^b	21.1 ^a	21.0 ^a	0.001	0.001	0.001	1.14
ADIN, % total N	13.5 ^{bc}	13.5 ^{bc}	13.4 ^{bc}	18.4 ^d	14.0 ^c	12.4 ^b	19.5 ^d	12.3 ^b	10.2 ^a	0.01	0.001	0.001	0.42
NDF	74.1 ^c	70.6 ^c	66.4 ^b	73.8 ^{de}	70.6 ^c	67.4 ^b	72.3 ^d	70.7 ^c	64.5 ^a	0.01	0.001	0.09	0.52
ADF	46.6 ^d	41.1 ^b	39.0 ^a	47.4 ^d	42.8 ^c	39.5 ^a	46.1 ^d	44.2 ^c	39.3 ^a	0.05	0.01	0.05	0.53
ADL	6.82 ^{cde}	5.82 ^{ab}	5.21 ^a	7.74 ^e	7.10 ^{de}	5.95 ^{abc}	7.45 ^{de}	7.01 ^{de}	6.60 ^{bcd}	0.01	0.01	0.51	0.30
TDN ⁷	49.6 ^c	51.6 ^d	54.3 ^e	46.9 ^a	48.6 ^{bc}	52.0 ^d	47.8 ^{ab}	49.7 ^c	52.3 ^d	0.001	0.001	0.92	0.48
NFC	14.9 ^{ab}	16.4 ^{bc}	19.3 ^d	14.2 ^a	16.0 ^{bc}	18.6 ^d	15.6 ^{abc}	16.7 ^c	22.0 ^e	0.001	0.001	0.08	0.49
ME, ⁷ Mcal/kg	1.58 ^c	1.67 ^d	1.79 ^f	1.46 ^a	1.54 ^{bc}	1.69 ^{de}	1.50 ^{ab}	1.60 ^c	1.73 ^{ef}	0.001	0.001	0.91	0.02

^{a-f}Means within a row with different superscripts differ ($\alpha = 0.05$)

¹CF = crude fat; NFC = nonfiber carbohydrates.

²Z24 = tillering stage.

³Z31 = stem elongation stage.

⁴ P_{CR} = cutting regimens (uncut, Z24 and Z31).

⁵ P_Y = year (2014 and 2015).

⁶ $P_{C \times CR}$ = cereal species (rye triticale, wheat) $\times$ cutting regimens (uncut, Z24 and Z31).

⁷According to the NRC (2001).

cut at the tillering stage and a further decline to 6.3% in straw cut at the stem elongation stage. The change in ash concentration of rye straw was marginal, whereas the straw of triticale had a greater ash concentration than the control straw only at cutting at the tillering stage.

There were cereal and cutting regime interactions for the NDIN, ADIN, and ADF concentrations of the cereal straws ($P < 0.05$). Overall, cutting in the spring compared with the control treatment resulted in reductions in NDIN concentration of rye and wheat straw, but this effect was not consistent for triticale straw. Similar effects of cutting regimen were observed for the ADIN concentration of the cereals, except for rye straw, which had a similar ADIN concentration for each cutting regimen. Regardless of the cereal crop, NDF and ADF concentrations of straw decreased for spring cutting regimens compared with uncut cereal forages. Triticale and wheat ADF concentration consistently declined with defoliation, and the effect was more prominent at stem elongation cutting. The ADF concentration of rye was comparable following defoliation at the tillering and stem elongation stages.

Digestibility

Interactions were detected ($P < 0.01$) between the type of cereal straw and cutting regimens for DM digestibility (**DMD**), OM digestibility, CP digestibility, NDF digestibility (**NDFD**), and ADF digestibility (**ADFD**; Table 5). Cutting at the stem elongation stage

resulted in an increased DMD compared with the control straw for each cereal species. However, cutting at the tillering stage increased the DMD only for rye straw. A similar trend ($P < 0.01$) was evident in OM digestibility of the cereal straw under various cutting regimens. Cutting at the tillering stage did not affect ($P < 0.01$) NDFD and ADFD of the cereal straw, except for rye. Although the NDFD and ADFD of wheat straw increased by 9 and 12%, respectively, when cut at the stem elongation stage compared to the control, neither cutting regime affected NDFD or ADFD of triticale straw. The CP digestibility values of the cereal straw followed the same pattern as NDFD and ADFD.

Body Weight Change and Intake

Ewes that received rye, triticale, or wheat straw-based diets had comparable BWG ($P = 0.90$), DMI ($P = 0.83$), and OMI ($P = 0.86$). The ewes grew at 183, 181, and 177 g/d for rye, wheat, and triticale straw-based diets, respectively (Table 5). Similarly, spring cutting regimens did not affect BWG of ewes ($P = 0.77$). However, ewes that received diets containing the straw that was regrown from cutting at the tillering and stem elongation stages had greater DMI and OMI, exceeding 50 g per ewe per day, compared with ewes fed uncut straw.

An interaction occurred ($P < 0.01$) between straw type and cutting regimen for ewe CP intake. Ewes that consumed diets containing wheat straw had greater CP intake compared with those that consumed rye and

Table 5. Nutrient intake (g/d), nutrient digestibility of total mixed ration (g/kg DM), and performance of ewes

Parameters	Rye			Triticale			Wheat			P_C ³	P_{CR} ⁴	$P_{C \times CR}$ ⁵	SEM
	Uncut	Z24 ¹	Z31 ²	Uncut	Z24	Z31	Uncut	Z24	Z31				
Intake													
DM, g/d	1,192 ^a	1,269 ^b	1,268 ^b	1,214 ^a	1,261 ^b	1,260 ^b	1,224 ^a	1,265 ^b	1,257 ^b	0.83	0.01	0.38	11.5
OM, g/d	1,125 ^a	1,197 ^b	1,199 ^b	1,137 ^a	1,191 ^b	1,183 ^b	1,151 ^a	1,187 ^b	1,187 ^b	0.86	0.01	0.36	10.8
CP, g/d	119 ^a	127 ^d	145 ^h	122 ^b	124 ^c	129 ^e	126 ^d	135 ^f	138 ^g	0.01	0.01	0.01	0.6
NDF, g/d	680 ^a	724 ^c	685 ^a	716 ^{bc}	713 ^{bc}	691 ^{ab}	674 ^a	694 ^{ab}	675 ^a	0.01	0.01	0.11	8.8
ADF, g/d	385 ^c	385 ^c	344 ^a	383 ^c	375 ^{bc}	360 ^{ab}	380 ^c	375 ^{bc}	357 ^a	0.86	0.01	0.15	5.5
ME, ⁶ Mcal/kg	2.39 ^a	2.80 ^c	2.94 ^d	2.48 ^a	2.64 ^b	2.65 ^b	2.61 ^b	2.66 ^b	2.86 ^{cd}	0.01	0.001	0.01	0.044
Digestibility, g/kg DM													
DM	54.8 ^a	60.6 ^c	63.8 ^d	55.7 ^{ab}	56.7 ^{ab}	57.4 ^b	58.0 ^b	57.7 ^b	62.2 ^{cd}	0.001	0.001	0.001	0.84
OM	57.0 ^a	62.6 ^{cd}	65.6 ^e	58.0 ^{ab}	59.3 ^{ab}	59.9 ^b	60.4 ^{bc}	59.8 ^b	64.3 ^{de}	0.001	0.001	0.001	0.84
CP	46.9 ^a	52.8 ^c	60.2 ^e	50.8 ^{bc}	49.3 ^{ab}	51.2 ^{bc}	56.6 ^d	57.6 ^{de}	58.8 ^{de}	0.001	0.001	0.001	0.97
NDF	46.9 ^a	53.4 ^b	55.2 ^b	48.3 ^a	48.4 ^a	47.3 ^a	48.7 ^a	47.9 ^a	52.6 ^b	0.001	0.001	0.001	1.08
ADF	46.1 ^b	53.6 ^d	51.0 ^{cd}	41.7 ^a	43.8 ^{ab}	43.2 ^{ab}	43.6 ^{ab}	41.1 ^a	49.4 ^c	0.001	0.001	0.001	1.13
Performance													
BWG, ⁷ g/d	168	199	183	181	177	172	191	182	170	0.90	0.77	0.79	18.5
G:F	0.14	0.16	0.14	0.15	0.14	0.14	0.16	0.14	0.14	0.89	0.68	0.86	0.015

^{a-h}Means within a row with different superscripts differ ($\alpha = 0.05$)

¹Z24 = tillering stage.

²Z31 = stem elongation stage.

³ P_{CR} = cutting regimens (uncut, Z24 and Z31).

⁴ P_Y = year (2014 and 2015).

⁵ $P_{C \times CR}$ = cereal species (rye triticale, wheat) $\times$ cutting regimens (uncut, Z24 and Z31).

⁶According to the Agricultural Food Research Council (1993).

⁷BWG = BW gain.

triticale straw-based diets. Ewes fed diets containing rye straw had greater CP intake than those were fed triticale straw-based diets. Overall, cutting at the stem elongation stage led to the greatest CP intake of the ewes followed by cutting at the tillering stage and the control straw, but the rate of increase in the delay of cutting was variable among the 3 cereal crops.

Intake of ADF did not differ among diets, but ewes fed diets containing straw produced after cutting at the stem elongation stage had less ADF intake than those receiving diets containing uncut straw or straw produced after cutting at the tillering stage. Intake of NDF had an opposite trend to CP intake. Neither the straw source ($P = 0.89$) nor the cutting regime ($P = 0.68$) affected the G:F of the lambs.

DISCUSSION

Agronomic Responses to Spring Defoliation

The agronomic performance of the cereal crops under dual-purpose management in the current study was primarily dictated by the prevailing climatic conditions and the growth stage of the crops at the time of spring defoliation. The results of this study support the findings of previous studies that reported that harvest of cereal crops either in the form of mechanical defoliation or

grazing at the tillering stage of growth (Z21–Z29) does not always curtail the grain or fodder production (Rao, 1989; Bonachela et al., 1995; Fieser et al., 2006; Cazzato et al., 2012). In contrast, increases in grain yields following early vegetative grazing have been occasionally reported (Royo et al., 1993; Virgona et al., 2006). Delaying livestock grazing to the stem elongation stage (Z31–Z34) provides a greater availability of forage biomass for a longer period but can reduce grain and forage production in summer (Epplin et al., 2000; de Ruiter et al., 2002; Virgona et al., 2006; Jacobs et al., 2009).

Wheat appeared to be more resilient to spring defoliation, with a less sharp decline in grain production, than rye and triticale. The wheat cultivar tested in this study had total DM production comparable to the control wheat even in the dry 2013/2014 growing season. Wheat being the most predominantly grown crop in the region indicates the potential impact of dual-purpose management for reducing the feed gap and the ease of adoption of the system by the crop–livestock farmers. Grain production of wheat following the defoliation at the tillering stage was compared to that of undefoliated crops when the rainfall followed the long-term average.

Grain protein concentration and the 1,000-grain weight had an inverse relationship in the adverse growing season of 2013/2014. Several studies reported similar effects of drought on grain quality and

noted an improved grain protein level ranging from 2 to 34% under drought conditions (Kimball et al., 2001; Gooding et al., 2003; Balla et al., 2011). This effect was largely attributed to the decline in grain size, which was also observed in the current study. The CP concentration of grain and 1,000-grain weight were not affected by the cutting regimens in 2014/2015, indicating that the quality of grains was primarily affected by environmental conditions. This result is in line with the findings of Francia et al. (2006), who reported that grain protein concentration was not affected by dual-purpose management of oat and barley.

Feeding Value and Animal Performance

Studies conducted under conventional management of cereal crops reported large variations in the nutritive value and digestibility of straw in relation to genotype, cultivar, and location (Capper et al., 1986; Dias-da-Silva and Guedes, 1990; Rao and Dao, 1994). Although there is a paucity of information on the nutritive value of cereal straw under dual-purpose management, a few studies reported significant changes in chemical characteristics of small grain cereal forages in response to defoliation at the vegetative stages, albeit with contrasting results (Francia et al., 2006; Jacobs et al., 2009; Cazzato et al., 2012).

In the current study, a substantial improvement in the nutritive value of the straw obtained from spring-defoliated cereals occurred, as evidenced by the reduced NDF and ADF concentrations and increased CP and TDN concentrations. This effect of spring defoliation was similar for all tested cereal species, but the improvement in nutritive values was more prominent for the cereal crops that were defoliated at the stem elongation stage compared with those were harvested at the tillering stage. These results are in line with the findings of Jacobs et al. (2009), who observed varying rates of increases in ME and water soluble carbohydrate concentration of barley and oat varieties at silage harvest following 2 spring grazings at the tillering and stem elongation stages. However, changes in the overall nutritive value of the small grain cereals were variable across species and grazing management. Francia et al. (2006) also reported a similar response of barley to spring defoliation that led to lower fiber concentration in the whole plant. However, these findings are in conflict with the results reported by Cazzato et al. (2012), who found that mechanical harvest of vegetative triticale in winter resulted in an increase in NDF and a decrease in ADL values at the heading stage. However, the change in the nutritive value of triticale was not reflected in the *in vitro* digestibility of NDF, suggesting that the difference was biologically insignificant.

Changes in nutritive values of triticale, rye, and wheat straw under dual-purpose management were also reflected in the TMR. Digestibility of TMR and voluntary DMI of ewes increased when ewes were fed TMR with spring-defoliated straw. This effect was more prominent for the ewes that were fed the TMR consisting of straw regrown following defoliation at the stem elongation stage. The positive response in digestibility and intake was mainly due to the fact that the NDF and the ADF concentration of the straw and, subsequently, in the TMR were lower for the spring-cut cereals. The increased DMI was possible a result of shorter gastrointestinal transit time of straw produced under dual-purpose management (Pearson et al., 2006). Voluntary DMI is closely associated with the digestibility, fiber level, and fiber quality of the feedstuff offered to livestock (Fraser et al., 2000; Huhtanen et al., 2007). It is possible that the slight increases in the nutritive value of feedstuffs that are characterized by a high concentration of fiber may lead to substantial animal intake responses. However, the BWG of the ewes did not respond to the increase in the nutritive value of the straw at the level (35%) included in the TMR. Likewise, McCartney et al. (2006) reported that differences in NDF disappearance between 2-row and 6-row barley straw had no considerable impact on beef cattle performance. This finding also agrees with the results reported by Cazzato et al. (2012).

Implications for Crop–Livestock Farming

Cereal crops can provide high-quality forage in early spring, allowing farmers to reduce the use of concentrate feeds and feeding costs through increased grazing days. In addition, straw obtained from the regrown material may offer higher quality feed for winter feeding of the livestock. Although grazing would still have a positive impact on the straw produced following the defoliation at the tillering stage and on animal performance, this effect would be less profound than grazing at the stem elongation stage. Once plants reach stem elongation stages, grazing impedes the regrowth potential of the plants, resulting in a large reduction in total grain, forage, and straw yields. However, this management strategy results in sizeable increases in straw quality.

The economic benefit of grazing on high-quality forage and the improvement of the nutritive value of straw may offset the yield reduction depending on the meat, grain, and straw prices. When the value of wheat fodder is large relative to the value of grain, it would be more profitable to graze cereal crops at the stem elongation stage. This possibly will, in turn, provide greater quality forage and straw production. Feeding such forage at high levels may have an impact on animal performance. Alternatively, when the economic value of grain

is great relative to the value of forage, ceasing grazing at the tillering stage may provide greater net returns.

The ability to graze small grain winter cereals during their vegetative stage provides a unique production niche for crop–livestock farming. This study indicated a great potential to fill the winter–spring feed shortage with cereal grazing and improve straw feeding value through dual-purpose management of cereals. Animal performance was unresponsive to the changes in straw quality and cereal type under optimal feeding conditions in this study, which were balanced to meet the nutrient requirements of ewes. However, it is quite likely that even small increases in the nutritive value of straw would affect the BWG of animals, particularly in prolonged feeding periods or when the proportion of straw in the diet is increased. A bioeconomic analysis will be required to assess the best management strategy for both grain and straw production in light of the improvement of the nutritive of straw and the growth performance of ewes.

LITERATURE CITED

- Agricultural Food Research Council (AFRC). 1993. Energy and protein requirements of ruminants. Technical Committee on Responses to Nutrients. CAB Int., Wallingford, UK.
- AOAC. 2003. Official methods of analysis. 17th ed. 2nd rev. AOAC Int., Gaithersburg, MD.
- Association of Official Analytical Chemists. 1990. Official methods of analysis. 15th ed. Association of Official Analytical Chemists, Arlington, VA.
- Balla, K., M. Rakszegi, Z. Li, F. Békés, S. Bencze, and O. Veisz. 2011. Quality of winter wheat in relation to heat and drought shock after anthesis. *Czech J. Food Sci.* 29:117–128.
- Bonachela, S., F. Orgaz, and E. Fereres. 1995. Winter cereals grown for grain and for the dual purpose of forage plus grain I. Production. *Field Crops Res.* 44:1–11. doi:10.1016/0378-4290(95)00045-1
- Capper, B. S., E. F. Thomson, S. Rihawi, A. Termanini, and R. Macrae. 1986. The feeding value of straw from different genotypes of barley when given to Awassi sheep. *Anim. Prod.* 42:337–342. doi:10.1017/S0003356100018109
- Cazzato, E., V. Laudadio, and V. Tufarelli. 2012. Effects of harvest period, nitrogen fertilization and mycorrhizal fungus inoculation on triticale ($\times$ Triticosecale Wittmack) forage yield and quality. *Renew. Agric. Food Syst.* 27:278–286. doi:10.1017/S1742170511000482
- Coblentz, W. K., and R. P. Walgenbach. 2010. Fall growth, nutritive value, and estimation of total digestible nutrients of cereal-grain forages in the north-central United States. *J. Anim. Sci.* 88:383–399. doi:10.2527/jas.2009-2224
- de Ruiter, J., R. Hanson, A. S. Hay, K. W. Armstrong, and R. D. Harrison-Kirk. 2002. Whole-crop cereals for grazing and silage: Balancing quality and quantity. *Proc. N. Z. Grassl. Assoc.* 64:181–190.
- Dias-da-Silva, A. A., and C. V. Guedes. 1990. Variability in the nutritive value of straw cultivars of wheat, rye and triticale and response to urea treatment. *Anim. Feed Sci. Technol.* 28:79–89. doi:10.1016/0377-8401(90)90070-O
- Epplin, F. M., I. Hossain, and E. G. Krenzer Jr. 2000. Winter wheat fall–winter forage yield and grain yield response to planting date in a dual-purpose system. *Agric. Syst.* 63:161–173. doi:10.1016/S0308-521X(00)00004-4
- Fieser, B. G., G. W. Horn, J. T. Edwards, and E. G. Krenzer. 2006. Timing of grazing termination in dual-purpose winter wheat enterprises. *Prof. Anim. Sci.* 22:210–216.
- Francia, E., N. Pecchioni, O. Li Destri Nicosia, G. Paoletta, L. Taibi, V. Franco, M. Odoardi, A. M. Stanca, and G. Delogu. 2006. Dual-purpose barley and oat in a Mediterranean environment. *Field Crops Res.* 99:158–166. doi:10.1016/j.fcr.2006.04.006
- Fraser, M. D., R. Fychan, and R. Jones. 2000. Voluntary intake, digestibility and nitrogen utilization by sheep fed ensiled forage legumes. *Grass Forage Sci.* 55:271–279. doi:10.1046/j.1365-2494.2000.00225.x
- Gooding, M. J., R. H. Ellis, P. R. Shewry, and J. D. Schofield. 2003. Effects of restricted water availability and increased temperature on the grain filling, drying and quality of winter wheat. *J. Cereal Sci.* 37:295–309. doi:10.1006/jcrs.2002.0501
- Huhtanen, P., M. Rinne, and J. Noisiainen. 2007. Evaluation of the factors affecting silage intake of dairy cows: A revision of the relative silage dry-matter intake index. *Animal* 1:758–770. doi:10.1017/S175173110773673X
- Hussein, E., D. T. Thomas, L. W. Bell, and D. Blache. 2016. Grazing winter and spring wheat crops improves the profitability of prime lamb production in mixed farming systems of Western Australia. *Anim. Prod. Sci.* 57:2082–2090. doi:10.1071/AN15850
- Jacobs, J. L., J. Hill, and T. Jenkin. 2009. Effect of different grazing strategies on dry matter yields and nutritive characteristics of whole crop cereals. *Anim. Prod. Sci.* 49:608–618. doi:10.1071/EA08245
- Keles, G., S. Ates, B. Coskun, M. S. Alatas, and S. Isik. 2016. Forage yields and feeding value of small grain winter cereals for lambs. *J. Sci. Food Agric.* 96:4168–4177. doi:10.1002/jsfa.7619
- Keles, G., S. Ates, B. Coskun, and S. Koc. 2013. Re-growth yield and nutritive value of winter cereals. In: *Revitalising grasslands to sustain our communities: Proc. 22nd Int. Grassl. Congr.*, 15–19 September, 2013, Sydney, Australia. New South Wales Department of Primary Industry. p. 951–953.
- Kelman, W. M., and H. Dove. 2009. Growth and phenology of winter wheat and oats in a dual-purpose management system. *Crop Pasture Sci.* 60:921–932. doi:10.1071/CP09029
- Kimball, B. A., C. F. Morris, P. J. Pinter, G. W. Wall, D. J. Hunsaker, F. J. Adamsen, R. L. LaMorte, S. W. Leavitt, T. L. Thompson, A. D. Matthias, and T. J. Brooks. 2001. Elevated CO₂, drought and soil nitrogen effects on wheat grain quality. *New Phytol.* 150:295–303. doi:10.1046/j.1469-8137.2001.00107.x
- McCartney, D. H., H. C. Block, P. L. Dubeski, and A. J. Ohama. 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. doi:10.4141/A05-092
- NRC. 2001. Nutrient requirements of dairy cattle. 7th rev. ed. Natl. Acad. Press, Washington, DC.
- Pearson, R. A., R. F. Archibald, and R. H. Muirhead. 2006. A comparison of the effect of forage type and level of feeding on the digestibility and gastrointestinal mean retention time of dry forages given to cattle, sheep, ponies and donkeys. *Br. J. Nutr.* 95:88–98. doi:10.1079/BJN20051617

- Rao, S. C. 1989. Regional environment and cultivar effects on the quality of wheat straw. *Agron. J.* 81:939–943. doi:10.2134/agronj1989.00021962008100060018x
- Rao, S. C., and T. H. Dao. 1994. Straw quality of 10 wheat cultivars under conventional and no-till systems. *Agron. J.* 86:833–837. doi:10.2134/agronj1994.00021962008600050016x
- Royo, C., E. Montesinos, J. L. Molina-Cano, and J. Serra. 1993. Triticale and other small grain cereals for forage and grain in Mediterranean conditions. *Grass Forage Sci.* 48:11–17.
- Van Keulen, J., and B. A. Young. 1977. Evaluation of acid-insoluble ash as a natural marker in ruminant digestibility studies. *J. Anim. Sci.* 44:282–287. doi:10.2527/jas1977.442282x
- Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. *J. Dairy Sci.* 74:3583–3597. doi:10.3168/jds.S0022-0302(91)78551-2
- Virgona, J. M., F. A. J. Gummer, and J. F. Angus. 2006. Effects of grazing on wheat growth, yield, development, water use, and nitrogen use. *Crop Pasture Sci.* 57:1307–1319. doi:10.1071/AR06085
- Zadoks, J. C., T. T. Chang, and C. F. Konzak. 1974. A decimal code for the growth stages of cereals. *Weed Res.* 14:415–421. doi:10.1111/j.1365-3180.1974.tb01084.x