Productivity of lactating dairy cows fed diets with teff hay as the sole forage

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ABSTRACT

Groundwater depletion is one of the most pressing issues facing the dairy industry in arid regions. One strategy to improve the industry's drought resilience involves feeding drought-tolerant forage crops in place of traditional forage crops such as alfalfa and corn silage. The objective of this study was to assess the productivity of lactating dairy cows fed diets with teff hay (*Eragrostis tef*) as the sole forage. Teff is a warm-season annual grass native to Ethiopia that is well adapted to drought conditions. Nine multiparous Holstein cows (185 ± 31 d in milk; mean $\pm$ standard deviation) were randomly assigned to 1 of 3 diets in a 3×3 Latin square design with 18-d periods (14 d acclimation and 4 d sampling). Diets were either control, where dietary forage consisted of a combination of corn silage, alfalfa hay, and native grass hay, or 1 of 2 teff diets (teff-A and teff-B), where teff hay [$13.97 \pm 0.32\%$ crude protein, dry matter (DM) basis] was the sole forage. All 3 diets were formulated for similar DM, crude protein, and nonfiber carbohydrate concentrations. Control and teff-A were matched for concentrations of neutral detergent fiber (NDF) from forage ($18.2 \pm 0.15\%$ of DM), and teff-B included slightly less, providing 16.6% NDF from forage. Dry matter intake, milk and component production, body weight, body condition score, as well as DM and NDF digestibility were monitored and assessed using mixed model analysis, with significance declared at $P < 0.05$. Treatment had no effect on dry matter intake (28.1 ± 0.75 kg/d). Similarly, treatment had no effect on milk production (40.7 ± 1.8 kg/d). Concentrations of milk fat ($3.90 \pm 0.16\%$) and lactose ($4.68 \pm 0.07\%$) were also unaffected by treatment. Teff-A and teff-B increased milk protein concentration compared with the control (3.07 vs. $3.16 \pm 0.09\%$). Treatment had no effect on energy-corrected milk yield (43.4 ± 1.3 kg/d), body weight, or body condition score change. Additionally, treatment had no effect on total-tract DM or

NDF digestibility. Results from this study indicate that teff hay has potential to replace alfalfa and corn silage in the diets of lactating dairy cattle without loss of productivity.

Key words: drought, forage, lactation, grass

INTRODUCTION

Drought is one of the most significant issues threatening the dairy industry today. For producers located in arid regions of the United States, irrigation for growing feed presents the greatest water-utilization challenge. In fact, water used for growing the crops that feed cattle accounts for more than 90% of the water used to support milk production (Innovation Center for US Dairy, 2013). Declining ground water levels are making it more difficult to produce feed locally in some areas (Cross, 2015), and management strategies intended to maintain surface water levels will only put more stress on groundwater reserves (Famiglietti, 2014). As groundwater levels decrease, some wells are no longer able to support the production of alfalfa and corn silage, forage crops with significant water demands. Without an industry-wide shift toward water conservation, the sustainability of the dairy industry in arid regions is questionable.

Water-efficient forage crops with acceptable nutritional value could prove an attractive alternative to traditional forage crops. Teff (*Eragrostis tef*) is a warm-season annual grass (C4 physiology) native to Ethiopia that is well adapted to arid conditions. Since 4000 B.C., teff has been used as a grain crop for human consumption. Upon its introduction to the United States, researchers evaluated teff as a forage crop (Miller, 2011). Although teff grass has potential to fit the needs for forage production in areas threatened by drought, very little is currently known about how dairy cows might perform when fed a teff-based diet.

Because teff is primarily a grain crop in Ethiopia (Mengesha, 1966), several Ethiopian studies have investigated opportunities to improve the feeding value of teff straw (Bonsi et al., 1995, 1996; Mesfin and Ledin, 2004). To optimize the quality of teff grass, harvest should occur well before the development of seed heads.

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As forages mature, quality decreases as photosynthetic products are converted to fibrous, structural components (Van Soest, 1982). In a recent study (Saylor, 2017), greenhouse-grown teff grass harvested well before seed head development (45 d after planting) contained an average of $24.6 \pm 0.49\%$ CP. Additionally, the 24-h in vitro NDF digestibility averaged $54.8 \pm 0.95\%$. These results show that, if harvested at an early stage of maturity, teff grass has potential to be a highly nutritious forage. Still, very little work has been done to assess the effects of feeding high-quality teff grass to dairy cattle. Several studies have evaluated responses to teff hay in growing cattle and horses (Stanier et al., 2010; Young et al., 2014). Although studies like these are certainly valuable, maintaining the high DMI and passage rate to support the nutrient requirements of a lactating dairy cow is a more challenging proposition. The objective of this study was to assess the productivity of high-producing dairy cows fed diets with teff hay as the sole forage.

MATERIALS AND METHODS

Experimental procedures were approved by the Institutional Animal Care and Use Committee at Kansas State University.

Design and Treatments

Nine multiparous Holstein cows (185 ± 31 DIM; mean $\pm$ SD) from the Kansas State University Dairy Cattle Teaching and Research Unit were randomly assigned to treatment sequence in a replicated 3×3 Latin square design. Treatment periods were 18 d, with the final 4 d used for data and sample collection. At the beginning of the experiment, BW of cows were 694 ± 50 kg with a BCS of 3.18 ± 0.24 .

Cows were offered 1 of 3 diets, all fed as TMR. Diets were either control (**CON**), where dietary forage consisted of a combination of corn silage, alfalfa hay, and prairie hay, or 1 of 2 teff diets (**teff-A** and **teff-B**), where teff hay was the sole forage. Prairie hay and teff hay were processed with a bale processor to achieve a 3.8 cm theoretical length of cut, and alfalfa hay was processed with a TMR wagon. Chemical composition of the forages used in this study is shown in Table 1. All 3 diets were formulated for similar DM, CP, ether extract, and NFC concentrations (Table 2). The teff-A diet was formulated to provide equivalent NDF from forage (**fNDF**) compared with CON, with the intention of evaluating the effect of teff fiber versus the replaced forage fibers. Because this approach increased dietary NDF, a second experimental diet, teff-B, was formulated to provide equivalent effective fiber as CON, quantified as $(\text{fNDF} \times 2) + \text{NDF}$ (DM basis; Bradford and Mullins, 2012). A portion of the teff was replaced with soybean hulls to accomplish this change while maintaining total NDF at a similar concentration as in the teff-A diet. Although diets were less divergent in effective fiber than the original formulation predicted, this metric for effective fiber equated to 68, 70, and 67 for CON, teff-A, and teff-B, respectively, based on analyzed nutrient concentrations.

Data and Sample Collection

Throughout the experiment, cows were fed twice daily at $\geq 105\%$ of expected intake. On d 15 to 18 of each treatment period, the amount of feed offered and refused was recorded to determine DMI. Samples of forages and wet corn gluten feed (**WCGF**) were collected at feeding on d 15 to 18, concentrate samples were collected on d 16 and 18, and samples of orts were collected 23.5 h postfeeding on d 15 to 18. Feed

Table 1. Nutrient composition of forages used in the experiment¹

Nutrient ²	Teff hay		Corn silage		Alfalfa hay		Prairie hay	
	% of DM	SD	% of DM	SD	% of DM	SD	% of DM	SD
DM, % as fed	92.3	0.3	33.6	2.0	90.4	0.5	93.9	0.6
CP	12.9	0.4	8.4	0.4	19.9	1.0	5.1	0.1
aNDFom ³	56.1	1.9	40.9	2.5	35.3	2.3	63.4	1.2
ADF	29.8	0.8	24.2	2.3	29.2	1.2	40.3	0.5
NFC	12.2	2.1	40.5	3.2	21.1	0.4	12.8	0.5
Ether extract	1.9	0.1	3.4	0.4	1.8	0.3	2.2	0.1
Ash	8.0	0.3	5.3	0.3	10.1	0.9	8.9	1.2
uNDFom ⁴	12.4	5.5	10.9	1.6	20.3	1.5	13.0	4.6

¹Acquired from samples taken on d 15 to 18 of all 4 periods.

²All nutrients, except DM, are reported on a DM basis.

³Amylase-treated, ash-free NDF.

⁴Ash-free, undigested NDF remaining after 240 h of in vitro ruminal fermentation.

samples were composited into one sample per period. Fecal samples were collected every 16 h from d 15 to 18 so that 6 samples were taken from each cow each period, representing duplicated 8-h intervals of a 24-h day. Fecal samples were composited for analysis. Ash-free, undigested NDF (**uNDFom**, 240 h) of feeds, orts, and fecal samples was used as an internal marker to determine apparent total-tract digestibility of DM and NDF (Lee and Hristov, 2013).

Cows were milked 2 times daily (0400 and 1600 h) in a milking parlor, and milk was sampled and yield was recorded for every milking on d 15 to 18 of each

period. Body weight and BCS were measured on d 1 of each period and d 18 of the last period. Body condition score was measured on a scale of 1 to 5 according to Wildman et al. (1982).

Nutrient and Milk Analyses

The Penn State Particle Separator was used to measure particle size for both TMR and orts (Lammers et al., 1996). Diet ingredients were sent frozen to Dairy One Forage Testing Laboratory (Dairy One Inc., Ithaca, NY) and analyzed for DM, CP, amylase-treated, ash-free NDF (**aNDFom**), ADF, ether extract, ash, and uNDFom. Fecal samples were dried for 72 h in a 55°C forced-air oven, ground to pass through a 1-mm screen using a Wiley mill (Arthur H. Thomas, Philadelphia, PA), then sent to Dairy One Forage Testing Laboratory (Ithaca, NY) to be analyzed for DM, aNDFom, and uNDFom. Dry matter was determined by drying samples for 16 to 24 h in a 55°C forced-air oven. Crude protein was determined (Etheridge et al., 1998) by oxidation and detection of N₂ (Leco Analyzer, Leco Corp., St. Joseph, MI). Concentrations of aNDFom and ADF (Van Soest et al., 1991) were determined using an Ankom Fiber Analyzer (Ankom Technology, Macedon, NY) and filter bags with a pore size of 25 µm. Sodium sulfite was added to the detergent solution for the aNDFom analysis. Crude fat was determined by ether extraction (AOAC method 2003.05; AOAC International, 2012). Ash concentration was determined using AOAC method 942.05 (AOAC International, 2012). Undigested NDF concentration was defined as the amount of NDF present after 240 h incubation (Raffrenato and Van Amburgh, 2010) in the Daisy^{II} Incubator (Ankom Technology Method 3, Ankom Technology). In determining uNDF concentration, feed samples (0.25 g) were weighed into filter bags with a pore size of 25 µm and incubated in rumen fluid collected from 3 dairy cows at Cornell University. Concentrations of all nutrients except DM were expressed as percentages of DM determined by drying at 105°C in a forced-air oven for 3 h.

Milk samples were analyzed for concentrations of fat, true protein, lactose (B-2000 Infrared Analyzer; Bentley Instruments, Chaska, MN), MUN (MUN spectrophotometer, Bentley Instruments), and somatic cells (SCC 500, Bentley Instruments) by MQT Lab Services (Kansas City, MO). Energy-corrected milk ($0.327 \times \text{milk kg} + 12.86 \times \text{fat kg} + 7.65 \times \text{protein kg}$) was calculated.

Statistical Analysis

Data were analyzed according to the following model using JMP (version 10.0, SAS Institute, Cary, NC):

Table 2. Ingredient and nutrient composition of dietary treatments

Item	Diet		
	Teff-A	Teff-B	Control
Ingredient, % of DM			
Teff hay	29.6	27.3	—
Corn silage	—	—	23.9
Alfalfa hay	—	—	19.4
Prairie hay	—	—	1.6
Wet corn gluten feed ¹	23.2	23.2	23.2
Teff grain mix ²	36.7	36.7	—
Control grain mix ³	—	—	27.9
Ground corn	7.0	7.1	—
Soybean hulls	—	2.2	—
Cottonseed	3.5	3.5	4.0
Water, % as fed	26.2	26.2	—
Nutrient ⁴			
DM, % as fed	60.0	60.0	59.6
CP	17.1	17.1	16.8
NDF	33.6	33.6	31.7
NDF from forage	18.1	16.6	18.3
ADF	16.7	17.0	18.6
NFC ⁵	35.3	35.5	36.7
Ether extract	3.7	3.7	4.1
Ash	8.8	8.7	9.1
Undigested NDF (240 h)	5.8	5.5	9.0

¹Sweet Bran, Cargill Inc. (Minneapolis, MN).

²Teff grain mix consisted of 56.88% ground corn, 15.68% soybean meal, 10.93% soy hulls, 4.84% Soy Best (Soy Best, West Point, NE), 3.5% limestone, 3.04% sodium bicarbonate, 2.17% Megalac R (Arm & Hammer Animal Nutrition, Princeton, NJ), 0.7% magnesium oxide, 0.43% stock salt, 0.43% trace mineral salt, 0.43% vitamin E premix (20 kIU/g), 0.43% potassium chloride, 0.27% Biotin 100 (ADM Alliance Nutrition, Quincy, IL), 0.07% Zinpro 4-Plex (Zinpro Corp., Eden Prairie, MN), 0.07% selenium 0.06%, 0.04% vitamin A premix (30 kIU/g), 0.03% Zinpro 120 (Zinpro Corp.), 0.02% Rumensin 90 (Elanco Animal Health, Greenfield, IN), 0.01% vitamin D premix (30 kIU/g), and 0.002% ethylenediamine dihydriodide premix.

³Control grain mix consisted of 62.22% ground corn, 22.62% Soy Best (Soy Best), 4.52% limestone, 3.96% sodium bicarbonate, 2.83% Megalac R (Arm & Hammer Animal Nutrition), 0.91% magnesium oxide, 0.57% stock salt, 0.57% trace mineral salt, 0.57% vitamin E premix (20 kIU/g), 0.57% potassium chloride, 0.35% Biotin 100 (ADM Alliance Nutrition), 0.10% selenium 0.06%, 0.09% Zinpro 4-Plex (Zinpro Corp.), 0.06% vitamin A premix (30 kIU/g), 0.05% Zinpro 120 (Zinpro Corp.), 0.02% vitamin D premix (30 kIU/g), 0.02% Rumensin 90 (Elanco Animal Health), and 0.002% ethylenediamine dihydriodide premix.

⁴Nutrients other than DM expressed as a percentage of diet DM.

⁵Calculated as DM - (CP + NDF + ether extract + ash).

$$Y_{ijk} = \mu + T_i + P_j + C_k + e_{ijk},$$

where μ = overall mean, T_i = fixed effect of treatment ($i = 1$ to 3), P_j = random effect of period ($j = 1$ to 3), C_k = random effect of cow ($k = 1$ to 9), and e_{ijk} = residual error. Treatment effects were declared significant at $P < 0.05$ and tendencies for treatment effects were declared at $P < 0.10$. When significant treatment effects were observed, means were separated by Tukey's honestly significant difference test.

RESULTS AND DISCUSSION

Diet Composition and Particle Size

Diets were formulated to meet or exceed NRC (2001) requirements for a Holstein cow producing 43.1 kg/d of milk; diet ingredient and nutrient analyses are shown in Table 2. The teff hay used in this study was supplied from a single source (Marc Oster, La Salle, CO), and nutrient variability of this product, across the 3 collection periods, was relatively low (Table 1). Table 3 shows particle size analysis and sorting index for the treatments. Compared with CON, teff-A and teff-B contained a greater proportion of particles longer than 19 mm ($P < 0.001$) but a lesser proportion of particles between 8 and 19 mm ($P < 0.001$). Additionally, teff-A and teff-B contained a greater proportion ($P < 0.001$) of particles smaller than 8 mm compared with CON. The greater proportion of small particles was most likely a result of how the teff diets were formulated; teff-A and teff-B contained 8.8% more grain mix and roughly 7% more ground corn than CON (Table 2). An adequate supply of long particles is necessary to maintain rumen function (Lammers et al., 1996). Although there was no effect ($P > 0.05$) of diet on sorting of particles greater than 19 mm and less than 8 mm, diet had a significant effect on sorting of particles between 8 and 19 mm ($P = 0.04$, Table 3). Cows fed CON selectively consumed this intermediate particle size fraction, whereas cows fed teff-B selectively avoided this fraction.

DMI and Performance

The teff-based diets fed in this study were designed in such a way as to test 2 different strategies for formulating a diet containing teff hay as the sole forage. The teff-A and CON were formulated to contain similar concentrations of NDF from forage (fNDF, Table 2). Average fNDF for the 2 diets was 18.2% of DM. The teff-B diet was formulated to contain slightly less fNDF (16.6% of DM), arrived at by equalizing effective fiber calculated using the following equation: (fNDF $\times$ 2) + NDF (Bradford and Mullins, 2012).

There was no significant effect of diet on DMI ($P = 0.76$). Across all 3 diets, DMI averaged 28.1 ± 0.76 kg/d (Table 4). According to Van Soest (1982), plant cell wall is the primary restriction on feed intake in high-forage diets. Osbourn et al. (1976) found that increasing forage cell wall content significantly decreased OM intake. Although the NDF content of teff hay is much greater than that of corn silage and alfalfa hay (56.1 vs. 40.9 and 35.3% of DM, respectively), the total inclusion rate of forage in the teff diets was lower than that in the control diet (28.5 vs 44.9% of DM). The low inclusion rate of teff in teff-A and teff-B likely explains the similarities in DMI between the 3 treatments. Rezac et al. (2012) reported similar findings. A diet containing only 19.2% tallgrass prairie hay (NDF = $67.5 \pm 5.3\%$ of DM) as the sole forage resulted in intakes similar to a control diet that contained corn silage and alfalfa hay.

There was no apparent difference in dry matter digestibility (DMD) or NDF digestibility (NDFD) between the 3 diets ($P > 0.10$, Table 4). Across the 3 diets, DMD averaged $65.8 \pm 3.2\%$ and NDFD averaged $52.4 \pm 5.4\%$. Digestibility is inherently complex in that it is dependent on several factors, including the amount and composition of fiber in the diet, intake level, passage rate, and particle size (Van Soest, 1982). In this case, the similarities in DMD and NDFD may be due to differences in retention time of the forage portion of the diet. Compared with grasses like teff, alfalfa particles are more fragile and have a shorter period of buoyancy in the rumen (Allen, 2000). These factors alone could increase the retention time of teff while decreasing the retention time of alfalfa. The result would be similar digestibilities between teff-based and traditional diets. The particle size distribution of teff-A and teff-B compared with CON (Table 3) would also support increased ruminal retention time with the teff diet.

Table 3. Particle size analysis (% , as-fed basis)¹

Item	Diet		
	Teff-A	Teff-B	Control
TMR			
>19 mm	13.5 ^a	12.0 ^a	4.0 ^b
8 to 19 mm	11.5 ^b	11.7 ^b	30.1 ^a
<8 mm	75.0 ^a	76.2 ^a	66.0 ^b
Sorting index ²			
>19 mm	1.37	1.07	1.03
8 to 19 mm	0.88 ^{ab}	0.82 ^b	1.07 ^a
<8 mm	0.99	1.06	0.99

^{a,b}Means within a row with different superscripts are significantly different by Tukey's honestly significant difference ($P < 0.05$).

¹Measured using a 3-compartment Penn State Particle Separator (Lammers et al., 1996).

²Calculated as proportion in TMR/proportion in refusals. Sorting index >1.0 means preferential sorting occurred for a given particle size.

Table 4. Effects of treatments on performance of lactating cows

Item	Diet			SEM	P-value
	Teff-A	Teff-B	Control		
DMI, kg/d	28.0	28.4	28.0	0.75	0.76
Milk, kg/d	40.6	41.0	40.4	1.79	0.65
ECM, kg/d	42.9	43.5	43.4	1.26	0.80
ECM/DMI	1.54	1.53	1.55	0.045	0.75
Apparent total-tract DM digestibility, %	65.4	67.7	64.3	3.18	0.47
Apparent total-tract NDF digestibility, %	52.2	54.9	50.0	5.42	0.58
BW change, kg/18 d	-2.3	-0.7	-4.4	15.2	0.91
BCS change/18 d	0.11	-0.03	0.06	0.12	0.48

Milk yield averaged 40.7 ± 1.8 kg/d and was not significantly altered by treatment ($P > 0.10$, Table 4). Likewise, milk fat concentration and yield were unaffected by diet ($P > 0.10$, Table 5). Milk protein concentration was significantly greater in cows fed teff-A and teff-B than in those fed CON ($P < 0.001$, Table 5). Due to the similarities in milk production and differences in milk protein concentration, milk protein yield tended to be greater in the teff diets compared with the control ($P = 0.06$, Table 5). A tendency ($P = 0.06$, Table 5) was observed for greater MUN concentrations with teff-A compared with teff-B and control. Somatic cell linear score was unaffected by diet ($P = 0.82$, Table 5).

The milk protein response seen with teff-A and teff-B is consistent with protein responses associated with increases in overall diet fermentability. In a meta-analysis completed by Ferraretto et al. (2013), increasing diet fermentability by increasing concentrations of dietary starch resulted in greater milk protein concentrations. Although there were no significant differences in digestibility of DM or NDF between the 3 diets, numerical differences between digestibility means are not inconsistent with the possibility of increased fermentability with the teff diets (Table 4).

Table 5. Effects of treatments on milk components

Item	Diet			SEM	P-value
	Teff-A	Teff-B	Control		
Milk fat, %	3.83	3.84	4.03	0.16	0.19
Milk protein, %	3.14 ^a	3.18 ^a	3.07 ^b	0.09	<0.001
Lactose, %	4.68	4.70	4.66	0.07	0.53
SCLS ¹	2.43	2.51	2.29	0.81	0.82
MUN, mg/dL	12.08	11.63	11.53	0.53	0.06
Yield, kg/d					
Milk fat	1.55	1.56	1.61	0.05	0.43
Milk protein	1.27	1.30	1.23	0.03	0.06
Milk lactose	1.91	1.93	1.88	0.10	0.60

^{a,b}Means with different superscripts are significantly different by Tukey's honestly significant difference ($P < 0.05$).

¹Somatic cell linear score. Calculated as described by Schukken et al. (2003): $\log_2 (\text{SCC}/100) + 3$.

Ferraretto et al. (2013) also showed that increasing concentrations of dietary starch resulted in decreased milk fat concentrations. In this study, however, no such milk fat response was seen. Considering that, compared with the control, the teff-based diets contained a significantly greater proportion of long particles (>19 mm), we expected to see increased concentrations of milk fat in cows fed teff-A and teff-B. Diets lacking long particles are generally more fermentable (Grant et al., 1990), which can lead to greater acid production and a decrease in rumen pH (Mullins et al., 2010). Ruminal acidosis often results in a drop in milk fat concentration (Enjalbert et al., 2008). Yang and Beauchemin (2007) found the proportion of particles longer than 8 mm to be a useful predictor of ruminal pH dynamics. In this case, compared with teff-A and teff-B, CON contained a significantly greater proportion ($P < 0.001$) of particles longer than 8 mm (34.0 vs. 25.0 and 23.8%, respectively). This could explain why a difference in milk protein concentration between the treatments was found.

Despite the differences in protein concentration and yield, we found no significant effect of diet on ECM yield ($P = 0.80$, Table 4) or production efficiency (calculated as ECM/DMI; $P = 0.75$). We found no evidence that similar milk yields were maintained through differences in mobilization of body reserves, as there was no effect of diet on 18-d BW or BCS change ($P > 0.10$). The absence of detected BCS differences could be due to the relatively short treatment periods.

It is important to note that, although this study shows that a diet containing teff has potential to maintain milk and component production, many practical questions still need to be answered before adoption of this forage on commercial dairy farms. One of the first factors that needs to be addressed is yield potential. In an area like Kansas, annual corn silage and alfalfa yields average 6.0 and 3.6 t of DM, respectively (USDA, 2016). Although published data are limited, teff yields have potential to average 5.0 t of DM per year with adequate irrigation and fertilization (Roseberg et al.,

2005, 2006; Miller, 2011). The more relevant scenario is in nonirrigated, somewhat water-restricted conditions, and very few data are currently available to compare teff yields with yields of other dryland crops in these conditions. Additionally, comparison of reported commercial yields to limited, controlled agronomy research findings may be misleading, and additional work is needed to better understand expected teff yields in various conditions.

Nevertheless, the approach used in this study has potential to significantly affect land and water requirements for a dairy farm. Annual forage needs for a dairy milking 100 cows would be approximately 413 t of DM for the CON diet, but would drop to approximately 256 t of DM with the teff-B diet, due to a greater NDF concentration in teff, and in turn, less forage inclusion. The dietary space left by decreased forage inclusion was filled with dry ground corn, soybean meal, and soyhulls (Table 2). On farms with adequate land and water, this shift would likely increase feed costs, but with inadequate land or water availability, such a strategy could prove attractive. It is more cost effective (per t of DM) to transport concentrates compared with forages. Therefore, generating adequate forage NDF locally, while importing other nutrients from areas with greater water resources, may be a more sustainable option than drawing on local water resources for corn silage and alfalfa production. It is important to note that there are many factors to consider in this sort of shift, including additional costs associated with harvesting teff 3 to 4 times in a growing season compared with a single harvest for corn or sorghum silage.

Commercial utilization of teff by dairy farms would likely involve ensiling. Other ensiled grasses are commonly fed to lactating dairy cows, so there is reason to believe that ensiled teff would offer similar benefits. Cherney et al. (2004) investigated the lactation performance of cows fed diets based on ensiled fescue, orchardgrass, and alfalfa, and concluded that, with the help of additional concentrate, cows consuming first-cutting fescue and orchardgrass silage-based diets performed as well as those consuming alfalfa silage-based diets. Amer and Mustafa (2010) found that cows fed pearl millet silage, another drought-tolerant forage crop, produced more ECM than cows fed corn silage. Additionally, continued research into exogenous cellulase application at the time of ensiling may improve the potential for producing high-quality silage from high-NDF grasses (Khota et al., 2016). Finally, studies investigating the effects of a teff-based diet on whole-lactation performance are needed. Responses to diets often differ by stage of lactation, and diets in early lactation often have carryover effects for months.

CONCLUSIONS

Results from this study indicate that teff grass has potential to be used as an alternative forage source for lactating dairy cows without negatively affecting DMI or milk and component production. A high-NDF forage like teff can be incorporated into the diet at a lower inclusion rate and, by filling space with additional concentrate, diet fermentability and rumen stability can be maintained. Feeding teff has potential to improve the resilience of the dairy industry to regional water shortages.

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REFERENCES

- Allen, M. S. 2000. Effects of diet on short-term regulation of feed intake by lactating dairy cattle. *J. Dairy Sci.* 83:1598–1624.
- Amer, S., and A. F. Mustafa. 2010. Short communication: Effects of feeding pearl millet silage on milk production of lactating dairy cows. *J. Dairy Sci.* 93:5921–5925.
- AOAC International. 2012. Official Methods of Analysis of AOAC International. 19th ed. Association of Official Analytical Chemists, Gaithersburg, MD.
- Bonsi, M. L. K., P. O. Osuji, A. K. Tuah, and N. N. Umunna. 1995. Intake, digestibility, nitrogen balance, and certain rumen characteristics of Ethiopian Menz sheep fed teff straw supplemented with cotton seed cake, dry sesbania, dry leucaena, or fresh leucaena. *Agrofor. Syst.* 31:243–256.
- Bonsi, M. L. K., A. K. Tuah, P. O. Osuji, V. I. Nsahlai, and N. N. Umunna. 1996. The effect of protein supplement source or supply pattern on the intake, digestibility, rumen kinetics, nitrogen utilization, and growth of Ethiopian Menz sheep fed teff straw. *Anim. Feed Sci. Technol.* 64:1996.
- Bradford, B. J., and C. R. Mullins. 2012. Invited review: Strategies for promoting productivity and health of dairy cattle by feeding nonforage fiber sources. *J. Dairy Sci.* 95:4735–4746.
- Cherney, D. J. R., J. H. Cherney, and L. E. Chase. 2004. Lactation performance of Holstein cows fed fescue, orchardgrass, or alfalfa silage. *J. Dairy Sci.* 87:2268–2276.
- Cross, J. A. 2015. Change and sustainability issues in America's dairy-land. *Focus on Geography* 58:173–183.
- Enjalbert, F., Y. Videau, M. C. Nicot, and A. Troegeler-Meynadier. 2008. Effects of induced subacute ruminal acidosis on milk fat content and milk fatty acid profile. *J. Anim. Physiol. Anim. Nutr. (Berl.)* 92:284–291.
- Etheridge, R. D., G. M. Pesti, and E. H. Foster. 1998. A comparison of nitrogen values obtained utilizing the Kjeldahl nitrogen and Dumas combustion methodologies (Leco CNS 2000) on samples

- typical of an animal nutrition analytical laboratory. *Anim. Feed Sci. Technol.* 73:21–28.
- Famiglietti, J. S. 2014. The global groundwater crisis. *Nat. Clim. Chang.* 4:945–948.
- Ferraretto, L. F., P. M. Crump, and R. D. Shaver. 2013. Effect of cereal grain type and corn grain harvesting and processing methods on intake, digestion, and milk production by dairy cows through a meta-analysis. *J. Dairy Sci.* 96:533–550.
- Grant, R. J., V. F. Colenbrander, and D. R. Mertens. 1990. Milk fat depression in dairy cows: Tole of silage particle size. *J. Dairy Sci.* 73:1834–1842.
- Innovation Center for US Dairy. 2013. U.S. Dairy's Environmental Footprint. Accessed Dec. 12, 2016. <https://www.usdairy.com/~media/usd/public/dairysenvironmentalfingerprintbrochure-july.pdf>.
- Khota, W., S. Pholsen, D. Higgs, and Y. Cai. 2016. Natural lactic acid bacteria population of tropical grasses and their fermentation factor analysis of silage prepared with cellulase and inoculant. *J. Dairy Sci.* 99:9768–9781.
- Lammers, B. P., D. R. Buckmaster, and A. J. Heinrichs. 1996. A simple method for the analysis of particle sizes of forage and total mixed rations. *J. Dairy Sci.* 79:922–928.
- Lee, C., and A. N. Hristov. 2013. Short communication: Evaluation of acid-insoluble ash and indigestible neutral detergent fiber as total-tract digestibility markers in dairy cows fed corn silage-based diets. *J. Dairy Sci.* 96:5295–5299.
- Mengesha, M. H. 1966. Chemical composition of teff (*Eragrostis tef*) compared with that of wheat, barley and grain sorghum. *Econ. Bot.* 20:268–273.
- Mesfin, R., and I. Ledin. 2004. Comparison of feeding urea-treated teff and barley straw based diets with hay based diet to crossbred dairy cows on feed intake, milk yield, milk composition and economic benefits. *Livest. Res. Rural Dev.* 16.
- Miller, D. 2011. Teff grass: Crop overview and forage production guide. Accessed Feb. 1, 2017. <http://teffgrass.com/wp-content/themes/tg/downloads/TeffGrassManagementGuide.pdf>.
- Mullins, C. R., K. N. Grigsby, D. E. Anderson, E. C. Titgemeyer, and B. J. Bradford. 2010. Effects of feeding increasing levels of wet corn gluten feed on production and ruminal fermentation in lactating dairy cows. *J. Dairy Sci.* 93:5329–5337.
- National Research Council (NRC). 2001. Nutrient Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Sci., Washington, DC.
- Osborn, D. F., R. A. Terry, G. E. Outen, and S. B. Cammell. 1976. The significance of a determination of cell walls as the rational basis for the nutritive evaluation of forages. *Proc. XII Int. Grassl. Congr., Moscow, Russia.* 3:374–380.
- Raffrenato, E., and M. E. Van Amburgh. 2010. Development of a mathematical model to predict sizes and rates of digestion of a fast and slow degrading pool and the indigestible NDF fraction. Page 52 in *Proc. Cornell Nutr. Conf. Feed Manuf.*, Syracuse, NY. Cornell University, Ithaca, NY.
- Rezac, D. J., K. N. Grigsby, N. M. Bello, and B. J. Bradford. 2012. Effects of varying rates of tallgrass prairie hay and wet corn gluten feed on productivity of lactating dairy cows. *J. Dairy Sci.* 95:842–849.
- Roseberg, R. J., B. A. Charlton, S. Norberg, J. Kugler. 2006. Yield and forage quality of six teff seed brands grown in three Pacific Northwest environments. *Klamath Exp. Stn. 2006 Annu. Rep.* 31–45.
- Roseberg, R. J., S. Norberg, J. Smith, B. Charlton, K. Rykbost, and C. Shock. 2005. Yield and quality of teff forage as a function of varying rates of applied irrigation and nitrogen. *Klamath Exp. Stn. 2005 Annu. Rep.* 119–136.
- Saylor, B. A. 2017. Drought-tolerant teff grass as an alternative forage for dairy cattle. MS Thesis. Kansas State Univ., Manhattan.
- Schukken, Y. H., D. J. Wilson, F. Welcom, L. Garrison-Tikofsky, and R. N. Gonzalez. 2003. Monitoring udder health and milk quality using somatic cell counts. *Vet. Res.* 34:579–596.
- Stanier, W. B., J. R. Bussard, N. M. Repard, M. H. Hall, and A. O. Burk. 2010. Voluntary intake and digestibility of teff hay fed to horses. *J. Anim. Sci.* 88:3296–3303.
- USDA. 2016. Crop production 2015 summary. USDA National Agricultural Statistics Service, Washington, DC.
- Van Soest, P. J. 1982. Nutritional Ecology of the Ruminant. O & B Books Inc., Corvallis, OR.
- Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, non-starch polysaccharides in relation to animal nutrition. *J. Dairy Sci.* 74:3583–3597.
- Wildman, E. E., G. M. Jones, P. E. Wagner, R. L. Boman, H. F. Troutt, and T. N. Lesch. 1982. A dairy cow body condition scoring system and its relationship to selected production characteristics. *J. Dairy Sci.* 65:495–501.
- Yang, W. Z., and K. A. Beauchemin. 2007. Altering physically effective fiber intake through forage proportion and particle length: Chewing and ruminal pH. *J. Dairy Sci.* 90:2826–2838.
- Young, A., E. Creech, D. ZoBell, C. Israelsen, and J. Eun. 2014. Integrating Teff into Livestock Operations. Utah State Univ. Febr. 2014 Ext. Rep.