COMPARISON OF TWO DIFFERENT GRAZING SYSTEMS INCORPORATING COOL AND WARM SEASON FORAGES FOR ORGANIC DAIRY CATTLE

A THESIS

SUBMITTED TO THE FACULTY OF

UNIVERSITY OF MINNESOTA

BY

KATHRYN ELIZABETH RUH

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF MASTER OF SCIENCE

ADVISOR BRADLEY J. HEINS

JANUARY, 2017

ACKNOWLEDGEMENTS

There are many people who have contributed to the work involved in carrying out research for this thesis and for supporting me during my time in graduate school. First, I believe it is important to acknowledge those who motivated and encouraged me to pursue a Master's degree and played important roles in my interest in Dairy Nutrition and in the projects I chose to pursue. These people include my undergraduate professor, Dr. Dave Combs, and the many graduate students I met and worked with, especially Dr. Fernanda Lopes, during my undergraduate career at the University of Wisconsin-Madison. It has been fun catching up with all of you at conferences and random coffee shops throughout my graduate school career. I also want to thank the lab manager of the Dairy Nutrition lab at UW-Madison, Sandy Bertics, for instilling in me the sense of safe laboratory practices and detailed research techniques which have been crucial in my graduate research.

Thank you to Dr. Brad Heins for being a wonderful Master's adviser and being encouraging but not demanding about finishing projects. Thank you for the invitations to Pizza Ranch and family dinners (and a big thank you to Joni who didn't always know she would have extra dinner guests but was always a wonderful hostess). Thank you also for your guidance in my future and assistance in finding a job after grad school.

Thank you to Darin Huot and all the workers at the WCROC, for their help with cows and forages in the grazing studies, and to Jason Leonard at the Saint Paul Dairy Barn for his help taking care of my donor cow for the fermenter study. Thank you to Marshall Stern for the use of his lab for the continuous culture rumen fermenter portion of my research. Thank you also to all those who have welcomed me into their labs to use various machines including Rob Gardner, Marcia Hathaway, and Adrian Stec.

My graduate school experience was enriched by my time spent living at the West Central Research and Outreach Center, and I appreciated the extensive help with forage sample and cow data collection as well as the camaraderie of research interns during my time there. Therefore, thank you to the interns at the WCROC including Ruby Richardson, Marilyn Lewis, Doriane Dodin, and especially to Laura Yourd for being a huge help with forage sample collection and grinding, and to Jacqui Mueller for her constant enthusiasm, and hard work.

Thank you to all the grad students who helped me throughout grad school, and especially to Isaac Salfer for welcoming and encouraging me to attend graduate student events when I first came to the U of M, but mostly for being so incredibly helpful with my endless questions about the fermenters and lab techniques, long-distance from Pennsylvania. Thank you to Hannah Phillips who was a huge help for forage sample and cow data collection, and even did her best to help with fermenter sample collection, and to Glenda Pereira for her help with fermenter sample collection and visiting me at the guest house in Morris while I was a hermit writing this thesis. Thank you to Haley Larson and Trent Dado for helping me in the fermenter lab. Thank you to all the friends I have made during my time in graduate school for their contributions to my graduate school experience: Lee Kloeckner, Kelly Froehlich, Georgina Cousillas, Mauricio Rosales, Amanda Grev, Devan Catalano, Mike Donnelly, Christina Fehrman, Brittany Shonka-Martin, Kirsten Sharpe, and Justin Siewert. Thank you to my awesome roommate, Megan Nelson, for being my Wisconsin Badger buddy in this land of Minnesota Gophers.

Thank you to my new husband Nicholas for participating in this long-distance relationship while I have been in grad school. Thank you so much for supporting my decision to pursue a Master’s degree, helping me work through crazy research adventures and frustrations, and helping me prepare for presentations.

ABSTRACT

Two pasture systems with enhanced in-field and landscape level species diversity were analyzed for yield, forage quality, and mineral characteristics across the grazing season at the West Central Outreach and Research Center organic dairy in Morris, MN from 2013 to 2015. System 1 was a diverse-mixture of cool season grasses and legumes. System 2 was the same combination of perennial grasses and included warm season annual grasses (BMR sorghum-sudangrass (*Sorghum* × *drummondii;* **BMRSS**) and teff (*Eragrostis tef*) grass). Organic dairy cows (n = 90) of Holstein and crossbred genetics were used to evaluate the effect of the two pasture systems on milk production, milk components (fat, protein, MUN, SCS), body weight, body condition score (BCS), and activity and rumination (min/d). The rumen fermentation of BMRSS, teff, cool season perennial pastures, and alfalfa were also studied using a dual flow continuous culture rumen fermentation system.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS i
ABSTRACT iii
TABLE OF CONTENTS iv
LIST OF TABLES vii
Manuscript 1 vii
Manuscript 2: viii
Manuscript 3: ix
INTRODUCTION 1
Organic dairy production in the United States 1
Pasture management 2
Pasture herbage mass and allowance 4
Forage quality of pastures 6
Cool season perennial pastures 9
Warm season grasses 10
Sorghum sudangrass 11
Teff grass 12
Cows in grazing systems 12
Milk production of cows on pasture 14
Dual flow continuous culture rumen fermentation system 16
REFERENCES 20
Manuscript 1 36
Forage quality and herbage mass of two different pasture systems incorporating cool season and warm season forages for grazing organic dairy cattle. 36
Interpretive Summary 36
ABSTRACT 37
INTRODUCTION 39
MATERIALS AND METHODS 41
Pasture Establishment 41

Weather Data 42
Cattle Grazing of Pastures 43
Forage samples 43
Statistical analysis 44
RESULTS AND DISCUSSION 45
Weather Data 45
Forage production by system 46
Forage quality across grazing season 46
Forage Quality by year 48
Forage Quality for CSP and WSA by month 49
Forage Quality for CSP, BMR sorghum-sudangrass and teff grass 51
CONCLUSION 54
ACKNOWLEDGEMENTS 54
REFERENCES 55
Manuscript 2 67
Milk production, body measurements, activity, and rumination of organic dairy cattle grazing two different pasture systems incorporating cool and warm season forages. 67
Interpretive Summary 67
ABSTRACT 68
INTRODUCTION 70
MATERIALS AND METHODS 72
Experimental Design and Grazing Management 72
Milk Production, BW, and BCS 75
Activity and Rumination 75
Weather Data 76
Statistical analysis 76
RESULTS AND DISCUSSION 77
Milk production between systems 77
BW, BCS, rumination, activity 79
CONCLUSIONS 81
ACKNOWLEDGEMENTS 82

REFERENCES 82
Manuscript 3 99
Dual flow continuous culture fermentation of organic brown midrib sorghum-sudangrass and teff grass to determine digestibility of forages in an organic dairy grazing system. . 99
Interpretive Summary 99
INTRODUCTION 101
MATERIALS AND METHODS 102
Experimental Design and Treatments 102
Continuous culture operation 104
Sample collection and analysis 105
Statistical Analysis 106
RESULTS AND DISCUSSION 107
Digestibility 107
Volatile Fatty Acids 109
CONCLUSION 115
ACKNOWLEDGEMENTS 116
REFERENCES 117
COMPREHENSIVE REFERENCES 128

LIST OF TABLES

Manuscript 1

Table 1. Weather data for 2013-2015 collected from the West Central Research and Outreach Center, Morris, MN weather station……………………………………………..62

Table 2. Least squares means and standard errors for forage quality characteristics of cool season perennial and warm season annual forage species……………………….63

Table 3. Least squares means and standard errors for forage quality characteristics of cool season perennial and warm season annual forage species for each specific grazing year………………………………………………………………………………… 64

Table 4. Least square means for forage quality characteristics of cool season forage species and warm season forage species for each month across grazing season...65

Table 5. Least squares means and standard errors for forage quality characteristics for each cool season perennial, BMR sorghum sudangrass (BMRSS), and Teff grass across the grazing season………………………………………………………...66

Manuscript 2:

Table 1. Weather data for 2014-2015 collected from the West Central Research and Outreach Center, Morris, MN weather station..94

Table 2. Least squares means and standard errors for milk production, milk components, and SCS across the grazing season for organic dairy cows grazing alternative forage systems..95

Table 3. Least squares means and standard errors for milk production, milk components, and SCC across the grazing season for specific forages within alternative forage systems for organic dairy cows…………………………………………………….96

Table 4. Least squares means and standard errors for body weight, BCS, and rumination and activity across the grazing season for organic dairy cows grazing alternative forage systems………………………………………………………………………97

Table 5. Least squares means and standard errors for body weight, BCS, rumination and activity across the grazing season for specific forages within alternative forage systems for organic dairy cows……………………………………………………..**Error! Bookmark not defined.**

Manuscript 3:

Table 1. Chemical composition (% DM) of four forage diets (alfalfa, cool season perennial pasture, BMR sorghum sudangrass, and teff grass) used in continuous culture fermentation……………………………………………………………124

Table 2. Nutrient digestibility and pH of four forage diets (alfalfa, cool season perennial pasture, BMR sorghum sudangrass, and teff grass) during continuous culture fermentation…………………………………………………………………125

Table 3. Volatile fatty acid production of four forage diets (alfalfa, Cool season perennial pasture, BMR sorghum sudangrass, and teff grass) in continuous culture fermentation…………………………………………………………………126

Table 4. Nitrogen metabolism of four forage diets (alfalfa, cool season perennial pasture, BMR sorghum sudangrass, and teff grass) in continuous culture fermentation..**Error! Bookmark not defined.**

INTRODUCTION

Organic dairy production in the United States

There has been a recent increase in consumer demand of organic products due to interest in sustainable farming practices and animal welfare concerns associated with conventional dairy farming (Sorge et al., 2016). The total sale of organic products in the United States was $6.2 billion in 2015, and sale of organic products increased 13% from 2014 to 2015 (USDA-NASS, 2016). In particular, organic dairy production is one of the fastest growing organic industries, and the number of organic dairy farms continues to increase. Milk was the top commodity in organic sales in 2015 with $1.2 billion in sales (USDA-NASS, 2016).

All aspects of organic production are thoroughly regulated by the United States Department of Agriculture. The recent Organic Pasture Rule clarified existing pasture regulations for ruminant livestock, now stating that all ruminant livestock must graze pasture for at least 120 days of the year and that at least 30% of their dry matter intake must come from pasture. Farmers must have a documented pasture management plan and pastures must be managed as a crop to meet the feed requirements for grazing livestock as well as to protect soil and water quality (USDA-AMS, 2010). Organic crop production standards require that soil fertility and crop nutrients be managed through tillage and cultivation practices, crop rotations, and cover crops, supplemented with animal and crop waste materials (Rinehart and Baier, 2011). Chemical herbicides and pesticides, as well as most synthetic fertilizers are prohibited for crop production. In organic livestock production, synthetic growth hormones like rBST, and antibiotics including medications and ionophores are prohibited from use. If antibiotics are required to treat a sick animal, treatment may not be withheld, but once an animal has been treated, it is no longer considered organic. Organic farmers must therefore focus on forage quality and availability of pasture to maintain or increase milk production and must implement management strategies aimed to prevent diseases.

The Midwest is an important region for organic dairy production in the United States. A survey of organic dairy farms in Wisconsin concluded that organic dairies had smaller herd sizes and lower milk production per cow, and also were more likely to use intensive grazing, but did not differ on many management parameters when compared to conventional farmers (Sato, 2005). Another study in Wisconsin which surveyed organic farms also found that organic dairy farms differ in size, breeds used, production, and income over feed costs (Hardie, 2014). An economic study in Minnesota showed that organic dairies may contribute to the economy more than conventional dairies (O'Hara et al., 2013). Organic production in the Midwest has specific challenges. With an already limited grazing season due to harsh winters, Midwestern farmers must make the most of the grazing season in order to meet the pasture requirements for organic certification. Pasture management is therefore an important skill for organic dairy farmers in the Midwest. Because of the chemical fertilizer and herbicide restrictions imposed on organic dairy farmers and the regulations about pasture use for dairy production, organic dairy farmers are more likely to practice good pasture management than non-organic dairy farmers (Hafla et al., 2013).

Pasture management

Like any other crop, pasture forages may be affected by factors including management and weather events including drought, excessive rain, ambient air and soil temperature, soil quality and moisture. Methods to help extend the length of the grazing season as well as to maintain or increase the quality of the forages in pasture are extremely useful for organic dairy producers. Feed is the greatest cost associated with milk and meat production, so when grazed forage can replace purchased grain or forage, the input cost on dairies may be decreased (White et al., 2002). Efficient pasture and grazing management may help to decrease feed costs for farmers (Peyraud and Delagarde, 2013). In addition, there may be lower input costs for pasture-based dairies than confinement dairies, such as labor, facilities, and machinery. Organic dairies in Minnesota have greater returns to labor for a given level of sales than conventional dairy farms (O'Hara, 2013).

Several management practices have been found to improve performance of pastures. Rotational grazing has been found to increase pasture production, as well as increase animal performance. The amount of rest between grazing events can be important to forage quality, yield, and sustainability. A study by Oates (2011) showed that cool season grasses are especially sensitive to the timing and frequency of grazing (Oates et al., 2011). Forages in a management intensive rotational grazing system had greater forage quality that more consistently met the high nutritive value needs of dairy cows than grasses in a continuously grazed pasture system (Oates, 2011). Complementary grazing systems involve rotating cattle among different pasture species based on the different growth and development patterns of the grasses (Jung, 1985). For example, farmers may graze a cool season grass in spring, then a warm season grass in summer. Complementary grazing systems utilizing cool and warm grasses in a sequential rotation can be beneficial for grazing cows because they may have more available forage in pasture throughout the grazing season. This would ultimately be beneficial to farmers who could effectively extend the grazing days of their herd and have less need to supplement cows with stored forage in summer. This type of system may also be beneficial to the sustainability of the pastures involved, depending on management, because it may provide cool season grass ample rest between grazing events (Moore et al., 2004).

Enhancing forage species diversity is one way to increase forage production and reduce weeds in pastures (Sanderson et al., 2005). This is an especially important pasture management strategy for organic producers, as they are prohibited from using herbicides for weed management. Incorporating legumes in grass systems is another important way to increase forage production and create a sustainable pasture yield, as well as to improve nutritive value of pastures. The systematic use of legumes is a promising strategy to increase the nutrient inputs into a pasture system and lessen the effects of nutrient and quality variations due to weather (Peyraud and Delagarde, 2013). Grass-legume mixtures had further improved forage yield and quality when forbs like chicory were included in pastures for grazing dairy cows (Pembleton, 2016).

Pasture herbage mass and allowance

Pasture herbage mass and pasture allowance are important parameters to manage in a grazing system to ensure a healthy and sustainable pasture system, optimal forage yield, and maximal animal performance. Medium herbage mass and low pasture allowance in a rotational grazing system resulted in higher milk production and more grazing days per hectare compared to high herbage mass and pasture allowance (McEvoy et al., 2009). Grazing cows at lower herbage mass resulted in more grazing days, higher crude protein and higher organic matter digestibility of forage in pastures than when cows grazed at higher herbage mass (Curran, 2010).

Accurate estimates of available pasture are important in order to properly manage the amount of feed available to grazing cows, and also to compare results from grazing studies. The recommended best estimate of actual available pasture in a ryegrass based pasture is a measurement of 2-3 cm above the ground (Perez-Prieto and Delagarde, 2012). There are several tools available to farmers to measure the pasture availability (Piggot, 1989) and dry matter intake throughout the grazing season. Dry matter intake is directly related to milk production and the potential dry matter intake is directly affected by the availability of dry matter in pasture (Maher, et al., 2003). Perhaps the simplest way to estimate the available herbage mass in pasture is to clip samples of forage and determine the dry matter. Dry matter intake and pasture dry matter intake estimates are important for effectively managing dairy grazing systems (Vazquez and Smith, 2000). These clipping samples can also be used to test forage quality of pastures, which can be important for monitoring grazing animal nutrition. In a survey of organic dairy herds in Minnesota, very few organic herds used clippings to analyze pasture quality and allowance (Sorge, 2016). Another method to determine pasture dry matter availability is to use a rising plate meter that measures and records the height of the grass, and may also estimate the dry matter availability when calibrated. A meta-analysis looked at different approaches of measuring pasture availability and found some discrepancies in the current research due to differences in measuring techniques, such as the height at which forage samples were clipped (Vazquez and Smith, 2000). The authors concluded that it is important to use similar measurements of pasture availability when comparing results of pasture availability (Vazquez and Smith, 2000). Using different heights as measurement can drastically affect pasture estimates in terms of dry matter availability and forage quality. A grazing study performed by Hudson et al., (2010) assumed that the estimate of dry matter availability in grazed pastures using a calibrated rising plate meter was more accurate than the dry matter clipping, but noted that there are times that it is not possible to use rising plate meter including during excessive wind or rain (Hudson et al., 2010).

Forage quality of pastures

Dry matter intake is affected by fiber content of the diet, and content of NDF, ADF, and digestibility. The amount of physically effective fiber is important for maintaining milk production and rumen health (Allen, 1996). Fiber can be described by NDF (hemicellulose, cellulose and lignin) and ADF (cellulose and lignin) and digestibility. Forages that are higher in NDF or ADF may cause more rumen fill, and decreased DMI (Allen, 2000). Total tract NDF digestibility (TTNDFD) is a measurement of NDF digestibility that uses an in vitro method to predict the digestibility of a feed (Lopes, 2015). The TTNDFD is a better representation of the quality of forage than simply using NDF and ADF values to compare feeds because the digestibility between two forages may be different even with similar NDF and ADF values. A study comparing diets of similar NDF and CP, but different NDF digestibility, found that higher NDF digestibility resulted in higher DMI and milk production (Oba and Allen, 1999). De Veth and Kolver (2001) suggested that the performance of cows grazing high quality pasture may not be limited by a lower physically effective fiber, based on a continuous culture study which did not find different fermentation performance even at a lower pH for a pasture only diet (De Veth and Kolver, 2001). The authors suggested that this result may have been a function of higher digestibility of fiber components in the pasture forage (De Veth and Kolver, 2001).

Crude protein (CP) is another important component of forage quality. The recommended CP for lactating cow diets is 16-18% (NRC, 2001). The CP of cool season grasses can be very high, especially in the early part of the grazing season. Previous grazing studies have found pasture CP to be about 25% (Bargo et al., 2003; Soder et al., 2010;). A study from Wisconsin determined that the optimal CP which maximized milk production while limiting the amount of N excreted in dairy cows was 16.5% CP (Colmenero and Broderick, 2006). Milk nitrogen efficiency decreases as dietary CP increases (Huhtanen et al., 2008). High protein diets may cause metabolic stress, as an animal must use energy to process and excrete nitrogen from excess protein (Milano et al., 2000). Evidence of this can be observed in greater milk urea nitrogen as dietary CP increases (Broderick, 2003). High protein diets have been associated with decreased milk yield, as well as changes in protein and fat concentrations in milk. A study looking at the effect of concentrate supplementation in grazing cows found lower MUN and higher milk production in supplemented cows (Bargo et al., 2002a). A combination of pasture and TMR also resulted in a diet that produced lower MUN and greater milk fat and protein percentages (Bargo et al., 2002b).

Mineral composition is important in cattle diets because cows have different mineral requirements at different stages of lactation. For grazing cows, minerals already available in the soil can cause toxicities or may cause other minerals to be limiting, if pastures are not monitored carefully. Mineral concentration of pasture forages fluctuates throughout the grazing season (Jones and Tracy, 2013). In addition, heavy manure application could lead to high phosphorus levels. Some grasses are high in potassium, which could be a potential problem for grazing herds, as high potassium diets for dry cows have been shown to cause milk fever after calving. Even though organic producers generally focus on disease prevention, a survey conducted in Minnesota found that organic farmers were actually less likely to monitor potassium levels in dry cow diets than conventional farmers (Sorge et al., 2016). However, a New Zealand study of mineral composition of pastures suggested that because of fluctuations in the ratio of potassium / (calcium+magnesium) and in calcium/phosphorus across the grazing season, the amount of potassium may not be great enough or sustained for enough time to pose a serious problem to grazing cattle (Metson and Saunders, 1978).

One reason that managing a grazing system for dairy cows is so challenging is because forage quality of pastures fluctuates across the grazing season due to weather (Tozer et al., 2003) and growth patterns of the plants (Peyraud and Delagarde 2013). Dairy cows perform better with more consistent diets. The harsh winter conditions in the Midwestern U.S. increase the variation in pasture-based cow diets because of the need to switch to a TMR diet in the winter (Hardie et al., 2014). A study conducted in North Carolina, which kept cows on pasture during the winter, noted extreme variability in the amount of pasture and supplement in the pasture cow diets during winter (White et al., 2002). A study compared high and low energy diets of winter TMR and pasture and found delayed effects of winter feeding strategies for grazing dairy systems, but also determined that cows have the ability to adapt production and tissue mobilization when presented with different diets (Delaby et al., 2009). Confinement systems have a less variable feed supply than grazing systems because they are not as affected by weather events. In addition, conventional farmers are more likely to use a nutritionist to formulate rations and provide feeding advice (Stiglbauer et al., 2013).

Cool season perennial pastures

Many grazing producers in the Midwestern United States use cool season grasses as their main pasture forage. Cool season perennial grasses typically have high nutritive quality and forage production in pasture, which is desirable for dairy cow diets. However, the specific growth pattern of cool season grasses means there is decreased forage production during times of high temperature and low precipitation, commonly known as the "summer slump" (Undersander et al., 2004).

One common method of pasture management to increase production of cool season pastures is to include legumes in cool season grass pastures. This has been shown to increase pasture forage production, improve sustainability of pastures from year to year and across the grazing season, and increase the protein content of cool season pastures. Legumes fix nitrogen from the atmosphere which provides more nitrogen to the cool season perennial grasses. This makes it easier and more efficient for farmers to manage cool season pastures without needing to physically apply nitrogen for maintenance of the cool season pastures. In addition, legumes have slightly different growth patterns than many cool season grasses and experience a peak in production later in the season than most cool season grasses. This may compensate somewhat for the lower forage production by the cool season grasses during the summer slump.

Warm season grasses

Warm season grasses are gaining interest in the Upper Midwest because their growth pattern overlaps the growing season and highest production of the cool season grasses most typically used for grazing (Najda, 2003). Some farmers may be reluctant to incorporate warm season annual grasses into their grazing system because of concerns about the reduced forage quality of these grasses. It is widely accepted that warm season grasses have lower forage quality, including lower nonstructural carbohydrates and crude protein and higher NDF content than cool season grasses (Barbehenn et al., 2004). One grazing study found overall lower forage quality of switchgrass and big bluestem to mixed cool season pastures, and concluded that warm season grasses lose forage quality more rapidly over the grazing season (Moore, 2004). Another study incorporating the warm season grasses switchgrass and big bluestem found that cows grazing cool season only pastures had access to forage with higher crude protein and lower NDF and ADF concentration for most of the grazing season (Hudson et al., 2010). A study that compared low-quality cool season grass to warm season grass found greater digestible DM and NDF in cool season grass, even though both types of grass had similar CP, NDF, and ADF levels (Bohnert et al., 2011).

For producers with the goal of providing most of a cow's diet through pasture forage, warm season grasses may still be beneficial despite the potentially lower forage quality than that of cool-season grasses. In some years, and in times of drought, warm season grasses performed well (Moore, 2004). In another study, warm season grasses in had similar CP to cool season grasses in July and August (Tracy, 2010). The animal response to grazing warm season versus cool season grass is not clear and is heavily dependent on management and weather.

Sorghum sudangrass

There has been interest by grazing producers in the Upper Midwest to utilize sorghum, sudangrass, and their hybrids as feed for dairy cattle (McCartney et al., 2009; Tracy et al., 2010; White et al., 2002). Sorghum and sudangrass and their hybrids are desired for their persistent yield in drought conditions in mid to late summer when perennial cool season grasses become dormant (Undersander et al., 2000). Brown midrib (BMR) sorghum, sudangrass, and their hybrids have lower lignin and higher digestibility than their normal counterparts (Cherney et al., 1991; Fritz et al., 1990). The BMR sorghum sudangrass (BMRSS) silage studied in dairy diets was reported to elicit similar lactation performance compared to cows on a diet including corn silage (Dann et al., 2008). The BMRSS silage also had similar organic matter digestibility as corn silage in the diets (Dann et al., 2008). However, there has been little research evaluating the forage quality of BMRSS as pasture forage for grazing dairy cattle.

Sorghum sudangrass is associated with a risk of prussic acid poisoning but this can be avoided with adequate grazing management. Sorghum sudangrass should not be grazed when less than 45 cm in height (Griggs et al., 2008). After a frost event or extreme drought, sorghum sudangrass should not be grazed for 2 weeks. Sorghum sudangrass has the potential to have high nitrate accumulation and could lead to nitrate toxicity in grazing livestock (Koch and Paisley, 2002). Stored forages like hay and silage of harvested sorghum sudangrass do not have the high prussic acid properties that are found in fresh pasture, and ensiling also reduces nitrate levels of forage.

Teff grass

Teff grass (*Eragrostis tef*) originated in Ethiopia and is extremely tolerant to high temperatures and drought. It has been used as an emergency crop for cattle (Hunter et al., 2007), but is typically fed as hay or straw for livestock in drought conditions. Teff is also relatively popular as forage for horses in the form of hay or pasture grass (Staniar et al., 2010). Several studies have looked at the forage quality and growing parameters of teff hay (Norberg et al., 2009; Hunter et al., 2009; Griggs et al., 2008), but there is very limited research on teff as pasture forage for grazing dairy cattle.

Cows in grazing systems

Grazing systems, including organic dairy systems, utilize a variety of cattle breeds and herds often include crossbred cattle. A survey of Wisconsin organic dairy farms found that important breeds included Holstein, Jersey, Milking Shorthorn, Brown Swiss, and Jersey and Normande (Hardie et al., 2014). Another survey in Wisconsin which compared organic farms to conventional farms determined that organic farmers have a preference for non-Holstein and mixed breeds, including Jersey, Brown Swiss, and Guernsey (Sato et al., 2005). A study in Minnesota found that pure Holstein cows had significantly greater 305 day milk production than Montbeliarde, Normande, and Swedish Red crossbreds, but Swedish Red-Holsteins had similar fat production to Holsteins (Heins et al., 2006). A study conducted in Ireland found that crossbreeds of Montbeliarde-Holstein and Normande-Holstein had similar milk production to pure Holsteins (Walsh et al., 2008). Another study in Ireland found a higher persistence of milk yield in Montbeliarde and Normande cows compared to two strains of Holsteins, and concluded that the non-Holstein breeds experience less physical stress in early lactation (Dillon et al., 2003).

There are many challenges for grazing cattle that cattle in confinement systems may not experience. Pasture based diets are lower in energy than confinement diets. High producing or high-net merit cows may not meet their energy requirements from grazing alone (Peyraud, 2013). Some farmers may try to overcome this by supplementing energy through concentrates or a partial TMR to cows on pasture. A study that compared pasture plus concentrate, TMR, or pasture plus a partial TMR diet found that animal performance was improved from the pasture plus concentrate to the pasture plus TMR diet (Bargo et al., 2002). However, supplementing concentrates and TMR may limit the efficiency of utilizing pasture forage as feed (Vibart et al., 2010). It is important for grazing cows to be able to walk long distances to and from the milking parlor and while grazing through the pasture. This has been proposed as one reason that grazing cattle may have lower prevalence of lameness than confined cows, but may also further expend energy in animals already consuming a low energy diet. A difference in milk production between pasture and TMR feeding systems has been attributed to a difference in energy maintenance requirements including additional walking and grazing energy requirements for grazing cows, as well as a lower energy intake on pasture (Bargo et al., 2002). Grazing cows will be exposed to the elements and weather conditions they may experience include wind, rain, excessive heat and sun in the summer, and freezing temperatures and snow in the winter. The harsh weather conditions that grazing cattle can be exposed to may decrease milk production (Sjostrom et al., 2015). A study in Europe found that cows decreased milk production with high thermal heat index, wind speed, and precipitation (Hill and Wall, 2015). Many lactating cows on pasture do not have access to shade or cooling mechanisms like fans or sprinklers compared to conventional cows (Sorge et al., 2016). Because of the nutritional and environmental challenges in a grazing system, cows in these systems may have lower body condition scores and lower body weight than cows in confinement systems, which can lead to lower milk production. In one study, lower BCS and BW were found in cows on organic farms than conventional farms in spring, but were similar again in September (Sato et al., 2005). Another survey study found that organic farms were less likely than conventional farms to have cows with a BCS >4.5 on a 5 point scale (Bergman et al., 2014). Body condition score, body weight, and body weight change can have a significant effect on milk production (Roche, 2007).

Milk production of cows on pasture

There is interest from consumers about potential health benefits of dairy products from cows raised organically because of their higher access to pasture (Schwendel et al., 2015). Cows that graze have higher levels of omega-3 fatty acids in their milk, which has been shown to have many benefits to human health (Benbrook et al., 2013). A study conducted in the United Kingdom found higher omega-3 fatty acid and polyunsaturated fatty acid content in organic milk than conventional milk (Ellis et al., 2006). A nationwide study in the United States found that organic milk contained 25% less omega-6 fatty acids and 62% more omega-3 fatty acids than conventional milk (Benbrook et al., 2013). Conjugated linoleic acid content of milk produced from cows grazing pasture was higher than that of cows supplemented with concentrate on pasture (Bargo et al., 2006).

Milk production may be lower for cows in grazing systems than from cows in confinement systems. As discussed previously, this can be due to the variety of breeds typically used in grazing systems, amount of forage available in pasture, and weather challenges. An additional factor that could directly affect milk production of cows on pasture is inconsistent pasture quality across the grazing season. Cows with consistent diets produce more milk than cows with inconsistent diets. Cows in grazing systems have more energy expenditure than cows in confinement systems, as they must walk further distances to and from the parlor each day, as well as walking while they graze (Fontaneli, 2005). The NRC accounts for grazing energy requirements, but it is still difficult to measure actual intake of cows on pasture (NRC, 2001). In addition, cows in grazing systems often consume higher dietary CP than cows in confinement systems because cool season grasses in pasture are often high in CP. This could cause cows to use more energy to excrete excess nitrogen and not as much of that energy goes to milk production, which is part of the reason that carbohydrate supplementation is beneficial to grazing cattle performance (Bargo et al., 2002 a.) Cows may also be selecting for a different diet than the total pasture available to them. One grazing study found that cows selected nutrients with higher digestibility and higher CP than were offered in pasture, which can lead to seasonal nutrient imbalances in the diet (Wales et al., 1999).

Income over feed cost of pasture-based dairies can be similar to that of confinement dairy farms because of reduced input costs for feed, shelter, and labor (White et al., 2002). Depending on the market, organic dairies may also see higher profits than conventional dairies due to a premium paid for organic milk (Hardie et al., 2014). Pasture cows produced 11.1% less milk, but also had lower feed costs than in a confinement system, resulting in a similar income over feed cost for the two systems (White et al., 2002). In a study conducted in Florida, cows in freestalls produced 19% more milk than cows on pasture, but also had 20% higher feed costs, resulting in a similar income over feed cost for both systems (Fontaneli et al., 2005). A survey study comparing management of organic and conventional farms in the U.S. reported significantly different milk production between organic cows on pasture, conventional cows on pasture, and conventional cows in a confinement system, most likely because conventional farmers tend to feed more grain than organic producers (Stiglbauer et al., 2013).

Dual flow continuous culture rumen fermentation system

In vitro laboratory techniques have long been used to simulate the rumen fermentation that would take place in a cow in order to more easily and cheaply estimate the effect that certain feeds may have on ruminal fermentation and animal performance (Tilley and Terry, 1963; Goering and Van Soest, 1970; Hoover et al., 1976). A continuous culture rumen fermenter system uses rumen fluid inoculum from a cannulated cow as the source of microbes to simulate a rumen (Stern et al., 1997). Dual flow continuous culture rumen fermenters are a reliable method to simulate results of rumen fermentation (Hoover et al., 1976). Defaunation occurs in most continuous culture systems, meaning that protozoa from the original inoculant are flushed from the system (Hannah et al., 1986). This may cause a discrepancy in the results seen in the lab compared to those found in an animal. However, in one study investigating VFA production and absorption, defaunation did not have an effect on VFA proportions (Djikstra et al., 1994). As with all in vitro systems, the goal of a continuous culture system is to provide preliminary results that will compare treatments in a relatively similar environment to the model system, in order to predict whether further research in a live animal or with additional products is warranted.

A dual flow continuous culture rumen fermenter has been shown to provide a reasonable estimate of rumen fermentation, with similar true OM degradability, crude protein degradability, and amino acid degradability (Hannah et al., 1986). However, results presented by Mansfield et al., (1995) indicate that dual flow continuous culture rumen fermentation systems may have a difficult time simulating fermentation of total nonstructural carbohydrates (Mansfield et al., 1995). A dual flow continuous culture rumen fermentation system allows for sampling of individual outflow fractions by regulating separate outflows for the solid and liquid fractions (Hoover et al., 1976). Input of synthetic saliva and outflows of solid and liquid fractions of outflowing material are regulated based on flow rates estimated from in situ rumen fermentation studies (Crawford et al., 1980; Hannah et al., 1986). Flow rates determine the amount of time a feed will be retained in the rumen and the amount of time to potentially be degraded by microbes in the rumen. A study using a diet of 60% concentrate and 40% forage compared various liquid dilution rates and pH levels while maintaining a constant solid dilution rate and found that a pH of 6.5 was optimal for fiber and organic matter digestibility regardless of liquid dilution rate (Hoover et al., 1984).

Digestibility of feed is affected by factors such as amount of potentially digestible amount of the feed, flow rate, pH, and amounts of different nutrients in the diet. Another important measurement is microbial efficiency, which is a measurement of how much protein is utilized by bacteria for their own use and can be useful for interpreting results of nitrogen use efficiency. Bach et al., (1999) found that better use of nitrogen by rumen microbes resulted in greater microbial nitrogen flow and higher fiber digestion. Volatile fatty acid (VFA) production can also provide insight on the process of fermentation, including information about acetate to propionate. One study performed on in vivo systems concluded that total VFA production may not be a good indication of treatment effects on ruminal fermentation (Hall et al., 2015). Therefore, proportions of individual VFAs are often used when interpreting results from an in vitro fermentation. For example higher fiber degradation is associated with a higher molar proportion of acetate to propionate (Van Soest, 1994) while a higher concentrate diet may be associated with a higher molar proportion of propionate to butyrate (Castillejos et al., 2005).

The pH is an important factor during fermentation that can affect protein and fiber degradation, and some continuous culture systems are able to regulate pH. A continuous culture rumen fermenter study researching effects of pH levels for pasture diets determined that the optimal pH for high quality pasture forage is 6.35 (de Veth and Kolver, 2001). A low pH that strays may cause the loss of certain microbial species, such as the elimination of fibrolytic bacteria from the system (Russell and Dumbrowski, 1980) and fermentation results may be affected, including lower fiber degradation and VFA production (Calsamiglia et al., 2002). A study by Bargo et al., (1995) shows an inverse correlation between pH patterns and VFA production. Low pH can also affect N flow rates and may increase microbial protein synthesis (Calsamiglia et al., 2002). A study that compared different patterns of suboptimal pH for 4, 8, or 12 hours total, determined that the total time at low pH is what affects overall ruminal fermentation and that splitting the time at suboptimal pH into fragments does not alter negative outcomes (Cerrato-Sanchez et al., 2007).

REFERENCES

Allen, M. S. (2000). Effects of diet on short-term regulation of feed intake by lactating dairy cattle. *Journal of Dairy Science*, *83*(7), 1598–1624. http://doi.org/10.3168/jds.S0022-0302(00)75030-2

Barbehenn, R. V., Chen, Z., Karowe, D. N., & Spickard, A. (2004). C3 grasses have higher nutritional quality than C4 grasses under ambient and elevated atmospheric CO2. *Global Change Biology*, *10*(9), 1565–1575. http://doi.org/10.1111/j.1365-2486.2004.00833.x

Bach, a, Yoon, I. K., Stern, M. D., Jung, H. G., & Chester-Jones, H. (1999). Effects of type of carbohydrate supplementation to lush pasture on microbial fermentation in continuous culture. *Journal of Dairy Science*, *82*(1), 153–160. http://doi.org/10.3168/jds.S0022-0302(99)75219-7

Bargo, F., Muller, L. D., Delahoy, J. E., & Cassidy, T. W. (2002a). Milk Response to Concentrate Supplementation of High Producing Dairy Cows Grazing at Two Pasture Allowances. *Journal of Dairy Science*, *85*(7), 1777–1792. http://doi.org/10.3168/jds.S0022-0302(02)74252-5

Bargo, 2002 Bargo, F., Muller, L. D., Varga, G. a, Delahoy, J. E., & Cassidy, T. W. (2002b). Ruminal digestion and fermentation of high-producing dairy cows with three different feeding systems combining pasture and total mixed rations. *Journal of Dairy Science*, *85*(11), 2964–2973. http://doi.org/10.3168/jds.S0022-0302(02)74381-6

Bargo, F., Varga, G. a, Muller, L. D., & Kolver, E. S. (2003). Pasture intake and substitution rate effects on nutrient digestion and nitrogen metabolism during continuous culture fermentation. *Journal of Dairy Science*, *86*(4), 1330–1340. http://doi.org/10.3168/jds.S0022-0302(03)73718-7

Bargo, F., Delahoy, J. E., Schroeder, G. F., & Muller, L. D. (2006). Milk fatty acid composition of dairy cows grazing at two pasture allowances and supplemented with different levels and sources of concentrate. *Animal Feed Science and Technology*, *125*(1-2), 17–31. http://doi.org/10.1016/j.anifeedsci.2005.05.010

Bergman, M. A., Richert, R. M., Cicconi-Hogan, K. M., Gamroth, M. J., Schukken, Y. H., Stiglbauer, K. E., & Ruegg, P. L. (2014). Comparison of selected animal observations and management practices used to assess welfare of calves and adult dairy cows on organic and conventional dairy farms. *Journal of Dairy Science*, *97*(7), 4269–4280. http://doi.org/10.3168/jds.2013-7766

Benbrook, C. M., Butler, G., Latif, M. A., Leifert, C., & Davis, D. R. (2013). Organic production enhances milk nutritional quality by shifting fatty acid composition: A United States-wide, 18-month study. *PLoS ONE*, *8*(12). http://doi.org/10.1371/journal.pone.0082429

Bohnert, D. W., DelCurto, T., Clark, a a, Merrill, M. L., Falck, S. J., & Harmon, D. L. (2011). Protein supplementation of ruminants consuming low-quality cool- or warm-season forage: differences in intake and digestibility. *Journal of Animal Science*, *89*(11), 3707–17.

Broderick, G. A. (2003). Effects of varying dietary protein and energy levels on the production of lactating dairy cows. *Journal of Dairy Science*, *86*(4), 1370–81. http://doi.org/10.3168/jds.S0022-0302(03)73721-7

Calsamiglia, S., Ferret, a, & Devant, M. (2002). Effects of pH and pH fluctuations on microbial fermentation and nutrient flow from a dual-flow continuous culture system. *Journal of Dairy Science*, *85*(3), 574–579. http://doi.org/http://dx.doi.org/10.3168/jds.S0022-0302(02)74111-8

Cerrato-Sánchez, M., Calsamiglia, S., & Ferret, a. (2007). Effects of patterns of suboptimal pH on rumen fermentation in a dual-flow continuous culture system. *Journal of Dairy Science*, *90*(9), 4368–4377. http://doi.org/10.3168/jds.S0022-0302(07)71634-X

Cherney, J.H., Cherney, D.J.R., Akin, D.E. and Axtell, J.D. (1991) Potential of Brown-Midrib Low-Lignin Mutants for Improving Forage Quality. *Advances in Agronomy*, 46, 157-198.

Colmenero, J. J. O., & Broderick, G. A. (2006). Effect of dietary crude protein concentration on milk production and nitrogen utilization in lactating dairy cows. *Journal of Dairy Science*, *89*(5), 1704–1712.

Crawford, R. J., Hoover, W. H., & Knowlton, P. H. (1980). Effects of Solids and Liquid Flows on Fermentation in Continuous Cultures . I . Dry Matter and Fiber Digestion, VFA Production and Protozoa Numbers. *Journal of Animal Science*, *51*(4), 975–985.

Curran, J., Delaby, L., Kennedy, E., Murphy, J. P., Boland, T. M., & O'Donovan, M. (2010). Sward characteristics, grass dry matter intake and milk production performance are affected by pre-grazing herbage mass and pasture allowance. *Livestock Science*, *127*(2-3), 144–154. http://doi.org/10.1016/j.livsci.2009.09.004

Dann, H.M., R.J. Grant, K.W. Cotanch, E.D. Thomas, C.S. Ballard, and R. Rice. (2008). Comparison of brown midrib sorghum-sudan- grass with corn silage on lactational performance and nutrient digestibility in Holstein dairy cows. *J. Dairy Sci*. 91:663–672.

Delaby, L., Faverdin, P., Michel, G., Disenhaus, C., & Peyraud, J. L. (2009). Effect of different feeding strategies on lactation performance of Holstein and Normande dairy cows. *Animal*, *3*(JUNE 2009), 891–905. http://doi.org/10.1017/S1751731109004212 de Veth, M. J., & Kolver, E. S. (2001). Digestion of ryegrass pasture in response to change in pH in continuous culture. *Journal of Dairy Science*, *84*(6), 1449–1457. http://doi.org/10.3168/jds.S0022-0302(01)70178-6

Dijkstra, J. (1994). Production and absorption of volatile fatty acids in the rumen. *Livestock Production Science*, *39*(1), 61–69. http://doi.org/10.1016/0301-6226(94)90154-6

Dillon, P., Buckley, F., O'Connor, P., Hegarty, D., & Rath, M. (2003). A comparison of different dairy cow breeds on a seasonal grass-based system of milk production. 1. Milk production, live weight, body condition score and DM intake. *Livestock Production Science*, *83*(1), 21–33. http://doi.org/10.1016/S0301-6226(03)00041-1

Ellis, K. a, Innocent, G., Grove-White, D., Cripps, P., McLean, W. G., Howard, C. V, & Mihm, M. (2006). Comparing the Fatty Acid Composition of Organic and Conventional Milk. *Journal of Dairy Science*, *89*(6), 1938–1950. http://doi.org/10.3168/jds.S0022-0302(06)72261-5

Fritz, J.O., Moore, K.J. and Jaster, E.H. (1990) Digestion Kinetics and Cell Wall Composition of Brown Midrib Sorghum x sudangrass Morphological Components. *Crop Science*, 30, 213-219.

Fontaneli, R. S., Sollenberger, L. E., Littell, R. C., & Staples, C. R. (2005). Performance of lactating dairy cows managed on pasture-based or in freestall barn-feeding systems.

Journal of Dairy Science, *88*(3), 1264–1276. http://doi.org/10.3168/jds.S0022-0302(05)72793-4

Griggs, T.C., Drake, D. R., Parkinson, S.C. (2008). Production and Quality of warm-season annual forage grasses. *Proceedings, Idaho Alfalfa and Forage Conference,* 26-27 February 2008.

Goering, H. K., Van Soest, P.J., (1970). Forage fiber analyses (apparatus, reagents, prcedures, and some applications). Agric. Handbook.

Hafla, A. N., MacAdam, J. W., & Soder, K. J. (2013). Sustainability of US organic beef and dairy production systems: Soil, plant and cattle interactions. *Sustainability (Switzerland)*, *5*(7), 3009–3034.

Hannah, S. M., Stern, M. D., & Ehle, F. R. (1986). Evaluation of a dual flow continuous culture system for estimating bacterial fermentation in vivo of mixed diets containing various soya bean products. *Animal Feed Science and Technology*, *16*(1-2), 51–62. http://doi.org/10.1016/0377-8401(86)90049-0

Hardie, C. A., Wattiaux, M., Dutreuil, M., Gildersleeve, R., Keuler, N. S., & Cabrera, V. E. (2014). Feeding strategies on certified organic dairy farms in Wisconsin and their effect on milk production and income over feed costs. *Journal of Dairy Science*, *97*(7), 4612–23.

Hardeng, F., & Edge, V. L. (2001). Mastitis, ketosis, and milk fever in 31 organic and 93 conventional Norwegian dairy herds. *Journal of Dairy Science*, *84*(12), 2673–2679. http://doi.org/10.3168/jds.S0022-0302(01)74721-2

Heins, B. J., Hansen, L. B., & Seykora, A. J. (2006). Production of Pure Holsteins versus crossbreds of Holstein with Normande, Montbeliarde, and Scandinavian Red. *Journal of Dairy Science*, *89*(7), 2799–804. http://doi.org/10.3168/jds.S0022-0302(06)72357-8

Hill, D. L., & Wall, E. (2015). Dairy cattle in a temperate climate: the effects of weather on milk yield and composition depend on management. *Animal*, *9*(01), 138–149. http://doi.org/10.1017/S1751731114002456

Hoover, W. H., Crooker, B.A. and Sniffen, C.J. (1976). Effects of differential solid-liquid removal rates on protozoa numbers in continuous cultures of rumen contents. *Journal of Animal Science,* 43:528–534

Hoover, W., Kincaid, C. R., Varga, G. A., Thayne, W. V., & Junkins, Jr., L. L. (1984). Effects of solids and liquid flows on fermentation in continuous cultures. IV. pH and dilution rate. *Journal of Animal Science*, *54*(3), 849–854. http://doi.org/10.2134/jas1984.583692x

Hudson, Leep, Dietz, Ragavendron, Kravchenko, (2010). Integrated Warm- and Cool Season Grass and Legume Pastures: I. Seasonal Forage Dynamics. *Agronomy Journal, 102 (1), 303-309.*

Huhtanen, P., Nousiainen, J. I., Rinne, M., Kytölä, K., & Khalili, H. (2008). Utilization and partition of dietary nitrogen in dairy cows fed grass silage-based diets. *Journal of Dairy Science*, *91*(9), 3589–3599.

Hunter, M., P. Barney, T. Kilcer, J. Cherney, J. Lawrence, and Q. Ketterings. 2007. Teff as Emergency Forage. Cornell Univ. Cooperative Extension Agronomy Fact Sheet 24, http://nmsp.css.cornell.edu/publications/factsheets/factsheet24.pdf.

Hunter, M., Ketterings, Q. M., Cherney, J. H., Barney, P., Kilcer, T., & Godwin, G. (2009). Nitrogen Needs of Teff Managed as Forage Crop in New York. *Fg*, *7*(1), 5–6.

Jones, G. B., & Tracy, B. F. (2013). Evaluating seasonal variation in mineral concentration of cool-season pasture herbage. *Grass and Forage Science*, *70*(1), 94–101.

Jung, G.A., J.L. Griffin, R.E. Kocher, J.A. Shaffer, and C.F. Gross. (1985). Performance of Switchgrass and Bluestem Cultivars Mixed with Cool-Season Species. *Agronomy Journal* 77(6): 846-850.

Koch, D.W., and S. Paisley. 2002. Managing Forages to Minimize Nitrate Poisoning. Univ. of Wyoming Cooperative Extension Publ. B-1122.8, http://ces.uwyo.edu/PUBS/B1122-8.pdf.

Lopes, F., Ruh, K., Combs D. (2015).Validation of an approach to predict total-tract fiber digestibility using a standardized in vitro technique for different diets fed to high-producing dairy cows. *Journal of Dairy Science.* 98(4) 2596-2602

Maher, J., Stakelum, G., Rath, M. (2003). Effect of daily herbage allowance on the performance of spring calving dairy cows. Ir. J. Agric. Food Res. 42:229–241

Mansfield, H. (1995). Comparison of microbial fermentation in the rumen of dairy cows and dual flow continuous culture. *Animal Feed Science and Technology*, *55*(1-2), 47–66. http://doi.org/10.1016/03778-4019(59)82028-

McCartney, D., Fraser, J., Ohama, A., (2009). Potential of warm-season annual forages and Brassica crops for grazing: A Canadian Review. *Canadian Journal of Animal Science*, 89(4): 431-440

McEvoy, M., O'Donovan, M., Kennedy, E., Murphy, J. P., Delaby, L., & Boland, T. M. (2009). Effect of pregrazing herbage mass and pasture allowance on the lactation performance of Holstein-Friesian dairy cows. *Journal of Dairy Science*, *92*(1), 414–422. http://doi.org/10.3168/jds.2008-1313

Metson, A. J., & Saunders, W. M. H. (1978). Seasonal variations in chemical composition of pasture. 1. Calcium, magnesium, potassium, sodium, and phosphorus. *New Zealand Journal of Agricultural Research*, *21*(2), 341–353. http://doi.org/10.1080/00288233.1978.10427419

Milano, G. D., A. Hotston-Moore, and G. E. Lobley. (2000). Influence of hepatic ammonia removal on ureagenesis, amino acid utilization and energy metabolism in the ovine liver.
Br. J. Nutr. 83:307–315.

Moore, K. J., White, T. A., Hintz, R. L., Patrick, P. K., & Brummer, E. C. (2004). Sequential grazing of cool- and warm-season pastures. *Agronomy Journal*, *96*(4), 1103–1111.

Najda, H. 2003. Sorghum, sudangrass, and sorghum-sudangrass hybrids for forage. Alberta Agriculture, Food and Rural Development. Edmonton, AB. Agdex 126 20:1.

Norberg, S., (2009). Teff, A new warm season annual grass for Oregon. *Oregon State University Extension Service*.

NRC. (2001). Nutrient Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Press, Washington, DC.

Oates, L. G., Undersander, D. J., Gratton, C., Bell, M. M., & Jackson, R. D. (2011). Management-intensive rotational grazing enhances forage production and quality of subhumid cool-season pastures. *Crop Science*, *51*(2), 892–901. http://doi.org/10.2135/cropsci2010.04.0216

Oba, M., & Allen, M. S. (1999). Evaluation of the importance of the digestibility of neutral detergent fiber from forage: effects on dry matter intake and milk yield of dairy cows. *Journal of Dairy Science*, *82*(3), 589–596. http://doi.org/10.3168/jds.S0022-0302(99)75271-9

O'Hara, J., & Parsons, R. (2013). The economic value of organic dairy farms in Vermont and Minnesota. *Journal of Dairy Science*, *96*(9), 6117–6126. http://doi.org/10.3168/jds.2013-6662

Perez-Prieto, L. a, & Delagarde, R. (2012). Meta-analysis of the effect of pregrazing pasture mass on pasture intake, milk production, and grazing behavior of dairy cows strip-grazing temperate grasslands. *Journal of Dairy Science*, *95*(9), 5317–5330. http://doi.org/10.3168/jds.2012-5609

Pembleton, K. G., Hills, J. L., Freeman, M. J., Mclaren, D. K., French, M., & Rawnsley, R. P. (2016). More milk from forage: Milk production, blood metabolites, and forage intake of dairy cows grazing pasture mixtures and spatially adjacent monocultures. *Journal of Dairy Science*, *99*(99), 1–17 (in press). http://doi.org/http://dx.doi.org/10.3168/jds.2015-10542

Peyraud, J. L., & Delagarde, R. (2013). Managing variations in dairy cow nutrient supply under grazing. *Animal : An International Journal of Animal Bioscience*, *7 Suppl 1*(2013), 57–67. http://doi.org/10.1017/S1751731111002394

Piggot, G. J. (1989). A comparison of four methods for estimating herbage yield of temperate dairy pastures. *New Zealand Journal of Agricultural Research*, *32*(1), 121–123. http://doi.org/10.1080/00288233.1989.10423486

Rinehart, B. L., & Baier, A. (2011). Pasture for Organic Ruminant Livestock : *United States Department of Agriculture, National Center for Appropriate Technology, National Sustainable Agriculture Information Service (ATTRA); Washington DC, USA*.

Roche, J. R., Lee, J. M., Macdonald, K. A., & Berry, D. P. (2007). Relationships Among Body Condition Score , Body Weight , and Milk Production Variables in Pasture-Based Dairy Cows. *Journal of Dairy Science*, *90*(8), 3802–3815. http://doi.org/10.3168/jds.2006-740

Sato, K., Bartlett, P. C., Erskine, R. J., & Kaneene, J. B. (2005). A comparison of production and management between Wisconsin organic and conventional dairy herds. *Livestock Production Science*, *93*(2), 105–115. http://doi.org/10.1016/j.livprodsci.2004.09.007

Schwendel, B. H., Morel, P. C. H., Wester, T. J., Tavendale, M. H., Deadman, C., Fong, B., Otter, D. E. (2015). Fatty acid profile differs between organic and conventionally produced cow milk independent of season or milking time. *Journal of Dairy Science*, *98*(3), 1411–1425. http://doi.org/http://dx.doi.org/10.3168/jds.2014-8322

Sjostrom, L. S. (2015). Alternative Housing and Management for Organic Dairy Production. MS Thesis. University of Minnesota, St. Paul. http://hdl.handle.net/11299/178916

Sanderson, M. A., Soder, K. J., Muller, L. D., Klement, K. D., Skinner, R. H., & Goslee, S. C. (2005). Forage mixture productivity and botanical composition in pastures grazed by dairy cattle. *Agronomy Journal*, *97*(5), 1465–1471. http://doi.org/10.2134/agronj2005.0032

Soder, K. J., & Gregorini, P. (2010). Relationship Between Supplemental Protein and Ruminal Fermentation of an Herbage Diet. *The Professional Animal Scientist*, *26*, 290–297. http://doi.org/10.15232/S1080-7446(15)30596-9

Sorge, U. S., Moon, R., Wolff, L. J., Michels, L., Schroth, S., Kelton, D. F., & Heins, B. (2016). Management practices on organic and conventional dairy herds in Minnesota. *Journal of Dairy Science*, *99*(4), 3183–92. http://doi.org/10.3168/jds.2015-10193

Staniar, W. B., Bussard, J. R., Repard, N. M., Hall, M. H., & Burk, A. O. (2010). Voluntary intake and digestibility of teff hay fed to horses. *Journal of Animal Science*, *88*(10), 3296–3303. http://doi.org/10.2527/jas.2009-2668

Stern, M. D., Bach, a, Calsamiglia, S., Stern, M. D., Bach, A., & Calsamiglia, S. (1997). Alternative techniques for measuring nutrient digestion in ruminants. *Journal of Animal Science*, 75:2256–2276.

Stiglbauer, K. E., Cicconi-Hogan, K. M., Richert, R., Schukken, Y. H., Ruegg, P. L., & Gamroth, M. (2013). Assessment of herd management on organic and conventional dairy farms in the United States. *Journal of Dairy Science*, *96*(2), 1290–300. http://doi.org/10.3168/jds.2012-5845

Tilley, J. M. A., and R. A. Terry. (1963). A two-stage technique for the in vitro digestion of forage crops. J. Br. Grassl. Soc. 18:104–111

Tracy, B. F., Maughan, M., Post, N., & Faulkner, D. B. (2010). Integrating annual and perennial warm-season grasses in a temperate grazing system. *Crop Science*, *50*(5), 2171–2177. http://doi.org/10.2135/cropsci2010.02.0110

Tozer, P. R., Bargo, F., & Muller, L. D. (2003). Economic analyses of feeding systems combining pasture and total mixed ration. *Journal of Dairy Science*, *86*(3), 808–18. http://doi.org/10.3168/jds.S0022-0302(03)73663-7

Undersander, D., Smith, L. H., Kaminiski, A. R., Kelling, K. A. and Doll, J. D. (2000). Sorghum Forage. In Alternative field crops manual. University of Wisconsin-Extension, Cooperative Extension, Madison, WI.

US Department of Agriculture, National Agricultural Statistics Service. (2016). Certified Organic Survey 2015 Summary.

http://usda.mannlib.cornell.edu/usda/current/OrganicProduction/OrganicProduction-09-15-2016.pdf

US Department of Agriculture, Agricultural Marketing Service. (2010). National Organic Program: Access to Pasture (Livestock). 7 CFR part 205. Fed. Regist. 75:7154-7195

Wales, W. J., Doyle, P. T., Stockdale, C. R., & Dellow, D. W. (1999). Effects of variations in herbage mass, allowance, and level of supplement on nutrient intake and milk production of dairy cows in spring and summer. *Australian Journal of Experimental Agriculture*, *39*(2), 119–130. http://doi.org/10.1071/EA98151

Walsh, S., Buckley, F., Pierce, K., Byrne, N., Patton, J., & Dillon, P. (2008). Effects of breed and feeding system on milk production, body weight, body condition score, reproductive performance, and postpartum ovarian function. *Journal of Dairy Science*, *91*(11), 4401–4413. http://doi.org/10.3168/jds.2007-0818

White, S.L., Benson, G.A., Washburn, S.P., Green, Jr., J.T. (2002). Milk Production and Economic Measures in Confinement or Pasture Systems Using Seasonally Calved Holstein and Jersey Cows. J. Dairy Science. 85:95-104.

Van Soest, P. J. (1994). Nutritional ecology of the ruminant. Cornell University Press, Ithaca, NY

Vazquez, O. P., & Smith, T. R. (2000). Factors Affecting Pasture Intake and Total Dry Matter Intake in Grazing Dairy Cows. *Journal of Dairy Science*, *83*(10), 2301–2309. http://doi.org/10.3168/jds.S0022-0302(00)75117-4

Manuscript

Forage quality and herbage mass of two different pasture systems incorporating cool season and warm season forages for grazing organic dairy cattle.

Interpretive Summary

Organic cattle must graze pasture 120 days of the year and 30% of their DMI must come from pasture. The forage quality and herbage mass of two warm season annuals, brown midrib sorghum-sudangrass and teff grass, were compared to cool season perennial pastures in two grazing systems for organic dairy cows. Warm season annual grasses had similar forage quality, but lower crude protein, than cool season perennial pasture. Warm season annual grass had higher herbage mass than cool season perennial pasture.

ABSTRACT

Two pasture systems (cool season perennial and warm season annual grass species) with enhanced in-field and landscape level species diversity were analyzed for yield, forage quality, and mineral characteristics across the grazing season at the West Central Outreach and Research Center organic dairy in Morris, MN from 2013 to 2015. System 1 was a diverse-mixture of cool season grasses and legumes [perennial ryegrass (*Lolium perenne*), white clover (*Trifolium repens*), red clover (*Trifolium pretense*), chicory (*Cichorium intybus*), orchardgrass (*Dactylis glomerata*), meadow bromegrass (*Bromus biebersteinii*), alfalfa (*Medicago sativa*), meadow fescue (*Festuca pratensis*)]. System 2 was a combination of the same perennial grasses and legumes as System 1, but included annual-warm season grasses (brown midrib sorghum-sudangrass (BMRSS) and teff grass). Grazing of lactating cows was initiated when forages were 20-30 cm tall and strip size was adjusted to leave 7-13 cm of refusals. Three random samples of pasture forage were clipped every two days, before grazing, in a 0.23 m^2 square of pasture when a group of cows moved to a new paddock. Forage samples were sent to Rock River Laboratory, Inc., Watertown, WI and were analyzed with NIR spectrophotometry for DM, crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), and total tract NDF digestibility (TTNDFD). Data were analyzed using the MIXED procedure of SAS. Independent variables for analyses were the fixed effects of system (1: cool season perennial pasture or 2: cool season perennial pasture and warm season annual grasses), month (June to October), forage (perennial cool season pasture, BMRSS or teff), year (2013, 2014, 2015) and their interactions, and date of harvest was a random variable. Herbage mass was greater in system 2 (2,788 kg DM/ha) than system 1(2,259

kg DM/ha), due to greater herbage mass for warm season grasses (3,088 kg DM/ha) than cool season perennials (2,228 kg DM/ha) across the grazing season. The BMRSS had greater yield (3,455 kg DM/ha) compared to cool season pasture (2,228 kg DM/ha) and teff grass (2,722 kg DM/ha). The CP for cool season pasture was 20.9% in 2013, 23.2% in 2014, and 24.7% in 2015. The CP for warm season annual grass was 14.6% in 2013, and 18.9% in 2014, and 20.5% in 2015. The TTNDFD was 63.8% in 2013, 48.0% in 2014, 51.9% in 2015 for cool season pasture, and 59.3% in 2013, 46.3% in 2014, and 59.0% in 2015 for warm season annual grass. In summary, yearly effects, soil fertility, and weather patterns may affect forage quality in for both cool season perennial pasture and warm season annual grasses.

INTRODUCTION

The profitability of grazing dairy farms relies on pastures that produce a large quantity of high-quality forage for cattle to graze, as well as increased milk production per cow or production per acre of pasture. The DMI, and ultimately milk production, is controlled by pasture allowance (Maher et al., 2003). In the upper Midwest, cool season grass and legume species are the traditional pasture forages for many dairy grazing producers. However, cool season perennial (CSP) pasture species experience a decreased growth rate, or “summer slump,” during periods of high temperatures and low precipitation, such as are observed in July and August in the upper Midwest (Moore et al., 2004; Hudson et al., 2010). Warm season annual (WSA) grasses have been suggested as a potential solution to maintain pasture production and to overlap this decreased cool season forage biomass production during the warmest parts of summer (Najda, 2003). Incorporating WSA grass into a grazing system provides an opportunity to rest CSP when growth conditions are limiting and to add flexibility to the grazing system (Moore et al., 2004).

Some farmers may be reluctant to incorporate WSA grasses into their grazing system because of concerns about potentially reduced forage quality of these grasses. It is widely proposed that warm season grasses may have lower forage quality, including lower CP and higher NDF content than cool season grasses. (Bohnert et al., 2011; Hudson et. al., 2010; Moore et al., 2004; Pederson et al., 1996; Tracy et al., 2010; Weichenthal et al., 2003). Because forage quality is an important component of the diet for dairy cattle (Hafla et al., 2013), it is important for grazing producers to consider how

WSA may be utilized in grazing systems and if the potential for increased pasture herbage mass will compensate for the perceived lower forage quality.

There has been interest by grazing producers in the Upper Midwest and Northeast United States to utilize WSA, such as sorghum, sudangrass, and their hybrids as feed for dairy cattle (McCartney et al., 2009; Tracy et al., 2010; White et al., 2002). Sorghum and sudangrass and their hybrids are desired for their persistent yield in drought conditions in mid to late summer when CSP grasses may become dormant (Griggs et al., 2008). Brown midrib (BMR) sorghum, sudangrass, and their hybrids have lower lignin and higher digestibility than their sorghum and sudangrass, separately (Cherney et al., 1991; Fritz et al., 1990). A BMR sorghum×sudangrass (BMRSS) silage studied in dairy cattle diets was reported to elicit similar lactation performance compared to cows on a diet including corn silage. The BMRSS silage also had similar organic matter digestibility as corn silage in the diets (Dann et al., 2008). A study in Illinois found greater herbage mass from BMRSS than CSP in July and August but did not compare animal performance of BMRSS to CSP in a beef cow-calf grazing system (Tracy et al., 2010). However, there has been little research evaluating the forage quality of BMRSS as pasture forage for grazing dairy cattle. Additionally, there is limited research on using BMRSS and teff grass in a pasture system incorporating CSP and WSA in separate pastures in the Upper Midwest and Northeast United States.

Pasture based dairy production can potentially be an economically competitive management system, with some benefits including less labor, and lower investments in facilities, with comparable income over feed cost (White et al., 2002). Pasture is the primary source of forage for organic dairies and organic dairy cattle need at least 120 d of grazing, with 30% of their DMI coming from pasture according to the National Organic Pasture rule (USDA-AMS, 2010). An organic dairy producer must have a documented pasture management plan and pastures must be managed as a crop to meet the feed requirements for grazing livestock, as well as protect soil and water quality (USDA AMS, 2010). For grazing dairy herds, effective pasture management is crucial for maintaining the production and health of the animals grazing pasture.

Therefore, the objective of this study was to analyze the pasture herbage mass, forage quality characteristics, and mineral content of CSP pastures compared to WSA pastures containing BMRSS and teff in an organic grazing system for dairy cattle in the Upper Midwest.

MATERIALS AND METHODS

Pasture Establishment

The University of Minnesota West Central Research and Outreach Center is located in Morris, MN and has an organic dairy research herd with 130 lactating cows, as well as a conventional dairy research herd with 150 lactating cows. All aspects of organic production are thoroughly regulated by the USDA National Organic Program and certifying agencies (USDA AMS, 2010). Pastures in this study were managed organically and were fertilized with manure by grazing animals moving through paddocks throughout the grazing season. No additional fertilizer was used, and pastures were not irrigated.

The two grazing systems were: 1) **System 1;** diverse-mixture of CSP grasses and legumes [perennial ryegrass (*Lolium perenne*), white clover (*Trifolium repens*), red clover (*Trifolium pretense*), chicory (*Cichorium intybus*), orchardgrass (*Dactylis* *glomerata*), meadow bromegrass (*Bromus biebersteinii*), alfalfa (*Medicago sativa*), meadow fescue (*Festuca pratensis*)] 2) **System 2;** combination of CSP, as listed above, and WSA (BMRSS (*Sorghum × drummondii*) and teff (*Eragrostis tef*) grass). The CSP pastures were established in 2012. These species were chosen to optimize forage production in a cool season grazing system. There were a total of 46.4 hectares of t pasture utilized in this study. System 1 had 17.4 ha of CSP pasture, and System 2 had 11.9 ha CSP pastures and 17.1 ha WSA pasture. Grazing of CSP was initiated when pasture reached a height of 20 to 30cm tall and strip size was adjusted to leave 7 to 13 cm of refusals.

The WSA pastures (BMRSS and teff grass) were planted in individual paddocks on May 28 of 2013, 2014, and 2015. The BMRSS (Black Hawk 12 Organic, Blue River Hybrids, Ames, IA) was seeded at 22 kg/ha. Teff grass was seeded at 9 kg/ha. Both WSA species were planted at 16 to 18^{o} C soil temp and 2.54 cm to 3.8 cm deep. Pasture grasses were grown on loamy Hokans-Buse and Barnes-Buse soil. The BMRSS was allowed to grow at least 45 cm before grazing, in order to minimize risk of prussic acid poisoning (Griggs, 2008). Teff grass was grazed in a similar manner to the CSP, initiating grazing at 20 to 30 cm, and leaving 7 to 13 cm refusals. The resting time for each paddock was from 21 to 35 d.

Weather Data

Weather data was recorded daily at the University of Minnesota West Central and Outreach Center Weather station in Morris, MN. Weather data was reported as monthly high, low, and average monthly temperature and total monthly precipitation for the months of the grazing season and is reported in Table 1.

Cattle Grazing of Pastures

Ninety lactating Holstein and crossbred certified organic cows were used in this study to graze forages of the two pasture systems (3 replicates per system = 6 groups of cows on pasture) over three summer grazing seasons: May through October of 2013, 2014, and 2015. Cows were Holstein and crossbreeds of Holstein, Jersey, Normande, Swedish Red, and Montebeliarde. Cows were blocked in three replicates by breed, DIM, and parity, and randomly assigned to system, 1) System 1 or 2) System 2, as defined above. Free choice mineral was provided ad libitum and 2.3 kg ground corn was supplemented to cows to manage MUN levels.

Cows moved to a new paddock every two days, but the decision to move cows was based on the availability of grass in paddocks. There were 18 cows in each grazing group and stocking density was 0.51 hectare per cow. Cows in system 1 were always moved to a new paddock of CSP. In the case of System 2, the decision to move cows was based on the availability of WSA, so cows were either moved to a new CSP paddock or to a WSA paddock if BMRSS or teff were ready to be grazed. In System 2, each replicate grazing group was assigned a CSP and WSA pasture.

Forage samples

Forage samples from pastures were collected immediately before cows moved into a new replicate paddock, resulting in 3 to 4 sampling days per week per pasture. Three random samples were taken from each paddock by randomly throwing a 0.23 m^2 square into the pasture and clipping the forage within the square, to a height of 5 cm above ground. The three clipping samples were used to determine the DM and herbage mass for each sample. Dry matter was obtained by weighing the fresh clipping, drying samples for 48 hours at 60^{o} C and weighing the dry weight and using the equation: DM=dry sample/fresh sample*100. Samples from all collection days across the grazing season were used to analyze for herbage mass. Herbage mass (kg DM/ha) was determined from the DM. Herbage mass was only analyzed for 2014 and 2015 due to differences in sampling for 2013 compared to the other two years. The area of the pasture square was 0.000023 of a hectare. Dry matter samples were ground through a 2 mm screen (Model 4, Wiley Mill, Thomas Scientific). Samples were randomly chosen for forage quality analysis by selecting one of the three samples for each paddock from the first day of each week throughout the grazing season for each year. A total of 280 CSP, 69 BMRSS, and 26 teff grass samples were analyzed over the course of three grazing seasons. Ground samples were stored in plastic canisters before being analyzed by near infrared reflectance spectroscopy (NIR) at Rock River Laboratory, Inc. in Watertown, WI for forage quality characteristics. The ADF and NDF were analyzed using Ankom procedures (Ankom A2000, Method 12 and Method 13). Forage samples were measured using near-infrared reflectance spectroscopy using standard equations (Rock River Labs, Inc.). Mineral composition of forages was determined using wet chemistry with ICP-OES (Rock River Labs, Inc.). The total tract NDF digestibility (TTNDFD) procedures were carried out using validated in vitro procedures (Lopes, et al., 2015). Milk2006 values were analyzed using the technique of Shaver, (2006).

Statistical analysis

For the analysis of forage characteristics and mineral composition, the independent variables for analysis were the fixed effects of pasture type (CSP or WSA), month (June to October), forage species (CSP pasture, BMRSS or teff grass), year (2013, 2014, 2015) and the interaction of month nested in forage species by pasture type, month by pasture type, forage species nested within pasture type, year nested within pasture type, and year nested within forage species by pasture type. Individual pasture and date of harvest were random variables using the PROC MIXED procedure of SAS. For herbage mass, independent variables were grazing system (System 1 or System 2), month nested within forage species by system, forage species nested within system, year by system, and year nested within forage species by system. Replicate group was a random effect. Pasture samples collected in May were merged with the June samples because of the few samples collected only in the last week of May of each year. When significant ($P < 0.05$) effects due to pasture type were detected, mean separation was conducted by the PDIFF option in SAS.

RESULTS AND DISCUSSION

Weather Data

Months with the highest precipitation across the three years include June 2013, June 2014, August 2014, May 2015, and August 2015. The year of 2014 had low total precipitation during the months of the grazing season compared to the other years of the study. The driest months were August 2013, September 2014, October 2014 and September 2015. Typically, July and August were months with the highest temperatures and high humidity in all three years. The year with the highest average temperature during the months of the grazing season was 2015. The high temperatures and low precipitation of July and August may have challenged the CSP pastures. The diverse weather conditions between the three years of the study provide the opportunity to study the productivity of the pastures under different growing conditions.

Forage production by system

There was greater herbage mass ($P < 0.05$) in the pasture system incorporating WSA (2,788 kg DM/ha) than the system only consisting of CSP (2,259 kg DM/ha) (data not shown). Although pastures planted with WSA may not be in use for the entire grazing period, they provide additional pasture forage when CSP are dormant (Moore et al., 2004). For the current study, incorporating WSA into a grazing system may help extend the grazing season and help organic farmers to more readily comply with the organic pasture rule.

Forage quality across grazing season

Least square means and standard errors for forage quality across the grazing season are shown in Table 2. Average herbage mass across the grazing season was greater ($P < 0.01$) for WSA (3,088 kg DM/ha) than CSP (2,228 kg DM/ha). A previous study from Wisconsin reported lower forage yield (1,976 kg DM/ha) of CSP throughout the grazing season (Paine et al., 1999), compared to the current study. Possible reasons for the higher forage yield in the current study may include differences in weather, soil quality, grazing management, and forage species diversity. A study investigating herbage yield of ryegrass/clover pasture found similar results for forage yield (2,530 kg DM/ha) to the current study (Crush et al., 2006). Another study also found similar results for smooth bromegrass-based CSP pasture yield (2,352 kg DM/ha), and WSA yield (3,689 kg/ha) was greater than the CSP (Moore et al., 2004). Average dry matter percentage did not differ ($P = 0.44$) between CSP (23%) and WSA (22%).

Crude protein was greater ($P < 0.01$) in CSP (23%) than in WSA (18%). This is consistent with previous research that shows CSP has higher CP values than WSA, (Bohnert, 2011; Hudson, et. al., 2010; Moore, 2004; Tracy, 2010). The CP of CSP in the current study (23%) was higher than the CP of CSP found in some previous studies (Moore et al., 2004; Bainbridge et al., 2017; Hudson et al., 2010), but similar to other studies using CSP (Soder et al., 2006). The average CP for WSA in this study was 18% which meets the recommendation of 16 to18% CP in lactating dairy cow diets (NRC, 2001). A study from Wisconsin determined that the optimal CP that maximized milk production while limiting the amount of N excreted in dairy cows is 16.5% CP (Colmenero and Broderick, 2006). Milk nitrogen efficiency decreases as dietary CP increases (Huhtanen et al., 2008). Though CP results of WSA from the current study are still higher than the optimal CP level, the lower protein observed in the WSA compared to the CSP may be beneficial for the cows, because they may not expend as much energy on excreting excess nitrogen (Milano et al., 2000).

The NDF, ADF, TTNDFD, and Milk/Ton did not differ ($P > 0.1$) between CSP and WSA. The NDF values found for CSP (49.6%) in the current study are higher than some previous grazing studies (32.3% and 42.5%) (Soder et al., 2006; Bainbridge et al., 2017) but similar to results (38% to 54%) found by Hudson et al., (2010) and lower than results (60%) found by Moore et al., (2004). The ADF of CSP (32.2%) was greater than results reported for CSP (22%) by Soder et al., (2006) but similar to results (32.8%) reported by Bainbridge et al., (2017). While the current study found similar NDF and ADF for CSP and WSA, prior studies found that WSA had greater NDF and ADF values than CSP (Moore et al., 2004; Hudson et al., 2010; Bainbridge et al., 2017). Calcium content of forages did not differ ($P = 0.20$) between CSP (0.67%) and WSA (0.58%) pastures. Phosphorus, potassium, and magnesium were all greater ($P < 0.05$) in WSA than in CSP. Mineral contents of CSP were lower than results found in similar diverse mixtures of cool season pastures in a previous study (Soder et al., 2006).

Forage Quality by year

Results for forage quality of CSP and WSA by year are in Table 3. Herbage mass analysis by year only included 2014 and 2015 because there was incomplete herbage mass data for 2013. Herbage mass of CSP was greater ($P < 0.01$) in 2014 (2,440 kg DM/ha) than 2015 (2,016 kg DM/ha), but WSA produced similar ($P = 0.42$) yields in both 2014 and 2015 (2,950 kg DM/ha and 3,226 kg DM/ha). Weather may have had an important role in differences in forage production between years. Conditions in 2015 may have been challenging to CSP because of the higher average temperature that summer (Table 1). Another possible reason for the observed decreased forage production in CSP from one year to the next is that in 2015 a higher number of animals were included in the grazing groups at the start of the summer. These additional three animals per grazing group were removed from the study about two weeks into the grazing season, when it was determined that forages were being consumed too quickly. The increased grazing pressure in this year at the start of the grazing season could have slowed the regrowth of these CSP for the entire grazing season (McEvoy, 2009).

Crude protein was greater ($P < 0.05$) in CSP than WSA for all years. The NDF and ADF were variable across years, but were similar ($P > 0.05$) in CSP and WSA during 2015. The TTNDFD was different between CSP and WSA for 2013 (63.8%, 59.3%; $P = 0.04$) and 2015 (51.9%, 59.1%; $P = 0.05$), but was similar (48.0%, 46.3%; $P = 0.31$) between forages in 2014. Calcium, phosphorus, potassium, and magnesium content all varied between years for CSP and WSA. Fluctuations in forage quality in different years are expected because weather conditions are different from year to year. Previous studies also experienced yearly variations in results for both CSP and WSA (Soder et al., 2006; Tracy et al., 2010; Moore et al., 2004; Hudson et al., 2010).

Forage Quality for CSP and WSA by month

Least square means of forage quality of CSP and WSA across the grazing season by month are in Table 4. The CSP was the only grass in June due to the growth patterns of the different grass species. One limitation to using WSA in a grazing system is that for the early part of the season, those pastures are unavailable to grazing animals (Hudson et al., 2010). Both CSP and WSA experienced a decline in herbage mass as the grazing season progressed from spring to fall. The WSA had 26.8%, 32.8%, and 42.9% greater herbage mass than CSP for July, August, and September, respectively, which can be attributed to higher temperatures in these months. These results convey the potential for WSA to be used in dairy grazing systems to compensate for pasture herbage mass when CSP experience decreased growth. Similarly, in another study WSA produced greater herbage mass in August (4,576 kg DM/ha) than CSP (1,890 kg DM/ha) (Tracy et al., 2010). Conversely, unlike the current study, Tracy et al., (2010) found that CSP (2,190 kg DM/ha) and WSA (2,850 kg DM/ha) also had similar production in July.

The WSA had similar ($P = 0.14$) CP (20.0%) to CSP (21.6%) in July, although for the remainder of the grazing season, WSA had lower ($P < 0.01$) CP than CSP. Another study found no significant difference between CSP and WSA for CP for the summer months of July and August (Tracy et al., 2010). Values of CP for WSA in the current study (20% for July, 17% for August) were similar to values of CP found in a previous study (17% for July, 15% for August) (Tracy, et al., 2010), but values of CP for CSP in the previous study (14% for July and August) were much lower than in the current study (22% for July and August). Although overall CP is higher in CSP (Table 2), results of monthly CP values in WSA in the current study point to a promising future of using WSA in grazing systems in the Midwest because WSA would be most desired to graze during the summer months. The similar CP in CSP and WSA in July indicate that WSA have similar forage quality to CSP when they would be of most interest to the grazing system.

The NDF and ADF content of CSP and WSA were similar ($P > 0.05$) in July, but ADF of CSP was lower ($P < 0.01$) than WSA in August, and NDF and ADF of CSP were both lower ($P < 0.05$) than WSA in September. A previous study found higher ADF values for CSP (38.7%) than WSA (32.9%) in July, and similar values for CSP (35.8%) and WSA (34.5%) in August (Tracy et al., 2010). The same study found higher NDF values than were found in the current study for both CSP and WSA. The NDF was 67.5% for CSP and 64.9% for WSA in July, and 64.8% for CSP and 66.3% for WSA in August (Tracy, et al., 2010). The TTNDFD content of forages was greater ($P < 0.01$) in WSA than CSP in July, most likely due to the lower maturity of the WSA at this time of the grazing season. The mineral content of forages was generally high in the spring, decreased in the summer, and was high again in the fall. Similarly, Jones and Tracy (2013) found the patterns of mineral content in CSP to generally follow pattern of high content in spring, low content in summer, and high content again in the fall, following the pattern of grass maturity across the growing season.

Analysis of the CSP and WSA by month across the grazing season demonstrates that at certain times of the grazing season, WSA may be more favorable as pasture forage than CSP. During July especially, WSA had greater CP, higher herbage mass, and higher TTNDFD than CSP.

Forage Quality for CSP, BMR sorghum-sudangrass and teff grass

Least square means and standard errors for average forage quality of each forage species CSP, BMRSS, and teff grass are presented in Table 5. Herbage mass of BMRSS was greater ($P < 0.01$) than CSP, while teff was intermediate and similar to CSP ($P > 0.05$) and BMRSS ($P > 0.05$). Previous studies exploring sorghum-sudangrass yield have focused on its use as harvested forage (Venuto and Kindiger, 2008) which makes it difficult to compare to yield achieved in a grazing study. Studies that have reported yields of sorghum-sudangrass or other WSA in a grazing system have used different heights of sample harvest and different grazing schedules (Tracy et al., 2010; Moore et al., 2004) which also makes it difficult to compare yield in a grazing system. Dry matter was significantly lower in BMRSS (20.2%) than CSP (23.3%) and teff grass (24.6%).

Crude protein was significantly greater ($P < 0.01$) in the CSP (23%) than BMRSS (18.5%) and teff grass (17.5%). Similar CP values were reported for several BMRSS hybrids in New Zealand, 14.2% to 16.8% (Millner, et al., 2001). A range of 11% to 19% CP has been reported for teff grass (Hunter et al., 2009; Norberg, 2009), which corresponds to results from the current study. As discussed above, the crude protein of both BMRSS and teff grass used in this study averaged 18% and met the recommended 16 to 18% dietary protein requirements of a lactating dairy cow (NRC, 2001). A concurrent study found significantly lower MUN in cows grazing BMRSS than CSP or teff grass, which may indicate better nitrogen use efficiency and less metabolic stress from excess nitrogen (Ruh, et al., 2017).

The NDF, ADF, TTNDFD, and Milk/Ton did not differ (P > 0.05) between the forage species CSP, BMRSS, and teff grass. The BMRSS was similar to reported values of NDF (45 to 63%) and ADF (32 to 36%) (Griggs et al., 2008; Weichenthal et al., 2003; Millner et al., 2011). The NDF and ADF of teff in the current study (52% and 33%) are within the range found in Oregon and Washington (53-63% NDF and 28-43% ADF) and the range found in New York (62-65% NDF and 33-36% ADF) (Norberg, 2009; Hunter et al., 2009). Each of the forage species in this study had greater than 50% TTNDFD, which is the goal for good quality grass forages (Goeser, 2016).

Calcium did not differ ($P > 0.05$) between forage species. Phosphorus was greater ($P < 0.05$) teff grass (0.40%) than the CSP (0.33%) and BMRSS (0.34%). Potassium was greater ($P = 0.02$) in teff grass (3.71%) than cool season pasture forage (3.10%), but BMRSS (3.25%) was similar ($P > 0.05$) in potassium content to both CSP and teff grass. Normally, grasses with high potassium are monitored carefully when grazed by late lactation and dry cows, but organic producers are less likely than conventional producers to limit potassium levels in dry cow diets (Sorge et al., 2016). Further research may be needed to determine how management of grasses high in potassium affect cows in an organic grazing system. Magnesium was similar ($P = 0.43$) between BMRSS and teff grass, and both WSA had greater ($P < 0.01$) magnesium content than CSP.

This study demonstrated that WSA can be successfully grown and grazed in the Upper Midwest, but farmers should expect yearly and monthly variation. This study found similar forage quality for WSA and CSP, so farmers should feel confident when using WSA in a grazing system for dairy cows without worrying about sacrificing forage quality.

Farmers will ultimately need to consider what will work best for their grazing operation. One disadvantage of WSA in a grazing system is that the WSA do not provide forage until the middle of the grazing season. However, a system that incorporates WSA may provide more herbage mass across the whole grazing season. Therefore, farmers should determine whether they will have adequate CSP at the beginning of the grazing season to successfully graze their animals when WSA may not be available. Additional labor may be needed to plant WSA each year, manage more rotations of animals, and monitor BMRSS to prevent prussic acid and nitrate poisoning.

As reported in this study, high quality CSP pastures often have high protein content that may exceed dairy cattle nutrition requirements (Soder et al., 2006, Tozer et al., 2003; Peyraud and Delagarde, 2013). One of the most important things to keep dietary protein balanced in a dairy diet is to ensure the cows also have adequate energy in the diet. Grasses alone may not meet NRC energy requirements for cows, especially in order to keep energy in balance with the high protein available in grasses (Peyraud and Delagarde, 2013). One solution to this situation is to provide cows with grain or other concentrates as an energy source.

Economic analysis of WSA in pasture systems in the Midwest is needed. Although there may be a higher cost for seed and additional labor each year, there may be a greater benefit to including WSA, especially in years of drought. There is also a need for future research to estimate the optimal amount and different species of WSA incorporated in a grazing system. It may be useful to determine categories of organic and grazing farms that would achieve the greatest benefits from incorporating warm season grasses in their grazing system.

CONCLUSION

This study demonstrates that BMRSS and teff grass may be successfully grazed by organic dairy cattle and that WSA can provide favorable forage yields with similar nutritional quality to CSP. Warm season grasses may be beneficial forages to include in pastures for dairy grazing operations in the upper Midwest and have the potential to extend the grazing season without sacrificing forage quality. At certain times of the grazing season, WSA had higher yield and higher forage quality than CSP. The opportunity to extend the grazing season is extremely valuable for organic farmers and may make it easier to comply with the organic pasture rule, as well as make it easier to provide quality nutrition to animals in pasture.

ACKNOWLEDGEMENTS

The authors of this paper acknowledge Darin Huot and the workers at the West Central Research and Outreach Center that helped with grazing management and forage clippings that made this study possible. This study is based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award number 2012-51300-20015.

REFERENCES

Bainbridge, M. L., Egolf, E., Barlow, J. W., Alvez, J. P., Roman, J., & Kraft, J. (2017). Milk from cows grazing on cool-season pastures provides an enhanced profile of bioactive fatty acids compared to those grazed on a monoculture of pearl millet. *Food Chemistry*, *217*, 750–755. http://doi.org/10.1016/j.foodchem.2016.08.134

Bohnert, D. W., DelCurto, T., Clark, a, Merrill, M. L., Falck, S. J., & Harmon, D. L. (2011). Protein supplementation of ruminants consuming low-quality cool- or warm-season forage: differences in intake and digestibility. *Journal of Animal Science*, *89*(11), 3707–17.

Cherney, J.H., Cherney, D.J.R., Akin, D.E. and Axtell, J.D. (1991) Potential of Brown-Midrib Low-Lignin Mutants for Improving Forage Quality. *Advances in Agronomy*, 46, 157-198.

Colmenero, J. J. O., & Broderick, G. a. (2006). Effect of dietary crude protein concentration on milk production and nitrogen utilization in lactating dairy cows. *Journal of Dairy Science*, *89*(5), 1704–1712.

Crush, J., Woodward, S., Eerens, J., & MacDonald, K. (2006). Growth and milksolids production in pastures of older and more recent ryegrass and white clover cultivars under dairy grazing. *New Zealand Journal of Agricultural Research*, *49*(September), 119–135.

Dann, H.M., R.J. Grant, K.W. Cotanch, E.D. Thomas, C.S. Ballard, and R. Rice. (2008). Comparison of brown midrib sorghum-sudan- grass with corn silage on lactational performance and nutrient digestibility in Holstein dairy cows. J. Dairy Sci. 91:663–672.

Fritz, J.O., Moore, K.J. and Jaster, E.H. (1990) Digestion Kinetics and Cell Wall Composition of Brown Midrib Sorghum x sudangrass Morphological Components. *Crop Science*, 30, 213-219.

Goeser, J. (2016). Total tract NDF digestibility (TTNDFD) Guidelines, Rock River Laboratories, Accessed Nov. 1, 2016 Inc. http://rockriverlab.com/file_open.php?id=119.

Griggs, T.C., Drake, D. R., Parkinson, S.C. (2008). Production and Quality of warm-season annual forage grasses. *Proceedings, Idaho Alfalfa and Forage Conference,* 26-
27 February 2008.

Hafla, A. N., MacAdam, J. W., & Soder, K. J. (2013). Sustainability of US organic beef and dairy production systems: Soil, plant and cattle interactions. *Sustainability (Switzerland)*, *5*(7), 3009–3034.

Hardie, C. A., Wattiaux, M., Dutreuil, M., Gildersleeve, R., Keuler, N. S., & Cabrera, V. E. (2014). Feeding strategies on certified organic dairy farms in Wisconsin and their effect on milk production and income over feed costs. *Journal of Dairy Science*, *97*(7), 4612–23.

Hudson, Leep, Dietz, Ragavendron, Kravchenko, (2010). Integrated Warm- and Cool Season Grass and Legume Pastures: I. Seasonal Forage Dynamics. *Agronomy Journal, 102 (1), 303-309.*

Huhtanen, P., Nousiainen, J. I., Rinne, M., Kytölä, K., & Khalili, H. (2008). Utilization and partition of dietary nitrogen in dairy cows fed grass silage-based diets. *Journal of Dairy Science*, *91*(9), 3589–3599.

Hunter, M., P. Barney, T. Kilcer, J. Cherney, J. Lawrence, and Q. Ketterings. (2007). Teff as Emergency Forage. Cornell Univ. Cooperative Extension Agronomy Fact Sheet 24

Hunter, M., Ketterings, Q. M., Cherney, J. H., Barney, P., Kilcer, T., & Godwin, G. (2009). Nitrogen Needs of Teff Managed as Forage Crop in New York. *Fg*, *7*(1), 5–6.

Jones, G. B., & Tracy, B. F. (2015). Evaluating seasonal variation in mineral concentration of cool-season pasture herbage. *Grass and Forage Science*, *70*(1), 94–101.

Lopes, F., Ruh, K., Combs D. (2015). Validation of an approach to predict total-tract fiber digestibility using a standardized in vitro technique for different diets fed to high-producing dairy cows. *Journal of Dairy Science.* 98(4) 2596-2602

Maher, J., Stakelum, G., Rath, M. (2003). Effect of daily herbage allowance on the performance of spring calving dairy cows. Ir. J. Agric. Food Res. 42:229–241

McCartney, D., Fraser, J., Ohama, A., (2009). Potential of warm-season annual forages and Brassica crops for grazing: A Canadian Review Canadian Journal of Animal Science, 89(4): 431-440

McEvoy, M., O'Donovan, M., Kennedy, E., Murphy, J. P., Delaby, L., & Boland, T. M. (2009). Effect of pregrazing herbage mass and pasture allowance on the lactation performance of Holstein-Friesian dairy cows. *Journal of Dairy Science*, *92*(1), 414–422. http://doi.org/10.3168/jds.2008-1313

Milano, G. D., A. Hotston-Moore, and G. E. Lobley. (2000). Influence of hepatic ammonia removal on ureagenesis, amino acid utilization and energy metabolism in the ovine liver.

Br. J. Nutr. 83:307–315.

Millner, J. P., Silungwe, D., & Mcgill, C. R. (2011). Forage quality of sorghum , sudan-grass sorghum x sudan-grass and pearl millet cultivars in Manawatu. Agronomy NZ Journal 41, 13–22.

Moore, K. J., White, T. A., Hintz, R. L., Patrick, P. K., & Brummer, E. C. (2004). Sequential grazing of cool- and warm-season pastures. *Agronomy Journal*, *96*(4), 1103–1111.

Najda, H. (2003). Sorghum, sudangrass, and sorghum-sudangrass hybrids for forage. Alberta Agriculture, Food and Rural Development. Edmonton, AB. Agdex 126 20:1.

Norberg, S., (2009). Teff, A new warm season annual grass for Oregon. *Oregon State University Extension Service*.

NRC. (2001). Nutrient Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Press, Washington, DC.

Paine, L.K., Undersander, D., Casler, M.D. (1999). Pasture growth, production, and quality under rotational and continuous grazing management. Journal of Production Agriculture *Vol. 12 No. 4, p. 569-577*

Pedersen, J.F. (1996). Annual Forages: New Approaches for C-4 Forages. In: Janick, J., Ed., *Progress in New Crops*, ASHS Press, Alexandria, 246-251.

Peyraud, J. L., & Delagarde, R. (2013). Managing variations in dairy cow nutrient supply under grazing. *Animal : An International Journal of Animal Bioscience*, *7 Suppl 1*(2013), 57–67. http://doi.org/10.1017/S1751731111002394

Shaver, R. D. (2006)."Corn silage evaluation: The MILK2006 update." *Proc. 41st Pacific Northwest Anim. Nutr. Conf. Vancouver, Canada*.

Soder, K. J., Sanderson, M. a, Stack, J. L., & Muller, L. D. (2006). Intake and performance of lactating cows grazing diverse forage mixtures. *Journal of Dairy Science*, *89*(6), 2158–2167. http://doi.org/10.3168/jds.S0022-0302(06)72286-X

Sorge, U. S., Moon, R., Wolff, L. J., Michels, L., Schroth, S., Kelton, D. F., & Heins, B. (2016). Management practices on organic and conventional dairy herds in Minnesota. *Journal of Dairy Science*, *99*(4), 3183–92. http://doi.org/10.3168/jds.2015-10193

Tracy, B. F., Maughan, M., Post, N., & Faulkner, D. B. (2010). Integrating annual and perennial warm-season grasses in a temperate grazing system. *Crop Science*, *50*(5), 2171–2177. http://doi.org/10.2135/cropsci2010.02.0110

Tozer, P. R., Bargo, F., & Muller, L. D. (2003). Economic analyses of feeding systems combining pasture and total mixed ration. *Journal of Dairy Science*, *86*(3), 808–18. http://doi.org/10.3168/jds.S0022-0302(03)73663-7

US Department of Agriculture, Agricultural Marketing Service. (2010). National Organic Program: Access to Pasture (Livestock). 7 CFR part 205. Fed. Regist. 75:7154-7195

Venuto, B., & Kindiger, B. (2008). Forage and biomass feedstock production from hybrid forage sorghum and sorghum-sudangrass hybrids. *Grassland Science*, *54*(4), 189–196.

Weichenthal, B.A., Baltensperger, D.D., Vogel, K., Masterson, S., Blumenthal, J. *and* Krall, J. (2003). G03-1527 Annual Forages for the Nebraska Panhandle. *Historical Materials from University of Nebraska-Lincoln Extension:* 1734.

White, S. L., Benson, G. a, Washburn, S. P., & Green, J. T. (2002). Milk production and economic measures in confinement or pasture systems using seasonally calved Holstein and Jersey cows. *Journal of Dairy Science*, *85*(1), 95–104. http://doi.org/10.3168/jds.S0022-0302(02)74057-5

Table 1. Weather data for 2013-2015 collected from the West Central Research and Outreach Center, Morris, MN weather station.

		Temperature			Rainfall
Year	Month	High	Low	Average	Monthly total
		---------------------^{o}C---------------------			---cm---
2013	May	18.3	6.1	12.2	6.1
	June	23.9	13.3	18.3	23.7
	July	27.2	15.6	21.7	6.5
	August	26.7	13.3	20.0	2.7
	September	23.9	10.6	17.2	8.8
	October	12.2	2.2	7.2	9.2
2014	May	17.2	6.7	12.8	7.5
	June	24.4	13.9	19.4	20.8
	July	25.6	13.9	20.0	4.6
	August	25.0	15.0	20.0	14.6
	September	21.7	9.4	15.6	3.6
	October	15.0	1.7	8.3	1.3
2015	May	18.9	7.2	13.3	19.7
	June	25.6	13.9	20.0	4.7
	July	27.2	16.1	21.7	9.3
	August	25.6	13.3	19.4	16.0
	September	25.0	12.2	18.9	3.4
	October	15.6	3.3	9.4	4.0

Table 2. Least squares means and standard errors for forage quality characteristics of cool season perennial and warm season annual forage species

	Cool season perennial		Warm season annual	
Variable	Mean	SEM	Mean	SEM
Herbage mass (kg DM/ha)	2,228[b]	63	3,088[a]	241
Dry matter, %	23.3	0.6	22.4	1.1
Crude protein, %DM	23.0[a]	0.5	18.0[b]	0.9
NDF, %DM	49.6	0.5	52.6	1.2
ADF, %DM	32.2	0.4	33.7	0.7
TTNDFD, %NDF	54.6	0.9	54.9	1.7
Milk/ton, %DM	2,653	37	2,566	69
Calcium, %DM	0.67	0.03	0.58	0.06
Phosphorus, %DM	0.33[b]	0.01	0.37[a]	0.02
Potassium, %DM	3.10[b]	0.1	3.48[a]	0.16
Magnesium, %DM	0.23[b]	0.01	0.31[a]	0.02

[a,b]Means within a row with different superscripts are different at $P < 0.05$.

Table 3. Least squares means and standard errors for forage quality characteristics of cool season perennial and warm season annual forage species for each specific grazing year.

	Cool season perennial						Warm season annual					
Year	2013		2014		2015		2013		2014		2015	
Variable	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Herbage mass (kg DM/ha)			2,440^{b}	97	2016^{c}	81			2,950^{a}	224	3226^{a}	352
Dry matter	25.9^{a}	1.0	22.5^{b}	0.8	21.4^{b}	0.8	27.0^{a}	1.3	21.2^{b}	1.2	19.0^{b}	2.3
Crude protein	20.9^{c}	0.8	23.2^{b}	0.6	24.8^{a}	0.6	14.6^{d}	1.1	19.0^{c}	0.9	20.5^{bc}	1.8
NDF	51.6^{bc}	1.3	49.8^{cd}	1.0	48.4^{d}	1.0	56.9^{a}	1.8	53.8^{ab}	1.5	45.4^{d}	2.7
ADF	34.7^{b}	0.7	30.7^{d}	0.5	31.3^{cd}	0.5	37.7^{a}	0.9	32.7^{c}	0.8	30.5^{cd}	1.5
TTNDFD	63.8^{a}	1.4	48.0^{d}	1.2	51.9^{c}	1.3	59.3^{b}	1.9	46.3^{d}	1.7	59.1^{ab}	3.4
Milk/Ton	2,466^{b}	54.3	2,740^{a}	44.6	2,753^{a}	53.9	2,256^{c}	73.4	2,702^{a}	64.0	2,741^{ab}	152.1
Calcium	0.74^{a}	0.05	0.60^{b}	0.04	0.66^{ab}	0.04	0.58^{ab}	0.08	0.53^{b}	0.07	0.64^{ab}	0.13
Phosphorus	0.34^{a}	0.02	0.33^{a}	0.01	0.30^{b}	0.01	0.35^{a}	0.02	0.35^{a}	0.02	0.39^{a}	0.04
Potassium	3.36^{b}	0.14	2.92^{cd}	0.11	3.03^{c}	0.11	3.05^{bcd}	0.19	2.68^{d}	0.16	4.71^{a}	0.31
Magnesium	0.24^{cd}	0.01	0.22^{d}	0.01	0.22^{d}	0.01	0.30^{ab}	0.02	0.27^{bc}	0.02	0.36^{a}	0.04

^{a,b}Means within a row with different superscripts are different at $P < 0.05$.

Table 4. Least square means for forage quality characteristics of cool season forage species and warm season forage species for each month across grazing season.

	Cool season perennial										Warm season annual							
	June		July		August		September		October		July		August		September		October	
Variable	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Herbage mass (kg DM/ ha)	3,168^{b}	127	2,757^{c}	126	2,024^{d}	114	1,690^{de}	132	1,501^{e}	193	3,766^{a}	207	3,014^{bc}	258	2,962^{abc}	463	2,609^{abcde}	679
DM, %	24.4^{abc}	1.0	21.1^{d}	1.0	25.0^{ab}	0.95	21.9^{cd}	1.0	23.9^{abcd}	0.0	15.9^{e}	1.1	23.8^{abcd}	1.6	21.9^{bcd}	1.6	28.0^{a}	2.7
Crude protein, % DM	20.7^{b}	0.7	21.6^{b}	0.7	22.1^{b}	0.7	25.2^{a}	0.7	25.3^{a}	1.0	20.0^{b}	0.9	17.2^{c}	1.3	17.0^{c}	1.3	17.9^{bc}	2.14
NDF, % DM	53.5^{a}	1.2	52.2^{ab}	1.2	51.6^{ab}	1.2	47.4^{c}	1.3	45.1^{c}	1.7	51.8^{ab}	1.4	55.5^{a}	2.0	54.4^{a}	2.0	46.4^{bc}	3.44
ADF, %DM	33.0^{b}	0.6	33.2^{b}	0.6	32.9^{b}	0.6	31.4^{c}	0.6	30.6^{c}	0.9	32.8^{bc}	0.7	35.9^{a}	1.1	34.3^{ab}	1.1	31.7^{bc}	1.85
TTNDFD, %NDF	53.2^{bc}	1.4	50.8^{c}	1.4	50.3^{c}	1.5	57.7^{a}	1.6	60.7^{a}	2.3	56.1^{ab}	1.7	50.5^{c}	2.3	56.9^{ab}	2.3	56.0^{abc}	3.88
Milk/ton	2,620	58	2,603	54	2,671	59	2,628	58	2,743	83	2,618	69	2,528	91	2,610	92	2,509	149
Calcium, %DM	0.56^{d}	0.05	0.59^{cd}	0.05	0.71^{ab}	0.05	0.76^{a}	0.05	0.71^{abc}	0.07	0.57^{bcd}	0.06	0.59^{abcd}	0.09	0.46^{d}	0.09	0.70^{abcd}	0.15
Phosphorus, %DM	0.30^{b}	0.01	0.30^{b}	0.02	0.30^{b}	0.01	0.37^{a}	0.02	0.36^{a}	0.02	0.37^{a}	0.02	0.34^{ab}	0.02	0.37^{a}	0.03	0.39^{a}	0.04
Potassium, %DM	2.74^{d}	0.12	2.89^{cd}	0.13	2.97^{cd}	0.12	3.43^{b}	0.13	3.47^{ab}	0.17	3.85^{a}	0.16	3.31^{bc}	0.22	3.28^{bc}	0.22	3.49^{abc}	0.36
Magnesium, %DM	0.18^{e}	0.01	0.20^{de}	0.01	0.25^{c}	0.01	0.26^{bc}	0.01	0.24^{cd}	0.02	0.28^{abc}	0.02	0.31^{ab}	0.03	0.31^{ab}	0.03	0.35^{a}	0.04

^{a,b}Means within a row with different superscripts are different at $P < 0.05$.

Table 4. Least squares means and standard errors for forage quality characteristics for each cool season perennial, BMR sorghum sudangrass (BMRSS), and Teff grass across the grazing season

Variable	Cool season perennial		BMRSS		Teff	
	Mean	SEM	Mean	SEM	Mean	SEM
Herbage mass (kg DM/ha)	2,228[b]	63	3,455[a]	306	2,722[ab]	365
Dry Matter	23.3[a]	0.6	20.2[b]	1.1	24.6[a]	1.7
Crude protein, % DM	23.0[a]	0.5	18.5[b]	0.9	17.5[b]	1.4
NDF, % DM	50.0	0.9	51.9	1.5	52.1	2.2
ADF, % DM	32.2	0.4	33.3	0.8	34.0	1.2
TTNDFD, %NDF	54.6	0.9	54.2	1.6	55.6	2.6
Milk/Ton	2,653	37.0	2,578	64.1	2,555	112.6
Calcium, % DM	0.67	0.03	0.60	0.07	0.56	0.10
Phosphorus, % DM	0.33[b]	0.01	0.34[b]	0.02	0.40[a]	0.03
Potassium, % DM	3.10[b]	0.1	3.25[ab]	0.17	3.71[a]	0.25
Magnesium, % DM	0.23[b]	0.01	0.33[a]	0.02	0.30[a]	0.03

[a,b]Means within a row with different superscripts are different at $P < 0.05$.

Manuscript

Milk production, body measurements, activity, and rumination of organic dairy cattle grazing two different pasture systems incorporating cool and warm season forages.

Interpretive Summary

Organic dairy cows were used to evaluate the effect of two pasture production systems on milk production, milk components, body weight, body condition score, and activity and rumination. Milk production increased when cows grazed sorghum-sudangrass compared to when they grazed cool season perennial pasture. Warm season annual forages may be incorporated into grazing systems for organic dairy cattle while maintaining milk production and quality.

ABSTRACT

Organic dairy cows (n = 90) of Holstein and crossbred genetics were used to evaluate the effect of two pasture production systems (cool season perennial and warm season annual grass species) across 2 grazing seasons (May to October of 2014 and 2015) on milk production, milk components (fat, protein, MUN, SCS), body weight, body condition score (BCS), and activity and rumination (min/d). Cows were assigned to 1 of 2 replicated pasture systems: 1) System 1 was a diverse-mixture of cool season grasses and legumes [perennial ryegrass (*Lolium perenne*), white clover (*Trifolium repens*), red clover (*Trifolium pretense*), chicory (*Cichorium intybus*), orchardgrass (*Dactylis glomerata*), meadow bromegrass (*Bromus biebersteinii*), alfalfa (*Medicago sativa*), meadow fescue (*Festuca pratensis*)] or 2) System 2 was the same combination of perennial grasses and warm season annual grasses (BMR sorghum-sudangrass (*Sorghum × drummondii;* **BMRSS**) and teff (*Eragrostis tef*) grass). There were 3 replicates of each system, and therefore, 6 total cow groups. Cows rotationally grazed pasture and moved to a new paddock every 2 days, were provided free-choice mineral, and were supplemented with corn (2.27kg/day) to manage MUN levels. Weekly milk production, and bi-weekly milk components, body weight and BCS were recorded for each of the 6 replicate groups. Activity and rumination time (daily) were monitored electronically using HR-LD Tags (SCR Engineers Ltd., Netanya, Israel) during the grazing season. The PROC MIXED of SAS was used for statistical analysis, and independent variables were fixed effects of system (1 or 2), forage (perennial grass, BMRSS or teff) nested within system, year (2014 or 2015), system nested within year, and week nested within system, with replicate group nested within system as a random effect with repeated measures.

System 1 and system 2 cows had similar milk production (14.7 and 14.8 kg/d), fat percentage (3.92% vs. 3.80%), protein percentage (3.21% vs. 3.17%), MUN (12.5 and 11.5 mg/dl), and SCS (4.05 and 4.07), respectively. For yearly effects, milk production was greater in 2015 compared to 2014 (15.6 vs 13.9 kg/d. The BW (485 and 497 kg) and BCS (3.10 and 3.06) were similar for system 1 and 2, respectively. Cows in system 1 had greater daily rumination (530 min/d) compared to cows in system 2 (470 min/d). In summary, warm season annual forages may be incorporated into grazing systems for organic dairy cattle while maintaining milk production and quality.

INTRODUCTION

There has been a recent increase in consumer demand of organic products due to interest in sustainable farming practices and animal welfare concerns associated with conventional dairy farming (Sorge et al., 2016). Therefore, consumer demand for organic dairy products has triggered an increase in the number of organic farms, including organic dairy farms. Organic dairy cattle need at least 120 days of grazing, with 30% of their DMI coming from pasture according to the National Organic Pasture rule (USDA-AMS, 2010). Furthermore, conventional dairy producers also utilize pasture forages for feed for their cows. Pasture-based dairy production may potentially be an economically competitive management system, with benefits that include less labor, lower investments in facilities, with comparable income over feed cost (White et al., 2002). Current milk prices also favor organic dairy production, with some organic dairy producers receiving $36.00/cwt compared to the conventional milk price at about $16.60/cwt for conventional milk (USDA-AMS, 2016). In grazing dairy herds, effective pasture management is crucial for maintaining the production and health of the animals grazing pasture.

Pasture is the primary source of forage for organic dairies, and the National Organic Program organic livestock production regulations require a minimum of 120 days grazing per animal (USDA, 2016). In the northern United States, this requirement is typically met by a May to September grazing season, and profitability depends on pastures that provide a uniform, season-long supply of high quality forage (Undersander et al., 2004). However, in the northern United States, seasonal variation in temperature and precipitation creates a challenge, as the predominant forage plants, which include perennial grasses such as Kentucky bluegrass, quackgrass, and smooth bromegrass, and legumes such as white clover, undergo a “summer slump” in production (Undersander et al., 2004), and do not actively grow in late fall. Extending the grazing season late into fall would reduce the high costs of harvested feed (Ball et al., 2008). To create a more uniform and extended forage supply, Ball et al. (2008) recommended diversifying pasture systems to include warm season species in the summer and annual cool season species in the fall. However, these recommendations have never been evaluated under organic grazing.

Compared to monocultures, diversity reduces risks associated with loss of any single pasture species, provides for variable resource use within a field, supplies potentially more uniform biomass during the growing season, and improves soil health (Tilman, et al., 1996; Minns et al., 2001; Sanderson et al., 2004; van Eekeren et al., 2010). Diversity can be increased by adding functional groups (e.g., grasses and forbs) and by increasing numbers of species within functional groups (Mangan et al., 2011). A traditional example is to grow nitrogen-fixing legumes with grasses. Although legumes supply nitrogen to grasses and provide a higher energy feedstuff than grasses, legumes are generally less persistent and require higher levels of soil fertility than grasses (Marten et al., 1989). Increases in diversity in a farm’s forage base can be achieved by planting mixtures in individual pastures, and by planting separate pastures with different species (Powers and McSorley, 2000).

Another approach to increasing diversity in a farm’s forage base is to combine annual and perennial crops in separate fields (Undersander et al., 2004). An example for the northern United States would be to use cool season grasses and legumes like Kentucky bluegrass and white clover for forage in spring and early fall, and warm season annuals (**WSA**) like teff (*Eragrostis tef)* (Clapham et al., 2011) and sudangrass (McCartney et al., 2009) for forage in summer. To extend the grazing season, small grains and *Brassica* spp. have been proposed for the fall (Jung et al., 1986; Ball et al., 2008, Undersander et al., 2004). Grazing systems using these different approaches to achieve diversity require biological, environmental and economic analysis.

Organic and grazing dairy producers are constantly searching for ways to improve milk production in their herds. The opportunity to potentially produce higher amounts of high quality forage on the same amount of land may help organic farmers to achieve this goal of higher milk production (McBride and Greene, 2009). Therefore, the objective of this study was to compare two grazing systems in an organic grazing dairy herd to determine if incorporating warm season grasses may be beneficial in a grazing system for organic dairy cows. Milk production and components, rumination, activity, body condition score and body weight, as well as forage production of the systems were evaluated for these two distinct grazing systems.

MATERIALS AND METHODS

Experimental Design and Grazing Management

Ninety-six organic dairy cows were blocked by lactation number, season of calving (fall or spring), breed group, and previous lactation milk production, and all treatment groups contained both fall- and spring-calving cows. Cows were randomly assigned to one of two systems, with three replicate groups of 18 cows per system (2 replicates per grazing system; 6 total groups of cows on pasture). Breed groups of cows included pure Holsteins and various crossbreds of Jersey, Normande, Holstein, Montbéliarde, and

Swedish Red; breed groups were balanced across treatment groups and replicates. Cows were managed under certified organic management at the University of Minnesota West Central Research and Outreach Center (WCROC) dairy farm in Morris, MN. The WCROC organic dairy herd consists of 120 lactating dairy cows and cows were milked in a swing-9 para-bone milking parlor at 0600 and 1700 h. The experiment was conducted for two grazing seasons, May through October of 2014 and 2015. All animal procedures involving animal care and management were approved by the University of Minnesota Institutional Animal Care and Use Committee (#1508-32966A).

There were a total of 38.5 ha of total pasture utilized in this study. System 1 had 18.86 ha of cool-season pasture, and System 2 had 10.29 ha cool season pastures and 9.34 ha of warm season annual pasture (19.63 ha total). System 1 (**SYS1**) was a pasture system of a diverse mixture of cool season perennial grasses and legumes (**CSP**) [perennial ryegrass (*Lolium perenne*), white clover (*Trifolium repens*), red clover (*Trifolium pretense*), chicory (*Cichorium intybus*), orchardgrass (*Dactylis glomerata*), meadow bromegrass (*Bromus biebersteinii*), alfalfa (*Medicago sativa*), meadow fescue (*Festuca pratensis*)]. System 2 (**SYS2**) was a combination of cool season perennial pasture, as listed above, and 2 warm season annual grasses (BMR sorghum-sudangrass (*Sorghum × drummondii;* **BMRSS**) and teff (*Eragrostis tef*) grass). The cool season periennial pastures were established in 2012. These species were chosen to optimize forage production in a cool season grazing system. Grazing of cool-season pasture was initiated when pasture reached a height of 20 to 30cm tall and strip size was adjusted to leave 7 to 13 cm of refusals. Both SYS1 and SYS2 cows grazed pasture mixtures of this type when grazing was initiated in spring, but cows in the two different systems were kept in separate pastures designated to the respective system.

Cows moved to a new paddock every two d, but the decision to move cows was based on the availability of grass in paddocks. There were 18 cows in each grazing group and stocking density was 0.51 hectare per cow. Cows in SYS1 were always moved to a new paddock of CSP. In the case of SYS2, the decision to move cows was based on the availability of WSA, so cows were either moved to a new CSP paddock or to a WSA paddock if BMRSS or teff were ready to be grazed. In SYS2, each replicate grazing group was assigned a CSP and WSA pasture.

Cows were managed in an intensive rotational grazing method in both systems. In SYS1, cows were moved to a new paddock of cool season perennial grass approximately every two days throughout the entire grazing season (May through October). The resting time for each paddock was from 21 to 35 d.In SYS2, cows were moved to a new paddock of cool season perennial grass every two days in May and June. In July through October, these cows were moved to a new paddock of either CSP or a paddock of one of two WSA, depending on the availability and visually observed quality of pasture choices. The BMRSS was allowed to grow at least 45 cm before grazing, in order to minimize risk of prussic acid poisoning (Griggs, 2008). Teff grass was grazed in a similar manner to the cool season pastures, initiating grazing at 20-30 cm, and leaving 7-13 cm refusals. In 2015, the teff paddocks were not well established, and the paddocks were overrun with weeds. As a result, cows only grazed teff paddocks one time in 2015. In October, pastures of oats and turnips were included in the rotation so cows were possibly moved to cool season perennial, warm season annual, or cool season brassica pastures depending on availability of forage in the pastures. Water and mineral were provided ad libitum. All cows were supplemented with 2.3 kg corn daily while on pasture to manage MUN levels.

The decision to move cows into a new pasture, as well as the decision about stocking density in pastures, was made based on visually observed forage availability. For BMRSS pastures, decisions to move cows into pastures were based on the height of the forage in the new pasture. Forage clippings were taken within 48 hours prior to cows being let into a new paddock to estimate pasture dry matter allowance and forage quality. Detailed forage sampling methods and analyses of pasture production and forage quality can be found in a complementing paper (Ruh et al, unpublished, 2017).

Milk Production, BW, and BCS

Milk production was quantified with daily yield from the Boumatic Smart Dairy system (Madison, WI) and monthly DHI measures of milk, fat, protein, MUN, SCS. Average daily milk production per cow of each replicate group was used for the statistical analysis. To evaluate animal health, cow BW and BCS were recorded bi-weekly using a digital scale as cows exited the milking parlor in the morning. Body condition scores were 1 = excessively thin to 5 = excessively fat (Wildman et al., 1982).

Activity and Rumination

All cows were fitted with a HR-LD activity and rumination monitoring collar (SCR Engineers, Netanya, Israel) around the neck (Schirmann, et al., 2009). The neck monitors recorded 24 h of data and communicated with the data recorder via a long-distance antenna placed on top of the milking center. The antenna had a range of several hundred meters, depending on the weather and other environmental factors. Each time the cattle returned to the milking center, and if they were in paddocks near the milking center, the antenna would download data as often as every 20 Min. (Sjostrom et al., 2016). Data from the activity and rumination monitoring systems was activity and rumination per d. Rumination results are presented in min/d and activity results are presented as SCR units based on a proprietary algorithm.

Weather Data

Weather data was recorded daily at the University of Minnesota West Central and Outreach Center Weather station in Morris, MN. Weather data was reported as monthly high, low, and average monthly temperature and total monthly precipitation for the months of the grazing season and is reported in Table 6.

Statistical analysis

For statistical analysis of milk, fat, and protein production, SCS, and MUN, independent variables were effects of grazing system (SYS1 or SYS2), forage (perennial pasture, BMRSS, teff, or oats and turnips), year (2014 or 2015), forage nested within system, system nested within year, and date nested within system by year. For milk production, rumination, and activity, replicate nested within system was a random effect with date as a repeated measure. For percent fat, percent protein, MUN, SCS, BW, and BCS, replicate nested within system was a random effect with week as the repeated measure. The compound symmetry covariance structure was used because it resulted in the lowest Akaike's information criterion (Littell et al., 1998).

The MIXED procedure of SAS was used for the analysis of fat percentage, protein percentage, MUN, SCS, BW, and BCS data. The HPMIXED procedure of SAS (SAS Institute, 2014) was used for daily rumination, daily activity, and average daily milk production data. All observations within replicates and dates were averaged for analyses. Replicate pen of cows on pasture was the experimental unit for analysis. All treatment results were reported as least squares means, with significance declared at $P < 0.05$.

RESULTS AND DISCUSSION

Weather Data

Weather results are presented in Table 1. Months with the highest precipitation across the two years include June 2014, August 2014, May 2015, and August 2015. The year 2014 had lower total precipitation during the months of the grazing season compared to the grazing season of 2015. The driest months were September 2014, October 2014 and September 2015. July and August were the months with the highest temperatures and high humidity in both years. The year with the highest average temperature during the months of the grazing season was 2015. The high temperatures and low precipitation of July and August may have challenged the CSP pastures. The diverse weather conditions between the three years of the study provide the opportunity to study the productivity of the pastures under different growing conditions.

Milk production between systems

Least squares means and standard errors of means for milk production, SCS, and MUN for SYS1 and SYS2 are in Table 2. Cows from both SYS1 and SYS2 grazing systems had similar milk production (14.6 kg/d, 14.8 kg/d), fat percentage (3.9%, 3.8%), protein percentage (3.2%), SCS (4.1), and MUN (12.5 mg/dl, 11.5mg/dl), respectively. A reason that differences in milk production were not observed between the grazing systems in the current study may be because cows in both systems produced relatively low levels of milk (average of 15 kg). The cows were not supplemented much grain on pasture, and in the same herd of cows, Sjostrom et al., (2016) reported similar production levels for cows consuming 100% pasture and no grain. In a previous study using low producing cows (17 kg/d), Naves et al., (2015) attributes the low base level of milk production in both treatment groups of cows as the reason no difference in milk production was seen between different treatments. Many studies that have compared organic dairy production to conventional production note a lower average daily milk production in organic farms (Fontaneli et al., 2005; Hardie et al., 2014; Sato et al., 2002; Sorge et al., 2016; Stiglbauer et al., 2013). Further research is needed to determine effects for cows in different types of organic systems when utilizing these warm season grasses in a grazing system, for example for organic farms that may include higher levels of concentrate or supplement pasture with TMR, or farms with different breeds of cows.

Cows in both systems followed similar trends in milk production across the grazing season, based on the weather patterns. When there were extreme weather events like high temperature and high humidity, both systems of cows experienced a dip in production. Although forage yield and quality are important for production, production for cows in grazing systems is also highly associated with weather patterns (Hill and Wall, 2015).

Table 3 has milk production for cows grazing specific forages in the two systems. Milk production was greater ($P < 0.05$) for cows grazing BMRSS (15.4 kg/d) compared to cool season grass (14.4 kg/d) and teff grass (14.5 kg/d) within SYS2. However, cows grazing cool season grass in SYS1 (14.6 kg/d) had similar milk production to cows on all forages in SYS2. One factor that may contribute to the higher milk production of cows grazing BMRSS is the lower MUN that was seen in those cows (Bargo et al., 2002; Broderick and Reynal, 2009). The conversion of ammonia to urea in the liver costs the animal 12 Kcal/g excess N excreted (Van Soest, 1994), thereby depleting the amount of energy available for milk production. However, research regarding the relationship between MUN and milk production is not conclusive, as some studies show positive relationships (Carlsson et al., 1995; Oltner et al., 1985), no relationship (Baker et al, 1995; Carroll et al., 1988) or negative relationships (Broderick and Clayton (1997; a statistical evaluation of animal and nutritional factors influencing concentrations of milk urea nitrogen; Bargo, 2002; Broderick and Reynal, 2009) between MUN and milk production. The MUN was lower ($P < 0.05$) for cows on BMRSS (9.3 mg/dL) than cows grazing cool season grass (13.3 mg/dL). The lower MUN observation in cows grazing BMRSS is most likely due to the lower crude protein content of BMRSS than cool season grass (Ruh et al., unpublished, 2017), as MUN levels are closely associated to levels of dietary CP (Roseler et al., 1993; Broderick, 2003; Wattiaux and Karg, 2004; Nousiainen, 2004). Crude protein and fiber concentrations vary across a season of pasture growth due to different maturities of the grass (Tracy et al., 2010; Moore et al., 2004).

BW, BCS, rumination, activity

Least squares means and standard errors for rumination, activity, body weight, and body condition scores for cows in SYS1 and SYS2 are shown in Table 4. Cows had similar BCS (3.1) and BW (SYS1 = 485 kg, SYS2 = 498 kg) throughout the study, whether they were in SYS1 or SYS2. It has been determined that the optimum milk production would come from cows that have a BCS of 3.5, but that no significant decrease in milk production is found at a BCS of 3.0 (Roche et al., 2007). This corresponds to our results of BCS of 3.1 and 3.0 throughout the grazing season. Milk production can be correlated with BCS loss (Roche et al., 2007), but there was no change in BCS and no difference in milk production between cows in the different systems in the current study. Cows in SYS1 and SYS2 had similar activity levels (596 SCR units, 614 SCR units, respectively) across the grazing season. Rumination (470 min/d) was lower ($P < 0.05$) for cows grazing SYS2, which incorporated the WSA, than cows in SYS1 (530 min/d). Rumination is considered an important component of digestion and animal welfare for ruminants (Krawczel and Grant, 2009). Lower rumination times may be caused by a variety of dietary and animal factors including lower NDF, higher diet digestibility, lower DMI, stress, and illness, and may decrease milk production or lead to a greater risk of ruminal acidosis (Bristow and Holmes, 2007; DeVries et al., 2009). Cows in both systems have rumination times that are within the range of 428 min/d to 555 min/d (DeVries et al., 2009; Adin et al., 2009; Storm and Kristensen et al., 2010) found in previous research. Cows in SYS2 were grazing grass that was consistently at a lower maturity than grass in SYS1 throughout the grazing season due to the different growing patterns of the different grasses. This may have led to these cows having lower amounts of physically effective fiber in their diet than cows in SYS1, which may have experienced increasing maturity of cool season grass as the grazing season progressed (Moore et al., 2004).

Table 5 has BW, BCS, daily rumination, and daily activity, for cows on each specific type of forage in the two systems. Cows had similar BCS and BW on all types of grasses. Cows had lower rumination when grazing BMRSS (445 min/d) and teff grass

(437 min/d) than when grazing cool season grass (506 min/d). Grazing dairy cows will reduce rumination to increase effective grazing (Gregorini et al., 2012). It is possible that cows grazing BMRSS and teff in the current study were spending more time eating than ruminating, which is most likely a component of the higher activity levels that were observed for cows grazing BMRSS. In addition, cows grazing cool season grass in SYS2 (506 min/d) had lower ($P < 0.01$) rumination than cows grazing cool season grass in SYS1 (530 min/d). As discussed above, this is probably due to cows in SYS2 grazing cool season grass that was at a lower maturity and was less lignified than cool season grass that cows in SYS1 were grazing.

Activity was highest for cows grazing BMRSS (663 SCR units), which is most likely due to the physical structure of the plant, as cows must be more active to move about the pasture because of the tall stems and long leaves of the BMRSS. Activity was lowest for cows in oats and turnips (582 SCR units), which could be due to the cooler ambient air temperatures at the time of year they were grazing these pastures, as cooler temperatures can be associated with lower activity levels (Sjostrom, 2015). Cows grazing teff grass had similar activity (615 SCR units) to cows grazing cool season perennial pastures (595 SCR units) in either system.

CONCLUSIONS

Although grazing producers may be concerned about detrimental effects to cows grazing warm season grasses, this study reports that warm season grasses may be incorporated into a grazing system for organic dairy cattle while maintaining milk production and quality. Furthermore, BW and BCS of the cattle were similar when grazing cool season and warm season grasses. An interesting finding was that cows on

BMRSS produced more milk than cows on cool season perennial grasses within the same grazing system, which indicates a potential benefit to incorporating this grass in a grazing system. Further research should be conducted on the economics of incorporating warm season grasses into a grazing system for dairy cows and on the optimal proportion of warm season grasses compared to cool season grasses in the grazing system to maximize milk production and minimize economic risk associated with seed costs and weather effects.

ACKNOWLEDGEMENTS

The authors express gratitude to Darin Huot and coworkers at University of Minnesota West Central Research and Outreach Center, Morris, for their assistance in data collection and care of the animals. This material is based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award number 2012-51300-20015.

REFERENCES

Adin, G., R. Solomon, M. Nikbachat, A. Zenou, E. Yosef, A. Brosh, A. Shabtay, S. J. Mabjeesh, I. Halachmi, and J. Miron. (2009). Effect of feeding cows in early lactation with diets differing in roughage- neutral detergent fiber content on intake behavior, rumination, and milk production. J. Dairy Sci. 92:3364–3373.

Astigarraga, L., Bianco, A., Mello, R., & Montedónico, D. (2014). Comparison of brown midrib sorghum with conventional sorghum forage for grazing dairy cows. *American Journal of Plant Sciences*, *5*(7), 955

Baker, L. D., Ferguson, J.D., and Chalupa, W. (1995). Responses in urea and true protein of milk to different protein feeding schemes for dairy cows. J. Dairy Sci. 78:2424–2434

Ball, D.M., E.N. Ballard, M.L. Kennedy, G.D. Lacefield, and D. J. Undersander. (2008). Extending grazing and reducing stored feed needs. Grazing Lands Conservation Initiative Pub. 8-01. Byran, TX.

Bargo, F., Muller, L. D., Delahoy, J. E., & Cassidy, T. W. (2002). Milk Response to Concentrate Supplementation of High Producing Dairy Cows Grazing at Two Pasture Allowances. *Journal of Dairy Science*, *85*(7), 1777–1792.

Benbrook, C. M., Butler, G., Latif, M. A., Leifert, C., & Davis, D. R. (2013). Organic production enhances milk nutritional quality by shifting fatty acid composition: A United States-wide, 18-month study. *PLoS ONE*, *8*(12)

Bristow, D. J., and D. S. Holmes. 2007. Cortisol levels and anxiety- related behaviors in cattle. Physiol. Behav. 90:626–628

Broderick, G. a, & Clayton, M. K. (1997). A statistical evaluation of animal and nutritional factors influencing concentrations of milk urea nitrogen. *Journal of Dairy Science*, *80*(11), 2964–2971. http://doi.org/10.3168/jds.S0022-0302(97)76262-3

Broderick, G. a. (2003). Effects of varying dietary protein and energy levels on the production of lactating dairy cows. *Journal of Dairy Science*, *86*(4), 1370–81. http://doi.org/10.3168/jds.S0022-0302(03)73721-7

Broderick, G. A., & Reynal, S. M. (2009). Effect of source of rumen-degraded protein on production and ruminal metabolism in lactating dairy cows. *Journal of Dairy Science*, *92*(6), 2822–2834

Carlsson, B. J., Bergstrom, J. and Pehrson, B. (1995). Variations with breed, age, season, yield, stage of lactation, and breed in the concentration of urea in bulk milk and individual cow's milk. Acta Vet. Scand. 36:245–254.

Carroll, D. J., Barton, B. A., Anderson, G. W., and Smith, R. D. (1988). Influence of protein intake and feeding strategy on reproductive performance of dairy cows. J. Dairy Sci. 71:3470–3481

Cherney, J.H., Cherney, D.J.R., Akin, D.E. and Axtell, J.D. (1991) Potential of Brown-Midrib Low-Lignin Mutants for Improving Forage Quality. *Advances in Agronomy*, 46, 157-198.

Clapham, W.M. and J. M. Fedders. (2011). Interseeding teff into tall fescue swards to improve late summer forage production. Online: Forage and Grazinglands doi:10:1094/FG-2011-1128-01-RS.

Dann, H.M., R.J. Grant, K.W. Cotanch, E.D. Thomas, C.S. Ballard, and R. Rice. (2008). Comparison of brown midrib sorghum-sudan- grass with corn silage on lactational performance and nutrient digestibility in Holstein dairy cows. J. Dairy Sci. 91:663–672.

DeVries, T. J., K. A. Beauchemin, F. Dohme, and K. S. Schwartzkopf- Genswein. 2009. Repeated ruminal acidosis challenges in lactating dairy cows at high and low risk for developing acidosis: Feeding, ruminating, and lying behavior. J. Dairy Sci. 92:5067–5078.

Ellis, K. a, Innocent, G., Grove-White, D., Cripps, P., McLean, W. G., Howard, C. V, & Mihm, M. (2006). Comparing the Fatty Acid Composition of Organic and Conventional Milk. *Journal of Dairy Science*, *89*(6), 1938–1950.

Fritz, J.O., Moore, K.J. and Jaster, E.H. (1990) Digestion Kinetics and Cell Wall Composition of Brown Midrib Sorghum x sudangrass Morphological Components. *Crop Science*, 30, 213-219.

Fontaneli, R. S., Sollenberger, L. E., Littell, R. C., & Staples, C. R. (2005). Performance of lactating dairy cows managed on pasture-based or in freestall barn-feeding systems. *Journal of Dairy Science*, *88*(3), 1264–1276.

Gregorini, P., Dela Rue, B., McLeod, K., Clark, C., Glassey, C., Jago, J., 2012. Rumination behavior of grazing dairy cows in response to restricted time at pasture. Livest. Sci. 146, 90–95.

Gregorini, P., Dela Rue, B., Pourau, M., Glassey, C., & Jago, J. (2013). A note on rumination behavior of dairy cows under intensive grazing systems. *Livestock Science*, *158*(1-3), 151–156.

Griggs, T.C., Drake, D. R., Parkinson, S.C. (2008). Production and Quality of warm-season annual forage grasses. *Proceedings, Idaho Alfalfa and Forage Conference,* 26-27 February 2008.

Hardie, C. A., Wattiaux, M., Dutreuil, M., Gildersleeve, R., Keuler, N. S., & Cabrera, V. E. (2014). Feeding strategies on certified organic dairy farms in Wisconsin and their effect on milk production and income over feed costs. *Journal of Dairy Science*, *97*(7), 4612–23.

Hill, D. L., & Wall, E. (2015). Dairy cattle in a temperate climate: the effects of weather on milk yield and composition depend on management. *Animal*, *9*(01), 138–149.

Hudson, D.J., Leep, R.H., Dietz, T.S., Ragavendron, A., Kravchenko, A., (2010). Integrated Warm- and Cool Season Grass and Legume Pastures: I. Seasonal Forage Dynamics. *Agronomy Journal, 102 (1), 303-309.*

Hunter, M., P. Barney, T. Kilcer, J. Cherney, J. Lawrence, and Q. Ketterings. (2007). Teff as Emergency Forage. Cornell Univ. Cooperative Extension Agronomy Fact Sheet 24

Jung, G.A., R.A. Byers, M. Panciera, and J.A. Shaffer. (1986). Forage dry matter accumulation and quality of turnip, swede, rape, Chinese cabbage hybrids, and kale in the eastern USA. Agron. J. 78:2454-253.

Krawczel, P., Grant, R., 2009. Effects of cow comfort on milk quality, productivity and behavior. In: Proceedings of the NMC Annual Meeting, Charlotte, NC, USA, pp. 15–24.

Maher, J., Stakelum, G., Rath, M. (2003). Effect of daily herbage allowance on the performance of spring calving dairy cows. Ir. J. Agric. Food Res. 42:229–241

Mangan, M.E., C.C. Sheaffer, D.L. Wyse, N.J. Ehlke, and P.B. Reich (2011). Native perennial grassland species for bioenergy: establishment and biomass productivity. Agron. J. 103:1-13.

Marten, G.C., A.G. Matches, R. F. Barnes, R.W. Brougham, R.J. Clements, and G.W. Sheath (1989). Persistence of forage legumes. Proc. Trilateral workshop 18-22 July 1988. ASA, CSSA, and SSSA, Madison, WI.

McBride, W. and C. Greene. 2009. Characteristics, costs, and issues for organic dairy farming. Economic Research Report Number 82, United States Department of Agriculture, USDA Economic Research Service 82:1-42.

McCartney, D., Fraser, J., and Ohama, A. (2009). Potential of warm-season annual forages and Brassica crops for grazing: A Canadian Review Canadian Journal of Animal Science, 89(4): 431-440

Minns, A., J. Finn, A. Hector, M. Caldeira and J. Joshi. (2001). The functioning of European grassland ecosystems: Potential benefits of biodiversity to agriculture. Outlook Agric., 30: 179-185.

Moore, K. J., White, T. A., Hintz, R. L., Patrick, P. K., & Brummer, E. C. (2004). Sequential grazing of cool- and warm-season pastures. *Agronomy Journal*, *96*(4), 1103–1111

Najda, H. (2003). Sorghum, sudangrass, and sorghum-sudangrass hybrids for forage. Alberta Agriculture, Food and Rural Development. Edmonton, AB. Agdex 126 20:1.

Naves, J. R., de Jesus, E. F., Martins, C. M. M. R., Tomazi, T., de Freitas Junior, J. E., Rennó, F. P., and Santos, M. V. (2015). Efficiency of dietary nitrogen utilization and digestive metabolism of dairy cows fed different nitrogen sources and sugarcane. Journal of Animal and Plant Sciences. 25(4):941-949.

Norberg, S., (2009). Teff, A new warm season annual grass for Oregon. *Oregon State University Extension Service*.

Nousiainen, J., Shingfield, K. J., & Huhtanen, P. (2004). Evaluation of milk urea nitrogen as a diagnostic of protein feeding. *Journal of Dairy Science*, *87*(2), 386–98. http://doi.org/10.3168/jds.S0022-0302(04)73178-1

Oltner, R.,M. Emanuelson, and H. Wiktorsson. (1985). Urea concentration in cows' milk in relation to milk yield, live weight, lactation number and composition of feed given. Livest. Prod. Sci. 12:45–57

Powers, L.E., and R. McSorley, (2000). Ecological principles of agriculture. Delmar Thompson Learning, Albany, NY.

Roche, J. R., Lee, J. M., Macdonald, K. A., & Berry, D. P. (2007). Relationships Among Body Condition Score , Body Weight , and Milk Production Variables in Pasture-Based Dairy Cows. *Journal of Dairy Science*, *90*(8), 3802–3815.

Roseler, D. K., J. D. Ferguson, C. J. Sniffen and J. Herrema. 1993. Dietary protein degradability effects of plasma and milk urea nitrogen and milk nonprotein nitrogen in Holstein cows. J. Dairy Sci. 76:525-534.

Ruh, et al., unpublished 2016 Forage quality paper

Sanderson, M.A., B.F. Tracy, R.H. Skinner, D.J. Barker, G.R. Edwards, B.F. Tracy, and D. A. Wedin. (2004). Plant species diversity and management of temperate forage and grazing land ecosystems. Crop Sci. 44:1132-1144.

Sato, K., Bartlett, P. C., Erskine, R. J., & Kaneene, J. B. (2005). A comparison of production and management between Wisconsin organic and conventional dairy herds. *Livestock Production Science*, *93*(2), 105–115.

Schirmann, K., M. a. G. von Keyserlingk, D.M. Weary, D.M. Veira, and W. Heuwieser. (2009). Technical note: Validation of a system for monitoring rumination in dairy cows. J. Dairy Sci. 92:6052–6055. doi:10.3168/jds.2009-2361.

Sjostrom, L. S. (2015). Alternative Housing and Management for Organic Dairy Production. MS Thesis. University of Minnesota, St. Paul. http://hdl.handle.net/11299/178916

Sjostrom, L. S., Heins, B. J., Endres, M. I., Moon, R. D., & Paulson, J. C. (2016). Short communication: Relationship of activity and rumination to abundance of pest flies among organically certified cows fed 3 levels of concentrate. *Journal of Dairy Science*, *99*(12), 9942–9948. http://doi.org/10.3168/jds.2016-11038

Sorge, U. S., Moon, R., Wolff, L. J., Michels, L., Schroth, S., Kelton, D. F., & Heins, B. (2016). Management practices on organic and conventional dairy herds in Minnesota. *Journal of Dairy Science*, *99*(4), 3183–92. doi.org/10.3168/jds.2015-10193

Stiglbauer, K. E., Cicconi-Hogan, K. M., Richert, R., Schukken, Y. H., Ruegg, P. L., & Gamroth, M. (2013). Assessment of herd management on organic and conventional dairy farms in the United States. *Journal of Dairy Science*, *96*(2), 1290–300.

Storm, A. C., & Kristensen, N. B. (2010). Effects of particle size and dry matter content of a total mixed ration on intraruminal equilibration and net portal flux of volatile fatty acids in lactating dairy cows. *Journal of Dairy Science*, *93*(9), 4223–38. http://doi.org/10.3168/jds.2009-3002

Tilman, D. (1996). Biodiversity: Population versus ecosystem stability. Ecology 77:350-363.

Tracy, B. F., Maughan, M., Post, N., & Faulkner, D. B. (2010). Integrating annual and perennial warm-season grasses in a temperate grazing system. *Crop Science*, *50*(5), 2171–2177.

USDA-AMS (USDA Agricultural Marketing Service). (2010). National Organic Program: Access to Pasture (Livestock). 7 CFR Part 205.

Undersander, D., Smith, L. H., Kaminiski, A. R., Kelling, K. A. and Doll, J. D. (2000b). Sorghum Forage. In Alternative field crops manual. University of Wisconsin-Extension, Cooperative Extension, Madison, WI.

Undersander, D., Albert, B., Cosgrove, D., Johnson, D., and Peterson, P. (2004). Pastures for profit. A guide to rotational grazing. A3529. University of Wisconsin-Extension, Madison, WI.

USDA-AMS (Agricultural Marketing Service). (2016). Milk Marketing Order Statistics. Accessed Nov. 30, 2016. https://www.ams.usda.gov/resources/marketing-order-statistics.

United States Department of Agriculture. (2016). National Organic Program. United States Department of Agriculture, Agricultural Marketing Service. Accessed Nov. 30, 2016. https://www.ams.usda.gov/about-ams/programs-offices/national-organic-program

van Eekeren,N., M.Bos, J.de Wit, H.Keidel, and J.Bloem. (2010). Effect of individual grass species and grass species mixtures on soil quality as related to root biomass and grass yield. Applied Soil Ecology 45:275-283.

Van Soest, P. J. (1994). Nutritional ecology of the ruminant. Cornell University Press. Ithaca, New York.

Wattiaux, M. A., & Karg, K. L. (2004). Protein Level for Alfalfa and Corn Silage-Based Diets: I. Lactational Response and Milk Urea Nitrogen. *Journal of Dairy Science*, *87*(10), 3480–3491. http://doi.org/10.3168/jds.S0022-0302(04)73483-9

White, S.L., Benson, G.A., Washburn, S.P., Green, Jr., J.T. (2002). Milk Production and Economic Measures in Confinement or Pasture Systems Using Seasonally Calved Holstein and Jersey Cows. J. Dairy Science. 85:95-104.

Table 1. Weather data for 2014-2015 collected from the West Central Research and Outreach Center, Morris, MN weather station.

		Temperature			Rainfall
Year	Month	High	Low	Average	Monthly total
		---------------------- ^{o}C ----------------------			---cm---
2014	May	17.2	6.7	12.8	7.5
	June	24.4	13.9	19.4	20.8
	July	25.6	13.9	20.0	4.6
	August	25.0	15.0	20.0	14.6
	September	21.7	9.4	15.6	3.6
	October	15.0	1.7	8.3	1.3
2015	May	18.9	7.2	13.3	19.7
	June	25.6	13.9	20.0	4.7
	July	27.2	16.1	21.7	9.3
	August	25.6	13.3	19.4	16.0
	September	25.0	12.2	18.9	3.4
	October	15.6	3.3	9.4	4.0

Table 2. Least squares means and standard errors for milk production, milk components, and SCS across the grazing season for organic dairy cows grazing alternative forage systems.

	Perennial grazing system		Perennial-annual grazing system	
Variable	Mean	SEM	Mean	SEM
Milk production (kg/d)	14.6	0.53	14.8	0.54
Fat percent (%)	3.9	0.1	3.8	0.1
Protein percent (%)	3.2	0.02	3.2	0.02
Somatic cell score	4.1	0.1	4.1	0.1
Milk-urea nitrogen (mg/dL)	12.5	0.8	11.5	0.9

No significant difference between feeding groups for all variables.

0

Table 3. Least squares means and standard errors for milk production, milk components, and SCC across the grazing season for specific forages within alternative forage systems for organic dairy cows.

	Perennial grazing system		Perennial-annual grazing system							
Variable	Perennial grass		Perennial grass		BMRSS		Teff		Oats/Turnips	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Milk (kg/d)	14.6[ab]	0.5	14.4[b]	0.5	15.4[a]	0.6	14.5[b]	0.6	14.9[ab]	0.6
Fat (%)	3.9	0.6	3.8	0.1	3.8	0.2	3.8	0.4	3.8	0.3
Protein (%)	3.2	0.02	3.2	0.03	3.2	0.04	3.1	0.08	3.2	0.08
MUN	12.5[a]	0.8	13.3[a]	1.0	9.3[b]	1.3	10.5[ab]	2.6	12.5[ab]	2.4
SCS	4.1	0.1	4.0	0.1	4.1	0.1	4.5	0.2	3.7	0.2

[a,b]Means within a row with different superscripts are different at $P < 0.05$.

Table 4. Least squares means and standard errors for body weight, BCS, and rumination and activity across the grazing season for organic dairy cows grazing alternative forage systems.

	Perennial grazing system		Perennial-annual grazing system	
Variable	Mean	SEM	Mean	SEM
Body weight (kg)	481	10.2	494	12.4
Body condition score	3.1	0.04	3.1	0.04
Rumination (min/d)	530^{a}	4.4	470^{b}	5.1
Activity (SCR units)	596	34.5	614	34.9

^{a,b}Means within a row with different superscripts are different at $P < 0.05$.

Table 5. Least squares means and standard errors for body weight, BCS, rumination and activity across the grazing season for specific forages within alternative forage systems for organic dairy cows.

	Perennial grazing system		Perennial-annual grazing system							
Variable	Perennial grass		Perennial grass		BMRSS		Teff		Oats/Turnips	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Body weight (kg)	481	10.2	491	12.3	494	17.8	498	25.6	492	36.3
Body condition score	3.1	0.04	3.1	0.04	3.1	0.05	3.0	0.06	3.1	0.08
Rumination (min/d)	530^{a}	4.4	506^{b}	4.9	445^{c}	5.9	437^{c}	9.1	493^{ab}	11.7
Activity (SCR units)	596^{b}	34.5	595^{b}	34.8	663^{a}	35.5	615^{b}	38.4	582^{c}	41.4

^{a,b}Means within a row with different superscripts are different at $P < 0.05$.

Manuscript

Dual flow continuous culture fermentation of organic brown midrib sorghum-sudangrass and teff grass to determine digestibility of forages in an organic dairy grazing system.

Interpretive Summary

Rumen fermentation of two warm season annuals, brown midrib sorghum-sudangrass (BMRSS) and teff grass, were compared to cool season perennial pasture and alfalfa using a dual flow continuous culture fermentation system. The BMRSS, teff and perennial pasture had lower digestibility, nitrogen flow as a percentage of total nitrogen, and pH compared with alfalfa. Fermentation of the warm season grasses was similar to the cool season perennial pasture, indicating the potential for successful use of warm season grasses in grazing systems for dairy cows.

ABSTRACT

The objective of this study was to compare warm season annual grasses to cool season perennial pasture for ruminal nutrient digestibility and nitrogen synthesis in a dual-flow continuous culture rumen fermentation system. Dietary treatments were 1) alfalfa, 2) cool season perennial pasture (CSP), 3) brown midrib sorghum-sudangrass (BMRSS), and 4) teff grass from the organic dairy production system at the University of Minnesota organic dairy in Morris, MN. Treatments were randomly assigned to fermenters with 7 d for diet adaptation and 3 d for data and sample collection. Fermenter samples for pH, NH_3-N, and VFAs were collected on day 8, 9, and 10. Apparent dry matter, organic matter, neutral detergent fiber, and acid detergent fiber digestibility were lower in pasture grasses, (49.8%, 33.3%, 58.4%, and 60.8%, respectively), compared to alfalfa (69.4%, 54.1%, 75.5%, and 75.5%, respectively). True dry matter and organic matter digestibility were lower for pasture grasses (65.4% and 47.2%, respectively) compared to alfalfa (85.8% and 69.2%, respectively). Fermenter pH and total volatile fatty acids were not affected by forage. Ammonia N concentrations were highest in alfalfa compared to the other pasture grasses. Crude protein degradation was not affected by forage treatment. The flow of NH_3-N was greatest for alfalfa, reflecting the greatest NH_3-N concentration. The flow of total N was greatest for alfalfa, lowest for CSP and BMRSS, and intermediate for teff. Flows of bacterial N, efficiency of bacterial N, non-NH_3-N, and dietary N were not affected by forage treatment. Overall, the fermentation of the warm season grasses was similar to the CSP, indicating the potential for successful use of warm season grasses in grazing systems for organic dairy cows.

INTRODUCTION

Continuous culture rumen fermentation systems are in vitro systems that can provide estimates of rumen fermentation, (Hannah, 1986). Pasture forage makes up a large portion of the diet of organic dairy cows. Previous continuous culture studies using pasture diets generally compared a pasture-based diet to a diet with an additive or a diet that is not pasture based. Soder et al. (2011) compared high quality pasture, and low quality pasture, with either 5% or 10% inclusion rate of molasses as four diets in continuous cultures. A study by Soder et al. (2013a) compared a 100% orchardgrass diet to orchardgrass diets including 10% flaxseed, canola, or sunflower seed (Soder et al., 2013a). In another study, Soder et al., (2013b) compared an orchardgrass pasture diet to a 50%TMR, 50% pasture diet, a 100% TMR diet, and a pasture diet supplemented with 10% flaxseed (Soder et al., 2013b). Bargo et al. (2003) compared different levels of pasture intake using low DMI, medium DMI, and high DMI, as well as a pasture diet supplemented with concentrate (Bargo et al., 2003). One study compared fresh alfalfa to alfalfa hay in continuous culture to determine differences in rumen fermentation when using stored feed (Ribeiro et al., 2005).

Warm season grasses are gaining interest for cattle producers as important pasture forage that may help to extend the grazing season by providing adequate herbage mass during summer because of their heat and drought tolerance (Moore et al., 2004; Hudson et al., 2010; Tracy et al., 2010). However, there is limited research regarding the effects of dairy cattle grazing warm season grasses. This study is the first to examine warm season grasses in continuous culture. There are few studies that compare digestibility and ruminal fermentation of pasture diets of different species composition in continuous culture, although one study was conducted that used fresh orchardgrass or red clover in combination with different inclusion of corn grain in continuous culture (Loor et al., 2003). In complementary grazing systems, farmers often rotate grazing cows to pastures of different species composition at different times throughout the grazing season. Therefore, the objectives of this study were to compare nutrient digestibility, ruminal fermentation, and microbial protein synthesis using different types of forages that may be used in grazing systems in the Midwest as substrate. This study used a dual-flow continuous culture rumen fermentation system to evaluate digestibility and microbial fermentation response to four treatments of forages: 1) BMR sorghum sudangrass (BMRSS), 2) teff grass, 3) cool season perennial pasture (CSP), which consisted of samples of grazed pasture composed of a mixture of cool season perennial grasses and legumes, and 4) alfalfa.

Results from this study may provide insight into the forage quality of warm season grasses used in pasture systems for organic dairy cattle and how alternative forages may affect rumen fermentation within a cow. The objective of this study was to compare fermentation of warm season grasses (BMRSS and teff grass) with two pasture control diets (CSP and alfalfa) in a dual-flow continuous culture rumen fermentation system.

MATERIALS AND METHODS

Experimental Design and Treatments

Four experimental forage treatments (CSP, alfalfa, BMRSS, teff grass) were randomly allocated to an 8-unit, dual flow continuous culture rumen fermentation system designed to simulate rumen fermentation and outflow to the small intestine. Four forage dietary treatments were compared during two experimental periods. The forage component of the study was conducted at the West Central Research and Outreach Center (Morris, MN) from May to October 2015. Perennial pastures were established in 2012 and grazing began in 2013. The current study was conducted with CSP and warm season grasses during the 2015 grazing year. The BMRSS and teff grass were chosen as the warm season grasses because these grasses are starting to be utilized by organic farmers in their grazing systems in the Midwest. The BMRSS (Black Hawk 12 Organic, Blue River Hybrids, Ames, IA) and teff grass were planted on May 28, 2015. Perennial pasture samples were harvested every other day in June by randomly tossing a $0.23m^2$ square into each paddock before grazing and hand clipping to 5 cm above the ground. Because the alfalfa was not grazed, a large quantity of third cut alfalfa was harvested at one time using hand clippers at random locations in the field. The BMRSS and teff grass samples were harvested before grazing by cutting sample to 5 cm above the ground. Teff was not well established in the pastures at the WCROC, so in order to collect adequate DM for the study additional teff samples were collected from a university research plot in St. Paul, MN and a farm in Peterson, MN. Samples were dried in an oven at 60 degrees C for 48 hours and ground (2-mm screen; Wiley mill, Thompson Scientific, Philadelphia, PA). Dried, ground forage samples were mixed thoroughly in their respective treatment and pelleted in a pellet mill with a CL-5 California Pellet Mill (California Pellet Mill Co., Crawfordsville, IN) to a final dimension of 6mm diam x 12 mm long. Ground forage samples were analyzed with NIR and minerals were analyzed using wet chemistry for the dietary composition (Rock River Labs, Watertown, WI). Chemical compositions of the four forage treatment diets are in Table 1.

Continuous culture operation

An 8-unit, dual flow continuous culture rumen fermenter system, similar to that described by Hannah et al., (1986) was used in the current study, and fermenter operation was similar to (Ruiz-Moreno et al., 2015). Fermenter volumes ranged from 1,055 mL to 1,103 mL. Ten liters of ruminal fluid and 1.5 kg of ruminal digesta were collected approximately four hours after the morning feeding from one ruminally cannulated lactating Swedish Red×Montbeliarde×Holstein cow consuming a high forage TMR twice daily, (70% forage, 30% concentrate, no Rumensin). Liquid samples were collected from the rumen using a cup by hand. To maintain sample temperature, liquid was transported from the dairy facility to the laboratory in an insulated thermos container. Within 20 minutes of digesta and fluid collection, liquid and whole rumen samples were mixed using a homogenizer, squeezed through 2 layers of cheesecloth, and fermenters were inoculated with 1 L of rumen fluid. Solid dilution rate and liquid dilution rate were 4% per h similar to Bargo et al. (2003), and 10% per h similar to Cerrato-Sanchez et al. (2007), respectively, attained by regulation of buffer input, and filtrate removal.

Fermenters were maintained at a constant temperature of 39^{o} C and were constantly purged with N_2 gas at a rate of 40 ml/min to maintain anaerobiosis. Total DM intake for fermenters was maintained at 60g of DM/fermenter daily (de Veth and Kolver, 2001) and was fed to fermenters in eight equal proportions throughout the day with a motorized auger which slowly pushed feed into the fermenter over eight equally spaced, 1.5 hour periods per day. The pH was maintained in a range of 5.6 to 6.7 with automatic influx of HCl and NaOH as needed, and recorded using Daqboard and Dasylab software (Daisy Lab, National Instrument Services, Austin, TX).

Sample collection and analysis

Fermenters were operated for two consecutive 10-d periods consisting of a 7-d diet adaptation period followed by a 3-d sample collection period. Fermenter pH was recorded automatically per second and mean, minimum, and maximum pH were analyzed for the 3-d sampling time by fermenter for each period.

Effluent was collected for the first 7 d in 4-L containers and weighed at 1500 h and discarded. On days 8 to 10, a water bath maintained the temperature of the effluent containers at 2^{o} C to prevent further microbial fermentation. Solids and liquid effluent samples were collected on d 8, 9 and 10 and homogenized (PT10/3S homogenizer, Kinematica GmbH, Bohemia, NY) for 2 min. A subsample of 500 mL of effluent was taken each day, and the three sample days were composited. This sample was kept frozen at -20^{o} C until analysis for total N, Ammonia-N, and VFA. A subsample, approximately 500 mL of the composited 1,500 mL effluent from each fermenter was lyophilized and used for analysis of DM, OM, NDF, ADF, ash and purines. On the final day of sampling, fermenter contents were squeezed through cheesecloth, the liquid was centrifuged at 1,000 x g for 10 minutes to remove feed particles and then centrifuged at 20,000 x g for 20 minutes to isolate the microbial pellet. The microbial pellet was suspended in distilled water, frozen at -20^{o} C and then lyophilized prior to analysis of DM, Ash, total N, and purines.

Pelleted forage samples (dietary forage treatments), effluent, and microbial pellets were analyzed for DM by drying at 105^{o}C for 24 h. Ash was determined by the weight difference after 24 h combustion at 550^{o}C (AOAC, 1984; method 967.04). The total N content of the diets, effluent, and bacteria and ammonia N of diets and effluent were determined by steam distillation using a 2300 Kjeltec Analyser Unit (Foss Tecator AB, Hogonas, Sweden). Sequential fiber analyses (Van Soest, 2015) were used to determine NDF and ADF concentrations of the diet and effluents. Purine concentrations were determined by the method of Zinn and Owens (1986). Purine contents of the effluent and bacteria were used to calculate nitrogen metabolism and microbial efficiency. Effluent samples were prepared for VFA analysis using the procedure for luminal fluid preparation as described by (Erwin et al. 1961). Rumen fluid effluent was centrifuged to remove heavy feed particles, then (2.0 mL) was mixed with a 25% meta-phosphoric acid solution (0.5 mL), and centrifuged at 10,000 g for 15 minutes until supernatant was clear. The supernatant was stored at -20^{o} C until analyzed. Analysis was performed via gas chromatography (Agilent 7890B GC-FID with a G4567A Autosampler). The Agilent DB-FFAP column was 30 m length, 0.25 mm diameter, and had a film thickness of 0.15 micro meters. Chromatographic conditions were 1 microliter injection with an inlet temperature of 240°C, helium as carrier gas at 1 mL/min constant flow, initial oven temperature of 60°C with a 2 min hold time, ramp at 20°C/min to 220°C and a 1 min hold time at 220°C. The FID detector was set at 250°C.

Statistical Analysis

Data were analyzed using the MIXED procedure in SAS (SAS Inst. Inc., 2013). Forages were analyzed as a fixed effect and period was a random effect. Contrasts of the warm season annuals compared to the cool season perennials (BMRSS, Teff vs CSP/Alfalfa), and warm season annuals compared to alfalfa and cool season perennials (CSP/Alfalfa vs BMRSS/Teff) were conducted. All treatment results were reported with least squares means, with significance declared at $P<0.05$. The pH was analyzed for mean, maximum, and minimum pH for the three-day sampling period. Furthermore, pH was also analyzed using the MIXED procedure in SAS for amount of time each fermenter spent below pH 5.8 and above pH 6.4 (de Veth and Kolver, 2001).

RESULTS AND DISCUSSION

The chemical composition of the forage treatments are in Table 1. Most composition results are from analyses performed by Rock River Labs Inc., while the CP, NDF, and ADF represent results using the same lab equipment as the post-fermenter results. The warm season grasses (BMRSS and teff grass) have lower CP than alfalfa and cool season perennial pasture diets. Dietary protein levels may affect ruminal fermentation patterns and digestibility and create confounding results (Bach, 1999), which is why many in vitro studies feed isonitrogenous diets when investigating alternative treatments. However, the current study investigated the differences in ruminal fermentation between alternative pasture grasses, and it was important to keep the treatments at their original protein levels, with the understanding that this may ultimately affect fermentation, and may be of interest to reflect a grazing situation (Bach, 1999). This difference in N content of the diets was accounted for by expressing results as a percentage of total N intake (Bach, 1999).

Digestibility

Least square means of apparent and true digestibility and pH flow for forage treatments are in Table 2. The CSP, BMRSS and teff grass had lower ($P < 0.05$) apparent DM, OM, NDF, and ADF digestibility than alfalfa. True DM and OM digestibilities were lower ($P < 0.05$) in grasses compared with alfalfa. The contrast of warm season grasses to

CSP and alfalfa had a tendency to be different for apparent OM digestibility ($P = 0.06$) and true OM digestibility ($P = 0.02$), but not for the warm season grasses compared to CSP. A study by de Veth and Kolver (2001) found a range of apparent DM digestibility (44.7 to 56.4%) and OM digestibility (48.1 to 58.7%) which was similar to the results from the current study for DM (47.1%) and OM (32.5%) digestibility. A study by Soder et al. (2013) found much higher apparent digestibility of DM (64.3%), OM (70.0%), and NDF (84.9%) for CSP in a dual flow continuous culture fermenter system, which may have been due to a greater CP level (25%) or the higher level of daily diet (70 g DM/day) in the study by Soder et al. (2013). A study evaluating alfalfa in continuous culture found lower apparent NDF and ADF digestibility (39.1% and 40.2%) than results from the current study (75.5% and 75.5%), respectively for alfalfa (Ribeiro et al., 2005). The apparent NDF and ADF digested in this study for CSP (52.6% and 55.4%) are similar to the apparent NDF and ADF digested (52.6% and 54.3%), respectively in a previous study using pasture in continuous culture diets (Cerrato-Sanchez et al., 2007) and another study which used pasture (59.8 to 71.1% and 60.5 to 74.8%) fed at 60 g of DM/d (de Veth and Kolver, 2001). There are no previous studies investigating warm season grasses in continuous culture, so it is difficult to compare the results of BMRSS and teff grass used in this study. The overall findings of apparent digestibility are consistent with previous research comparing alfalfa to grass in vivo, in which alfalfa disappeared more quickly from the rumen than the perennial ryegrass because a faster rate of digestion and faster particle size reduction of alfalfa (Waghorn et al., 1989). True OM digestibility for alfalfa in the current study (69.2%) is higher than a previous study found for OM digestibility of alfalfa (46.1%) in continuous culture (Ribeiro et al., 2005). Results for CSP of true DM

(64.0%) and true OM (47.0%) digestibility was lower than results found in a previous study using CSP for true DM (81.1%) and true OM (84.2%) digestibility (Soder et al., 2013). However, the results of CSP are higher than true DM digestibility (41.2%) and true OM digestibility (37.8%) in another study using pasture diets in continuous culture (Bach et al., 1999). A previous study found that higher nutrient digestibility resulted in higher bacterial OM flow (Ribeiro, 2005). Results from Ribeiro et al., (2005) were different than results from the current study because although there was higher nutrient digestibility in alfalfa, bacterial OM flow was similar across all treatments (Table 14).

Volatile Fatty Acids

Least square means of volatile fatty acids for the forage treatments are in Table 3. Total VFA produced was not different between different forage diets. The amount of total VFA for CSP (77.6 mM) was similar to amount of total VFA found in a previous study for medium (65 g DM/d) pasture intake (81.8 mM) in continuous culture (Bargo et al., 2003) but higher than total VFAs produced in a ryegrass only diet in continuous culture fed at 60 g DM/d (62.3 mM) (de Veth and Kolver, 2001).

There were some differences in individual VFA concentrations and in molar proportions of VFA. These differences may indicate differences in the shift of the rumen microbial population when on the different grass species studied (Ribeiro et al., 2005). Similar results of individual VFA production for CSP were found for a pasture diet in continuous culture (Bargo et al., 2003). Molar proportions of acetate (71.2 mol/100mol), propionate (20.0 mol/100 mol), and butyrate (7.2 mol/100 mol) were similar to previous results of a cool season perennial and legume pasture diet in continuous culture with results of 71.4, 17.8, and 9.6 mol/100 mol for acetate, propionate, and butyrate, respectively (Bach et al., 1999).

A study by Bargo et al., (2003) showed an inverse correlation between pH patterns and VFA production. There were no differences in mean pH between the forage treatments in this study and the differences in individual VFAs do not match the pattern of pH. However, another study found no large differences of individual proportions of VFA with change in pH (de Veth and Kolver, 2001), and a model developed by Russell et al., (1998) found that diet has more impact than pH on changes in VFA production. The molar proportion of butyrate was greatest for BMRSS compared to the other forage treatments. A study reviewing the relationship between rumen VFA and milk production found this relationship was lowest for acetate and greatest for butyrate (Seymour et al., 2005). This is consistent with the results of a concurrent grazing study which found significantly higher milk production from cows grazing BMRSS than cows on teff or CSP (Ruh et al., 2017).

Isobutyrate was greater in alfalfa than the grass treatments, which is similar to the pattern of true and apparent digestibility of DM and OM of the dietary treatments (Table 12). Alfalfa may have provided more RDP than the grass diets, which could have led to higher isobutyrate production (Brito and Broderick, 2007). The CP degradation (Table 4) was not different between treatments; however, the contrast of warm season grasses vs alfalfa and CSP was significant, which may support this theory. Molar proportions of acetate (72.1 mol/100 mol), propionate (16.5 mol/100 mol), and butyrate (7.9 mol/100 mol) of alfalfa from this study were similar to previously reported values of acetate (73.6

mol/100 mol), propionate (14.8 mol/100 mol), and butyrate (8.3 mol/100 mol) for fresh alfalfa in continuous culture (Ribeiro et al., 2005).

There are no previous studies that evaluated warm season grass in continuous culture. One study investigated warm season and cool season grasses fed to cannulated steers and found significance for the contrast of warm season vs cool season for the molar proportions of the VFAs propionate, butyrate, and valerate in rumen fluid (Bohnert et al., 2011), which was in agreement to the current study. A study that used a semi-continuous RUSITEC system to investigate fermentation of a perennial warm season grass, *Andropogon gayanus*, reported different molar proportions of VFA (Kouazounde et al., 2015) than the current study for annual warm season grasses using a continuous culture system.

Nitrogen metabolism

Table 4 depicts nitrogen metabolism of fermenters fed the various forages. Nitrogen intake was highest for alfalfa, intermediate for CSP, and lowest for warm season grasses based on the dietary CP of the forage treatments. It is well documented that alfalfa has high protein, and that CSP have higher crude protein than warm season grasses (Ruh et al., 2017, unpublished). Table 1 shows CP values of the dietary forage treatments for this study, which reflects the amount of nitrogen intake by the fermenters displayed in Table 4. Both contrasts were significant ($P < 0.001$) for amount of N intake per day. The N-intake can affect rates of microbial growth and ultimately digestibility measured in in vitro systems like the continuous culture system and in cows (Bach et al., 1999). For this reason, diets are traditionally formulated to be isonitrogenous when determining effects of treatments. However, for this study we were interested in observing the effect of each type of dietary forage on fermentation. Farmers grazing these warm season grasses as complementary grasses to cool season grasses in a grazing system would most likely not be supplementing protein to create isonitrogenous grazing diets for cows. Therefore, we chose to examine the effects of grasses with their natural nitrogen and protein levels. Crude protein degradation averaged 73% and was similar ($P > 0.05$) between dietary treatments in the fermenters. This observation is slightly lower than CP digestibility (84.2%) found in a previous study using pasture diets in continuous culture (Soder et al., 2013). The CP degradation was significant for the contrast of AC vs BT ($P = 0.04$) but similar for warm season versus CSP.

Ammonia-N was greater ($P < 0.05$) in alfalfa fed fermenters (22.5 mg/dl) than for CSP (7.5 mg/dl), BMRSS (7.4 mg/dl) and teff (8.9 mg/dl) fermenters. Similar results of ammonia-N were found for pasture in continuous culture (10.5 mg/dL) compared to the CSP in the current study (Bach et al., 1999). The CSP (1.50 g/d) and BMRSS (1.51 g/d) had similar total N flow, while alfalfa had the greatest ($P < 0.05$) total N flow (1.99 g/d) and teff was intermediate in total N flow (1.71 g/d). As a percent of total N flows, ammonia nitrogen was greater ($P < 0.05$) in alfalfa than the grasses, which reflects the pattern of total ammonia nitrogen for each treatment. There was no difference between treatments for non-ammonia nitrogen, bacterial nitrogen, or dietary nitrogen flows as a percent of total nitrogen. Even though alfalfa had greater ammonia nitrogen concentrations, there were no differences in the efficiency of microbial protein synthesis between any of the treatments, on either a DM or OM basis. This is interesting, but shows that although there was lower ammonia-N in all the grass treatments than alfalfa, there were still adequate amounts of ammonia-N for microbial protein synthesis. The minimum amount of ammonia-N required for microbial protein synthesis was estimated to be 5 mg/dL for in vitro systems (Satter and Slyter, 1974), and all treatments in this study were well above that value. Efficiency of microbial protein synthesis on a DM basis in the current study ranged from 15.0 g N/kg DM to 19.9 g N/kg DM which is slightly lower than the previous result of 23.9 g N/kg DM for pasture in continuous culture (Bargo et al., 2003). Efficiency of microbial protein synthesis on an organic matter basis in the current study ranged from 21.3 to 33.3 g N/kg OM which is similar to previous results for alfalfa (37.6 g N/kg OM) (Ribeiro et al., 2005) and pasture (15.1 to 31.4 g N/kg OM) in continuous culture (de Veth and Kolver, 2001; Cerrato-Sanchez et al., 2007; Soder et al., 2013; Soder et al., 2016).

There was no difference ($P < 0.05$) between mean, minimum, or maximum pH between dietary treatments. One continuous culture rumen fermenter study researching effects of pH levels determined that the optimal pH for high quality pasture forage is 6.35 (de Veth and Kolver, 2001), which is very close to the mean pH for our treatments, 6.38, 6.18, 6.19, and 6.22 for alfalfa, CSP, BMRSS, and teff grass, respectively. Some studies indicate that decreased fermentation may take place beginning at a pH of lower than 6.25 (Sauvant, 1999), but a large decrease in digestibility may not occur until below a ruminal pH of 5.8 in a high quality pasture diet (Bargo et al., 2003; de Veth et al., 2001). We analyzed the amount of time spent below 5.8 as well as the amount of time spent above 6.4 for this study. Time spent below pH 5.8 ranged from 1 to 5 minutes/day. Sauvant et al., (1999) found that it may be possible to experience a pH below 6.0 for 4 hours without affecting microbial fermentation. We analyzed the pH of lower than 5.8 because this was high quality pasture forage from spring pastures (de Veth and Kolver, 2001), but did not observe the amount of time below this low range to be anywhere near four hours. Time spent above pH of 6.4 was also analyzed, assuming the optimal pH level for these diets would be 6.35 (de Veth and Kolver, 2001). Treatments averaged 4, 6, 7, and 12 hours per day above pH 6.4 for CSP, BMRSS, Teff, and alfalfa, respectively, however there is limited research about the effect of extended amounts of time above optimal pH.

Because this is an in vitro system, diets may be affected differently when actually consumed by cows (Mansfield, et al, 1995). Although “fresh pasture grass” was used, it underwent heating and pressure in the drying and pelleting processes which could change some components of the grass. These changes should have been uniform across all treatments; however, it is important to note that dietary values of pelleted grasses may be different than the actual pasture forage grasses that cows would be consuming in a grazing system. Fresh forages have higher concentrations of rapidly fermented sugars as well as higher concentrations of more digestible protein, which could have been lost during some of the heating processes of our forages (Van Soest, 1994). This continuous culture system excludes protozoa from the system, which could also affect some results, as this leaves fermentation to be completed only by bacteria (Hannah, et al., 1986; Mansfield, et al., 1995). In addition, most grazing cows do not consume pasture-only diets, so there may be more complex interactions if grazing cows were to be supplemented with concentrate or processed forages while grazing pasture. Previous studies have shown alterations in bacterial growth rates with different combinations of carbohydrates, which may decrease fiber digestibility (Russel and Baldwin 1978), but improve N utilization when grazing cows are supplemented with TMR (Vibart, 2010). Minimum effective fiber requirements may be different for cows grazing high quality pasture than for cows fed mixed forage and concentrate diets because of interactions that occur in a mixed diet (Kolver et al., 1998; De Veth and Kolver, 2001).

It is accepted that grazing cows will experience changes in their diet throughout the grazing season due to weather and the gradually increasing maturity of pastures. Cows in a complementary grazing system may have additional disruptions to their diet because they often graze one type of grass, then sequentially another type of grass in a different pasture. Results from the current study found several changes in ruminal fermentation between forage treatments of different species. A concurrent grazing study found that cows grazing BMRSS have significantly lower daily rumination and higher milk production than cows grazing CSP (Ruh et al., 2017, unpublished). Future research could investigate how this shift in microbial population, possibly every few days or every few weeks, affects a grazing dairy cow. It would be interesting to determine what kind of effect a sequential pasture rotation may have on the rumen microbial population and fermentation.

CONCLUSION

This study found several differences in molar concentration of VFA of the warm season grasses BMRSS and teff grass compared to CSP and alfalfa, which may indicate slightly different ruminal fermentation. Overall, fermentation of warm season grasses was similar to the CSP. The BMRSS, teff and CSP all had similar digestibility, nitrogen flows as a percentage of total nitrogen, and which were lower than values for alfalfa. All forage treatments had similar pH. This is an indication that warm season grasses may be successfully grazed by dairy cows and may be included in a complementary grazing system with cool season perennials, without concerns about negative impact on rumen or animal health. Further research dealing with warm season grasses in continuous culture systems should include variations of concentrate and TMR supplementation. Research on the fermentation characteristics of warm season grasses should be studied more because very little previous research has been conducted on this topic. Economic analysis of warm season grasses used in a grazing system will also be important and valuable research for farmers managing pastures with warm season grasses.

ACKNOWLEDGEMENTS

The authors express gratitude to the interns and graduate students at the University of Minnesota West Central Research and Outreach Center, Morris, for their assistance in data collection. This material is based upon work that is supported by the Ceres Trust.

REFERENCES

AOAC. 1984. Official Methods of Analysis (14th Ed.). Association of Official Analytical Chemists, Washington, DC

Bach, a, Yoon, I. K., Stern, M. D., Jung, H. G., & Chester-Jones, H. (1999). Effects of type of carbohydrate supplementation to lush pasture on microbial fermentation in continuous culture. Journal of Dairy Science, 82(1), 153–160. http://doi.org/10.3168/jds.S0022-0302(99)75219-7

Bargo, F., Varga, G. a, Muller, L. D., & Kolver, E. S. (2003). Pasture intake and substitution rate effects on nutrient digestion and nitrogen metabolism during continuous culture fermentation. Journal of Dairy Science, 86(4), 1330–1340. http://doi.org/10.3168/jds.S0022-0302(03)73718-7

Brito, A. F. and Broderick, G. A. (2007). Effects of feeding different protein supplements on production and nutrient utilization in dairy cows. Journal of Dairy Science 90:1816-1827.

Bohnert, D. W., DelCurto, T., Clark, a a, Merrill, M. L., Falck, S. J., & Harmon, D. L. (2011). Protein supplementation of ruminants consuming low-quality cool- or warm-season forage: differences in intake and digestibility. Journal of Animal Science, 89(11), 3707–17. http://doi.org/10.2527/jas.2011-3915

Erwin, E. S., Marco, G. J., & Emery, E. M. (1961). Volatile fatty acid analyses of blood and rumen fluid by gas chromatography. Journal of Dairy science, 44(9), 1768-1771.

Cerrato-Sánchez, M., Calsamiglia, S., & Ferret, a. (2007). Effects of patterns of suboptimal pH on rumen fermentation in a dual-flow continuous culture system. Journal of Dairy Science, 90(9), 4368–4377. http://doi.org/10.3168/jds.S0022-0302(07)71634-X

de Veth, M. J., & Kolver, E. S. (2001). Digestion of ryegrass pasture in response to change in pH in continuous culture. Journal of Dairy Science, 84(6), 1449–1457. http://doi.org/10.3168/jds.S0022-0302(01)70178-6

ERS (Economic Research Service). (2014). Organic market overview. Accessed Nov. 17, 2015. http://www.ers.usda.gov/topics/natural-resources-environment/organic-agriculture/organic-market- overview.aspx.

Hannah, S. M., Stern, M. D., & Ehle, F. R. (1986). Evaluation of a dual flow continuous culture system for estimating bacterial fermentation in vivo of mixed diets containing various soya bean products. Animal Feed Science and Technology, 16(1-2), 51–62.

Hoover, W. H., T. K. Miller, S. R. Stokes, and W. V. Thayne. (1989). Effects of fish meals on rumen bacterial fermentation in continu- ous culture. J. Dairy Sci. 72:2991–2998.

Hudson, Leep, Dietz, Ragavendron, Kravchenko, (2010). Integrated Warm- and Cool Season Grass and Legume Pastures: I. Seasonal Forage Dynamics. *Agronomy Journal, 102 (1), 303-309.*

Kolver, E. S., and L. D. Muller. (1998). Performance and nutrient intake of high producing Holstein cows consuming pasture or a total mixed ration. J. Dairy Sci. 81:1403–1411.

Kouazounde, J. B., Gbenou, J. D., He, M., Jardim, T., Jin, L., Wang, Y., and McAllister, T. A. (2015). Effects of essential oils from african basil on fermentation of andropogon gayanus grass in the artificial rumen (RUSITEC). Canadian Journal of Animal Science, 95(3), 425–431. http://doi.org/10.4141/CJAS-2014-189

Maher, J., Stakelum, G., & Rath, M. (2003). Effect of daily herbage allowance on the performance of spring-calving dairy cows. Irish Journal of Agricultural and Food Research, 42(2), 229–241.

Mansfield, H. (1995). Comparison of microbial fermentation in the rumen of dairy cows and dual flow continuous culture. Animal Feed Science and Technology, 55(1-2), 47–66. http://doi.org/10.1016/03778-4019(59)82028

Moore, K. J., White, T. A., Hintz, R. L., Patrick, P. K., & Brummer, E. C. (2004). Sequential grazing of cool- and warm-season pastures. Agronomy Journal, 96(4), 1103–1111. http://doi.org/10.2134/agronj2004.1103

Najda, H. (2003). Sorghum, sudangrass, and sorghum-sudan-grass hybrids for forage. Alberta Agriculture, Food and Rural Development. Edmonton, AB. Agdex 126 20 1.

Ribeiro, C. V. D. M., Karnati, S. K. R., & Eastridge, M. L. (2005). Biohydrogenation of fatty acids and digestibility of fresh alfalfa or alfalfa hay plus sucrose in continuous culture. Journal of Dairy Science, 88(11), 4007–4017. http://doi.org/10.3168/jds.S0022-0302(05)73087-3

Ruiz-Moreno, M., Binversie, E., Fessenden, S. W., & Stern, M. D. (2015). Mitigation of in vitro hydrogen sulfide production using bismuth subsalicylate with and without monensin in beef feedlot diets. Journal of Animal Science, 93(11), 5346–5354. http://doi.org/10.2527/jas.2015-9392

Russell, J. B., and R. L. Baldwin. (1978). Substrate preferences in rumen bacteria: Evidence of catabolite regulatory mechanisms. Appl. Environ. Microbiol. 36:319–329.

Russell, J.B. (1998). The importance of pH in the regulation of ruminal acetate to propionate ratio and methane production in vitro. J. Dairy Sci. 81, 3222–3230

Satter, L. D., and L. L. Slyter. (1974). Effect of ammonia concentra- tion on rumen microbial protein in vitro. Br. J. Nutr. 32:199– 208. doi:10.1079/BJN19740073.Zinn, R.A. and F.N.

Statistical Analysis Systems (SAS) Institute. (2013). SAS User's Guide. SAS Institute, Cary, NC

Sauvant, D., Meschy, F., & Mertens, D. (1999). Components of ruminal acidosis and acidogenic effects of diets. Productions Animales (France).

Seymour, W. M., Campbell, D. R., & Johnson, Z. B. (2005). Relationships between rumen volatile fatty acid concentrations and milk production in dairy cows: A literature study. Animal Feed Science and Technology, 119(1-2), 155–169. http://doi.org/10.1016/j.anifeedsci.2004.10.001

Soder, K. J., Brito, A. F., & Rubano, M. D. (2013). Effect of supplementing orchardgrass herbage with a total mixed ration or flaxseed on fermentation profile and bacterial protein synthesis in continuous culture. Journal of Dairy Science, 96(5), 3228–37. http://doi.org/10.3168/jds.2012-6307

Soder, K. J., Brito, A. F., Hafla, A. N., & Rubano, M. D. (2016). Effect of starchy or fibrous carbohydrate supplementation of orchardgrass on ruminal fermentation and methane output in continuous culture. Journal of Dairy Science, 99(6), 4464–4475. http://doi.org/10.3168/jds.2015-10471

Tracy, B. F., Maughan, M., Post, N., & Faulkner, D. B. (2010). Integrating annual and perennial warm-season grasses in a temperate grazing system. *Crop Science*, *50*(5), 2171–2177. http://doi.org/10.2135/cropsci2010.02.0110

US Department of Agriculture, Agricultural Marketing Service. (2010). National Organic Program: Access to Pasture (Livestock). 7 CFR part 205. Fed. Regist. 75:7154-7195

Ruh et al., 2017 unpublished

Van Soest, P. J. 1994. Nutritional Ecology of the Ruminant. 2nd ed. Comstock Publishing, Ithaca, NY.

Vibart, R. E., Burns, J. C., & Fellner, V. (2010). Effect of replacing total mixed ration with pasture on ruminal fermentation. Professional Animal Scientist, 26(4), 435–442.

Waghorn, G.C., I.D. Shelton, and V.J. Thomas. 1989. Particle breakdown and rumen digestion of fresh ryegrass (Lolium perenne L.) and lucerne(Medicago sativa L.) fed to cows during a restricted feeding period. Brit. J. Nutr. 61:409-423.

Wales, W. J., Kolver, E. S., Thorne, P. L., & Egan, a R. (2004). Diurnal variation in ruminal pH on the digestibility of highly digestible perennial ryegrass during continuous culture fermentation. Journal of Dairy Science, 87(6), 1864–1871.

Zinn and Owens, 1986. A rapid procedure for purine measurement and its use for estimating net ruminal protein synthesis. Can. J. Anim. Sci, 66:157.

Table 1. Chemical composition (% DM) of four forage diets (alfalfa, cool season perennial pasture, BMR sorghum sudangrass, and teff grass) used in continuous culture fermentation.

	Forage Treatment			
Chemical composition, % of DM[1]	Alfalfa	Perennial pasture	BMRSS	Teff
OM	88.1	90.5	89.3	85.5
CP	25.1	18.0	16.9	17.0
NDF	29.8	50.1	50.0	51.2
ADF	22.0	27.2	25.7	26.3
Ether extract	1.61	2.54	2.09	2.94
Ash	11.9	9.5	12.4	14.5
Ca	1.69	0.63	0.71	0.41
Mg	0.51	0.19	0.37	0.30
P	0.38	0.28	0.31	0.42
K	3.84	2.72	3.54	5.78
TTNDFD[2]	43.9	50.2	56.6	62.4

[1]Chemical composition results from Rock River Labs, Watertown, WI analyses; CP, NDF, and ADF represent results from Stern lab, St. Paul, MN.
[2]Total tract NDF digestibility
[a,b]Means within a row with different superscripts are different at $P < 0.05$.

Table 2. Nutrient digestibility and pH of four forage diets (alfalfa, cool season perennial pasture, BMR sorghum sudangrass, and teff grass) during continuous culture fermentation.

Item	Forage					Contrast (*P*-value)	
	Alfalfa	Perennial pasture	BMRSS	Teff	SEM	BMRSS/Teff vs pasture	Alfalfa/pasture vs BMRSS/Teff
Apparent digestibility, %							
DM, %	69.4[a]	47.1[b]	52.6[b]	49.8[b]	5.2	0.53	0.20
OM, %	54.1[a]	32.5[b]	38.1[b]	29.4[b]	4.7	0.83	0.06
NDF, %	75.5[a]	52.6[b]	65.9[ab]	56.6[b]	5.3	0.21	0.61
ADF, %	75.5[a]	55.4[b]	67.5[ab]	59.4[ab]	5.3	0.24	0.72
True digestibility,[1] %							
DM, %	85.8[a]	64.0[b]	66.2[b]	65.9[b]	5.7	0.74	0.09
OM, %	69.2[a]	47.0[b]	50.4[b]	44.1[b]	4.1	0.96	0.02
pH							
Mean	6.38	6.18	6.19	6.22	0.10	0.84	0.46
Minimum	5.88	5.14	5.41	5.92	0.31	0.19	0.63
Maximum	7.26	6.76	7.23	7.01	0.25	0.27	0.67

[1]Corrected for contribution of bacterial flow

[a,b]Means within a row with different superscripts are different at $P < 0.05$.

Table 3. Volatile fatty acid concentration of four forage diets (alfalfa, cool season perennial pasture, BMR sorghum sudangrass, and teff grass) in continuous culture fermentation

	Forage					Contrast (*P*-value)	
VFA	Alfalfa	Perennial pasture	BMRSS	Teff	SEM	BMRSS/Teff vs pasture	Alfalfa/pasture vs BMRSS/Teff
Total VFA, mM	78.58	77.59	75.61	82.32	13.05	0.93	0.95
Individual VFA (mol/100mol)							
Acetate	72.06[a]	71.23[ab]	67.70[b]	74.99[a]	1.30	0.94	0.82
Propionate	16.51[b]	19.98[a]	18.42[ab]	17.11[b]	0.54	<0.01	0.38
Butyrate	7.92[b]	7.18[b]	10.05[a]	6.71[b]	0.58	0.05	0.08
Isobutyrate	0.69[a]	0.27[b]	0.25[b]	0.17[b]	0.03	0.18	0.01
Isovalerate	0.82[ab]	0.30[ab]	1.20[a]	0.09[b]	0.31	0.39	0.79
Valerate	1.71[a]	0.90[b]	2.06[a]	0.83[b]	0.17	0.02	0.43
Caproate	0.29[a]	0.14[b]	0.32[a]	0.10[b]	0.03	0.13	0.94
A:P ratio	4.37[a]	3.57[b]	3.70[b]	4.41[a]	0.18	0.05	0.63

[a,b]Means within a row with different superscripts are different at $P < 0.05$.

Table 4. Nitrogen metabolism of four forage diets (alfalfa, cool season perennial pasture, BMR sorghum sudangrass, and teff grass) in continuous culture fermentation

	Forage					Contrast (P-value)	
Variable	Alfalfa	Cool	BMRSS	Teff	SEM	BMRSS/Teff vs pasture	Alfalfa/pasture vs BMRSS/Teff
N intake, g/d	3.09[a]	2.31[b]	2.18[c]	2.20[c]	0.01	0.01	0.01
NH3-N, mg/dl	22.5[a]	7.5[b]	7.4[b]	8.9[b]	0.75	0.47	0.01
CP degradation, %	79.8	77.2	69.1	65.9	4.6	0.12	0.04
N flows, g/d							
Total N	1.99[a]	1.50[b]	1.51[b]	1.70[ab]	0.11	0.43	0.18
NH3-N	0.52[a]	0.17[b]	0.17[b]	0.20[b]	0.02	0.65	0.01
NAN	1.46	1.33	1.34	1.50	0.12	0.52	0.84
Bacterial N	0.84	0.81	0.67	0.75	0.14	0.57	0.42
Dietary N	0.62	0.53	0.67	0.75	0.12	0.23	0.27
N flows, % of total N flow							
NH3-N	26.5[a]	11.6[b]	11.4[b]	11.8[b]	1.8	0.99	0.01
NAN	73.5[a]	88.4[b]	88.6[b]	88.2[b]	1.8	0.99	0.01
Bacterial N	41.3	54.1	44.4	43.8	6.1	0.21	0.57
Dietary N	32.1	34.3	44.2	44.4	6.0	0.20	0.09
Efficiency of Microbial protein synthesis							
g N/kg DM truly digested	15.0	19.9	16.0	18.7	2.7	0.45	0.96
g N/kg OM truly digested	21.3	30.4	24.0	33.3	4.9	0.78	0.58

[a,b]Means within a row with different superscripts are different at $P < 0.05$

COMPREHENSIVE REFERENCES

Adin, G., R. Solomon, M. Nikbachat, A. Zenou, E. Yosef, A. Brosh, A. Shabtay, S. J. Mabjeesh, I. Halachmi, and J. Miron. (2009). Effect of feeding cows in early lactation with diets differing in roughage- neutral detergent fiber content on intake behavior, rumination, and milk production. J. Dairy Sci. 92:3364–3373.

Allen, M. S. (2000). Effects of diet on short-term regulation of feed intake by lactating dairy cattle. *Journal of Dairy Science*, *83*(7), 1598–1624. http://doi.org/10.3168/jds.S0022-0302(00)75030-2

AOAC. 1984. Official Methods of Analysis (14th Ed.). Association of Official Analytical Chemists, Washington, DC

Astigarraga, L., Bianco, A., Mello, R., & Montedónico, D. (2014). Comparison of brown midrib sorghum with conventional sorghum forage for grazing dairy cows. *American Journal of Plant Sciences*, *5*(7), 955

Bach, a, Yoon, I. K., Stern, M. D., Jung, H. G., & Chester-Jones, H. (1999). Effects of type of carbohydrate supplementation to lush pasture on microbial fermentation in continuous culture. Journal of Dairy Science, 82(1), 153–160. http://doi.org/10.3168/jds.S0022-0302(99)75219-7

Bainbridge, M. L., Egolf, E., Barlow, J. W., Alvez, J. P., Roman, J., & Kraft, J. (2017). Milk from cows grazing on cool-season pastures provides an enhanced profile of bioactive fatty acids compared to those grazed on a monoculture of pearl millet. *Food Chemistry*, *217*, 750–755. http://doi.org/10.1016/j.foodchem.2016.08.134

Baker, L. D., Ferguson, J.D., and Chalupa, W. (1995). Responses in urea and true protein of milk to different protein feeding schemes for dairy cows. J. Dairy Sci. 78:2424–2434

Ball, D.M., E.N. Ballard, M.L. Kennedy, G.D. Lacefield, and D. J. Undersander. (2008). Extending grazing and reducing stored feed needs. Grazing Lands Conservation Initiative Pub. 8-01. Byran, TX.

Barbehenn, R. V., Chen, Z., Karowe, D. N., & Spickard, A. (2004). C3 grasses have higher nutritional quality than C4 grasses under ambient and elevated atmospheric CO2. *Global Change Biology*, *10*(9), 1565–1575. http://doi.org/10.1111/j.1365-2486.2004.00833.x

Bargo, F., Muller, L. D., Delahoy, J. E., & Cassidy, T. W. (2002a). Milk Response to Concentrate Supplementation of High Producing Dairy Cows Grazing at Two Pasture Allowances. *Journal of Dairy Science*, *85*(7), 1777–1792. http://doi.org/10.3168/jds.S0022-0302(02)74252-5

Bargo, 2002 Bargo, F., Muller, L. D., Varga, G. a, Delahoy, J. E., & Cassidy, T. W. (2002b). Ruminal digestion and fermentation of high-producing dairy cows with three different feeding systems combining pasture and total mixed rations. *Journal of Dairy Science*, *85*(11), 2964–2973. http://doi.org/10.3168/jds.S0022-0302(02)74381-6

Bargo, F., Varga, G. a, Muller, L. D., & Kolver, E. S. (2003). Pasture intake and substitution rate effects on nutrient digestion and nitrogen metabolism during continuous culture fermentation. Journal of Dairy Science, 86(4), 1330–1340. http://doi.org/10.3168/jds.S0022-0302(03)73718-7

Bargo, F., Delahoy, J. E., Schroeder, G. F., & Muller, L. D. (2006). Milk fatty acid composition of dairy cows grazing at two pasture allowances and supplemented with different levels and sources of concentrate. *Animal Feed Science and Technology*, *125*(1-2), 17–31. http://doi.org/10.1016/j.anifeedsci.2005.05.010

Benbrook, C. M., Butler, G., Latif, M. A., Leifert, C., & Davis, D. R. (2013). Organic production enhances milk nutritional quality by shifting fatty acid composition: A United States-wide, 18-month study. *PLoS ONE*, *8*(12)

Bergman, M. A., Richert, R. M., Cicconi-Hogan, K. M., Gamroth, M. J., Schukken, Y. H., Stiglbauer, K. E., & Ruegg, P. L. (2014). Comparison of selected animal observations and management practices used to assess welfare of calves and adult dairy cows on organic and conventional dairy farms. *Journal of Dairy Science*, *97*(7), 4269–4280. http://doi.org/10.3168/jds.2013-7766

Bohnert, D. W., DelCurto, T., Clark, a a, Merrill, M. L., Falck, S. J., & Harmon, D. L. (2011). Protein supplementation of ruminants consuming low-quality cool- or warm-season forage: differences in intake and digestibility. Journal of Animal Science, 89(11), 3707–17. http://doi.org/10.2527/jas.2011-3915

Bohnert, D. W., DelCurto, T., Clark, a a, Merrill, M. L., Falck, S. J., & Harmon, D. L. (2011). Protein supplementation of ruminants consuming low-quality cool- or warm-season forage: differences in intake and digestibility. *Journal of Animal Science*, *89*(11), 3707–17.

Bristow, D. J., and D. S. Holmes. 2007. Cortisol levels and anxiety- related behaviors in cattle. Physiol. Behav. 90:626–628

Brito, A. F. and Broderick, G. A. (2007). Effects of feeding different protein supplements on production and nutrient utilization in dairy cows. Journal of Dairy Science 90:1816-1827.

Broderick, G. a, & Clayton, M. K. (1997). A statistical evaluation of animal and nutritional factors influencing concentrations of milk urea nitrogen. *Journal of Dairy Science*, *80*(11), 2964–2971. http://doi.org/10.3168/jds.S0022-0302(97)76262-3

Broderick, G. a. (2003). Effects of varying dietary protein and energy levels on the production of lactating dairy cows. *Journal of Dairy Science*, *86*(4), 1370–81. http://doi.org/10.3168/jds.S0022-0302(03)73721-7

Broderick, G. A., & Reynal, S. M. (2009). Effect of source of rumen-degraded protein on production and ruminal metabolism in lactating dairy cows. *Journal of Dairy Science*, *92*(6), 2822–2834

Calsamiglia, S., Ferret, a, & Devant, M. (2002). Effects of pH and pH fluctuations on microbial fermentation and nutrient flow from a dual-flow continuous culture system. *Journal of Dairy Science*, *85*(3), 574–579. http://doi.org/http://dx.doi.org/10.3168/jds.S0022-0302(02)74111-8

Carlsson, B. J., Bergstrom, J. and Pehrson, B. (1995). Variations with breed, age, season, yield, stage of lactation, and breed in the concentration of urea in bulk milk and individual cow's milk. Acta Vet. Scand. 36:245–254.

Carroll, D. J., Barton, B. A., Anderson, G. W., and Smith, R. D. (1988). Influence of protein intake and feeding strategy on reproductive performance of dairy cows. J. Dairy Sci. 71:3470–3481

Cerrato-Sánchez, M., Calsamiglia, S., & Ferret, a. (2007). Effects of patterns of suboptimal pH on rumen fermentation in a dual-flow continuous culture system. *Journal of Dairy Science*, *90*(9), 4368–4377. http://doi.org/10.3168/jds.S0022-0302(07)71634-X

Cherney, J.H., Cherney, D.J.R., Akin, D.E. and Axtell, J.D. (1991) Potential of Brown-Midrib Low-Lignin Mutants for Improving Forage Quality. *Advances in Agronomy*, 46, 157-198.

Clapham, W.M. and J. M. Fedders. (2011). Interseeding teff into tall fescue swards to improve late summer forage production. Online: Forage and Grazinglands doi:10:1094/FG-2011-1128-01-RS.

Colmenero, J. J. O., & Broderick, G. A. (2006). Effect of dietary crude protein concentration on milk production and nitrogen utilization in lactating dairy cows. *Journal of Dairy Science*, *89*(5), 1704–1712.

Crawford, R. J., Hoover, W. H., & Knowlton, P. H. (1980). Effects of Solids and Liquid Flows on Fermentation in Continuous Cultures . I . Dry Matter and Fiber Digestion, VFA Production and Protozoa Numbers. *Journal of Animal Science*, *51*(4), 975–985.

Crush, J., Woodward, S., Eerens, J., & MacDonald, K. (2006). Growth and milksolids production in pastures of older and more recent ryegrass and white clover cultivars under dairy grazing. *New Zealand Journal of Agricultural Research*, *49*(September), 119–135.

Curran, J., Delaby, L., Kennedy, E., Murphy, J. P., Boland, T. M., & O'Donovan, M. (2010). Sward characteristics, grass dry matter intake and milk production performance are affected by pre-grazing herbage mass and pasture allowance. *Livestock Science*, *127*(2-3), 144–154. http://doi.org/10.1016/j.livsci.2009.09.004

Dann, H.M., R.J. Grant, K.W. Cotanch, E.D. Thomas, C.S. Ballard, and R. Rice. (2008). Comparison of brown midrib sorghum-sudan- grass with corn silage on lactational performance and nutrient digestibility in Holstein dairy cows. *J. Dairy Sci*. 91:663–672.

Delaby, L., Faverdin, P., Michel, G., Disenhaus, C., & Peyraud, J. L. (2009). Effect of different feeding strategies on lactation performance of Holstein and Normande dairy cows. *Animal*, *3*(JUNE 2009), 891–905. http://doi.org/10.1017/S1751731109004212

de Veth, M. J., & Kolver, E. S. (2001). Digestion of ryegrass pasture in response to change in pH in continuous culture. *Journal of Dairy Science*, *84*(6), 1449–1457. http://doi.org/10.3168/jds.S0022-0302(01)70178-6

DeVries, T. J., K. A. Beauchemin, F. Dohme, and K. S. Schwartzkopf- Genswein. 2009. Repeated ruminal acidosis challenges in lactating dairy cows at high and low risk for developing acidosis: Feeding, ruminating, and lying behavior. J. Dairy Sci. 92:5067–5078.

Dijkstra, J. (1994). Production and absorption of volatile fatty acids in the rumen. *Livestock Production Science*, *39*(1), 61–69. http://doi.org/10.1016/0301-6226(94)90154-6

Dillon, P., Buckley, F., O'Connor, P., Hegarty, D., & Rath, M. (2003). A comparison of different dairy cow breeds on a seasonal grass-based system of milk production. 1. Milk production, live weight, body condition score and DM intake. *Livestock Production Science*, *83*(1), 21–33. http://doi.org/10.1016/S0301-6226(03)00041-1

Ellis, K. a, Innocent, G., Grove-White, D., Cripps, P., McLean, W. G., Howard, C. V, & Mihm, M. (2006). Comparing the Fatty Acid Composition of Organic and Conventional Milk. *Journal of Dairy Science*, *89*(6), 1938–1950.

ERS (Economic Research Service). (2014). Organic market overview. Accessed Nov. 17, 2015. http://www.ers.usda.gov/topics/natural-resources-environment/organic-agriculture/organic-market- overview.aspx.

Erwin, E. S., Marco, G. J., & Emery, E. M. (1961). Volatile fatty acid analyses of blood and rumen fluid by gas chromatography. Journal of Dairy science, 44(9), 1768-1771.

Fritz, J.O., Moore, K.J. and Jaster, E.H. (1990) Digestion Kinetics and Cell Wall Composition of Brown Midrib Sorghum x sudangrass Morphological Components. *Crop Science*, 30, 213-219.

Fontaneli, R. S., Sollenberger, L. E., Littell, R. C., & Staples, C. R. (2005). Performance of lactating dairy cows managed on pasture-based or in freestall barn-feeding systems. *Journal of Dairy Science*, *88*(3), 1264–1276.

Gregorini, P., Dela Rue, B., McLeod, K., Clark, C., Glassey, C., Jago, J., (2012). Rumination behavior of grazing dairy cows in response to restricted time at pasture. Livest. Sci. 146, 90–95.

Gregorini, P., Dela Rue, B., Pourau, M., Glassey, C., & Jago, J. (2013). A note on rumination behavior of dairy cows under intensive grazing systems. *Livestock Science*, *158*(1-3), 151–156.

Goering, H. K., Van Soest, P.J., (1970). Forage fiber analyses (apparatus, reagents, prcedures, and some applications). Agric. Handbook.

Goeser, J. (2016). Total tract NDF digestibility (TTNDFD) Guidelines, Rock River Laboratories, Accessed Nov. 1, 2016 Inc. http://rockriverlab.com/file_open.php?id=119.

Griggs, T.C., Drake, D. R., Parkinson, S.C. (2008). Production and Quality of warm-season annual forage grasses. *Proceedings, Idaho Alfalfa and Forage Conference,* 26-

27 February 2008.

Hafla, A. N., MacAdam, J. W., & Soder, K. J. (2013). Sustainability of US organic beef and dairy production systems: Soil, plant and cattle interactions. *Sustainability (Switzerland)*, *5*(7), 3009–3034.

Hannah, S. M., Stern, M. D., & Ehle, F. R. (1986). Evaluation of a dual flow continuous culture system for estimating bacterial fermentation in vivo of mixed diets containing various soya bean products. *Animal Feed Science and Technology*, *16*(1-2), 51–62. http://doi.org/10.1016/0377-8401(86)90049-0

Hardie, C. A., Wattiaux, M., Dutreuil, M., Gildersleeve, R., Keuler, N. S., & Cabrera, V. E. (2014). Feeding strategies on certified organic dairy farms in Wisconsin and their effect on milk production and income over feed costs. *Journal of Dairy Science*, *97*(7), 4612–23.

Hardeng, F., & Edge, V. L. (2001). Mastitis, ketosis, and milk fever in 31 organic and 93 conventional Norwegian dairy herds. *Journal of Dairy Science*, *84*(12), 2673–2679. http://doi.org/10.3168/jds.S0022-0302(01)74721-2

Heins, B. J., Hansen, L. B., & Seykora, A. J. (2006). Production of Pure Holsteins versus crossbreds of Holstein with Normande, Montbeliarde, and Scandinavian Red. *Journal of Dairy Science*, *89*(7), 2799–804. http://doi.org/10.3168/jds.S0022-0302(06)72357-8

Hill, D. L., & Wall, E. (2015). Dairy cattle in a temperate climate: the effects of weather on milk yield and composition depend on management. *Animal*, *9*(01), 138–149. http://doi.org/10.1017/S1751731114002456

Hoover, W. H., Crooker, B.A. and Sniffen, C.J. (1976). Effects of differential solid-liquid removal rates on protozoa numbers in continuous cultures of rumen contents. *Journal of Animal Science,* 43:528–534

Hoover, W., Kincaid, C. R., Varga, G. A., Thayne, W. V., & Junkins, Jr., L. L. (1984). Effects of solids and liquid flows on fermentation in continuous cultures. IV. pH and dilution rate. *Journal of Animal Science*, *54*(3), 849–854. http://doi.org/10.2134/jas1984.583692x

Hoover, W. H., T. K. Miller, S. R. Stokes, and W. V. Thayne. (1989). Effects of fish meals on rumen bacterial fermentation in continu- ous culture. J. Dairy Sci. 72:2991–2998.

Hudson, Leep, Dietz, Ragavendron, Kravchenko, (2010). Integrated Warm- and Cool Season Grass and Legume Pastures: I. Seasonal Forage Dynamics. *Agronomy Journal, 102 (1), 303-309.*

Huhtanen, P., Nousiainen, J. I., Rinne, M., Kytölä, K., & Khalili, H. (2008). Utilization and partition of dietary nitrogen in dairy cows fed grass silage-based diets. *Journal of Dairy Science*, *91*(9), 3589–3599.

Hunter, M., P. Barney, T. Kilcer, J. Cherney, J. Lawrence, and Q. Ketterings. (2007). Teff as Emergency Forage. Cornell Univ. Cooperative Extension Agronomy Fact Sheet 24, http://nmsp.css.cornell.edu/publications/factsheets/factsheet24.pdf.

Hunter, M., Ketterings, Q. M., Cherney, J. H., Barney, P., Kilcer, T., & Godwin, G. (2009). Nitrogen Needs of Teff Managed as Forage Crop in New York. *Fg*, *7*(1), 5–6.

Jones, G. B., & Tracy, B. F. (2013). Evaluating seasonal variation in mineral concentration of cool-season pasture herbage. *Grass and Forage Science*, *70*(1), 94–101.

Jung, G.A., J.L. Griffin, R.E. Kocher, J.A. Shaffer, and C.F. Gross. (1985). Performance of Switchgrass and Bluestem Cultivars Mixed with Cool-Season Species. *Agronomy Journal* 77(6): 846-850.

Jung, G.A., R.A. Byers, M. Panciera, and J.A. Shaffer. (1986). Forage dry matter accumulation and quality of turnip, swede, rape, Chinese cabbage hybrids, and kale in the eastern USA. Agron. J. 78:2454-253.

Krawczel, P., Grant, R., 2009. Effects of cow comfort on milk quality, productivity and behavior. In: Proceedings of the NMC Annual Meeting, Charlotte, NC, USA, pp. 15–24.

Koch, D.W., and S. Paisley. 2002. Managing Forages to Minimize Nitrate Poisoning. Univ. of Wyoming Cooperative Extension Publ. B-1122.8, http://ces.uwyo.edu/PUBS/B1122-8.pdf.

Kolver, E. S., and L. D. Muller. (1998). Performance and nutrient intake of high producing Holstein cows consuming pasture or a total mixed ration. J. Dairy Sci. 81:1403–1411.

Kouazounde, J. B., Gbenou, J. D., He, M., Jardim, T., Jin, L., Wang, Y., and McAllister, T. A. (2015). Effects of essential oils from african basil on fermentation of andropogon gayanus grass in the artificial rumen (RUSITEC). Canadian Journal of Animal Science, 95(3), 425–431. http://doi.org/10.4141/CJAS-2014-189

Lopes, F., Ruh, K., Combs D. (2015).Validation of an approach to predict total-tract fiber digestibility using a standardized in vitro technique for different diets fed to high-producing dairy cows. *Journal of Dairy Science.* 98(4) 2596-2602

Maher, J., Stakelum, G., Rath, M. (2003). Effect of daily herbage allowance on the performance of spring calving dairy cows. Ir. J. Agric. Food Res. 42:229–241

Mangan, M.E., C.C. Sheaffer, D.L. Wyse, N.J. Ehlke, and P.B. Reich (2011). Native perennial grassland species for bioenergy: establishment and biomass productivity. Agron. J. 103:1-13.

Mansfield, H. (1995). Comparison of microbial fermentation in the rumen of dairy cows and dual flow continuous culture. *Animal Feed Science and Technology*, *55*(1-2), 47–66. http://doi.org/10.1016/03778-4019(59)82028-

Marten, G.C., A.G. Matches, R. F. Barnes, R.W. Brougham, R.J. Clements, and G.W. Sheath (1989). Persistence of forage legumes. Proc. Trilateral workshop 18-22 July 1988. ASA, CSSA, and SSSA, Madison, WI.

McBride, W. and C. Greene. 2009. Characteristics, costs, and issues for organic dairy farming. Economic Research Report Number 82, United States Department of Agriculture, USDA Economic Research Service 82:1-42.

McCartney, D., Fraser, J., Ohama, A., (2009). Potential of warm-season annual forages and Brassica crops for grazing: A Canadian Review. *Canadian Journal of Animal Science*, 89(4): 431-440

McEvoy, M., O'Donovan, M., Kennedy, E., Murphy, J. P., Delaby, L., & Boland, T. M. (2009). Effect of pregrazing herbage mass and pasture allowance on the lactation performance of Holstein-Friesian dairy cows. *Journal of Dairy Science*, *92*(1), 414–422. http://doi.org/10.3168/jds.2008-1313

Metson, A. J., & Saunders, W. M. H. (1978). Seasonal variations in chemical composition of pasture. 1. Calcium, magnesium, potassium, sodium, and phosphorus. *New Zealand Journal of Agricultural Research*, *21*(2), 341–353. http://doi.org/10.1080/00288233.1978.10427419

Milano, G. D., A. Hotston-Moore, and G. E. Lobley. (2000). Influence of hepatic ammonia removal on ureagenesis, amino acid utilization and energy metabolism in the ovine liver.

Br. J. Nutr. 83:307–315.

Millner, J. P., Silungwe, D., & Mcgill, C. R. (2011). Forage quality of sorghum , sudan-grass sorghum x sudan-grass and pearl millet cultivars in Manawatu. Agronomy NZ Journal 41, 13–22.

Minns, A., J. Finn, A. Hector, M. Caldeira and J. Joshi. (2001). The functioning of European grassland ecosystems: Potential benefits of biodiversity to agriculture. Outlook Agric., 30: 179-185.

Moore, K. J., White, T. A., Hintz, R. L., Patrick, P. K., & Brummer, E. C. (2004). Sequential grazing of cool- and warm-season pastures. *Agronomy Journal*, *96*(4), 1103–1111.

Najda, H. (2003). Sorghum, sudangrass, and sorghum-sudangrass hybrids for forage. Alberta Agriculture, Food and Rural Development. Edmonton, AB. Agdex 126 20:1.

Naves, J. R., de Jesus, E. F., Martins, C. M. M. R., Tomazi, T., de Freitas Junior, J. E., Rennó, F. P., and Santos, M. V. (2015). Efficiency of dietary nitrogen utilization and digestive metabolism of dairy cows fed different nitrogen sources and sugarcane. Journal of Animal and Plant Sciences. 25(4):941-949.

Norberg, S., (2009). Teff, A new warm season annual grass for Oregon. *Oregon State University Extension Service*.

Nousiainen, J., Shingfield, K. J., & Huhtanen, P. (2004). Evaluation of milk urea nitrogen as a diagnostic of protein feeding. *Journal of Dairy Science*, *87*(2), 386–98. http://doi.org/10.3168/jds.S0022-0302(04)73178-1

NRC. (2001). Nutrient Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Press, Washington, DC.

Oates, L. G., Undersander, D. J., Gratton, C., Bell, M. M., & Jackson, R. D. (2011). Management-intensive rotational grazing enhances forage production and quality of subhumid cool-season pastures. *Crop Science*, *51*(2), 892–901. http://doi.org/10.2135/cropsci2010.04.0216

Oba, M., & Allen, M. S. (1999). Evaluation of the importance of the digestibility of neutral detergent fiber from forage: effects on dry matter intake and milk yield of dairy cows. *Journal of Dairy Science*, *82*(3), 589–596. http://doi.org/10.3168/jds.S0022-0302(99)75271-9

O'Hara, J., & Parsons, R. (2013). The economic value of organic dairy farms in Vermont and Minnesota. *Journal of Dairy Science*, *96*(9), 6117–6126. http://doi.org/10.3168/jds.2013-6662

Oltner, R.,M. Emanuelson, and H. Wiktorsson. (1985). Urea concentration in cows' milk in relation to milk yield, live weight, lactation number and composition of feed given. Livest. Prod. Sci. 12:45–57

Paine, L.K., Undersander, D., Casler, M.D. (1999). Pasture growth, production, and quality under rotational and continuous grazing management. Journal of Production Agriculture *Vol. 12 No. 4, p. 569-577*

Pedersen, J.F. (1996). Annual Forages: New Approaches for C-4 Forages. In: Janick, J., Ed., *Progress in New Crops*, ASHS Press, Alexandria, 246-251.

Pembleton, K. G., Hills, J. L., Freeman, M. J., Mclaren, D. K., French, M., & Rawnsley, R. P. (2016). More milk from forage: Milk production, blood metabolites, and forage intake of dairy cows grazing pasture mixtures and spatially adjacent monocultures. *Journal of Dairy Science*, *99*(99), 1–17 (in press). http://doi.org/http://dx.doi.org/10.3168/jds.2015-10542

Perez-Prieto, L. a, & Delagarde, R. (2012). Meta-analysis of the effect of pregrazing pasture mass on pasture intake, milk production, and grazing behavior of dairy cows strip-grazing temperate grasslands. *Journal of Dairy Science*, *95*(9), 5317–5330. http://doi.org/10.3168/jds.2012-5609

Peyraud, J. L., & Delagarde, R. (2013). Managing variations in dairy cow nutrient supply under grazing. *Animal : An International Journal of Animal Bioscience*, *7 Suppl 1,* 57–67. http://doi.org/10.1017/S1751731111002394

Piggot, G. J. (1989). A comparison of four methods for estimating herbage yield of temperate dairy pastures. *New Zealand Journal of Agricultural Research*, *32*(1), 121–123. http://doi.org/10.1080/00288233.1989.10423486

Powers, L.E., and R. McSorley, (2000). Ecological principles of agriculture. Delmar Thompson Learning, Albany, NY.

Ribeiro, C. V. D. M., Karnati, S. K. R., & Eastridge, M. L. (2005). Biohydrogenation of fatty acids and digestibility of fresh alfalfa or alfalfa hay plus sucrose in continuous culture. Journal of Dairy Science, 88(11), 4007–4017. http://doi.org/10.3168/jds.S0022-0302(05)73087-3

Rinehart, B. L., & Baier, A. (2011). Pasture for Organic Ruminant Livestock : *United States Department of Agriculture, National Center for Appropriate Technology, National Sustainable Agriculture Information Service (ATTRA); Washington DC, USA*.

Roche, J. R., Lee, J. M., Macdonald, K. A., & Berry, D. P. (2007). Relationships Among Body Condition Score , Body Weight , and Milk Production Variables in Pasture-Based Dairy Cows. *Journal of Dairy Science*, *90*(8), 3802–3815.

Roseler, D. K., J. D. Ferguson, C. J. Sniffen and J. Herrema. 1993. Dietary protein degradability effects of plasma and milk urea nitrogen and milk nonprotein nitrogen in Holstein cows. J. Dairy Sci. 76:525-534.

Ruiz-Moreno, M., Binversie, E., Fessenden, S. W., & Stern, M. D. (2015). Mitigation of in vitro hydrogen sulfide production using bismuth subsalicylate with and without monensin in beef feedlot diets. Journal of Animal Science, 93(11), 5346–5354. http://doi.org/10.2527/jas.2015-9392

Russell, J. B., and R. L. Baldwin. (1978). Substrate preferences in rumen bacteria: Evidence of catabolite regulatory mechanisms. Appl. Environ. Microbiol. 36:319–329.

Russell, J.B. (1998). The importance of pH in the regulation of ruminal acetate to propionate ratio and methane production in vitro. J. Dairy Sci. 81, 3222–3230

Sanderson, M. A., Soder, K. J., Muller, L. D., Klement, K. D., Skinner, R. H., & Goslee, S. C. (2005). Forage mixture productivity and botanical composition in pastures grazed by dairy cattle. *Agronomy Journal*, *97*(5), 1465–1471. http://doi.org/10.2134/agronj2005.0032

Satter, L. D., and L. L. Slyter. (1974). Effect of ammonia concentra- tion on rumen microbial protein in vitro. Br. J. Nutr. 32:199– 208. doi:10.1079/BJN19740073.

Sato, K., Bartlett, P. C., Erskine, R. J., & Kaneene, J. B. (2005). A comparison of production and management between Wisconsin organic and conventional dairy herds. *Livestock Production Science*, *93*(2), 105–115. http://doi.org/10.1016/j.livprodsci.2004.09.007

Sauvant, D., Meschy, F., & Mertens, D. (1999). Components of ruminal acidosis and acidogenic effects of diets. Productions Animales (France).

Schirmann, K., M. a. G. von Keyserlingk, D.M. Weary, D.M. Veira, and W. Heuwieser. (2009). Technical note: Validation of a system for monitoring rumination in dairy cows. J. Dairy Sci. 92:6052–6055. doi:10.3168/jds.2009-2361.

Schwendel, B. H., Morel, P. C. H., Wester, T. J., Tavendale, M. H., Deadman, C., Fong, B., Otter, D. E. (2015). Fatty acid profile differs between organic and conventionally produced cow milk independent of season or milking time. *Journal of Dairy Science*, *98*(3), 1411–1425. http://doi.org/http://dx.doi.org/10.3168/jds.2014-8322

Seymour, W. M., Campbell, D. R., & Johnson, Z. B. (2005). Relationships between rumen volatile fatty acid concentrations and milk production in dairy cows: A literature study. Animal Feed Science and Technology, 119(1-2), 155–169. http://doi.org/10.1016/j.anifeedsci.2004.10.001

Shaver, R. D. (2006)."Corn silage evaluation: The MILK2006 update." *Proc. 41st Pacific Northwest Anim. Nutr. Conf. Vancouver, Canada*.

Sjostrom, L. S. (2015). Alternative Housing and Management for Organic Dairy Production. MS Thesis. University of Minnesota, St. Paul. http://hdl.handle.net/11299/178916

Sjostrom, L. S., Heins, B. J., Endres, M. I., Moon, R. D., & Paulson, J. C. (2016). Short communication: Relationship of activity and rumination to abundance of pest flies among organically certified cows fed 3 levels of concentrate. *Journal of Dairy Science*, *99*(12), 9942–9948. http://doi.org/10.3168/jds.2016-11038

Soder, K. J., Sanderson, M. a, Stack, J. L., & Muller, L. D. (2006). Intake and performance of lactating cows grazing diverse forage mixtures. *Journal of Dairy Science*, *89*(6), 2158–2167. http://doi.org/10.3168/jds.S0022-0302(06)72286-X

Soder, K. J., & Gregorini, P. (2010). Relationship Between Supplemental Protein and Ruminal Fermentation of an Herbage Diet. *The Professional Animal Scientist*, *26*, 290–297. http://doi.org/10.15232/S1080-7446(15)30596-9

Soder, K. J., Brito, A. F., & Rubano, M. D. (2013). Effect of supplementing orchardgrass herbage with a total mixed ration or flaxseed on fermentation profile and bacterial protein synthesis in continuous culture. Journal of Dairy Science, 96(5), 3228–37. http://doi.org/10.3168/jds.2012-6307

Soder, K. J., Brito, A. F., Hafla, A. N., & Rubano, M. D. (2016). Effect of starchy or fibrous carbohydrate supplementation of orchardgrass on ruminal fermentation and methane output in continuous culture. Journal of Dairy Science, 99(6), 4464–4475. http://doi.org/10.3168/jds.2015-10471

Sorge, U. S., Moon, R., Wolff, L. J., Michels, L., Schroth, S., Kelton, D. F., & Heins, B. (2016). Management practices on organic and conventional dairy herds in Minnesota. *Journal of Dairy Science*, *99*(4), 3183–92. http://doi.org/10.3168/jds.2015-10193

Staniar, W. B., Bussard, J. R., Repard, N. M., Hall, M. H., & Burk, A. O. (2010). Voluntary intake and digestibility of teff hay fed to horses. *Journal of Animal Science*, *88*(10), 3296–3303. http://doi.org/10.2527/jas.2009-2668

Stern, M. D., Bach, a, Calsamiglia, S., Stern, M. D., Bach, A., & Calsamiglia, S. (1997). Alternative techniques for measuring nutrient digestion in ruminants. *Journal of Animal Science*, 75:2256–2276.

Statistical Analysis Systems (SAS) Institute. (2013). SAS User's Guide. SAS Institute, Cary, NC

Stiglbauer, K. E., Cicconi-Hogan, K. M., Richert, R., Schukken, Y. H., Ruegg, P. L., & Gamroth, M. (2013). Assessment of herd management on organic and conventional dairy farms in the United States. *Journal of Dairy Science*, *96*(2), 1290–300. http://doi.org/10.3168/jds.2012-5845

Storm, A. C., & Kristensen, N. B. (2010). Effects of particle size and dry matter content of a total mixed ration on intraruminal equilibration and net portal flux of volatile fatty acids in lactating dairy cows. *Journal of Dairy Science*, *93*(9), 4223–38. http://doi.org/10.3168/jds.2009-3002

Tilley, J. M. A., and R. A. Terry. (1963). A two-stage technique for the in vitro digestion of forage crops. J. Br. Grassl. Soc. 18:104–111

Tilman, D. (1996). Biodiversity: Population versus ecosystem stability. Ecology 77:350-363.

Tracy, B. F., Maughan, M., Post, N., & Faulkner, D. B. (2010). Integrating annual and perennial warm-season grasses in a temperate grazing system. *Crop Science*, *50*(5), 2171–2177. http://doi.org/10.2135/cropsci2010.02.0110

Tozer, P. R., Bargo, F., & Muller, L. D. (2003). Economic analyses of feeding systems combining pasture and total mixed ration. *Journal of Dairy Science*, *86*(3), 808–18. http://doi.org/10.3168/jds.S0022-0302(03)73663-7

Undersander, D., Smith, L. H., Kaminiski, A. R., Kelling, K. A. and Doll, J. D. (2000). Sorghum Forage. In Alternative field crops manual. University of Wisconsin-Extension, Cooperative Extension, Madison, WI.

Undersander, D., Albert, B., Cosgrove, D., Johnson, D., and Peterson, P. (2004). Pastures for profit. A guide to rotational grazing. A3529. University of Wisconsin-Extension, Madison, WI.

US Department of Agriculture, Agricultural Marketing Service. (2010). National Organic Program: Access to Pasture (Livestock). 7 CFR part 205. Fed. Regist. 75:7154-7195

US Department of Agriculture, National Agricultural Statistics Service. (2016). Certified Organic Survey 2015 Summary. http://usda.mannlib.cornell.edu/usda/current/OrganicProduction/OrganicProduction-09-15-2016.pdf

USDA-AMS (Agricultural Marketing Service). (2016). Milk Marketing Order Statistics. Accessed Nov. 30, 2016. https://www.ams.usda.gov/resources/marketing-order-statistics.

United States Department of Agriculture. (2016). National Organic Program. United States Department of Agriculture, Agricultural Marketing Service. Accessed Nov. 30, 2016. https://www.ams.usda.gov/about-ams/programs-offices/national-organic-program

van Eekeren, N., M.Bos, J.de Wit, H.Keidel, and J.Bloem. (2010). Effect of individual grass species and grass species mixtures on soil quality as related to root biomass and grass yield. Applied Soil Ecology 45:275-283.

Van Soest, P. J. (1994). Nutritional ecology of the ruminant. Cornell University Press, Ithaca, NY

Vazquez, O. P., & Smith, T. R. (2000). Factors Affecting Pasture Intake and Total Dry Matter Intake in Grazing Dairy Cows. *Journal of Dairy Science*, *83*(10), 2301–2309. http://doi.org/10.3168/jds.S0022-0302(00)75117-4

Venuto, B., & Kindiger, B. (2008). Forage and biomass feedstock production from hybrid forage sorghum and sorghum-sudangrass hybrids. *Grassland Science*, *54*(4), 189–196.

Vibart, R. E., Burns, J. C., & Fellner, V. (2010). Effect of replacing total mixed ration with pasture on ruminal fermentation. Professional Animal Scientist, 26(4), 435–442.

Waghorn, G.C., I.D. Shelton, and V.J. Thomas. 1989. Particle breakdown and rumen digestion of fresh ryegrass (Lolium perenne L.) and lucerne(Medicago sativa L.) fed to cows during a restricted feeding period. Brit. J. Nutr. 61:409-423.

Wales, W. J., Doyle, P. T., Stockdale, C. R., & Dellow, D. W. (1999). Effects of variations in herbage mass, allowance, and level of supplement on nutrient intake and milk production of dairy cows in spring and summer. *Australian Journal of Experimental Agriculture*, *39*(2), 119–130. http://doi.org/10.1071/EA98151

Wales, W. J., Kolver, E. S., Thorne, P. L., & Egan, a R. (2004). Diurnal variation in ruminal pH on the digestibility of highly digestible perennial ryegrass during continuous culture fermentation. Journal of Dairy Science, 87(6), 1864–1871.

Walsh, S., Buckley, F., Pierce, K., Byrne, N., Patton, J., & Dillon, P. (2008). Effects of breed and feeding system on milk production, body weight, body condition score, reproductive performance, and postpartum ovarian function. *Journal of Dairy Science*, *91*(11), 4401–4413. http://doi.org/10.3168/jds.2007-0818

Wattiaux, M. A., & Karg, K. L. (2004). Protein Level for Alfalfa and Corn Silage-Based Diets: I. Lactational Response and Milk Urea Nitrogen. *Journal of Dairy Science*, *87*(10), 3480–3491. http://doi.org/10.3168/jds.S0022-0302(04)73483-9

Weichenthal, B.A., Baltensperger, D.D., Vogel, K., Masterson, S., Blumenthal, J. *and* Krall, J. (2003). G03-1527 Annual Forages for the Nebraska Panhandle. *Historical Materials from University of Nebraska-Lincoln Extension:* 1734.

White, S. L., Benson, G. a, Washburn, S. P., & Green, J. T. (2002). Milk production and economic measures in confinement or pasture systems using seasonally calved Holstein and Jersey cows. *Journal of Dairy Science*, *85*(1), 95–104. http://doi.org/10.3168/jds.S0022-0302(02)74057-5

Zinn and Owens, (1986). A rapid procedure for purine measurement and its use for estimating net ruminal protein synthesis. Can. J. Anim. Sci, 66:157.