Sustainable Agriculture Research; Vol. 11, No. 2; 2022
ISSN 1927-050X E-ISSN 1927-0518
Published by Canadian Center of Science and Education

White Prairie Clover (Dalea candida Michx. ex Willd.) and Purple Prairie Clover (Dalea purpurea Vent.) in Binary Mixtures with Grass Species

Samuel Peprah[1], Enkhjargal Darambazar[1], Bill Biligetu[2], Kathy Larson[3], Alan Iwaasa[4], Daalkhaijav Damiran[1], Murillo Ceola Stefano Pereira[1] & Herbert Lardner[1]

[1] Department of Animal and Poultry Science, University of Saskatchewan, 51 Campus Drive Saskatoon, SK S7N 5A8, Canada

[2] Department of Plant Sciences, University of Saskatchewan, 51 Campus Drive Saskatoon, SK S7N 5A8, Canada

[3] Department of Agricultural and Resource Economics, University of Saskatchewan, 51 Campus Drive, Saskatoon, Saskatchewan, S7N 5A8, Canada

[4] Agriculture and Agri-Food Canada, Swift Current Research and Development Centre, Swift Current, Saskatchewan, S9H 3X2, Canada

Correspondence: Herbert Lardner, Department of Animal and Poultry Science, University of Saskatchewan, 51 Campus Drive, Saskatoon, SK S7N 5A8, Canada. Tel: 306-966-2147. E-mail: bart.lardner@usask.ca

Received: January 26, 2022 Accepted: March 2, 2022 Online Published: March 9, 2022

doi:10.5539/sar.v11n2p30 URL: https://doi.org/10.5539/sar.v11n2p30

Abstract

Native forage legumes may have potential for summer/fall grazing in semiarid prairie regions in mixture with grasses. The objective of this study was to evaluate two native clovers in binary mixtures with the introduced grasses when harvested in July and September to simulate late summer or fall stockpile forage. Eight binary clover–grass mixtures were seeded in a split-plot design with 4 replications at Swift Current, Saskatchewan, Canada. Mixtures included (i) AC Antelope white prairie clover (WPC)-Admiral meadow bromegrass (MBG), (ii) WPC-AC Success hybrid bromegrass (HBG), (iii) WPC-Bozoisky Russian wildrye (RWR), (iv) WPC-TomRWR, (v) AC Lamour purple prairie clover (PPC)-AdmiralMBG, (vi) PPC-AC SuccessHBG, (vii) PPC-BozoiskyRWR, and (viii) PPC-TomRWR. Clover establishment differed (p = 0.03) in July where WPC had 77.8% greater proportion in mixture than PPC, although both clovers increased (p < 0.001) in September to similar legume proportions, 663.2 and 876.1 kg/ha, respectively. Clovers with bromegrasses produced 41.9% more forage dry matter yield in summer than clovers with Russian wildryes (p < 0.001), though the latter mixtures had slightly better nutritive value (avg. 7.0% vs. 5.2% crude protein (CP). Clover–MBG exhibited higher (53.6%) *in vitro* organic matter digestibility (IVOMD) than Clover–HBG (51.2%) (p = 0.04). Purple prairie clover with grass or both clovers in mixture with bromegrasses, produced adequate forage biomass for summer and fall grazing, except clovers with Bozoisky RWR, while clovers with both RWR cultivars had acceptable forage nutritive value for summer in this semiarid prairie region.

Keywords: clover, forage yield, grazing, legume, mixtures, nutritive value

1. Introduction

In the semiarid prairie region of the Northern Great Plains of North America, grazing ruminant livestock productivity and sustainability depends on forage dry matter yield (DMY) and nutritive value in late summer and early fall months prior to freezing temperatures that terminate forage growth. Although forage production and quality of alfalfa (*Medicago sativa* L.) and Russian wildrye (*Psathyrostachys junceus* [Fisch.] Nevski) (RWR) mixture can be adequate for summer and fall grazing for cattle (Holt & Jefferson, 1999; Peprah et al., 2021a), alfalfa may cause frothy ruminant bloat which can result in mortalities in grazing cattle (Popp, McCaughey, Cohen, McAllister, & Majak, 2000; Cox, 2013). There is an interest in alternative non-bloating legumes for grazing in this region.

In Virginia, growing crimson clover (*Trifolium incarnatum* L.) in mixtures with annual ryegrass (*Lolium multiflo-rum*) as winter cover crops increased forage biomass and nutritive value (Brown, Ferreira, Teets, Thomason, & Teutsch, 2017). In northern Europe and Canada, white clover (*Trifolium repens* L.), red clover (*T. pratense* L.), timothy (*Phleum pretense* L.), and Kentucky bluegrass (*Poa pratensis* L.) in mixtures created greater herbage yield than sown in monocultures (Sturludóttir et al., 2014). In northeastern Oregon of the United States, red clover was one the primary forb components in the herbage mass with the highest CP content (16.8% CP) and had been readily utilized by cattle on a riparian pasture during a late-summer grazing season (Darambazar, DelCurto, & Damiran, 2013). Although, in southeastern United States, autumn-planted ryegrass or clovers including crimson, arrowleaf (*Trifolium vesiculosum* Savi), ball (*T. nigrescens* Viv.), and red clovers provided minimal to nonexistent forage mass for grazing during the fall (Mullenix & Rouquette, 2018).

White prairie clover (*Dalea candida* Michx. ex Willd; WPC) and purple prairie clover (*D. purpurea* Vent.; PPC) are widely distributed throughout the south and central Prairies and Parklands in Canada (Iwaasa, Li, Wang, Scianna, & Han, 2014) and occur in the Great Plains, south to Wisconsin, Illinois, Tennessee, eastern half of Kansas, Indiana, Montana, Arkansas, Texas, and New Mexico in USA (Wynia, 2008a, 2008b). Purple prairie clover and WPC are forage legumes with moderate to high concentration of condensed tannins (Iwaasa et al., 2014; Li et al., 2014); non-bloating (Li, Tanner, & Larkin, 1996; Berard et al., 2011), and protect plant protein from ruminal microbial degradation (Waghorn, John, Jones, & Shelton, 1987; Aerts, Barry, & McNabb, 1999) resulting in improved protein utilization, live weight gain, and milk yield (Wang, Douglas, Waghorn, Barry, & Foote, 1996; Berard et al., 2011). In addition, condensed tannins are implicated to have antibacterial properties in the digestive tract of animals (Li, Iwaasa, Birkedal, & Han, 2012). Much of the clover growth occurs during July and August but it can complement and improve the forage nutritional profile for grazing livestock during spring to fall grazing periods (Iwaasa et al., 2014). Also, *Dalea* species showed increases on prairie restoration areas in Illinois (Gardner, 2006).

White prairie clover is a native, warm season, herbaceous, perennial legume in the northern Great Plains, produces palatable browse for livestock and wildlife (Damiran, 2005, 2006; Wynia, 2008b), and resumes its growth later than many cool-season grasses and forbs. White prairie clover is mainly adapted to short grass prairies (Khanal, Schellenberg, & Biligetu, 2018), while on tallgrass prairie in Kansas, WPC accumulated very low biomass (~1 kg/ha; Towne & Knapp, 1996).

Purple prairie clover is, also, a native warm season legume which produces excellent forage for livestock and wildlife because of high protein, digestibility, palatability, readily consumed by grazing sheep (*Ovis aries* L.; (Sheaffer, Wyse, & Ehlke, 2009), and mixtures containing PPC with adapted warm-season grasses appeared promising forage crops yielding more forage and increased protein (Posler, Lenssen, & Fine, 1993; Kusler, 2009). In Nebraska, PPC yielded a biomass between 1800 and 2100 kg/ha (Beran, Masters, & Gaussoin, 1999), while the legume had a lower biomass (4 kg/ha) on tallgrass prairie upland soils in the Kansas Flint Hills (Gene Towne & Knapp, 1996). In addition, establishment and persistence of PPC were low and poor at several locations in western Canada (Jefferson et al., 2002). Several native prairie clover germplasm or ecological varieties have been released including, Antelope (WPC) from Plant Materials Centers in Montana and North Dakota (Wynia, 2008b) and AC Lamour (PPC) at Swift Current Research and Development Centre (SCRDC), Agriculture and Agri-Food Canada (AAFC) in Saskatchewan and available in North America for land reclamation and pasture/forage seeding (Iwaasa et al., 2014).

As well, Russian wildrye has adequate nutritive value for mature stock on winter maintenance rations (Sedivec, Tober, Duckwitz, Dewald, & Printz, 2007). ‘Tom’ RWR (TomRWR) developed by SCRDC AAFC, Saskatchewan and registered in 2002, is well adapted to the semiarid prairie region and available as a summer, fall, and early winter pasture (McLeod, Jefferson, Muri, & Lawrence, 2003). ‘Bozoisky-Select’ RWR (BozoiskyRWR) was selected for greater seedling vigor and higher forage yield than cv. Vinall (about 123% of cv. Vinall) by USDA ARS at Logan Utah in 1984 (Anderson & Sharp, 1994) and is very competitive. Meadow bromegrass (*Bromus riparius* Rehm.; MBG) is highly palatable to livestock and wildlife (Sedivec et al., 2007; Lardner, Ward, Darambazar, & Damiran, 2013; Lardner, Damiran, & McKinnon, 2015) and has excellent regrowth and nutritive value for grazing (Holt & Jefferson, 1999; Ogle, St. John, Holzworth, & Jensen, 2006). ‘AC Admiral’ is a MBG cultivar release at Saskatoon Research and Development Centre (SRDC), AAFC in 2009 with improved vigor and greenness in fall and highest relative yield potential reported in Brown (140% of cv. Fleet) and Dark Brown (105% of cv. Fleet) soil zones (Coulman, 2009). Further, hybrid bromegrass (*B. riparius* Rehm × *B. inermis* Leyss; HBG) developed in Canada is a dual-purpose forage for both hay and pasture systems, has good regrowth for grazing and stockpiling and potential for use in beef production system (Ferdinandez & Coulman, 2001) in the Canadian prairies. ‘AC Success’ is a HBG cultivar release from SRDC AAFC in 2003 (Coulman, 2006). Clover or other native legumes would be desirable in seeding with introduced grasses for improving rangelands due to the symbiotic N_2 fixation of the legume, the improved ruminant diet quality and animal performance. However, much of the previous research in this area has focused on stockpiling pure stands of introduced annual and perennial forage species. The objective of this study was to evaluate two native clovers (*Dalea candida* Michx. ex Willd. and *Dalea purpurea* Vent.) in binary mixtures with the introduced grasses when harvested in July and September to simulate late summer or fall stockpile forage.

2. Materials and Methods

2.1 Site Description and Environmental Conditions

A 3-yr (2016-2018) study was conducted at Swift Current, Saskatchewan, Canada, at SCRDC AAFC (50°16′N 107°44′W). Soil at Swift Current is classified as Orthic Brown Chernozem, Swinton association of a silt-loam texture on a gently sloping topography (Saskatchewan Soil Survey, 1990).

In the spring of 2015, soil composite samples were collected at the site from the individual plots to a depth of 15 cm and analyzed for N and phosphorus (P) levels. The soil nutrients' mean contents before planting were 34 kg/ha NO_3-N and 36 kg/ha P_2O_5-P. Based on the soil test recommendations (Government of Saskatchewan, 2016), no fertilizer was applied, while herbicide applications of N-(phosphonomethyl) glycine (Roundup Transorb®) and bentazon (Basagran®) (Monsanto, Creve Coeur, Greater St. Louis, Missouri, USA) were applied at 2.5 and 2.2 l/ha, respectively, for pre-seeding weed control 20 May 2015.

Monthly mean air temperature (℃) and total precipitation (mm) data from 2015 to 2018 and long-term average (LTA; 30-yr, 1971-2000) were obtained from the Swift Current Research and Development Center in Saskatchewan according to Environmental Canada's climate data online (www.climate.weatheroffice.ec.gc.ca) which is based on the weather stations located 1 km from the study site (Table 1). In 2016, total precipitation during the growing season (April to October) was 165% of LTA, while total precipitation recorded in 2017 and 2018 was 47% and 51% of LTA, respectively, in Swift Current. These dry growing seasons at the study site were particularly noticeable from June to August in 2017 and June to September in 2018.

Average monthly temperatures followed mostly similar patterns as the LTAs recorded at the site over the study years, although, they varied in some years with lower temperatures for April and September being observed in 2018 (–24.5% and 71.9% of LTA for April and September, respectively) and higher temperatures observed in October 2015 (150% of LTA). In all, the precipitation data in 2016 reflected a wet season for forage production, as opposed to the dry growing seasons in 2017 and 2018. Overall, these data suggested that the trials were conducted in an environment with similar temperatures over the 3-yr study period, but lower precipitation in the later years compared to the 30-yr average weather condition of this area.

2.2 Experimental Design, Seeding, Stand Establishment, Harvesting, and Sampling

Sixty-four plots were randomly assigned to 1 of 8 replicated (n=4) treatments (WPC–MBG, WPC–HBG, WPC–BozoiskyRWR, WPC–TomRWR, PPC–MBG, PPC–HBG, PPC–BozoiskyRWR, and PPC–TomRWR): 2 clover species/cultivars (WPC cv. Antelope and PPC cv. AC Lamour) in binary mixtures with 3 grass species of 4 cultivars (MBG cv. AC Admiral, HBG cv. AC Success, RWR cv. Bozoisky-Select, and RWR cv. Tom), with two harvesting dates (full bloom and mature stage of clovers).

Most of the binary mixture seeds were obtained from a commercial source (Crop Production Services, Inc., now Nutrien Ag Solutions), however, AC Success HBG and AC Admiral MBG seeds were from SRDC AAFC, and AC Lamour PPC and Antelope WPC seeds were obtained from NRCS Bismarck Plant Material Center (Bismarck, North Dakota, USA). Plots were seeded 28 May 2015. Seeding was completed as a mixed row seeding with a Swift Current plot seeder (Fabro Ltd., Swift Current, SK, Canada) equipped with zero-till disk openers and on-row packing wheels. Seeding rates were 167 pure live seeds per m^2 for each species/cultivar and seeding depth was 1.9 centimeters. Individual plot was consisted of 6 rows (50 seeds per m row) spaced 30 cm apart and 6 m in length or was 1.2×6 m in size (7.2 m^2).

Guard rows of creeping red fescue [*Festuca rubra* L. ssp. *arenaria* (Osbeck) F. Aresch.] were seeded on each side of the trial. The plots were enclosed by a deer fence (Deer Fence Canada Inc., Dunrobin, Ontario, Canada) to prevent grazing by wildlife during the trial. Forage mixtures were harvested once in July (full bloom) or September (mature) during the study years to determine summer and fall grazing potentials of the mixtures. No cutting was done in the seeding year (2015). The harvest dates were 4-5 July and 13 September in 2016, 11 July and 6 September in 2017, and 3 July and 20 August in 2018. Forage cutting was completed with a flail plot harvester (Swift Machine and Welding, Swift Current, SK, Canada).

Table 1. Monthly (April-October), annual, and long-term precipitation and temperature during four consecutive years at Swift Current, SK, Canada

	Temperature, ℃					Precipitation, mm				
Item	2015	2016	2017	2018	LTA[2]	2015	2016	2017	2018	LTA
April	6.1	6.4	4.4	1.2	4.9	12.4	22.0	8.6	7.1	22.6
May	10.1	12.4	12.1	14.4	10.9	2.3	129.7	16.4	14.9	47.9
June	17.1	16.6	15.2	16.9	15.5	16.1	80.4	31.1	20.2	80.9
July	19.0	17.8	20.4	18.9	18.4	96.1	119.0	7.5	32.0	53.3
August	18.2	16.7	18.2	18.5	17.9	49.2	45.9	24.8	28.0	47.8
September	12.6	12.2	13.4	9.2	12.8	39.0	37.1	2.5	41.8	32.5
October	7.8	4.1	4.8	3.8	5.2	33.8	72.1	51.7	10.6	20.3
GS[1]	-	-	-	-	-	248.9	506.2	142.6	154.6	305.3
Annual	-	-	-	-	-	304.0	522.6	189.2	182.3	372.1

Note. [1]GS, growing degrees for the growing season (April-October); [2]Long-term average (1971−2000).

Dry matter yield (DMY), botanical composition, and nutritive value were evaluated to binary mixtures. Forage cutting of a 0.6 × 5.0 m area to a 3-cm stubble height was completed and all clipped samples were separated by live and dead materials, the latter of which was discarded. Dry matter (DM) content was determined by weighing a fresh sample, drying in a forced air oven at 60 ℃ for 48 h to a constant weight, and re-weighing, and a subsample was collected for further laboratory analysis. Dry matter yield was determined by multiplying the DM content by the fresh weight and expressed in kg/ha. Botanical composition was determined by clipping a 1.0-m linear row length (middle row) within each plot and then hand-separating into grass and legume components and the first year-standing dead was discarded. Each component was then dried and re-weighed to calculate its contribution to the total yield. Botanical composition was calculated based on DMY of individual species.

2.3 Nutritive Analysis

Samples were ground to pass through a 1-mm screen using a Wiley mill (Thomas-Wiley, Philadelphia, PA) for further analysis. Forage nutritive value analyses included crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), organic matter (OM), *in vitro* organic matter digestibility (IVOMD), acid detergent lignin (ADL), calcium (Ca), total phosphorus (P), and potassium (K). Sequential NDF and ADF were determined using an ANKOM^{200} fiber analyzer (Model 200; ANKOM; Fairport, NY). The ADL was analyzed through the Klason technique (Van Soest, 1994). Total nitrogen (N) was determined using the micro-Kjeldahl method (AOAC, 2012) and N was multiplied by 6.25 to determine CP content. Calcium concentration was determined using an atomic absorption spectrophotometer (Method 978.02; AOAC, 2012; PerkinElmer, Model 2380, CN, USA), total P was analyzed using a spectrophotometer (Method 946.06, AOAC, 2012; Pharmacia, LKB-Ultraspec® III, Stockholm, Sweden), and K concentration was determined through the method adapted from Steckel and Flannery, (1965). The IVOMD was determined using the procedure developed by Tilley and Terry (1963) and as described by Damiran, DelCurto, Bohnert, & Findholt (2008). Ash was determined by heating at 600 ℃ for 4 h (AOAC method 923.03; AOAC, 2012). Total digestible nutrients (TDN) were calculated using the grass–legume Penn State equation according to Adams (1995).

2.4 Calculation of Nutrient Yield

Nutrients yields as crude protein (CPY); digestible organic matter (DOMY), and total digestible nutrients (TDNY) yields per hectare were calculated by multiplying crop forage yield (kg/ha) by nutrient content (% DM) to allow a comparison of nutrient yield potential for animal feed production among the forage mixtures.

2.5 Statistical Analysis

Initial data analysis employed a split-split-plot design with legume as the main plot, grass as the subplot, and harvest date as the sub-subplot with four (n = 4) replications. However, comparison of forage × harvesting date interactions are not reported, because they were not central to the objective of evaluating the forage mixtures included in this study. Therefore, data are presented by harvesting date. Data were subjected to an analysis of variance (ANOVA) using the MIXED procedure of SAS 9.4 (SAS Institute, 2014) for a completely randomized design and with a 2 × 4 factorial arrangement of treatments as a split-plot design with clover as the main plot and grass as the subplot with four (n = 4) replications.

Firstly, the model used was $Y_{ij} = \mu + Clover_i + Grass_j + (Clover \times Grass)_{ij} + e_{ij}$, where Y_{ij} = response variable; μ = mean; clovers (Clover) and grasses (Grass) in binary mixtures were both fixed effects; $Clover_i$ = clovers included in binary mixtures (WPC cv. Antelope and PPC cv. AC Lamour); $Grass_j$ = grasses included in binary mixtures (MBG cv. Admiral, HBG cv. AC Success, RWR cv. Bozoisky-Select , and RWR cv. Tom); and error was e_{ij}. Each plot was considered an experimental unit for a total of 96 experimental units over the 3-yr study for each harvest date. Analysis showed that the effect of clover and grass was significant ($p < 0.05$), however, clover × grass was not significant ($p > 0.05$) excluding NDF, hence, clover × grass interaction was removed from the model and the data (except NDF data) were re-analyzed to assess only clover and grass effect of forage mixture.

Secondly, within a treatment (forage mixtures), data were, also, analyzed with pair-wise comparisons to determine harvest date effect using the MIXED procedure of SAS 9.4 (SAS Institute, 2014). The model used for the analysis was: $Y_{ij} = \mu + T_i + e_{ij}$; where Y_{ij} was an observation of the dependent variable $_{ij}$; μ was the population mean for the variable; T_i was the fixed effect of the harvest date (July or September); and e_{ij} was the random error associated with the observation ij. Year was treated as a random variable in all analysis because the objective was to characterize forage mixtures the entire growing life and not at individual year points. The differences between treatment means were determined using Tukey's multiple range test and were considered significant at $p < 0.05$ and a tendency declared at $0.05 < p < 0.10$.

3. Results

3.1 Dry Matter Yield and Nutritive Value

3.1.1 White Prairie Clover–Grass

Clover × Grass interaction was not detected ($p > 0.05$) for forage DMY at both harvest dates (Table 2). White prairie clover in July did not produce much biomass with only 0.6% (9.0 ± 2.26 kg/ha) of total DMY of WPC–Grass mixtures (Grass includes MBG, HBG, BozoiskyRWR, and TomRWR), which was still higher ($p = 0.031$) than the legume proportion (0.1%) in PPC–Grass mixtures (2.0 ± 2.26 kg/ha), whereas lower ($p = 0.004$) grass component (1499.6 vs. 2235.7 ± 173.4 kg/ha) was accumulated in WPC–Grass mixtures. Otherwise, clover contribution did not differ within a harvest date ($p = 0.203$ for July and $p = 0.967$ for September) between the clover mixtures with any of the grasses. Nutritional composition of WPC–Grass mixtures did not change during the season due to harvest date with similar low CP (averaged at 5.7 ± 0.40%) and identical NDF values (58.4 ± 0.64%) detected at July and September harvest dates (Table 3). Mixtures of WPC with a grass species (any of the four grasses) at July harvest, produced lower total DMY (1508.6 vs. 2237.7 kg/ha, ±173.61, $p = 0.004$), CPY (77.3 vs. 112.7 kg/ha, ± 6.8, $p < 0.001$), DOMY (778.9 vs. 1148.8 kg/ha, ± 85.0, $p = 0.003$), and TDNY (839.4 vs. 1259.4 kg/ha, ± 94.24, $p = 0.002$), as compared to PPC–Grass mixtures (Table 4).

3.1.2 Purple Prairie Clover–Grass

Lower legume as mentioned above, but higher grass proportion (2235.7 vs. 1499.6 kg/ha, ±173.35, $p < 0.001$) of PPC–Grass mixtures than those of WPC–Grass mixtures were detected at July harvest, although there were no differences at September harvest. Like WPC–Grass, PPC–Grass mixtures did not vary in nutritive value over the growing season remaining at relatively low CP averaged at 6.0 ± 0.40% and high NDF (57.8 ± 0.64%) or had no changes in ADL (8.6 ± 0.33%), IVOMD (52.4 ± 0.43%), TDN (56.3 ± 0.74%), P, K, or Ca concentration over the harvest dates (Tables 3 and 4). For the estimated nutrient yields obtainable from a hectare, the summer productions of PPC–Grass mixtures were greater than WPC–Grass, as mentioned above.

3.1.3 Clover–bromegrass and Clover–Russian Wildrye

Grasses interacted ($p < 0.05$) in forage DMY estimates. Total forage DMY of Clover–MBG (Clover included WPC and PPC) and Clover–HBG mixtures (2412.9 and 2865.7 kg/ha for Clover–MBG and Clover–HBG, respectively, vs. 1012.5 and 1201.4 kg/ha, for Clover–BozoiskyRWR and–TomRWR, respectively, ±245.52, $p < 0.001$; averaged at 2639.3 vs. 1107 kg/ha) and the proportion of bromegrasses at July harvest were higher as compared to total DMY and the proportion of ryegrasses of Clover–BozoiskyRWR and –TomRWR mixtures (2404.1 and 2864.4 kg/ha, of MBG and HBG, respectively, vs. 1003.5 and 1198.6 kg/ha, ±245.16, of BozoiskyRWR and TomRWR, respectively, $p < 0.001$) (Table 2). As well, Clover–MBG had higher IVOMD than Clover–HBG in July (53.6 vs. 51.2%, ±0.64, $p = 0.035$). Clover–HBG mixtures in July tended to exhibit lower Ca concentration than Clover–TomRWR (0.34 vs. 0.5%, ±0.04, $p = 0.061$). There were no differences between the bromegrasses mixed with clovers in yield or legume composition or nutritive components including CP, NDF, ADL, TDN, P or K concentration.

Similarly, no difference was found between Bozoisky–Select and Tom cultivars of RWR in DMY, CP, TDN, IVOMD, or mineral composition in mixtures with clover. Both cultivars in mixtures at July harvest, however, differed from bromegrasses ($p < 0.001$) with lower grass proportion and total herbage production. Also, at July harvest, clovers with bromegrasses produced greater ($p < 0.001$) CPY, DOMY, and TDNY (averaged at 116.2, 1361.2, and 1480.6 kg/ha vs. 73.7, 566.5, 618.2 kg/ha of DM, ±9.58, ±120.17, ±133.27, respectively) than clovers with RWRs (Table 5).

3.1.4 Harvest Date

September harvest resulted in greater forage DMY than July harvest for clovers mixed with RWRs (1012.5 ± 245.5 kg/ha in July vs. 1615.2 ± 282.2 kg/ha in September, $p < 0.05$ and 1201.4 ± 245.5 kg/ha in July vs. 2095.7 ± 282.2 kg/ha in September, $p < 0.01$, for Clover–BozoiskyRWR and Clover–TomRWR mixtures, respectively), while there was a trend of decreased DMY in September from July for Clover–HBG mixtures (2865.7 ± 245.5 kg/ha in July vs. 1971.8 ± 282.2 kg/ha in September, $p = 0.052$) (Table 2). Highest total DMY increase (by 74.4%) in September was obtained for Clover–TomRWR ($p < 0.01$), whereas highest decrease (by 61.3%) in grass proportion was exhibited by Clover–HBG ($p < 0.001$) mixture.

Legume growth was substantial ($p < 0.001$) during the growing season for all treatment mixtures with the proportions ranging from 1.4 to 9.0 kg/ha in July vs. from 663.2 to 876.1 kg/ha in September, specifically, it was up by 99, 99.7, and 99.8% for WPC–Grass, PPC–Grass, and Clover–HBG, respectively.

Table 2. Crop yield of clover-grass binary mixtures in July and September at Swift Current, Saskatchewan, Canada during 2016 to 2018

	DMY, kg/ha					
Entry	Clover		Grass		Total Yield	
Harvest time	July	September	July	September	July	September
Clover						
WPC–Grass[1]	9.0a	876.1***	1499.6a	911.8***	1508.6a	1787.9
PPC–Grass	2.0b	663.2***	2235.7b	1293.0**	2237.7b	1956.2
SEM	2.26	151.00	173.4	152.23	173.61	199.57
Grass						
Clover–MBG	8.8	745.9**	2404.1a	1059.5***	2412.9a	1805.4
Clover–HBG	1.4	863.5**	2864.4a	1108.5***	2865.7a	1971.8*
Clover–BozoiskyRWR	9.0	736.3***	1003.5b	879.0	1012.5b	1615.2*
Clover–TomRWR	2.8	733.0***	1198.6b	1362.7	1201.4b	2095.7**
SEM	3.20	213.55	245.16	215.3	245.5	282.2
	-------------------*p*-value----------------------					
Clover	0.031	0.321	0.004	0.080	0.004	0.553
Grass	0.203	0.967	<0.001	0.465	<0.001	0.653
Clover × Grass	0.194	0.885	0.577	0.923	0.569	0.962

Note. [1]WPC, Antelope white prairie clover; PPC, AC Lamour purple prairie clover; MBG, Admiral meadow bromegrass; HBG, AC Success hybrid bromegrass; BozoiskyRWR, Bozoisky−Select Russian wildrye; TomRWR, Tom Russian wildrye; The different letters within column and within legume and grass indicate significant difference at $p < 0.05$. *, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels between harvesting date within each chemical composition, respectively.

Table 3. Nutrient composition and digestibility of clover-grass binary mixtures in July and September at Swift Current, Saskatchewan, Canada during 2016 to 2018

	% of DM									
Item	CP		NDF		ADL		IVOMD		TDN	
Harvest time	July	September	July	September	July	September	July	September	July	September
Clover										
WPC−Grass[1]	5.9	5.5	58.4	58.4	9.0	8.9	52.3	52.7	56.2	55.8
PPC−Grass	6.2	5.7	57.7	58.0	8.3	9.0	52.1	52.6	57.1	55.5
SEM	0.41	0.38	0.62	0.65	0.43	0.23	0.46	0.40	0.83	0.65
Grass										
Clover−MBG	5.5	5.4	57.3	59.2	8.3	9.0	53.6a	51.3b**	57.1	55.3
Clover−HBG	4.9	5.5	57.9	58.3	8.1	9.3	51.2b	52.9ab*	57.6	55.7
Clover−BozoiskyRWR	7.0	6.0	58.7	56.1	9.3	9.1	52.7ab	53.0ab	55.9	56.1
Clover−TomRWR	7.0	5.6	58.2	59.2	8.8	8.6	51.5ab	53.4ab	56.1	55.5
SEM	0.58	0.54	0.87	0.92	0.61	0.32	0.64	0.56	1.17	0.91
	-----------------------------*p*-value-----------------------------									
Clover	0.585	0.756	0.457	0.722	0.233	0.688	0.748	0.886	0.457	0.759
Grass	0.022	0.870	0.745	0.061	0.481	0.419	0.035	0.042	0.699	0.922
Clover × Grass	0.883	0.963	0.725	0.033	0.738	0.204	0.335	0.531	0.861	0.387

Note. [1]WPC, Antelope white prairie clover; PPC, AC Lamour purple prairie clover; MBG, Admiral meadow bromegrass; HBG, AC Success hybrid bromegrass; BozoiskyRWR, Bozoisky−Select Russian wildrye; TomRWR, Tom Russian wildrye. The different letters within column and within legume and grass indicate significant difference at $p < 0.05$. *, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels between harvesting date within each chemical composition, respectively; CP, crude protein; NDF, neutral detergent fiber; ADL, acid detergent lignin; IVOMD, *in vitro* organic matter digestibility; TDN, total digestible nutrients.

Table 4. Mineral composition of clover-grass binary mixtures in July and September at Swift Current, Saskatchewan, Canada during 2016 to 2018

	% of DM					
Item	Ca		P		K	
Harvest time	July	September	July	September	July	September
Clover						
WPC−Grass[1]	0.44	0.38	0.11	0.06***	1.21	1.43
PPC−Grass	0.39	0.38	0.10	0.06***	1.17	1.44*
SEM	0.028	0.037	0.012	0.003	0.091	0.082
Grass						
Clover−MBG	0.41ab	0.36	0.10	0.06**	1.27	1.45
Clover−HBG	0.34b	0.40	0.09	0.05**	1.06	1.28
Clover−BozoiskyRWR	0.43ab	0.39	0.12	0.06**	1.25	1.56
Clover−TomRWR	0.50a	0.36*	0.11	0.06*	1.16	1.45
SEM	0.040	0.053	0.016	0.004**	0.128	0.116
	-------------------*p*-value----------------------					
Clover	0.215	0.942	0.516	0.836	0.789	0.879
Grass	0.061	0.934	0.669	0.261	0.639	0.411
Clover × Grass	0.514	0.966	0.995	0.555	0.290	0.787

Note. [1]WPC, Antelope white prairie clover; PPC, AC Lamour purple prairie clover; MBG, Admiral meadow bromegrass; HBG, AC Success hybrid bromegrass; BozoiskyRWR, Bozoisky−Select Russian wildrye; TomRWR, Tom Russian wildrye. The different letters within column and within legume and grass indicate significant difference at $p < 0.05$. *, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels between harvesting date within each chemical composition, respectively.

Table 5. Crude protein, digestible organic matter and nutrients yield of clover-grass binary mixtures in July and September at Swift Current, Saskatchewan, Canada during 2016 to 2018

	kg/ha of DM					
Item	CPY		DOMY		TDNY	
Harvest time	July	September	July	September	July	September
Clover						
WPC−Grass[1]	77.3b	81.9	778.9b	938.4	839.4b	979.2
PPC−Grass	112.7a	89.0	1148.8a	1029.0	1259.4a	1064.5
SEM	6.77	7.44	84.97	104.17	94.24	105.88
Grass						
Clover−MBG	110.5ab	80.3	1270.3a	922.0	1345.6a	977.0
Clover−HBG	122.0ab	85.8*	1452.0a	1042.0	1615.6a	1063.5*
Clover−BozoiskyRWR	67.92c	80.1	524.5b	861.0	563.5b	903.3*
Clover−TomRWR	79.5bc	95.7	608.5b	1109.8	672.9b	1143.5**
SEM	9.579	10.53	120.17	147.32	133.27	149.74
Clover	<0.001	0.498	0.003	0.540	0.002	0.571
Grass	<0.001	0.695	<0.001	0.626	<0.001	0.694
Clover × Grass	0.140	0.911	0.518	0.954	0.465	0.954

Note. [1]WPC, Antelope white prairie clover; PPC, AC Lamour purple prairie clover; MBG, Admiral meadow bromegrass; HBG, AC Success hybrid bromegrass; BozoiskyRWR, Bozoisky−Select Russian wildrye; TomRWR, Tom Russian wildrye. CPY, crude protein yield; DOMY, digestible organic matter yield; TDNY, total digestible nutrients yield. The different letters within column and within legume and grass indicate significant difference at $p < 0.05$. *, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels between harvesting dates within each chemical composition, respectively.

Whereas grass proportion at September harvest declined for all excluding clover mixtures with RWRs (by 39.2%, $p = 0.001$; 42.2%, $p = 0.003$; 55.9%, $p = 0.001$; and 61.3%, $p < 0.001$ for WPC–Grass, PPC–Grass, Clover–MBG, and Clover–HBG mixtures, respectively).

Nutritionally, clover mixtures with grass did not vary over the harvest dates. However, a significant Clover × Grass interaction ($p = 0.033$) was detected for NDF concentration at September harvest (data not shown). There was a trend for WPC–MBG and –TomRWR mixtures exhibiting the highest NDF contents (60.6 and 60.4 ± 1.30% for WPC–MBG and WPC–TomRWR, respectively), while WPC–BozoiskyRWR containing the lowest NDF content (54.0 ± 2.01%) in September ($p = 0.061$) with a tendency of declining ($p = 0.078$) from July (59.0 ± 0.88%) (data not shown). Otherwise, there was no difference between Bozoisky and TomRWR cultivars in clover mixtures for DMY or for several nutritive parameters. During the growing season, Clover–MBG decreased in IVOMD ($p < 0.01$) by September harvest, while Clover–HBG and –TomRWR mixtures increased ($p < 0.05$).

Also, Clover–MBG had higher IVOMD than Clover–HBG (53.6 vs. 51.5%, ± 0.64) in July, but lower than Clover–TomRWR mixtures (51.3 vs. 53.4%, ± 0.56) in September ($p = 0.042$). Reduced total P content (by 44.4-50%) was observed from July to September in all mixtures (0.09-0.12%, ±0.02 in July vs. 0.05-0.06%, ±0.004 in September, $p < 0.01$). The Ca concentration at September harvest declined from July harvest by 28% in Clover–TomRWR mixtures (0.36 ± 0.05% in September vs. 0.50 ± 0.04%, in July $p < 0.05$), whereas 23.1% increase in K concentration in PPC–Grass mixtures (1.2 ± 0.09% vs. 1.4 ± 0.08%, $p < 0.05$) was detected from July to September.

4. Discussion

4.1 Forage Dry Matter Yield and Nutritive Value

4.1.1 White Prairie Clover–Grass

In the companion study (Peprah et al., 2021b), there were 18 forage mixture treatments of binary combinations consisting of 4 legume species that included alfalfa cv. AC Yellowhead and 3 grass species harvested at the same dates as in the current study. Hence, for a comparison purpose only, we are using the alfalfa (cv. AC Yellowhead)-grass mixture from the companion study as a check forage in the current study.

White prairie clover in binary mixture with grass accumulated 58% and 5.4% less total forage DMY and legume contribution of WPC at July harvest was far from being comparable to check forage (0.6% vs. 34.7%), i.e., almost 60 times less than that of check forage, whereas in September it increased with 14.2% units higher of WPC (49.0% vs. 34.8%).

At Swift Current, SK, Canada, Serajchi et al. (Serajchi, Schellenberg, Mischkolz, & Lamb, 2018) reported that WPC in binary mixture with western wheatgrass (*Pascopyrum smithii* (Rydb.) Löve) yielded approximately 1300 and 1400 kg/ha in early-July and late-August, respectively, and CP did not change over the harvest dates remaining at around 6% (Serajchi et al., 2018), compared to which, the WPC–Grass binary mixtures in the present study, produced 208 and 388 kg/ha greater at July and September harvests, respectively, and consistent CP values.

As the legume composition at July harvest indicated, both clover species in the present study were not able to develop well in the summer, they did better only later in the season though were still dominated by the grass (grass comprised 99.4% and 51.0% of DMY of WPC–Grass mixture in July and September, respectively), suggesting that the nutritive value of the mixtures at summer harvest illustrated that of the grass component and with the legume component reaching 49% of DMY by the fall, though both grass and legume may have likely been at nutritionally declining stage at this time.

Comparing seeding of native grasses and forbs in Montana, Majerus, Kilian, & Scianna (2020) obtained good white prairie clover establishment and performance producing 92 kg/ha biomass and had moderate basal cover (4%) and plant density (2 plants/m^2) when seeded with other forbs and grasses. A study from Swift Current, SK demonstrated that WPC can be present at more than 50% in mixture with Nodding bromegrass (*Bromus porter* (Coult.) Nash), while it was less than 10% in mixture with Western wheatgrass (*Pascopyrum smithii* (Rydb.) Löve) indicating that the grass species in the mixture will affect its contribution to the forage (Serajchi et al., 2018). Likewise, Jefferson et al. (2002) observed a grass cultivar effect on clover biomass productivity at western Canadian prairie locations. The three grass species in July, in the current study, performed more like Western wheatgrass in competition with WPC in Serajchi et al. (2018).

Also, white clover (*Trifolium repens* L.) on a coarse loamy soil in Nova Scotia, Canada, seeded in binary, tertiary, and quaternary mixtures with common pasture grass species contributed the lowest proportion of the total herbage biomass (ranging from 5.8 to 25.1%, with an average of 15.5% in binary mixture) and was affected by sward mixture with inferior yield of clover in Kentucky bluegrass (*Poa pratensis* L.)-containing mixtures (Papadopoulos et al., 2012). Others, however, reported that regardless of companion grass species, mixtures with white clover were productive with 11835-13303 kg/ha of annual DMY on loamy-sand soil in Denmark where plots were irrigated to avoid drought stress, and white clover proportion in binary mixtures with perennial ryegrass (*Lolium perenne* L.) or timothy (*Phleum pratense* L.) or meadow fescue (*Festuca pratensis* Huds.) or hybrid ryegrass (*Lolium × boucheanum* Kunth) harvested in July was in the range of 30-50% of DMY, decreased to 20-30% harvested in August and October, ranging 22-34% during May to August, and contained around 20% CP and 40% NDF (Elgersma &Soegaard, 2016). On a pasture of predominantly perennial ryegrass and white clover, with 16380 kg/ha production near Hamilton, New Zealand, the clover content was measured at 15.2% (Papadopoulos et al., 2012).

Nutritionally, WPC–Grass mixtures contained 31.4% lower but 5.8% higher CP in July and September harvests, respectively, and 10.4% greater NDF in July and 6.3% greater ADL in September, as compared to check forage. Differences were minimal (under 5%) in ADL in July, in IVOMD, TDN or P concentration at both harvest dates between WPC–Grass mixtures and check forage, however, Ca and K concentrations were 42.1% and 6.2% lower, respectively, in July, but K was 26.6% higher in September. Elsewhere, WPC consistently had higher OMD compared to PPC at any phenological stage, with 51.3% OMD, 12.9% CP, and 45.9% NDF at flowering grown near Swift Current, SK, (Iwaasa et al., 2014), while WPC grown in Missouri contained 12.7% CP and 50.7% NDF (McGraw, Shockley, Thompson, & Roberts, 2004), of which OMD value was similar, but CP was twice as high and NDF was lower; compared to the values in the current study. Also, at Swift Current, SK, six populations of WPC exhibited differences in CP (ranged from 15 to 18%) and NDF (ranged from 34 to 41%) at the bloom stage, while little or no differences at maturity stage (ranged from 6.2 to 7.1% and from 45 to 52% for CP and NDF, respectively (Khanal, Schellenberg, & Biligetu, 2018), the latter partly agreed with the current study in that the clover species remained unchanged in nutrients at maturity.

Wynia (2008b) noted that WPC is adapted to locations with 250 to 450 mm of growing season precipitation. Precipitation in 2017 and 2018 at the current study site was well below this level with 175 mm in 2017 and 128 mm in 2018 from April to October. Therefore, water stress may account for the extremely low forage production and presence of WPC in July in the current study. Our results further conflicted in part with the findings that WPC had low forage biomass but good forage nutritive value, with 12.7% protein and was more digestible (had lower ADF) than commonly used introduced forage legumes (McGraw et al., 2004). Overall, as indicated in the current study, WPC may have better competitive ability as compared to PPC in mixture with introduced grass, that would be exhibited stronger in the fall.

4.1.2 Purple Prairie Clover–Grass

Purple prairie clover produced 64.9% less forage yield in September as compared to check forage. Since at July harvest legume proportion of PPC was almost nonexistent in the mixture, it was not comparable with check forage (0.11 vs. 34.7% of DMY), while at September harvest it was closer (29.5 vs. 34.8% of DMY) to check forage. As well, the lack of establishment or competitive ability of PPC with grasses was noted by others; PPC mixed with native grasses delivered biomass ranging from zero at Swift Current-irrigation to 1000 kg/ha at Brandon-sandy soil site (Jefferson et al., 2002), in Minnesota, second-year biomass yield of legume for PPC in mixture with little bluestem (*Schizachryium scoparium* (Michx.) Nash) was 1100 kg/ha (Fischbach et al., 2006), low proportion of PPC (21%) in binary mixture with Bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) Löve) but up to 58% legume in mixture with sideoats grama (*Bouteloua curtipendula* (Michz.) Torr.; (Serajchi et al., 2018) and PPC made up a very small portion of the mixtures with native cool-season and warm-season grasses on seeded pastures near Swift Current, SK (Schellenberg, Biligetu, & Iwaasa, 2012).

Purple prairie clover was, also, less productive than alfalfa and less competitive in mixtures with native shrubs (Schellenberg & Banerjee, 2002). Partly on the contrary to our study, PPC was readily established with comparable nutrient content to that of alfalfa and sainfoin under dryland condition, but its yearly yield was substantially lower than conventional legume forages (Wang et al., 2019). The results on PPC in mixture with tame grass in our study mostly agreed with the aforementioned studies, and particularly, the summer yield of PPC in mixtures coincided with that Jefferson et al. (2002) reported at Swift Current-irrigation site. Clover contribution of PPC in binary mixtures in the current study, expectedly, was much lower compared to the DM yields of 2014 and 2297 kg/ha of PPC grown alone under dryland condition at full flower and late flower stages, respectively (Wang, Iwaasa, Acharya, & McAllister, 2019).Iwaasa, Xu, Acharya, & McAllister, 2019).Xu, Acharya, & McAllister, 2019). Regarding nutritional composition, PPC–Grass mixtures had 9.1% higher NDF, 27.9% lower CP, and 34% lower Ca concentration in July, but 9.6% higher CP content in September than check forage. Otherwise, there was minimal difference (<5%) in ADL, IVOMD, or TDN between PPC–Grass and check forage. As well, no difference in P or K concentration was detected between all mixture/treatments at the harvest dates and check forage. Conversely, Ca concentration of PPC–Grass mixtures differed by almost half (~50% lower) the amount check forage contained, remaining unchanged over the harvest dates.

Elsewhere, PPC in monoculture exhibited lower NDF (47.3%) and higher CP concentration (15.2%) than other legumes including WPC, when harvested at early flowering stage in central Missouri (McGraw et al., 2004), while Iwaasa, Sottie, Wang, and Birkedal (2016) in Swift Current, SK found higher CP (16.9% vs. 14.2%) and OMD (58.8% vs. 51.3%) in WPC than in PPC harvest-ed at full flower/seed set stage and similar NDF (38.4%, WPC and 40.7%, PPC). As well, similar NDF and CP contents were reported at semiarid prairie in Swift Current, SK, 53.7% NDF and 9.8% CP during flowering (Iwaasa et al., 2014) and 52.6% NDF and 10% CP at full flower stage on rehabilitated native mixed grass pasture, with NDF and ADF contents increased, while CP decreased as PPC matured (Peng et al., 2020). Whereas, grown on irrigated plots in Orthic Brown Chernozem soil in Lethbridge, AB, harvested at full-flower stage, freeze-dried green chop of PPC contained on average about 16% CP, 44% NDF, and 8% ADL (Peng et al., 2020). As the clover was grown alone in these studies, the lower NDF and higher CP in PPC was expected. Comparable to our findings were though the relatively high NDF concentrations in the native legumes compared to common introduced forage legumes reported in McGraw et al. (2004).

In our study, the CP and IVOMD values of PPC–Grass mixtures at July harvest were comparable to those values (6.0% CP and 50.9% IVDMD) of PPC–Sideoats grama (*Bouteloua curtipendula* Michx.) or (51.5% IVDMD) of PPC–Indiangrass [*Sorghastrum nutans* (L.) Nash] binary mixtures from July harvests near Manhattan, Kansas (Posler et al., 1993). Furthermore, PPC–Grass mixtures harvested at full bloom in the current study had greater IVOMD as compared to the OMD (40.6%) determined in PPC at flowering in the Orthic Brown Chernozem soil (Iwaasa et al., 2014) and similar or higher to the IVDMD values (50.9 or 46.3%) at full flower stage for mixtures that included 25 or 50% of PPC and cool-season native grasses (Peng et al., 2020) and as the latter study found IVDMD decreased with increasing PPC percentage in mixture. Conversely, on a very fine sandy loam soil in Kansas, PPC in binary mixture with warm-season grass did not influence IVDMD of mixtures (Posler et al., 1993). On the other hand, organic matter digestibility and protein digestibility of a mixture of alfalfa and PPC in a ratio of 40:60 (DM basis Mix) were lower than those of alfalfa (Huang et al., 2015). Nevertheless, our findings on IVOMD, P, ADL and TDN contents of PPC–Grass mixtures were adequate for grazing beef cows in the first and second trimester of gestation (NASEM, 2016).

4.1.3 Comparison of White and Purple Prairie Clovers

Studying native legumes near Columbia, Missouri, McGraw et al. (2004) reported similar forage yield, 10.2 and 11.6 g/plant at flowering and 5.7 and 22.1 g/plant at mature stages, for WPC and PPC, respectively, and this was partially in agreement with the results in the present study. Still, literature have been conflicting on growth performance of the two clover species; among three *Dalea* species ranked on germination PPC cv. AC Lamour was the greatest and WPC cv. Antelope the intermediate (Schellenberg & Biligetu, 2015) and WPC and PPC had 78% vs. 65% survival and 76% vs. 237.2% selection differential for biomass, respectively, in Swift Current, SK, Canada (Khanal et al., 2016), while in Stephenville, Texas, the United States, *Dalea candida* produced 124% more herbage biomass and 80% greater root biomass than *D. purpurea* (Girgin, 2019).

Difference between the two clovers in legume proportion in the mixtures obtained in the current study (77.8% and 32.1% greater WPC proportion than PPC in July and September harvests, respectively,) was more related to the findings of Girgin (2019) than of the others. Additionally, the legume proportions in September for WPC–Grass (49%) and PPC–Grass (29.5%) mixtures in the present study differed by 19 and 9% units higher for WPC while PPC proportion was at the lower range value, respectively, in comparison to the optimal legume percentages of 30–40% in the harvested biomass achieved in Sanderson, Brink, Stout, and Ruth (2013) study on grass-legume proportions in forage seed mixtures that included white, red, and kura clovers (*Trifolium ambiguum* L.), which revealed, also, that the differences in yield were related to the dominant species in the mixture.

Moreover, CP content in clovers with RWRs at July harvest was on average 25.7% greater (although statistically not significant) than in clovers with bromegrasses, which agreed to Russian wildrye being high in protein but did not agree to it retaining higher CP content than most grasses after maturity (Ogle et al., 2012). There were trends for lower (6.4% units) NDF content in WPC–BozoiskyRWR ($p = 0.078$) than in WPC–TomRWR in September and for Clover–TomRWR containing greater (0.16% units) Ca concentration ($p = 0.061$) than Clover–HBG in July, the latter was 55.3% lower as compared to check forage.

As well, in an irrigated, 4-year trial at Powell, Wyoming, alternate-row yield of Bozoisky-Select Russian wildrye paired with alfalfa was 6913.6 kg/ha (USDA NRCS, 2013), compared to which the summer and fall yields of this cultivar in mixtures with clover in the present study were substantially (>3 times) lower. As both 'Bozoisky-Select' and 'Tom' cultivars of RWR were originally selected for similar traits, albeit at different locations and countries (first in Utah, USA and latter in Saskatchewan, Canada), performance of BozoiskyRWR in mixture with clover was not different of TomRWR nutritionally and yield-wise (in the summer) in this semiarid region of western Canada, however, numerically the first yielded less than the latter in the fall.

Clover–HBG mixtures exhibited numerically 15.8% more forage yield than Clover–MBG mixtures and both grasses with clovers yielded 27% higher than RWRs in clover mixtures, the latter partly contradicted with Holt and Jefferson (1999) who reported that MBG and alfalfa pastures produced similar forage DMY to RWR and alfalfa pastures. Russian wildrye has a caespitose growth form while both HBG and MBG are rhizomatous grasses. When compared to other introduced grasses, Russian wildrye is slow to establish. When seeded in rows, rhizomatous grasses can fill the interplant space with new shoots originating from rhizome meristems when sufficient resources permit.

Therefore, rhizomatous grasses are more competitive with legume associates in this semiarid environment where seasonal droughts create resource competition (Biligetu, Jefferson, Muri, & Schellenberg, 2014; Peprah et al., 2021). Also, Jefferson et al. (2002) seen a grass cultivar effect on PPC biomass productivity when seeded several native warm-season and cool-season grass species with only legume as PPC and they further stated that while the PPC biomass was low, the PPC grown with warm-season grasses produced more biomass than clover grown with cool-season grasses suggesting that the cool-season grasses are more competitive in mixture with PPC than the warm-season species.

The early growth of cool-season grasses that was observed in the current study could reduce light quality and quantity reaching clovers. However, as others implied, improved seeding management (Kenno, Brick, & Townsend, 1987) may alleviate stand establishment problems of binary mixtures of the prairie clovers with grass. For example, forage yield of RWR with legumes can be increased by seeding in alternate rows (USDA NRCS). Thus, as our results indicated, HBG in native clover mixture has more potential in the semiarid Brown soil zone of western Canada for beef cattle pasture production. Our findings, also, suggested that PPC and BozoiskyRWR appeared to have reduced competitive effects on the grass and legume species, respectively, in the binary mixtures studied.

The interest in using these native legumes as non-bloating alternatives to alfalfa for late summer and fall grazing will be restricted by these limitations in forage yield, plant persistence in grass mixture, and lower forage nutritive value compared to alfalfa. Freedom for any potential bloat risk with these legumes will be weighed relative to their performance to support cattle live weight gains in comparison to the bloat risk of alfalfa. The decision of individual producers must account for these performance limitations when contemplating the substitution of these native legume species for alfalfa in binary mixtures for late summer and early fall pastures for beef cattle.

The goal of the beef producer is paramount to the selection of species for stockpile grazing in the late summer and fall. If yield was the major goal of the producer, then PPC–Grass, or either WPC or PPC with MBG or HBG mixtures would be the top choice. However, if nutritive value was the goal, then both legumes in mixtures with either one of the two RWR cultivars seem would be adequate for summer grazing, while in mixtures with either one of the three grass species would not provide adequate nutritive value for dry beef cow for fall. Furthermore, CP and TDN yields expressed in kg/ha are of significant importance to producers for determination of winter feed (hay) value and supplemental protein feed. In that regard, also, PPC–Grass mixtures showed advantage producing 45.8 and 50% higher CPY and TDNY, respectively, and 47.5% more DOMY in the summer as compared to WPC–Grass. Likewise, McGraw et al. (2004) concluded that it does not appear that native legumes would be a good substitute for the common, introduced legumes when forage nutritive value is the only consideration. If species diversity and ecological restoration is the primary goal, the WPC and PPC can be used as the legume component but grazing animal performance will likely be less than as it is with alfalfa.

In addition, the results of the current study demonstrated that during the summer and fall, binary mixtures of PPC–Grass (2237.7 kg/ha in July and 1956.2 kg/ha in September) and of both clovers with HBG (2865.7 kg/ha in July and 1971.8 kg/ha in September) produced DMY above or at the minimum requirement (2000 kg/ha) for forage production for fall grazing (Aasen & Bjorge, 2009). On the contrary though, WPC–Grass (1508.6 kg/ha in July and 1787.9 kg/ha in September), Clover-BozoiskyRWR (1012.5 kg/ha in July and 1615.2 kg/ha in September), Clover–TomRWR (1201.4 kg/ha in July), and Clover–MBG (1805.4 kg/ha in September) mixtures failed to meet the minimum requirement possibly because of their more vulnerability to the dryer conditions, suggesting these mixtures may not be good option for late summer and fall grazing. The lower precipitation experienced during the growing seasons of 2017 and 2018 compared to 2016, had a significant effect on both yield and nutritive value, thereby making most binary mixtures unable to meet the nutrient requirements for fall grazing by beef cattle.

According to NASEM (2016), the CP and TDN requirements for mature cows and heifers in pre-calving, postpartum, lactating and pregnant, and mid-gestation periods ranged from 6.2 to 12.9% and 44.9 to 64.5%, respectively. In the current study, only mixtures PPC–Grass and clovers with RWR of both cultivars at July harvest were in the CP range requirement, the latters were, also, at the NRC (2000) recommended level (7% CP), as well, TDN in all binary mixtures were in close range to each other (55.3-57.6%) meeting the nutrient requirement. Further, as Van Soest (1965) suggested, when NDF concentration increases to more than 55 to 60% of the DM it may limit intake because of rumen fill. Nevertheless, NDF in the mixtures in the present study, averaged at 58%, thus were of medium nutritive value according to NASEM (2016) nutrient requirement. Inability of the other binary mixtures in the present study, to meet the CP requirement of beef cattle indicates their limitations for late summer and fall grazing under dryland farming conditions, especially in dryer than usual years.

5. Conclusions

The addition of white and purple prairie clovers as native forage legumes in mixtures with introduced grass species resulted in lower herbage yield and nutritive value in summer, yet these measures were comparable to or higher in fall compared to conventional legume–grass mixtures. Clover mixtures with Bozoisky–Select or Tom cultivar of Russian wildrye could be adequate summer forage based on the nutritive value, while clover mixtures with Admiral meadow bromegrass or AC Success hybrid bromegrass were suitable based on the yield. Overall, current study results suggest that white and purple prairie clover in mixture with hybrid bromegrass, along with purple prairie clover with either of the three grass species can offer sufficient forage production. Although forage nutritive value of these mixtures was average, the yields per hectare of crude protein, total digestible nutrients, and digestible organic matter were acceptable for summer or fall grazing in southwest Saskatchewan, Canada. Finally, future research should focus on evaluating white and purple prairie clover-grass mixtures under grazed conditions for forage persistence and animal performance in different soil zones.

Acknowledgements

We would like to acknowledge Leah Pearce and Krystal Savenkoff from Western Beef Development Centre and Byambatseren Dashnyam, Ed Birkadal, Russ Muri, Dale Sandau and Lindsay Haubrich from Agriculture and Agri-Food Canada for their help with sample collection and processing.

References

Aasen, A., & Bjorge, M. (2009). *Alberta Forage Manual*. Alberta Agriculture and Rural Development. Edmonton, Alberta.

Adams, R. S. (1995). Dairy nutrition. In C. Walker (Ed.), *Dairy Reference Manual* (3rd ed., pp. 108-109). Northeast Regional Agricultural Engineering Service, Ithaca, NY, USA.

Aerts, R. J., Barry, T. N., & McNabb, W. C. (1999). Polyphenols and agriculture: beneficial effects of proanthocyanidins in forages. *Agriculture, Ecosystems and Environment, 75*, 1-12. https://doi.org/10.1016/S0167-8809(99)00062-6

Anderson J., & Sharp, W. C. (1994). *Grass varieties in the United States.* (USDA-SCS Agriculture Handbook 170). Washington, DC: U.S. Government Printing Office. https://doi.org/10.5962/bhl.title.97052

AOAC. (2012). *Official methods of analysis* (19th ed.). AOAC, Gaithersburg, MD, USA.

Beran, D. D., Masters, R. A., & Gaussoin, R. E. (1999). Grassland establishment with imazethapyr and imazapic. *Agronomy Journal, 91*, 592-596. https://doi.org/10.2134/agronj1999.914592x

Berard, N. C., Wang, Y., Wittenberg, K. M., Krause, D. O., Coulman, B. E., McAllister, T. A., & Ominski, K. H. (2011). Condensed tannin concentrations found in vegetative and mature forage legumes grown in western Canada. *Canadian Journal of Plant Science, 91*, 669-675. http://doi.org/10.4141/cjps10153

Biligetu, B., Jefferson, P. G., Muri, R., & Schellenberg, M. P. (2014). Late summer forage yield, nutritive value, compatibility of warm- and cool-season grasses seeded with legumes in western Canada. *Canadian Journal of Plant Science, 94*, 1139-1148. https://doi.org/10.4141/cjps2013-269

Brown, A. N., Ferreira, G., Teets, C. L., Thomason, W. E., & Teutsch, C. D. (2017). Nutritional composition and in vitro digestibility of grass and legume winter (cover) crops. *Journal of Dairy Science, 101*, 2037-2047. https://doi.org/10.3168/jds.2017-13260

Coulman, B. (2006). Success hybrid bromegrass. *Canadian Journal of Plant Science, 86*, 745-747. https://doi.org/10.4141/P05-200

Coulman, B. (2009). *AC Admiral meadow bromegrass.* Technical Bulletin.

Cox, S. R. (2013). *Forage yield and quality of binary grass-legume mixtures of tall fescue, orchardgrass, meadow brome, alfalfa, birdsfoot trefoil, and cicer milkvetch* (Master's thesis). Utah State University, Logan, Utah. Retrieved from https://digitalcommons.usu.edu/etd/4998

Damiran, D. (2005). *Palatability of Mongolian rangeland plants*. Circular of Information No.3. Union, Oregon, USA: Oregon State University, Eastern Oregon Agricultural Research Station. p. 92. Retrieved from https://ir.library.oregonstate.edu/concern/administrative_report_or_publications/wm117q40w

Damiran, D. (2006). *Influence of previous cattle and elk grazing on the subsequent quality and nutrient intake rate of cattle, deer and elk grazing late-summer mixed-conifer rangelands* (Doctoral dissertation). Retrieved from https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/9k41zk18t

Damiran, D., DelCurto, T., Bohnert, D. W., & Findholt, S. L. (2008). Comparison of techniques and grinding sizes to estimate digestibility of forage based ruminant diets. *Animal Feed Science and Technology, 141*, 15-35. https://doi.org/10.1016/j.anifeedsci.2007.04.007

Darambazar, E., DelCurto, T., & Damiran, D. (2013). Changes in forage quantity and quality with continued late-summer cattle grazing a riparian pasture in Eastern Oregon of United States. *Sustainable Agriculture Research, 2*(4), 64-76. https://doi.org/10.5539/sar.v2n4p64

Elgersma, A., & Soegaard, K. (2016). Effects of species diversity on seasonal variation in herbage yield and nutritive value of seven binary grass-legume mixtures and pure grass under cutting. *European Journal of Agronomy, 78*, 73-83. https://doi.org/10.1016/j.eja.2016.04.011

Ferdinandez, Y. S. N., & Coulman, B. E. (2001). Nutritive values of smooth bromegrass, meadow bromegrass, and meadow x smooth bromegrass hybrids for different plant parts and growth stages. *Crop Science, 41*(2), 473-478. http://doi.org/10.2135/cropsci2001.412473x

Fischbach, J. A., Ehlke, N. J., Peterson, P. R., Wyse, D. L., Swanson, D. R., & Sheaffer, C. C. (2006). Seeding rate affects establishment of *native perennial legumes* in the upper midwestern US. *Native Plants Journal, 7*(1), 61-68. https://doi.org/10.2979/NPJ.2006.7.1.61

Gardner, D. (2006). Continuing vegetation analyses of a prairie restoration in Ford County, Illinois. *Illinois Native Plant Society Erigenia, 21*, 3-9.

Girgin, G. (2019). *Dalea aurea, Dalea candida, Dalea multiflora and Dalea purpurea herbage and root nitrogen and dry matter yield as influenced by soil, phosphorus amendment and rhizobium inoculant* (Master's thesis). Texas A&M University. College Station, TX 77843, United States. https://doi.org/10.3368/npj.21.3.341

Government of Saskatchewan. (2016). *Fertilizing seeded forages in Saskatchewan*. Retrieved from https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/soils-fertility-and-nutrients/fertilizing-seeded-forages-in-saskatchewan.

Holt, N., & Jefferson, P. G. (1999). Productivity and sustainability of four grazed grass - alfalfa mixtures. *Canadian Journal of Animal Science, 79*, 83-89. https://doi.org/10.4141/A98-064

Huang, Q. Q., Jin, L., Xu, Z., Barbieri, L. R., Acharya, S., Hu, T. M., … Wang, Y. (2015). Effects of purple prairie clover (*Dalea purpurea* Vent.) on feed intake, nutrient digestibility and faecal shedding of Escherichia coli O157:H7 in lambs. *Animal Feed Science and Technology, 207*, 51-61. https://doi.org/10.1016/j.anifeedsci.2015.06.009

Iwaasa, A. D., Li, Y., Wang, Y., Scianna, J. D., & Han, G. (2014). Forage and nutritional benefits of grazing purple prairie clover and white prairie clover on western Canadian grasslands. In: *Proceedings of the 10th Prairie Conservation and Endangered Species Conference*, (pp. 246-254), Red Deer, Alberta, Canada.

Iwaasa, A. D., Sottie, E. T., Wang, Y., & Birkedal, E. (2016). *Effect of drying methods on condensed tannin concentration and nutritive value of purple and white prairie clovers*. Proceedings of the 10th International Rangeland Congress, Saskatoon, Saskatchewan, Canada. p. 305-306.

Jefferson, P. G., McCaughey, W. P., May, K., Woosaree, J., & McFarlane, L. (2004). Forage quality of seeded native grasses in the fall season on the Canadian prairie provinces. *Canadian Journal of Plant Science, 84*, 503-509. https://doi.org/10.4141/P03-145

Jefferson, P. G., McCaughey, W. P., May, K., Woosaree, J., McFarlane, L., & Wright, S. M. B. (2002). Performance of American native grass cultivars in the Canadian prairie provinces. *Native Plants Journal, 3*(1), 24-33. https://doi.org/10.3368/npj.3.1.24

Kenno, H., Brick, M. A., & Townsend, C. E. (1987). Establishment of cicer milkvetch with four cool-season grasses. *Crop Science, 27*, 810-812. https://doi.org/10.2135/cropsci1987.0011183X002700040042x

Khanal, N., Schellenberg, M. P., & Biligetu, B. (2018). Agro-morphology and forage nutritive value of white prairie clover [*Dalea candida* (Michx.) Willd.] populations native to the Canadian prairies. *Canadian Journal of Plant Science, 98*, 1234-1244. https://doi.org/10.1139/cjps-2017-0255

Khanal, N., Schellenberg, M. P., Biligetu, B., & Coulman, B. E. (2016). *Promising native forage options for semi-arid prairies of western Canada*. [Poster session] presented at University of Saskatchewan. *Proceedings of the Soils and Crops Conference of Canada*, Saskatoon, Saskatchewan, Canada. Retrieved from http://hdl.handle.net/10388/8790

Kusler, J. (2009). *Comparing simple and complex native forage mixtures in southern Saskatchewan* (Master's thesis). Department of Animal and Poultry Science. University of Saskatchewan, Saskatoon, Saskatchewan, Canada. Retrieved from http://hdl.handle.net/10388/etd-12292009-102319

Lardner, H. A., Damiran, D., & McKinnon, J. J. (2015). Evaluation of 3 bromegrass species as pasture: Herbage nutritive value, estimated grass dry matter intake and steer performance. *Livestock Science, 175*, 77-82. https://doi.org/10.1016/j.livsci.2015.03.006

Lardner, H. A., Ward, C. I., Darambazar, E., & Damiran, D. (2013). Comparison of cool season perennial grasses for forage production and nutritive value, steer performance and economic analysis. *The Professional Animal Scientist, 29*, 403-412. https://doi.org/10.15232/S1080-7446(15)30253-9

Li, Y. G., Tanner, G., & Larkin, P. (1996). The DMACA-HCl protocol and the threshold proanthocyanidin content for bloat safety in forage legumes. *Journal of the Science of Food and Agriculture, 70*, 89-101. https://doi.org/10.1002/(SICI)1097-0010(199601)70:1<89::AID-JSFA470>3.0.CO;2-N

Li, Y., Iwaasa, A. D., Birkedal, E., & Han, G. (2012). *Forage quality constituents of purple prairie clover (Dalea purpurea) and white prairie clover (Dalea candida) harvested at different phenological stages in southwest Saskatchewan*. Soils and Crops, Prairieland Park, Saskatoon, SK. p. 13-14.

Li, Y., Iwaasa, A. D., Wang, Y., Jin, L., Han, G., & Zhao, M. (2014). Condensed tannins concentration of selected prairie legume forages as affected by phenological stages during two consecutive growth seasons in western Canada. *Canadian Journal of Plant Science, 94,* 817-826. http://doi.org/10.4141/cjps2013-234

McGraw, R. L., Shockley, F. W., Thompson, J. F., & Roberts, C. A. (2004). Evaluation of native legume species for forage yield, quality, and seed production. *Native Plants, 5*(2), 152-159. https://doi.org/10.2979/NPJ.2004.5.2.152

McLeod, J. G., Jefferson, P. G., Muri, R., & Lawrence, T. (2003). Tom Russian wildrye. *Canadian Journal of Plant Science, 83*, 789-791. https://doi.org/10.4141/P02-155

Mullenix, M. K., & Rouquette Jr., F. M. (2018). Review: Cool-season annual grasses or grass-clover management options for extending the fall-winter-early spring grazing season for beef cattle. *The Professional Animal Scientist, 34*(3), 231-239. https://doi.org/10.15232/pas.2017-01714

NASEM. (2016). *National Academics of Sciences, Engineering, and Medicine.* Nutrient requirement of beef cattle. Eighth revised edition. Washington, DC.

NRC. (2000). *Nutrient requirements of beef cattle* (7th revised ed.), Update 2000. National Academy Press, Washington, DC. p. 15.

Ogle, D., St. John, L., Cornwell, J., Holzworth, L., Majerus, M., Tober, D., Jensen, K., & Sanders, K. E. (2012). *Plant guide for Russian wildrye* [*Psathyrostachys junceus* (Fisch.) Nevski.]. USDA-Natural Resources Conservation Service, Aberdeen Plant Materials Center. Aberdeen, ID. Retrieved from http://plants.usda.gov/plantguide

Ogle, D., St. John, L., Holzworth, L. K., & Jensen, K. B. (2006). *Plant guide for meadow brome (Bromus biebersteinii Roem. & Schult.) USDA NRSC*. Aberdeen Plant Materials Center. Aberdeen, ID. Retrieved from http://plants.usda.gov/plantguide/pdf/pg_brbi2.pdf

Papadopoulos, Y. A., McElroy, M. S., Fillmore, S. A. E., McRae, K. B., Duyinsveld, J. L., & Fredeen, A. H. (2012). Sward complexity and grass species composition affect the performance of grass-white clover pasture mixtures. *Canadian Journal of Plant Science, 92,* 1199-1205. https://doi.org/10.4141/cjps2012-015

Peng, K., Gresham, G.L., McAllister, T.A., Xu, Z., Iwaasa, A., Schellenberg, M., … Wang, Y. (2020). Effects of inclusion of purple prairie clover (*Dalea purpurea* Vent.) with native cool-season grasses on *in vitro* fermentation and *in situ* digestibility of mixed forages. *Journal of Animal Science and Biotechnology, 11*, 23. https://doi.org/10.1186/s40104-019-0418-6

Peprah, S. A., Darambazar, E., Biligetu, B., Jefferson, P. G., Iwaasa, A. D., Larson, K., & Lardner, H. A. (2021b). Effect of harvest date on biomass yield, botanical composition, and nutritive value of novel legume-grass forage mixtures. *Agronomy, 11*, 2184-2198. https://doi.org/10.3390/agronomy11112184

Peprah, S., Damiran, D., Biligetu, B., Iwaasa, A. D., Larson, K., & Lardner. H, A. (2021a). Evaluation of cool-season binary mixtures as pasture: herbage yield, nutritive value, and beef cattle performance. *Livestock Science, 175*, 77-82. https://doi.org/10.1016/j.livsci.2021.104501

Popp, J. D., McCaughey, W. P. Cohen, R. D. H., McAllister, T. A., & Majak, W. (2000). Enhancing pasture productivity with alfalfa: A review. *Canadian Journal of Plant Science, 80,* 513-519. https://doi.org/10.4141/P99-049

Posler, G. L., Lenssen, A. W., & Fine, G. L. (1993). Forage yield, quality, compatibility, and persistence of warm season grass-legume mixtures. *Agronomy Journal, 85*, 554-560. https://doi.org/10.2134/agronj1993.00021962008500030007x

Sanderson, M. A., Brink, G., Stout, R., & Ruth, L. (2013). Grass-legume proportions in forage seed mixtures and effects on herbage yield and weed abundance. *Agronomy Journal, 105*, 1289-1297. https://doi.org/10.2134/agronj2013.0131

SAS Institute. (2014). *The SAS system for Windows*. Release 9.4. Cary, NC: SAS Institute.

Saskatchewan Soil Survey. (1990). *The soils of rural municipality of Swift Current, Number 137*. Saskatchewan Soil Survey Staff, University of Saskatchewan, Saskatoon, SK.

Schellenberg, M. P., & Banerjee, M. R. (2002). The potential of legume-shrub mixtures for optimum forage production in southwestern Saskatchewan: A greenhouse study. *Canadian Journal of Plant Science, 82*, 357-363. https://doi.org/10.4141/P00-162

Schellenberg, M. P., & Biligetu, B. (2015). The effects of temperature and scarification on seed germination of three Dalea species. *Canadian Journal of Plant Science, 95*, 1117-1120. https://doi.org/10.4141/cjps-2015-153

Schellenberg, M. P., Biligetu, B., & Iwaasa, A. D. (2012). Species dynamic, forage yield, and nutritive value of seeded native plant mixtures following grazing. *Canadian Journal of Plant Science, 92*, 699-706. https://doi.org/10.4141/cjps2011-273

Sedivec, K., Tober, D., Duckwitz, W., Dewald, D., & Printz, J. (2007). *Grasses for the Northern Plains*. Volume 1. Cool Season. North Dakota State University Extension, Fargo, ND.

Serajchi, M., Schellenberg, M. P., Mischkolz, J. M., & Lamb, E. G. (2018). Mixtures of native perennial forage species produce higher yields than monocultures in a lont-term study. *Canadian Journal of Plant Science, 98*, 633-647. https://doi.org/10.1139/cjps-2017-0087

Sheaffer, C. C., Wyse, D. L., & Ehlke, N. J. (2009). Palatability and nutritive value of native legumes. *Native Plants Journal, 10*, 224-231. https://doi.org/10.3368/npj.10.3.224

Steckel, J. E., & Flannery, R. L. (1965). *Automatic determination of phosphorus, potassium, calcium and magnesium in wet digestion solutions of plant tissue.* Technicon Symposium of Automated Analytical Chemistry, New York. p. 83-96. https://doi.org/10.2136/1971.instrumentalmethods.c5

Sturludóttir, E., Brophy, C., Bélanger, G., Gustavsson, A. M., Jørgensen, M., Lunnan, T., & Helgadóttir, Á. (2014). Benefits of mixing grasses and legumes for herbage yield and nutritive value in northern Europe and Canada. *Grass and Forage Science, 69*(2), 229-240. https://doi.org/10.1111/gfs.12037

Tilley, J. M. A., & Terry, R. A. (1963). A two stage technique for the in vitro digestion of forage crops. *Journal of British Grassland Society, 18*, 104-111. https://doi.org/10.1111/j.1365-2494.1963.tb00335.x

Towne, E. G, & Knapp, A. K. (1996). Biomass and density responses in tallgrass prairie legumes to annual fire and topographic position. *American Journal of Botany, 83*(2), 175-179. https://doi.org/10.1002/j.1537-2197.1996.tb12694.x

USDA NRCS. (2013). *Release brochure for 'Bozoisky-Select' Russian wildrye (*Psathyrostachys juncea *(Fisch.) Nevski) USDA-NRCS, Bridger PMC, Bridger, MT*. Retrieved from https://www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/mtpmcrb11686.pdf

Van Soest, P. J. (1994). *Nutritional Ecology of the Ruminant* (2nd ed.). Cornell University Press, Ithaca, New York. https://doi.org/10.7591/9781501732355

Waghorn, G. C., John, A., Jones, W. T., & Shelton, I. D. (1987). Nutritive value of *Lotus corniculatus* L. containing low and medium concentrations for sheep. *Proceedings of New Zealand Society of Animal Production, 47*, 25-30.

Wang, Y., Douglas, S. G. B., Waghorn, G. C., Barry, T. N., & Foote, A. G. (1996). Effect of condensed tannins in *Lotus corniculatus* upon lactation performance in ewes. *The Journal of Agricultural Science, 126*, 353-362. https://doi.org/10.1017/S0021859600074918

Wang, Y., Iwaasa, A., Xu, Z-J., Acharya, S., & McAllister, T. A. (2019). Agronomic characteristics and nutrient composition of purple prairie clover grown under irrigated and dryland conditions. *Journal of Animal Science, 97*(Supplement 3), 298. https://doi.org/10.1093/jas/skz258.602

Wynia, R. (2008b). *Plant guide for white prairie clover (Dalea candida Michx. ex Willd.) USDA-Natural Resources Conservation Service, Manhattan Plant Materials Centre, Manhattan, KS 66502*. Retrieved from http://plant-materials.nrcs.usda.gov

Copyrights