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ARTICLE

Seasonal patterns of forage quality in six native forb species

Roy Vera-Velez and Eric G. Lamb

Abstract: The forage value of native forbs is rarely considered in pasture mixtures, even though such species can make up a substantial proportion of the diet of cattle on native rangelands. Incorporating non-leguminous forbs into pasture grazing systems can provide additional ecosystem services such as pollination habitat, and ideally those forbs would also provide some forage value. We therefore assessed the seasonal variation in protein and fiber [neutral detergent fiber (NDF) and acid detergent fiber (ADF)] content of six common western Canadian native forb and sub-shrub species: yarrow (*Achillea millefolium*), smooth aster (*Symphyotricum laeve*), prairie crocus (*Pulsatilla patens*), prairie rose (*Rosa arkansana*), Canada goldenrod (*Solidago canadensis*), and American vetch (*Vicia americana*). The legume *V. americana* displayed the highest protein followed by *S. canadensis* and *S. laeve*. *V. americana* also has the highest fiber concentration through the growing season. *S. canadensis* and *S. laeve* had lower fiber content; thus, making them a good choice for addition in seed mixes to meet the energy and nutrient requirements of cattle. Forb protein and fiber content showed opposite trends during the growing season. Crude protein decreased while NDF and ADF increased as a general pattern tied to physiological stage and degree of senescence. The promising nutritional profile of some forb species suggests that these species should be considered in pasture mixes.

Key words: native grasslands, mixed pastures, grazing systems, biodiversity.

Résumé : On tient rarement compte de la valeur fourragère des herbacées à feuilles large dans les mélanges à pâturage, même si ces espèces constituent une part importante du régime des bovins mis à l'herbe sur les grands parcours naturels. L'intégration d'autres herbacées à feuilles larges que des légumineuses aux systèmes de paissance présenterait des avantages supplémentaires pour l'écosystème, comme favoriser la pollinisation. Idéalement, ces herbacées auraient aussi une certaine utilité comme fourrage. Les auteurs ont évalué la variation saisonnière de la concentration de protéines et de fibres (au détergent neutre et au détergent acide) chez six herbacées à feuilles larges indigènes et espèces sous-arbustives courantes dans l'ouest Canadien, en l'occurrence l'achillée millefeuille (*Achillea millefolium*), l'aster lisse (*Symphyotricum laeve*), la pulsatille multifide (*Pulsatilla patens*), la rose sétigère (*Rosa arkansana*), la verge d'or (*Solidago canadensis*) et la vesce d'Amérique (*Vicia americana*). La vesce d'Amérique, une légumineuse, est la plante la plus riche en protéines, suivie par *S. canadensis* et *S. laeve*. La vesce d'Amérique a aussi la plus forte concentration de fibres durant la période végétative. *S. canadensis* et *S. laeve* étaient moins riches en fibres, ce qui en fait un bon choix pour les mélanges de semences devant respecter les besoins en énergie et en oligoéléments des bovins. Chez les herbacées à feuilles large, la concentration de protéines et celle de fibres suivent des tendances opposées durant la période végétative. La teneur en protéines brutes diminue, alors que celles de fibres au détergent neutre et au détergent acide augmentent généralement avec le stade physiologique et le degré de sénescence. Le profil nutritionnel prometteur de certaines herbacées à feuilles larges laisse croire qu'on pourrait envisager de les ajouter aux mélanges pour pâturage. [Traduit par la Rédaction]

Mots-clés : prairies naturelles, prairies mixtes, systèmes de paissance, biodiversité.

Introduction

Forb species are a major component of grassland biomass, represent the majority of grassland diversity, and are widely used in habitat restoration (Meissen et al. 2017; Smith 2017; Freund et al. 2020). There is growing evidence that more diverse plant communities can be more productive and resilient to drought (Tilman et al. 2001; Cardinale et al. 2007; Mischkolz et al. 2013), mainly

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due to complementarity among traits and resource use by different taxa (Hooper et al. 2005; Brooker et al. 2008). Multi-species forb assemblages also provide improved wildlife habitat quality and food sources for pollination (Woodcock et al. 2014; Franklin et al. 2015).

The value of leguminous forbs in pastures is well recognized with benefits including high protein content, palatability, digestibility, and nitrogen fixation (Jefferson et al. 2004; Biligetu et al. 2014). The forage value of non-leguminous forbs is rarely considered, even though such species can make up a substantial proportion of the diet of cattle on native rangelands (Beck and Peek 2005; Craine et al. 2016; Gutiérrez et al. 2019). Pastures comprising diverse functional groups of plants may also enhance the distribution of forage and available nutrients throughout the growing season (Mischkolz et al. 2013; Biligetu et al. 2014; Elgersma et al. 2014; Belesky et al. 2020). While there is interest in the inclusion of forbs other than legumes into perennial pasture mixes, there is limited forage quality information available to guide species selection. The information available on nutrient content is focused on a narrow range of harvesting dates and limited numbers of native species (e.g., Jefferson et al. 2004; Serajchi et al. 2017). The objective of this project was to assess the seasonal variation in nutritional quality (i.e., protein and fiber) of six common western Canadian native forb and sub-shrub species (*Achillea millefolium*, *Symphyotricum laeve*, *Pulsatilla patens*, *Rosa arkansana*, *Solidago canadensis*, and *Vicia americana*) from green-up to senescence.

Materials and Methods

Plant samples were collected from two very different native grassland sites in central Saskatchewan, Kernen Prairie and Biddulph natural area in 2020. Kernen (52.16 N–106.53 W) is a 130 ha rough fescue grassland on the edge of Saskatoon, Saskatchewan. The prairie supports a diverse native plant community dominated by the grasses Plains Rough Fescue (*Festuca hallii*), Wheatgrasses (*Elymus* spp.), and Needlegrass (*Hesperostipa curtiseta*), forbs including *Solidago* spp., Northern Bedstraw (*Galium boreale*), Pasture Sage (*Artemisia frigida*), and Prairie Rose (*Rosa arkansana*) and the low shrub Western Snowberry (*Symphoricarpos occidentalis*) (Pylypec 1986). A number of invasive species including Smooth Brome (*Bromus inermis*), Kentucky Bluegrass (*Poa pratensis*), Canada Thistle (*Cirsium arvense*), and perennial sow thistle (*Sonchus arvensis*) are also common (Slopek and Lamb 2017). Kernen is regularly grazed by cattle. Biddulph (51.91 N–106.72 W) is a 120 ha native grassland and aspen forest on stabilized sand dune topography 25 km south of Saskatoon, SK. Biddulph grasslands are dominated by needlegrasses (*Hesperostipa comata*), Wheatgrasses (*Elymus* spp.), and sedges (*Carex* spp.). Common forbs include *Artemisia* and *Solidago* species. *Populus tremuloides* forests on moister locations support a diverse understory of herbaceous species (Pylypec 1989). Biddulph has been ungrazed for at least 20 yr.

Six native forb species (Table 1) were selected for screening of nutritional quality and fiber using three criteria. First, the species were common in a recent survey of Kernen Prairie (Bell et al. 2020), second, they were described as having either fair or good forage quality (Tannas 2003), and finally they were native to Saskatchewan. At each of two locations, the six species were sampled over the growing season (May–Oct. 2020). Sampling was done at minimum weekly to detect temporal variation in quality. Typical plants of each species were selected, leaf tissue collected, and dried. Petioles were included in the samples, and in the case of very young plants or small species such as *Vicia*, stem tissue was also collected. We chose to focus on leaves as these are the most nutritious tissue and the plant parts most likely to be sensitive to seasonal change. 1–3 samples of each species were collected from each site weekly to generate a large overall sample size (~40 samples per species per site over the whole season). Replicate samples of a particular species were selected whenever possible from plants at least 50 m apart.

A total of 466 samples were collected in the field. Samples were air dried and stored at room temperature. Later, they were ground to pass a 1-mm screen in a Wiley mill. This step included brushing out the Willey mill every time a sample was ground to avoid cross-contamination. Each sample was then analyzed for nitrogen with a Leco TruSpec nitrogen determinator. Crude protein concentration was calculated by multiplying nitrogen content of each sample by 6.25. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) was also determined using the ANKOM fiber analyzer. For fiber analysis, replicates of samples were combined where tissue was insufficient.

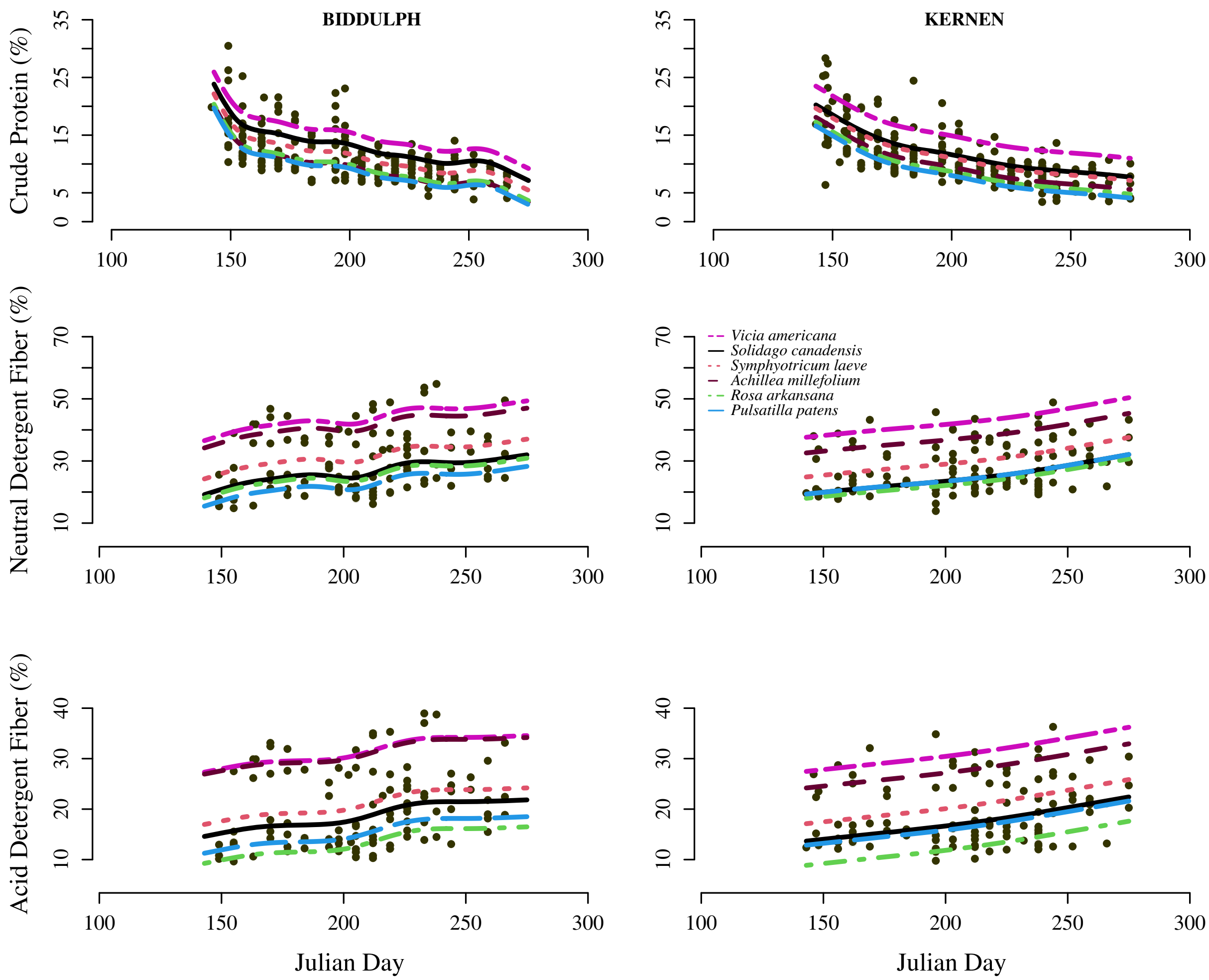
The contribution of each species to overall forage availability through the growing season was assessed using 300 plant survey plots sampled at Kernen prairie in 2014 (Bell et al. 2020). These 300 samples are a subset of the data excluding 261 plots with more than 25% biomass of invasive plant species. Briefly, these randomly located 50 cm by 50 cm quadrats were clipped and the biomass of each species was separately weighed. Further, since Bell et al. (2020) report aggregate protein content for these same plots, these data allow us to analyze the relationship of the whole native plant community's protein per plot throughout the growing season. We also examined the relationship of the crude protein concentration with the vegetation's total biomass and per each plant functional group (i.e., graminoid, forbs, and shrubs). Details of collection times and procedures for this dataset can be found in Bell et al. (2020).

We evaluated the relationship between crude protein concentration and fiber and the collection day with generalized additive models (GAMs). GAMs are a flexible linear modeling technique to examine non-linear

Table 1. Forb species evaluated in this study.

Forb name (common + Latin)	Family	Growth habit
Common yarrow (*Achillea millefolium* L.)	Asteraceae	Herbaceous perennial
Smooth aster [*Symphyotricum laeve* (L.) Á. Löve & D. Löve]	Asteraceae	Herbaceous perennial
Prairie crocus [*Pulsatilla patens* (L.) Mill.]	Ranunculaceae	Herbaceous perennial
Prairie rose (*Rosa arkansana* Porter)	Rosaceae	Subshrub perennial
Canada goldenrod (*Solidago canadensis* L.)	Asteraceae	Herbaceous perennial
American vetch (*Vicia americana* Muhl. ex Willd.)	Fabaceae	Vine perennial

Fig. 1. Generalized additive model (GAM) plots showing significant relationship between date (Julian Day) and crude protein concentration, NDF, and ADF for each of the six forb species at two sites: Biddulph and Kernen in 2020. [Colour online.]



relationships between crude protein, fiber, and time in the growing season, without making assumptions about the shape of the nonlinear relationships (Wood 2006). Models were fit with protein, NDF, and ADF as response variables. Sampling site, species, and their interaction were included as categorical fixed factors. Sample collection date (Julian Day) was incorporated with a nonlinear smoothed term. Total community protein levels were also fit using GAMs with Julian Day and forage biomass as explanatory variables. The models assumed a gaussian distribution family with identity link function; we visually checked the normality and homogeneity of variance by plotting each models' residuals against fitted values. The analysis was conducted using the function 'gam' in the package 'mgcv' (Wood 2006) in R statistical software (R Core Team 2021).

Results

Vicia americana has the highest protein followed by *Solidago canadensis* and *Symphyotricum laeve* (Fig. 1). *Rosa arkansana*, *Pulsatilla patens*, and *Achillea millefolium* displayed the lowest values particularly at the end of

Table 2. Summary of the outcome of the analysis of crude protein, neutral detergent fiber, and acid detergent fiber of six forb species collected in Biddulph and Kernen, SK.

Parameters	Crude protein	Neutral detergent fiber (NDF)	Acid detergent fiber (ADF)
Species	$F = 33.34$; $p < 0.001$	$F = 83.79$; $p < 0.001$	$F = 156.11$; $p < 0.001$
Site	$F = 0.42$; $p = 0.520$	$F = 8.16$; $p = 0.005$	$F = 13.61$; $p = < 0.001$
Species × Site	$F = 0.96$; $p = 0.440$	$F = 1.80$; $p = 0.112$	$F = 2.79$; $p = 0.018$
s (Julian Day)	Edf = 5.81, $F = 97.36$; $p < 0.001$	Edf = 4.32, $F = 16.05$; $p < 0.001$	Edf = 4.79, $F = 20.38$; $p < 0.001$
% Deviance explained	70.1%	72.8%	83%

Note: Table shows the edf, *F* values, *p* values, and deviance explained obtained from the generalized additive models (GAMs). Models show the fix parameters = species, site, and interaction species × site, and the smoothed term(s) = Julian Day.

Table 3. Mean ± SD of crude protein concentrations, neutral detergent fiber, and acid detergent fiber of individual selected forbs species from May to October in 2020.

Month	*A. millefolium*	*S. laeve*	*P. patens*	*R. arkansana*	*S. canadensis*	*V. americana*
			Crude protein (%)			
May	15.07 ± 2.10	20.73 ± 3.37	15.12 ± 1.47	15.32 ± 3.31	20.43 ± 10.16	25.93 ± 2.78
June	12.14 ± 2.44	13.20 ± 3.32	10.88 ± 1.11	12.24 ± 2.00	15.76 ± 4.83	18.06 ± 2.33
July	9.49 ± 1.04	10.81 ± 1.94	9.09 ± 2.10	9.02 ± 1.60	12.16 ± 2.81	15.79 ± 3.96
Aug.	7.91 ± 2.10	9.10 ± 1.08	7.40 ± 2.33	7.32 ± 1.33	9.47 ± 0.88	10.34 ± 2.66
Sept.	5.86 ± 1.99	8.58 ± 1.61	—	5.43 ± 1.34	8.93 ± 0.99	—
Oct.	3.98 ± 0.00	6.64 ± 0.00	—	4.10 ± 0.00	8.96 ± 1.57	—
			Neutral detergent fiber (%)			
May	30.65 ± 0.00	19.09 ± 1.65	16.67 ± 1.71	20.97 ± 4.12	20.97 ± 0.00	35.90 ± 2.99
June	33.98 ± 2.31	21.80 ± 3.37	20.76 ± 3.27	25.69 ± 1.33	27.84 ± 4.93	41.22 ± 3.23
July	38.66 ± 4.35	27.43 ± 9.50	22.15 ± 2.68	25.73 ± 5.33	23.61 ± 6.48	41.09 ± 3.39
Aug.	43.39 ± 6.37	34.19 ± 3.50	25.25 ± 3.90	22.47 ± 1.88	26.65 ± 5.08	54.02 ± 0.68
Sept.	37.92 ± 0.00	39.49 ± 4.78	—	22.14 ± 1.99	29.76 ± 3.22	—
Oct.	—	43.27 ± 0.00	—	—	33.59 ± 5.60	—
			Acid detergent fiber (%)			
May	22.37 ± 0.00	13.01 ± 0.08	11.62 ± 1.12	10.89 ± 1.31	15.18 ± 0.00	25.21 ± 2.39
June	24.97 ± 2.11	15.11 ± 1.77	14.21 ± 2.35	12.67 ± 0.90	20.18 ± 4.10	29.81 ± 2.33
July	28.95 ± 3.49	18.68 ± 6.93	14.46 ± 1.75	13.01 ± 1.66	16.67 ± 3.89	29.59 ± 3.08
Aug.	32.35 ± 4.12	23.79 ± 2.43	16.85 ± 2.81	12.92 ± 1.07	19.00 ± 3.44	37.62 ± 0.97
Sept.	29.58 ± 0.00	25.95 ± 4.07	—	13.47 ± 1.37	20.89 ± 1.84	—
Oct.	—	30.40 ± 0.00	—	—	22.49 ± 3.14	—

the growing season. There were no significant site or site by species interactions (Table 2). There was a significant non-linear association for all species between plant protein and collection day, with a general decline through the season (Fig. 1, Table 3). *V. americana* also has the highest NDF and ADF values through the growing season followed by *A. millefolium* (Fig. 1). *S. laeve*, *S. canadensis*, and particularly *P. patens* and *R. arkansana* showed the lowest fiber content. Both NDF and ADF have a significant non-linear association with a general increase with the sample collection day; also displaying differences between sites (Fig. 1, Table 2).

Crude protein content of the total plant community showed a similar significant non-linear relationship characterized by a general decline through the growing season (Table 4, Fig. 2*a*). There was also a significant negative association between plant community protein and graminoid biomass (Fig. 2*b*). Similar relationships were found for biomass of the whole plant community, graminoids, and for forbs, however, the explained variance was low (Supplementary data Fig. S1A[1], C, and D). There was no significant association between shrub biomass and collection day (Supplementary data Fig. S1B[1]). The biomass in the native prairies is mainly dominated

[1]Supplementary data are available with the article at https://doi.org/10.1139/cjps-2021-0151.

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Table 4. Mean ± SD of percentage of nitrogen and crude protein of the total plant community from May to November in 2014.

Month	Crude protein %	Biomass (kg·ha^{-1})				
				Forbs		
		Total biomass	Graminoid	Total forbs	Legumes	Shrubs
May	12.91 ± 4.62	8553.12 ± 14038.63	**(34.5)** 724.76 ± 556.54	**(4.0)** 127.16 ± 299.55	—	**(61.4)** 7701.19 ± 14123.52
June	11.57 ± 2.25	8415.32 ± 6730.54	**(41.4)** 2170.66 ± 1180.22	**(15.4)** 1729.36 ± 4501.44	**(0.66)** 9.55 ± 17.06	**(43.1)** 4515.31 ± 4935.63
July	9.96 ± 2.02	12610.32 ± 7149.65	**(43.4)** 4516.57 ± 2618.06	**(18.4)** 1988.96 ± 2286.46	**(0.68)** 15.84 ± 37.88	**(38.2)** 6104.79 ± 7233.73
Aug.	8.42 ± 1.26	12510.80 ± 5556.64	**(40.3)** 4311.24 ± 2057.58	**(28.6)** 3452.04 ± 2919.12	**(2.33)** 21.42 ± 37.28	**(31.1)** 4747.51 ± 5076.39
Sept.	7.99 ± 0.98	11808.19 ± 4925.38	**(51.7)** 5546.42 ± 3103.65	**(21.8)** 2286.44 ± 2131.84	**(1.92)** 24.37 ± 78.53	**(26.6)** 3975.33 ± 5239.08
Oct.	6.57 ± 1.05	12320.93 ± 7621.34	**(46.5)** 4691.89 ± 2938.44	**(25.4)** 2617.13 ± 2885.08	**(0.18)** 47.67 ± 198.38	**(28.1)** 5011.92 ± 7327.24
Nov.	5.85 ± 0.13	2676.35 ± 2246.39	**(5.4)** 167.23 ± 146.47	**(25.5)** 1014.39 ± 882.16	—	**(69.0)** 1494.73 ± 1225.08

Note: Biomass values are also distributed by graminoids, forbs, and shrubs. Forbs are allocated by total and legumes biomass. Bold numbers in parenthesis shows the percentage of each functional group in the total plant community's biomass. Data obtained from Bell et al. (2020).

by graminoid species, especially from July to October, whereas forbs biomass (especially legumes) is much lower (Table 4).

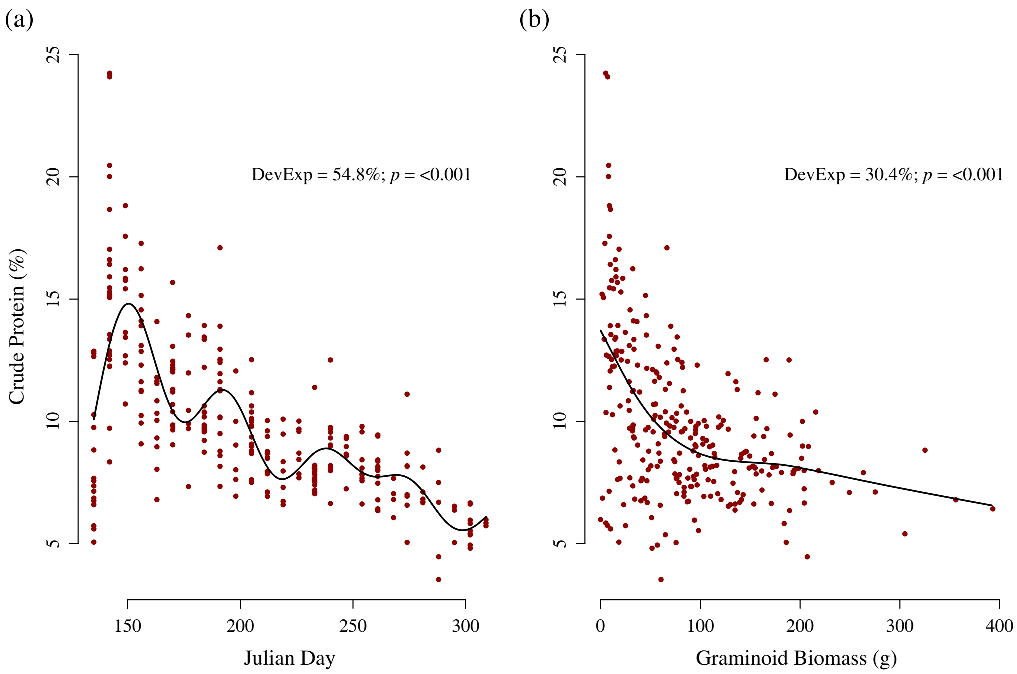
Discussion

With the growing demand for both livestock products to meet the human population's meat-based diets, and the demand for non-forage ecosystem services, the optimization of pasture systems is a complex challenge. The rising interest in the inclusion of local and non-graminoid forage species in mixes (Meissen et al. 2017; Smith 2017; White et al. 2018) requires an understanding of the nutritional profiles of forbs. Here we found that several common native forbs can provide good quality forage and could be reasonably included in mixes. Among the screened species, three forbs (i.e., *V. americana*, *S. canadensis*, and *S. laeve*) contained the highest seasonal average of crude protein. *V. americana* is a legume that has been previously investigated in mixed pastures (Schellenberg and Banerjee 2002). *S. canadensis* and *S. laeve* had lower fiber content; thus, making them a good choice for addition in seed mixes to meet the energy and nutrient requirements of cattle.

Crude protein, fiber content, and palatability are the main factors affecting forage quality and animal performance. Forage crude protein needs to be at least 7% to meet the diet requirements of an adult cow during lactation and gestation (Hersom 2007). *V. americana*, *S. canadensis*, and *S. laeve* all exceed 7% protein late into the growing season, complementing the average of 6% crude protein found in common native graminoids (Serajchi et al. 2017). The low fiber concentrations in the forbs evaluated here is also promising as this indicates good digestibility (Kopp et al. 2003). We found a seasonal average of 29.95% for NDF and 20.44% for ADF for all six forbs species. These fiber values are relatively low compared with the early stages in plant growth in alfalfa and bromegrass (Elizalde et al. 1999; Kopp et al. 2003). Specifically, the average concentration of ~30% of NDF and ~20% of ADF in *S. canadensis* and *S. laeve* might suggest low amount of cellulose and lignin in the biomass and good parameters of digestibility and energy input. Given that non-legume forbs may represent up to 28% of native prairie biomass (Table 4), these favorable quality parameters indicate that these species' contribution to the cattle food regime may be significant. In contrast legume density is low in native pastures and maintaining legumes in grass legume mixes can be challenging (Serajchi et al. 2017). As a result, even though legumes are very high quality, the legume contribution to overall food intake in cattle can be limited (Forbes 2007).

Forb protein and fiber content displayed opposite trends during the growing season. Crude protein decreased while NDF and ADF increased. This is a general pattern tied to physiological stage and degree of

Fig. 2. Generalized additive model (GAM) plots showing significant relationship between crude protein concentration and Julian Day (*a*) and Graminoid biomass (*b*). The crude protein includes the whole native plant community in the prairies in Kernen, SK in 2014. [Colour online.]



senescence (Werner et al. 1980; Oikawa et al. 2005; Hirose 2012). All these species are perennials with substantial requirements to transfer carbohydrates and nitrogen from dying leaves into new rhizomes and other perennial organs late in the growing season (Yuan and Li 2007; Botta-Dukát and Dancza 2008).

It should be noted that the nutrient profiles of the six forbs in our study are predominantly based on leaves and do not include stem tissue. Young stems can provide nutrients at the beginning of the growing season, thus our results may underestimate the nutrients available in early May from forbs. It is also important to consider that some forbs investigated here may contain undesirable elements that can harm animals when ingested in large quantities (e.g., *Achillea millefolium*; Warwick and Black 1982). The abundance of these potentially toxic plants must be carefully considered if they are to be included in pasture mixes. Recent evidence, however, suggests that cattle routinely broaden their food options to forbs when nutrients in grasses are low, even if these plants have secondary compounds (Craine et al. 2016). Hence, the contributions of many of these species to the livestock diet and how animals cope with plant toxins remain largely unexplored. Further, the role of environmental conditions (e.g., droughts) on the year-to-year variation in the nutrient values of these six forbs remains unknown.

In summary, incorporating selected forbs into pasture grazing systems may have important ecosystem benefits. Firstly, increasing the diversity of forbs in grasses expands cattle's forage opportunity (Beck and Peek 2005). Cattle typically select based on plant quality, excluding forage with low secondary metabolites and nutrients (Shipley 1999; Estell et al. 2012). While cattle forage primarily on graminoids, there is substantial evidence from native pasture systems that cattle will consume a wide array of non-leguminous forbs (Beck and Peek 2005; Craine et al. 2016; Gutiérrez et al. 2019). Hence, including forbs in seeded pastures may increase the options of food for cattle, particularly if environmental conditions have limited the growth of preferred graminoids. Secondly, more diverse plant communities may produce positive environmental feedbacks that influence landscape health. A pasture ecosystem with a larger number of species can be more resilient to disturbances such as overgrazing, fire, and drought (Lane et al. 2020). Further, a wide array of flower fertilization types may encourage higher numbers and diversity of pollinators and therefore enhanced pollination services to surrounding crops fields (Morandin and Winston 2006; Aizen et al. 2009; Kleijn et al. 2009).

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