Abstract: Many questions remain concerning the viability and productivity of seeding native legumes in the Canadian Prairies for forage production. Field research was conducted with four native legume species (Astragalus flexuosus, Dalea purpurea, Hedysarum boreale, and Vicia americana) to evaluate performance in Swift Current and Saskatoon, SK. The experimental design was a randomized complete block design with four replicates to evaluate legume–grass mixtures and monoculture performance, botanical composition, and effect of harvest dates (July and August) from 2016 to 2018. The native legume–grass mixtures performed differently at the sites, with greater foliar cover at Saskatoon but a greater proportion of legumes in mixtures at Swift Current. The mixtures had similar forage nutritive value as monoculture Bromus riparius, with legumes contributing 10% or less of the forage dry matter yield (DMY) at both sites. Astragalus flexuosus showed the greatest foliar cover and produced the greatest DMY in monoculture at both sites. Based on this study, native legumes would need to make up a larger proportion of forage dry matter yield to change the nutritional value of mixtures. In a subsequent seeding rate evaluation, the four legume species were planted at three seeding rates [300, 200, and 100 pure live seeds (PLS) per metre] and tested for DMY one year following establishment near Swift Current. Increasing seeding rates up to 300 PLS·m⁻¹ corresponded with an increase in seedling density and foliar cover, but DMY was not affected. Additional research with A. flexuosus is needed to demonstrate its value as a forage.

Key words: legume (native), establishment, forage, composition (botanical), mixtures, rates (seeding).

Résumé : Beaucoup de questions sur la viabilité et la productivité des légumineuses indigènes semées pour la production fourragère dans les Prairies canadiennes demeurent sans réponse. Les auteurs ont effectué des recherches sur le terrain sur quatre légumineuses indigènes (Astragalus flexuosus, Dalea purpurea, Hedysarum boreale et Vicia americana) en vue d’en évaluer le rendement à Swift Current et à Saskatoon, en Saskatchewan. L’expérience, conçue en blocs randomisés complets répétés quatre fois, devait préciser le rendement (mélanges légumineuses-graminées et monoculture), la composition botanique et l’incidence de la date de récolte (juillet et août), de 2016 à 2018. Les mélange de légumineuses et de graminées indigènes ont donné des résultats variables selon le site, avec une meilleure couverture foliaire à Saskatoon et une plus grande proportion de légumineuses dans le mélange, à Swift Current. Le fourrage des mélanges avait une valeur nutritive similaire à celle de la monoculture de Bromus riparius, les légumineuses représentant 10 % ou moins du rendement en matière sèche aux deux endroits. Astragalus flexuosus a donné la plus importante couverture foliaire et le meilleur rendement en matière sèche des monocultures aux deux sites. D’après cette étude, pour que la valeur nutritive du mélange change, les légumineuses indigènes devraient représenter une plus grande proportion du rendement en matière sèche du fourrage. Lors d’une évaluation subséquente portant sur la densité des semis, les auteurs ont semé les quatre légumineuses à raison de 300, 200 ou 100 graines pures vivantes par mètre, puis vérifié le rendement en matière sèche, un an après l’établissement de la culture, près de Swift Current. Augmenter le taux de semis jusqu’au maximum précité entraîne une hausse de la densité des plantules et de la couverture foliaire, sans que le rendement en
Introduction

There is growing interest in the use of native plant materials for forage production in the Canadian Prairies because of adaptation to severe environments, unique nutritional value, and to maintain natural biodiversity (Schellenberg et al. 2013; Kilkenny et al. 2016). Native perennial legumes are of particular interest because they have the potential to increase the mineral balance of pastures (Yoshihara et al. 2013), soil nitrogen (Smoliak 1988; Serajchi et al. 2015), and late-season forage digestibility in mixed legume–grass stands (Mischkolz et al. 2013; Biligetu et al. 2014). Legume–grass mixtures can yield greater forage dry matter than monoculture legumes and the forage produced can vary significantly in yield, energy, and protein levels (Caballero et al. 1995; Simili da Silva et al. 2014). In addition, diverse species mixtures with differing drought mechanisms can increase overall pasture productivity in dry environments (Tamayo-Chim et al. 2012).

Native perennial legumes have been recognized as important components of plant communities when seeded in rangelands for forage production (Luscher et al. 2014), however there is a need to evaluate the productivity of a wider range of native legumes in mixtures with grasses in semi-arid environments (Schellenberg and Banerjee 2002; Scheaffer et al. 2009; Mischkolz et al. 2013; Muir et al. 2014). Most research to date has focused on single site studies using a limited number of native legume species, whereas little attention has been given to the forage production of multiple species mixtures in semi-arid climates (Schellenberg and Banerjee 2002; McGraw et al. 2004; Mischkolz et al. 2013; Muir et al. 2014).

Research is needed not only to make species selections for mixed stands, but also to determine species-specific seeding rates and ideal harvest management practices (Foster et al. 2014). The assessment of native perennial legumes should be made at multiple sites over multiple years, and early- versus late-season production and nutritive value should be assessed to understand their performance (Sleugh et al. 2000; Mitchell et al. 2015). Identifying highly productive native legumes for mixed grass–forage stands in semi-arid regions will contribute to rangeland sustainability and increase the diversity of native perennial species available for forage establishment (Luscher et al. 2014).

Four native perennial legumes with favourable attributes were selected for this study. Astragalus flexuosus (Hook.) Don has shown fair value as a forage and despite low palatability, it is grazed by both livestock and wildlife (Stubbendieck and Conrad 1989; Tannas 2004). Dalea purpurea Vent. has shown promise for inclusion in pastures to increase forage protein and reduce fecal shedding of Escherichia coli in cattle (Stubbendieck and Conrad 1989; Jin et al. 2015). Hedysarum boreale Nutt. is a moderately nutritious species that has been extensively cultivated for forage production in the United States, particularly in Utah (Pahl and Smreciu 1999; Tannas 2004; Mader et al. 2011; Swoboda and Cane 2012). Vicia americana Willd. is a drought-tolerant legume with good to excellent forage value but will disappear from heavily used rangelands (Looman 1983; Stubbendieck and Conrad 1989; Tannas 2004; Reaume 2009; Allen and Tilley 2014). There is limited data on these four legumes for inclusion in forage mixtures in the Brown and Dark Brown soil zones of the Canadian Prairies.

There appears to be a wide range of suggested forage legume seeding rates with little species-specific information for native legume species, ranging from 40 to 150 pure live seeds (PLS) per metre depending on the species (Alberta Agriculture and Food 2018). This variation makes economic analysis of incorporating these native species into mixtures difficult. The optimal seeding rates are likely species, soil type, and climate specific, and should be evaluated for species of interest at particular locations. Suggested seedling densities are higher in the Dark Brown compared to the Brown soil zone for both monoculture legume and legume–grass mixtures in western Canada (Alberta Agriculture and Food 2018). Determination of establishment success based on dry matter yield, foliar cover, proportion of legumes in the mixture, as well as nutritive value and optimal seeding rates for the selected native legumes will serve as a guide for their practical application in the Canadian Prairies. The objectives of this study were to evaluate the establishment success and nutritive value of four perennial native legumes in mixtures with Bromus riparius Rehmann. in the Brown (Swift Current) and Dark Brown (Saskatoon) soil zones of Saskatchewan for two production years, and of the effect of seeding rate on stand establishment for one production year in the Brown soil zone.

Materials and Methods

Experiment 1: forage dry matter yield, botanical composition, and nutritive value of native legumes in legume–grass mixtures and monocultures

Dalea purpurea was purchased from Pickseed (Calmar, AB), V. americana from Brett Young Seed (Winnipeg, MB), and H. boreale from Applewood Seed Co. via Brett Young Seed. Certified seed of ‘Armada’ B. riparius was obtained from the University of Saskatchewan, and A. flexuosus seeds were obtained from the Agriculture and Agri-Food Canada Swift Current Research and
Development Centre. Additional *H. boreale* seed was purchased from Granite Seeds (North Lehi, UT) for the seeding rate test. Germination and viability data were used for calculation of pure live seed to obtain target seeding rates of 100 PLS m$^{-1}$ for all treatments.

At each site, the experiment was designed as a factorial randomized complete block design (RCBD) with four replications of 22 treatment combinations. Treatment combinations consisted of 11 species mixtures and two harvest dates (July and August). The 11 mixtures included monoculture of each species (*B. riparius*, *A. flexuosus*, *D. purpurea*, *H. boreale*, and *V. americana*), and six legume–grass mixtures (Table 1). Two legume species were used in each legume–grass mixture because previous studies have indicated that planting multiple species can increase the utilization of various ecological niches and result in complementary over-yielding effects (Harris 2001; Suter et al. 2007; Nyfeler et al. 2009). The legume–grass mixtures were composed of 33% of each species by weight, adjusted by percent germination, to obtain seeding rates of 100 PLS m$^{-1}$ for both mixtures and legume monocultures.

The southern study site is located in the Brown soil zone southeast of Swift Current, SK (50°27′ N, 107°74′ W). This site has loam and silty soils, which are low in organic matter and nitrogen, underlain with limy subsoils (Smoliak 1988; Acton et al. 1998). The more northern study site in Saskatoon, SK (52°16′ N, 106°57′ W) is located in the Dark Brown soil zone and has loamy soils that have a thicker and more nutrient-rich surface layer compared to the Brown soil zone (Smoliak 1988; Acton et al. 1998). The starting fertility of plots was not measured, however, sampling in 2017 showed only small differences between plots, indicating the treatments did not affect fertility between the establishment year in 2016 and 2017. Sampling in 2018 also did not indicate treatment differences. The soil analyses are included in Supplementary Tables S1–S4.

Experimental plots were sprayed with 48% by weight glyphosate herbicide with a 1:1 glyphosate-to-water ratio, harrowed and packed prior to seeding. Plots were seeded using a six-row disc seeder at a depth of 1.3 cm with four seeded rows per plot and two guard rows at 0.3 m spacing on 16 May 2016 in Saskatoon and 17 May 2016 in Swift Current. Row spacing of 0.3 m is recommended for seeding pastures in the semiarid prairie region (Jefferson and Kielly 1998). Each plot had an area of 7.3 m$^2$ in Saskatoon, with dimensions of 1.2 m × 6.1 m, and an area of 7.2 m$^2$ in Swift Current, with dimensions of 0.9 m × 8.0 m. Forage stands were mowed multiple times in 2016 to control weed growth during the first growing season. No fertilizer or pesticides were applied to the plots throughout the experiment. Weeds were hand rogued during the establishment year, but no control measures were taken in subsequent years.

A visual assessment of foliar cover by plot was completed at both sites in the fall of 2016 and again in the spring of 2018. At the Swift Current site, foliar cover was assessed on 9–10 Sept. 2016 and 11 June 2018 and at Saskatoon on 13–14 Sept. 2016 and 8 June 2018. The foliar cover of each plant species in the plot, as well as the percent of bare ground and weeds, were recorded. Measurements were taken linearly along a 1-m ruler placed randomly in plot rows 0.3 m away from the edges, and visual estimation of the total coverage for each category along that metre was assessed (adapted from Anderson 1986). This procedure was repeated twice per plot to obtain a mean foliar cover for each target species in the plot.

Sampling for dry matter yield (DMY), nutritive value and botanical composition was conducted twice per growing season, with half of the plots at each site harvested in July, and the remaining half in August. At Swift Current harvest dates were 6 July and 15 Aug. 2017 and 12 July and 20 Aug. 2018. At Saskatoon harvest dates were 4 July and 31 July 2017 and 16 July 2018 with no August harvest at this site in 2018. At the time of harvest a 0.9 m wide strip was cut from each plot, placed on a tarp, and weighed to obtain the wet weight per plot. A biomass subsample weighing approximately 300–400

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**Table 1.** The 11 species mixtures/monoculture stands used in the experiment.

| Mixture | Percent mix | Species | Abbreviation |
|---------|-------------|---------|--------------|
| 1       | 100%        | *Bromus riparius* | BR |
| 2       | 100%        | *Astragalus flexuosus* | AF |
| 3       | 100%        | *Dalea purpurea* | DP |
| 4       | 100%        | *Hedysarum boreale* | HB |
| 5       | 100%        | *Vicia americana* | VA |
| 6       | 33% : 33% : 33% | *B. riparius–D. purpurea–V. americana* | BR–DP–VA |
| 7       | 33% : 33% : 33% | *B. riparius–D. purpurea–H. boreale* | BR–DP–HB |
| 8       | 33% : 33% : 33% | *B. riparius–D. purpurea–A. flexuosus* | BR–DP–AF |
| 9       | 33% : 33% : 33% | *B. riparius–V. americana–H. boreale* | BR–VA–HB |
| 10      | 33% : 33% : 33% | *B. riparius–V. americana–A. flexuosus* | BR–VA–AF |
| 11      | 33% : 33% : 33% | *B. riparius–H. boreale–A. flexuosus* | BR–HB–AF |

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1Supplementary data are available with the article at [https://doi.org/10.1139/cjps-2020-0249](https://doi.org/10.1139/cjps-2020-0249).
grams was obtained and dried in the forage oven at 60 °C for 48 hours. The percent moisture was calculated to determine the DMY per plot. Dried subsamples were analyzed for crude protein (CP), acid detergent fibre (ADF), and neutral detergent fibre (NDF) at the Forage Breeding lab at the University of Saskatchewan.

An assessment of the botanical composition of stands was conducted to compare the seeded mixture ratios with stand compositions and repeated for two growing seasons to observe changes over time (George et al. 1995). Two subsamples of 0.5 m length along a row were clipped from each plot in July and August during bio-seasons to observe changes over time (George et al. 1995). Two subsamples of 0.5 m length along a row were clipped from each plot in July and August during bio-seasons to observe changes over time (George et al. 1995).

Experiment 2: Effect of seeding rate on native legume foliar cover, seedling density, and forage dry matter yield

The field test was organized as a RCBD with four replications at Swift Current, SK. The two factors used in this study were legume species (A. flexuosus (AF), D. purpurea (DP), H. boreale (HB), V. americana (VA), and seeding rate (100, 200, and 300 PLS m⁻¹-row⁻¹). The test was seeded on 18 May 2018 at AAFC Swift Current Research and Development Centre using a 6-row disc seeder at a depth of 1.3 cm with three seeded rows per plot at 0.3 m spacing. Each plot had an area of 4 m², with dimensions of 4 m × 1 m. Winter wheat pathways were seeded between replications and around the test plots. Seeds were scarified prior to seeding using a mechanical scarification machine designed for the small seeded species (A. flexuosus and D. purpurea) and air scarification for the relatively large seeded species (H. boreale and V. americana) using a modified design from Griffith and Booth (1988). The scarification machines were custom built at Agriculture and Agri-Food Canada’s Swift Current Research and Development Centre.

Foliar cover was assessed during the establishment year on 31 July and 19 September in 2018 by counting seedling number along two 1-m rows randomly selected in each plot. The percent foliar cover was measured on 7 June 2019 during the first production year using the same method described in Exp. 1. This procedure was repeated twice per plot to obtain a mean percent cover for the legume species in the plot. The distinction between plants to repeat seedling number counts could not accurately be conducted during the second production year. Each plot was sampled for biomass in July of 2019, using sickles to hand harvest two randomly selected 1 m rows. The samples were dried in the forced air oven at 60 °C for 48 hr to obtain dry weight. During the experiment, weeds were individually removed by hand once during each growing season and no herbicides were applied.

Statistical analysis

For Exp. 1, the data was analyzed for analysis of variance using the proc mixed procedure (SAS Statistical Software 2011) to examine the effects of species mixture and harvest date on foliar cover, botanical composition, and DMY. Data were analyzed as a RCBD with 2 × 11 factorial treatments with the main effects of species mixture and harvest date, and their interaction. The random effect in the model is the replicate. The site and year were included as fixed effects initially. Due to significant effects of site × mixture for foliar cover, and site × mixtures × year for DMY, we analyzed the data by each site as the focus of the study was the agronomic performance of the legumes and legume–grass mixtures at each site specifically. If the treatment effect was significant at $P \leq 0.05$, means comparisons were made using the studentized Tukey multi-treatment method. Degrees of freedom were calculated using Satterthwaite’s method.

In Exp. 2, the data were analyzed for analysis of variance using the mixed model (SAS Statistical Software 2011) to examine the effects of legume species and seeding rate on foliar cover, seedling count, and DMY. Legume species and seeding rate were considered fixed effects, and experimental replicate was treated as the random effect in the model. A significance value of $P \leq 0.05$ was used and means comparisons were made using the studentized Tukey multi-treatment method at $P = 0.05$. Degrees of freedom were calculated using Satterthwaite’s method. DMY data at 300 PLS m⁻¹ were not normally distributed, arcsine transformations were performed to improve normality and stabilize the sample variance (Tsai et al. 2017).

Results

Experiment 1

Foliar cover (%)

The results for foliar cover showed an interaction effect ($P < 0.0001$) of mixture × year, indicating foliar cover was different for certain mixtures between 2016 and 2018 (Table 2). Overall, the plots had greater foliar cover at the
Saskatoon site, with both sites showing increasing cover over the study period (Table 3). The foliar cover of the mixture plots in 2016 was similar to the monoculture of B. riparius in Saskatoon, but was less than B. riparius in Swift Current. By 2018, there was no difference between mixtures at the Saskatoon site, and all except the mixture of B. riparius–D. purpurea–H. boreale performed similarly at the Swift Current site. Vicia americana had the greatest foliar cover of the monoculture legumes at both sites in 2016 followed by A. flexuosus, but by 2018 A. flexuosus had greater foliar cover than V. americana. Dalea purpurea had higher foliar cover in monoculture at the Saskatoon site throughout the study, but it made up only 3%–5% of plot cover at the Swift Current site. Hedysarum boreale monoculture also had higher foliar cover at the Saskatoon site, while it had disappeared from the Swift Current stands by 2018 (Table 3).

Table 3. Estimated foliar cover (%) of legume monocultures (A. flexuosus, D. purpurea, H. boreale, and V. americana) and legume–grass mixtures with B. riparius measured in September 2016 and July 2018 at Swift Current and Saskatoon, SK.

| Mixture       | Swift Current | Saskatoon |
|---------------|---------------|-----------|
|               | 2016          | 2018      | 2016 | 2018 |
| BR            | 82a           | 92a       | 68a  | 93a  |
| BR–DP–AF      | 47bc          | 85ab      | 52ab | 88a  |
| BR–VA–HB      | 60b           | 87ab      | 62a  | 91a  |
| BR–DP–HB      | 55b           | 79b       | 66a  | 85a  |
| BR–HB–AF      | 56b           | 82ab      | 65a  | 84a  |
| BR–DP–VA      | 57b           | 81ab      | 65a  | 88a  |
| BR–VA–AF      | 64b           | 89ab      | 59a  | 88a  |
| AF            | 23d           | 49c       | 42bc | 65b  |
| VA            | 34cd          | 9d        | 64a  | 40c  |
| DP            | 5e            | 3d        | 32c  | 44c  |
| HB            | 4e            | 0d        | 26c  | 42c  |
| P value       | <0.0001       | <0.0001   | <0.0001 | <0.0001 |
| SEM           | 3.9           | 3.1       | 3.8  | 3.5  |

Note: AF, Astragalus flexuosus; BR, Bromus riparius; DP, Dalea purpurea; HB, Hedysarum boreale; VA, Vicia americana; SEM, standard error of the mean. Means within a column with different letters differ (P < 0.05) by Tukey’s HSD.

Table 4. The analysis of variance for foliar dry matter yield (dry matter %) of legumes and grass (B. riparius) in legume–grass mixtures at Swift Current and Saskatoon, SK, in July and August of 2017 and 2018.

| Factor | DF  | Swift Current | Saskatoon |
|--------|-----|---------------|-----------|
| Mixture (M) | 5  | 0.001         | 0.007     |
| Date (D) | 1  | 0.197         | 0.101     |
| Year (Y) | 1  | 0.810         | 0.433     |
| M × D | 5  | 0.634         | 0.202     |
| M × Y | 5  | 0.634         | 0.050     |
| D × Y | 1  | 0.148         | 0.120     |
| M × D × Y | 5 | 0.754         | 0.643     |

Note: DF, degrees of freedom.

Table 5. Percent forage dry matter yield (dry matter %) of legumes in legume–grass mixtures with B. riparius at Swift Current and Saskatoon, SK, in 2017 and 2018.

| Mixture | Swift Current | Saskatoon |
|---------|---------------|-----------|
| BR–DP–AF | 7.7a         | 1.6       |
| BR–VA–HB | 0.2c         | 0.8       |
| BR–DP–HB | 0.0c         | 3.4       |
| BR–HB–AF | 7.1ab        | 1.1       |
| BR–DP–VA | 1.3bc        | 1.1       |
| BR–VA–AF | 4.9abc       | 1.4       |
| P value | 0.0003       | 0.1       |
| SEM     | 1.51          | 1.0       |

Note: AF, Astragalus flexuosus; BR, Bromus riparius; DP, Dalea purpurea; HB, Hedysarum boreale; VA, Vicia americana; SEM, standard error of the mean. Means within a column with different letters differ (P < 0.05) by Tukey’s HSD.

Botanical composition of mixtures
The botanical composition of legume–grass mixtures varied by forage mixture for both percent of legumes (P = 0.001, P = 0.029) and grass (B. riparius) (P = 0.007, P = 0.049) at Swift Current and Saskatoon, respectively. Harvest date and year did not have significant effects on botanical composition (P > 0.05). At the Saskatoon site, there was an interaction effect of mixture × year for both legumes (P = 0.002) and grass (P = 0.006) (Table 4). The percentage of legumes in mixture differed by legume–grass mixture in Swift Current (P = 0.0003), but this pattern was not observed at Saskatoon where legumes contributed little biomass in all of the mixtures (Table 5). At the Swift Current site, the B. riparius mixtures containing A. flexuosus had the highest amount of legume forage DMY contributing to the mixtures (Tables 6 and 7).

Forage dry matter yield
The results for DMY showed an interaction effect of mixture × harvest date (P = 0.045) at Swift Current and
Table 6. Botanical composition (% dry matter) of legume–grass mixtures with *B. riparius* by individual species at Swift Current, SK, in July 2017 and 2018.

| Year | Mixture | BR  | DP  | AF  | VA  | HB  |
|------|---------|-----|-----|-----|-----|-----|
| 2017 | BR–DP–AF | 98 ± 1.1 | 0 ± 0.0 | 2 ± 1.1 | — | — |
|      | BR–DP–VA | 99 ± 0.5 | 0 ± 0.0 | — | 10 ± 0.5 | — |
|      | BR–VA–AF | 96 ± 1.9 | — | 4 ± 1.9 | 0.1 ± 0.1 | — |
|      | BR–HB–AF | 99 ± 1.2 | — | 1 ± 1.2 | — | 0 ± 0.0 |
|      | BR–VA–HB | 100 ± 0.0 | — | — | 0 ± 0.0 | 0 ± 0.0 |
|      | BR–DP–HB | 100 ± 0.0 | 0 ± 0.0 | — | — | 0 ± 0.0 |
| 2018 | BR–DP–AF | 72 ± 13.7 | 6 ± 5.9 | 9 ± 4.0 | — | — |
|      | BR–DP–VA | 50 ± 8.6 | 0 ± 0.0 | — | 1 ± 0.8 | — |
|      | BR–VA–AF | 42 ± 2.4 | — | 7 ± 2.6 | 0 ± 0.0 | — |
|      | BR–HB–AF | 74 ± 12.0 | — | 7 ± 5.5 | — | 0 ± 0.0 |
|      | BR–VA–HB | 55 ± 11.1 | — | — | 0 ± 0.0 | 0 ± 0.0 |
|      | BR–DP–HB | 54 ± 10.7 | 0 ± 0.0 | — | — | 0 ± 0.0 |

*Note:* AF, *Astragalus flexuosus*; BR, *Bromus riparius*; DP, *Dalea purpurea*; HB, *Hedysarum boreale*; VA, *Vicia americana*; SE, standard error.

Table 7. Botanical composition (% dry matter) of mixtures by individual legume species (*A. flexuosus*, *D. purpurea*, *H. boreale*, and *V. americana*) at Swift Current, SK, in August 2017 and 2018.

| Year | Mixture | BR  | DP  | AF  | VA  | HB  |
|------|---------|-----|-----|-----|-----|-----|
| 2017 | BR–DP–AF | 91 ± 2.3 | 0 ± 0.0 | 9 ± 2.3 | — | — |
|      | BR–DP–VA | 93 ± 4.6 | 7 ± 4.6 | — | 0 ± 0.0 | — |
|      | BR–VA–AF | 91 ± 3.6 | — | 9 ± 3.6 | 0 ± 0.0 | — |
|      | BR–HB–AF | 89 ± 5.9 | — | 11 ± 5.9 | — | 0 ± 0.0 |
|      | BR–VA–HB | 100 ± 0.4 | — | — | 0.4 ± 0.4 | 0 ± 0.0 |
|      | BR–DP–HB | 100 ± 0.0 | 0 ± 0.0 | — | — | 0 ± 0.0 |
| 2018 | BR–DP–AF | 53 ± 5.0 | 0 ± 0.0 | 9 ± 5.0 | — | — |
|      | BR–DP–VA | 61 ± 6.0 | 0 ± 0.0 | — | 0 ± 0.0 | — |
|      | BR–VA–AF | 59 ± 5.3 | — | 4 ± 0.6 | 0 ± 0.0 | — |
|      | BR–HB–AF | 43 ± 5.1 | — | 14 ± 7.4 | — | 0 ± 0.0 |
|      | BR–VA–HB | 66 ± 11.9 | — | — | 0.7 ± 0.7 | 0 ± 0.0 |
|      | BR–DP–HB | 74 ± 10.5 | 0 ± 0.0 | — | — | 0 ± 0.0 |

*Note:* AF, *Astragalus flexuosus*; BR, *Bromus riparius*; DP, *Dalea purpurea*; HB, *Hedysarum boreale*; VA, *Vicia americana*; SE, standard error.

mixture × year at Swift Current (*P* = 0.0003) and Saskatoon (*P* < 0.0001), indicating yield was different for certain mixtures between harvest dates and years (Table 8). The forage stands produced greater DMY at Saskatoon in 2017, but decreased in 2018, while at Swift Current, yields increased in 2018 (Table 9). The mixtures produced significantly more biomass compared to monoculture legumes producing similar amounts as monoculture *B. riparius*, except in August 2018 at the Saskatoon site, where *B. riparius* had the highest yield. *Astragalus flexuosus* was the highest yielding native legume in monoculture at both sites by 2018, producing comparably to *B. riparius* monoculture and maintaining high biomass production in August (Table 9). *Dalea purpurea* did not start producing biomass until August 2017 at Swift Current. *Vicia americana* appeared to be productive at both sites in 2017, however, it had lower yield in monoculture plots at Swift Current in July 2018 and produced no biomass in August 2018 at Swift Current and both harvest dates in 2018 at Saskatoon. *Hedysarum boreale* forage DMY was generally low at Swift Current compared to Saskatoon.

Overall, the forage DMY was different (*P* = 0.048) between July and August harvests in Saskatoon (Table 9), but this was not consistent between the sites. Mixtures of *B. riparius–D. purpurea–A. flexuosus*, *B. riparius–H. boreale–A. flexuosus*, and *B. riparius–V. americana–A. flexuosus* had greater July yields compared to August at Swift Current in 2017. At Saskatoon in 2017, monoculture *B. riparius* and *H. boreale* had lower August yields. These treatment differences were not observed at either site in 2018, with mixtures of *B. riparius–V. americana–A. flexuosus* in Swift Current and *B. riparius–H. boreale–A. flexuosus* in Saskatoon yielding greater in August. No treatment differences were observed in July.
Neutral detergent fibre values showed interaction effects (P < 0.0001) at Swift Current and Saskatoon respectively. There was no correlation between DMY and seed size across all species. The objectives of this study were to evaluate the foliar cover, forage production, nutritive value, and optimal seeding rate of four native legumes (A. flexuosus, D. purpurea, H. boreale, and V. americana) for forage production in the Brown (Swift Current) and Dark Brown (Saskatoon) soil zones of Saskatchewan. Since forage legumes are commonly seeded in mixed stands with grasses, the performance of these legumes was assessed in the mixtures with B. riparius. Seeding rate was also assessed to determine whether increasing seeding rates had an effect on seedling density, foliar cover, or DMY of monoculture legume plots. The native legume–grass mixtures performed differently in the Dark Brown (Saskatoon) and Brown (Swift Current) soil zones, with greater foliar cover at Saskatoon, but greater concentrations of legumes present in mixtures at Swift Current.
The legumes contributed no more than 10% of the total forage DMY in the mixtures at both sites. The foliar cover of field plots increased over the course of the study for all mixtures containing *B. riparius*, but did not increase for all of the native legume monoculture plots. The native legume monocultures had higher levels of foliar cover at the Saskatoon site, potentially because of greater levels of precipitation and soil.
Table 11. Concentrations of crude protein (CP), acid detergent fibre (ADF), and neutral detergent fibre (NDF) of legume monocultures (*A. flexuosus*, *D. purpurea*, *H. boreale*, and *V. americana*) and legume–grass mixtures with *B. riparius* at Swift Current and Saskatoon, SK, in 2017.

| Year | Mixture | Swift Current | | | | Saskatoon | | | |
|-------|---------|---------------|---|---|---|-----------------|---|---|---|
|       |         | July          | August | July | August | July | August | August |
|       |         | CP | ADF | NDF | CP | ADF | NDF | CP | ADF | NDF | CP | ADF | NDF | CP | ADF | NDF |
| 2017  | BR      | 5b | 34  | 53a | 6b | 39ab | 56ab | 6b | 32ab | 54a | 3c | 39a | 63a |
|       | BR–DP–AF| 5b | 38  | 54a | 4b | 41a | 63a | 7b | 31abc | 54a | 4c | 40a | 63a |
|       | BR–VA–HB| 4b | 26  | 55a | 4b | 42a | 63a | 6b | 31abc | 54a | 3c | 40a | 63a |
|       | BR–DP–HB| 5b | 36  | 55a | 4b | 42a | 64a | 6b | 31abc | 54a | 3c | 41a | 65a |
|       | BR–HB–AF| 5b | 35  | 54a | 4b | 42a | 65a | 5b | 33a  | 56a | 3c | 40a | 63a |
|       | BR–DP–VA| 5b | 36  | 54a | 4b | 41a | 63a | 6b | 31abc | 53a | 3c | 39a | 63a |
|       | BR–VA–AF| 5b | 36  | 54a | 4b | 43a | 63a | 5b | 32ab | 55a | 4c | 38a | 61a |
|       | AF      | 12a | 33  | 44ab | 9a | 34bc | 43c | 12a | 27cd | 33b | 11b | 31b | 39b |
|       | VA      | 10a | 34  | 34b | 12a | 30c | 41c | 12a | 28bcde | 34bc | 14a | 29b | 37b |
|       | DP      | IS  | IS  | IS  | 12a | 33abc | 42bc | 13a | 22e | 29b | 13ab | 25b | 35bc |
|       | HB      | IS  | IS  | IS  | IS  | IS  | IS  | 13a | 25de | 24c | 12ab | 27b | 27c |
|       | P value | <0.0001 | 0.461 | 0.007 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| SEM   | 0.5* | 3.6* | 3.8* | 0.6* | 2.1* | 2.4* | 0.6* | 1.0* | 1.2* | 0.5* | 0.9* | 1.4* |

**Note:** AF, *Astragalus flexuosus*; BR, *Bromus riparius*; DP, *Dalea purpurea*; HB, *Hedysarum boreale*; VA, *Vicia americana*; SEM, standard error of the mean; IS, insufficient sample for analysis. Means within a column followed by different lowercase letters differ (*P < 0.05*) according to Tukey’s HSD.

*Mean standard error of the means where missing data resulted in an unbalanced statistical design.
Table 12. Concentrations of crude protein (CP), acid detergent fibre (ADF), and neutral detergent fibre (NDF) of legume monocultures (*A. flexuosus*, *D. purpurea*, *H. boreale*, and *V. americana*) and legume–grass mixtures with *B. riparius* at Swift Current and Saskatoon, SK, in 2018.

| Year | Mixture   | Swift Current |          |          | Saskatoon |          |          |
|------|-----------|---------------|----------|----------|-----------|----------|----------|
|      |           | July          | August   |          | July      | August   |          |
|      |           | CP | ADF | NDF | CP | ADF | NDF | CP | ADF | NDF | CP | ADF | NDF |
| 2018 | BR        | 7b | 34a | 60a | 5b | 38 | 65a | 7c | 35ab | 64a | 9abc | 36a | 66a |
|      | BR–DP–AF  | 8b | 33a | 57ab | 6b | 35 | 63a | 7c | 35ab | 65a | 8abc | 35a | 65a |
|      | BR–VA–HB  | 8b | 33a | 61a | 6b | 36 | 64a | 8c | 34ab | 64a | 7bc | 34a | 64a |
|      | BR–DP–HB  | 8b | 34a | 59a | 6b | 36 | 63a | 7c | 35ab | 65a | 7c | 35a | 64a |
|      | BR–HB–AF  | 9b | 33a | 57ab | 7b | 35 | 64a | 7c | 35ab | 65a | 7c | 35a | 64a |
|      | BR–DP–VA  | 8b | 34a | 60a | 5b | 37 | 65a | 7c | 36ab | 66a | 8abc | 36a | 66a |
|      | BR–VA–AF  | 10b | 30ab | 52ab | 7b | 35 | 62a | 7c | 36ab | 66a | 8abc | 36a | 66a |
|      | AF        | 14a | 27bc | 35c | 11a | 31 | 41b | 11ab | 34ab | 46b | 11ab | 32ab | 44b |
|      | VA        | 13ab | 32abc | 42bc | IS | IS | IS | IS | IS | IS | IS | IS | IS |
|      | DP        | 17d | 27c | IS | IS | IS | IS | IS | IS | IS | IS | IS | IS |
|      | HB        | 17a | 21cd | 27c | IS | IS | IS | IS | IS | IS | IS | IS | IS |
|      | P value   | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | 0.087 | <0.0001 | 0.005 | 0.0003 | <0.0001 |
|      | SEM       | 1.0* | 1.6* | 2.9* | 0.6* | 1.7* | 2.4* | 0.8* | 1.4* | 1.8 | 1.0* | 1.4* | 1.7* |

**Note:** AF, *Astragalus flexuosus*; BR, *Bromus riparius*; DP, *Dalea purpurea*; HB, *Hedysarum boreale*; VA, *Vicia americana*; SEM, standard error of the mean; IS, insufficient sample for analysis. Means within a column followed by different lowercase letters differ (*P < 0.05*) according to Tukey’s HSD.

*Mean standard error of the means where missing data resulted in an unbalanced statistical design.
Table 13. The analysis of variance for seedling count (plants $m^{-1}$), foliar cover (%), and forage dry matter yield (kg ha$^{-1}$) of legume monocultures (A. flexuosus, D. purpurea, H. boreale, and V. americana) at different seeding rates (100, 200, and 300 PLS $m^{-1}$) harvested at Swift Current, SK, in 2018.

| Factor               | DF | Seeding count | Foliar cover | DMY |
|----------------------|----|---------------|--------------|-----|
| Species (S)          | 3  | <0.0001       | <0.0001      | 0.005|
| Seeding rate (R)     | 2  | <0.0001       | 0.012        | 0.716|
| S × R                | 6  | <0.0001       | 0.652        | 0.721|

Note: DF, degrees of freedom.

Table 14. Seedling count (count $m^{-2}$) by legume species (A. flexuosus, D. purpurea, H. boreale, and V. americana) and by seeding rate (100, 200, and 300 PLS $m^{-1}$) at Swift Current, SK, in 2018.

| Species | Seeding rate (PLS $m^{-1}$) | July P value | SEM | September P value | SEM |
|---------|-----------------------------|--------------|-----|-------------------|-----|
| AF      | 100 bB                      | 43bA         | 25bAB | 1354ab            | 3201a|
|        | 200 bB                      | 43bA         | 25bAB | 1354ab            | 3201a|
|        | 300 bB                      | 43bA         | 25bAB | 1354ab            | 3201a|
| DP      | 100 bB                      | 43bA         | 25bAB | 1354ab            | 3201a|
|        | 200 bB                      | 43bA         | 25bAB | 1354ab            | 3201a|
|        | 300 bB                      | 43bA         | 25bAB | 1354ab            | 3201a|
| HB      | 100 bB                      | 43bA         | 25bAB | 1354ab            | 3201a|
|        | 200 bB                      | 43bA         | 25bAB | 1354ab            | 3201a|
|        | 300 bB                      | 43bA         | 25bAB | 1354ab            | 3201a|
| VA      | 100 bB                      | 43bA         | 25bAB | 1354ab            | 3201a|
|        | 200 bB                      | 43bA         | 25bAB | 1354ab            | 3201a|
|        | 300 bB                      | 43bA         | 25bAB | 1354ab            | 3201a|

Note: AF, Astragalus flexuosus; DP, Dalea purpurea; HB, Hedysarum boreale; VA, Vicia americana; SEM, standard error of the mean. Means within a column followed by different lowercase letters and means within a row followed by different uppercase letters differ ($P < 0.05$) according to Tukey’s HSD.

Table 15. Foliar cover (%) by legume species (A. flexuosus, D. purpurea, H. boreale, and V. americana) and by seeding rate (100, 200, and 300 PLS $m^{-1}$) at Swift Current, SK, in 2018.

| Species | Seeding rate (PLS $m^{-1}$) | P value | SEM |
|---------|-----------------------------|---------|-----|
| AF      | 13bB                        | 43bA    | 25bAB |
|         | 17b                         | 35b     | 25bAB |
|         | 86a                         | 88a     | 25bAB |
|         | 65aB                        | 86aAB   | 89A   |
| DP      | 13bB                        | 43bA    | 25bAB |
|         | 17b                         | 35b     | 25bAB |
|         | 86a                         | 88a     | 25bAB |
|         | 65aB                        | 86aAB   | 89A   |
| HB      | 13bB                        | 43bA    | 25bAB |
|         | 17b                         | 35b     | 25bAB |
|         | 86a                         | 88a     | 25bAB |
|         | 65aB                        | 86aAB   | 89A   |
| VA      | 13bB                        | 43bA    | 25bAB |
|         | 17b                         | 35b     | 25bAB |
|         | 86a                         | 88a     | 25bAB |
|         | 65aB                        | 86aAB   | 89A   |

Note: AF, Astragalus flexuosus; DP, Dalea purpurea; HB, Hedysarum boreale; VA, Vicia americana; SEM, standard error of the mean. Means within a column followed by different lowercase letters and means within a row followed by different uppercase letters differ ($P < 0.05$) according to Tukey’s HSD.

Table 16. Forage dry matter yield (kg ha$^{-1}$) by legume species (A. flexuosus, D. purpurea, H. boreale, and V. americana) and by seeding rate (100, 200, and 300 PLS $m^{-1}$) harvested July 2019 at Swift Current, SK.

| Species | Seeding rate (PLS $m^{-1}$) | P value | SEM |
|---------|-----------------------------|---------|-----|
| AF      | 1354ab                      | 3201a   | 3925|
| DP      | 259b                        | 413c    | 323 |
| HB      | 2979a                       | 2543ab  | 2406|
| VA      | 1133ab                      | 1103bc  | 1140|

Note: AF, Astragalus flexuosus; DP, Dalea purpurea; HB, Hedysarum boreale; VA, Vicia americana; SEM, standard error of the mean. Means followed by different letters differ ($P < 0.05$) by Tukey’s HSD.
nutrients at this site compared to Swift Current. *Astragalus flexuosus* and *V. americana* had the greatest foliar cover among the native legumes in monoculture at both sites. *Dalea purpurea* and *H. boreale* disappeared from stands by the second year at the Swift Current site. Differential survival was expected since legumes in mixtures with multiple other legumes face competitive stress from companion species and weeds (Cooper 1977). Although the native legumes showed foliar cover in monoculture, they contributed very little DMY to mixtures, especially at the Saskatoon site. Since *B. riparius* is more competitive than the native legumes (Knowles et al. 1993), it is possible that the native legumes could not compete with this grass.

For botanical composition, it was expected that the more vigorous species would make up a greater proportion of the stand (Haynes 1980). *Bromus riparius* dominated mixtures at both sites even though seeding rates were proportional between species (i.e., each species was 33% of the mixture at seeding). The native legumes made up a small or negligible concentration of total DMY of the mixtures by 2018 at both sites. There were greater concentrations of legumes in mixtures based on forage DMY at the Swift Current site in 2017 and 2018, even though foliar cover was greater at the Saskatoon site in 2018. At the Swift Current site, only mixtures that contained *A. flexuosus* had legumes contributing to the DMY in 2018. Studies have shown that native legumes take longer to establish, and are less competitive compared to *B. riparius*, which was supported by this study (Knowles et al. 1993; Hamel et al. 2008).

The weather at both sites was cool and wet during the establishment year in 2016 compared to the long-term averages and hot and dry during the following two years in 2017 and 2018 (Figs. 1 and 2). Despite sufficient precipitation at the Swift Current site during the establishment year, the foliar cover of legumes in the stands was higher at the Saskatoon site. There was a low presence of native legumes in the DMY of mixtures at both sites during the two production years, however, monoculture *A. flexuosus* consistently produced appreciable amounts of forage at both sites. By 2018, sustained lack of precipitation and limited spring rainfall were evident with dry spring soils, which provided plants with little moisture to start growing in the 2018 season. But in 2018, monoculture *A. flexuosus* was producing comparable DMY as the mixture treatments and *B. riparius* monoculture. Although native plants can provide relatively stable forage in semi-arid environments (Schellenberg and Banerjee 2002), biomass was still expected to be reduced under drought conditions (Komainda et al. 2019). The lower DMYs in the second growing year are likely the result of these relatively dry conditions. Future studies are recommended to assess the performance of these legume species in mixture with native perennial C4 grasses that maintain higher productivity than C3 grasses in dry environments (Wedin 2004).

Even though the legumes did not increase the yield of mixtures, the yields of legume–grass mixtures has been previously shown to be slightly greater than, or generally equal to, monoculture grass stands (Springer et al. 2001). Furthermore, the yield of mixtures has been related to the dominant species in the legume–grass mixture, which in this case is *B. riparius* (Sanderson et al. 2013). *Dalea purpurea* forage DMY increased over time and was greater overall at the Saskatoon site. The forage yield of *H. boreale* monoculture plots in Saskatoon was moderate, whereas in Swift Current it was mostly absent from monoculture plots and did not contribute to the
forage yield of mixtures, indicating low growth under dry conditions. *Vicia americana* produced high forage yield at both sites in 2017, with higher yield than *A. flexuosus* at Swift Current. Low yields have previously been noted for *V. americana* (Ruyle and Bowns 1985), but it did not produce forage yield at either site in August 2018, possibly due to poor adaptation to drought conditions. Although this legume is thought to be drought-resistant due to a branching root (Reaume 2009; Allen and Tilley 2014), its lack of production in the second year may indicate that it is a short-lived species under our study environment, or that it is not tolerant to cutting.

Legume–grass mixtures were expected to vary not only by yield, but also by digestibility (Simili da Silva et al. 2014). Our monoculture legume plot results support previous findings that native legumes can increase the quality of forage by increasing crude protein and reducing ADF and NDF (Faris et al. 1987; Posler et al. 1993; McGraw et al. 2004; Collins and Newman 2018), particularly in the late season when digestibility and nutrient value generally decline (Schellenberg and Banerjee 2002). This supports previous work showing the extension of forage yield and quality later in the growing season by the addition of native legumes (Sleugh et al. 2000; McGraw et al. 2004; Cardinale et al. 2007), however the concentration of legumes in mixture with *B. riparius* was not sufficient to change the nutritive value of the legume–grass stands.

This study focused on mixtures with *B. riparius*, but many tame and native forage grass species remain to be tested with these legumes. Furthermore, our study only compared mixtures that included two legume species and we could have looked at the effects of increasing the number of legume species in mixture. Given the comparative establishment of *B. riparius* to native legumes in mixture, seeding rates could be manipulated to increase the ratio of native legumes and explore changes in botanical composition.

Under variable conditions such as moisture stress and high competition, rapid germination is the most critical factor for successful legume establishment, even though it is still not well understood (Baskin 2003; McGraw et al. 2003). A seeding rate experiment was conducted to determine if the success of stand establishment varies under field conditions since germination itself does not account for the emergence and survival of the seedling (Vogel 2002; Hillhouse and Zedler 2011; Shaban 2013). Despite being viable, it is common that seeds do not imbibe water and fail to germinate in favourable conditions due to physical exogenous dormancy, such as hard seed coats and other conditions such as temperature striation (Rolston 1978). Seed dormancy must be broken to use viability as a measure of germination (Bradbeer 1988), so scarification was performed to reduce physical dormancy and increase the germination of hard seeded legumes (Schellenberg and Biligetu 2015; Jones et al. 2016).

There is known to be a positive correlation between seed size and seedling establishment, since larger seeds develop more vigorous seedlings which are more competitive than smaller seedlings (Turnbull et al. 1999; Jakobsson and Eriksson 2000). These differences in seed size and seedling survival are thought to allow for different reproductive strategies in stressful environments (Marshall 1986). Our study does support the theory that small-seeded forage species are more difficult to establish (Townsend and McGinnies 1972), since fewer seedlings emerged per area for the smaller seeded *A. flexuosus* and *D. purpurea* and they had lower foliar cover compared to larger seeded *H. boreale* and *V. americana*. Previous studies have shown linear...
increases in native plant establishment with higher seeding rates in the first year (Fishbach et al. 2006).

In the present study, seeding rate did have a positive effect on the seedling densities of *D. purpurea*, *H. boreale*, and *V. americana*, but no clear trend was observed for *A. flexuosus*. Seeding rate did not have a significant effect on forage yield for any of the legume species seeded. Of the four legumes, *H. boreale* and *V. americana* had the highest seedling count and the greatest foliar cover, but this did not correlate with the forage yields. This suggests that neither seedling count, nor estimates of foliar cover are accurate predictors of biomass production in native legume stands. The biomass production should be reassessed during the second growing season since the correlation between seeding rate and biomass production begins to differ by species in years following the first production year (Fishbach et al. 2006).

The DMY of the native legumes did not increase linearly with increased seeding rate for the four legume species. *Dalea purpurea* in particular is known to have low seedling vigour and low biomass production (Fishbach et al. 2006). Increasing plant densities in the plots may have created greater intraspecies competition and crowded out seedlings. Research is still needed to determine whether reductions from 100 PLS m⁻¹ would produce comparable biomass, thereby saving cost on seed.

Conclusions

Our experiments were conducted to better understand the agronomic characteristics of four native legume species to determine their forage potential in mixtures with *B. riparius* in the Brown (Swift Current) and Dark Brown (Saskatoon) soil zones of Saskatchewan. The proportion of native legume seed in the legume–grass seed mixtures was double *B. riparius* seed, yet there was a very low proportion of native legumes in the field plots. This study highlights the need to understand the agronomic characteristics of a wider range of native legumes and establish better recommendations for seeding them in mixtures. *Astragalus flexuosus* outperformed the other three native legumes in this study with greater foliar cover and forage production in both soil zones. The seeding rate test showed *A. flexuosus* had greater foliar cover at 200 PLS m⁻¹, but seeding rate did not have effects on seedling density or DMY. Since *B. riparius* is a tame forage grass, it is recommended that *A. flexuosus* also be studied in mixture with native grasses to assess its potential as a component in native pasture seed mixtures. This native legume produced appreciable amounts of forage under drought conditions suggesting an adaptation to water limiting conditions. *Astragalus flexuosus* may contribute to the sustainability of pasture systems in hot and dry conditions which are commonly encountered by forage producers in the Canadian Prairies.

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