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Forage production, economic performance indicators and beef cattle nutritional suitability of multispecies annual crop mixtures in northwestern Alberta, Canada

Akim Omokanye[a], Herbert Lardner[b], Lekshmi Sreekumar[a,c] and Liisa Jeffrey[a]

[a]Peace Country Beef & Forage Applied Research Association, Fairview, Canada; [b]Department of Animal and Poultry Science, University of Saskatchewan, Saskatoon, Canada; [c]South Country Co-op Ltd, Brooks, Canada

ABSTRACT

A 2-year field study compared annual crop mixtures and monoculture cereal crops (controls) for forage yield and quality value for beef cattle production. Each of the mixtures consisted of 2 to 9 crop species. The cropping treatments investigated significantly influenced ($P < 0.05$) forage dry matter (DM) yield, quality and economic performance parameters. Forage DM yield was up to 9.25 t/ha for the mixtures compared to 7.72 t/ha for the control crops. Forage yield advantage from mixtures was up to 50% over controls. Forage crude protein (CP) was >13.0% for most mixtures, while CP for controls was ≤12.0%. All mixtures and controls mostly exceeded the suggested required levels of K, Mg, Na, S, Fe and Zn for beef cattle. The four top ranked mixtures in terms of marginal returns and benefit/cost ratio were mixtures #4, 8, 10 and 12 in that order. Study results demonstrated that growing a minimum of 3 annual crops, rather than 1 or 2 crops, increased forage production and offered a forage-based diet that, which in most cases, was able to adequately meet the nutritional requirements of beef cattle. The mixture with the highest forage yield consisted of crops from 3 different species categories: *Poaceae*, *Leguminosae* and *Brassicaceae*.

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Introduction

In western Canada, feed accounts for a large portion of the total cost of beef cattle production. Winter feeding costs alone account for more than two-thirds of the total annual feeding and management expenses in beef cow-calf production (Damiran et al. 2016; Krause et al. 2013; Kaliel 2004). Traditionally, the winter feeding period for a cow/calf enterprise lasts approximately 200 days (McCartney et al. 2000). Beef cows are commonly fed hay from perennial forages, greenfeed from annual crops or cereal grain silage, and limited amounts of feed grains such as barley (*Hordeum vulgare* L.), during this period. Beef cows are also managed extensively through swath grazing with cereal crops such as oats (*Avena sativa* L.) or triticale (X *Triticosecale Wittmack*).

Typically, annual cover crops are sown as monocultures within annual crop rotations to protect soil from erosion or give other agroecosystem services such as building soil fertility and organic matter, retaining nutrients, or suppressing weeds during periods when cash crops are not actively growing (Smith et al. 2011; Snapp et al. 2005; Teasdale 1996). Forage production from cereal-legume intercrops have been widely reported in western Canada and elsewhere (Gill and Omokanye 2018; Ojeda et al. 2018a; Strydhorst et al. 2008; Aasen et al. 2004; Carr et al. 2004). In northern Alberta, the latest trend among beef cattle producers is growing a multispecies annual crop mixture for forage production. Growing multi-species annual crop mixtures (4 to 6 or greater number of species) (Malézieux et al. 2009) or annual crops sequences/intercrops (Ojeda et al. 2018b) may often be considered as a practical application of ecological principles based on biodiversity, plant interactions and other natural regulation mechanisms as well as improved soil C stocks. Such mixtures could increase forage production (BCRC 2016; Davis et al. 2015; Smith et al. 2014; Wortman et al. 2012), improve water and soil quality, increase nutrient cycling, moisture conservation, and crop productivity (Chu et al. 2017; Hobbs et al. 2008). A multispecies annual crop mixture can be selected from a diversity of plant families (Polygonaceae, Brassicaceae, Poaceae, and Fabaceae), corresponding to different plant functional groups (Lavorel et al. 1997). Each crop species in a mixture may reach maturity at slightly different times, therefore providing available immature forage continuously through the growing season (BCRC 2016).

Several new annual crop mixtures are currently available on the market in western Canada. When making decisions about which annual crop species to include in a mixture, producers need to be aware of the adaptation, potential forage productivity and ecological stability of any newly introduced crop species (warm season crop such as sorghum (*Sorghum bicolor* L. Moench), cowpea (*Vigna unguiculata* L. Walp.), mungbean (*Vigna radiate* (L.) R. Wilczek) in their area (Omokanye 2018). Cool season annual forage-type cereal crop varieties such as barley, oat, triticale and field peas (*Pisum sativum* L.) are well suited to western Canadian growing conditions and provide acceptable forage yield and quality for winter grazing (McCartney et al. 2004; Kelln et al. 2011; Gill et al. 2013; Gill and Omokanye 2018).

CONTACT Akim Omokanye akim@pcbfa.ca; aomokanye@gmail.com Peace Country Beef & Forage Applied Research Association, 11235-98 Ave, Box 3000, Fairview, Alberta, T0H 1L0, Canada

The present study had two objectives: (1) evaluate annual crop mixtures for forage yield and quality; and (2) estimate production costs and associated economic performance of mixtures in comparison to commonly grown cool season forage-type cereal crops. Our first hypothesis was that a multispecies annual crop mixture could provide greater forage production and quality, and offer a diet that is better able to meet the nutritional requirements of beef cattle, compared with a single crop. Secondly, using forage biomass as benefit, we hypothesized that a single crop and a multispecies annual crop mixture would differ in economic outcomes (returns and benefit/cost ratios), which would greatly be in favour of a multispecies annual crop mixture.

Materials and methods

Site information and pre-sowing soil tests

Field experiments were carried out over two growing seasons from May 18 to August 2, 2016 and from May 31 to August 14, 2017 at the Fairview Research Farm, located in Fairview Alberta (56° 04′ 53″ N, 118° 26′ 05″ W; 670 m above sea level), which is found in northern Alberta, Canada. The site has a subarctic climate (boreal climate), which is characterized by long, usually very cold winters, and short, cool to mild summers. The soil type at the experimental site is a Gray Luvisolic soil with eluvial and Bt horizons (Soil Classification Working Group 1998). The surface soil characteristics (0–15 cm soil depth) during the field experiments are shown in Table 1. Long-term averages (over 30 years) and monthly-recorded precipitation during the 2016 and 2017 growing seasons (Table 2) were collected from the nearest Alberta of Agriculture and Forestry metrological station, which was within the premises (100–200 m) of the fields used for the present study.

Table 1. Soil characteristics (0–15 cm soil depth), spring soil moisture and temperature at sowing for both trial years.

	2016	2017
Nutrients and quality		
Soil organic matter	7.3	6.6
pH (1:2.5 H2O)	5.5	6.0
EC (dS/m)	0.58	0.39
Nitrate-N (ppm)	75	43
Bray 1-P (ppm)	30	12
K (ppm)	151	188
Sulphate-S (ppm)	11	4
Ca (ppm)	2010	1990
Mg (ppm)	370	349
% Nutrient saturation		
Ca (%)	39.0	51.7
Mg (%)	11.8	15.0
Na (%)	0.9	0.7
K (%)	1.5	2.5
% Base saturation	53.1	69.9
Total exchangeable cations (meq/100 g)	25.8	19.2
Spring soil moisture (%)		
0–5 cm soil depth	12.0	13.1
0–20 cm soil depth	13.3	21.3
Spring soil temperature (^{O}C)		
0–5 cm soil depth	12.1	11.1
0–20 cm soil depth	9.94	8.95
Available water holding capacity (mm) for a 120-cm deep profile (Jong and Shields 1988)	250	

Table 2. Monthly mean air temperature and precipitation during two growing seasons (2016, 2017) and long-term averages at the experimental site.

	Temperature (°C)			Precipitation (mm)		
Month	2016	2017	30-year average	2016	2017	30-year average
April	7.3	2.5	3.2	5.4	31.3	18.9
May	9.9	11.5	9.8	68.6	30.2	40.0
June	13.4	14.5	13.9	73.7	53.7	64.3
July	15.9	15.9	15.8	22.6	57.2	68.7
August	11.6	15.7	14.7	92.1	14.2	47.8
Total	–	–	–	262.4	186.6	239.7

Experimental location and treatments

The experiment was designed as a randomized complete block design with 4 replicates for each treatment. Eighteen annual crop treatments were tested in total (Table 3). The 18 treatments consisted of 14 annual crop mixtures and 4 monoculture cereal crops (barley, oat, triticale and soft white wheat). Each of the 14 mixtures had 2 to 9 annual crop species. The 4 cereal crops were used as controls. It is important to note that the composition of the 14 mixtures used was based on samples of actual mixtures used by local beef cattle producers in the study area from 2014 to 2016. The annual crops sown were from 3 different categories (C_4 & C_3 *Poaceae*), *Leguminosae* (C_3) and *Brassicaceae.* Nine grass species were sown, including barley, oat, triticale, soft white wheat (*Triticum aestivum* L.), Italian ryegrass (*Lolium multiflorum* Lam.), proso millet (*Panicum miliaceum* L.), brown midrib (BMR) sorghum (*S. bicolor* L.), forage sorghum (*S. bicolor* L.), sorghum Sudan grass (Sorghum × drummondii (Nees ex *Steud.*) *Millsp*) and teff (*Eragrostis tef* (Zucc.) Trotter). The forage legumes were field pea, hairy vetch (*Vicia villosa* Roth L.), crimson clover (*Trifolium incarnatum* L.), frosty berseem clover (*Trifolium alexandrinum* L.*),* Persian clover (*Trifolium resupinatum* L.) and fababean (*Vicia faba* L.). Eight forage-type brassicas and crosses were sown, including tillage radish (*Raphanus sativus* L.), purple top turnips (*Brassica rapa* L.), kale (*Brassica oleracea* L), rape (*Brassica napus* L.), forage radish (*Brassica napus* L.). Sunflower (*Helianthus annuus* L.) was also sown (warm season broadleaf).

Planting procedure and crop management

Pure cereal crops were sown at recommended sowing rates (Table 3). For the mixture sowing rates (Table 3), a substitutive approach (proportional replacement design) was used as described by Jolliffe (2000). The substitutive method ensures that sowing rates for each species in the mixture are proportional to their monoculture rate. With this approach, the sowing rates for individual species in the mixture were determined by dividing each recommended sowing rate by the total number of species in the mixture (e.g. 6 for mixture #1 and 3 for mixture #8). It is important to note that this approach can only adjust for the number of annual crop species in a mixture but not the number of seeds per kilogram for the different species. Therefore, the total number of seeds per ha varied between mixtures. However, the substitutive approach minimizes potentially confounding effects of a higher overall sowing rate in the mixture and preserves the ability to use well established intercropping indices such as the land equivalent ratio (Jolliffe 2000; Smith et al. 2014).

Table 3. Sowing rates for pure cereals and multispecies annual crop mixtures (with their common names/varieties for the different crop species).

Cover crop treatment	Sowing rate (Kg ha^{-1})	Cover crop treatment	Sowing rate (Kg ha^{-1})
Pure CDC Maverick barley (*H. vulgare* L.)	135	*Mixture #7*	
Pure CDC Haymaker oat (*A. sativa* L.)	113	CDC Maverick barley variety (*H. vulgare* L.)	67.2
Pure Bunker triticale (X *Triticosecale Wittmack*)	124	Hairy vetch (*V. villosa* Roth L.) – not inoculated	14.0
Pure AC Andrew soft white wheat (*T. aestivum* L.)	135	*Mixture #8*	
Mixture #1		CDC Maverick barley variety (*H. vulgare* L.)	44.8
CDC Horizon field pea variety (*P. sativum* L.)	18.7	40–10 forage pea variety (*P. sativum* L.)	37.3
CDC Haymaker oat variety (*A. sativa* L.)	18.7	Bunker triticale variety (X *Triticosecale Wittmack*)	41.1
Hairy vetch (*V. villosa* Roth L.)	4.67	*Mixture #9*	
Tillage radish (*R. sativus* L.)	1.87	CDC Horizon pea variety (*P. sativum* L.)	28.0
Purple top turnips (*B. rapa* L.)	1.87	Hairy vetch (*V. villosa* Roth L.)	7.00
Crimson clover (*T. incarnatum* L.)	3.73	Crimson clover (*T. incarnatum* L.)	5.60
Mixture #2		Snowbird fababean (*V. faba* L.)	50.4
Green Spirit Italian ryegrass (*L. multiflorum* Lam.)	3.20	*Mixture #10*	
Red proso millet (*P. miliaceum* L.)	4.00	Hairy vetch (*V. villosa* Roth L.)	3.11
CDC Maverick barley variety (*H. vulgare* L.)	19.2	Green Spirit Italian ryegrass (*L. multiflorum* Lam.)	2.49
CDC Horizon pea variety (*P. sativum* L.)	16.0	Brown midrib sorghum (*S. bicolor* L.)	4.36
Purple top turnips (*B. rapa* L.)	1.60	Crimson clover (*T. incarnatum* L.)	2.49
Kale (*B. oleracea* L)	0.80	Winfred forage brassica	0.62
Crimson clover (*T. incarnatum* L.)	3.20	Hunter forage rape (*B. napus* L.)	0.62
Mixture #3		Goliath forage radish**	0.62
Green Spirit Italian ryegrass (*L. multiflorum* Lam.)	3.73	CDC Haymaker oat variety (*A. sativa* L.)	12.4
CDC Haymaker oat variety (*A. sativa* L.)	18.7	CDC Horizon pea variety (*P. sativum* L.)	12.4
CDC Horizon pea variety (*P. sativum* L.)	18.7	*Mixture #11*	
Purple top turnips (*B. rapa* L.)	1.87	Green Spirit Italian ryegrass (*L. multiflorum* Lam.)	4.48
Forage rape (*B. napus* L.)	0.93	Hairy vetch (*V. villosa* Roth L.)	5.60
Laser Persian clover (*T. resupinatum* L.)	0.93	Hunter forage turnips***	1.12
Mixture #4		Winfred forage brassica	1.12
Red proso millet (*P. miliaceum* L.)	3.11	CDC Haymaker oat variety (*A. sativa* L.)	22.4
CDC Haymaker oat variety (*A. sativa* L.)	12.4	*Mixture #12*	
CDC Maverick barley variety (*H. vulgare* L.)	14.9	Hairy vetch (*V villosa* Roth L.)	4.00
40–10 forage pea variety (*P. sativum* L.)	12.4	Sorghum Sudan grass****	4.29
Tillage radish (*R. sativus* L.)	1.24	Bunker triticale (X *Triticosecale Wittmack*)	17.9
Hairy vetch (*V. villosa* Roth L.)	3.11	Frosty berseem clover (*T. alexandrinum* L.)	3.21
Kale (*B. oleracea* L)	0.62	Winfred forage brassica	0.80
Crimson clover (*T. incarnatum* L.)	2.49	CDC Haymaker oat (*A. sativa* L.)	16.0
Laser Persian clover (*T. resupinatum* L.)	0.62	40–10 forage pea variety (*P. sativum* L.)	16.0
Mixture #5		*Mixture #13*	
CDC Maverick barley variety (*H. vulgare* L.)	19.2	Green Spirit Italian ryegrass (*L. multiflorum* Lam.)	3.21
CDC Horizon pea variety (*P. sativum* L.)	16.0	Forage sorghum (*S. bicolor* L.)	5.62
Hairy vetch (*V villosa* Roth L.)	4.00	Frosty berseem clover (*T. alexandrinum* L.)	2.41
Crimson clover (*T. incarnatum* L.)	3.20	Barsica forage rape (*B. napus* L.)	0.81
Winfred forage brassica*	0.80	T-raptor forage hybrid brassica*****	0.81
Green Spirit Italian ryegrass (*L. multiflorum* Lam.)	3.20	Teff (*Eragrostis tef* (Zucc.) Trotter)	1.28
Sunflower (C4) *(H. annuus* L)	0.80	Laser Persian clover (*T. resupinatum* L.)	2.42
Mixture #6		*Mixture #14*	
CDC Maverick barley variety (*H. vulgare* L.)	67.2	CDC Horizon pea variety (*P. sativum* L.)	37.3
Hairy vetch (*V. villosa* Roth L.) – inoculated	14.0	CDC Haymaker oat variety (*A. sativa* L.)	37.3
		Hairy vetch (*V. villosa* Roth L.)	9.33

*Winfred forage brassica – a cross between a turnip and a kale.
**Goliath forage brassica – a rape and kale interspecies cross.
***Hunter forage brassica – an intra-specific hybrid developed by crossing turnips with related Asiatic leaf vegetables of the same species.
****Sorghum Sudan grass (Sorghum × drummondii (Nees ex *Steud.*) *Millsp*).
*****T-raptor forage hybrid brassica – a cross between a forage turnip and a forage rape.

Each year, land preparation prior to sowing included disking and harrowing. The seeds were pre-weighed and mixed before sowing. The seeds were sown using a plot drill equipped with disc-type openers on 23 cm row spacing. Six rows that were 8 m long were sown per plot. Sowing was done on May 18, 2016 and May 31, 2017. An extended period of precipitation and high soil moisture caused a delay in sowing in 2017. Sowing depth was 1.90 to2.50 cm. In both years, no fertilizer was applied to any of the treatments including monoculture cereal crops. This was done to mimic most of the production practices in growing annual crop mixtures by beef cattle producers in the study area. It is important emphasize that beef cattle producers would normally apply dry fertilizers to monoculture cereals for forage production in northwestern Alberta.

All legumes in the mixtures (except for mixture #7) were inoculated with Cell-Tech® granular nitrogen-fixing inoculant at sowing. Both mixtures #6 and #7 contained only 2 species (barley and hairy vetch). The hairy vetch in mixture #6 was inoculated at sowing, but the hairy vetch in mixture #7 was not. This was done to allow us to examine how the nature of soil *Rhizobial* populations can affect hairy vetch in a new environment.

Three days after sowing and before any crop emergence, Roundup WeatherMax® herbicide was sprayed as pre-emergent herbicide at 0.8 L/ha. No in-crop spraying of herbicide was carried out to control weeds after crop emergence. Instead, hand weeding was conducted ~5 weeks after sowing on all treatment plots.

Forage yield determination and nutritive value analysis

For each treatment plot, the above ground biomass was harvested from the 4 inner rows, in a strip 2 m long, and weighed fresh on August 2 2016 and August 14 2017. Approximately 0.7 kg of freshly harvested material (sub-sample) was oven-dried at 50°C to a constant weight for dry matter content (% DM). The DM was weighed, and the data were extrapolated to t ha^{-1} forage dry matter yield (FDMY). For both mixtures and monoculture cereals, harvesting was done at soft-dough stage for barley and late milk stage for oat, triticale and soft white wheat. Mixture #9 which did not have any cereals, was harvested when the forage peas were in the mid-pod stage.

The oven-dried samples were used for nutritive value analysis. The forage nutritive value (% DM basis) was determined by A&L Canada Laboratories Inc., London, Ontario using 2 dry composite forage samples per treatment – one for replications 1 & 3, and the other for replications 2 & 4. Mineral content (macro minerals- P, K, Ca, Mg, S, Na; micro minerals – Zn, Fe, Mn, Cu) were determined by wet chemistry, using modified AOAC 968.08 and 935.13A procedures (AOAC 1995). The laboratory used near infrared reflectance spectroscopy (NIR) to measure crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF), soluble crude protein (Sol-CP), undegraded intake protein (or bypass protein, UIP), acid detergent fibre crude protein (ADF-CP) and neutral detergent fibre crude protein (NDF-CP). A&L laboratory determined the following parameters from prediction equations provided by Adams (1980): net energy for gain (NE_G), net energy for lactation (NE_L), net energy for maintenance (NE_M), total digestible nutrients (TDN), digestible energy (DE), metabolizable energy (ME) and relative feed value (RFV). The non-fibre carbohydrate (NFC) content (DM basis) was a calculated value based upon nutrient percentages subtracted from 100% of forage DM. Both DM intake (DMI, % of body weight) and DM digestibility (DDM, % DM) were calculated from equations provided by Undersander and Moore (2002), while digestible CP (DCP, % DM) was calculated as $DCP = 0.929CP - 3.52$ (Demarquilly and Weiss 1970).

Both nutrient yield per hectare for CP yield (CPY) and TDN yield (TDNY) were calculated by multiplying crop forage yield (tonne/ha) by the respective nutrient content of CP and TDN to allow a comparison of nutrient yield potential for animal feed production among the cropping treatments.

Partial budget analysis

A partial budget analysis of the input costs and output revenue (forage DM yield & hay price) to determine returns and benefit: cost ratios (BCR) on a per hectare basis was done for all cropping treatments including the four monoculture cereal controls. Custom field work rates from AgriProfits Cropping Alternatives were used (AAF 2018).

Seed costs were collected from seed suppliers/companies in northern Alberta from February to April 2018. Seed costs (CAD $/kg) used were: oat ($0.35), soft white wheat ($0.55), triticale ($0.66), barley ($0.60), field peas ($0.53), hairy vetch ($5.40), tillage radish and purple top turnips ($5.58), crimson clover ($4.30), annual and Italian ryegrass ($3.20), proso millet ($2.20), kale ($9.59), forage rape, Winfred brassica and T-raptor ($7.61), Persian clover ($7.54), sunflower ($3.09), faba bean ($0.44), sorghum ($2.82), hybrid sorghum ($6.59), frosty berseem clover ($7.54), and teff ($7.78).

Other direct input costs that were applied to all treatments came from tillage and sowing costs, and greenfeed cutting, baling and hauling. In the present study, no fixed costs, crop insurance premiums or paid capital interest were used.

Revenue was estimated as forage DM yield (kg ha^{-1}) multiplied by the average unit price of hay/greenfeed (CAD $0.18 kg^{-1}) in Alberta from August to October 2018. Returns were derived by subtracting total variable costs from revenues. For each cropping treatment, BCRs were calculated by dividing returns by total variable costs. The results of the BCR analyses were compared to a standard index of 1:1 to assess the performance of the cropping treatments. The higher the BCR, the better the economic and management efficiency of the treatment. In the present study, the only revenue used was forage DM yield. No economic adjustments were made for different nutrient values (e.g. CP and TDN).

Forage DM yield per CAD $ spent on seed was calculated by dividing forage DM yield (t/ha)/seed cost. The cost per ton of protein was derived from: seed cost/CP yield.

Data analysis

Data were analyzed using a pre-defined model procedure from the CoStat – Statistics Software (version 6.2; CoStat 2005) to determine cropping treatment effects on all measured parameters. For the partial budget analysis data, only seed costs were not subjected to any statistical analysis because of the uniformity in seed costs for both years and replications for any particular cropping treatments. Where ANOVA indicated significant effects, the means were separated by the least significant difference (LSD) at the 0.05 probability level. Significant differences in the text refer to $P < 0.05$. Of the 33 monitored forage yield and quality parameters, the ANOVA for only 11 (FDMY, Sol-CP, ADF-CP, UIP, P, Mg, S, Fe, DMI, TDNY, RFV) indicated significant annual crop mixture x year interactions. Here, only the means of the measurements for the annual crop mixtures (across both years) are presented in tables and discussed in text.

Results

Forage dry matter yield and notes on crop growth

The forage dry matter (DM) differed significantly ($P < 0.05$) between cropping treatments. Except for mixture #8, which had similar ($P > 0.05$) forage DM yield to mixture #4, forage DM yield was generally significantly higher for mixture #4 (9.25 t ha^{-1}) than other mixtures and controls (monoculture cereal crops, Table 4). Three of the mixtures (#4, #8 and #12) had >8 t ha^{-1} forage DM yield, while other mixtures and monoculture cereals had values <8 t ha^{-1} forage DM. Among the monoculture cereal crops, triticale had significantly greater forage DM yield than oat and barley, but not soft white wheat. Also, triticale gave higher ($P < 0.05$) forage DM yield values than five of the fourteen mixtures (#3, #7, #9, #13 and #14). The forage yield advantage from mixtures was as high

Table 4. Forage dry matter (DM) content at harvest, forage DM yield (FDMY), crude protein (CP), crude protein fractions [soluble protein (Sol-CP), acid detergent fibre-CP (ADF-CP), neutral detergent fibre (NDF-CP), undegradable intake protein (UIP)], and forage crude protein yield (CPY) for all cropping treatments [14 multispecies annual crop mixtures and 4 monoculture cereals].

Annual crop mixture	DM %	FDMY t ha^{-1}	CP %	Sol-CP %	ADF-CP %	NDF-CP %	UIP %	CPY t ha^{-1}
Barley	34.5	6.76	12.0	49.2	1.04	2.23	25.4	0.81
Oat	33.4	6.21	9.80	55.4	0.91	2.46	22.3	0.58
Soft white wheat	32.7	7.13	11.1	59.3	1.00	2.76	20.3	0.81
Triticale	37.8	7.72	10.5	55.7	1.12	2.71	22.2	0.81
Mixture #1	31.1	7.13	13.9	51.2	0.92	2.73	24.4	0.99
Mixture #2	30.8	7.15	14.7	50.1	1.04	3.05	25.0	1.08
Mixture #3	27.6	6.63	12.4	53.9	0.90	2.82	23.1	0.85
Mixture #4	25.3	9.25	14.6	50.7	0.85	3.08	24.7	1.38
Mixture #5	35.7	7.79	13.0	49.5	0.91	3.21	25.2	1.01
Mixture #6	36.1	7.98	12.0	44.9	1.03	3.30	27.6	0.97
Mixture #7	35.2	7.34	11.7	44.6	0.89	2.96	27.7	0.86
Mixture #8	37.9	8.48	11.2	53.1	0.77	2.27	23.5	0.95
Mixture #9	29.3	6.28	17.3	52.2	1.34	3.29	23.9	1.09
Mixture #10	16.6	7.92	21.3	54.5	1.23	4.09	22.8	1.76
Mixture #11	27.5	7.98	22.9	61.0	0.93	1.90	19.5	1.88
Mixture #12	25.9	8.26	23.8	61.3	0.87	2.98	19.3	2.03
Mixture #13	19.2	6.08	22.0	53.1	0.90	3.54	23.4	1.33
Mixture #14	29.8	6.93	13.3	65.7	0.68	3.76	17.1	0.92
Significance (*P* 0.05)	*	*	*	*	*	NS+	*	*
$LSD_{0.05}$	3.55	0.77	2.36	8.42	0.27	1.35	4.20	0.26
Mean	69.8	7.39	14.6	53.6	0.96	2.91	23.2	1.11
CV^z (%)	3.97	9.13	11.3	9.23	20.2	32.5	12.6	16.3

*Significant at $P < 0.05$.
+NS = not significant at $P < 0.05$.
Note: $LSD_{0.05}$ = least significant difference at $P < 0.05$.
zCV = means coefficient of variation.

as 37, 48, 29 and 20% respectively over barley, oat, soft white wheat and triticale. Only 3 of the mixtures (#4, #8 and #12) appeared to have consistently higher forage yield advantage (>5%) over all of the monoculture cereal crops. Other mixtures did not seem to have consistent forage yield advantages over the annual cereal crops. However, on several occasions other mixtures did have some yield advantage over barley and oat crops. Also, 2–3 way mixtures with only cereals and legumes showed yield advantages of 0.17–2.27 t ha^{-1} forage DM yield over control cereals.

It was observed that BMR sorghum and forage sorghum, hunter forage rape and teff performed poorly in the mixtures. These species had poor seed germination and limited establishment in stands. It was also noted that the barley in mixture #6 grew slightly taller than the barley in mixture #7. Generally, the monoculture cereal crops seemed to grow slightly taller than their counterparts in mixtures. Though control cereal crops grew taller, no lodging was observed during any of the 2 growing seasons.

Forage nutritive value

The forage CP, most protein fractions (Sol-CP, ADF-CP and UIP) and CP yield were all significantly affected by cropping treatments (Table 4). Forage NDF-CP did not differ ($P < 0.05$) among cropping treatments. Forage CP for 5 mixtures (#9, #10, #11, #12 and #13) showed higher values ($P < 0.05$) than other mixtures and monoculture cereals. Most mixtures had >12.0% forage CP, while monoculture cereals had <12.0% forage CP. Interestingly, the forage CP of mixtures increased by as much as 198%, 214%, 227% and 242% respectively over barley, wheat, triticale and oat. Overall, oat had the least forage CP (9.84%). The forage Sol-CP, ADF-CP, UIP and CPY values were respectively higher for mixtures #14, #9, both #6 & #7, and #12 than other cropping treatments. Most of the cropping treatments showed some form of similarity with UIP.

The forage ADF, NFC and RFV were all significantly affected ($P < 0.05$) by cropping treatments (Table 5). Monoculture oat crop had significantly higher ADF and NDF level compared to most mixtures, as well as other cereal crops. Overall, mixtures #11, #12 and #13 seemed to fare better than other mixtures with lower forage ADF and NDF, and higher forage NFC. Three (mixtures #11, #12 and #13) of the 14 mixtures showed significantly higher RFV than other mixtures and monoculture cereal crops.

The forage TDN and other determinations of energy (NE_L, NE_G and NE_M) value, and TDNY were all significantly affected ($P < 0.05$) by cropping treatments (Table 5). In most cases, 3 of the mixtures (#11, #12 and #13) produced significantly higher ($P < 0.05$) forage energy (TDN) than other mixtures and monoculture cereals. The forage TDN varied from 62 to 69% for all cropping treatments. The forage TDNY was highest for mixture #4 (6.01 t TDNY ha^{-1}), followed by mixture #11 (5.64 6.01 t TDNY ha^{-1}). The other forms of forage energy measured (NE_L, NE_G and NE_M) were all significantly higher for mixtures #11, #12 and #13 than monoculture cereal crops. Monoculture oat crop consistently gave the least NE_L, NE_G and NE_M values.

All forage macro minerals (Ca, P, K, Mg, Na and S) and trace minerals (Cu, Fe, Zn and Mn), as well as Ca:P and tetany ratios measured here were affected ($P < 0.05$) by cropping treatments (Table 6). Except for mixture #9 (forage K and S), the forage Ca, P, Ca:P, K, Mg, S and Fe differed significantly from most mixtures as well as all monoculture cereal crops. Forage Na was by far higher for mixture #12 than other mixtures and monoculture cereals. As shown in Table 6, mixtures #3 and #8 had higher

Table 5. Forage acid detergent fibre (ADF), neutral detergent fibre (NDF), non-fibre carbohydrate (NFC), forms of energy [total digestible nutrients (TDN), net energy for lactation (NE_L), net energy for gain (NE_G) & net energy for maintenance (NE_M)], TDN yield (TDNY) and relative feed value (RFV) of forage on dry weight basis for the cropping treatments [14 annual crop mixtures and 4 monoculture cereals].

Cover crop treatment	ADF %	NDF %	NFC %	TDN %	TDNY t ha^{-1}	NE_L Mcal/kg	NE_G Mcal/kg	NE_M Mcal/kg	RFV
Barley	31.3	53.6	22.4	62.9	4.25	1.41	0.86	1.59	107
Oat	35.6	58.6	20.0	61.5	3.82	1.35	0.77	1.49	97
Soft white wheat	32.8	53.0	24.7	63.2	4.51	1.42	0.83	1.55	112
Triticale	33.0	53.1	24.9	63.1	4.87	1.41	0.82	1.54	111
Mixture #1	32.6	52.3	22.3	63.3	5.15	1.42	0.83	1.55	116
Mixture #2	27.5	43.2	30.6	66.3	4.74	1.54	0.95	1.67	146
Mixture #3	33.9	55.3	20.8	62.6	4.15	1.39	0.81	1.53	106
Mixture #4	29.7	47.2	26.7	65.0	6.01	1.49	0.90	1.62	131
Mixture #5	27.0	46.0	29.5	66.6	5.19	1.55	0.96	1.68	139
Mixture #6	29.2	49.3	27.2	65.3	5.21	1.50	0.91	1.63	125
Mixture #7	27.4	47.2	29.6	66.3	4.87	1.54	0.95	1.67	134
Mixture #8	30.0	48.8	28.5	65.0	5.50	1.48	0.89	1.61	128
Mixture #9	30.6	38.7	32.5	64.5	4.05	1.47	0.88	1.60	156
Mixture #10	27.9	36.7	33.1	66.0	5.23	1.53	0.94	1.66	174
Mixture #11	23.3	33.5	36.6	68.7	5.48	1.63	1.04	1.76	198
Mixture #12	24.1	30.1	34.6	68.3	5.64	1.61	1.03	1.75	229
Mixture #13	22.5	33.1	34.0	69.2	4.21	1.65	1.06	1.78	202
Mixture #14	27.4	52.7	22.4	66.3	4.59	1.54	0.83	1.54	120
Significance ($P < 0.05$)	*	*	*	*	*	*	*	*	*
$LSD_{0.05}$	3.66	5.91	5.26	2.1	0.88	0.08	0.08	0.08	22.3
Mean	29.2	46.8	27.8	65.2	4.86	1.50	0.90	1.62	141
CV ^{z} (%)	8.69	8.84	13.3	2.25	12.6	3.80	6.71	3.73	11.1

*Significant at $P < 0.05$.
Note: $LSD_{0.05}$ = least significant difference at $P < 0.05$.
$^+$NS = not significant at $P < 0.05$.
^{z}CV = means coefficient of variation.

forage Mn values than other mixtures, while pure oat and triticale showed higher forage Mn values than other cereals and most mixtures. Mixture #9 had higher forage Cu and Zn than other mixtures and pure cereals. The forage tetany ratio was significantly higher (P < 0.05) for pure cereals than mixtures, ranging from 3.24:1.0 to 3.87:1.0 for monoculture cereals and 0.95:1.0 to 2.88:1.0 for mixtures.

The forage digestible feed energy (DFE), digestible crude protein (DCP), dry matter intake (DMI) and digestible dry matter (DDM) were all significantly affected ($P < 0.05$) by cropping treatments (Table 7). Three mixtures (#11, #12 and #13) appeared to be consistently higher ($P < 0.05$) in forage DFE, DCP, DMI and DDM than other mixtures as well as monoculture cereal crops.

Table 6. Forage macro and trace mineral contents, Ca:P ratio and tetany ratio (K/(Ca + Mg) for the cropping treatments [14 annual crop mixtures and 4 monoculture cereals].

	Macro-minerals								Trace-minerals			
Cover crop treatment	Ca %	P %	Ca:P	K %	Mg %	Na %	S %	Tetany ratio	Cu ppm	Fe ppm	Zn ppm	Mn ppm
Barley	0.32	0.20	1.60	1.75	0.22	0.50	0.24	3.24	4.08	77.5	40.3	84.2
Oat	0.30	0.18	1.67	1.78	0.16	0.22	0.17	3.87	3.85	90.8	30.6	92.5
Soft white wheat	0.23	0.18	1.28	1.58	0.18	0.02	0.17	3.85	4.92	54.8	37.7	60.9
Triticale	0.25	0.21	1.19	1.54	0.20	0.11	0.20	3.42	3.87	77.1	47.9	93.2
Mixture #1	0.59	0.19	3.11	1.63	0.23	0.48	0.23	1.99	4.46	82.6	40.1	70.6
Mixture #2	0.74	0.19	3.89	1.56	0.29	0.24	0.25	1.51	5.48	88.2	47.2	34.1
Mixture #3	0.60	0.19	3.16	2.02	0.23	0.45	0.28	2.43	4.28	86.4	37.5	91.9
Mixture #4	0.63	0.22	2.86	1.77	0.26	0.35	0.31	1.99	5.04	80.8	44.0	46.6
Mixture #5	0.60	0.21	2.86	1.70	0.21	0.14	0.21	2.10	5.32	80.5	42.8	33.4
Mixture #6	0.36	0.18	2.00	1.50	0.18	0.15	0.18	2.78	5.23	70.0	39.0	32.3
Mixture #7	0.31	0.18	1.72	1.38	0.17	0.12	0.17	2.88	5.00	67.3	41.3	27.7
Mixture #8	0.40	0.17	2.35	1.41	0.18	0.11	0.18	2.43	5.01	105	42.7	95.5
Mixture #9	1.29	0.21	6.14	1.57	0.36	0.14	0.16	0.95	6.72	110	72.6	41.8
Mixture #10	1.66	0.25	6.64	3.32	0.35	0.39	0.48	1.65	4.99	121	61.2	37.4
Mixture #11	1.44	0.22	6.55	3.27	0.38	0.38	0.43	1.80	4.53	184	44.3	65.6
Mixture #12	1.57	0.27	5.81	3.09	0.49	0.98	0.81	1.50	4.93	122	57.1	54.8
Mixture #13	1.67	0.22	7.59	3.38	0.43	0.55	0.42	1.61	5.13	181	45.1	59.5
Mixture #14	0.53	0.22	2.41	1.24	0.17	0.23	0.14	1.77	5.48	85.9	37.8	72.1
Significance	*	*	*	*	*	*	*	*	*	*	*	*
$LSD_{0.05}$	0.36	0.04	1.09	0.61	0.07	0.34	0.09	0.89	1.29	31.5	10.9	44.6
Mean	0.76	0.2	3.49	1.97	0.26	0.31	0.28	4.34	4.91	97.9	45.0	63.1
CV ^{z} (%)	22.5	17	20.6	22.1	20.8	80.1	25.6	16.4	18.6	23.0	17.0	49.5

*Significance at $P < 0.05$.
Note: $LSD_{0.05}$ = least significant difference at $P < 0.05$.
$^+$NS = not significant at $P < 0.05$.
^{z}CV = means coefficient of variation.

Table 7. Calculated forage digestibility (digestible feed energy, DFE; digestible crude protein, DCP; digestible dry matter, DDM) and intake (dry matter intake, DMI) for different cropping treatments (14 annual crop mixtures and 4 monoculture cereals).

Cover crop treatment	DFE Mcal/kg	DCP %	DMI %	DDM %
Barley	2.77	7.52	2.17	63
Oat	2.71	5.26	2.05	61.1
Soft white wheat	2.78	6.76	2.28	63.4
Triticale	2.78	6.25	2.27	63.2
Mixture #1	2.79	9.39	2.31	63.5
Mixture #2	2.92	10.1	2.79	67.5
Mixture #3	2.75	8.04	2.18	62.5
Mixture #4	2.86	10.1	2.56	65.8
Mixture #5	2.93	8.52	2.63	67.9
Mixture #6	2.87	7.67	2.44	66.1
Mixture #7	2.92	7.37	2.55	67.6
Mixture #8	2.85	7.45	2.51	65.6
Mixture #9	2.84	12.6	3.1	65.1
Mixture #10	2.91	16.3	3.34	67.2
Mixture #11	3.02	17.8	3.61	70.8
Mixture #12	3.00	18.6	4.17	70.1
Mixture #13	3.04	16.9	3.65	71.4
Mixture #14	2.92	8.79	2.3	67.6
Significance ($P < 0.05$)	*	*	*	*
$LSD_{0.05}$	0.09	2.21	0.36	2.84
Mean	2.87	10.3	2.72	66.06
CV [z] (%)	2.25	15.2	9.45	3.00

*Significant at $P < 0.05$.
Note: $LSD_{0.05}$ = least significant difference at $P < 0.05$.
[+]NS = not significant at $P < 0.05$.
[z]CV = means coefficient of variation.

Partial budget analysis comparison

Table 8 shows the economic performance of pure cereal crops (controls) and 14 mixtures investigated. The estimated revenue, returns and BCR were influenced significantly ($P < 0.05$) by cropping treatments. The estimated revenue was highest for mixture #4 (CAD $1664/ha), followed closely by mixture #8 (CAD $1528/ha) and then mixture #12 (CAD $1486/ha). Except for mixture #8, the revenue generated from mixture #4 was significantly higher than other mixtures and monoculture cereal crops. Other than mixtures #4, #12 & #14 and pure triticale crop, estimated total input costs were significantly ($P < 0.05$) higher for mixture #6 (CAD $563/ha) than other mixtures and pure cereal crops.

Except for mixtures #8 (with a marginal returns of CAD $993/ha), the estimated marginal return was significantly higher for mixture #4 (~CAD $1112/ha) than other cropping treatments, including cereal controls. Triticale had higher marginal returns than the other cereal crops (Table 8). Only 7 of the mixtures (#4, #5, #6, #8, #10, #11 and #12) consistently had more profits (CAD $20–466/ha) over all cereal crops compared to the mixtures. Overall, there were more profits from mixtures compared to barley and oat than soft white wheat and triticale. Mixtures #7 and #13 did not result in any profits over any of the pure cereal crops.

The estimated BCR for all cropping treatments was generally >1.00. With the exception of mixture #8, the BCR was significantly higher for mixtures #4 and #10 than other mixtures and all pure cereal crops. Only both mixtures #4 and #10 had >2.00:1:00 BCR. Other mixtures, as well as pure cereal crops, had between 1.18:1.00 and 1.85:1.00 BCR.

Overall, oat was the least expensive in seed cost (CAD $40/ha), while dual crop species mixtures #6 and #7 were the most expensive in seed cost. The higher seed cost from mixtures #6 and #7 resulted from the seed cost of hairy vetch, which was about 66% of the total seed cost. Forage DM yield per dollar spent was highest for pure oat crop (0.16 t/CAD $), followed by both mixtures #3 and #4, with about 0.13 t/CAD $. The least forage DM yield per dollar spent came from mixture #7, which consisted of barley + non-inoculated hairy vetch. The cost per ton of protein was highly variable, with the most expensive in the mixture #7 (CAD $157), followed by mixture #6 (CAD $121) and pure barley and triticale crops (CAD $102). The least cost to produce a ton of protein came from mixture #11 (~CAD $38). Overall, mixtures #3, #4, #11 and #10 could be considered the least expensive mixes to produce for both dry matter and protein yield. The most expensive mixtures were #6, #7, #9 and #14.

Discussion

Multispecies annual crop mixtures have recently become more popular in northern Alberta. Producers need information on the performance of mixtures to implement successful production/farming operations.

This study evaluated the forage yield and quality obtained from growing several multispecies annual crop mixtures compared with the traditional monocrop cereals grown for forage in the study area. Profit potential for beef cattle producers depends on producing enough forage per hectare, with adequate feeding value including crude protein and mineral level, low fibre and high energy and digestibility, in order to keep production costs below selling price. The findings from the present study are discussed as relating to assessing diverse mixtures of annual crop species in comparison with the traditional (monoculture) cereal crops (oat, barley and triticale) for use in beef cattle production systems, with a focus on nutritional quality in relation to the National Research Council (NASEM 2016) nutrient requirements of beef cattle (Table 9) and economic performance.

Forage dry matter (DM) yield

In the present study, the top 3 forage treatments for DM yield were mixtures #4, #8 and #12, with 8.26 to 9.25 t/ha forage DM yield. Mixtures #4, #8 and #12 had 3 to 9 crop species in the mixtures. This shows that increasing plant community diversity with different complementary functional groups above monoculture and binary mixtures can significantly result in higher forage production. In the United States, Wortman et al. (2012) reported that a 6-species mixture seemed to be the most promising out of the 2-, 4-, 6- and 8-species mixtures evaluated. Diversity-productivity theory suggests that increased productivity associated with species diversity is due to more efficient resource use (Ojeda et al. 2018a; Tilman 1999; Trenbath 1974).

Overall, the mixtures investigated established successfully in both years in the present study. However, certain crop species which are new to the study area did not grow well in mixtures #10, 12, 12 and 13. Three warm season crops (forage sorghum, BMR sorghum and teff) and a cool season crop (hunter forage turnips) performed poorly during the study. This therefore

Table 8. Partial budget analysis comparison of different cropping treatments (14 annual crop mixtures and 4 monoculture cereals).

Cover crop treatment	Revenue	Input costs (CAD $/ha) Seed	Total Variable	Marginal Returns	BCR[¶]	Forage DM/$ spent on seed	CAD $/t of CP
Barley	1216	80	509	707	1.39	0.08	102
Oat	1118	40	470	647	1.38	0.16	70
Soft white wheat	1282	74	521	761	1.46	0.10	92
Triticale	1390	82	535	854	1.60	0.09	102
Mixture #1	1282	79	529	753	1.42	0.09	81
Mixture #2	1288	69	495	793	1.60	0.10	64
Mixture #3	1192	53	465	727	1.55	0.13	63
Mixture #4	1664	72	552	1112	2.01	0.13	53
Mixture #5	1402	74	516	886	1.70	0.11	77
Mixture #6	1436	116	563	874	1.55	0.07	121
Mixture #7	1322	116	520	621	1.19	0.05	157
Mixture #8	1528	74	534	993	1.85	0.12	78
Mixture #9	1130	99	474	656	1.38	0.06	93
Mixture #10	1426	73	471	954	2.05	0.11	42
Mixture #11	1438	70	517	920	1.77	0.11	38
Mixture #12	1486	90	544	942	1.73	0.09	45
Mixture #13	1094	84	482	613	1.27	0.07	64
Mixture #14	1248	83	538	710	1.32	0.08	95
Significance	*	NA[+]	*	*	*	*	*
$LSD_{0.05}$	161	NA	28.2	141	0.22	0.01	18
Mean	1320	NA	513	806	1.57	0.10	81
CV[z] (%)	10.6	NA	4.80	15.0	12.5	11.4	16

[¶]BCR stands for Benefit/cost ratio
*Significance at $P < 0.05$. Means within a column with the same superscript (s)/letter(s) were not significantly different according to LSD ($P < 0.05$).
[+]NA = not available.
Note: This is only a simple cost analysis and is not intended as an in depth study of the cost of production. The costs are in Canadian Dollar (CAD $). CAD $1 = US $0.78. Total variable consisted of seed costs, tillage, sowing, forage conservation processes (e.g. cutting, hauling).

shows that care would need to be taken by producers in including crops that are not adapted to an area and in particular those that may not have had evidence of good production potential in a new environment. It is important to note that mixture #4, which had the highest forage DM yield consisted of the top performing forage-type crops (when grown as monocrops) in the study area.

The differences in forage DM yield (0.64 t ha^{-1}) between mixtures #6 (inoculated hairy vetch) and #7 (with non-inoculated hairy vetch), which was in favour of mixture #6 further confirms the need to inoculate legumes with appropriate rhizobia species and strains before sowing, especially if a legume species is new to an area or if effective rhizobia are not present in the soil in sufficient quantities. Hairy vetch would be considered new to the study area.

Table 9. Recommended nutrient requirements for beef cattle from NASEM (2016).

Nutrient	Requirement Growing and finishing calves	Dry gestating cows	Lactating cows
CP (%)	12–14	7–9*	11
Ca (%)	0.31	0.18	0.58
P (%)	0.21	0.16	0.26
Mg (%)	0.1	0.12	0.2
K (%)	0.6	0.6	0.7
Na (%)	0.06–0.08	0.06–0.08	0.1
S (%)	0.15	0.15	0.15
Cu (ppm)	10	10	10
Zn (ppm)	30	30	30
Fe (ppm)	50	50	50
Mn (ppm)	20	40	40
NE_M (MCal kg^{-1})	1.08–2.29	0.97–1.10	1.19–1.28
NE_G (MCal kg^{-1})	0.53–1.37	NA[Y]	NA
TDN (%)	65–70[W]	55–60[Z]	65

*7% for middle 1/3 of pregnancy, 9% for late 1/3 of pregnancy.
[Z]55% for middle 1/3 of pregnancy, 60% for late 1/3 of pregnancy.
[Y]NA, not available.
[W]for 6–10 months old growing bulls.

Forage nutritive value

Matching the nutrient requirements of beef cattle and the nutrients supplied by forage type feeds will help identify nutritional sufficiency and inadequacies. In the present study, in almost in all cases, the mixture had better forage nutritive value than the pure cereal crops (controls). The better forage nutritive value from most mixtures than pure cereals could be attributed to complementary N functions in mixtures that included legume (s). Complementary N function can lead to facilitation, an increased N availability to non-legume species due to the presence of N_2 fixing legumes. Including other non-legume crop species like Italian ryegrass and forage brassicas like Winfred, Goliath and T-Raptor were thought to have improved forage quality of mixtures that consisted of any of these crops.

The forage CP, TDN, Ca, K, Mg, Na, S, Fe, Zn, Mn and RFV were greater for mixtures #9, #10, #11, #12 & #13, compared to other mixtures and the control cereals. This shows that a mixture with the right type of multispecies crops can be fed reliably to beef cattle as another forage feed source in the study area.

The NASEM (2016) model for diet of mature beef cows suggests 7% CP for maintenance in mid pregnancy, 9% CP for a beef cow in late pregnancy, and 11% CP for lactating cows (See Table 9). The TDN is a useful measure for energy content of beef cow rations that are primarily forage. For a mature beef cow, using percent TDN, NASEM (2016) suggests 55% in mid pregnancy, 60% in late pregnancy and 65% after calving (Table 9). Going by these recommendations, it is evident that all mixtures as well as control cereals tested in the present study, exceeded the CP and TDN requirements of dry, pregnant (gestating) beef cows. For a lactating beef cow, which requires 11% CP and 65% TDN, only the control oat and triticale treatments appeared to not meet CP requirements, while none of the monoculture cereal crops and mixtures #1 and #3, had the 65% TDN required for beef cattle.

For young beef cattle, 12–14% CP and 65–70% TDN is suggested for their total diet content (NASEM 2016). In the present study, in most cases, the mixtures (except for # 7 and #8) exceeded the CP requirement for young beef cattle. In the control group, only barley was able to meet the 12–14% CP required. Most mixtures appeared to be within the 65–70% TDN suggested for young beef cattle, while none of the control cereal crops had sufficient TDN. In the present study, because of the failure of most mixtures to be in the upper limit of the required TDN for young beef cattle, producers will need to test their mixtures for feed quality and use energy supplementation where needed to ensure that the TDN requirements are met. Further research is therefore needed to determine the right mixture of cover crop species, their sowing rates, and the appropriate stage to cut for silage or geenfeed for back grounding beef calves in the environment of northern Alberta. The net energy system separates the energy requirements into fractional components used for tissue maintenance, tissue gain, and lactation (NASEM 2016). All tested mixtures and monoculture cereals exceeded the NE_M levels suggested for a mature beef cow (1.19 to1.28 Mcal kg^{-1} NE_M) and were well with the 0.53 to 1.37 Mcal kg^{-1} NE_G suggested for growing and finishing beef calves (NASEM 2016).

Mineral imbalances and/or deficiencies can result in decreased performance, decreased disease resistance, and reproductive failure, which results in significant economic losses (GOS 2015). The NASEM (2016) suggested requirements for minerals for beef cattle are shown in Table 9. In the present study, all mixtures as well as pure cereal crops far exceeded the suggested minimum target levels of K, Mg, Na (except for pure soft white wheat), S (except for mixture #14), Fe and Zn for young and mature beef cattle. All mixtures and pure cereal crops had enough Ca and P for a mature gestating beef cow. However, for a lactating beef cow, all pure cereal crops and mixtures #6, #7, #8 and #14 fell short of meeting the Ca requirements of this category of beef cows. Only mixtures #12 had sufficiently met the P requirements of a lactating beef cow. No cropping treatments (mixtures and pure cereal crops) met the requirements for Cu, and some mixtures (mixtures #2, #5, #6, #7 and #10) did not meet the required amount of Mn needed by mature beef cattle. In the present study, forage Cu, Fe, Zn and Mn contents were far lower than the maximum tolerable levels for beef cattle as provided by NASEM (2016).

For growing and finishing calves, all of the mixtures had adequate Ca, while only one of the pure cereal crops (barley) was able to meet the 0.31% Ca needed by these calves. Also for young beef cattle, all mixtures and pure cereals met the suggested minimum levels of K, Mg, Na (except for pure soft white wheat), S (except for mixture #14), Fe and Zn. Only 8 of the 14 mixtures and pure triticale conveniently met the 0.21% P requirement for calves.

Six NDF and ADF based forage quality standards (prime, 1, 2, 3, 4 & 5) have been described for beef cattle (Ball et al. 2007). In the present study, only 5 of the mixtures (mixtures #9, #10, #11, #12 and #13) qualified for the prime standard (<31% ADF and <40% NDF). No pure cereals could be considered for the prime standard. The ADF values are important because they inversely relate to the ability of an animal to digest the forage. The NDF values reflect the amount of forage the animal can consume. In the present study, pure cereals generally had higher forage ADF and NDF values than mixtures. Mixtures #11, #12 and #13 had lower ADF and NDF values than other mixtures and pure cereals. With the lower ADF and NDF values obtained for mixtures #11, #12 and #13, when all the treatments tested here are presented side by side to cows in a preference study, mixtures #11, #12 and #13 would likely be preferred and consumed more than other treatments. Future study is needed to determine how beef cattle will utilize and respond in terms of growth performance to mixtures versus traditional cereal crops used for livestock production in western Canada.

Mixtures with brassicas species seemed to improve forage CP, TDN, detergent fibres (ADF and NDF) and forage Ca more than mixtures without brassica species. Brassicas have a readily digestible carbohydrate content but are relatively low in fibre so cattle should be provided a fibre source to prevent rumen acidosis or bloat (Arnold and Lehmkuhler 2014; Lemus and White 2014).

Economic performance indicators

The economics of a mixture depends primarily upon the costs and returns associated with forage DM production and nutritive value.

As expected, mixtures #4, which had the highest forage DM yield, also had the highest revenue from forage production as well as significantly higher returns than the other mixtures and pure cereals. The significantly higher revenue obtained for mixture #4 compared to other mixtures (except for #8, which had similar revenue), and pure cereal crops in particular, was a reflection of the benefits of growing a mixture containing a functionally diverse and adaptable group of cover crops representing different plant families (Brassicaceae, Fabaceae and Poaceae; C4 and C3 grasses; nitrogen-fixers, nutrient scavengers).

Seed costs for 8 of the mixtures were within the CAD $40–80/ha seed costs for the more traditional pure oat and barley crops for forage production in the study area. Higher seed costs for some mixtures could be attributed to higher seed costs of some imported annual crop species such as hairy vetch, brassicas and annual clovers (Crimson and Frosty berseem). Local seed production of such crops that have great forage production potential in northwestern Alberta would help reduce seed and total input costs/ha when such a crop is included in a mixture.

In the present study, the BCR was generally >1, an indication that the cropping treatments' benefits outweigh the costs. On a BCR basis, mixtures #4 and #10 were more profitable, followed by mixture #8. Overall, mixtures #1, #7, #9, #13 and #14 did not seem to have any improvement in BCRs over the more traditional oat and barley crops grown in northwestern Alberta for livestock feed. It is important to note that grazing animals (e.g. annual pasture or swath grazing) would be the key to making mixtures work better on a cow-calf operation. This will eliminate forage processing costs (e.g. cutting, baling, silage and hauling) and make the mixtures more profitable. But where mixtures are to be harvested and stored for later use, silage would work better due to the higher moisture content of most mixtures at harvest compared to the traditional oat or barley monocrop.

Forage DM yield per CAD $ spent was highest for the pure oat crop (0.16 t/CAD $), followed by both mixtures #3 and #4, with about 0.13 t/CAD $. The difference in the forage DM yield per CAD $ spent between both mixture #6 (inoculated hairy vetch) and #7 (un-inoculated hairy vetch), which was in favour of mixture #6, further confirms the need for a legume inoculation, particularly when the legume is new to an environment. The cost per ton of protein was highly variable. Overall, in the present study, mixtures #3, #4, #11 and #10 could be considered the least expensive mixes to produce both forage dry matter and protein.

Conclusion

The study demonstrated that growing the right annual crop mixture can increase forage production and provide beef cattle with a diet that in most cases is able to adequately meet the nutritional requirements for gestating beef cattle. Overall, in terms of forage yield advantage, marginal returns and benefit/cost ratio, 3 of the mixtures (#4, #8 and #12) were consistently satisfactory compared to all the monoculture cereal crops. Most of the mixtures had >12.0% forage CP compared to <12.0% forage CP for controls. Because most mixtures did not meet the required TDN level for young beef cattle, some form of energy supplementation would still be needed to ensure that TDN requirements are met. The present study results therefore suggest that growing an annual crop mixture with diverse plant functional groups compared to a monoculture cereal, can be used to improve forage production in northwest Alberta.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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References

[AAF] Alberta Agriculture & Forestry. 2018. Cropping alternatives-economics & competitiveness for 2018. Alberta Agriculture & Forestry, Government of Alberta.

Aasen A, Baron VS, Clayton GW, Dick AC, McCartney DH. 2004. Swath grazing potential of spring cereals, field pea and mixtures with other species. Can J Plant Sci. 84:1051–1058. doi:10.4141/P03-143.

Adams RS. 1980. Penn State forage testing service revised regression equations. Dairy Sci. Ext. Memo DSE-90–56. The Pennsylvania State Univ., University Park.

[AOAC] Association of Official Analytical Chemists. 1995. Official methods of analysis, 16th ed. Gaithersburg, MD, USA: AOAC Int.

Arnold M, Lehmkuhler J. 2014. Brassicas: be aware of the animal health risks. [accessed 2018 September 11]. https://uknowledge.uky.edu/cgi/viewcontent.cgi?article=1171&context=anr_reports.

Ball DM, Hoveland CS, Lacefield GD. 2007. Southern forages, 4th ed. Norcross, GA: Potash and Phosphate Institute and Foundation for Agronomic Research.

[BCRC] Beef Cattle Research Council. 2016. Cover crops as forage for beef cattle. [accessed 2018 September 11]. http://www.beefresearch.ca/files/pdf/BCRC_Cover_Crops_Fact_Sheet.pdf.

Carr PM, Richard DH, Woodrow WP. 2004. Barley, Oat, and Cereal-Pea mixtures as Dryland forages in the northern great Plains. Agron J. 96:677–684. doi:10.2134/agronj2004.0677.

Chu M, Jagadamma S, Walker FR, Eash NS, Buschermohle MJ, Duncan LA. 2017. Effect of multispecies Cover crop Mixture on soil Properties and crop yield. Agr Env Lett. 2(1).

CoStat Statistical Software. 2005. Cohort version 6.2. Monterey, Calif.: Costat.

Damiran D, Lardner HA, Larson K, McKinnon J. 2016. Effects of supplementing spring-calving beef cows grazing barley crop residue with canola meal and wheat-based dry distillers' grains with solubles on performance, reproductive efficiency, and system cost. Prof Anim Sci. 32:400–410. doi:10.15232/pas.2015-01479.

Davis C, Presley D, Farney JK, Sassenrath GF. 2015. Evaluating multispecies Cover crops for forage production. Kansas Agr Exp Station Res Reports. 1(4). [accessed 2018 August 4]. doi:10.4148/2378-5977.1058.

Demarquilly C, Weiss P. 1970. Tableau de la valeur alimentaire des fourrages. Paris: INRA.

Gill KS, Omokanye AT. 2018. Potential of Spring barley, Oat and triticale intercrops with field peas for forage production, Nutrition quality and beef cattle diet. J Agric Sci. 10:1–17. doi:10.5539/jas.v10n4p1.

Gill KS, Omokanye AT, Pettyjohn JP, Elsen M. 2013. Evaluation of forage type barley varieties for forage yield and nutritive value in the Peace Region of Alberta. J Agric Sci. 5:24–36. doi:10.5539/jas.v5n2p24.

[GOS] Government of Saskatchewan. 2015. Pasture Rejuvenation. Government of Saskatchewan, August 2015. [accessed 2018 August 9]. http://www.saskforage.ca/images/pdfs/Publications/Pasture%20rejuvenation% 20Aug%202015.pdf.

Hobbs PR, Sayre K, Gupta R. 2008. The role of conservation agriculture in sustainable agriculture. Philos Trans R Soc B. 363:543–555. doi:10.1098/rstb.2007.2169.

Jolliffe PA. 2000. The replacement series. J Ecol. 88:371–385. doi:10.1046/j.1365-2745.2000.00470.x.

Jong RD, Shields JA. 1988. Available water-holding capacity maps of Alberta, Saskatchewan and Manitoba. Can. J Soil Sci. 68:157–163.

Kaliel DA. 2004. Insights into managing winter feed costs in Alberta cow/calf operations. Agriprofits Research Bulletin. Alberta Agriculture, Food and Rural Development. [accessed 2018 August 22]. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/econ9538/$FILE/winterfeed.pdf.

Kelln MB, Lardner HA, McKinnon JJ, Campbell JR, Larson R, Damiran D. 2011. Effect of winter feeding system on beef cow performance, reproductive efficiency and system cost. Prof Anim Sci. 27:410–421. doi:10.15232/S1080-7446(15)30513-1.

Krause AD, Lardner HA, McKinnon JJ, Hendrick S, Larson K, Damiran D. 2013. Comparison of grazing oat and pea crop residue versus feeding grass-legume hay on beef-cow performance, reproductive efficiency, and system cost. Prof.Ani Sci. 29:535–545. doi:10.15232/S1080-7446(15)30275-8.

Lavorel S, McIntyre S, Landsberg J, Forbes TDA. 1997. Plant functional classifications: from general groups to specific groups based on response to disturbance. Trends Ecol Evol. 12:474–478.

Lemus R, White JA. 2014. Forage Brassicas for Winter Grazing Systems. Extension Service of Mississippi State University, Publication 2845. [accessed 2018 August 28]. https://extension.msstate.edu/sites/default/files/publications/publications/p2845.pdf.

Malézieux E, Crozat Y, Dupraz C, Laurans M, Makowski D, Ozier-Lafontaine H, Rapidel B, de Tourdonnet S, Valantin-Morison M. 2009. Mixing plant species in cropping systems: concepts, tools and models: a review. In: *Sustainable agriculture*. Dordrecht: Springer; p. 329–353.

McCartney DH, Baron V, Basarab J, Okine E, Lastiwka G, Depalme A, Young D. 2000. Winter Grazing and Feeding Systems in Western Canada. http://www.internationalgrasslands.org/publications/pdfs/id2217.pdf.

McCartney D, Okine EK, Baron VS, Depalme AJ. 2004. Alternative fall and winter feeding systems for spring calving beef cows. Can J Anim Sci. 84:511–522.

[NASEM] National academies of sciences, engineering, and medicine. 2016. Nutrient requirements of beef cattle, eighth revised edition. Washington, DC: The national academies press. doi:10.17226/19014.

Ojeda JJ, Caviglia OP, Agnusdei MG. 2018b. Vertical distribution of root biomass and soil carbon stocks in forage cropping systems. Plant Soil. 423(1–2):175–191.

Ojeda JJ, Caviglia OP, Agnusdei MG, Errecart PM. 2018a. Forage yield, water- and solar radiation-productivities of perennial pastures and annual crops sequences in the south-eastern Pampas of Argentina. Field Crop Res. 221:19–31.

Omokanye AT. 2018. Forage Feed Resources for Goats. Presentation at 2018 Alberta Goat Association Conference, October 26–28th, 2018, Evergreen Park, Grande Prairie, Alberta, Canada.

Smith RG, Atwood LW, Warren ND. 2014. Increased productivity of a Cover crop Mixture Is Not associated with Enhanced agroecosystem services. PLoS ONE. 9:e97351. doi:10.1371/journal.pone.0097351.

Smith RG, Gareau TP, Mortensen DA, Curran WS, Barbercheck ME. 2011. Assessing and visualizing agricultural management practices: A multivariable hands-on approach for education and extension. Weed Technol. 25:680–687.

Snapp SS, Swinton SM, Labarta R, Mutch D, Black JR, et al. 2005. Evaluating cover crops for benefits, costs and performance within cropping system niches. Agron J. 97:322–332.

Soil Classification Working Group. 1998. The Canadian system of soil classification. Agriculture and Agri-Food Canada Publication, 1646 (revised).

Strydhorst SM, King JR, Lopetinsky KJ, Harker KN. 2008. Forage potential of intercropping barley with faba bean, lupin, or field pea. Agron J. 100:182–190. doi:10.2134/agrojnl2007.0197.

Teasdale JR. 1996. Contribution of cover crops to weed management in sustainable agricultural systems. J Prod Agric. 9:475–479.

Tilman D. 1999. The ecological consequences of changes in biodiversity: a search for general principles. Ecology. 80:1455–1474.

Trenbath BR. 1974. Biomass productivity of mixtures. Adv Agron. 26:177–210.

Undersander D, Moore JE. 2002. Relative forage quality (RFQ) indexing legumes and grasses for forage quality. University of Wisconsin Extension. [accessed 2018 April 20]. http://www.uwex.edu/ces/forage/pubs/ rfq.htm.

Wortman SE, Francis CA, Bernards ML, Drijber RA, Lindquist JL. 2012. Optimizing cover crop benefits with diverse mixtures and an alternative termination method. Agron J. 104:1425–1435.