Received: 3 February 2020 | Revised: 11 June 2020 | Accepted: 4 July 2020

DOI: 10.1002/cft2.20056

Crop, Forage & Turfgrass Management

FORAGE AND GRAZINGLANDS

Forage potential of corn intercrops for beef cattle diets in northwestern Alberta

Akim Omokanye[1,3] | **Buthaina Al-Maqtari**[1] | **Herbert A. Lardner**[2] | **Guillermo Hernandez**[3] | **Kabal S. Gill**[4] | **Lekshmi Sreekumar**[1,5] | **Alan Lee**[3]

[1] Peace Country Beef & Forage Association, Room 229 TIB, Grande Prairie Regional College, Fairview Campus, Box 3000, Fairview, Alberta T0H 1L0, Canada

[2] Department of Animal and Poultry Science, University of Saskatchewan, Saskatoon, Saskatchewan S7N 5A8, Canada

[3] Department of Renewable Resources, Faculty of Agricultural, Life & Environmental Sciences, University of Alberta, 2–06 Agriculture Forestry Centre, Edmonton, Alberta T6G 2P5, Canada

[4] SARDA Ag Research, 701 Main Street, Box 90, Falher, Alberta T0H 1M0, Canada

[5] Present Address: South Country Co-op Ltd, Box 1179, 7th St & Industrial Road, Brooks, Alberta T1R 1B9

Correspondence

Akim Omokanye, Peace Country Beef & Forage Association, Room 229 TIB, Grande Prairie Regional College, Fairview Campus, Box 3000, Fairview Alberta, T0H 1L0, Canada.

Email: akim@pcbfa.ca; aomokanye@gmail.com

Abstract

Intercropping systems involving cereals with legumes provide several advantages such as elevated forage yield and improved forage nutritive value. This study was designed to assess viability of corn (*Zea mays* L.) intercrops to improve the forage crude protein (CP) of corn forage for beef cattle production. A corn monocrop (C-M) was compared with seven corn intercrops (five annual legumes, a non-legume crop (radish (*Raphanus sativus* L.), C-RA) and an annual crop mixture (ACM)). The corn forage dry matter (DM) yield was significantly improved ($P < .05$) for C-M than all intercrops. Of the seven intercrops, only corn-radish intercrop (C-RA) produced significantly lower total forage DM yield (corn + companion) than C-M. Of the seven corn intercrops, only corn-hairy vetch (*Vicia villosa* Roth) (C-HV) and corn–annual crop mixture (C-ACM) had significantly ($P < .05$) improved forage CP and digestible CP than C-M. Both C-HV and C-ACM exceeded the CP recommendations for mature beef cattle and also had adequate CP for young (growing and finishing calves) beef cattle, thereby eliminating the need for protein supplementation during the feeding of either C-HV or C-ACM beef cattle. Forage minerals were not significantly affected ($P > .05$) by corn intercrops. Forage total digestible nutrients (TDN) was significantly ($P < .05$) influenced by intercrops and varied from 65.9-71.2%. Results indicate that selected corn intercrops can improve nutritive value of forage for beef cattle production.

Abbreviations: ACM, annual crops mixture; C-ACM, corn intercrop with an annual crops mixture; CC, crimson clover; C-CC, corn intercrop with crimson clover; C-FB, corn intercrop with fababean; C-FP, corn intercrop with field pea; CHU, corn heat unit; C-HV, corn intercrop with hairy vetch; C-M, corn monocrop; CP, crude protein; C-RA, corn intercrop with radish; C-SB, corn intercrop with soybean; DE, digestible energy; DM, dry matter; FB, fababean; FP, field pea; HV, hairy vetch; LTA, long-term average; NDFD, neutral detergent fiber digestibility; RA, radish; SB, soybean; TDN, total digestible nutrients; Tmax, maximum temperature; Tmin, minimum temperature.

1 | THE IMPORTANCE OF STANDING CORN TO BEEF CATTLE

Winter feeding costs are a major contributor to the overall cost of production for beef cattle producers in western Canada (Krause et al., 2013). Crops that are adapted to warmer climates are increasing in western Canada due to changing climate conditions. Corn for silage and grazing has attracted great interest beef production. Grazing standing corn is an option with great potential to extend the grazing season into the fall and winter months to reduce winter feeding costs (McMillan et al., 2018). Also, shorter season corn is being grown for silage for beef cattle production in areas of northwestern Alberta where corn is fairly to moderately adapted, resulting in a steady increase in corn hectarage for livestock feed (grazing and silage) over the past number of years in northwestern Alberta (Omokanye, 2014).

Corn forage can fit well in the grazing system as it meets the nutritive composition requirements for many categories of cattle, particularly beef cows in mid- and late-stage pregnancy (Lardner, Pearce, & Damiran, 2017; Omokanye, 2019). A long-term evaluation of feed test results for several forages showed that whole plant corn had improved total digestible nutrients (TDN) than oats (*Avena sativa* L.) at milk stage and barley (*Hordeum vulgare* L.) at soft-dough stage, because of its high starch and low fiber content (Omokanye, 2019). Lardner et al. (2017) reported that whole plant corn and barley had similar TDN content. However, the forage of standing corn hybrids had lower CP content than barley across the Canadian prairie environments (Lardner et al., 2017) as well as oats and barley in northwestern Alberta (Omokanye, 2019). Several reports have indicated that corn forage protein concentrations would not normally be adequate for beef cattle diet at all physiological stages (e.g. Abeysekara, Christensen, Niu, Theodoridou, & Yu, 2013; Armstrong, Albrecht, Lauer, & Riday, 2008; Darby & Lauer, 2002; Lardner et al., 2017; Omokanye, 2016). Karsten, Roth, and Muller (2003) found that corn forage CP and fiber content decreased from silking to milk–dough stage.

In addressing the shortfall in corn forage CP for beef cattle, producers can use CP additive (Damiran, Lardner, Larson, & McKinnon, 2016; Jose, 2015; Van De Kerckhove, Lardner, Walburger, McKinnon, & Yu, 2011) or good legume hay (Krause et al., 2013) to supplement corn forage CP for beef cattle (Omokanye, 2016). However, this process adds extra costs to the already expensive beef production. Corn intercropping with legumes or other annual crops is an option to consider for improving forage corn CP content (Dahmardeh, Ghanbari, Syasar, & Ramroudi, 2009) at a minimal extra cost. Intercropping can enable efficient use of resources, which leads a reduction of production costs (Hauggaard-Nielsen et al., 2009; Jensen, 1996; Morris & Garrity, 1993a,b), offers greater financial stability (Ofor & Stem, 1987) and greater total forage yield (Brooker, Bennett, & Cong, 2015; Dhima, Lithourgidis, Vasilakoglou, & Dordas, 2007) as well as improved forage nutritive value (Gill & Omokanye, 2018). The review by Hauggaard-Nielsen and Jensen (2005) provided a list of disadvantages when intercropping to include possible overextraction of nutrients, the difficulty of mechanizing intercropping systems, the possibility of supporting a proliferation of harmful flora and fauna for the crops, and the reality that more complex cropping systems are less understood compared with sole crops. Beef cattle producers are unlikely to adopt the increased cost and complexity of managing intercrops without demonstrated evidence of their potential advantages over corn monocrops.

The objective of this study was to compare corn intercrops with annual legumes and non-legume crops to C-M in terms of forage yield and quality. Our initial hypothesis was that intercrops could provide greater forage yield and improve quality compared with C-M, and offer a balanced forage diet that is better able to meet the protein requirements of beef cattle.

Core Ideas

- The choice of companion crop species affected corn growth and forage production.
- Forage protein content was significantly improved by most intercrops.
- Intercrops can eliminate the need for protein supplementation of beef cattle diets.

2 | SITE DESCRIPTION AND EXPERIMENTAL DESIGN

Field experiments were carried out over two growing seasons, from 25 May to 15 Sept. 2017, and from 28 May to 24 Sept. 2018, at the Fairview Research Farm, Fairview (56° 04′ 53″ N lat., 118° 26′ 05″ W long.; 670 m), located in northwestern Alberta, Canada. The site has a subarctic climate (boreal climate), which is characterized by long, very cold winters and cool to mild, short 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 (2017 and 2018) are shown in Table 1.

Long-term average (over 30 years) and monthly-recorded precipitation during both growing seasons (Table 2) were collected from the nearest Alberta Agriculture and Forestry meteorological station, which was located within 200 m of the research site used for the present study. The monthly average precipitation, temperature and corn heat units (CHU) at the experimental site are shown Table 2. Corn heat units (CHU) is a measurement of cumulative heat over the growing season. The CHU were calculated on a daily basis, using

TABLE 1 Cropping history, soil characteristics (0-15 cm depth) and spring soil moisture, and spring soil temperatures at seeding for the two experimental years

Parameter	2017	2018
Cropping history	2011: Corn	2011-2012: Chemical fallow[a]
	2012: Canola	2013–2016: Oats for forage
	2013–2015: Oats for forage	2017: Forage-type soybeans
	2016: Forage brassicas	
Nutrients and properties of soil		
Soil organic matter, %	5.8	6.4
pH (1:2.5 H_2O)	5.6	6.8
Electrical conductivity (dS/m)	0.25	0.39
Nitrate-N (kg/ha)	36	60
P (Bray 1-P method) (kg/ha)	58	36
K (kg/ha)	330	400
Sulphate-S (kg/ha)	13	18
Total exchangeable cations (meq/100 g)	24.7	13
Cation Saturation		
Ca (%)	43.7	64
Mg (%)	14.6	22.7
Na (%)	0.8	1.2
K (%)	1.5	3.5
Base saturation (%)	60.7	91.5
Spring soil moisture	13.0% (0-5 cm)[b]	12.0% (0-5 cm)
	12.1% (0-20 cm)	12.2% (0-20 cm)
Spring soil temperature	10.9°C (0-5 cm)	10.4°C (0-5 cm)
	8.95°C (0-20 cm)	8.61°C (0-20 cm)

[a]Chemical fallow (left unseeded but sprayed during the growing season) with Roundup WeatherMax herbicide at a rate of 1.65 L ha^{-1} with 100 L ha^{-1} of water.
[b]Values in parentheses indicate soil depths.

TABLE 2 Monthly mean air temperature, total corn heat units (CHU) and total precipitation during the 2017 and 2018 growing seasons, and the long-term average (LTA, 30-year)

	Temperature (°C)			CHU[a]			Precipitation (mm)		
Month	2017	2018	LTA	2017	2018	LTA	2017	2018	LTA
May	11.9	14.3	9.81	128	46	128	30.2	5.3	40.0
June	14.5	14.9	13.9	474	479	426	53.7	77.3	64.3
July	15.9	16.3	15.8	552	576	558	57.2	108.5	68.7
August	15.7	14.7	14.7	554	485	498	14.2	23.3	47.8
September[b]	11.9	7.14	11.6	49.3	9.9	44.6	1.4	1.6	7.7
Total	-	-	-	1758	1596	1655	156.7	216	228.5

[a]CHU in 2017 and 2018 - from seeding (25 May 2017 and 28 May 2018) to first fall frost (4 September in both years and LTA).
[b]Last data in September coincides with date of first fall at the experimental site.
May temperature and precipitation was from 1 to 31 May each year.
Source: Environment Canada (www.climate.weatheroffice.ec.gc.ca)

the maximum (Tmax) and minimum (Tmin) daily air temperatures, measured from midnight to midnight, in °C. The following equation was used to calculate daily CHU: Daily CHU = (Ymax + Ymin)/2; where Ymax = [3.33 × (Tmax-10)] - [0.084 × $(\text{Tmax-10})^2$] (if Ymax <0, set Ymax = 0) and Ymin = [1.8 × (Tmin-4.4)] (if Ymin <0, set Ymax = 0) (Brown & Bootsma, 1997).

The study was a randomized complete block design with four replicates of each treatment. The following eight treatments were investigated (Table 3):

TABLE 3 Corn intercrop treatments descriptions

Treatment no.	Acronym	Intercrop	Latin name	Cultivar	Other characteristics
1	C-M	Corn monocrop	*Zea mays* L.	39F44	Early maturity, glyphosate resistance
2	C-FP	Corn intercrop with field pea (FP)	*Pisum sativum* L.	CDC Horizon	Forage pea
3	C-CC	Corn intercrop with crimson clover (CC)	*Trifolium incarnatum* L.	NA[a]	
4	C-HV	Corn intercrop with hairy vetch (HV)	*Vicia villosa* Roth L.	NA	
5	C-FB	Corn intercrop with fababean (FB)	*Vicia faba* L.	Tabasco	
6	C-SB	Corn intercrop with soybean (SB)	*Glycine max* L.	TH 33003	Medium maturity,glyphosate resistance
7	C-RA	Corn intercrop with radish (RA)	*Raphanus sativus* L.	Daikon radish	Forage brassica
8	C-ACM	Corn intercrop with an annual crops mixture (ACM)[b]			

[a]Not available.
[b]Crops in the mixture: barley (cv. CDC Maverick), FB, HV, CC, forage brassica [cv. Winfred forage brassica), Italian ryegrass (*Lolium multiflorum* Lam.; cv. Green Spirit) and sunflower (*Helianthus annuus* L.).

3 | CULTURAL PRACTICES

Each year, the land was prepared with a three-point hitch Ferguson row crop cultivator (Type 9BO-20; Harry Ferguson, Inc., Detroit, MI) and diamond harrows before seeding. Forage treatments were established using a six-row Fabro plot drill (with two cone seeders, a seed box, and a fertilizer box) equipped with disc type openers on 25 May 2017 and on 28 May 2018. The plot drill had 23-cm row spacing. Typical corn planting recommendations for silage production are generally employed for establishing corn for grazing. The corn in all treatments was seeded in 69-cm rows apart, to achieve corn population of 80,000 plants ha^{-1} (recommended rate). Between two corn rows, two rows of companion crops were also seeded, spaced 23-cm apart (Figure 1). Both corn (seed box) and companion crops (cone seeder) were seeded simultaneously. To achieve a row spacing of 69-cm for corn, we blocked off two rows at a time so that one in three rows drops corn seed (69-cm spacing). In addition, we set the drill opening on the desired setting. Depth of seeding for both corn and companion crops was 2 cm. The companion crops in the corn intercropping treatments were seeded at 40% of their respective monocrop recommended seeding rates (FP = 69 kg ha^{-1}, CC = 6.47 kg ha^{-1}, FB = 96.3 kg ha^{-1}, HV = 6.47 kg ha^{-1}, SB = 20.2 kg ha^{-1}, RA = 2.24 kg ha^{-1}, and ACM = 28.7 kg ha^{-1}). The C-ACM seeding rates were 21.5 kg ha^{-1} barley (cv. CDC Maverick), 3.58 kg ha^{-1} pea, 1.79 kg ha^{-1} HV field pea, 0.45 kg ha^{-1} CC, 0.45 kg ha^{-1} forage brassica [cv. Winfred - a cross between a turnip (*Brassica rapa* L.) and a kale (*Brassica oleracea var. acephala*)], 0.45 kg ha^{-1} Italian ryegrass (*Lolium multiflorum* Lam.; cv. Green Spirit) and 0.45 kg ha^{-1} sunflower (*Helianthus annuus* L.).

Plot size was 22.1 m^2 (2.76 × 8 m). There were 0.69 m unseeded alleys between plots. Only 50% of the recommended fertilizer blend following soil tests was applied each year, at 56 kg N ha^{-1}, 16 kg P_2O_5 ha^{-1}, 17 kg K_2O ha^{-1} and 11 kg S ha^{-1} in 2017, and 62 N ha^{-1} 21 P_2O_5 ha^{-1}, 27 K_2O ha^{-1} and 12 kg S ha^{-1} in 2018. The inorganic fertilizer blend was only applied to corn rows by banding at planting in each year. No inorganic fertilizer blend was applied to the companion crop and annual crop mixture at seeding. However, all the legumes were inoculated at seeding with appropriate *Rhizobium* inoculants (Nitragin Gold for clover seed, Nodulator Duo SCG for FP, FB and HV seed, and N-Rhizo Soy for SB). Pre-emergent weeds were controlled with glyphosate herbicide at 1.70 L ha^{-1}. Except for C-ACM and C-RA intercrops, post-emergence (in crop) weed control of broadleaf such as lamb's quarters (*Chenopodium album* L.), stinkweed (*Thlaspi arvense* L.) and wild buckwheat (*Fallopia convolvulus* (L.) Á. Löve) was with Basagran Forte herbicide at 2.25 L ha^{-1} when

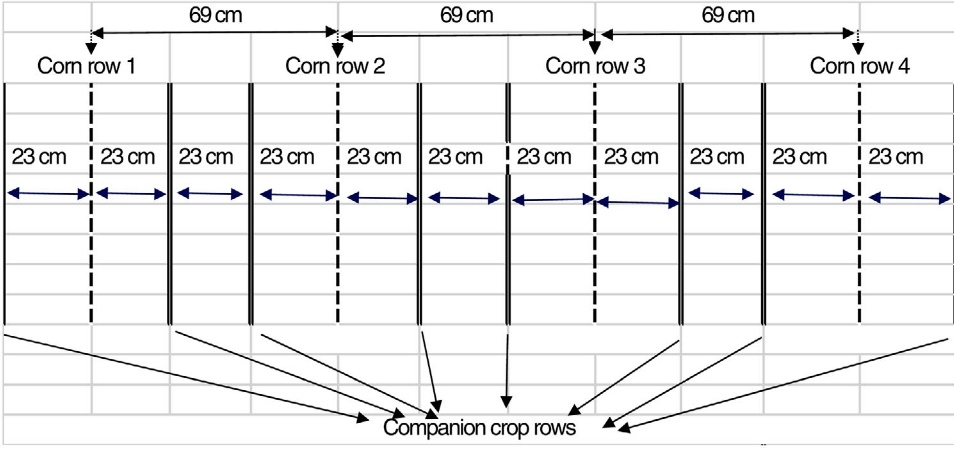

FIGURE 1 Schematic diagram of corn and companion crops arrangement and row spacing

the corn was at 5 to 6 leaf stage. Both C-ACM and C-RA intercrops were hand weeded the same day the other plots sprayed.

4 | FIELD MEASUREMENTS

The day before harvest for forage yield and quality, plant height of ten corn plants from each plot were measured, while plant height of the companion crops was not measured. Two corn rows (corn rows 2 and 3, see 1), which were 3-m in length at 0.69 m row spacing and two center rows of each companion crop (3-m in length × 0.23-m row spacing) were hand-harvested at about 8-cm above ground from each plot and weighed to determine forage yield on September 15, 2017 and September 24, 2018. Corn was harvested at kernel half milk line stage in 2017 and kernel blister stage in 2018, as described by Abendroth, Elmore, Boyer, and Marlay (2011). This corresponds to silage harvest stage, with a kernel maturity of 45% DM. All harvested (at about 8-cm above ground) materials (including whole corn plant with ears and tassels) were shredded using a wood chipper shredder (Samson Machinery, 15HP 420CC Gas Powered), and a 750-g subsample was dried to a constant weight at 60 °C. Another set of two corn–companion crop rows of two meters in length from each plot was harvested for determination of corn and companion crops percentages on a biomass dry matter basis.

5 | FORAGE NUTRITIVE VALUE ANALYSIS

Every year, dried forage samples were analyzed for forage nutritive value by A&L Canada Laboratories Inc. (London, Ontario, Canada). Nutritive value parameters are reported on a DM basis. The forage DM content of sub-samples was determined by drying in a forced air oven at 65°C overnight (Horwitz, 2000). Forage CP was determined by the Dumas direct combustion method using LECO FP628 Nitrogen analyser (AOAC-990.03, 2005). ANKOM Method 5 using ANKOM 200 was used for measuring ADF (AOAC- 973.18, 1990), while NDF was determined with ANKOM Method 6 using ANKOM 200 (AOAC-2002.04, 2007). Mineral content of P, K, Ca and Mg were determined using modified AOAC 968.08 and 935.13A procedures (Cunniff, 1995). The 48-h neutral detergent fiber digestibility (NDFD) was determined from in vitro true digestibility in a Daisy^{II} incubator (ANKOM Technology, Macedon, NY), which consisted of a thermostatic chamber (39 °C) with four rotating jars, following the Tilley and Terry (1963) approach modified by Goering and Van Soest (1970), as described by Ammar, López, Bochi, García, and Ranilla (1999). Both digestible energy (DE) and total digestible nutrients (TDN) parameters were calculated from equations provided by Adams (1980).

6 | STATISTICAL ANALYSIS

To determine treatment effects, data from both years were analyzed with CoStat statistical software package, version 6.311 (CoStat, 2005). Means were separated by the least significant differences (LSD) at the 0.05 probability level when parameters were found significant. Significant differences in the text refer to $P < .05$. Pearson's correlation coefficients (r) were determined among selected nutrients, total forage yield, and companion crop yield.

7 | CORN PLANT HEIGHT, FORAGE DRY MATTER YIELD, AND PERCENT OF CORN AND COMPANION CROPS

Intercropping corn with other annual crop species significantly affected ($P < .05$) corn plant height, corn forage DM yield and total forage DM yield (Table 4). Significant ($P < .05$) differences also existed among the companion crop DM yield and the forage botanical contribution of companion crops towards total production (yield) (Table 4).

The C-M treatment had the highest plant height (230 cm), which was similar ($P > .05$) to those of corn in C-FB (215 cm) and C-SB (220 cm) and significantly ($P < .05$) greater than those of corn in C-HV, C-CC, C-RA, C-ACM and C-FP intercrops. The C-RA significantly ($P < .05$) reduced corn height than other intercrops.

Corn forage DM yield was significantly ($P < .05$) greater for MC (11.8 Mg ha^{-1}) than all intercrops (Table 4). Out of the intercrops investigated, C-SB produced more corn forage DM yield than other intercrops (except for C-CC). Interestingly, C-ACM produced significantly ($P < .05$) improved companion crop forage DM yield (9.31 Mg ha^{-1}) than other companion crops (Table 4). The C-ACM gave 4.49 to 6.57 Mg ha^{-1} more companion crop forage DM yield than other companion crops in the different intercrops. Total yield was the same for C-M as for every intercrop other than C-RA.

Overall, except for C-RA, total forage DM yields were not decreased by the additional seeding of other crops with corn, but the yields were similar or slightly increased numerically when compared with C-M treatment.

The companion crop forage DM yield from C-ACM constituted 65% of the total forage DM yield in the C-ACM intercrop, followed by that of C-RA, which consisted of 54% (Table 4). In comparison, other companion crops only contributed 20 to 37% to the total forage production (DM yield).

8 | FORAGE NUTRITIVE VALUE

Forage CP was significantly ($P < .05$) influenced by intercrops (Table 4). Both C-HV and C-ACM significantly ($P < 0.05$) had greater forage CP content than other intercrops and C-M. The C-ACM and C-HV had 40 and 44%, respectively increased forage CP compared with C-M.

Forage macro minerals measured in the present study (Ca, P, K and Mg) were unaffected significantly ($P > 0.05$) by intercropping (Table 4).

Forage TDN was affected significantly ($P < .05$) by intercropping (Table 5). The C-SB had significantly more ($P < 0.05$) TDN than C-FB, but had similar levels to other

TABLE 4 Corn height (cm), forage DM yields and the contribution of companion crops towards total forage production, and forage crude protein (CP) and macro mineral contents for all intercrops (DM basis)

Intercrop	Corn height (cm)	Forage DM yield (Mg ha^{-1}) Corn	Companion crop	Total production	Companion crop, % of total DM yield	CP (%)	Ca (%)	P (%)	K (%)	Mg (%)
C-M	230^{a}	11.8a		11.8a		10.0c	0.41	0.21	1.02	0.39
C-HV	209^{b}	9.10 cd	4.78b	13.9a	33.8 cd	14.4a	0.45	0.21	1.28	0.41
C-SB	220^{ab}	10.3b	2.74b	13.1a	20.4e	11.5b	0.51	0.19	1.05	0.43
C-CC	208^{b}	9.51bc	3.06b	12.6a	24.1de	11.0c	0.49	0.19	1.02	0.41
C-RA	160^{d}	3.25f	3.93b	7.18b	54.4b	11.5b	0.59	0.18	1.08	0.37
C-ACM	169^{cd}	5.04e	9.31a	14.4a	65.1a	14.0a	0.64	0.22	1.29	0.47
C-FB	215^{ab}	8.16d	4.82b	13.0a	37.0c	11.4b	0.34	0.21	0.94	0.36
C-FP	184^{c}	9.13 cd	2.87b	11.9a	23.9de	10.9b	0.63	0.18	0.97	0.34
[a]CV, %	9.3	6.8	23.1	9.3	9.6	6.9	28.2	20.1	15.8	15.6

Note: Means within a column with different letters differ ($P < .05$) according to LSD.

[a]CV means coefficient of variation.

TABLE 5 Forage total digestible nutrients (TDN), digestible energy (DE), acid detergent fiber (ADF), neutral detergent fiber (NDF) and neutral detergent fiber digestibility (NDFD) after 48 h

Intercrop	TDN %	DE Mcal kg^{-1}	ADF %	NDF %	NDFD 48 h %
C-M	68.7ab	3.02ab	35.2ab	54.6a	65.6d
C-HV	70.0ab	3.07ab	32.7b	47.5c	64.0f
C-SB	71.2a	3.13a	32.3b	48.7bc	71.8ab
C-CC	69.4ab	3.05ab	37.0a	55.1a	72.5a
C-RA	69.3ab	3.05ab	33.8ab	48.4bc	64.6e
C-ACM	67.4ab	2.96ab	34.2ab	48.0bc	58.3 g
C-FB	65.9b	2.91b	32.21b	51.5b	50.4h
C-FP	69.7ab	3.06ab	33.3b	48.9bc	71.4b
[a]CV, %	2.7	3.0	4.9	3.4	0.7

Note: Means within a column with the same superscript(s)/letter(s) were not significantly different according to LSD ($P < 0.05$).
[a]CV means coefficient of variation.

TABLE 6 Significant Pearson's correlation coefficients (r) between some select measured parameters and their levels

Parameters	Correlation (r)	P ($r = 0$)	n
Yield and TDN%	0.59	0.004**	64
Yield and corn yield	0.59	0.000***	64
Yield and companion yield	0.74	0.000***	56
Companion yield and P	0.51	0.005**	28
Ca and P	−0.64	0.000***	64
Ca and Mg	0.51	0.002**	64

** and ***, significant *at* $P < .01$ and $P < .001$, respectively.

intercrops and C-M. On the other hand, only C-SB had significantly elevated ($P < 0.05$) forage DE than C-FB while forage DE values were similar levels with other intercrops.

Forage fiber contents (ADF and NDF) and NDFD 48 h were all affected ($P < .05$) by intercropping (Table 5). Both C-M and C-CC had significantly ($P < .05$) superior forage NDF than other intercrops. C-HV has shown lower NDF value overall. The C-M did not differ significantly ($P > .05$) with all corn intercrops in forage ADF.

9 | PEARSON'S CORRELATION COEFFICIENTS (*R*) OF SELECTED PARAMETERS

Table 6 shows correlations between some measured parameters. High positive correlation was observed between total and companion crop DM yield. Only Ca and P had negative correlation. Companion crop DM yield had moderate correlation with P content. The positive correlation of Ca content was moderate with Mg. The correlations between total DM yield and TDN% as well as total DM yield and corn DM yield moderate and significant.

10 | FORAGE YIELD AND NUTRITIVE VALUE, AND IMPLICATIONS

Developing year round sustainable forage-based grazing production systems for beef cattle that includes grazing standing corn to extend the grazing season into the fall and winter months requires improving nutritive value, especially energy and protein during cold winter months. Energy and protein are some of the most important criteria for nutritive value evaluation. Our hypothesis was that the inadequacies of C-M forage for supplying adequate protein content for beef cattle could be improved by intercropping corn with either legumes or other annual crops. Adequate forage protein from potential intercrops would thus reduce the need for protein supplementation and associated costs of winter feeding beef cattle. The present study showed that of the different companion crops tested with corn, only C-HV and C-ACM intercrops greatly improved forage CP over C-M, increasing CP content considerably by as much as 3.5 percent. The HV in the C-HV intercrop was slow to establish in the spring and early summer during the study, but it did grow vigorously and became a long sprawling vine in the fall. Similarly, the HV, Winfred forage brassica and Italian ryegrass in the C-ACM were all still in vegetative stage when forage harvesting was done. The vegetative stage of these crops during harvest contributed to the greater forage CP obtained for C-HV and C-ACM than C-M and other intercrops. However, it is important to note that the greater forage protein content from the C-ACM intercrop came from the combination of crops in the ACM, particularly those of legumes (FB, HV and CC). When including legumes in an intercrop system, the symbiotic N_2 fixation and residue incorporation also contribute to ameliorating soil fertility (Jensen, 1996). Furthermore, implementation of intercrops in agroecosystems has been shown to increase diversity of microbes, flora and fauna, which often have a positive impact on crop productivity (Vandermeer, 1995). Recent research by Omokanye (2019) in the same geographic region revealed that Winfred forage brassica and ryegrass also showed great benefits in improving the nutritive value of multispecies annual crop mixtures over cereal monocultures. When forage crops are used within intercropping systems, the producers gain long-term environmental and soil quality benefits, while potentially achieving short-term economic value within their operations (Fae et al., 2009).

The winter months make up most of the gestation period for calf–cow operations in the study region. The NASEM (2016) model for formulating diets for beef cows suggests a 7 to 11% CP content for mature beef cows from mid-pregnancy to lactation and 12 to 14% CP for growing and finishing beef calves. All corn intercrops in the current study had adequate CP for a mature beef cow, but only C-HV and C-ACM intercrops met the CP requirements of both young and mature beef cattle. This shows that for backgrounding and finishing calves, C-HV and C-ACM intercrops are potential protein alternatives to low protein C-M in the study region. It is therefore evident from the present study that some corn intercrops (as seen from both C-HV and C-ACM) would provide beef cattle protein adequate diets and savings in the cost of protein supplementation than is typical with feeding or grazing C-M, particularly beyond the mid-pregnancy stage of mature beef cattle. The present study therefore shows the potential of both C-HV and C-ACM to provide high quality feed for categories of beef cattle whose level of performance may be limited by the low protein content of C-M such as backgrounding cattle. The ACM was the dominant component of the intercrops largely because the crops in the mixture have been selected from a diversity of plant families (Polygonaceae, Brassicaceae, Poaceae, and Fabaceae), corresponding to different plant functional groups (Lavorel, McIntyre, Landsberg, & Forbes, 1997). Each crop species in the mixture reached maturity at slightly different times, therefore providing available immature forage continuously through the growing season (BCRC 2016).

In the study area, FB is a late-maturing crop and may be suitable for intercropping and ensiling with corn under the climate conditions for the area. Thus, FB may be a good alternative to FP or CC, which are early-maturing crops. A further investigation is needed on suitable production systems for practical farming to improve forage and nutritive value of silage corn and FB intercrop for beef cattle.

The present study reveals that, in terms of corn growth (height) and production (yield), there was clear evidence of competition from companion crops used in the intercrop treatments. The corn height in C-RA, C-ACM and C-FP was as much as 70 cm less in height than C-M. In 2017 and 2018, the corn in C-RA consistently had lower height (data not shown) and RA is considered a problematic crop when interceded simultaneously with corn for C-RA intercrops and forage production. Forage crops are more competitive and have greater shade adaptability, thus accumulating sufficient forage mass in intercropping systems (Pariz et al., 2016). This explains why the forage-type multispecies crops used in C-ACM resulted in lower corn stand forage yield compared to other intercrops.

The greater reduction in corn forage DM yield from C-RA or C-ACM further confirms that corn does not have the ability to withstand competition with many crop types and that corn would not be compatible with either of these companion crops for improved corn forage production (biomass). It is important to note that inherently FP, RA and most crops in the ACM would normally have successfully have grown within the study area. Corn on the other hand, as a C_4-warm season crop species, takes longer to germinate and has initial slow growth, and thus takes much longer establish. The findings from the present study that intercropping systems did not generally reduce corn productivity or intercropped forage DM are in agreement with La Guardia Nave and Corbin (2018), and Crusciol et al. (2013). For C-RA and C-ACM, which both reduced corn productivity in the present study, whether or not seeding RA or ACM on a later date (about two weeks) after corn seeding would reduce corn DM needs to be investigated. The expectation is that during this phase, the corn plants gradually grow above the intercrops, capturing an ever greater proportion of the available light, water and nutrient resources (Mao et al., 2012).

Although three of the companion crops in the current study, reduced corn growth (RA, FP and ACM), interestingly, all intercrops (except for RA) had similar total forage DM yield compared with C-M. As found in the present study with most intercrops, Riday and Albrecht (2008) also reported similar forage DM yield for different corn–legume intercrops and for C-M. However, Geren, Avcioglu, Soya, and Kir (2008) and Marchiol, Miceli, Pinosa, and Zerbi (1992) both reported lower total forage yield from C-M than most corn intercrops in their studies. Conversely, Stoltz, Nadeau, and Wallenhammar (2013) found that corn–faba beans with N fertilizer application greatly reduced forage DM yield compared to C-M. The findings in the present study showed that C-HV did not out yield C-M in total forage production (yield), but Javanmard, Majdi, Hamzepour, and Nasiri (2017) reported that C-HV greatly out yielded C-M as well as other intercrops of corn and other crops. The differences in the results obtained in both studies could be due to differences in final plant populations, seeding methods and environment (soil type, soil water availability and soil nutrient status). It is also important to state that factors as critical to crop growth as soil nutrient and water status should be noted. The present study however indicates that the companion crops were generally able to compensate or even overcompensate for reduced corn growth (plant height) in most cases by producing similar total forage DM yield compared with C-M. As noted in an earlier study elsewhere, grain legume–barley intercropping might not be the highest yielding as compared with the yield of one of the corresponding sole crops investigated in a single year, but it can be regarded as insurance against the complex abiotic and biotic stresses influencing crop performance, especially in organic systems (Hauggaard-Nielsen et al. 2008)

Energy is also one of the important criteria for nutritive value evaluation, particularly in beef cattle production in cold climates. The results from the present study particularly from C-M agree with published values for whole plant corn forage (TDN = 68.8%; NRC, 2001). Though, C-SB intercropping had the highest forage TDN value, all treatments investigated had adequate TDN to meet requirements for mature beef cattle, which require 55 to 65% TDN from mid-pregnancy to during lactation (NASEM, 2016; Yurchak & Okine, 2004). As well, the treatments investigated were well within the 65 to 70% TDN recommended for growing and finishing calves (NASEM, 2016). The C-SB had a 2.5% increase in forage TDN over C-M. This improvement in energy is crucial for winter range forage and could be translated into providing less supplementation and reduction in feeding costs.

Acidosis is a nutritional disease that is caused by cattle consuming too much starch (primarily grain). The severity of acidosis, generally related to the amount, frequency, and duration of grain feeding, varies from acute acidosis due to lactic acid accumulation, to subacute acidosis due to accumulation of volatile fatty acids in the rumen (Nagaraja & Titgemeyer, 2007). In the study area, because of the generally lower than 2000 CHUs during the growing season, only immature standing corn with Zadoks growth scales 71 to 75 (Zadoks, Chang, & Konzak, 1974) is usually available for grazing from current commercial corn hybrids. However, a combination of several factors such as warmer temperatures of the summer months, adequate precipitation and delayed date of killing frost in early fall, and availability of corn hybrids with lower CHUs than that used in the present study can allow corn to grow to maturity. To avoid acidosis in such situation, mature standing corn should be strip grazed during the winter and offered some hay as they graze the corn to reduce risk of acidosis.

In all cases, the forage minerals were not significantly affected by the treatments investigated, but C-ACM intercrop seemed to show greater potential for improved mineral content than other intercrops as well as C-M. The requirements for macro-minerals vary depending on the class of animal, and the level and state of production. The beef cattle requirements for K and Mg have been exceeded by all treatments investigated in the present study. However, all treatments fell short in meeting at least two of recommended concentrations of Ca (0.57% for young and 0.33% for mature beef cattle) and P (0.30% for young and 0.26% for mature beef cattle) (NASEM 2016). Overall, C-ACM produced the highest forage minerals, but still fell short of meeting P recommended for cows of different physiological stages (NASEM 2016). Therefore, designing a mineral supplementation program to ensure cattle requirements are met is essential for optimal beef production when feeding C-M or the intercropping systems investigated here.

The moderately to high positive correlation between companion forage DM yield and overall forage production (total forage DM yield) or P content seems to suggest the potential advantages of companion crops when intercropped with corn to improve both forage production (yield) and some nutritive value parameters.

11 | CONCLUSION

Corn growth (height) in the C-RA, C-FP and C-ACM intercrops did not grow as tall as C-M. In general, intercropping systems studied did not reduce total forage DM yield. However, C-RA, in particular produced lower corn stand forage DM yield over C-M compared with the other corn intercrops. Nutrients needs depend on the physiological state of the animal. In the study region, winter months make up most of the gestation period for calf–cow operations. Here, grazing standing will coincide to mid-pregnancy (or second trimester) of beef cows. Both C-ACM and C-HV intercrops greatly improved CP content (no supplementation necessary beef cattle). On the other hand, C-M was only able to meet the protein requirements of beef cows in the mid (7% CP) and late (9% CP) pregnancy stages, while all intercrops (C-FP just barely) met the 11% CP required by a lactating beef cow. Both C-HV and C-ACM intercrops were the only mixtures that sufficiently met the protein requirements beef cattle. The C-ACM intercrop seemed to have greater potential to improve forage Ca, P, K and Mg over C-M than the other intercrops. NASEM (2016) considers 0.58% Ca and 0.26% P adequate for mature beef cattle. In the present study, for a lactating beef cow, additional supplement will be needed for Ca (in most cases) and P for all corn intercrops and C-M to compensate for their mineral deficiencies. All intercrops as well as C-M had sufficient TDN content for beef cattle. For improved protein in corn forage diets for beef cattle (direct grazing or silage), C-HV and C-ACM intercrops would be recommended in that order when grown in similar environments. In addition to the selection of C-HV and C-ACM intercrops, an appropriate production technology also needs to be developed to mitigate the effect of possible competition among the intercropped plants and it should be possible to produce a crop that will be high yielding, nutritious and palatable to most livestock (Ćupina, Mikić, & Krstić, 2009).

ACKNOWLEDGEMENTS

The study was funded by Agricultural Opportunity Fund (AOF) of the Alberta Agriculture and Forestry (AAF) and municipality of Fairview. Thank you to Nutrien Ag Solutions in Fairview for providing seed and fertilizer for the study. Thank you also to DuPont Pioneer for providing the corn seed used for both years. The technical help by Peace Country Beef & Forage Association staff and summer students is highly appreciated.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

ORCID

Akim Omokanye https://orcid.org/0000-0003-0412-6586
Alan Lee https://orcid.org/0000-0003-4441-4638

REFERENCES

Abendroth, L. J., Elmore, R. W., Boyer, M. J., & Marlay, S. (2011). Corn growth and development. Iowa State Univ. Extension publication. PMR1009. Ames, IA: Iowa State University. https://store.extension.iastate.edu/product/6065 (accessed March 2019).

Abeysekara, S., Christensen, D. A., Niu, Z., Theodoridou, K., & Yu, P. (2013). Molecular structure, chemical and nutrient profiles, and metabolic characteristics of the proteins and energy in new cool-season corn varieties harvested as fresh forage for dairy cattle. *Journal of Dairy Science*, *96*, 6631–6643. https://doi.org/10.3168/jds.2013-6841

Adams, R. S. (1980). *Penn state forage testing service revised regression equations*. Dairy Sci. Ext. Memo DSE-90–56. University Park, PA: The Pennsylvania State Univ.

Ammar, H., López, S., Bochi, O., García, R., & Ranilla, M. J. (1999). Composition and in vitro digestibility of leaves and stems of grasses and legumes harvested from permanent mountain meadows at different maturity stages. *Journal of Animal Feed Science*, *8*, 599–610.

Association of Official Analytical Chemists. (2007). Official Method 2002.04, Amylase-treated neutral detergent fibre in feeds using refluxing in beakers or crucibles. Washington, DC: First Action, AOAC.

Association of Official Analytical Chemists. (2005). Official method 990.03. In: G.W. Latimer and W. Horwitz, (eds.), *Official methods of analysis of AOAC international* (18th Ed.). Gaithersburg, MD: AOAC Int..

AOAC (Association of Official Analytical Chemists). (1990). *Fiber (acid detergent) and lignin in animal feeds*. Arlington, VA: Association of Official Analytical Chemists: Official method of analysis of the Association of Official Analytical Chemists. 1990.

Armstrong, K. L., Albrecht, K. A., Lauer, J. G., & Riday, H. (2008). Intercropping corn with lablab bean, velvet bean, and scarlet runner bean for forage. *Crop Science*, *48*(1), 371–379. https://doi.org/10.2135/cropsci2007.04.0244

Beef Cattle Research Council. (2016). Cover crops as forage for beef cattle. Calgary, AB: Beef Cattle Research Council. http://www.beefresearch.ca/files/pdf/BCRC_Cover_Crops_Fact_Sheet.pdf

Brooker, R. W., Bennett, A. E., & Cong, W. F. (2015). Improving intercropping: A synthesis of research in agronomy, plant physiology and ecology. *New Phytologist*, *206*, 107–117. https://doi.org/10.1111/nph.13132

Brown, D. M., & Bootsma, A. (1997). *Crop heat units for corn and other warm season crops in Ontario*. Toronto, ON: Queen's Printer for Ontario.

CoStat Program (2005). CoStat 6.311. Monterey, CA: CoHort Software, PMB320.

Ćupina, B., Mikić, A., & Krstić, Đ. (2009). Field pea: A cover crop in establishing perennial legumes. *Grain Legum*, *52*(9).

Crusciol, C. A. C., Nascente, A. S., Mateus, G. P., Borghi, E., Leles, E. P., & Santos, N. C. B. (2013). Effect of intercropping on yields of corn with different relative maturities and palisade grass. *Agronomy Journal*, *105*, 599–606. https://doi.org/10.2134/agronj2012.0426

Cunniff, P.A. (1995). *Official methods of analysis* (16th ed). Gaithersburg, MD: AOAC Int.

Dahmardeh, M., Ghanbari, A., Syasar, B., & Ramroudi, M. (2009). Effect of intercropping maize (*Zea mays* L.) with cow pea (*Vigna unguiculata* L.) on green forage yield and quality evaluation. *Asian Journal of Plant Sciences*, *8*, 235–239. https://doi.org/10.3923/ajps.2009.235.239

Damiran, D., Lardner, H. A., Larson, K., & McKinnon, J. 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. *Professional Animal Scientist*, *32*, 400–410.https://doi.org/10.15232/pas.2015-01479

Darby, H. M., & Lauer, J. G. (2002). Planting date and hybrid influence on corn forage yield and quality. *Agronomy Journal*, *94*, 281–289. https://doi.org/10.2134/agronj2002.0281

Dhima, K. V., Lithourgidis, A. S., Vasilakoglou, I. B., & Dordas, C. A. (2007). Competition indices of common vetch and cereal intercrops in two seeding ratio. *Field Crops Research*, *100*, 249–256. https://doi.org/10.1016/j.fcr.2006.07.008

Fae, G. S., Sulc, R. M., Barker, D. J., Dick, R. P., Eastridge, M. L., & Lorenz, N. (2009). Integrating winter annual forages into a no-till corn silage system. *Agronomy Journal*, *101*, 1286–1296. https://doi.org/10.2134/agronj2009.0144

Geren, H., Avcioglu, R., Soya, H., & Kir, B. (2008). Intercropping of corn with cowpea and bean: Biomass yield and silage quality. *African Journal of Biotechnology*, *7*(22), 4100–4104.

Gill, K. S., & Omokanye, A. T. (2018). Potential of spring barley, oat and triticale intercrops with field peas for forage production, nutrition quality and beef cattle diet. *Journal of Agricultural Science*, *10*(4), 1–17. https://doi.org/10.5539/jas.v10n4p1

Goering, H. K., & Van Soest, P. J. (1970). *Forage fiber analysis (Apparatus, reagents, procedures, and some applications)*. Washington, DC: USDA Agricultural Research Service, Handbook No. 379.

Hauggaard-Nielsen, H., Gooding, M., Ambus, P., Corre-Hellou, G., Crozat, Y., Dahlmann, C., … Jensen, E. S. (2009). Pea–barley intercropping for efficient symbiotic N_2-fixation, soil N acquisition and use of other nutrients in European organic cropping systems. *Field Crops Research*, *113*(1), 64–71. https://doi.org/10.1016/j.fcr.2009.04.009

Hauggaard-Nielsen, H., Jørnsgaard, B., Kinane, J., & Jensen, E. S. (2008). Grain legume–cereal intercropping: The practical application of diversity, competition and facilitation in arable and organic cropping systems. *Renewable Agriculture and Food Systems*, *23*(1), 3–12. https://doi.org/10.1017/S1742170507002025

Hauggaard-Nielsen, H., & Jensen, E. S. (2005). Facilitative root interactions in intercrops. In: H. Lambers and T.D. Colmer, *Root physiology: From gene to function*. Dordrecht: Springer. p. 237–250.

Horwitz, W. (2000). *Official methods of analysis* (17th ed). Gaithersburg, MD: AOAC.

Jensen, E. S. (1996). Grain yield, symbiotic N2-fixation and interspecific competition for inorganic N in pea-barley intercrops. *Plant and Soil*, *182*, 25–38. https://doi.org/10.1007/BF00010992

Javanmard, A., Majdi, M., Hamzepour, N., & Nasiri, Y. (2017). Evaluation of forage production using maize-legume intercropping and biofertilizer under low-input conditions. *Philippine Agricultural Scientist*, *100*, 79–87.

Jose, D. (2015). Evaluation of winter feeding systems for crop yield and agronomy, beef cow performance, metabolism and economics. Unpublished MS. Thesis. Saskatoon, SK: University of Saskatchewan.

Karsten, H. D., Roth, G. W., & Muller, L. D. (2003). Evaluation of corn hybrids at two stages of development for grazing heifers. *Agronomy Journal*, *95*, 870–877. https://doi.org/10.2134/agronj2003.8700

Krause, A. D., Lardner, H. A., McKinnon, J. J., 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. *Professional Animal Scientist*, *29*, 535–545.https://doi.org/10.15232/S1080-7446(15)30275-8

La Guardia Nave, R., & Corbin, M. D. (2018). Forage warm-season legumes and grasses intercropped with corn as an alternative for corn silage production. *Agronomy*, *8*(10), 199. https://doi.org/10.3390/agronomy8100199

Lardner, H. A., Pearce, L., & Damiran, D. (2017). Evaluation of low heat unit corn hybrids compared to barley for forage yield and quality on the Canadian Prairies. *Sustainable Agriculture Research*, *6*, 90–102). https://doi.org/10.5539/sar.v6n1p90

Lavorel, S., McIntyre, S., Landsberg, J., & Forbes, T. D. A. (1997). Plant functional classifications: From general groups to specific groups based on response to disturbance. *Trends in Ecology & Evolution*, *12*, 474–478. https://doi.org/10.1016/S0169-5347(97)01219-6

Mao, L., Zhang, L., Li, W., van der Werf, W., Sun, J., Spiertz, H., & Li, L. (2012). Yield advantage and water saving in maize/pea intercrop. *Field Crops Research*, *138*, 11–20. https://doi.org/10.1016/j.fcr.2012.09.019

Marchiol, L., Miceli, F., Pinosa, M., & Zerbi, G. (1992). Intercropping of soybean and maize for silage in northern Italy: Effect of nitrogen level and plant density on growth, yield and protein content. *European Journal of Agronomy*, *1*(3), 207–211. https://doi.org/10.1016/S1161-0301(14)80071-3

McMillan, S., Penner, G. B., McKinnon, J. J., Larson, K., Anez-Osuna, F., Damiran, D., & Lardner, H. A. (2018). Use of extensive winter feeding systems for backgrounding beef calves and the effect on finishing. *Professional Animal Scientist*, *34*, 19–31. https://doi.org/10.15232/pas.2017-01614

Morris, R. A., & Garrity, D. P. (1993a). Resource capture and utilization in intercropping: Water. *Field Crops Research*, *34*, 303–317. https://doi.org/10.1016/0378-4290(93)90119-8

Morris, R. A., & Garrity, D.P. (1993b). Resource capture and utilization in intercropping: Non-nitrogen nutrients. *Field Crops Research*, *34*, 319–334. https://doi.org/10.1016/0378-4290(93)90120-C

Nagaraja, T. G., & Titgemeyer, E. C. (2007). Ruminal acidosis in beef cattle: The current microbiological and nutritional outlook. *Journal of Dairy Science*, *90*, E17–E38. https://doi.org/10.3168/jds.2006-478

NASEM (National Academies of Sciences, Engineering, and Medicine). (2016). *Nutrient requirements of beef cattle*, eighth revised edition. Washington, D.C.: The National Academies Press. https://doi.org/10.17226/19014.

NRC (National Research Council). (2001). *Nutrient requirements of dairy cattle*. 7th rev. ed. Washington, DC.: National Academy Press.

Ofori, F., & Stem, W. R. (1987). Cereal-legume intercropping systems. *Advance In Agronomy*, *14*, 41–90. https://doi.org/10.1016/S0065-2113(08)60802-0

Omokanye, A. (2019). Cover crop cocktails for livestock feed. In: Cocktail Cover Crop Workshop, Debolt, Alberta. 5 Feb. 2019. High Prairie, AB: Peace Country Beef and Forage Association.

Omokanye, A. (2016). Peace corn field trials: Research update. In: East Peace Beef Cattle Day, High Prairie, AB. 30 Nov. 2016. High Prairie, AB: Peace Country Beef and Forage Association.

Omokanye, A. T. (2014). Annuals for forage production. 2014 Peace Region Forage Agronomy Update, Rycroft, AB. 25 March 2014. Peace Region Forage Seed Association, Dawson Creek, BC.

Pariz, C. M., Costa, C., Crusciol, C. A. C., Meirelles, P. R. L., Castilhos, A. M., Andreotti, M., … Sarto, J. R. W. (2016). Production and soil responses to intercropping of forage grasses with corn and soybean silage. *Agronomy Journal*, *108*, 2541–2553. https://doi.org/10.2134/agronj2016.02.0082

Riday, H., & Albrecht, K. A. (2008). Intercropping tropical vine legumes and maize for silage in temperate climates. *Journal of sustainable agriculture*, *32*(3), 425–438. https://doi.org/10.1080/10440040802257280

Soil Classification Working Group. (1998). *The Canadian system of soil classification. Agriculture and Agri-Food Canada Publication 1646*, (Revised). Ottawa, ON: Agri-Food Canada.

Stoltz, E., Nadeau, E., & Wallenhammar, A. C. (2013). Intercropping maize and faba bean for silage under Swedish climate conditions. *Agricultural Researc*, (2013) *2*, 90. https://doi.org/10.1007/s40003-012-0048-0

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

Vandermeer, J. H. (1995). The ecological basis of alternative agriculture. *Annual Review of Ecology, Evolution, and Systematics*, *26*, 201–224. https://doi.org/10.1146/annurev.es.26.110195.001221

Van De Kerckhove, A. Y., Lardner, H. A., Walburger, K., McKinnon, J. J., & Yu, P. (2011). Effects of supplementing spring-calving beef cows grazing barley crop residue with a wheat-corn blend dried distillers grains with solubles on animal performance and estimated dry matter intake. *Professional Animal Scientist*, *27*, 219–227. https://doi.org/10.15232/S1080-7446(15)30477-0.

Yurchuk, T., & Okine, E. (2004). Agri-facts: Beef ration rules of thumb. Agdex 420/52-4. Red Deer, AB: Alberta Agriculture Food and Rural Development. http://www1.agric.gov.ab.ca/>department/deptdocs.nsf/all/agdex9146/>file/420_52-4.pdf?OpenElement (accessed April 2016).

Zadoks, J. C., Chang, T. T., & Konzak, C. F. (1974). A decimal code for the growth stages of cereals. *Weed research*, *14*(6), 415–421. https://doi.org/10.1111/j.1365-3180.1974.tb01084.x

How to cite this article: Omokanye A, Al-Maqtari B, Lardner HA, et al. Forage potential of corn intercrops for beef cattle diets in northwestern Alberta. *Crop, Forage & Turfgrass Mgmt*. 2020;6:e20056. https://doi.org/10.1002/cft2.20056