

# Evaluation of Methods of Pasture Rejuvenation for Improved Forage Production

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## Abstract

A 3-year on-farm study was conducted in northwestern Alberta to determine the effects of several pasture rejuvenation methods such as breaking and reseeding, spraying to control weeds and brush, forage-seeding methods, fertilizer application, pasture rest, and aeration/spiking on forage dry matter (DM) yield, botanical composition, and forage quality. Three years after methods were implemented, the pasture rejuvenation methods investigated significantly affected ( $P < 0.05$ ) forage DM yield; forage botanical composition; forage Ca, P, Ca:P ratio, K, Mg, and Cu; revenue generated for forage production; and marginal returns. Rejuvenation methods did not affect ( $P > 0.05$ ) forage C:P ratio, S, Na, Fe, Zn, Mn, and total digestible nutrients. Spring herbicide application + direct seeding (RSS), fertilizer application (FERT), and fall herbicide application + broadcast seed in spring (RFBSS) improved forage production and some forage quality parameters more than other methods over control. Legume composition in the total forage production was as much as 29% for RSS compared with 2–17% for other methods including the control. For a 2-year combined forage DM yield after methods were implemented, total forage DM yield, revenue generated, and marginal returns for forage production as well as profit over control were significantly greater ( $P < 0.05$ ) for RSS than other pasture rejuvenation methods investigated. The study demonstrated that RSS improved forage DM yield and some quality parameters (particularly crude protein, Ca, and Ca:P). Also, RSS increased both revenue and profit over most methods including control. Results suggest RSS can be recommended as an effective method or option of improving the forage productivity of depleted pastures.

In Canada, the province of Alberta, with its vast rangelands and feed supplies, beef production dominates (Statistics Canada, 2014). Alberta alone accounts for about 41% of the national cattle herd (Statistics Canada, 2018) with pastureland accounting for up to 43% of total farm area (Statistics Canada, 2012). Forages account for approximately 80% of the feed requirements of beef cattle (SFC, 2011). However, producing high quality forage and maintaining productive forage stands is a major challenge that Alberta's beef producers face several years after forage establishment. This is because over time, the productivity, quality, and longevity of pastures usually declines as a result of reduced plant stand vigor and loss of productive forage species. This is mostly a consequence of seasonal lack of moisture (drought), pests [such as leafhoppers (*Macrosteles quadrilineatus* Forbes) and alfalfa weevil (*Hypera postica*

## Forage & Grazinglands



### Core Ideas

- Methods to improving depleted forage stand by seeding, weed control, fertilizer application, and aeration were investigated.
- A combination of vegetation control + direct seeding improved forage yield, crude protein, and total digestible nutrients.
- A 2-year combined forage yield for four methods increased profit from forage production.

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Received 21 Dec. 2018.

Accepted 21 May 2019.

**Abbreviations:** AF, aerate/spike in fall; AS, aerate/spike in spring; B&R, complete renovation involving breaking + reseeding; BSAF, broadcast seed + aerate/spike in fall; BSAS, broadcast seed + aerate/spike in spring; BSS, broadcast seed in spring; CARA, Chinook Applied Research Association; CP, crude protein; FERT, fertilizer application; GRAZON, spray Grazon herbicide in spring; GRSEED, spray Grazon herbicide + seed in spring; REST, one year summer rest; RFBSS, spray Roundup in fall + broadcast seed in spring; ROS, spray Roundup WeatherMax in spring; RSS, spray herbicide + direct seed in spring; TDN, total digestible nutrients.

Conversions: For unit conversions relevant to this article, see Table A.

*Crop Forage Turfgrass Manage.*

5:180103. doi:10.2134/cftm2018.12.0103

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Table A. Useful conversions.

To convert Column 1 to Column 2, multiply by	Column 1 Suggested Unit	Column 2 SI Unit
0.405	acre	hectare, ha
0.454	pound, lb	kilogram, kg
1.12	pound per acre, lb/acre	kilogram per hectare, kg/ha
$1.12 \times 10^{-1}$	pound per acre, lb/acre	megagram per hectare, Mg/ha
2.54	inch	centimeter, cm ( $10^{-2}$ m)
1	parts per million, ppm	milligram per kilogram, mg/kg
6.90	pound per square inch, lb/sq inch	kilopascal, kPa
25.4	inch	millimeter, mm ( $10^{-2}$ m)
9.35	US gallon per acre, gal/acre	liter per hectare, L/ha
$9.29 \times 10^{-2}$	square foot, sq ft	square meter, sq m
5/9 ( $^{\circ}\text{F} - 32$ )	Fahrenheit, $^{\circ}\text{F}$	Celsius, $^{\circ}\text{C}$
10	percent, %	gram per kilogram, g/kg

Gyllenhal]), weeds, brush invasion, and overgrazing in pastures (Vasquez et al., 2010; Aasen and Bjorge, 2009; Stewart, 2004; Monaco et al., 2002). In pastures, weeds and shrubs or brush encroachment can be a serious problem and can be difficult to control. Controlling weeds and brush in pastures will restore pasture health and productivity and improve and sustain forage quality (Bradley and Kendig, 2004).

Rejuvenation can be a pasture management strategy for rapid improvement of existing and/or depleted forage stand/pasture that can bring new vigor or usefulness to a pasture and thereby restore it to its original state (Acharya, unpublished; Schellenberg, 2016). Breaking and reseeding old forage stands is the traditional method of pasture rejuvenation (Malhi et al., 2000), but this can be a complex and costly challenge as well as time consuming for producers (Omokanye et al., 2018). The high costs associated with the traditional method have encouraged producers to search for alternative strategies and technologies for improving and sustaining pastures. Recently in northern Alberta, Omokanye et al. (2018) reported that breaking and reseeding was associated with high input costs. In western Canada, several methods of rejuvenation have been investigated for the purpose of increasing pasture and livestock production, and these include: grazing management during growing season (Omokanye et al., 2018; Kemp et al., 2000), bale grazing during winter season (Picard, 2010; Omokanye, 2013; Jungnitsch et al., 2011; Omokanye et al., 2018), fertilizer application (Omokanye et al., 2018; Nazarko, 2008; Lardner et al., 2000), direct seeding of legumes into an existing pasture (Khatiwada, 2018), and pasture resting (Omokanye et al., 2018; Durunna et al., 2015). However, most of these studies have only examined a few methods at a time. On-farm research was therefore needed to compare all or at least most of the practicable methods of rejuvenation originating from such previous research to determine the most cost-effective and profitable methods for beef cattle producers. The objective of this study was to investigate several methods of pasture rejuvenation to enable a proper assessment of different methods on the farm.

## Methods Used to Assess Pasture Rejuvenation Methods

### Site Description

An on-farm study was conducted from spring 2016 to summer 2018 at Wanham (at the Alberta provincial grazing reserve) in the northwest of Alberta. The initial (before methods) surface soil (0–15 cm) characteristics for the site are provided in Table 1. The site has a subarctic climate (also called boreal climate), which is characterized by long, usually very cold winters, and short, cool to mild summers. Growing season rainfall and temperatures during the study (2016–2018) and long-term averages for the site are provided in Table 2.

### Methods and Experimental Design

All methods were arranged in a replicated ( $n = 3$ ) randomized complete block design, and plot size was  $27 \times 128$  m (0.35 ha). Eleven pasture rejuvenation methods were evaluated. A brief description of methods is provided:

1. Check (control)—no rejuvenation method.
2. Broadcast forage seed mixture + aerate/spike in spring (BSAS)—broadcast-seeded forage seed mixture at  $21.8 \text{ kg ha}^{-1}$  on 8 June 2016.
3. Broadcast forage seed mixture + aerate/spike in fall (BSAF)—broadcast-seeded forage seed mixture at  $21.8 \text{ kg ha}^{-1}$  on 5 Oct. 2016.
4. Aerate/spike in fall (AF)—AerWay land renovator was used on 5 Oct. 2016.
5. Aerate/spike in spring (AS)—AerWay land renovator was used on 8 June 2016.
6. Spray Grazon herbicide in spring (GRAZON)—Grazon XC was sprayed on 12 June 2016 at  $6.2 \text{ L ha}^{-1}$ .
7. Fertilizer application (FERT),  $\text{kg ha}^{-1}$ —broadcast fertilizer at  $86 \text{ kg ha}^{-1} \text{ N} + 41 \text{ kg ha}^{-1} \text{ P} + 15 \text{ kg ha}^{-1} \text{ S}$  on 6 June 2016. Initial soil tests showed a sufficient amount of K in the soil, so no K fertilizer was applied.
8. Spray herbicide + direct seed of forage in spring

Table 1. Study site description (including initial soil characteristics in 2016) at Wanham (provincial grazing reserve, PGR), AB.

	Wanham, Ab
Coordinates and elevation	55°52'N, 118°20'W; 765 m
Soil group/natural sub-region†	Orthic gray luvisol/dry mixed wood natural sub-region
Soil texture before methods	Silt clay
Initial soil organic matter (%)	10.7
Initial pH (1:2.5 H <sub>2</sub> O)	6.3
Initial electrical conductivity (dS/m)	1.85
Initial nitrate-N (ppm)	8
Initial P (Bray 1-P method) (ppm)	38
Initial K (ppm)	600
Initial sulfate-S (ppm)	14
Soil C to N ratio	11.5
Infiltration rate (mm/h)	1.78
Compaction reading (kPa)	3909
Year of pasture establishment and management	> 30 yr. The entire PGR is managed for grazing only. The size of paddocks vary ranging from 65 to 777 ha. Every year, a pasture manager and riders manage the cattle, which belong 51 patrons. The manager maintains records of cattle numbers entering and leaving the lease. Cattle numbers can vary from 300 to 700 and even up to 1400 for cow-calf pairs. Grazing is usually late May to end of October each year. Stocking rates are ~ 0.40 ha of improved pasture land/AUM, although pastures may not be utilized to capacity during all years. The PGR were fenced and cross-fenced. The section of PGR used for the current study was seeded to tame pasture species in the mid 1980s.
Initial vegetation identified	Shrubs and tree species: aspen ( <i>Populus tremuloides</i> Michx.), willow ( <i>Salix</i> spp.), rose ( <i>Rosa</i> spp.). Tame pasture grass species [mainly: timothy ( <i>Phleum pratense</i> L.), bromegrasses ( <i>Bromus biebersteinii</i> Roemer and J.A. Schultes), creeping red fescue ( <i>Festuca rubra</i> L.), tall fescue ( <i>Festuca elatior</i> L.), and clover ( <i>Trifolium</i> spp.)]. Forbs: Canada thistle ( <i>Cirsium arvense</i> L.), dandelion ( <i>Taraxacum officinale</i> F.H. Wigg), native vetches ( <i>Astragalus</i> spp.).

†Source: ALR (1995).

(RSS)—Roundup was applied at 2.5 L ha<sup>-1</sup> on 30 May 2016. Seeded forage seed mixture at 16.8 kg ha<sup>-1</sup> on 7 June 2016.

9. Herbicide applied in fall and broadcast forage seed mixture the following spring (RFBSS)—Roundup applied at 2.5 L ha<sup>-1</sup> on 30 Aug. 2016. Broadcast-seeded forage seed mixture at 21.8 kg ha<sup>-1</sup> on 19 May 2017.
10. Herbicide applied only in spring (ROS)—Roundup applied at 2.5 L ha<sup>-1</sup> on 30 May 2016.
11. Broadcast forage seed mixture only in Spring (BSS)—broadcast-seeded forage seed mixture at 21.8 kg ha<sup>-1</sup> on 8 June 2016.

The forage seed mixture used for direct and broadcast seeding consisted of 40% meadow bromegrass (*Bromus riparius* Rehm), 35% orchardgrass (*Dactylis glomerata* L.), 20% regular-blend alfalfa (*Medicago sativa* L.), and 5% Grindstad timothy. Seed broadcast was conducted with an all-terrain vehicle (ATV) mounted broadcast seeder/spreader (Model GT-77; Herd Seeder Company, Inc., Logansport, IN, USA) that covered a 7.32-m width. Direct seeding was conducted with a 4.6-m-wide John Deere 1590 drill at 19.1-cm-row spacing.

Where seed was broadcast (Methods 2, 3, and 11), seeding rate was 21.8 kg ha<sup>-1</sup> (30% higher than drilling rate). For both Methods 4 and 5, the AerWay equipment disturbed the surface soil to a depth of 6 to 8 cm at regular intervals. Roundup

WeatherMax (Acid equivalent concentration: 540 g/L) was used for the herbicide method.

## Forage Botanical Composition and Dry Matter Yield

Forage botanical composition (% grass and % legume) and forage dry matter (DM) yield were determined from within a 9-m<sup>2</sup> area on 6 June 2016, 22 June 2017, and 21 June 2018. Within the 9-m<sup>2</sup> area, three sampling points (three, 1 × 1 m quadrat) were evaluated in each method plot or 33 sampling points each year for the entire field. The average of the three sampling points for each method plot was assessed as a replicate. Every year, harvesting for forage botanical composition and DM yield was conducted when grass species were at the flowering stage and legumes at the mid-bloom stage as described by Moore et al. (1991). The harvested green forage samples were weighed fresh, and a 0.75-kg subsample was oven-dried at 60°C for 3 days to a constant weight for DM content, which was used for forage DM yield estimation.

The forage quality parameters (% DM basis) were determined at a commercial laboratory (A&L Canada Laboratories Inc., London, ON). The forage crude protein (CP) was determined by the Dumas direct combustion method using a LECO FP628 Nitrogen Analyzer (AOAC, 2005). Forage mineral content (macro-minerals: P, K, Ca, Mg, S, and Na;

**Table 2. Precipitation, maximum and minimum temperature for April to September, and long-term averages (LTA, 30-yr average) at the study site.<sup>†</sup>**

	2016	2017	2018	LTA
Precipitation (mm)				
April	6.90	29.7	8.80	22.5
May	61.6	41.3	5.00	40.0
June	69.5	40.8	30.0	69.1
July	74.1	33.6	149.9	70.9
August	53.8	31.8	14.5	51.1
September	48.1	50.2	36.1	39.1
Total	314.0	227.4	244.3	292.7
Maximum temperatures (°C)				
April	29.2	13.7	18.5	9.33
May	28.7	28.2	NA <sup>‡</sup>	16.3
June	28.4	30.4	32.8	20.1
July	27.7	29.5	29.9	21.9
August	27.4	29.7	29.5	21.1
September	25.8	30.7	NA	16.0
Minimum temperatures (°C)				
April	-5.44	-13.5	NA	-2.59
May	-4.68	-0.69	0.40	3.11
June	5.33	2.15	4.40	7.56
July	5.96	5.98	1.50	9.44
August	6.12	3.37	3.00	8.16
September	-5.00	-3.36	NA	3.69

<sup>†</sup> Source: Alberta Agriculture and Forestry, Canada ([www.agriculture.alberta.ca/acis/alberta-weather-data-viewer.jsp](http://www.agriculture.alberta.ca/acis/alberta-weather-data-viewer.jsp)); The Weather Network Source ([www.theweathernetwork.com](http://www.theweathernetwork.com)).

<sup>‡</sup> NA, Not available for some days in the month.

micro-minerals: Zn, Fe, Mn, and Cu) were determined with wet chemistry using modified AOAC 968.08 and 935.13A procedures (AOAC, 1995). Total digestible nutrients (TDN) were calculated using the grass-legume Penn State equation according to Adams (1980).

### Partial Budget Analysis

Direct input costs and output revenue (forage DM yield multiplied by hay price) were used to determine returns for forage production. Hay price used was Can\$180/t of forage DM yield based on the average hay price from July to October 2018 in Alberta (source: Alberta Hay and Pasture Directory; <http://www.agric.gov.ab.ca/app21/loadgs>). Custom fieldwork rates, including labor and equipment rental costs, were from AgriProfits Cropping Alternatives (AAF, 2018). Input costs/ha used were: forage seed (Can\$131), direct seeding (Can\$62), broadcast seeding (Can\$20), fertilizer (Can\$165), fertilizer application (Can\$31), land cultivation (i.e., plowing/discing/harrowing, Can\$151), aeration (Can\$20), glyphosate herbicide (Can\$18), Grazon herbicide (Can\$96), and spraying of herbicide (Can\$25). Marginal returns were calculated as revenue minus total input costs. Profit/loss over control was calculated as marginal returns for a particular method minus marginal returns for control. Capital items including land costs and paid capital interest were not used for the partial budget analysis in this study.

### Statistical Analysis

The collected data (forage composition, yield, and quality) were analyzed on a yearly basis using the GenStat statistical package (2009, 12th edition). For the partial budget analysis, the combined forage production data (2017 and 2018) from each method were used for statistical analysis. Where ANOVA indicated significant method effects, the means were separated by the least significant difference (LSD) method at the 0.05 probability level. Significant differences in the text refer to  $P < 0.05$ . The data for forage DM yield, forage composition, and forage CP and TDN are presented for 3 years (before and after methods were implemented). Forage mineral data are presented for 2018 only.

## Results and Discussion

### Effect of Rejuvenation Methods on Botanical Composition, Forage Yield, and Quality

Overall, in 2018, rejuvenation methods significantly affected ( $P < 0.05$ ) forage DM yield, percent grass composition; percent legume composition; and forage Ca, P, Ca:P, K, Mg, and Cu but did not have any effect ( $P > 0.05$ ) on forage CP, S, Na, Fe, Zn, Mn, and TDN.

### Botanical Composition

Generally, before methods were implemented in 2016 and after methods were implemented (2017 and 2018), grass composition increased and legume composition decreased for all methods (Table 3). Legumes consisted of mostly clovers and some native vetch species. Alfalfa composition was very low across the entire field before methods were implemented. In 2018, four of the methods that involved seeding (RSS, BSS, RFBSS, and BSAS) had higher amounts of legumes (15–29%) than the other methods (with 3–10% legumes) in the total forage production. Overall, in the current study, RSS, BSS, RFBSS, and BSAS methods successfully increased alfalfa composition into the pastures. In 2018, the percent of alfalfa had increased greatly in seeded plots particularly for RSS. Several studies have also used direct drilling successfully to introduce legumes and other forage species into depleted pastures (Khatiwada, 2018; Omokanye et al., 2018; Acharya, unpublished; Olsen et al., 1981). As expected, the GRAZON method resulted in the greatest increase in grass composition (100%) after methods were implemented. Grazon XC herbicide will effectively control brush, forbs, and other broadleaf weeds; hence the reason for 100% grasses in the GRAZON method.

### Forage Yield

In the years following implementation of methods (2017 and 2018), RSS consistently had significantly ( $P < 0.05$ ) higher forage DM yield compared with other methods (Table 3). Similarly, FERT showed higher ( $P < 0.05$ ) forage DM yield than most methods (except for RSS and RFBSS). Overall, in both 2017 and 2018, only three methods (RSS, FERT, and BSAS) had consistently higher ( $P < 0.05$ ) forage DM yield than control. The forage yield increases from RSS, FERT, and BSAS over the control were 52 to 90% in 2017 and 18 to 75% in 2018. Comparing

Table 3. Effect of rejuvenation method on forage dry matter (DM) yield and forage botanical composition over 3 yr.

Method	Forage DM yield			Forage botanical composition					
				2016		2017		2018	
	2016	2017	2018	Grass	Legume	Grass	Legume	Grass	Legume
	kg ha <sup>-1</sup>								
Control	1035 <sup>a†</sup>	1445 <sup>e</sup>	1321 <sup>efg</sup>	94.5 <sup>abc</sup>	5.49 <sup>bcd</sup>	95.5 <sup>abc</sup>	4.41 <sup>abc</sup>	96.7 <sup>a</sup>	3.30 <sup>d</sup>
AF	893 <sup>a</sup>	1974 <sup>cde</sup>	1424 <sup>defg</sup>	91.8 <sup>abcd</sup>	8.14 <sup>abcd</sup>	95.7 <sup>abc</sup>	4.21 <sup>abc</sup>	96.5 <sup>a</sup>	3.43 <sup>d</sup>
AS	983 <sup>a</sup>	2324 <sup>bc</sup>	1362 <sup>efg</sup>	87.8 <sup>bcd</sup>	12.2 <sup>abc</sup>	94.7 <sup>abc</sup>	5.24 <sup>abc</sup>	96.3 <sup>a</sup>	3.64 <sup>cd</sup>
BSAF	1036 <sup>a</sup>	1550 <sup>de</sup>	1234 <sup>g</sup>	86.5 <sup>cd</sup>	13.4 <sup>ab</sup>	90.6 <sup>bc</sup>	9.40 <sup>ab</sup>	96.7 <sup>a</sup>	3.24 <sup>d</sup>
BSAS	854 <sup>a</sup>	2195 <sup>bcd</sup>	1556 <sup>cd</sup>	93.9 <sup>abcd</sup>	6.04 <sup>abcd</sup>	90.9 <sup>abc</sup>	9.00 <sup>abc</sup>	85.3 <sup>b</sup>	14.6 <sup>b</sup>
BSS	795 <sup>a</sup>	1917 <sup>cde</sup>	1453 <sup>def</sup>	97.3 <sup>a</sup>	2.67 <sup>d</sup>	97.2 <sup>ab</sup>	2.78 <sup>bc</sup>	83.6 <sup>b</sup>	16.4 <sup>b</sup>
FERT	822 <sup>a</sup>	2752 <sup>b</sup>	1801 <sup>b</sup>	93.4 <sup>abcd</sup>	6.58 <sup>abcd</sup>	96.4 <sup>ab</sup>	3.54 <sup>bc</sup>	98.3 <sup>a</sup>	1.71 <sup>d</sup>
GRAZON	798 <sup>a</sup>	1581 <sup>cde</sup>	1324 <sup>efg</sup>	94.8 <sup>ab</sup>	5.18 <sup>cd</sup>	96.9 <sup>ab</sup>	3.01 <sup>bc</sup>	100.0 <sup>a</sup>	
RFBSS	886 <sup>a</sup>	NA‡	1818 <sup>b</sup>	89.3 <sup>abcd</sup>	10.6 <sup>ab</sup>			83.0 <sup>b</sup>	17.0 <sup>b</sup>
RSS	940 <sup>a</sup>	3861 <sup>a</sup>	2310 <sup>a</sup>	95.1 <sup>ab</sup>	4.86 <sup>cd</sup>	89.3 <sup>c</sup>	10.7 <sup>a</sup>	70.9 <sup>c</sup>	29.0 <sup>a</sup>
ROS	959 <sup>a</sup>	NA	586 <sup>h</sup>	86.1 <sup>d</sup>	13.8 <sup>a</sup>	100.0 <sup>a</sup>		89.5 <sup>b</sup>	10.4 <sup>bc</sup>
CV, %§	25.3	20.1	9.16	5.16	23.0	3.99	27.6	4.33	30.0

† Means within a particular column followed by different superscripts differ significantly ( $P < 0.05$ ).

‡ NA, not available because methods had been sprayed out the fall before.

§ CV, coefficient of variation.

2017 to 2016 (before methods were implemented), there was a greater increase in forage DM yield for both FERT (31%) and RSS (235%) than other methods. Generally, regardless of pasture rejuvenation method, forage DM yield was generally higher in the year following implementation of methods (2017) than before methods were implemented (2016) (Table 3).

In the present study, the higher forage DM yield in 2018 from both methods that involved spraying (RSS and RFBSS) further confirms the need for adequate suppression of existing vegetation before direct (sod) seeding (Cuomo et al., 2001; Schellenberg et al., 1998; Bowes and Zentner, 1992). The observed improvement in forage production in the present study with FERT was also reported by Omokanye et al. (2018), Springer (2002), and Lardner et al. (2000). While Omokanye et al. (2018) found some residual effect of fertilizer application on forage production even 3 years after methods, Lardner et al. (2000) did not see any apparent effect after 2 years of fertilizer application. In the present study, FERT method responded to the initial low fertility level. The initial soil N (16 kg N ha<sup>-1</sup>) was considered deficient (Kryzanowski et al., 1988) for yearly forage production.

Mechanical aeration partially disturbed the soil surface and did not generally reduce forage productivity in the present study. Lardner et al. (2000) found that aeration reduced forage DM yield at two sites but had no effect at three other sites in the year following implementation of method. In the present study, ROS was used with the intention of killing the existing vegetation and to initiate new seedling establishment from the existing seed bank in the soil. However, this method did not seem to work well as no significant seedlings came from the existing seed bank but rather left the soil exposed and prone to nutrient runoff and erosion. So, ROS wouldn't be recommended as a method to rejuvenate pastures.

## Forage Nutritive Value

The forage CP content did not differ in 2016 (before methods) and in 2018 (3 years after methods were implemented) but did differ ( $P < 0.05$ ) in 2017 (Table 4). In 2017, RSS had significantly ( $P < 0.05$ ) higher forage CP (13%) compared with other rejuvenation methods. As well, in 2017, of the 11 methods, only 4 (RSS, ROS, BSAF, and FERT) showed greater ( $P < 0.05$ ) forage CP compared with control forage samples. The consistently higher forage CP obtained for RSS in the years following implementation of the method clearly shows the benefit of new forage stands and the presence of more legumes than other methods. Though ROS also had greater forage CP in both 2017 and 2018, as already stated, ROS is not currently

Table 4. Effect of rejuvenation method on forage nutritive value over 3 yr.

Method	CP (%DM basis)			TDN (%DM basis)		
	2016	2017	2018	2016	2017	2018
Control	10.8 <sup>at</sup>	9.25 <sup>cd</sup>	11.8 <sup>a</sup>	56.6 <sup>a</sup>	61.0 <sup>a</sup>	58.5 <sup>a</sup>
AF	9.63 <sup>a</sup>	8.21 <sup>cd</sup>	11.6 <sup>a</sup>	56.5 <sup>a</sup>	58.2 <sup>a</sup>	63.6 <sup>a</sup>
AS	11.0 <sup>a</sup>	8.08 <sup>d</sup>	12.2 <sup>a</sup>	56.3 <sup>a</sup>	58.5 <sup>a</sup>	60.2 <sup>a</sup>
BSAF	9.83 <sup>a</sup>	10.6 <sup>abcd</sup>	11.3 <sup>a</sup>	57.0 <sup>a</sup>	58.6 <sup>a</sup>	63.0 <sup>a</sup>
BSAS	9.59 <sup>a</sup>	9.43 <sup>bcd</sup>	11.9 <sup>a</sup>	61.0 <sup>a</sup>	59.3 <sup>a</sup>	63.1 <sup>a</sup>
BSS	10.5 <sup>a</sup>	10.0 <sup>bcd</sup>	11.0 <sup>a</sup>	56.1 <sup>a</sup>	59.5 <sup>a</sup>	58.0 <sup>a</sup>
FERT	10.7 <sup>a</sup>	10.5 <sup>abcd</sup>	9.90 <sup>a</sup>	58.6 <sup>a</sup>	58.9 <sup>a</sup>	51.5 <sup>a</sup>
GRAZON	10.9 <sup>a</sup>	8.19 <sup>d</sup>	9.62 <sup>a</sup>	55.9 <sup>a</sup>	56.0 <sup>a</sup>	57.5 <sup>a</sup>
RFBSS	9.32 <sup>a</sup>	NA‡	13.0 <sup>a</sup>	55.8 <sup>a</sup>	NA	58.1 <sup>a</sup>
RSS	10.4 <sup>a</sup>	13.0 <sup>a</sup>	13.6 <sup>a</sup>	56.9 <sup>a</sup>	57.4 <sup>a</sup>	63.8 <sup>a</sup>
ROS	9.45 <sup>a</sup>	12.1 <sup>ab</sup>	13.2 <sup>a</sup>	57.7 <sup>a</sup>	60.3 <sup>a</sup>	55.7 <sup>a</sup>
CV, %§	14.7	12.5	18.0	13.8	10.7	11.4

† Means within a particular column followed by different superscripts differ significantly ( $P < 0.05$ ).

‡ NA, not available because methods had been sprayed out the fall before.

§ CV, coefficient of variation.

Table 5. Forage minerals (DM basis) in 2018 (3 yr after methods were implemented).

Method	Ca	P	Ca:P	K	Mg	S	Na	Cu	Fe	Zn	Mn
	%		%				ppm				
Control	0.65	0.27	2.41	2.11	0.23	0.13	0.01	6.13	89.0	27.0	45.8
AF	0.34	0.23	1.48	2.40	0.18	0.15	0.01	6.71	93.4	24.9	65.2
AS	0.80	0.25	3.20	1.77	0.47	0.24	0.01	7.81	100.3	26.2	78.1
BSAF	0.55	0.27	2.04	2.79	0.24	0.15	0.01	6.74	127.7	29.7	51.5
BSAS	0.57	0.25	2.28	2.12	0.27	0.14	0.01	6.11	93.6	28.6	48.4
BSS	0.42	0.20	2.05	1.60	0.18	0.12	0.01	6.09	107.2	25.9	55.4
FERT	0.68	0.22	3.09	1.51	0.25	0.12	0.01	5.88	105.2	32.8	53.4
GRAZON	0.37	0.21	1.80	1.49	0.19	0.13	0.01	5.18	100.6	21.8	122.1
RFBSS	0.93	0.35	2.70	2.94	0.30	0.16	0.01	8.30	95.0	32.4	38.4
RSS	1.15	0.26	4.40	2.36	0.27	0.17	0.02	8.14	85.0	27.0	44.3
ROS	0.78	0.31	2.54	2.26	0.29	0.22	0.02	8.21	135.9	32.7	68.6
Mean	0.63	0.25	2.47	2.09	0.25	0.15	0.01	6.70	99.7	27.5	58.4
Significance	*	*	*	*	*	NS†	NS	*	NS	NS	NS
LSD <sub>0.05</sub>	0.25	0.06	0.99	0.71	0.14	0.10	0.01	1.92	56.5	8.92	47.3
CV, %‡	21.3	12.6	26.9	15.6	25.9	29.1	25.4	13.1	25.6	14.7	36.8

\*, Significance at  $P < 0.05$ .

†, Not significant at  $P < 0.05$ .

‡ CV, coefficient of variation.

recommended as a pasture rejuvenation method. Regardless of method, the forage CP was primarily  $\geq 8\%$  in 2017 and primarily  $> 10\%$  in 2018. In 2018, though not significantly different from other methods, both GRAZON and FERT tended to have lower forage CP values than other methods, probably because both GRAZON and FERT had slightly higher grass and lower legume components in the total forage production.

In the present study, the effect of FERT on forage CP appeared to last only in the year following implementation of method application (2017) and not beyond that. This shows that the applied amount of fertilizer for FERT was only adequate for one forage production year. The initial low fertility level before the methods were applied (particularly for soil N [16 kg ha<sup>-1</sup>]) and lack of any residual effects from the applied fertilizer 3 years later were thought to be responsible for the lower forage CP level in 2018 forages. It is important to note that the paddock used for this project was grass dominated in the stand. The soil at the site also had a low water infiltration rate (1.78 mm h<sup>-1</sup>) and was highly compacted (3909 kPa) from decades of grazing (Table 1), which may have affected crop nutrient uptake for the FERT method. Omokane et al. (2018) reported a significant improvement in forage CP with fertilizer application in a recent pasture rejuvenation study. However, Lardner et al. (2000) reported no forage CP improvement following a fertilizer application in an earlier study. Lardner et al. (2000) found that the combination of fertilizer plus mechanical rejuvenation (aeration/spiking) increased forage CP significantly in the year following method implementation but declined by the third year of the study to control levels.

The NASEM (2016) model for a recommended diet of mature beef cows suggests 7% CP for maintenance in mid-pregnancy,

9% CP in late pregnancy, and 11–13% CP for young (first parity) growing or lactating cows. In 2017, except for RSS and ROS, which both exceeded the 11% CP requirement of mature beef cattle, the other methods were only able to meet the 7–8% CP recommended for a dry gestating beef cow mid pregnancy. However, in 2018, only FERT and GRAZON method forages did not meet the suggested 11% CP for a lactating beef cow.

Forage TDN level did not differ ( $P > 0.05$ ) by rejuvenation method in the current study (Table 4). When evaluating TDN content of forages as the energy source for beef cattle, the rule of thumb is 55–60–65 (percent TDN, DM) (Yurchuk and Okine, 2004). This rule suggests a mature beef cow requires 55% TDN in mid-pregnancy, 60% TDN in late pregnancy, and 65% TDN after calving. In the present study, with a few exceptions, most rejuvenation methods only met the 55–60% TDN level recommended for a dry gestating beef cow. Generally, no methods had adequate TDN levels for a lactating beef cow, which requires 65% TDN in total diet.

Table 5 shows mineral content of forages in 2018 (3 years after methods were implemented). The highest forage Ca level was found with the RSS method but was only significantly ( $P < 0.05$ ) higher than three other methods (BSS, GRAZON, and AF). Except for ROS, RFBSS differed significantly ( $P < 0.05$ ) in forage P compared with the other methods. The forage Ca:P ratio was higher for RSS than other methods. Nine of the methods had Ca:P ratios  $\geq 2.00:1.00$ . Only RFBSS had significantly higher ( $P < 0.05$ ) forage K than most methods. Forage Cu was similar for most methods, but only RFBSS, RSS, AS, and ROS showed significantly ( $P < 0.05$ ) higher forage Cu values than the control. Overall, for forage Ca, P, Ca:P, K, and Cu, three methods (RFBSS, RSS, and ROS) were consistently in the top four, and RFBSS ranked first in every respect.

Table 6. Effect of rejuvenation method on predicted economic returns over 2 yr. (Note: This is only a simple cost analysis and is not intended as an in-depth study of the cost of production. Can\$1 = US\$0.76.)

Treatment	Total DM yield kg ha <sup>-1</sup>	Revenue	Total cost	Marginal returns	Profit/loss over control
				Can\$/2 yr/ha	
Control	2766 <sup>d†</sup>	500 <sup>cd</sup>	NA‡	500 <sup>bcd</sup>	NA
AF	3398 <sup>cd</sup>	614 <sup>c</sup>	20 <sup>c</sup>	594 <sup>bc</sup>	94 <sup>b</sup>
AS	3586 <sup>cd</sup>	648 <sup>bc</sup>	20 <sup>c</sup>	628 <sup>b</sup>	129 <sup>b</sup>
BSAF	2784 <sup>d</sup>	503 <sup>cd</sup>	210 <sup>a</sup>	293 <sup>e</sup>	-206 <sup>d</sup>
BSAS	3751 <sup>bc</sup>	678 <sup>bc</sup>	210 <sup>a</sup>	468 <sup>cd</sup>	-31 <sup>c</sup>
BSS	3370 <sup>cd</sup>	609 <sup>c</sup>	190 <sup>a</sup>	419 <sup>de</sup>	-81 <sup>c</sup>
FERT	4553 <sup>b</sup>	823 <sup>b</sup>	196 <sup>a</sup>	627 <sup>b</sup>	127 <sup>b</sup>
GRAZON	2905 <sup>cd</sup>	525 <sup>c</sup>	120 <sup>b</sup>	405 <sup>de</sup>	-95 <sup>c</sup>
RFBSS§	1818 <sup>e</sup>	329 <sup>d</sup>	233 <sup>a</sup>	96 <sup>f</sup>	-404 <sup>e</sup>
ROS§	775 <sup>f</sup>	140 <sup>e</sup>	43 <sup>c</sup>	97 <sup>f</sup>	-403 <sup>e</sup>
RSS	6171 <sup>a</sup>	1115 <sup>a</sup>	236 <sup>a</sup>	879 <sup>a</sup>	380 <sup>a</sup>
CV, %¶	16.9	17.3	20.4	17.2	129.1

† Means within a particular column followed by different superscripts differ significantly ( $P < 0.05$ ).

‡, NA, not available because no input costs were involved.

§ Only 2018 data used.

¶ CV, coefficient of variation.

Mineral imbalances and/or deficiencies can result in decreased performance, decreased disease resistance, and reproductive failure, which results in significant economic losses (GOS, 2015). Using the NASEM (2016) suggested requirements for minerals for beef cattle to assess the different pasture rejuvenation methods investigated here, only RFBSS, RSS, and ROS had sufficient Ca, P, K, Mg, and S levels for mature beef cattle. Generally, except for Na, all methods in most cases exceeded the Ca, P, K, Mg, and S requirements of a beef cow in mid pregnancy, but they all fell short of meeting the requirements of a beef cow in late pregnancy for the same set of minerals. When compared with the control, RFSS and RSS particularly showed greater improvement in most forage minerals than other methods.

The suggested ratio of Ca:P for beef cattle ranges between 2.00:1.00 and 7.00:1.00, assuming actual required grams of each are adequate (Yurchuk and Okine, 2004). In the present study, all methods (except for AF and Grazon) had Ca:P values that were within the suggested range, but only the control, RFBSS, RSS, and ROS had adequate Ca (0.58%) and P (0.26%) for mature beef cattle. Throughout the study period, all methods failed to meet the Na and Cu requirements of all categories of beef cattle as recommended by NASEM (2016). Taking into consideration that a few methods had Ca:P ratios outside the recommended range for beef cattle and that no methods had enough Na or Cu, this therefore, indicates that appropriate mineral supplementation using commercial minerals is necessary when grazing cows (particularly lactating or nursing cows) on pastures in the study area.

### Partial Budget Analysis

The partial cost comparison summary using combined total forage production for 2017 and 2018 is presented in Table 6.

The total forage DM yield, revenue generated for total forage production, total cost incurred, marginal returns, and profit/loss of methods over control were all significantly affected ( $P < 0.05$ ) by methods investigated. Total forage production was highest for the RSS treatment at 6.2 tonne per hectare. The highest total revenue from the 2-year forage production came from RSS (Can\$1,115), followed by FERT (Can\$823), BSAS (Can\$678), AS (Can\$648), and then AF (Can\$614) in that order. Only six methods (AF, AS, BSAS, BSS, FERT, and RSS) appeared to have higher revenue than control. Both ROS and RFBSS (only 1 year of forage yield used here for both) had much lower revenue values than the control.

The total input cost was highest for RSS (Can\$236/ha) and lowest for both AS and AF (Can\$20/ha). The 2-year forage production data used showed that only four methods (RSS, FERT, AS and AF) had extra income over the control, with RSS resulting in a profit of Can\$380 ha<sup>-1</sup>, followed by AS and FERT with about Can\$130/ha, and then AF (Can\$94/ha).

In summary, although RSS incurred higher total costs (up to CAD \$216) than other methods (except for RFBSS), RSS, AS, AF, and FERT consistently showed greater forage production, higher revenue and returns, and increased profit over control than the other methods. Overall, RSS ranked first in economic value and therefore can be recommended for adoption by producers. Omokanye et al. (2018) also reported some monetary gains with fertilizer application compared with most pasture rejuvenation methods investigated. It is important to note that the effect of FERT on improved forage production does not normally last longer than 2 to 3 years (Omokanye et al., 2018; Lardner et al., 2000), so fertilization may not be economical for forage improvement in depleted pastures beyond 3 years following application.

## Conclusion

Three years after methods were implemented, pasture rejuvenation methods investigated significantly improved forage DM yield, botanical composition, and forage Ca, P, Ca:P, K, Mg, and Cu but did not have any influence on forage CP, S, Na, Fe, Zn, Mn, or TDN (energy) level in forage. Spring herbicide application + direct seeding (RSS), fertilizer application (FERT), and fall herbicide application + broadcast seed in spring (RFBSS) improved forage production and some forage quality parameters more than other methods over control. The composition of legumes in the total forage production was 29% for RSS compared with about 2 to 17% for other methods including control. The consistently higher forage CP obtained for the RSS treatment forage in the years following methods clearly shows the benefit of new forage stands and the presence of more legumes in the total forage production. Both GRAZON and FERT tended to have lower forage CP values than other methods, probably because both GRAZON and FERT had slightly higher grass and lower legume components in the total forage stand. The higher forage DM yield from RSS and RFBSS in 2018 further confirms the needs for adequate suppression of existing vegetation before direct (sod) seeding.

Generally, there was no particular rejuvenation method that was consistently able to improve forage mineral content and meet mineral requirements of lactating beef cattle, which would normally be the type of grazing cattle on pasture during that time. A feed supplement strategy to help compensate for such inadequacies is therefore necessary. Such strategies may include feeding cattle on pasture a free-choice mineral or protein supplement, designed to provide the required nutrient or minerals. The RSS method incurred higher total costs (up to Can\$216) than other methods (except for RFBSS) to incorporate on the forage stand. Compared with the other methods, RSS as well as AS, AF, and FERT had greater 2-year total forage production, revenue and returns, and profit over the control. Overall, the study demonstrated that RSS improved forage DM yield and quality (particularly CP, Ca, and Ca:P, and comparable TDN levels) and increased both revenue and profit over most methods including the control. These results yield several practical recommendations for producers. The combination of Roundup herbicide application followed later by direct seeding of forage mixtures in spring (RSS) would be the first rejuvenation method to be recommended, followed by spring aeration (AS), fertilizer application, and fall aeration.

## Acknowledgments

This project was funded by the Alberta Beef Producers (Project no. FRG.13.15). We also received financial support and donations (land, seed, fertilizer, and equipment) from the following: Wanham Grazing Association (WGA), Birch Hills County, Special Areas Board, Rocky Mountain Equipment, Nutrien Ag Solutions (formerly Dynamic Seeds and CPS, Fairview), James & Jodi Bozarth (Sexsmith, Alberta), and Soames & Melissa Smith (Uddersmith Dairy, Spirit River). We thank Gilbert Wasieczko (Farm Manager, WGA) for his support and the staff and summer students of Chinook Applied Research Association and Peace Country Beef and Forage Association for their technical assistance. Thank you to the

following beef cattle producers in Fairview, AB for initiating the project: Garth Shaw and Allan McLachlan.

## References

- Aasen, A., and M. Bjorge. 2009. Alberta forage manual. 2nd ed. Alberta Agriculture and Forestry, Edmonton, AB.
- Adams, R.S. 1980. Penn State forage testing service revised regression equations. *Dairy Sci. Ext. Memo DSE-90-56*, The Pennsylvania State Univ., University Park.
- ALR (Alberta Land Resource). 1995. Soil group map of Alberta. Research Branch, Agriculture and Agri-Food Canada. <http://www1.agric.gov.ab.ca/soils/soils.nsf/soilgroupmap> (accessed 24 Nov. 2018).
- AAF (Alberta Agriculture and Forestry). 2018. AgriProfit\$ cropping alternatives: Economics and competitiveness [https://www1.agric.gov.ab.ca/\\$Department/deptdocs.nsf/all/sis15425](https://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/sis15425) (accessed 20 Oct. 2018).
- AOAC (Association of Official Analytical Chemists). 1995. Official methods of analysis. 16th ed. AOAC Int., Gaithersburg, MD, USA.
- AOAC (Association of Official Analytical Chemists). 2005. Official methods of analysis. Method 990.03. 18th ed. AOAC Int., Gaithersburg, MD, USA.
- Bradley, K.W., and J.A. Kendig. 2004. Weed and brush control guide for forages, pastures, and noncropland. MP 581. University of Missouri Extension, Columbia, MO.
- Bowes, G.G., and R.P. Zentner. 1992. Effect of vegetation suppression on the establishment of sod-seeded alfalfa in the Aspen Parkland. *Can. J. Plant Sci.* 72(4):1349–1358. doi:10.4141/cjps92-167
- Cuomo, G.J., D.G. Johnson, and W.A. Head. 2001. Interseeding kura clover and birdsfoot trefoil into existing cool-season grass pastures. *Agron. J.* 93(2):458–462. doi:10.2134/agronj2001.932458x
- Durunna, O.N., V. Baron, S.L. Scott, C. Robins, M. Khakbazan, and H.C. Block. 2015. Effects of resting perennial pastures during the sensitive pre-dormancy period in western Manitoba: Pasture productivity and beef cattle performance. *Can. J. Anim. Sci.* 95:129–141. doi:10.4141/cjas-2014-046
- GenStat. 2009. GenStat for Windows. 12th ed. Introduction. VSN International, Hemel Hempstead, United Kingdom.
- GOS (Government of Saskatchewan). 2015. Pasture rejuvenation. <http://www.saskforage.ca/images/pdfs/Publications/Pasture%20rejuvenation%20Aug%202015.pdf>
- Jungnitsch, P., J.J. Schoenau, H.A. Lardner, and P.G. Jefferson. 2011. Winter feeding beef cattle on the western Canadian prairies: Impacts on soil nitrogen and phosphorous cycling and forage growth. *Agric. Ecosyst. Environ.* 141:143–152. doi:10.1016/j.agee.2011.02.024
- Kemp, D.R., D.L. Michalk, and J.M. Virgona. 2000. Towards more sustainable pastures: Lessons learnt. *Aust. J. Exp. Agric.* 40:343–356. doi:10.1071/EA99001
- Khatiwada, B. 2018. Rejuvenation of depleted pasture using bloat-free legumes for high performance cattle grazing. Ph.D diss., University of Lethbridge, Dep. of Biological Sciences, Lethbridge, AB.
- Kryzanowski, L., editor, D. Laverty, J. Ashworth, M. Nyborg, J. Harapiak, and R. Kucey. 1988. Soil test recommendations for Alberta: Technical Manual. Alberta Agriculture, Food and Rural Development.
- Lardner, H.A., S.B.M. Wright, R.D.H. Cohen, P. Curry, and L. MacFarlane. 2000. The effect of rejuvenation on Aspen Parkland ecoregion grass-legume pastures on dry matter yield and forage quality. *Can. J. Plant Sci.* 80:781–791. doi:10.4141/P99-127
- Malhi, S.S., K. Heier, K. Nielsen, W.E. Davies, and K.S. Gill. 2000. Efficacy of pasture rejuvenation through mechanical aeration or N fertilization. *Can. J. Plant Sci.* 80:813–815. doi:10.4141/P99-150
- Monaco, T.J., S.C. Weller, and F.M. Ashton. 2002. Pastures and range-lands. In: *Weed science principles and practices*. 4th ed. John Wiley & Sons Inc., New York. p. 522–530.

- Moore, K.J., L.E. Moser, K.P. Vogel, S.S. Waller, B.E. Johnson, and J.F. Pedersen. 1991. Describing and quantifying growth stages of perennial forage grasses. *Agron. J.* 83:1073–1077. doi:10.2134/agronj1991.00021962008300060027x
- NASEM (National Academies of Sciences, Engineering, and Medicine). 2016. Nutrient requirements of beef cattle. 8th revised edition. The National Academies Press, Washington, DC. doi:10.17226/19014.
- Nazarko, O. 2008. Seeding forages into existing stands using minimal tillage. Agriculture and Agri-Food Canada and Manitoba Forage Council, Winnipeg, MB.
- Olsen, F.J., J.H. Jones, and J.J. Patterson. 1981. Sod-seeding forage legumes in a tall fescue sward. *Agron. J.* 73:1032–1036. doi:10.2134/agronj1981.00021962007300060029x
- Omokanye, A.T., C. Yoder, L. Sreekumar, L. Vihvelin, and M. Benoit. 2018. Forage production and economic performance of pasture rejuvenation methods in northern Alberta, Canada. *Sustain. Agric. Res.* 7(2):94–110. doi:10.5539/sar.v7n2p94
- Omokanye, A.T. 2013. Soil nutrient trends and forage production following years of bale grazing in parts of the Peace Region of Alberta, Canada. *American-Eurasian J. Agric. and Environ. Sci.* 13(6):877–884. [https://www.idosi.org/aejaes/jaes13\(6\)13/21.pdf](https://www.idosi.org/aejaes/jaes13(6)13/21.pdf)
- PCBFA (Peace Country Beef and Forage Association). 2013. Perennial forage demonstration in Fairview and High Prairie: Yield and feed value following third year cutting. In: PCBFA 2013 Annual Report. p. 55–64.
- Picard, R. 2010. Nutrient cycling in winter grazing cattle on pasture; three years following bale grazing. Manitoba Agronomists Conference Proceedings 2010. [https://umanitoba.ca/faculties/afs/agronomists\\_conf/media/Rejean\\_Picard\\_bale\\_grazing.pdf](https://umanitoba.ca/faculties/afs/agronomists_conf/media/Rejean_Picard_bale_grazing.pdf) (accessed 5 Sept. 2018).
- Schellenberg, M.P. 2016. Forage stand rejuvenation considerations. Foraging into the Future. Agriculture and Agri-Food Canada.
- [http://www.sccws.com/files/Schellenberg\\_-rejuvenation.pdf](http://www.sccws.com/files/Schellenberg_-rejuvenation.pdf) (accessed 5 Sept. 2018).
- Schellenberg, M.P., J. Waddington, T. Jorgenson, S. Stranger, and S. Springer. 1998. Pasture renovation systems: Pasture and hayfield rejuvenation. Final report, Canada-Saskatchewan Agriculture Green Plan Agreement.
- SFC (Saskatchewan Forage Council). 2011. An economic assessment of feed costs within the cow/calf sector. Western Canadian Feed Innovation Network, University of Saskatchewan, Saskatoon, SK.
- Springer, B. 2002. Rejuvenation of tame forages. Saskatchewan Agriculture, Food and Rural Revitalization.
- Statistics Canada. 2012. 2011 census of agriculture. Agriculture Statistics. Statistics Canada, ON.
- Statistics Canada. 2014. [www.statcan.gc.ca/eng/subjects/Agriculture](http://www.statcan.gc.ca/eng/subjects/Agriculture).
- Statistics Canada. 2018. Number of cattle, by class and farm type (x 1000). Statistics Canada. <http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/prim50a-eng.htm> (accessed 29 Sept. 2018).
- Stewart, F. 2004. Options for improving forage production on pastures and hay lands manitoba forage council 2004. <http://www.farmwest.com/options-for-improving-forage-production-on-pastures-and-hay-lands-2004>
- Vasquez, E.A., J.J. James, T.A. Monaco, and D.C. Cummings. 2010. Invasive plants on rangelands: A global threat. *Rangelands* 32(1):3–5. <http://oregonstate.edu/dept/EOARC/sites/default/files/666.pdf> (accessed 29 Oct. 2018). doi:10.2111/RANGELANDS-D-09-00006.1
- Yurchuk, T., and E. Okine. 2004. Agri-facts: Beef ration rules of thumb. Alberta Agriculture Food and Rural Development. Agdex 420/52-4. [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/agdex9146/\\$file/420\\_52-4.pdf](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex9146/$file/420_52-4.pdf) (accessed 19 July 2018).