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Forage Production and Economic Performance of Pasture Rejuvenation Methods in Northern Alberta, Canada

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Abstract

Producing high quality forage and maintaining productive pastures is a major challenge that beef producers encounter, as rejuvenation is a complex and costly challenge. This is part of a series of papers looking at potential options and methods of rejuvenation to improve the productivity of older forage stands in northern Alberta. The methods of rejuvenation investigated were sub-soiling, break & re-seeding, a combination of manure application plus subsoiling, high stock density grazing, bale grazing, pasture rest, as well as direct seeding in spring and fall. In this series, forage dry matter (DM) yield, forage nutritive value and economic performance are presented and discussed. The top 5 forage DM yielders were bale grazing, manure + subsoil in fall, break & re-seeding, high stock density grazing and fertilizer application in that order. In both years, bale grazing consistently produced higher forage DM yield than other methods including control, with bale grazing giving up to 100% higher yield at site-1 and 219% at site- 2 for the 2-year total forage DM. Most forage nutritive value parameters measured were similar for the rejuvenation methods investigated. A simplified economic analysis done in this study showed that the direct input cost of rejuvenation an old forage stand was higher with the break & re-seeding method than other methods. However, for bale grazing, when the cost of hay bales used was factored in, then the cost of bale grazing far exceeded those of other methods including break & re-seeding. The implications of the results obtained in this study in relation to beef cattle production system are highlighted.

Keywords: pasture improvement, break & re-seeding, forage production, economic benefit

1. Introduction

Canada is one of the major beef exporting countries. The Canadian beef cattle industry is dominated by the three Prairie (grasslands) Provinces (Alberta, Saskatchewan and Manitoba) (Statistics Canada, 2018). The province of Alberta alone as of January 2018 accounted for about 41% of the national cattle herd (Statistics Canada, 2018). Forages are the cheapest source of food for cattle and account approximately 80% of the feed requirements of beef cattle (SFC, 2011). In 2011, pasture land accounted for 43% of total farm area in Alberta (Statistics Canada, 2012). This therefore shows that forage production is the foundation of beef cattle production in Alberta. Forages play a role in sustainable cropping systems, as healthy forage stands reduce wind and water erosion on land, and improve soil quality and fertility.

Beef cattle producers know that grazing their cows on productive pastures can be very profitable on their operations, but as stands of pasture become older, undesirable species and weeds begin to dominate the forage stand, causing a decline in productivity and quality (Aasen & Bjorge, 2009). The decline in pasture production can result from reduced forage stand vigor, which can occur because of occasional lack of moisture (rainfall), pests (such as leafhoppers and alfalfa weevil), weeds, overgrazing, poor soil fertility or poor general soil health conditions. Overgrazing is a harmful practice to any pasture, will shorten the life of pastures and increase production costs. Overgrazing is the most common way weeds take over a pasture. Rejuvenation can be a pasture management strategy for rapid improvement of existing and/or depleted pasture (Acharya, 2015), but improving existing forage stands is a complex and costly challenge for livestock producers. The traditional method of pasture rejuvenation is reseeding entire pastureland after completely breaking up the old stand (Malhi et al., 2000). Improvement of existing pasture without replacing resident vegetation is expected to take less time and be more economical method of pasture rejuvenation. Producers' questions in northern Alberta on forage-stand rejuvenation methods always include: How much more forage does a re-seed produce? Where will I see the benefits of forage stand rejuvenation? What re-seeding methods or seeding equipment should I use? How can I improve my pasture's soil health conditions including compaction, infiltration and soil organic matter? Can I seed in fall instead of spring?

A strong, productive forage stand that will last for several years is the desired objective of most producers in northern Alberta. To maintain strong annual forage production, soil fertility should match forage crop production nutrients requirements. However, inorganic fertilizer application on old forage stands is not a common practice in northern Alberta, indicating that there is considerable room for improvement in forage production with the effective use of fertilizer nutrients. On the other hand, manure application on pastures is done some by producers occasionally.

Soil compaction resulting from heavy clay often called 'gumbo soils' (Soil Classification Working Group, 1998) in northern Alberta and cattle trampling, and associated poor water infiltration rate are some of the common problems identified on pastures in northern Alberta (Omokanye, 2015). Cattle trampling in pastures could reduce soil respiration by reducing pore space and limiting O_2 diffusion (Conlin & van der Driessche, 2000; Shestak & Busse, 2005). Soil compaction can impair water infiltration into soil, root penetration and nutrient uptake, consequently, the profitability of the farm is negatively affected. Where a pasture condition is good, the pasture captures solar energy, uses rainwater efficiently, conserves soil condition and cycles nutrients. The economic value of pastures for optimum livestock carrying capacity is dependent on both its yield and feeding value. Recently as part of a just completed study on how to manage degraded soil under grazing systems with minimal environmental effects, Omokanye et al. (2018) indicated that without a producer having to break and reseed (pasture renewal) old pastures, bale grazing, manure application plus subsoiling, high stock density grazing and inorganic fertilizer application, in that order would be preferred methods of pasture rejuvenation for improving soil quality indicators.

Though, different methods of rejuvenation including fertilizer application, pasture resting, direct seeding and bale grazing have been examined in western Canada (Aasen & Bjorge, 2009; Durunna et al., 2015; GOS, 2015; Jungnitsch et al., 2011; Lardner et al., 2002; Nazarko, 2008; Schellenberg et al., 1998; Waddington, 2017) but most of these studies have only examined a few methods at a time. On-farm research is therefore needed to compare all or at least most of the practicable methods of rejuvenation to determine the most effective and profitable methods for producers.

The objective of this study was to compare practicable methods of rejuvenation to determine the most effective and profitable methods for livestock producers in comparison to a complete break and reseeding scenario. This paper is the second part in the two part series of methods of rejuvenation of pastures studies. In the first paper, on-farm performance of pasture rejuvenation methods on soil quality indicators in northern Alberta (Canada) methods have been discussed (Omokanye et al., 2018).

2. Materials and Methods

2.1 Study Sites Characteristics and Climate Data

Field experiments were carried out on-farm at two sites in northern Alberta, Canada from May 2015- July 2017. Both sites had cow-calf beef operations. Site 1 was located at Rycroft (50°12′ N, 111° 08′ E; altitude 765 m above sea level) on calcareous brown chernozem soil type. Site 2 was at Grovedale (55°02′ S, 118° 09′ W; altitude 676 m above sea level) on gleyed solonetzic gray luvisol soil type. The soil characteristics of the surface (0-15 cm) and sub-surface (15-30 cm) soil profiles at both experimental sites have been provided by Omokanye et al. (2018) in an earlier paper, which emanated from parts of this study.

Both sites have a subarctic climate (also called boreal climate), which is characterized by long, usually very cold winters, and short, cool to mild summers. Weather data during the trial years and long-term averages for both sites are shown in Table 1.

In this study, rainfall and temperatures (minimum & maximum) as shown in Table 1 were obtained from weather stations that were about 9 and 32 km form the study sites. The difference in maximum temperature between trial years and long-term averages (LTA, 30 year average) was high and in favour of the trial years at both sites. The minimum temperature appeared to be similar to LTA records. The total rainfall from April to September was 110.5 mm lower (2015), 22.2 mm higher (2016) and 64.4 mm lower (2017) than LTA at site 1. At site 2, rainfall was 12.4 mm higher (2015), 183.9 mm higher (2016) and 43.6 mm higher (2017) than LTA. It is important to note that Site 2 was >30 km from the weather station data used here, so there be some discrepancies in the actual weather obtained for that site 2. Generally, in 2015, northern Alberta was mostly very dry including both sites used here. Therefore, soil moisture was assumed to be limiting at both sites in 2015.

Table 1. Rainfall, maximum & minimum air temperatures during the study and long-term averages (LTA, 30 years average) at the study sites[Z]

	Site 1: Rycroft*				Site 2: Grovedale**			
	2015	2016	2017	LTA	2015	2016	2017	LTA
Rainfall (mm):								
April	24.5	6.90	29.7	22.3	33.5	19.1	44.3	21.1
May	15.4	61.6	41.3	39.2	24.8	72.7	75.1	37.5
June	34.9	69.5	40.8	69.9	136.5	163.8	39.3	70.9
July	19.0	74.1	33.6	70.8	22.8	54.2	45.4	68.9
August	57.7	53.8	31.8	51.1	49.8	137.7	42.3	56.1
September	29.8	48.1	50.2	38.5	39.5	30.9	91.7	40.0
Total	181.3	314.0	227.4	291.8	306.9	478.4	338.1	294.5
Maximum temperatures (^{o}C):								
April	25.0	29.2	13.7	9.33	23.8	29.4	14.4	9.45
May	28.5	28.7	28.2	16.3	27.8	27.6	27.1	16.4
June	30.0	28.4	30.4	20.1	28.7	28.1	28.6	20.1
July	30.9	27.7	29.5	21.9	31.0	28.2	29.2	22.1
August	27.3	27.4	29.7	21.1	26.7	26.9	30.8	21.4
September	27.4	25.8	30.7	16.0	27.9	24.8	28.7	16.3
Minimum temperatures (^{o}C):								
April	-6.37	-5.44	-13.5	-2.59	-5.10	-4.70	-6.80	-2.63
May	-4.44	-4.68	-0.69	3.11	-2.80	-3.00	-2.10	3.17
June	2.05	5.33	2.15	7.56	4.60	4.70	2.90	7.47
July	3.86	5.96	5.98	9.44	6.00	4.30	4.30	9.39
August	-2.14	6.12	3.37	8.16	1.40	6.70	4.40	8.10
September	-3.96	-5.00	-3.36	3.69	-4.60	-3.90	-4.20	3.56

*, weather station is 8.6 km from site 1. **, weather station is 32.4 km from site 2.

[Z]Source: Alberta Agriculture & Forestry, Canada (https://agriculture.alberta.ca/acis/alberta-weather-data-viewer.jsp); The Weather Network Source (www.the weathernetwork.com).

2.2 Pasture History and Management

As indicated earlier by Omokanye et al. (2018), pasture paddocks at both sites were planted to a mixture of meadow bromegrass (*Bromopsis biebersteinii*, variety- Fleet), and alfalfa (*Medicago sativa*, variety name was not known) 15 years before the start of the experiment. At site 1, the pasture paddock out of which a section was used for this experiment was 30 ha. At site 2, the entire pasture paddock was 57 ha in size. Four (4) ha were used for the field experiment at each site. Both pasture paddocks were used strictly for pasture for 5 years or more before the experiment commenced. At both sites, pastures were grazed by Angus beef cattle each year, primarily in spring/summer.

The pastures at both sites had declined in forage productivity over the years and forage dry matter (DM) yield at the sites just before the start of the study averaged 1093 kg ha^{-1} at Site 1 and 896 kg ha^{-1} at Site 2 or <20% of expected yearly forage DM yield. More details on pasture management at the sites are given in Omokanye et al. (2018).

2.3 Experimental Design and Methods of Rejuvenation of Pastures (Treatments)

The treatments (methods of pasture rejuvenation) were set up on-farm on a field scale using a randomized complete block design with three (3) replications at each site. Each treatment plot was 10 m x 100 m (1000 m^{2}) in size.

The methods of pasture rejuvenation that were evaluated at the sites and their descriptions are:

1. Control.
2. Spread stockpiled beef cattle manure, which as followed by sub-soiling (M+S) to 30 cm soil depth in the fall with an Agrowplow subsoiler, with 32.5 cm shank spacing.
   Site 1: Done on October 29, 2015.
   Site 2: Not done at this site 2.
3. Sub-soiling in fall (SSF) with an Agrowplow subsoiler to a soil depth of 30 cm in the fall.
   Site 1: Done on October 31, 2015.

Site 2: Done on October 30, 2015.

4. Pasture rest - no grazing or haying in 2015 only.
   Site 1: Paddock was rested all year in 2015
   Site 2: Not done at this site 2
5. Break & re-seeding (B&R) - The existing pasture was completely cultivated (plowing/discing/harrowing) and then reseeded with a forage mixture [60% smooth bromegrass (*Bromus inermis* Leyss, variety-Carlton), 10% cicer milkvetch (*Astragalus cicer*, variety- Oxley II) and 30% alfalfa (variety- *Algonquin*)]. The forage seed was seeded at 16.8 kg ha^{-1}.
   Site 1: Done on June 16, 2015.
   Site 2: Done on June 18, 2015.
6. High stock density grazing (HSDG) of pasture for a short time. Cows only grazed about 65% of forage, with the remaining 35% knocked down as plant litter. Cows were contained within the plots with an electric fence.
   Site 1: Used 173 livestock unit ha^{-1} [assuming 1.0 livestock units/head for cows (including suckling calves) and that cows were kept on the paddock for 3 months/year]. Grazing was done on July 25, 2015.
   Site 2: Used 117 livestock unit ha^{-1} [assuming 1.0 livestock units/head for cows (including suckling calves) and that cows were kept on the paddock for 3 months/year]. Grazing was done on July 30, 2015.
7. Bale grazing (BG). Used a density of 60 hay bales/hectare that averaged 545 kg/hay bale at each site. Hay bales were place on a grid of 12 m centers (leaving 10 m) between the hay bales, to allow even manure nutrient coverage). Cows were contained within the plots with an electric fence.
   Site 1: 70 cows with average live weight of 545 kg were used to graze the hay bales. Grazing started on February 18, 2016.
   Site 2: 65 cows with average live weight of 545 kg were used graze the hay bales. Grazing started on February 29, 2016.
8. Fertilizer application (FA). Top dressing with inorganic fertilizer blend following soil tests recommendations. Fertilizer application was made after the plot had been grazed in 2015. Cows were contained within the plots with an electric fence.
   Site 1: Treatment 8 not done at this site (organic farm)
   Site 2: Fertilizer blend applied (kg ha^{-1}) was: 58 N + 60 P + 31 K + 16 S on June 16, 2015.
9. Sod-seeding in the spring (SS) with an Agrowdrill (no-till seeding) of forage mixture as in treatment 5 above. This involved seeding directly into the unbroken sod with 16.8 kg ha^{-1} of seed at a depth of 1.25 cm.
   Site 1: Seeding was done on June 16, 2015.
   Site 2: Seeding was done on June 18, 2015.
10. Sod-seeding in the fall (SF) with an Agrowdrill (no-till seeding) of forage mixture as in treatment 5 above. This involved seeding directly into the unbroken sod with 16.8 kg ha^{-1} of seed at a depth of 1.25 cm.
    Site 1: Seeding was done on October 20, 2015.
    Site 2: Seeding was done on October 22, 2015.

Except for Treatments 2 (M+S) and 3 (SSF), which were done in the fall of 2015, and treatment 7 (BG), which was done during the winter of 2015/2016, all other treatments were implemented in the summer of 2015. More details on the methods of rejuvenation are given in Omokanye et al. (2018). In 2015, after initial base data collection, all treatments plots [except pasture rest treatment method (treatment 4) and B&R (treatment 5)] were either grazed before treatment implementation (BG, M+S, FA, SS, SF) or during treatment implementation (HSDG) as required. The control was also grazed in 2015.

In 2016 and 2017, after all field measurements have been done, all plots were grazed at once by cow-calf pairs and only done once a year.

2.4 Manure and Hay Bale Feed Samplings for Analysis

Stockpiled beef cattle solid manure was used for M+S treatment. The manure was analyzed for ammonium-N, total N, total P and moisture content to enable the calculation of desired N rate.

Feed samples of the hay bales used for bale grazing treatment (BG, treatment 7), were analyzed for feed quality indicators to determine if the hay would provide adequate nutrition for dry gestating beef cows in mid pregnancy (NRC, 1996, 2000). Feed analysis included: dry matter content, crude protein (CP), Ca, P, K, Mg, S, Na and total digestible nutrients (TDN).

More details on the manure and hay bale feed samplings for analysis are given in Omokanye et al. (2018).

2.5 Field Data Collection

Stand establishment success was determined by observing unseeded treatment compared to seeded treatments for plant counts in the fall of the seeding year (August 26-28, 2015) for B&R and SS treatments methods, and the following spring (June 20-22, 2016) after previous fall seeding (SF) to confirm stand density. A comparative methods of stand establishment, proposed by Vogel & Masters (2001) was performed using a 5 x 5 square grid consisting of a total of 25 squares that were 15 cm x 15 cm were used in the seeded treatments plots (B&R, SS and SF). The counts were converted into frequency of occurrence and then rated on a rating of 0 to 5 (5 = good establishment & 0= no establishment).

Forage botanical composition and forage DM yield were done in mid-July 2016 and 2017. All measurements were collected using a consistent grid that had 3 points spaced 20 m apart imposed within the length of each treatment plot. All measurements were taken within a radius of 3 m of each point. Measurements within 20 m from the two edges along the plot length and 10 m from both sides of each treatment plot were avoided. The grid points therefore provided 3 sampling points for each treatment plot or 21 sampling points for Site 1 and 18 for Site 2. The contents of different forage species and varieties, other plants, and their respective forage yields was determined from 1 m x 1m quadrat area (placed at 3 locations), clipped at a height of 3-4 inches above the soil surface.

2.6 Laboratory Determined Forage Nutritive Value

The forage nutritive value (reported on dry matter basis) was determined using one dry sample per replication (or 3 samples per treatment). The nutritive value was determined by the Central Testing Laboratory Ltd (Winnipeg, MB, Canada) using standard laboratory procedures for wet chemistry and near infrared reflectance spectroscopy (or NIRS). The content of N was measured by Dumas Method (dried, ground tissue combusted with oxygen and analysed by thermal conductivity) after which crude protein (CP) was calculated (%N x 6.25). Mineral contents were determined using modified AOAC 968.08 and 935.13A procedures (AOAC, 1995). Acid detergent fibre (ADF) and neutral detergent fiber (NDF) were measured by NIR. The following parameters were calculated according to equations provided by Adams (1980): net energy for gain (NE_G), net energy for lactation (NE_L), net energy for maintenance (NE_M), total digestible nutrients (TDN), digestible energy (DE) and metabolizable energy (ME).

2.7 Economic Performance

A simple economic analysis of the input costs and output revenue (forage DM yield & hay price) to determine returns/ha was performed. This simplified budget used custom field work rates, including labor and equipment rental costs from northern Alberta from AgriProfits Cropping Alternatives for 2015-2017 (AAF, 2015, 2016, 2017). A few data was collected from the collaborating producers as well. The forage mixture seeded cost more at site 1 (organic farm) than at site 2 (conventional beef farm). Other costs used were similar for both sites. Capital items including land costs and paid capital interest were not used for the simplified budget in this study.

2.8 Data Analysis

The collected data (particularly forage DM and nutritive value) from the two locations were analyzed separately (site basis) and on a yearly basis using the GenStat statistical package (2009, 12th Edition). Where ANOVA indicated significant treatment effects, the means were separated by the least significant difference (LSD) at the 0.05 probability level. Significant differences in the text refer to P<0.05.

For the simple economic analysis, the combined forage production data (2016 & 2017) from each treatment method was used and no statistical analysis was done on the simplified economic comparisons of pasture rejuvenation methods for both sites.

3 Results

3.1 Site 1

3.1.1 Seedling Establishment

As a reminder, only 3 (B&R, SS, SF) of the 10 rejuvenation methods were seeded with a forage mixture consisting of smooth bromegrass, alfalfa and cicer milkvetch. Using an establishment rating of 0 to 5 (5 = good establishment & 0= no establishment), only smooth bromegrass seemed to have some establishment success. Smooth bromegrass had a mean establishment rating of 3 for B&R rejuvenation method and an establishment rating of 1 for SS rejuvenation method (data not shown). No new stands of smooth bromegrass were found in SF method. Both alfalfa and cicer milkvetch had zero (0) establishment rating for the 3 methods that involved seeding (B&R, SS, SF).

3.1.2 Forage Composition

The percent of grasses, legumes and other types of plants in the field was significantly affected (P<0.05) by rejuvenation methods investigated in both years.

In 2016, only BG, B&R and HSDG consisted of >70% grasses in the available forage in the field (Table 2). In 2017, there appeared to be more rejuvenation methods (BG, B&R, HSDG, SSF, pasture rest) with >70% grasses. The legume component was generally <50%, with SF consistently having higher legumes (~50% in 2016 and 43% in 2017). Fall seeding and spring seeding seemed to have slightly higher forage legume particularly clovers, and native vetches than other methods.

Overall, the grass component of the forage yield was generally higher than legumes and other plants/weeds. For other plants, dandelions (*Taraxacum officinale*) was the most dominant, followed by some quack grass (*Elytrigia repens*) and stinkweed (*Thlaspi arvense*).

3.1.3 Forage Dry Matter (DM) Yield

Forage DM yield was significantly affected (P<0.05) by rejuvenation method investigated in both years as well as both years combined (Table 2).

In 2016, only BG appeared to have significantly higher forage DM yield than control. While in 2017, only BG, B&R and M+S showed significantly higher forage DM yield than control.

As shown in Table 2, for both years combined, the total forage DM yield value was highest for BG (6710 kg ha^{-1}), followed M+S (5816 kg ha^{-1}) and then B&R (5412 kg ha^{-1}). In general, for the 2 years forage DM yield, all rejuvenation methods investigated produced 5 - 100% higher forage DM yield than control.

Overall, forage DM yield increased substantially for each rejuvenation method from 2016 to 2017. Pooled over the rejuvenation methods, average forage DM yield was 1573 kg ha^{-1} higher in 2017 than 2016.

Table 2. Forage dry matter (DM) yields and forage composition for different methods in 2016 & 2017 at site 1 (Rycroft)

Rejuvenation Method	Forage DM Yield (kg ha^{-1})		Total DM Yield (kg ha^{-1})	Total DM as % of control	Forage composition (%)					
					Grasses		Legumes		Others/weeds	
	2016	2017			2016	2017	2016	2017	2016	2017
Control	1086	2261	3348	100	60.5	68.8	14.9	17.2	24.6	14.0
Bale grazing	2172	4538	6710	200	78.4	82.2	32.5	17.8	-	-
Break & re-seeding	1621	3791	5412	162	88.0	85.3	-	5.20	12.0	9.50
Seeding in fall	1297	2537	3834	115	51.1	54.0	48.9	43.2	-	2.70
Manure & subsoil in fall	1687	4129	5816	174	55.4	66.1	34.3	24.0	10.3	9.90
Subsoil in fall	1355	2707	4062	121	64.0	73.0	28.7	19.8	7.30	7.20
High stock density grazing	1191	3120	4311	129	89.0	71.0	4.20	6.70	6.80	22.3
Summer pasture rest	1357	2146	3503	105	63.0	74.8	21.6	7.80	-	17.4
Seeding in spring	1717	2407	4124	123	39.4	49.0	47.6	38.6	12.9	12.4
Mean	1498	3071	4569		65.4	69.4	29.1	20	12.3	11.9
Significance	*	**	***		***	***	***	***	*	***
$LSD_{0.05}$	741	985	1023		12.9	16.6	9.26	13.9	6.14	5.96
CV, %	17.3	22.3	16.8		8.14	13.6	21.9	25.7	27.4	23.9

-, indicates no stands available or found.

*, ** and ***, significant at $P<0.05$, $P<0.01$ and $P<0.001$, respectively.

$LSD_{0.05}$, least significant difference at $P<0.05$.

CV, coefficient of variation.

3.1.4 Forage Nutritive Value

Several forage nutritive value parameters were measured, but only 15 of those are provided here (Table 3). Of the 15 forage nutritive value parameters reported here, only forage CP, Ca and P were significantly affected (P<0.05) by rejuvenation methods, and in 2017 only, not in 2016. Other nutritive value parameters reported here were similar (P>0.05) for all methods of rejuvenation investigated including control at this site.

For those forage nutritive parameters that showed some significant differences with respect to rejuvenation methods investigated, M+S and HSDG had higher forage CP values, HSDG recorded higher forage Ca, while M+S, SSF, pasture rest and control showed higher forage P than most of the other rejuvenation methods.

Looking at the rejuvenation methods for forage CP, Ca and P, only M+S and HSDG appeared to have some significant increases in forage CP from 2016 to 2017. Other methods either had similar forage CP, Ca and P values for either years, or slightly lower values in 2017 than 2016.

Table 3. Forage nutritive value (on DM basis) for different methods of rejuvenation in 2016 & 2017 at Site 1 (Rycroft)

	CP (%)		Ca (%)		P (%)		Mg (%)		K (%)	
Rejuvenation method	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Control	10.8	11.1	0.58	0.63	0.20	0.25	0.21	0.20	2.57	2.65
Bale grazing	12.4	11.7	1.01	0.96	0.2	0.21	0.25	0.24	2.24	3.58
Break & re-seeding	12.0	11.1	0.81	0.34	0.24	0.19	0.22	0.20	2.85	3.06
Seeding in fall	10.1	10.2	0.55	0.53	0.22	0.22	0.17	0.17	2.81	2.60
Manure & subsoil in fall	11.2	14.3	0.83	0.81	0.22	0.26	0.30	0.19	2.16	2.64
Subsoil in fall	12.3	10.9	0.80	0.73	0.24	0.27	0.23	0.19	2.49	3.08
High stock density grazing	10.5	13.1	0.70	1.18	0.23	0.23	0.16	0.22	2.3	2.54
Summer pasture rest	11.4	10.2	0.71	0.62	0.25	0.26	0.24	0.17	2.59	2.72
Seeding in spring	9.59	7.87	0.60	0.29	0.27	0.18	0.23	0.13	2.77	2.29
Mean	10.9	11.5	0.69	0.69	0.22	0.23	0.22	0.18	2.51	2.78
Significance	NS[z]	*	NS	*	NS	*	NS	NS	NS	NS
$LSD_{0.05}$	3.55	2.15	0.63	0.43	0.10	0.06	0.15	0.08	0.66	1.23
CV, %	14.7	12.3	41.1	35.4	20.3	11.6	31.5	20.5	12.0	20.1
	ADF (%)		NDF (%)		NFC (%)		TDN (%)		DE (Mcal/kg)	
Rejuvenation method	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Control	40.9	37.1	66.6	59.5	11.8	18.6	55.0	59.0	2.42	2.60
Bale grazing	40.7	36.8	62.3	55.6	14.5	21.9	55.1	59.3	2.43	2.62
Break & re-seeding	40.6	39.0	62.7	64.8	14.6	13.3	55.3	57.0	2.44	2.51
Seeding in fall	43.5	37.6	67.3	60.8	11.8	18.2	52.2	58.5	2.31	2.58
Manure & subsoil in fall	42.1	34.7	66.2	55.4	11.8	19.5	53.6	61.5	2.37	2.71
Subsoil in fall	43.7	36.8	65.4	57.7	11.5	20.6	51.9	59.3	2.30	2.62
High stock density grazing	41.9	36.2	64.7	56.1	14.0	20.0	53.9	60.0	2.38	2.65
Summer pasture rest	42.5	37.6	67.2	61.1	10.6	17.9	53.2	58.5	2.35	2.58
Seeding in spring	41.5	38.4	66.2	64.3	13.4	17.0	54.3	57.6	2.40	2.54
Mean	42.2	37.2	65.7	59.6	12.4	17.9	53.4	58.8	2.35	2.59
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
$LSD_{0.05}$	4.47	5.13	7.45	9.13	5.81	8.28	4.77	5.48	0.21	0.24
CV, %	4.80	6.26	5.14	6.95	21.2	20.9	4.06	4.23	4.10	4.20
	ME (Mcal/kg)		NE_L (Mcal/kg)		NE_M (Mcal/kg)		NE_G (Mcal/kg)		RFV	
Rejuvenation method	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Control	2.01	2.16	1.23	1.33	1.17	1.30	0.61	0.73	80	94
Bale grazing	2.02	2.17	1.24	1.34	1.17	1.31	0.61	0.74	86	101
Break & re-seeding	2.02	2.08	1.24	1.28	1.18	1.23	0.61	0.67	86	85
Seeding in fall	1.91	2.14	1.16	1.32	1.07	1.29	0.52	0.71	77	91
Manure & subsoil in fall	1.97	2.25	1.20	1.39	1.12	1.39	0.56	0.81	79	105
Subsoil in fall	1.90	2.18	1.16	1.34	1.06	1.31	0.50	0.74	78	98
High stock density grazing	1.98	2.20	1.21	1.36	1.13	1.34	0.57	0.76	82	101
Summer pasture rest	1.95	2.14	1.19	1.32	1.11	1.29	0.55	0.71	77	91
Seeding in spring	1.99	2.11	1.21	1.30	1.14	1.25	0.58	0.69	80	86
Mean	1.95	2.15	1.19	1.32	1.11	1.29	0.55	0.72	79.2	94
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
$LSD_{0.05}$	0.17	0.20	0.11	0.13	0.16	0.18	0.15	0.16	13.1	21.8
CV, %	4.08	4.28	4.54	4.63	6.75	6.36	12.7	10.4	7.52	10.5

*, significant at $P<0.05$.

[z], NS, not significant ($P>0.05$)

$LSD_{0.05}$, least significant difference at $P<0.05$.

CV, coefficient of variation

3.1.5 Simplified Economic Performance of Rejuvenation Methods

The combined (2016 & 2017) cost comparison of different rejuvenation methods investigated compared to control is provided in Table 4. As expected, compared to control, the highest input cost was from B&R treatment (CAD $625/ha). However, if the cost of the 60 bales/ha (CAD $2283) used for BG was included in the input costs, then BG would by far have the highest total variable cost/ha with CAD $2570/ha.

Over the 2 years of forage yield data used for the simplified economic analysis, and without taking into consideration the cost of 60 bales/ha used for BG, then BG would have the highest returns/acre of CAD $169/ha, followed by HSDG with a marginal return of CAD $101/ha and then M+S with a marginal return of CAD $36. Using BG (without cost of 60 bales), HSDG, M+S and Rest seemed to give a profit of CAD $155, $87, $22 and $14 respectively over control. The following rejuvenation methods had negative returns/ha: BG (only when the cost of 60 bales was used), B&R, SF, SSF and SS.

Table 4. Summary of simplified economic comparisons of pasture rejuvenation methods at site 1 (Rycroft) for 2 years (2016 & 2017 combined) of forage production

	Control	BG	B&R	SF	M+S	SSF	HSDG[E]	Rest	SS
Output									
Forage DM yield (kg/ha)[A]	3348	6710	5412	3834	5816	4062	4311	3503	4124
Cost/kg hay	$0.09	$0.09	$0.09	$0.09	$0.09	$0.09	$0.09	$0.09	$0.09
Revenue/ha	$301	$604	$487	$345	$523	$366	$388	$315	$371
Input ($/ha)									
Seed[B]			$138	$138					$138
Manure[B]					$57				
Manure application[B]					$32				
Seeding[B]			$49	$49					$49
Land preparation[B]			$151						
Sub-soiling[B]					$111	$111			
Bale grazing[B]		$148 [C] ($2283)[D]							
Haying, baling & hauling*	$287	$287	$287	$287	$287	$287	$287	$287	$287
Total Variable cost/ha	$287	$435 ($2570)[D]	$625	$474	$487	$398	$287	$287	$474
Marginal Returns/ha	$14	$169 (-$1966)	-$138	-$129	$36	-$32	$101	$28	-$103

Note: This is only a simple cost analysis and is not intended as an in depth study of the cost of production. The costs are in Canadian Dollar (CAD $). CAD $1=US $0.78.

[A], Total forage DM yield for 2 years (2016 & 2017).

[B], Costs only used once (2016).

[C], Cost for placing the hay bales.

[D], Cost of 24 hay bales considered.

[E], did not include labour for moving cows.

*, Total costs used for 2 years (2016 & 2017).

3.2 Site 2: Grovedale

3.2.1 Seedling Establishment

Also here at this site, only 3 (B&R, SS, SF) of the 10 rejuvenation methods were seeded with a forage mixture consisting of smooth bromegrass, alfalfa and cicer milkvetch. With an establishment rating of 0 to 5 (5 = good establishment & 0= no establishment), only smooth bromegrass seemed to have some establishment success. Smooth bromegrass had a mean establishment rating of 3 for B&R and a rating of 1 for SS rejuvenation method. No new stands of smooth bromegrass were found in SF method. Alfalfa and cicer milkvetch had zero (0) establishment rating for the 3 methods that involved seeding (B&R, SS, SF).

3.2.2 Forage Composition

The composition of grasses, legumes and other types of plants in the field at site 2 was significantly affected by rejuvenation methods tested in both years (except for others/weeds in 2017).

In 2016, only B&R and SS had >50% grasses in the field (Table 5), while other methods had <50% grasses in the field. In 2017, most methods had >50% grasses in the field, with BG and B&R recording the higher grasses (~78 to 83%) than other methods including control.

In both years, there appeared to be lower legumes in the fields for all methods and generally <50% (Table 5). Both control and BG had significant reductions in legumes from 2016 to 2017. On the other hand, both HSDG and SS showed greater increases in legumes in the field over the same period.

In 2016, the significant effects of rejuvenation methods on other plants/weeds showed that HSDG and SS had more of other plants/weeds in the field than other methods including control. Generally, for some reason, there appeared to be a reduction in other plants from 2016 to 2017 for all methods, with HSDG showing the highest reduction, followed by SS and then BG.

3.2.3 Forage Dry Matter (DM) Yield

The forage DM yield in 2016 and 2017 as well as total forage DM yield from both years were significantly affected ($P<0.05$) by rejuvenation methods investigated here.

In 2016, only BG and FA showed significant ($P<0.05$) increases in forage DM over control. In 2017, other than SF, other methods seemed to show significantly higher forage DM than control. In both years, compared to other methods, BG by far had more forage DM yield than control, with as much as 1440 kg ha^{-1} higher DM in 2016 and up to 4111 kg ha^{-1} higher DM in 2017.

The resulting total forage DM from 2016 and 2017 (Table 5), showed that BG had the highest total forage DM (8084 kg ha^{-1}), followed by FA (5348 kg ha^{-1}), HSDG (4320 kg ha^{-1}) and then B&R (4110 kg ha^{-1}). Generally, all methods resulted in higher total forage DM yield than control, but the most increases with about 220% over control came from BG.

Table 5. Forage DM yields and forage composition for different methods in 2016 & 2017 at site 2 (Grovedale)

Rejuvenation Method	Forage DM Yield (kg ha^{-1})		Total DM Yield (kg ha^{-1})	Total DM as % of control	Forage composition (%)					
					Grasses		Legumes		Others/weeds	
	2016	2017			2016	2017	2016	2017	2016	2017
Control	1027	1506	2533	100	42.5	64.3	40.5	18.8	17.0	16.9
Bale grazing	2467	5617	8084	319	49.0	82.7	21.2	8.10	29.8	9.20
Break & re-seeding	1089	3022	4110	162	59.2	77.7	15.9	10.7	24.7	11.6
Seeding in fall	1331	1525	2856	113	46.8	53.2	31.5	36.5	21.8	10.3
Fertilizer application	1841	3507	5348	211	33.7	52.6	40.7	38.7	25.5	8.70
High stock density grazing	1546	2774	4320	171	48.7	55.1	10.0	39.0	41.3	8.90
Subsoil in fall	959	2401	3360	133	37.7	46.4	45.2	38.2	17.1	15.5
Seeding in spring	1034	2308	3342	132	54.2	49.7	10.2	41.5	35.5	8.90
Mean	1412	2833	4244		46.5	60.2	26.9	28.9	26.6	11.3
Significance	***	***	***		***	**	**	**	*	NS^{Z}
$LSD_{0.05}$	673	865	1219		8.02	10.3	20	17.5	1.9	13.2
CV, %	21.2	18.7	20.3		7.41	10.8	27.4	35.2	22.9	51.1

*, ** and ***, significant at $P<0.05$, $P<0.01$ and $P<0.001$, respectively.

^{Z}, Not significant ($P>0.05$)

$LSD_{0.05}$, least significant difference at $P<0.05$.

CV, coefficient of variation.

3.2.4 Forage Nutritive Value

Of the 15 forage nutritive value parameters reported here, only 2 (forage CP and NE_M, both in 2017) were significantly affected (P<0.05) by rejuvenation methods investigated here at this site (Table 6). The other 13 forage nutritive value parameters measured had similar results (P>0.05) with respect to methods of rejuvenation.

The significant effect of rejuvenation methods on forage CP in 2017 showed that BG in all cases significantly (P<0.05) had higher forage CP than other methods including control (Table 6). The forage CP from BG almost doubled those of control and SF.

The significant effect of methods investigated here on NE_M in 2017 showed that most methods were similar in forage NE_M, but with FA, SF, SSF and BG rejuvenation methods significantly (P<0.05) showing higher forage NE_M than control (Table 6). Other methods had similar forage NE_M with control.

Table 6. Forage nutritive values (DM basis) for different methods of rejuvenation in 2016 & 2017 at Site 2 (Grovedale)

	CP (%)		Ca (%)		P (%)		Mg (%)		K (%)	
Rejuvenation method	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Check	12.1	10.9	0.96	0.42	0.25	0.20	0.24	0.15	2.55	2.01
Bale grazing	12.9	20.6	0.70	0.76	0.22	0.28	0.16	0.17	2.56	3.33
Break & re-seeding	11.7	13.8	1.01	0.65	0.24	0.25	0.23	0.16	3.17	2.38
Fall seeding	13.4	10.7	1.03	0.44	0.24	0.23	0.24	0.13	2.82	2.24
Fertilizer application	12.6	15.9	0.96	0.99	0.29	0.26	0.21	0.25	2.78	2.82
High stock density grazing	13.6	15.3	1.09	0.98	0.21	0.22	0.22	0.18	2.96	2.73
Subsoil in fall	14.8	12.5	1.36	0.66	0.22	0.25	0.27	0.15	2.65	2.40
Spring seeding	14.0	11.8	1.12	0.41	0.23	0.26	0.28	0.14	2.88	2.25
Mean	13.1	13.9	1.0	0.7	0.2	0.2	0.2	0.2	2.8	2.5
Significance	NS [Z]	*	NS	NS	NS	NS	NS	NS	NS	NS
$LSD_{0.05}$	3.27	3.31	0.58	0.64	0.04	0.06	0.09	0.09	0.57	0.86
CV, %	10.9	13.9	25.0	46.8	9.13	11.5	18.1	25.7	9.39	15.3
	ADF (%)		NDF (%)		NFC (%)		TDN (%)		DE (mcal/kg)	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Check	35.7	38.1	54.1	62.9	23.0	15.4	60.5	58.0	2.67	2.56
Bale grazing	36.5	35.0	58.8	58.1	17.5	10.5	59.7	61.2	2.63	2.70
Break & re-seeding	36.3	38.3	55.0	63.2	22.5	12.2	59.9	57.8	2.64	2.55
Fall seeding	35.5	34.5	55.1	58.4	20.7	20.1	60.8	61.8	2.68	2.73
Fertilizer application	37.5	34.1	58.0	53.9	18.6	19.4	58.6	62.2	2.59	2.75
High stock density grazing	35.4	36.7	53.4	58.2	22.2	15.7	60.8	59.4	2.69	2.62
Subsoil in fall	35.7	34.8	53.0	59.0	21.4	17.7	60.5	61.5	2.67	2.71
Spring seeding	36.3	36.7	54.4	62.7	20.8	14.8	59.9	59.4	2.64	2.62
Mean	36.1	36.0	55.2	59.6	20.8	15.7	60.1	60.2	2.7	2.7
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
$LSD_{0.05}$	4.94	2.91	10.7	7.95	9.68	6.51	5.28	3.11	0.23	0.14
CV, %	6.19	3.65	8.75	6.00	20.7	18.2	3.92	2.31	3.99	2.36
	ME (mcal/kg)		NE_L (mcal/kg)		NE_M (mcal/kg)		NE_G (mcal/kg)		RFV (mcal/kg)	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Check	2.22	2.13	1.37	1.31	1.35	1.27	0.77	0.70	106	88
Bale grazing	2.19	2.24	1.35	1.39	1.33	1.38	0.75	0.80	99	99
Break & re-seeding	2.20	2.12	1.35	1.30	1.33	1.26	0.76	0.76	103	88
Fall seeding	2.23	2.27	1.37	1.40	1.36	1.40	0.78	0.82	104	99
Fertilizer application	2.15	2.28	1.32	1.41	1.29	1.41	0.72	0.82	97	108
High stock density grazing	2.23	2.18	1.38	1.34	1.36	1.32	0.79	0.74	107	97
Subsoil in fall	2.22	2.25	1.37	1.39	1.35	1.38	0.78	0.80	108	98
Spring seeding	2.19	2.17	1.35	1.34	1.33	1.32	0.76	0.74	104	90
Mean	2.2	2.2	1.4	1.4	1.3	1.3	0.8	0.8	103.5	95.9
Significance	NS	NS	NS	NS	NS	*	NS	NS	NS	NS
$LSD_{0.05}$	0.19	0.11	0.12	0.07	0.17	0.10	0.16	0.09	25.3	15.5
CV, %	3.92	2.26	4.25	2.52	5.88	3.35	9.40	5.67	10.9	7.27

*, significant at $P<0.05$.

[Z], NS, not significant ($P>0.05$)

$LSD_{0.05}$, least significant difference at $P<0.05$.

CV, coefficient of variation

3.2.5 Simplified Economic Performance of Rejuvenation Methods

Table 7 shows the combined (2016 & 2017) cost comparison of different rejuvenation methods investigated compared to control. As expected, the highest input cost was from the B&R treatment (CAD $692/ha), which was CAD $225 - $4051 higher than other methods including control. However, when the cost of the 60 bales/ha used for BG (CAD $2283) was factored into the input costs, then BG would by far have the highest total variable cost/ha with CAD $2570/ha. Over the 2 years of forage yield data used (2016 & 2017) for the simplified economic analysis, and without taking into consideration the cost of 60 bales used for BG, then BG would have the highest returns/ha of CAD $293/ha, followed by HSDG with a marginal return of CAD $102/ha and the FA with a return of CAD $24/ha. For other methods (including control), the returns were negative, with the highest loss coming from BG (-CAD $1842/ha) when the 60 bales used for BG system was taken into consideration. But, when the cost of 60 bales used for BG was not considered, then, B&R would have the most loss (-CAD $322/ha).

Table 7. Summary of simplified economic comparisons of pasture rejuvenation methods at site 2 for 2 years (2016 & 2017 combined) of forage production

	Control	BG	B&R	SF	FA	SSF	HSDG [E]	SS
Output								
Forage DM yield (kg/ha)[A]	2533	8084	4110	2856	5348	3360	4320	3342
Cost/kg hay	$0.09	$0.09	$0.09	$0.09	$0.09	$0.09	$0.09	$0.09
Revenue/ha	$228	$728	$370	$257	$481	$302	$389	$301
Input Cost ($/ha)								
Seed[B]			$131	$131				$131
Fertilizer (blend)[B]			$74		$148			
Fertilizer application[B]					$22			
Seeding[B]			$49	$49				$49
Land preparation[B]			$151					
Deep tillage (sub-soiling)[B]						$111		
Bale grazing[B]		$148 [C] ($2283)[D]						
Haying, baling & hauling*	$287	$287	$287	$287	$287	$287	$287	$287
Total Variable cost/ha	$287	$435 (2570)[C]	$692	$467	$457	$398	$287	$467
Marginal Returns/ha	-$59	$293 (-$1842)	-$322	-$210	$24	-$96	$102	-$166

Note: This is only a simple cost analysis and is not intended as an in depth study of the cost of production. The costs are in Canadian Dollar (CAD $). CAD $1=US $0.78.

[A], Total forage DM yield for 2 years (2016 & 2017).

[B], Costs only used once (2016).

[C], Cost for placing the hay bales.

[D], Cost of 24 hay bales considered.

[E], did not include labour for moving cows.

*, Total costs used for 2 years (2016 & 2017).

4. Discussion

The findings from the present study are discussed as relating to selecting appropriate pasture rejuvenation methods for optimum beef cattle production systems, with focus on forage seeding establishment success, forage yield and nutrition quality in relation to the National Research Council (NRC, 1996 & 2000) nutrient requirements of beef cattle (Table 8) as well as economic performance of the different methods investigated.

4.1 Seedling Establishment and Plant Survival

In the present study, at both sites, seedling establishment from the 3 methods that involved seeding (break & re-seeding, spring and fall seeding into the existing vegetation) was generally poor, though the initial laboratory germination tests showed about 94% germination for the forage seed used here. The year 2015 was generally dry (low moisture) and far warmer (than LTA) at both sites and that was thought to be partly responsible for the poor establishment particularly for break & re-seeding, which had very little or no competition from existing vegetation. The smooth bromegrass did better than cicer milkvetch and alfalfa probably because it is resistant to drought and extremes in temperature (Bush, 2006). Observations in 2015 and 2016 showed severe grasshopper infestations at both sites, with greater damages on young plants. The grasshoppers consumed the young plants to ground level. Forage losses are seldom estimated, but it has been shown that even a moderate infestation of 10 grasshoppers/square meter can typically consume up to 60 per cent of the available forage, depending on the condition of the forage stand (Calpas & Johnson, et al., 2003). Competition between any new seedlings and existing vegetation particularly for direct spring and fall seeding could also be responsible for the general poor seedling establishment particularly for spring seeded treatment methods.

4.2 Forage Components

At both sites, grasses were more dominant than legumes, with bale grazing and break & re-seeding recording >70% than other methods as well as control. The legume component on the other hand was generally <50%. The higher percent legumes particularly from clovers and native vetches from spring and fall seeding were thought to have resulted from seed banks in the field, as no clover and native vetches were seeded in this study. The slight soil disturbance created during the seeding in spring and fall may have helped to create better seed to soil contact for both clovers and native vetches, hence the higher percent of legumes for the spring and fall seeding methods.

Observations at both sites showed that bale grazing system with its high soil nutrients (N, P and K) density

(Omokanye et al. 2018) did not favour the growth of meadow brome grass stands and alfalfa. Both meadow brome grass stands and alfalfa tended to disappear quickly in bale grazed areas. On the other, smooth brome and quack grass did very well and dominated wherever they were present. Research effort is needed to on ways to increase the amount of legumes in pastures particularly for bale grazing system and high stock density grazing, as these 2 methods seemed to be dominated by grasses than legumes. Broadcast (over-seeding) prior to bale grazing or high stock density grazing could help increase the amount of legumes in the pastures. Broadcast seeding is an easy and inexpensive. Other methods that require further investigation are (i) mixing cicer milkvetch seed with minerals for cows and (ii) feeding hay bales containing mature cicer milkvetch pods to cows. These methods will let the cows do the seeding through their feces.

4.3 Forage Dry Matter (DM) Yield

By increasing forage production on grazing land, higher stocking rates can be used and animal performance may improve (BCRC, 2016).

Overall, in this study, over the 2 years of data collection at both sites, the top 4-5 forage DM yielder were bale grazing, manure + subsoil in fall, break & re-seeding, high stock density grazing and fertilizer application. Impressively, 2 years (2017) after the rejuvenation methods were implemented, bale grazing (at both sites), manure + subsoil in fall (only done at site 1) and inorganic fertilizer application (only done site 2) showed greater potential in improving forage DM yield than other methods investigated. In both years, bale grazing consistently produced higher forage DM yield than other methods including control, with bale grazing giving up to 100% higher yield at site 1 and 219% at site 2 for the 2-year total forage DM yield (see Tables 2 & 5 above). The higher forage production from bale grazing system compared to control over a short time in this study, further confirms earlier reports in western Canada by Jungnitsch et al. (2011), Omokanye (2013 & 2014) and Picard (2010) on the impressive forage production from bale grazing system. The higher forage DM yield produced across the years or in any particular year (mainly for the top forage DM yielders, such as bale grazing, manure + subsoil in fall, break & re-seeding, high stock density grazing and fertilizer application), could be associated in part to some or most of the following parameters: improved soil physical conditions (infiltration rate, soil moisture and compaction) and soil nutrients (N, P & K in particular) as reported by Omokanye et al. (2018) in the same study.

Using break & re-seeding rejuvenation as method to renew pastures will work well when conditions are favorable (e.g. weather and soil) and with the right management decisions (e.g. right forage mixture, seeding equipment and seeding date, history of site). In this study, at both sites, we did not get the much anticipated results (seedling establishment and forage DM yield) from break & re-seeding as a means of pasture renewal. The break & re-seeding treatment was tilled and seeded into dried soils in 2015. The year (2015) was a dry year (low moisture) generally in northern Alberta as well as at both sites used for this study.

In this study, when dry fertilizer application (as seen at site 2) was done as a method of forage stand rejuvenation, there seemed to be better forage production from it than control. The resulting benefit from fertilizer application was 814 kg ha^{-1} forage DM in 2016 and 2000 kg ha^{-1} forage DM in 2017 over control, indicating that the residual effect of fertilizer can last for more than a year fertilizer application as a strategy for rejuvenating pastures. As observed in the present study, earlier research also indicated that fertilization could bring the productivity of a stand back without the expense of re-seeding (BCRC, 2016).

Seeding directly into existing pastures as done in this study (spring vs fall) did not seem to improve forage DM yield to a large extent over control at both sites. The forage yield advantage from the no-till drill and seeding times did not exceed 631 kg ha^{-1} forage DM at site 1 and 955 kg ha^{-1} forage DM at site 2. The failure could be attributed again to dry weather, grasshopper infestations and in particular, the effect of competition from the existing vegetation at the time of seeding particularly for spring seeding.

Taking into consideration unpredictable yearly weather conditions (rainfall in particular), competition from existing stands with new seedlings (using direct seeding without spraying out the old forage stand) and the high cost (as seen in Tables 4 & 7 above) and time that could be associated with forage stand termination and re-establishment, and the fact that one may not get the expected results because of these various factors as noted in the present study, it is evident that bale grazing, manure + subsoiling and high stock density grazing in that order would be the top 3 potential methods of pasture rejuvenation or some of the best options for sustaining pasture production and livestock carrying capacity of tired pastures.

Since grazing puts a stress on pasture plants, a successful grazing system must include a sufficient rest period (Hand & Lopetinsky, 1998). In the present study, pasture rest treatment method that was done at site 1 did not seem to perform better than control. Earlier report on studies by Durunna et al. (2015), in western Canada, indicated that there was no difference in total forage yield, carrying capacity, forage disappearance or forage residue between the conventional and rested sections of the perennial pastures.

4.4 Forage Nutritive Value

In this study, over time (by 2017), better forage CP and Ca contents resulted from methods which had external nutrients [organic (manure & feces) or inorganic fertilizer] added to their systems such bale grazing, manure application + subsoiling, high stock density grazing and fertilizer application at both sites. Though most forage indicators reported were similar for the methods investigated, but one obvious fact was that forage CP from bale grazing at site 2 in 2017 far exceeded forage CP obtained from other methods. This further confirms the benefits of bale grazing in improving forage quality (Jungnitsch et al., 2011; Omokanye, 2013 & 2014; Picard, 2010).

To be effective, the nutrients supplied by the pasture must be in balance with the nutrients required by grazing cattle. It important to re-emphasize that the quality of pasture is just as critical for grazing beef cattle as the quantity of pasture available. Pasture provides livestock with nutrition, vitamins, minerals and trace elements - promoting animal health and productivity. Table 8 below shows some of the recommended nutrient requirements for beef cows from NRC (1996, 2000).

Taking into consideration that mature beef cattle require 11% CP, the resulting forages from the different rejuvenation methods was mostly adequate in CP for mature beef cattle (except on a few instances at site 1) in both years. At site 1, fall and spring seeding were only conveniently able to meet the CP requirements of a dry gestating cow either in mid (7% CP) or late pregnancy (9% CP) or both (9% CP). The lower forage CP obtained for fall and spring seeding at site 2 is difficult to explain, this is because both methods tended to have slightly higher legumes in the field than other methods including control. It was thought that the legumes would have improve the forage CP content than what was obtained here. Nevertheless, the importance of legumes still needs to be re-emphasize in pastures and ways of adding legumes into pastures without having to break & re-seeding require further investigation.

At site 1, except for break & re-seeding (in 2017), fall seeding (in 2016 & 2017) and spring seeding (in 2017), all methods of rejuvenation seemed to have adequate forage Ca for mature beef cattle according to NRC recommendations (NRC, 1996, 2000). At site 2, five (5) of the methods investigated (bale grazing, break & re-seeding, fertilizer application, high stock density grazing and subsoil alone in fall) consistently exceeded the Ca needed by mature beef cattle.

Table 8. Recommended nutrient requirements for beef cattle from NRC (1996, 2000)

Nutrient	Requirement		
	Growing & finishing calves	Dry gestating cows	Lactating cows
CP (%)	12-14	7-9*	11
Ca (%)	0.31	0.18	0.58
P (%)	0.21	0.16	0.26
Mg (%)	0.10	0.12	0.20
K (%)	0.60	0.60	0.70
Na (%)	0.06-0.08	0.06-0.08	0.10
S (%)	0.15	0.15	0.15
Cu (ppm)	10	10	10
Zn (ppm)	30	30	30
Fe (ppm)	50	50	50
Mn (ppm)	20	40	40
NE_M (MCal kg^{-1})	1.08-2.29	0.97-1.10	1.19-1.28
NE_G (MCal kg$^{-1)}$	0.53-1.37	NA^Y	NA
TDN (%)	65-70^W	55-60^Z	65

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

At both sites the P and Mg requirements of mature beef cattle were not consistently being met by all methods tested in both years. However, at both sites in both years (2016 & 2017), all methods including control had met and far exceeded the K requirements of mature beef cattle as suggested by NRC (1996, 2000). Because of the inability or inconsistencies of any particular methods examined in this study to meet the complete macro mineral requirements of mature beef cattle as recommended by NRC (1996 & 2000), it therefore suggests that some form of mineral supplementation to address the short fall of some macro minerals is needed for cows on pasture during grazing. Except on a few instances at site 1, all methods of rejuvenation as well as control had enough

TDN for a dry gestating cow in mid pregnancy in 2016. But in 2017, all methods had adequate TDN according to NRC (1996, 2000) recommended values for dry gestating cows in mid pregnancy, and only manure application + subsoil and high stock density grazing conveniently met the needed 60% TDN by a dry gestating cow in late pregnancy. However, at site 2, most methods had enough TDN for dry gestating cows in mid and late pregnancy in both years. None of the methods at both sites in any year was able to meet the TDN requirement of a lactating beef cow as suggested by NRC (1996, 2000), indicating some form of energy supplement may be necessary when grazing lactating or nursing cows on pastures.

In terms of the requirement for net energy for maintenance (NE_M), all methods were well within the 1.19-1.28 Mcal/kg for mature beef cattle, as well as the 1.08-2.29 Mcal/kg needed by young beef cattle as recommended by NRC (1996, 2000). But in terms of net energy for gain (NE_G) needed by growing and finishing calves, all methods including control were within the suggested 0.53-1.37 Mcal/kg at site 2, but not at site 1. At site 1, in 2016 only, fall seeding just fell short of meeting the required NE_G by growing and finishing calves.

Forage samplings for yield determination and quality indicators were done in July of 2016 and 2017, which coincided with the period of haying and baling in the area. The forage materials were thought to have slightly mature and this probably affected some forage quality indicators to some extent. Better quality would have been derived from sampling earlier in June than done in July.

4.5 Economic Performance

Finally, the choice of rejuvenation method will depend on relative cost of method, time and labor availability, and field limitations.

In the present study, at both sites, as expected, the highest input cost was from break & re-seeding treatment (CAD $625/ha). However, the input cost of bale grazing could be as high as CAD $2570/ha when the number of bales placed on one ha for bale grazing was considered. In the same environment, on-farm studies have shown that the effects of bale grazing on improved soil health conditions (infiltration, compaction, water holding capacity and soil N, P and K) and forage yield and quality could last for several years depending on pasture management and soil texture (Omokanye, 2015). Soil texture has been found to affect soil nutrient retention and leaching particularly those of N, P and K in bale grazing system (Omokanye, 2014).

With the total forage yield data (2016 & 2017) used for the simplified economic analysis over the period of this study, and without taking into consideration the cost of 60 bales used for bale grazing, then bale grazing would have the highest return/ha (CAD $169-293/ha for 2 years). This would be followed by high stock density grazing (which was done to create a mob grazing effect) with a return of just over CAD $100/ha for 2 years. The returns were negative for most of other methods investigated over the 3-year study period, an indication that further research is needed on strategies to improve older forage stands or pastures in northern Alberta. In the present study, most rejuvenation methods investigated entailed significant financial risk over the study period probably because moisture was limiting in 2015, a condition which did not seem to affect bale grazing system as the pastures in that system were able to bounce back easily following bale grazing in the following winter. Because of the long-term effects of bale grazing and high stock density grazing in terms of soil nutrients distribution and availability, both rejuvenation methods would not entail financial risk as they both appear to be cost effective.

5. Conclusion

Producing high quality forage and maintaining productive forage stands is a major challenge that Alberta's beef producers encounter, as rejuvenation is a complex and costly challenge for producers. However, rejuvenation as a pasture management strategy for rapid improvement of high performance grazing should still have a significant positive impact on sustainability and competitiveness of the cattle industry. There are a number of strategies that can improve the yield and quality of cultivated pastures.

In the present study, the top forage DM yielders were bale grazing, manure application + subsoil in fall, break & re-seeding, high stock density grazing and fertilizer application. Their performance in terms of forage DM yield could likely be associated in part to improved soil physical conditions such infiltration rate, soil moisture and compaction; and soil nutrients (N, P, and K in particular) earlier report as parts of the present study by Omokanye et al. (2018). Overall, bale grazing produced far more forage DM yield than other rejuvenation methods investigated here. Fertilizer application produced a forage yield advantage of up 2000 kg ha^{-1} forage DM in 2017 over control, indicating that fertilizer application can be used to bring the productivity of a stand back, without the expense of re-seeding. Using fertilizer has potential to substantially increase forage yield and quality, and has potential to improve condition of forage stand.

This study further confirms that manure can be a valuable source of plant nutrients and organic matter and when used as a fertilizer, will improve forage production and soil quality (as seen with manure application + subsoil in fall as well as bale grazing and high stock density grazing, which were thought to have higher manure (fresh or stockpile) concentrations than other methods of rejuvenation. Forages offer an opportunity for manure application, though not all of the nutrients in manure are immediately available to the crop. Depending on amounts of nutrients applied and growing conditions, improvement in forage yield and quality would usually last at least two to three years (Springer, 1999),

The simplified economic analysis done in this study shows that the direct input cost of renewing or rejuvenation an old forage stand could be as high as CAD $625/ha with the break & re-seeding method and as high as $2570/ha for bale grazing (cost of 60 hay bales/ha included). Bale grazing seemed to have higher direct input costs than other methods, but it is important to note that the effects of bale grazing on improved soil health conditions (infiltration, compaction, water holding capacity and soil N, P and K) and forage yield and quality could last far longer than other methods investigated here. In this study, most rejuvenation methods investigated entailed significant financial risk over the study period probably because moisture was limiting in 2015, a condition which did not seem to affect bale grazing system as the pastures in that system were able to bounce back easily following bale grazing in the following winter. Because of the long-term effects of bale grazing and high stock density grazing in terms of soil nutrients distribution and availability, both rejuvenation methods would not entail financial risk as they both appear to be cost effective.

Overall, without having to break & re-seeding, the 3 top suggested methods of pasture rejuvenation that are expected to reduce time for rejuvenation and loss of productivity, are bale grazing, manure application + sub-soiling and high stock density grazing (that is followed by a period of long pasture rest in the same year). Research will continue on methods of adding legumes in pastures for improving soil health, forage productivity, livestock carrying capacity and profit. The research will further help to identify appropriate legume species and cultivar that can give best complementary effects for different rejuvenation options.

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References

AAF (Alberta Agriculture & Forestry). (2015). *2015 Cropping Alternatives-Economics & Competitiveness.* Alberta Agriculture & Forestry, Government of Alberta. Prepared April 16, 2015. https://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/econ15298/$FILE/2015%20Cropping%20Alternatives.pdf

AAF (Alberta Agriculture & Forestry). (2016). *2016 Cropping Alternatives-Economics & Competitiveness.* Alberta Agriculture & Forestry, Government of Alberta. Prepared December 15, 2015. https://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/econ15298/$FILE/2016.pdf

AAF (Alberta Agriculture & Forestry). (2017). *2017 Cropping Alternatives-Economics & Competitiveness.* Alberta Agriculture & Forestry, Government of Alberta. Prepared January 23, 2017. https://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/econ15298/$FILE/2017%20Cropping%20Alternatives.pdf

Aasen, A., & Bjorge, M. (2009). *Alberta Forage Manual*. 2nd Edition. Alberta Agriculture & Forestry, Edmonton, Alberta.

Acharya, S. N. (2015). *Introduction of bloat free-legumes into existing pastures for high performance cattle grazing*. Poster presentation. ALMA conference, Calgary, Alberta.

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.

Association of Official Analytical Chemists (AOAC). (1995). *Official methods of analysis.* 16th edition. AOAC Int., Gaithersburg, MD, USA.

Barnhart, S. K. (1995). *Evaluating hay and pasture stands for winter injury*. Iowa State Univ. Coop. Ext. Serv. Bull. No. 1362. 4 pp.

BCRC (Beef Cattle Research Council). (2016). *Improving Forage Yields*, Beef Cattle Research Council. http://www.beefresearch.ca/research-topic.cfm/improving-forage-yields-84?language=&print

Bush, T. (2006). *Smooth brome* (*Bromus inermis* Leyss.). Plant Fact Sheet. USDA NRCS. https://plants.usda.gov/factsheet/pdf/fs_brin2.pdf

Calpas, J., & Johnson, D. (2003). *Grasshopper Management.* Alberta Agriculture, Food and Rural Development, March 2003, Agdex 622-27. https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex6463/$file/622-27.pdf?OpenElement

Conlin, T. S. S., & van den Driessche, R. (2000). Response of soil CO_2 and O-2 concentrations to forest soil compaction at the Long-term Soil Productivity sites in central British Columbia. *Can. J. Soil Sci., 80*, 625-632. https://doi.org/10.4141/S99-085

Durunna, O. N., Baron, V., Scott, S. L., Robins, C., Khakbazan, M., & Block, H. C. (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. https://doi.org/10.1139/CJAS-2014-046

GenStat. (2009). *GenStat for Windows* (12th Edition). *Introduction*. VSN International, Hemel Hempstead.

GOS (Government of Saskatchewan). (2015). *Pasture Rejuvenation.* Government of Saskatchewan, August 2015. http://www.saskforage.ca/images/pdfs/Publications/Pasture%20rejuvenation%20Aug%202015.pdf

Hand, R., & Lopetinsky, K. (1998). Grazing Tame Pastures Effectively, Alberta Agriculture. Agdex 130/53-1. https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex113?opendocument

Jungnitsch, P., Schoenau, J. J., Lardner, H. A., & Jefferson, P. G. (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. https://doi.org/10.1016/j.agee.2011.02.024

Lardner, H. A., Wright, S. B. M., Cohen, R. D. H., Curry, P., & MacFarlane, L. (2002). Rejuvenation affects nutritive value of long-established tame forages. *Can. J. Anim. Sci., 82*, 621-626. https://doi.org/10.4141/A02-032

Malhi, S. S., Heier, K., Nielsen, K., Davies, W. E., & Gill, K. S. (2000). Efficacy of pasture rejuvenation through mechanical aeration or N fertilization. *Can. J. Plant Sci., 80*, 813-815. https://doi.org/10.4141/P99-150

Nazarko, O. (2008). *Seeding forages into existing stands using minimal tillage*. Agriculture & Agri-Food Canada and Manitotba Forage Council, 39 pages. Winnipeg: MB, 2008

NRC (National Research Council). (1996). *Nutrient Requirements of Beef Cattle.* 7th rev. ed. Natl. Acad. Press, Washington, D.C.

NRC (National Research Council). (2000). *Nutrient Requirements of Beef Cattle.* 7th rev. ed. Update 2000. Washington, DC: The National Academies Press.

Omokanye, A. (2014). *Whole farm nutrient budgeting*: Soil nutrient changes and forage production (2012-2014). Peace Country Beef & Forage Association 2014 Annual Report. Pp. 68-81.

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. & Environ. Sci., 13*(6), 877-884.

Omokanye, A. T. (2015). Soil health and forage production potential of 6 beef cattle production systems in the Peace. Presentation at Peace Country Beef & Forage Association Annual General Meeting, DMI, Fairview, Alberta. Canada. February 20, 2015.

Omokanye, A. T., Yoder, C., Sreekumar, L., Vihvelin, L., & Benoit, M. (2018). On-farm Assessments of Pasture Rejuvenation Methods on Soil Quality Indicators in Northern Alberta (Canada). *Sustainable Agriculture Research*, *7*(2), 74-93. https://doi.org/10.5539/sar.v7n2p74

Pearen, J. R., & Koeghan, J. M. (1982). A review of factors influencing successful pasture renovation. *Trop. Agric. (Trinidad), 59*, 179-182.

Picard, R. (2010). Nutrient cycling in winter grazing cattle on pasture; three years following bale grazing. Manitoba Agronomists Conference Proceedings 2010. [Online].Available at http://umanitoba.ca/afs/agronomists_conf/2010/poster_pdf/Rejean_Picard _bale_grazing.pdf.

Schellenberg, M.P., Waddington, J., Jorgenson, T., Stranger, S., & Springer, S. (1998). *Pasture Renovation Systems: Pasture and Hayfield Rejuvenation.* Final Report, Canada - Saskatchewan Agriculture Green Plan Agreement. 25 pp Mimeo.

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. 38 pp.

Shestak, C. J., & Busse, M. D. (2005). Compaction alters physical but not biological indices of soil health. *Soil Sci. Soc. Am. J., 69*, 236-246. https://doi.org/10.2136/sssaj2005.0236

Soil Classification Working Group. (1998). *The Canadian system for soil classification*. Agric. and Agri-Food Canada, Publ.1646. Revised (3rd ed.), 187pp.

Springer, B. (1999). *Rejuvenation of tame forages*. Saskatchewan Agriculture, Food and Rural Revitalization. http://www1.foragebeef.ca/$foragebeef/frgebeef.nsf/all/frg48/$FILE/rejuvtameforagessouthernsk.pdf

Statistics Canada. (2012). *2011 Census of Agriculture*. Agriculture Statistics. Statistics Canada, Ottawa, released May 10, 2012.

Statistics Canada. (2018). *Cattle inventories, by province (Canada),* Statistics Canada. *http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/prim50a-eng.htm*

Vogel, K. P., & Masters, R. A. (2001). Frequency grid -A simple tool for measuring grassland establishment. *J. Range Manage. 54*, 653-655. https://doi.org/10.2307/4003666

Waddington, J. (2017). *Pasture Rejuvenation*. www.foragebeef.ca. https://www.google.ca/search?as_q=pasture+rejuvenation&as_qdr=all&as_sitesearch=foragebeef.ca&as_occt=any&safe=images&gws_rd=ssl#