Evaluation of alfalfa and grass species in binary and multi mixtures on performance under soil salinity conditions

ADOPT Project #20180455

Final Report

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Project Identification

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Objectives and Rationale

7. **Project Objectives**
Determine the effect of synergies between saline tolerant forages including grass and legume species on soil salinity, biomass, quality, composition, persistence, and weed suppression.

8. **Project Rationale**
Soil salinity is an issue that affects an estimated 6% of the world's land surface area or 12 780 million ha and secondary salinization from irrigation impacts an estimated 20% of irrigated land or 1474 M ha (Chinnusamy, et al., 2005; Munns, 2011). Steppuhn (1996) and Wiebe et al. (2007) concluded that some 20 million of 67 million ha (30%) of land across the Canadian Prairies either openly showed salinization (6 million ha) or were at risk of being salinized in 2001. Many livestock producers have observed a return of soil salinity issues on their pastures and hay fields during the recent wet growing seasons in Saskatchewan. Typical forage mixtures for hay and grazing lack the salinity tolerance needed for these affected soils and forage yield can be reduced. In extreme salinity situations, no forage yield is produced and economic returns from these areas to the producer are severely impacted. According to the Saskatchewan Ministry of Agriculture report (2017), there are 250,000 ha in Saskatchewan where the soil salinity has effectively reduced the yield potential to zero. This

is a cost to the landowner and to agriculture at large as neither will gain any economic value from these areas. In addition, there are several million acres where salinity has reduced yield but still allows for some production. These acres may benefit from reclamation with saline tolerant forages and then be returned to a higher productivity state in the future. Improving saline affected soils could generate millions of dollars in return to producers by mitigating these losses.

Methodology and Results

9. Methodology

The field site on NE corner of NE 21-34-03 was surveyed with an EM-38 soil meter to determine the area of salinity in spring 2019. Using a hand Dutch auger, spring soil samples (0-15, 15-30, and 30-60 cm depths) were taken for analyzing salt concentrations, soil nutrients (N, P, K, and S), soil carbon, moisture content, and electrical conductivity measurements.

- Following this, an area representing a gradient of soil salinity was selected for seeding in spring 2019 with slender wheatgrass (SWG, *Agropyron trachycaulum* [Malte]; cv. Revenue), smooth bromegrass (SBG, *Bromus inermis* Leyss.; cv. Radisson), creeping meadow foxtail (CMF, *Alopecurus arundinaceus;* cv. Garrison), and salt-tolerant alfalfa (HaALF, *Medicago sativa* L., cv. Halo).
- Alfalfa was seeded in binary mixtures with SWG, SBG, and CMF, and in quaternary mixture with all 3 grasses (SWG, SBG, and CMF). The 4 treatments included: (i) HaALFSWG; (ii) HaALFSBG; (iii) HaALFCMF; and (iv) HaALFSWGSBGCMF.
- Replicated treatments were randomly allocated to 6.2 × 1.2 m (7.44-m^2) plots for a total of 16 plots (n=4). Plots were established in the spring 2019.
- Before seeding, plots were weeded through rototilling. Plots were seeded on June 27, 2019 using pull-type 2019 Wintersteiger (WinterSteiger, Salt Lake, UT) at 15.2-cm row spacing and 1.3-cm seeding depth. Seeding rates were HaALF at 9.7 kg/ha, SBG at 13.75 kg/ha, CMF at 2.65 kg/ha, and SWG at 12.90 kg/ha in binary mixtures; for HaALF + SBG + CMF + SWG mixture, seeding rates were HaALF at 9.7 kg/ha, SBG at 13.2 kg/ha, CMF at 0.8 kg/ha, and SWG at 4.88 kg/ha. For HaALF, SWG, and CMF, germination rates were 96%, 88%, and 85%, respectively.
- Guard rows of HaALF were seeded on each side of the trial.
- Based on the soil test results and fertilization recommendation (Govt. of Saskatchewan, 2016), the site was fertilized with 56 kg/ha of 11-50-0 (Mono-ammonium phosphate; N-P-K) at seeding. This is also beneficial to improve seed flow. All plots received broadcast and incorporated urea (46-0-0) at 100 kg N ha^{-1}, K sulfate (0-0-44-17) at 20 kg S ha^{-1} and MAP (11-52-0) at 20 kg P ha^{-1} before seeding in 2019. Application rates of commercial fertilizer were based on normal forage fertilizer recommendations for this area.
- In early June 2020, soil amendments of biochar (BC), leonardite (LEO), and composted cattle manure (CM) were broadcast on Halo alfalfa and Revenue slender wheatgrass mixture (HaALFSWG) plots, using this particular combination of alfalfa and grass to evaluate effect of amendment on growth of the wheatgrass. The unamended HaALFSWG plots served as control (CNTL). Biochar BC 4000, composted manure, and leonardite were broadcast at 10 t hectare.
- Three subplots with soil amendment were set up as 1 × 1.2 m subplots with 1m pathway spacing between each block. The unamended subplot size was 6.2 × 1.2 m.

- Due to very dry conditions in spring 2019, no data taken on plant establishment and botanical composition since plots had not established enough to make these determinations. But plots were mowed mid-August 2019 to control weeds due to late establishment of the forage.
- Plant establishment, forage yield, and quality, botanical composition, and weed invasion including foxtail barley (*Hordeum jubatum* L.) were monitored over the growing seasons of 2020 and 2021. Plots were harvested September 2020 and August 2021 for DMY determination. Forage samples from 2020 and 2021 growing seasons were collected for nutritive value analysis.
- Data were analyzed using the Proc Mixed Model procedure of SAS (2003). For all statistical analyses, significance was declared at $P < 0.05$.
- The costs to seed each treatment plot were scaled up to a cost per hectare unit ($/ha). A combination of published custom rates, suggested retail prices (cropping inputs) and published values in enterprise budgets have been used to estimate the stand establishment costs for the 4 treatments. The trial was completed on small plots so the field activities have been scaled up. Rototilling the field plots was equated to cultivating and valued at $22.23 per ha ($9/acre) which falls within the custom rate range for cultivating in the 2020-21 Farm Machinery Custom and Rental Rate Guide published by the Saskatchewan Ministry of Agriculture. Seeding is valued at $56.81 per ha ($24/ac) which falls within the published custom rate range for air seeding and air drills in the 2020-21 Guide (SMA 2020). Fertilizer application was valued at $22.23 per ha ($9/ac) as per the suggested rate in Manitoba Agriculture's Forage Establishment budget. Seed prices were obtained from the seed suppliers for the trial; alfalfa (cv. Halo 2) was $10.78 per kg, creeping foxtail ($22.44 per kg), slender wheatgrass (cv. Revenue) was $10.34 per kg and smooth bromegrass was $10.89 per kg. Fertilizer values come from the 2019 Crop Planning Guide released by the Ministry of Agriculture; $1.28 per kg N, $1.21 per kg P, $0.43 per kg S. The only establishment cost differing between the treatments is the seed cost.
- The DM forage yield from 2020 and 2021 was valued at $0.099 per kg ($0.045 per lb) which is a mid-point between the fall 2020 price of $0.073 per kg ($0.033/lb) released in the Saskatchewan Forage Council's Forage Market Report and the drought-adjusted price of $0.13 per kg ($0.06 per lb) in the Fall 2021 report. The market value of the forage will be estimated by multiplying the DM yield by the price for standing hay.
- The returns will be discounted by 5% per year and the establishment costs subtracted in order to determine a present value of net returns for each treatment. Discounting future cashflows (market value of DM yield) to a present value basis is net present value analysis (a type of capital investment analysis) that recognizes a dollar expended/received today is worth more than a dollar expended/received a year from now.

10. Results

Trial Site Soil Properties

Soils at study site are loamy (sand: 47.9 ± 5.72%; silt: 45.5 ± 5.61%; and clay: 6.6 ± 2.09%). The baseline soil properties for the spring of 2019 are included in Table 1.

Table 1. Summary of baseline soil properties at Clavet, Saskatchewan

Soil depth, cm	pH	EC dS/m	pOC % DM	NO_3-N	SO_4-S	MK-P	MK-K
				-------------------	kg/ha	-------------------	
0-15	7.8	7.1a	2.1a	7.7a	1122.5	24.2a	886.2a
15-30	7.8	6.9a	1.0b	3.5b	1328.0	16.9b	597.1b
30-60	7.8	5.9b	0.5c	0.8c	1332.8	11.5b	412.1c
P-value	0.45	0.01	<0.01	<0.01	0.22	<0.01	<0.01

[a-c]Means with different letters differ ($P < 0.05$). Soil samples taken spring 2019. Ten points were selected randomly in transect across the study site.

No treatment × depth interaction was observed ($P > 0.05$) for all measured parameters. The electrical conductivity (EC; 6.6 ± 1.04 dS/m), particulate organic carbon (pOC; 1.2 ± 0.73% DM), and pH (7.8 ± 0.13) of the soils showed no differences across the treatment plots ($P > 0.05$) prior to the initiation of the field trial. While soil pH did not differ along the soil depths ($P = 0.45$) averaging at 7.8, the magnitude of EC differed: EC at 30-60 cm depth was lower ($P = 0.01$) (5.9 ± 0.24 dS/m) than either at 0-15 cm (7.1 ± 0.24 dS/m) and 15-30 cm (6.9 ± 0.24 dS/m). Likewise, background soil levels of pOC at the soil depths were different ($P < 0.01$), with the greatest being at 0-15-cm (2.1 ± 0.08 % DM) and the lowest at 30-60 cm depth (0.5 ± 0.08 % DM).

Overall, the results suggested that trial site soil was a saline sodic soil (EC > 4.0 dS/m and pH < 8.5; Waskom, et al., 2007; Havlin et al., 1999) or according to U.S. soil salinity classification (U.S. Salinity Laboratory Staff, 1954), the soil falls in moderate (EC ~8.0 dS/m) salinity soil category.

Greater amounts of plant available form of N, P, and K were stored at 0-15 cm depth which declined ($P < 0.001$) with increasing depth in the soil, whereas SO_4-S amount at either of the 3 soil depths was not different ($P = 0.216$). The spring soil N, P, and K fertility levels at the most plant available soil depth of 0-30-cm were 11.2, 41.1, and 1483.3 kg/ha, respectively, at the study site.

10A. Results of Halo alfalfa and grass mixtures in saline soil condition

Stand Establishment, Botanical Composition, and Forage Yield

Evaluation of stand establishment of Halo alfalfa and grass mixtures are presented in Table 2.

Table 2. Stand establishment of Halo alfalfa and grass mixtures at Clavet, Saskatchewan over 2 yr

Year	Treatment				SEM	*P*-value
	HaALFSWG	HaALFSBG	HaALFCMF	HaALFSWGSB GCMF		
	---------------------Stand establishment, %-----------------------					
2020	78.8	80.0	77.5	68.8	5.42	0.47
2021	85.0	90.0	88.8	85.0	5.44	0.87
2-yr Avg.	81.9	85.0	83.1	76.9	4.17	0.56

Note. HaALF, alfalfa cv. Halo; SWG, slender wheatgrass; SBG, smooth bromegrass; CMF, creeping foxtail.

All three binary mixtures (HaALFSBG; HaALFCMF; and HaALFSWG) and one quaternary mixture (HaALFSWGSBGCMF) had similar ($P = 0.563$; avg. 81.7%) stand establishment, although the binary mixtures seemed to establish better (6.4% units greater) than quaternary mixture (83.3 vs. 76.9%).

Forage total dry matter yield and botanical composition of the treatments are presented in Table 3. Treatments did not differ ($P > 0.05$) in DMY over the 2 years. However, based on 2-yr avg. DMY, forages/treatments can be ranked as follows: HaALFSWG (2677.1 kg/ha) < HaALFSWGSBGCMF (2906.5 kg/ha) < HaALFSBG (3167.3 kg/ha) < HaALFCMF (3468.7 kg/ha). Although there was no difference ($P>0.05$) in forage component yield between treatments, numerically, legume component, HaALF (1301.0 vs. 767.6 and 837.1 kg/ha in other two binary mixtures and 538.8 kg/ha in the quaternary mixture) mixed with CMF appeared to yield better. However, in 2021, there was a tendency ($P = 0.051$) of higher weed infestation (e.g., HaALFCMF was invaded 71.7% more with other weeds as compared to HaALFSWG) in HaALFCMF mixture. When comparing between the 2 years, total forage DMY of mixtures was reduced, ranging 21.2 to 38.5% in 2021 where there was drought conditions. These results suggest, also, that based on the 2-yr average, HaALFCMF produced 9 to 23% greater DMY relative to the other three forage mixtures in moderate saline soil.

Results of botanical composition (2-yr avg.) of HaALF and grass binary and quaternary mixtures are presented in Figure 1. There was greater ($P = 0.025$) grass component in HaALFSWG and HaALFSWGSBGCMF (45.6 and 48.4%, respectively) as opposed to in HaALFCMF (24.1%), but no difference in terms of percentage contribution of legume or weeds (foxtail barley + other weeds) to total yield. In relation to the latter, all treatment plots were infested severely with weed (incl. foxtail barley) which ranged widely from the lowest, 23.8% in HaALFSWG to the highest, 44.1% in HaALFCMF.

Table 3. Forage dry matter yield (DMY) of Halo alfalfa and grass mixtures at Clavet, Saskatchewan over 2 yr

Item[1]	Year	HaALFSWG	HaALFSBG	HaALFCMF	HaALFSWG SBGCMF	SEM	*P*-value
		-----------	-----------	kg/ha	-----------		
Total	2020	3210.2	3543.1	4147.8	3598.7	644.21	0.78
	2021	2144.0	2791.5	2789.5	2214.4	316.33	0.33
	Avg.	2677.1	3167.3	3468.7	2906.5	398.93	0.54
Grass	2020	1528.3	1138.6	759.5	1700.3	368.23	0.31
	2021	864.4	1048.7	812.8	961.0	191.60	0.82
	Avg.	1196.4	1093.6	786.2	1330.6	214.09	0.33
Legume	2020	1086.8	1122.9	2348.8	952.1	453.10	0.15
	2021	587.5	412.3	253.1	125.6	127.82	0.12
	Avg.	837.1	767.6	1301.0	538.8	315.50	0.39
Barley	2020	370.8	841.7	576.2	423.3	472.19	0.89
	2021	241.0	284.2	130.8	588.3	229.67	0.55
	Avg.	305.9	563.0	353.5	505.8	253.02	0.87
Weeds	2020	224.2	439.9	463.3	523.0	180.04	0.67
	2021	451.1	1046.2	1592.9	487.6	289.60	0.05
	Avg.	337.7	743.1	1028.1	505.3	200.16	0.10

Note. Means with a different letter are significantly different ($P < 0.05$). HaALF, alfalfa (cv. Halo); SWG, slender wheatgrass; SBG, smooth bromegrass; CMF, creeping foxtail; Plants were harvested in September 2020 and August 2021, Barley, Foxtail Barley; Weeds, Other Weeds.

These results suggest that Halo ALF with Revenue SWG was less, whereas with Garrison CMF was more susceptible to weed invasion. It is speculated that due to drought conditions experienced in the spring to summer of 2019, the poor spring moisture may have affected the treatments the most with severe weed competition. Some good moisture was received later in June and during the summer, but this only increased the weed competition and drought during the growing season in 2021 did not help either.

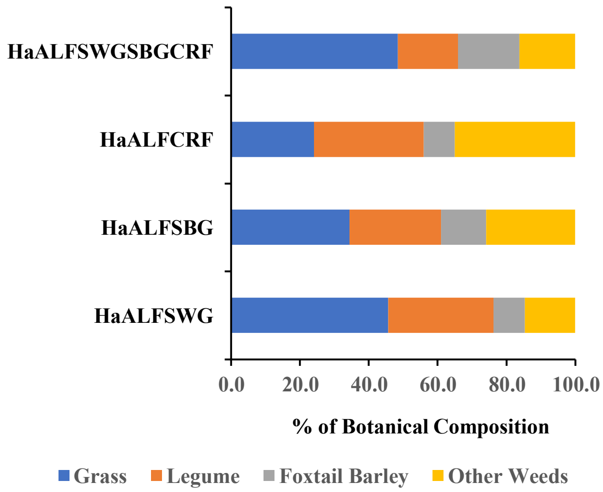


Figure 1. Botanical composition of (2-yr avg.) Halo alfalfa and grass mixtures on saline soil in Clavet, SK (The composition was evaluated 9 September 2020 and August 2021). *Note*. HaALF, alfalfa (cv. Halo); slender wheatgrass (SWG, cv. Revenue); SBG, smooth bromegrass (cv. Radisson); CMF, creeping meadow foxtail (cv. Garrison); HaALFSWG, HaALF+SWG; HaALFCMF, HaALF+CMF; HaALFSBG; HaALF+SBG; HaALFSWGSBGCMF, HaALF+SWG+SBG+CMF

Nutrient composition of Halo alfalfa and grass mixtures on saline soil condition at the LFCE, Clavet, SK is demonstrated in Table A1 and Table A2. All mixtures did not vary ($P > 0.05$) in nutrient composition including TDN, RFV, and mineral content over the 2 years, with 2-yr avg. of CP ranging 9.2-11.2%, ADF 37.2-38.9%, NDF 54.9-57.3%, and TDN 56.1-56.9% DM.

Nutrient yield and uptake of Halo alfalfa and grass mixtures are presented in Table A3. There was no nutrient yield or nutrient uptake differences ($P > 0.05$) between the binary and quaternary mixtures in the current study. The lowest protein yielding (246.4 kg/ha CPY) mixture was HaALFSWG, while HaALFCMF was the highest (395.5 kg/ha) and same pattern was observed for TDNY.

Overall, forage dry matter yield, nutrient composition, nutrients yield and uptake did not differ among the mixtures, however, in botanical composition, grass component as slender wheatgrass in binary mixture and three grass species in quaternary mixture with Halo alfalfa composed higher than smooth bromegrass or creeping foxtail did in their binary mixtures. According to NASEM (2016), the CP and TDN requirements for mature cows and heifers in pre-calving, postpartum, lactating and pregnant, and mid-gestation periods ranged from 6.2 to 12.9% and 44.9 to 64.5%, respectively. In the present study, all four mixtures met the aforementioned CP and TDN requirements of NASEM (2016). The results of the current study showed that all mixtures produced DMY well above the minimum requirement (2000 kg/ha) for fall grazing (Alberta Agriculture and Forestry, 2008).

10B. Results on soil amendment for Halo alfalfa and slender wheatgrass binary mixture in saline soil condition

Soil Properties

Table 4. Summary of baseline soil properties at the LFCE, Clavet, SK site

Soil Depth cm	NO_3 -N	SO_4-S	MK-P	MK-K	pH	EC
	ug/g	ug/g	ug/g	ug/g		dS/m
0-15	3.9	542.6	11.0	434.5	7.6	5.6
15-30	1.6	660.1	8.1	299.9	7.6	7.0
30-60	0.4	669.9	5.9	208.6	7.6	6.8

Note. Soil samples were taken in August 2019. 10 points were selected randomly in transect across study area.

- pH and EC values were similar among different soil amendments and alfalfa-grass mixtures ($P > 0.05$) (Table 4). No amendment effect in first year on salinity or other soil properties ($P > 0.05$) (Table 5).

Table 5. The soil properties at the LFCE, Clavet, SK site in August 2020 after forage harvest

Forage	Treatment	Depth cm	Bulk density g/cm^3	pH	EC dS/m	OC %	NO_3-N ug/g	P ug/g	K ug/g
HaALFCMF		0-15	1.4	7.7	8.0	1.9	7.2	12.6	440.5
		15-30	1.5	7.8	7.1	0.7	1.2	2.3	222.9
		30-60	1.4	7.7	5.9	0.4	0.6	1.3	138.7
HaALFSBG		0-15	1.4	7.8	8.7	2.0	6.7	10.1	418.0
		15-30	1.6	7.9	7.2	0.7	0.9	2.1	214.4
		30-60	1.4	7.6	6.4	0.8	0.6	1.0	168.7
HaALFSBGSWGCMF		0-15	1.3	7.9	8.3	2.3	5.9	7.4	398.6
		15-30	1.6	7.9	7.2	0.7	1.1	1.7	195.0
		30-60	1.3	7.8	6.4	0.5	0.6	1.1	171.7
HaALFSWG	CNTL	0-15	1.4	7.9	8.2	2.0	19.1	10.4	405.0
		15-30	1.7	7.9	7.6	0.8	1.1	2.8	233.1
		30-60	1.4	7.8	6.8	0.4	0.6	1.1	160.6
	BC	0-15	1.3	7.9	8.7	2.5	8.4	11.0	408.7
		15-30	1.6	7.9	7.4	0.9	1.7	3.1	221.4
		30-60	1.4	7.8	6.5	0.4	0.9	1.1	162.2
	LEO	0-15	1.4	7.8	8.4	2.2	7.1	8.9	402.1
		15-30	1.6	7.9	8.0	0.9	1.5	2.3	240.3
		30-60	1.4	7.8	6.5	0.4	0.9	1.2	157.8
	CM	0-15	1.4	7.8	7.5	2.2	10.5	13.7	438.6
		15-30	1.6	7.9	6.6	0.8	1.7	1.7	215.0
		30-60	1.3	7.8	5.9	0.5	2.0	1.1	185.8

Note. Values are means from analysis of four replicate soil cores taken at 0-15-cm, 15-30-cm and 30-60-cm depth increments under each amendment. HaALF, Halo Alfalfa; CMF, creeping foxtail; SBG, smooth bromegrass; SWG, slender wheatgrass; The soil properties were measured in soil cores collected from the LFCE, Clavet, SK section 21 field trial sites in August 2020 after forage harvest. CNTL= control (no amendment); BC= biochar applied at 10 t/ha broadcast in 2020; LEO = leonardite applied at 10 t/ha broadcast in 2020; CM = composted cattle manure applied at 10 t/ha broadcast in 2020.

Table 6. The soil properties measured in soil cores collected from the LFCE, Clavet, SK site in spring 2021

Treatment		Depth, cm	Bulk density g/cm^3	pH	EC dS/m	OC %	NO_3-N ug/g	P ug/g	K ug/g
HaALFCMF		0-15	1.3	7.9	7.3	2.3	8.4	10.9	434.6
		15-30	1.5	8.0	7.7	0.9	2.5	2.0	260.4
		30-60	1.2	7.8	6.7	.	0.6	1.3	168.6
HaALFSBG		0-15	1.4	8.0	8.2	2.1	5.6	10.7	416.2
		15-30	1.5	8.0	8.2	0.8	0.7	2.0	232.3
		30-60	1.1	8.0	6.0	.	0.8	1.4	166.4
HaALFSBGSWGCMF		0-15	1.3	7.9	7.1	2.1	5.9	8.7	408.4
		15-30	1.5	8.0	8.1	0.9	0.8	1.4	238.2
		30-60	1.1	7.9	6.9	.	0.4	1.6	142.1
HaALFSWG	CNTL	0-15	1.4	7.9	7.0	2.1	6.9	7.8	450.9
		15-30	1.5	8.0	8.0	0.8	1.1	2.2	242.8
		30-60	0.9	7.9	7.5	.	0.9	2.0	167.4
	BC	0-15	1.3	8.0	8.5	2.6	5.4	11.2	409.4
		15-30	1.5	8.0	7.8	0.8	1.6	2.4	204.3
		30-60	1.3	7.9	7.2	.	0.8	1.6	160.0
	LEO	0-15	1.4	7.9	8.1	2.5	5.6	8.4	427.8
		15-30	1.5	8.0	8.2	1.0	1.4	2.6	244.2
		30-60	1.3	7.8	6.9	.	0.3	1.7	154.7
	CM	0-15	1.3	7.9	7.7	2.2	8.7	12.4	440.7
		15-30	1.5	8.0	7.6	0.9	0.9	1.6	252.9
		30-60	0.9	7.8	6.7	.	0.5	1.4	183.4

Note. Values are means from analysis of four replicate soil cores taken at 0-15 cm, 15-30 cm, and 30-60 cm depth increments under each amendment and control. HaALF, Halo Alfalfa; CMF, creeping foxtail; SBG, smooth bromegrass; SWG, slender wheatgrass. CNTL= control (no amendment); BC= biochar applied at 10 t/ha broadcast in 2020; LEO = leonardite applied at 10 t/ha broadcast in 2020; CM = composted cattle manure applied at 10 t/ha broadcast in 2020.

- In 2021, amendments had no effect on soil properties or nutrient concentration in the soil at any of soil depths ($P > 0.05$; Table 6).

Soil Organic Carbon Mass

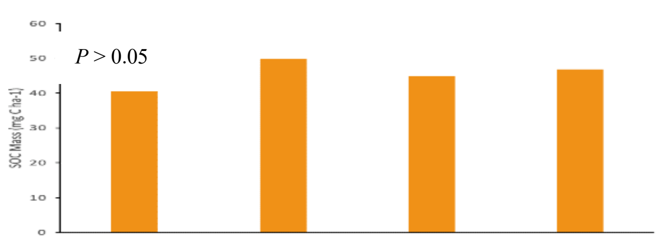


Figure 2. Total soil organic carbon mass in 0-15cm depth under alfalfa-slender wheatgrass mixture with soil amendment in fall 2020. SOC, soil organic carbon. CNTL= control (no amendment); BC= biochar applied at 10 t/ha broadcast in 2020; LEO = leonardite applied at 10 t/ha broadcast in 2020; CM = composted cattle manure applied at 10 t/ha broadcast in 2020

- None of the amendments had significant effect on soil organic carbon mass ($P > 0.05$). However, a trend existed for the biochar amendment to increase soil organic carbon mass (Figure 2).

Water Dynamics (Saturated Hydraulic Conductivity K_s)

Table 7. Saturated hydraulic conductivity at the LFCE, Clavet, SK site

Treatment[1]	K_s (m/s)
CNTL	$1.4\times10^{6\text{b}}$
BC	$3.2\times10^{6\text{a}}$
LEO	$3.2\times10^{6\text{a}}$
CM	$4.7\times10^{6\text{a}}$

Note. [1]Means (n = 4) followed by a different letter are significantly different ($P < 0.05$); CNTL = control (no amendment); BC = biochar applied at 10 t/ha broadcast in 2020; LEO = leonardite applied at 10 t/ha broadcast in 2020; CM = composted cattle manure applied at 10 t/ha broadcast in 2020. Saturated hydraulic conductivity was measured in August 2020.

- All amendments had ($P < 0.05$) increased saturated hydraulic conductivity after the application of which composted manure was most effective in improving soil permeability (Table 7). This could be explained by the strong root systems of alfalfa-slender wheatgrass mixture improving the permeability of soil.

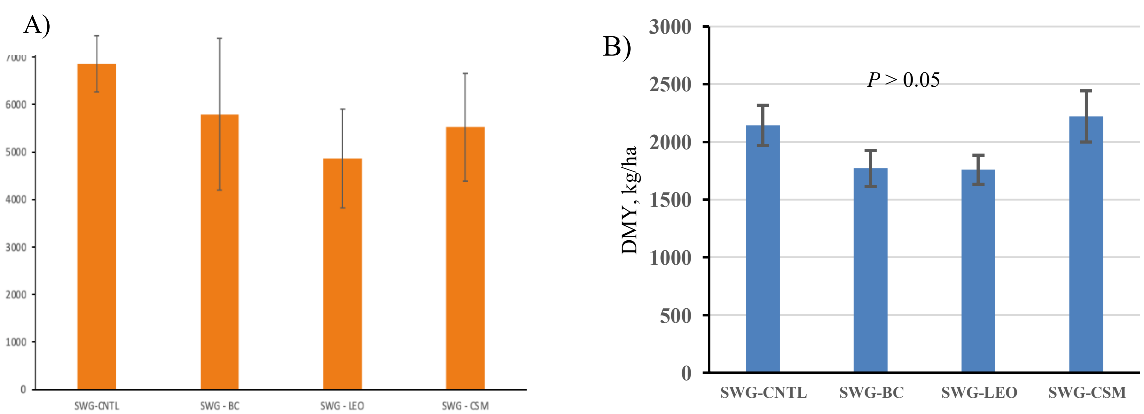


Figure 3. Total aboveground biomass of alfalfa-slender wheatgrass mixture with the soil amendments in fall of 2020 at the LFCE, Clavet, SK site. *Note*. Bars indicate standard error. Plants were harvested in August 2020 (**A**) and 2021 (**B**) (. HaALF, Halo alfalfa; SWG, slender wheatgrass; SBG, smooth bromegrass; CMF, creeping foxtail. CNTL= control (no amendment); BC = biochar applied at 10 t/ha broadcast in 2020; LEO = leonardite applied at 10 t/ha broadcast in 2020; CM = composted cattle manure applied at 10 t/ha broadcast in 2020.

- None of the amendments had a significant ($P > 0.05$) effect on forage production (Figure 3AB).
- In 2021, there was a trend to lower yield of alfalfa-slender wheatgrass mixtures with the biochar and leonardite amendments (Figure 3B).
- Forage aboveground biomass of the amended and control alfalfa-slender wheatgrass mixtures (HaALFSWG) were lower in 2021 as compared to 2020, likely due to the drought experienced in 2021 (Figure 3A, B).

Nutrient Uptake

Table 8. Comparison of nutrient uptake (N, P, and Zn) in aboveground forage biomass of Halo alfalfa- grass mixtures at the LFCE, Clavet, SK site in 2020

	Treatment	Total N ug/g	N Uptake kg N/ha	Total P ug/g	P Uptake kg P/ha	Total Zn ug/g	Zn Uptake kg Zn/ha
HaALFSWG	CNTL	13490.4[a]	94.1[a]	1569.8[b]	10.7[a]	8.7[b]	0.06[b]
	BC	10276.9[b]	61.1[b]	1506.7[b]	8.7[b]	13.8[a]	0.08[a]
	LEO	11774.3[b]	58.5[b]	1676.4[b]	8.0[b]	8.5[b]	0.04[c]
	CM	11390.2[b]	65.3[b]	1744.6[ab]	9.5[b]	8.9[b]	0.05[b]
HaALFCMF		12976.1[a]	66.3[b]	1833.1[a]	8.9[b]	10.7[ab]	0.05[b]
HaALFSBG		12204.0[a]	56.3[b]	1843.4[a]	8.4[b]	8.4[b]	0.04[c]
HaALFSBGSWGCMF		11963.2[a]	69.8[b]	1670.2[b]	9.7[b]	8.3[b]	0.05[b]

Note. Means followed by a different letter are significantly different ($P < 0.05$). Plants were harvested in August 2020. HaALF, Halo alfalfa; SWG, slender wheatgrass; SBG, smooth bromegrass; CMF, creeping foxtail. CNTL= control (no amendment); BC= biochar applied at 10 t/ha broadcast in 2020; LEO = leonardite applied at 10 t/ha broadcast in 2020; CM = composted cattle manure applied at 10 t/ha broadcast in 2020.

- In 2020, all soil amendments had ($P < 0.05$) negative effect on N and P uptake (Table 8).
- All alfalfa-grass mixtures with no amendment (incl. CNTL) had highest N and P uptake among the mixtures ($P < 0.05$). This suggests the amendments may tie up available N and P and the process may be responsible for reduced N and P uptakes.
- Biochar increased but leonardite decreased Zn uptake ($P < 0.05$) (Table 8).

Table 9. Comparison of nutrient uptake (N, P, K, and Zn) in aboveground biomass of forage alfalfa-grass mixture at the LFCE, Clavet, SK site in 2021

	Treatment	N Uptake kg N/ha	P Uptake kg P/ha	K Uptake kg K/ha	Zn Uptake kg Zn/ha
HaALFSWG	CNTL	30.7[bc]	2.6	22.7[b]	0.02
	BC	24.9[c]	2.2	18.7[b]	0.02
	LEO	24.3[c]	2.2	18.0[b]	0.02
	CM	30.3b[c]	2.8	22.5[b]	0.02
HaALFCMF		52.4[a]	4.1	37.8[a]	0.03
HaALFSBG		47.7[ab]	4.3	37.1[a]	0.04
HaALFSBGSWGCMF		31.7[abc]	2.7	22.5[b]	0.02
SEM		6.72	0.60	4.58	0.01
P-value		0.043	0.106	0.019	0.067

Note. Means followed by a different letter are significantly different ($P < 0.05$). HaALF, Halo alfalfa; CMF, creeping foxtail, SBG, smooth bromegrass, SWG, slender wheatgrass. Plants were harvested in August 2021. CNTL= control (no amendment); BC= biochar applied at 10 t/ha broadcast in 2020; LEO = leonardite applied at 10 t/ha broadcast in 2020; CM = composted cattle manure applied at 10 t/ha broadcast in 2020.

- In 2021, no amendment effect was observed on any of the nutrients' uptake ($P > 0.05$) (Table 9).
- Halo alfalfa in binary mixture with creeping foxtail (HaALFCMF) had the highest N uptake and this mixture and alfalfa with smooth bromegrass (HaALFSBG) had the

greatest K uptake among the amended and not amended mixtures ($P < 0.05$). Also, in HaALFSBG mixture, a tendency for higher Zn uptake was observed ($P = 0.07$) (Table 9).

In regard to Zn, the soil level of 0.7 ug/g of extractable available Zn at the trial site was determined in the current study (data not shown), which agreed with other researchers who evaluated Saskatchewan soils for Zn and found through DTPA test a "critical" value for Zn deficiency of 1.1 ug/g of soil (Edlin et al., 1983) or <0.5 mg Zn/kg that would be classified as potentially Zn deficient (Singh, 1986).

Cost and Returns Comparison

Costs for cultivating, seeding, fertilizer and fertilizer application were $340 per hectare for each treatment. After adding in seed costs, the costs to establish each treatment averaged $559 per ha for the binary treatments and $657 per ha for the multi-species mixture (Table 10). The seed cost, from lowest to highest, was $164, $238, $254, $267 per ha for HaALFCMF, HaALFSWG, HaALFSBG and HaALFSWGSBGCMF, respectively. The seed cost was highest for the multi-species treatment.

The market value for the forage (DM yield × $0.099 per kg) ranged from $530 per ha for HaALFSWG to $687 per ha for HaALFCMF; the average across all treatments was $605 per ha. After discounting the returns to a present value basis and subtracting the establishment costs, the present value of net returns was positive for one treatment (HaALFCMF) meaning within in two years the HaALFCMF treatment had grown enough forage (valued at $0.099/kg) to recoup the stand establishment costs incurred in 2019. The HaALFSBG treatment had recouped 98% of its establishment costs after two years of production, HaALFSWG 86% and HaALFSWGSBGCMF 82%.

As Figure 4 shows, discounted (present value) net returns were positive ($138 per ha) for HaALFCMF, but negative for the other three treatments. With no statistical difference in the DM yields between treatments, all four mixtures were satisfactory in generating forage yield on unproductive saline soils in drought conditions (2020-2021). There is a substantial cost with establishing forages, but reclaiming unproductive land with forage production that nearly recoups the initial investment cost after only two years are worth investigating for one's own operation. It is important to note that the cost of land was not included in this analysis. Land rental rates average $123.50 per ha or $50 per ac per year.

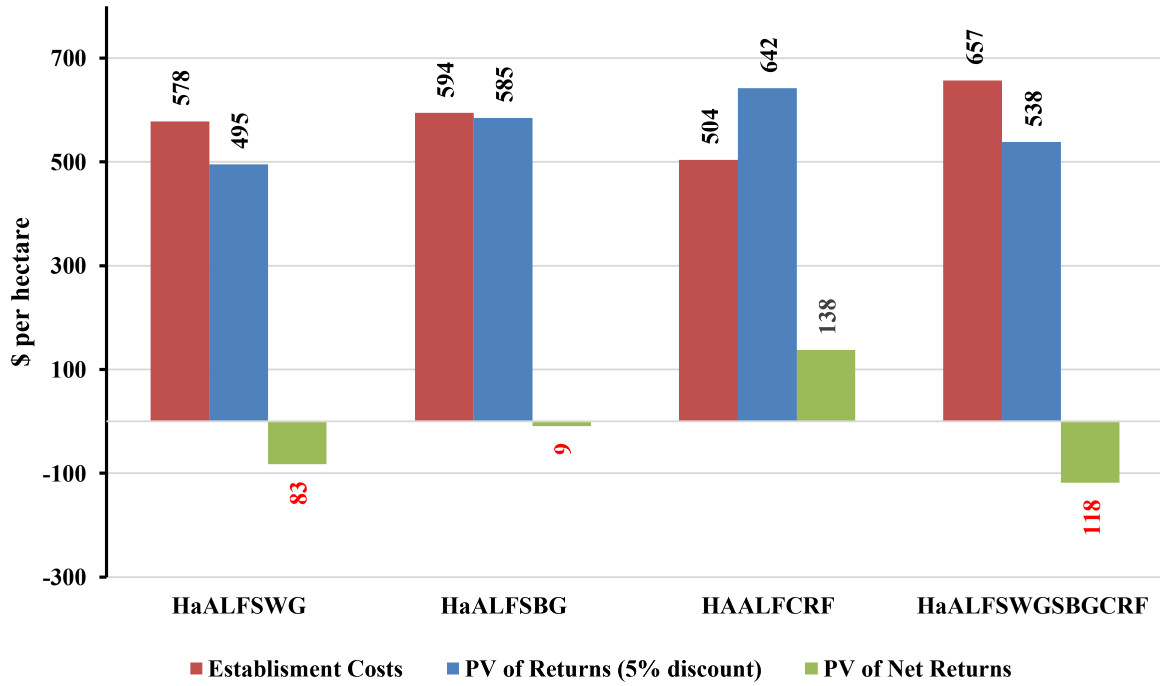


Figure 4. Establishment Costs and 2 Yr present value returns and net returns for legume-grass seeded on saline soils at LFCE, Clavet, SK.

Table 10. Establishment costs and estimated present value of net returns for grass-legume forages seeded into saline soil at the LFCE, Clavet, SK (2019-2021)

Item		HaALFSWG	HaALFSBG	HaALFCMF	HaALFSWGSBGCMF
		------ *$/hectare* ------			
Establishment Costs					
Harrowing		22.23	22.23	22.23	22.23
Seeding		56.81	56.81	56.81	56.81
Seed		237.95	254.30	164.03	316.73
Fertilizer		238.59	238.59	238.59	238.59
Fert Application		22.23	22.23	22.23	22.23
TOTAL COSTS	**A**	**577.82**	**594.17**	**503.90**	**656.59**
Returns					
2020 DM Yield, kg/ha		3210.2	3543.1	4147.8	3598.7
Market Value	**B**	317.81	350.77	410.63	356.27
2021 DM Yield, kg/ha		2144	2791.5	2789.5	2214.4
Market Value	**C**	212.26	276.36	276.16	219.23
2 Yr RETURNS	**B + C**	530.07	627.13	686.79	575.50
PV of Returns (5% discount)	**E**	495.20	584.73	641.56	538.15
PV of Net Returns	**E - A**	-82.62	-9.44	137.67	-118.44

Note. HaALF, Halo alfalfa; CMF, creeping foxtail, SBG, smooth bromegrass, SWG, slender wheatgrass

11. Conclusion

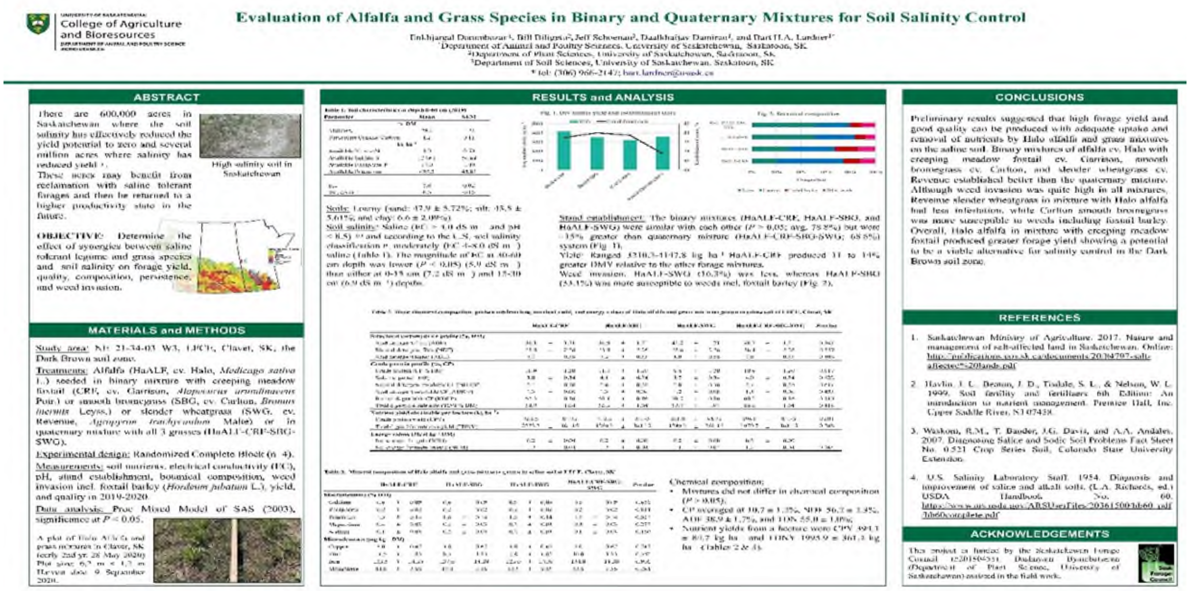
Results revealed that study site soil can be classified as moderately saline soil with slightly alkaline pH and major plant available nutrients being concentrated in the topsoil or 0-15 cm depth. In this saline soil, salt tolerant Halo alfalfa with grass species in binary and quaternary mixtures were established similarly well with binary mixtures having a slight advantage over the quaternary mixture. Forage mixtures did not differ in dry matter yield, nutrient composition, nutrients yield and uptake, although slender wheatgrass in binary mixture and 3 grass species in quaternary mixture with Halo alfalfa produced higher grass component yield. Also, creeping foxtail in binary mixture with Halo alfalfa may be more susceptible to weed infestation, especially in dryer than usual years. Overall, these salt tolerant mixtures can provide adequate yield and nutritive value forage for beef cattle for summer and fall grazing.

No differences in soil profile (salinity and organic carbon concentrations) or forage production were observed among the alfalfa-grass mixtures with different amendments applied over the two production years. Overall soil salinity at the site was numerically higher at the end (mid-August) than at the beginning of the trial (April), especially in the surface soil, likely reflecting drier conditions in 2020 and 2021. Overall, the forages were able to tolerate moderate soil salinity levels of 6 to 8 dS/m quite well. The biochar amendment showed a trend of increasing surface soil organic carbon mass compared to the unamended control. In first year, all amendments reduced N and P uptake that may be attributed to microbial immobilization, however, there was no effect in second year. Also in first year, the biochar amendment increased forage Zn content and uptake, whereas leonardite decreased plant Zn uptake. All amendments significantly increased the saturated hydraulic conductivity (water infiltration) of which numerically, composted manure was the most effective in improving soil permeability. In general, the amendment effect was more expressed, in the first year than in second year of the study, indicating perhaps an effect of dryer condition in the latter. The dry conditions experienced at the site in spring 2020 and entire growing season in 2021 were not conducive to showing treatment effects due to limitations on forage growth and downward leaching. Net returns were positive ($138 per ha) for HaALFCMF, but negative for the other three treatments. There is a substantial cost with establishing forages, but reclaiming unproductive land with forage production that nearly recoups the initial investment cost after only two years are worth investigating for one’s own operation.

Extension/Promotion Activities:

Abstract and Poster Presentation

Darambazar, E., B. Biligetu, J. Schoenau, D. Damiran, and H. A. Lardner. 2021. Evaluation of alfalfa and grass species in binary and quaternary mixtures for salinity control in the dark brown soil zone of Saskatchewan [abstract]. In: Abstracts for the Soils & Crops conference of Canada, 16-17 March 2021. Saskatoon, Saskatchewan, Canada. DOI: 10.13140/RG.2.2.33190.86088



12. General Conclusions and Recommendations

All forage treatments established in the moderately saline soil condition. Results indicated that binary Halo alfalfa-Revenue slender wheatgrass or with all 3 grasses: slender wheatgrass, Radisson smooth bromegrass, and Garrison creeping meadow foxtail in quaternary combinations can produce greater grass component yield, while Halo alfalfa mixed with creeping meadow foxtail had numerically greater total forage yield, although the latter mixture was more prone to weed invasion. Weather condition would have a strong effect on forage production, weed invasion of the stand, as well as soil amendment efficiency. Although amendments like biochar, leonardite, and composted manure applied to the Halo alfalfa-slender wheatgrass mixture increased soil permeability or improved water infiltration, they may have a negative effect on N and P uptake in some year. Biochar may be effective in increasing Zn content and uptake, however, leonardite may decrease, with the other amendments having no effect on forage production or nutrient uptake in the moderately saline soil condition of Saskatchewan. The impacts of the soil amendments were with mixed results that seem dependent on the amendment quality, soil type, crop species, and environmental condition. The results suggested that binary mixtures of Halo alfalfa with Revenue slender wheatgrass or Garrison creeping meadow foxtail could be viable alternatives for increasing forage production, forage quality and ultimately livestock gain per acre, and for controlling salinity in the Dark Brown soil zone. However, the higher seed price for the multi-species treatment currently may delay its expansion. But reclaiming unproductive land with forage production that nearly recoups the initial investment cost after only two years are worth investigating for one's own operation. Further research is needed to fully reveal the effects of saline tolerant species on soil salinity, fertility, and forage production potential.

Supporting Information

Acknowledgements
Appreciation expressed for the Saskatchewan ADOPT funding (#20180455).

13. Appendices

Abstract

The objective of this study was to determine the effect of synergies between saline tolerant grass and legume species on soil salinity, biomass, quality, composition, persistence and weed suppression. Halo alfalfa (HaALF) was seeded in binary mixtures with Revenue slender wheatgrass (HaALFSWG), Radisson smooth bromegrass (HaALFSBG), and Garrison creeping meadow foxtail (HaALFCMF), as well as in a complex mixture (quaternary) consisting of HaALF with all three grasses (HaALFSWGSBGCMF) in the saline soil. Four replicated treatments (n=4) were randomly allocated to 6.2 m × 1.2-m plots in spring 2019. In early June of 2020, soil amendments of biochar (BC), leonardite (LEO), and composted cattle manure (CM) were broadcast at 10 t ha^{-1} on the HaALFSWG plots, using this particular combination of alfalfa and grass to evaluate effect of amendment on growth of the wheatgrass. The unamended HaALFSWG plots served as control (CNTL). Three subplots with soil amendment were set up as 1 m x 1.2 m subplots with 1 m pathway spacing between each block. The unamended subplot size was 6.2 m × 1.2 m. All mixtures were similar in stand establishment over the two years with binary mixtures (HaALFSWG, HaALFSBG, and HaALFCMF) having slightly better stand establishment compared to quaternary mixture (HaALFSWGSBGCMF) (83.3% vs. 76.9%). Although there was relatively high weed infestation in all stands, Halo ALF-Revenue SWG mixture was less (23.8%), while Halo ALF-Garrison CMF was more (44.1%) susceptible to weeds including foxtail barley. When soil amendments like biochar, leonardite, and composted manure are applied to HaALFSWG mixture, they can increase soil permeability, but may, also, show negative effect on N and P uptake and differing effect e.g., improving or decreasing Zn uptake in some year. Overall, amendment effect seems will be stronger depending on weather during the growing season. The results suggested that in moderate saline soil in the Dark Brown soil zone of Saskatchewan, HaALFCMF and HaALFSWG binary mixtures produce 9 to 23% greater total DMY and relative to the other three forage mixtures. There is a substantial cost with establishing forages, but reclaiming unproductive land with forage production that nearly recoups the initial investment cost after only two years are worth investigating for one's own operation.

Finances

14. Budget Report- please see attached expenditures spreadsheet.

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15. Appendix Tables

Table A1. Chemical composition of Halo alfalfa and grass mixtures at the LFCE, Clavet, SK site in 2020 and 2021

Item	Year	HaALFCMF	HaALFSBG	HaALFSWG	SBGSWGCR	SEM	*P*-value
Crude protein (%, DM)	2020	10.9	11.7	9.5	10.9	1.20	0.62
	2021	11.6	10.3	8.9	9.0	1.07	0.30
	Avg.	11.2	11.0	9.2	10.0	0.78	0.24
Acid detergent fibre (% DM)	2020	39.1	36.5	41.2	38.7	1.71	0.34
	2021	37.8	37.9	36.6	38.8	0.74	0.28
	Avg.	38.4	37.2	38.9	38.7	0.98	0.62
Neutral detergent fibre (% DM)	2020	55.9	53.9	58.6	56.4	2.26	0.56
	2021	53.8	56.6	56.0	57.5	1.69	0.49
	Avg.	54.9	55.3	57.3	57.0	1.37	0.52
Acid detergent lignin (% DM)	2020	7.6	7.3	8.0	7.9	0.55	0.81
	2021	8.7	8.0	7.6	8.1	0.30	0.15
	Avg.	8.2	7.7	7.8	8.0	0.32	0.71
Starch (% DM)	2020	2.7	2.7	2.0	2.4	0.20	0.09
	2021	2.9	3.0	2.6	2.4	0.35	0.60
	Avg.	2.8	2.9	2.3	2.4	0.20	0.11
Sugar (%, DM)	2020	11.0	11.2	11.6	11.7	0.62	0.84
	2021	9.5	9.9	11.9	10.4	1.08	0.46
	Avg.	10.2	11.7	10.5	11.1	0.62	0.37
Crude fat (% DM)	2020	2.5	2.5	2.2	2.4	0.21	0.72
	2021	3.3	3.4	4.4	3.7	0.42	0.29
	Avg.	2.9	3.0	3.3	3.0	0.34	0.84
Total digestible nutrients (%, DM)	2020	54.9	56.3	53.7	55.0	1.04	0.42
	2021	57.2	57.4	60.1	57.9	0.80	0.09
	Avg.	56.1	56.8	56.9	56.4	0.93	0.92
Relative feed value, %	2020	97.5	106.3	90.8	97.3	6.39	0.43
	2021	103.0	98.0	101.0	95.5	3.54	0.48
	Avg.	100.3	102.1	95.9	96.4	3.65	0.57

Note. HaALF, alfalfa (cv. Halo); SWG, slender wheatgrass; SBG, smooth bromegrass; CMF, creeping foxtail; Plants were harvested in September 2020 and August 2021.

Table A2. Mineral composition of Halo alfalfa and grass mixtures at the LFCE, Clavet, SK site in 2020 and 2021

Item	Year	HaALFCMF	HaALFSBG	HaALFSWG	SBGSWGCR	SEM	*P*-value
Ash (% DM)	2020	8.7	8.4	8.1	7.9	0.64	0.85
	2021	6.4	6.4	5.8	5.7	0.38	0.35
	Avg.	7.6	7.4	6.9	6.8	0.54	0.71
Calcium (%, DM)	2020	0.6	0.6	0.5	0.5	0.09	0.64
	2021	0.8	0.5	0.6	0.5	0.16	0.47
	Avg.	0.7	0.6	0.6	0.5	0.09	0.34
Phosphorus (%, DM)	2020	0.2	0.2	0.2	0.2	0.02	0.83
	2021	0.1	0.2	0.1	0.1	0.02	0.50
	Avg.	0.2	0.2	0.1	0.1	0.01	0.57
Potassium (%, DM)	2020	1.3	1.6	1.5	1.5	0.14	0.53
	2021	1.3	1.3	1.0	1.0	0.12	0.16
	Avg.	1.3	1.4	1.3	1.3	0.11	0.57

Note. HaALF, alfalfa (cv. Halo); SWG, slender wheatgrass; SBG, smooth bromegrass; CMF, creeping foxtail; Plants were harvested in September 2020 and August 2021.

Table A3. Nutrient Yield and uptake of Halo alfalfa and grass mixtures at the LFCE, Clavet, SK site in 2020 and 2021

Item	Year	HaALFCMF	HaALFSBG	HaALFSWG	SBGSWGCR	SEM	*P*-value
Nutrient Yield, Kg/ha							
CP Yield (kg/ha)	2020	463.5	413.8	301.0	398.0	84.73	0.60
	2021	327.5	297.9	191.8	197.9	52.86	0.22
	Avg.	395.5	355.8	246.4	297.9	53.72	0.24
TDN Yield (kg/ha)	2020	2273.3	1989.8	1749.8	1970.7	361.15	0.79
	2021	1605.6	1598.7	1288.5	1280.4	188.92	0.45
	Avg.	1939.4	1794.2	1519.2	1625.5	217.02	0.54
Nutrient Uptake							
Phosphorus uptake (kg/ha)	2020	7.4	6.5	5.6	6.2	1.34	0.83
	2021	4.1	4.3	2.6	2.7	0.69	0.23
	Avg.	5.7	5.4	4.1	4.5	0.90	0.55
Potassium uptake (kg/ha)	2020	53.9	53.4	45.3	55.2	9.83	0.89
	2021	37.8	37.1	22.7	22.5	5.47	0.11
	Avg.	45.9	45.3	34.0	38.8	6.77	0.56
Nitrogen uptake (kg/ha)	2020	74.2	66.2	48.2	63.7	13.56	0.60
	2021	52.4	47.7	30.7	31.7	8.46	0.22
	Avg.	63.3	56.9	39.4	47.7	8.60	0.24

Note. HaALF, alfalfa (cv. Halo); SWG, slender wheatgrass; SBG, smooth bromegrass; CMF, creeping foxtail; Plants were harvested in September 2020 and August 2021.