Evaluation of Alfalfa and Grass Species in Binary and Complex Mixtures on Performance under Soil Salinity Conditions

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Abstract: The effect of synergies between saline-tolerant grass and legume species grown in saline soil, on yield, quality, composition, persistence, and weed suppression was studied in 2019–2021 in a moderately saline soil located in the dark brown soil zone near Saskatoon, Saskatchewan, Canada. ‘Halo’ alfalfa (ALF), a salt-tolerant cultivar of alfalfa, was seeded in binary mixtures with ‘Revenue’ slender wheatgrass (ALF-SWG), ‘Garrison’ creeping meadow foxtail (ALF-CMF), and ‘Radisson’ smooth bromegrass (ALF-SBG). A complex mixture (quaternary) with all three grasses was also included. Four replicated treatments (n = 4) were randomly allocated to 6.2 × 1.2 m plots in spring 2019. The binary mixtures had similar or slightly better stand establishment compared to the quaternary mixture over the two years (83.3 vs. 76.9%), the quaternary stand showed greater (p = 0.01) establishment in Yr 2 than in Yr 1 (85 vs. 68.8%). There was high weed infestation in all the stands, but ALF-SWG had less weed infestation (23.8 vs. 44.1%) than ALF-CMF, especially in Yr 2 (p = 0.05). There were no significant differences among mixtures in yield, nutritional composition, and nutrient uptake. The ALF-CMF and ALF-SWG binary mixtures had 9 to 23% greater mean total DMY than the other mixtures in the moderately saline soil. The cost of establishing forage mixtures on unproductive saline land can be up to 89% recovered after only two years. The results suggested that binary mixtures of ‘Halo’ alfalfa with ‘Revenue’ slender wheatgrass or ‘Garrison’ creeping meadow foxtail could be reasonable alternatives for adequate forage production and quality, high N-use efficiency, and ultimately livestock gain per hectare, as well as for controlling soil salinity and improving soil fertility in this saline area in the dark brown soil zone.

Keywords: salinity; salt-affected soil; salt tolerant forage

1. Introduction

Salinization of soil is a common phenomenon worldwide [1,2] that greatly reduces the productivity of affected lands. It is more prevalent in arid and semi-arid regions [3]. Some 20 million of 67 million ha (30%) of land across the Canadian Prairies is affected to a degree by salinity (6 million ha) or is at risk of salinization [4,5]. Many livestock producers have observed a return of soil salinity issues on their pastures and hay fields during recent wet growing seasons in Saskatchewan. According to a Saskatchewan Ministry of Agriculture report (2017) [6], there are 250,000 ha in Saskatchewan where the soil salinity has effectively reduced the yield potential to zero.

Typical forage mixtures for hay and grazing lack the salinity tolerance needed for salt-affected soils leading to reduced forage yield. Therefore, there is a need to evaluate
novel perennial forage mixtures in saline areas for hay production and pasture. Weakly saline soils will affect the growth and yields of most crops and moderate to severe soil salinity reduces yields of most cereal and oilseed crops by at least 50% [7]. A greenhouse study showed alfalfa (*Medicago sativa* L.) yield was drastically reduced once salt build-up began in the upper portion of the root zone [8].

Salt-affected land areas may benefit from reclamation with saline-tolerant forages with a return to a higher productivity state. Improving saline-affected soils could generate millions of dollars in returns to producers through improved land productivity. An earlier study on the effectiveness of alfalfa in controlling saline seepage on northern Great Plains small grain dryland farms concluded that alfalfa can effectively reduce water discharge in saline seep areas if it is grown on a major portion of the recharge area [9]. Moreover, greenhouse studies indicated that slender wheatgrass (*Agropyron trachycaulum* (Link) Malte] and alfalfa can alleviate some of the adverse conditions of neutral/alkaline gold mine tailings [10].

Plant performance can vary dramatically on sites affected by increased salt concentrations [11]. According to Dodds and Vasey [12], established alfalfa plants exhibit moderate tolerance. Studying genetic variability among nine alfalfa populations in response to sulfate salt, Bhattacharai et al. [13] noted a high relative shoot mass at 8 dS m$^{-1}$ in ‘Halo’ alfalfa. In another study, alfalfa cultivar ‘Halo’ had a better salt tolerance through various mechanisms resulting in a uniform biomass distribution and more stable shoot water content under the full range of NaCl concentrations [14]. Creeping foxtail (*Alopecurus arundinaceus* Poir.) is a perennial grass with dense, vigorous rhizomes that is tolerant of both moderately acidic and moderately alkaline soils [15]. Although creeping foxtail does not germinate rapidly in moderate to high saline-alkali soil [12], the variety ‘Garrison’ is recommended for use in saline soils [12]. Slender wheatgrass is one of the few self-pollinating grasses and is native to the prairies. It is often found where moderate soil salinity prevails. Researchers [12,16] described ‘Revenue’ slender wheatgrass as strongly tolerant to salts, short-lived in pure stands, performing better on drier sites than other wheatgrasses of similar salt tolerance, and with superior establishment ability, forage quality, and yield (4.1 Mg ha$^{-1}$) compared with ‘Primar’ (3.9 Mg ha$^{-1}$), the only other cultivar of slender wheatgrass licensed in Canada [16]. Smooth bromegrass (*Bromus inermis* Leyss.) possesses only moderate tolerance to salt [12]. ‘Radisson’ is a southern-type smooth bromegrass developed at Agriculture Canada, Saskatoon and registered in 1989 that has produced a high yield of forage dry matter (DM) in eastern Canada [17]. Smooth bromegrass shoot-and-root dry weight can be significantly higher when grown with alfalfa than when grown alone [18]. According to a list of herbaceous forage plants according to salinity tolerance developed at PMC Bismarck, North Dakota [11], slender wheatgrass belongs in the top or tolerant [electrical conductivity (EC) 15–25], creeping foxtail in moderately tolerant (EC 10–15), and smooth bromegrass and alfalfa are moderately sensitive (EC 5–10) plants. Still, limited information is available on performance of salt-tolerant legume–grass mixtures on saline soils in the northern Great Plains.

The objective of our study was to evaluate the performance of combinations of salt-tolerant alfalfa with salt-tolerant (creeping foxtail and slender wheatgrass) and non-salt-tolerant (smooth brome) grasses seeded on a moderately saline soil. Weed infestation, and forage yield and quality were measured in the two years following seeding and an economic assessment was completed using the results.

2. Materials and Methods

2.1. Weather

Monthly mean air temperature (°C) and total precipitation (mm) data from 2019 to 2021 and long-term averages (LTA; 30 yr, from 1981 to 2010) were obtained at the Saskatoon Research Farm in Saskatchewan according to Environmental Canada’s climate data online (www.climate.weatheroffice.ec.gc.ca (accessed on 31 December 2021)).
2.2. Study Site and Experimental Design

In spring 2019 (establishment year), a study site was selected at the Livestock and Forage Centre of Excellence (LFCE) located near Saskatoon, Saskatchewan, Canada. The soil type in the area is a Dark Brown Chernozem of Bradwell association, sandy loam texture [19]. The site was surveyed with an EM-38 soil meter to determine the area of salinity prior to trial start in 2019. Following this, an area representing relatively uniform soil salinity was seeded (27 June 2019) with salt-tolerant alfalfa (ALF, cv. ‘Halo’) in three binary mixtures with each of the grass species: slender wheatgrass (SWG, cv. ‘Revenue’), smooth bromegrass (SBG, cv. ‘Radisson’), and creeping meadow foxtail (CMF, cv. ‘Garrison’) and in a quaternary mixture with all three grasses (SWG, SBG, and CMF), with the treatments labelled as follows: (i) ALF-SWG; (ii) ALF-SBG; (iii) ALF-CMF; and (iv) ALF-SWG-SBG-CMF. Replicated treatments ($n = 4$) were randomly allocated to a total of 16 plots (Figure 1). Each plot was 6.2 × 1.2 m in size with 7.4 m$^2$ plot area. There was a 0.5 m gap between treatment plots and a 2 m gap between replicates (blocks). The experimental design was a randomized complete block design.

![Figure 1. Experimental field layout of trial. Note: ALF, alfalfa cv. ‘Halo’; CMF, creeping meadow foxtail cv. ‘Garrison’; SBG, smooth bromegrass cv. ‘Radisson’; SWG, slender wheatgrass cv. ‘Revenue’.](image)

2.3. Soil Properties, Weed Controlling, and Fertilizer Application

Soil core samples (0–15, 15–30, and 30–60 cm depths) were taken from each individual plot using a hand-operated Dutch auger for analysis of soil available nitrate–nitrogen (NO$_3$–N), phosphate–phosphorus (HPO$_4$/H$_2$PO$_4$–P), potassium (K), and sulfate–sulfur (SO$_4$–S), organic carbon, pH, and electrical conductivity (EC) measurements before seeding and fall of 2019 and after harvest 2020 and 2021. Before seeding, plots were prepared for seeding and weed control through rototilling. Based on the soil test results and fertilization recommendation [19], the site was fertilized with 56 kg ha$^{-1}$ of 11–52–0 [mono-ammonium phosphate (MAP); N-P-K] at seeding with the seed to supply starter P and to help improve
uniformity of seed flow through the seeder. 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$^{-1}$ in spring before seeding in 2019. Application rates of commercial fertilizer were based on normal forage fertilizer recommendations for this area.

2.4. Planting, Forage Stand Establishment, and Harvesting

Plots were seeded in the spring of 2019 using a pull-type Wintersteiger plot seeder (WinterSteiger, Salt Lake, UT, USA) at 15.2 cm row spacing and 1.3 cm seeding depth. Seeding rates were ALF at 9.7 kg ha$^{-1}$, SBG at 13.75 kg ha$^{-1}$, CMF at 2.65 kg ha$^{-1}$, and SWG at 12.90 kg ha$^{-1}$ for the binary mixtures and ALF at 9.7 kg ha$^{-1}$, SBG at 13.2 kg ha$^{-1}$, CMF at 0.8 kg ha$^{-1}$, and SWG at 4.88 kg ha$^{-1}$ for the quaternary mixture. Guard rows of ‘Halo’ alfalfa were seeded on each side of the trial. Germination rates for ALF, SWG, SBG, and CMF seeds were 95.6, 87, 63.5, and 81%, respectively.

Stand establishment, forage yield and quality, botanical composition, and weed invasion were monitored over the growing seasons of 2020 (Yr 1) and 2021 (Yr 2). Stand establishment was measured based on the line interception method [20] and expressed in percentage. The measurements were taken 28 May 2020 and 1 June 2021. Botanical composition was determined by clipping a 1 m center row within each plot, and then hand separating into grass, legume, and weeds. The weed component was further separated into foxtail barley (*Hordeum jubatum* L.) and other weed species. Forage components were then dried in a forced air oven at 60 °C for 48 h, then weighed, and the composition was calculated based on DM of individual components or species. For seeding year, in spring 2019, plots were mowed mid-August 2019 to control weeds that were due to the late establishment of the forages. Plots were harvested September 2020 and August 2021 at plant maturity stage.

2.5. Nutritive Analysis

Forage samples were collected during the 2020 and 2021 growing seasons for nutritive value analysis. Samples were dried in a forced-air oven at 55 °C for 72 h and were ground to pass through a 1 mm screen using a Wiley mill (Thomas-Wiley, Philadelphia, PA, USA). Forage quality analysis included crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), calcium (Ca), potassium (K), and total phosphorus (P). Total N was determined using the micro-Kjeldahl method according to AOAC 2012 [21] and was multiplied by 6.25 to determine CP content. Sequential NDF and ADF were analyzed using an ANKOM200 fiber analyzer (Model 200; ANKOM; Fairport, NY, USA) [21]. Ash was determined by heating at 600 °C for 4 h (Method 923.03) [21]. Calcium and total P concentrations were determined using an atomic absorption spectrophotometer (Method 978.02; PerkinElmer, Model 2380, CN, USA) [21] and a spectrophotometer (Method 946.06, Pharmacia, LKB-Ultraspec® III, Stockholm, Sweden) [21], respectively. Potassium concentration was determined through the method adapted from Steckel and Flannery [22]. Total digestible nutrients (TDN) were calculated using the grass–legume Penn State equation according to Adams [23]. Relative feed value (RFV) was calculated as RFV = (DDM × DMI)/1.29; where DDM = digestible dry matter calculated as 88.9 – (0.779 × %ADF) and potential DMI = potential dry matter intake calculated as 120/×%NDF [24].

2.6. Calculation of Nutrient Yield and Uptake

Nutrient yields as crude protein (CPY) and total digestible nutrient (TDNY) yields per hectare were calculated by multiplying crop forage dry matter yield (DMY, kg ha$^{-1}$) by nutrient content (% of DM) to allow a comparison of nutrient yield potential for animal feed production among the forages. Nitrogen, P, and K uptake per hectare (kg ha$^{-1}$) were calculated by multiplying crop forage dry matter yield (DMY, kg ha$^{-1}$) by nutrient content (% DM). The plant yield response to total N in the plant as forage N use efficiency (NUE)
was calculated as harvested plant DMY (kg ha\(^{-1}\)) divided by N uptake (kg N ha\(^{-1}\)) in the plant.

2.7. Economic Evaluation

The costs to seed each treatment plot were scaled up to a cost per hectare unit (CAD/ha\(^{-1}\)). A combination of published custom rates, suggested retail prices (cropping inputs) and published values in enterprise budgets were used to estimate the stand establishment costs for the four treatments. Rototilling the field plots was equated to cultivating and valued at 22.23 CAD/ha\(^{-1}\) (9 CAD/ac\(^{-1}\)) which falls within the custom rate range for cultivating in the 2020–2021 Farm Machinery Custom and Rental Rate Guide published by the Saskatchewan Ministry of Agriculture [25]. Seeding is valued at 56.81 CAD/ha\(^{-1}\) (24 CAD/ac\(^{-1}\)) which falls within the published custom rate range for air seeding and air drills in the 2020–2021 Guide [25].

Fertilizer application was valued at 22.23 CAD/ha\(^{-1}\) (9 CAD/ac\(^{-1}\)) as per the suggested rate published by Manitoba Agriculture’s Pasture Production Costs budget [26]. Seed prices were obtained from the seed suppliers for the trial; alfalfa (cv. ‘Halo’) was 10.78 CAD/kg\(^{-1}\), creeping foxtail (cv. ‘Garrison’) 22.44 CAD/kg\(^{-1}\), slender wheatgrass (cv. ‘Revenue’) was 10.34 CAD/kg\(^{-1}\) and smooth bromegrass (cv. ‘Radisson’) was 10.89 CAD/kg\(^{-1}\). Fertilizer values come from the 2019 Crop Planning Guide released by the Saskatchewan Ministry of Agriculture [27]: 1.28 CAD/kg\(^{-1}\) N, 1.21 CAD/kg\(^{-1}\) P, and 0.94 CAD/kg\(^{-1}\) S. The only establishment cost differing between the treatments was the seed cost.

The forage DM yield from 2020 and 2021 was valued at 0.099 CAD/kg\(^{-1}\) (0.045 CAD/lb\(^{-1}\)) which is a mid-point between the fall 2020 price of 0.073 CAD/kg\(^{-1}\) (0.033 CAD/lb\(^{-1}\)) for standing hay released in the Saskatchewan Forage Council’s Forage Market Report [28] and the drought-adjusted price of 0.13 CAD/kg\(^{-1}\) (0.06 CAD/lb\(^{-1}\)) in the fall 2021 report [28].

The market value of the forage was estimated by multiplying the DMY of the grass and legume by the 2 yr average price for standing hay. The returns were discounted by 5% per year and the establishment costs subtracted to determine a present value (PV) of net returns for each treatment. Discounting annual cashflows (market value of DMY) to a present value basis is a type of capital investment analysis called net present value analysis that accounts for differences in timing and size of cashflows between investments [29].

2.8. Statistical Analysis

Baseline soil properties were analyzed using the Proc Mixed model procedure of SAS 9.4 [30]. The model used for the analysis was: \(Y_{ij} = \mu + T_i + e_{ij}\); where \(Y_{ij}\) was an observation of the dependent variable \(ij\); \(\mu\) was the population mean for the variable; \(T_i\) was the fixed effect of soil depth (three depths included: 0–15, 15–30, and 30–60 cm).

The stand establishment, forage dry matter and nutrient yield, nutrient composition, and nutrient uptake were analyzed and subjected to a two-way analysis of variance (year and treatment) with SAS 9.4 [30]: the whole-plot experimental unit was treatment (four treatments included: ALF-SWG; ALF-SBG; ALF-CMF; and ALF-SWG-SBG-CMF) and the subplot experimental unit was year (2020 and 2021) within the treatment. The model used was: \(Y_{ijr} = \alpha_i + \beta_j + e_{ijr}\); where \(Y_{ijr}\) is the variable studied, \(\alpha_i\) is the treatment, \(\beta_j\) is the year effect, and \(e_{ijr}\) is the residual standard deviation used as the error term.

Soil physicochemical properties and nutrients after harvest were analyzed using the Proc Mixed model procedure of SAS 9.4 [30], where soil depth and year were treated as fixed effects in a factorial design, while replication was considered a random effect. The values for the total cost variable were identical across replications within treatment and year, so the main effects of treatment and year were tested by the combined interaction mean square in a modified ANOVA. Treatment means were determined using Tukey’s multiple range test and were considered significant when \(p \leq 0.05\) and trending towards significance when \(0.05 \leq p \leq 0.10\).
3. Results and Discussion

3.1. Environmental Conditions

Growing season (April to October) precipitation at the study site in 2019 and 2020 (Table 1) were similar (82% and 92% of LTA, respectively). However, precipitation in 2021 was much lower, at 54% of LTA, averaging 76% of LTA over the three study years. Average monthly temperatures over the study years followed similar patterns as the LTAs, although varied in some years with lower temperatures for February and October observed in 2019 (−11.5 and 28% of LTA, respectively), for April and October in 2020 (−11.5 and 28% of LTA, respectively), with higher temperatures experienced in 2021 for June, July, September (averaged at 113% of LTA), and October (125% of LTA).

Table 1. Monthly mean air temperature and precipitation at LFCE, Saskatchewan, Canada in the dark brown soil zone over 3 yrs (2019–2021).

| Month   | 2019 Mean | 2020 Mean | 2-Yr Avg. | LTA † | 2019 Mean | 2020 Mean | 2-Yr Avg. | LTA |
|---------|-----------|-----------|-----------|-------|-----------|-----------|-----------|-----|
| January | −14.1     | −14.4     | −11.2     | −12.8 | −13.9     |            |           | 7.2 |
| February| −24.2     | −12.4     | −19.4     | −15.9 | −11.4     | 11.1       | 1.5       | 1.4 |
| March   | −6.1      | −7.9      | −2.0      | −5.0  | −4.9      | 2.7        | 10.1      | 1.3 |
| April   | 4.8       | −0.6      | 4.5       | 2.0   | 5.2       | 0.4        | 10.9      | 3.5 |
| May     | 9.7       | 11.1      | 10.1      | 10.6  | 11.8      | 4.4        | 42.1      | 35.5|
| June    | 16.0      | 15.3      | 18.0      | 16.7  | 16.1      | 84.8       | 106.9     | 41.7|
| July    | 17.8      | 19.0      | 21.4      | 20.2  | 19        | 67.6       | 52.1      | 17.7|
| August  | 15.4      | 18.04     | 17.8      | 17.9  | 18.2      | 20.3       | 16.2      | 38.4|
| September| 12.3    | 11.70     | 13.7      | 12.7  | 12        | 39.5       | 23.6      | 5.6 |
| October | 0.8       | 1.24      | 5.5       | 3.3   | 4.4       | 11.2       | 3.5       | 6.7 |
| November| −5.5      | −6.71     | −2.4      | −4.6  | −5.2      | 13.1       | 20.5      | 10.2|
| December| −12.0     | −10.5     | −10.4     | −12.4 | 4.1       | 4.1        | 1.7       | 1.7 |

Note † LTA, Long-term average from 1981 to 2010. Data were obtained from Environment Canada (www.climate.weatheroffice.ec.gc.ca) for Saskatoon, SK (Climate ID 4057165; 52°17′N, 106°72′W).

Overall, the 3 yr average of precipitation and temperature data reflected dryer growing seasons with cooler fall temperatures with more severe drought conditions in 2021 at the study site.

3.2. Soil Properties

Physochemical properties of soil at three soil depths before trial are included in Table 2. Soils at the study site were sandy loam-loam (sand: 47.9 ± 2.42%; silt: 45.5 ± 2.31%; and clay: 6.6 ± 1.61%) and there were trends for proportions of sand decreased (p = 0.10) and silt increased (p = 0.09) at 15 to 60 cm depths. No treatment × depth interaction was observed (p > 0.05) for all measured parameters. The electrical conductivity (EC; 6.74 ± 0.228 dS m⁻¹), organic carbon (OC; 1.2 ± 0.01% DM), and pH (7.62 ± 0.025) of the soils averaged among depths showed no differences across the treatment plots (p > 0.05) prior to the initiation of the trial. While soil pH was uniform at the soil depths (7.62; p = 0.45), a trend to slightly lower EC at 30–60 cm depth (6.39 ± 0.67 dS m⁻¹) (p = 0.10) was observed. Soil salinity of EC > 4 dS m⁻¹ will restrict growth of many plants [31], which suggests under the salinity level (ranged 5.9–7.1 dS m⁻¹) at the study site, plant growth, in general, will be detrimentally affected by the salinity depending on their salt tolerance level. Thus, as spring soil results indicate, soil at the trial site is considered a saline soil (EC > 4.0 dS m⁻¹ and pH < 8.5; [32,33] or according to the U.S. Salinity Laboratory classification [34], fits in moderate (EC 4.0–8.0 dS m⁻¹) salinity interval. Soil levels of OC, available N, P, and K before trial, declined (p < 0.01) as the soil depths increased, with the greatest amounts in 0–15 cm depth. Sulfate-S levels were in the very high range determined in a Saskatchewan study [35] at all three soil depths because of the presence of sulfate salts associated with the salinity.
Table 2. Physicochemical properties of soil at three depths before seeding in Clavet, Saskatchewan, Canada.

| Property                                      | 0–15 | 15–30 | 30–60 | SEM | p-Value |
|-----------------------------------------------|------|-------|-------|-----|---------|
| pH (saturated paste)                          | 7.61 | 7.63  | 7.63  | 0.03| 0.45    |
| EC † (saturated paste) (dS m⁻¹)               | 7.01 | 6.82  | 6.39  | 0.67| 0.07    |
| Organic carbon (OC, %)                        | 2.1  | 1.0   | 0.5   | 0.01| <0.01   |
| Available nitrate-N (mg kg⁻¹)                 | 3.76 | 1.63  | 0.39  | 0.27| <0.01   |
| Available sulphate-S (mg kg⁻¹)                | 561  | 664   | 666   | 46.43| 0.22    |
| Available phosphate-P (mg kg⁻¹)               | 11.5 | 8.1   | 5.9   | 0.86| <0.01   |
| Available potassium (mg kg⁻¹)                 | 444.33 | 300 | 208   | 23.25| <0.01   |
| Particle Size Analysis:                        |      |       |       |     |         |
| Mini-Pipette Method                           |      |       |       |     |         |
| % Sand (2.0 mm–0.05 mm)                       | 54.4 | 43.8  | 45.6  | 2.42| 0.10    |
| % Silt (0.05 mm–2 μm)                         | 39.1 | 48.4  | 49.1  | 2.31| 0.09    |
| % Clay (<2 μm)                                | 6.6  | 7.8   | 5.3   | 1.61| 0.60    |
| Texture                                       |      |       |       |     |         |
| ——————————Loamy ——————————               |      |       |       |     |         |

Note. † EC, electrical conductivity; soil samples were taken spring 2019. Ten points were selected randomly in transect across the study site. SEM, standard error of the mean. a–c Means within row with different letters differ (p ≤ 0.05).

Physicochemical properties of soil at three soil depths after harvest averaged across the 3 years are included in Table 3. Soil pH at the site in fall was 7.84 ± 0.044 with a trend of more alkaline (7.87 ± 0.044; p = 0.073) condition at 15–30 cm soil depth, whereas the magnitude of EC differed (p < 0.01), as before the trial, with lower EC (6.40 ± 0.182 dS m⁻¹) at 30–60 cm depth than either at 15–30 cm (7.31 ± 0.182 dS m⁻¹) or 0–15 cm (7.75 ± 0.182 dS m⁻¹).

Table 3. Physicochemical properties of soil at three depths after harvest in Clavet, Saskatchewan, Canada (2019 to 2021 mean).

| Soil Depth, cm | pH   | EC † (dS m⁻¹) | OC (%) | Nitrate-N (mg kg⁻¹) | Phosphate-P (mg kg⁻¹) | Potassium (mg kg⁻¹) |
|---------------|------|--------------|--------|---------------------|----------------------|---------------------|
| 0–15          | 7.80 | 7.75 a       | 2.15 a | 8.06 a              | 9.4 a                | 408 a               |
| 15–30         | 7.87 | 7.31 a       | 0.96 b | 1.01 b              | 1.6 b                | 228 b               |
| 30–60         | 7.82 | 6.40 b       | 0.61 c | 0.65 b              | 1.0 b                | 163 c               |
| SEM           | 0.024| 0.182        | 0.058  | 1.048               | 0.325                | 7.478               |

Note. † EC, electrical conductivity; OC, organic carbon. Soil samples were taken fall 2019 for pH and EC and fall 2020–2021 for soil nutrients. Ten points were selected randomly in transect across the study site. SEM, standard error of the mean. a–c Means within row with different letters differ (p ≤ 0.05).

Soil nitrate-N, phosphate-P, and K levels were lower or comparable when compared to the average surface soil N levels across Alberta, Saskatchewan, and Manitoba (9 kg ha⁻¹) [36] and to the median amount of plant available inorganic N, P, and K (16, 17, and 671.3 kg ha⁻¹, respectively) in the top 45 cm of the dark brown soil of Saskatchewan [35]. Overall, establishment and growth of the forage mixtures over the 2019–2021 period had relatively little effect on soil properties (Tables 2 and 3), and no significant treatment effects were observed.
3.3. Stand Establishment, Botanical Composition, and Forage Yield of ‘Halo’ Alfalfa and Grass Mixtures

Evaluation of stand establishment of ‘Halo’ alfalfa and grass mixtures over two production years following the establishment year (2020, Yr 1, and 2021, Yr 2) is presented in Figure 2. Stand success is most reliably assessed in the second or third growing season following establishment under non-irrigated conditions [37].

![Figure 2](image)

**Figure 2.** Bar chart representing mean and standard deviation (SD) of stand establishment of ‘Halo’ alfalfa and grass mixtures at Clavet, Saskatchewan, Canada over 2 yrs (2020–2021). Note: ALF, alfalfa cv. ‘Halo’; CMF, creeping meadow foxtail cv. ‘Garrison’; SBG, smooth bromegrass cv. ‘Radisson’; SWG, slender wheatgrass cv. ‘Revenue’. Bars with different letter within a treatment are different among years at \( p \leq 0.05 \).

Stand establishment of all mixtures were similar \( (p > 0.05) \) (avg. 81.7%) over the two production years, but the binary mixtures had a slightly better establishment (6.5% greater) than quaternary mixture (83.4 vs. 76.9%), especially in Yr 1 (10% greater). Quaternary mixture stands in Yr 2 showed greater \( (p = 0.01) \) establishment than in Yr 1 (85 vs. 68.8%).

Forage total dry matter yield (DMY) and botanical composition of the treatments are presented in Table 4. Treatments did not differ \( (p > 0.05) \) in total DMY over 2 yrs, but a trend \( (p = 0.08) \) was observed for ALF-CMF of decreased total DMY in Yr 2 from Yr 1 (2.8 vs. 4.2 ± 0.46 Mg ha \(^{-1}\)). Forage mixtures in Yr 1 can be ranked according to mean yield as ALF-SWG the lowest yielding (3.2 ± 0.64 Mg ha \(^{-1}\)), ALF-SBG (3.5 ± 0.64 Mg ha \(^{-1}\)) and ALF-CMF-SBG-SWG (3.6 ± 0.64 Mg ha \(^{-1}\)) intermediate, and ALF-CMF (4.2 ± 0.64 Mg ha \(^{-1}\)) as highest yielding. Consistent with these results, at Swift Current, SK, in the semiarid region of the Canadian prairies, when Dahurian wildrye grass \([Elymus dahuricus]\) Turcz. Ex Griseb., intermediate wheatgrass \([Elytrigia intermedia]\) (Host) Nevski, and slender wheatgrass \([Elymus trachycaulus]\) (Link.) Gould ex Shinners were grown with alfalfa, the grasses produced similar forage yield and yield compensation by alfalfa grown with Dahurian wildrye and slender wheatgrass produced similar total forage yield [38].

In comparison, the total DMY of ALF-CMF (4.2 Mg ha \(^{-1}\)), ALF-SWG (3.2 Mg ha \(^{-1}\)), and ALF-SBG (3.5 Mg ha \(^{-1}\)), in the current study, were lower than in a study conducted in Wyoming, USA [15], with ‘Garrison’ creeping foxtail in mixture with alfalfa (10.1 Mg ha \(^{-1}\)), with ‘Lutana’ cicer milkvetch (6.5 Mg ha \(^{-1}\)), and with ‘Eski’ sainfoin (4.0 Mg ha \(^{-1}\)).

However, the total DMY of SWG in mixture with ‘Beaver’ alfalfa (3.5 Mg ha \(^{-1}\)) at Swift Current, SK, [38] on a non-saline soil was comparable with the yields obtained in the current study, and those of ‘VNS’ smooth brome in mixture with ‘55V48’ alfalfa (5.1 Mg ha \(^{-1}\)) in North Dakota, USA, [39] and of alfalfa + SBG mixture grown in the Mediterranean region of Turkey (2.6–3.3 Mg ha \(^{-1}\)) [40] were higher and comparable, respectively.

Although there was no difference \( (p > 0.05) \) in forage component yield between treatments, the legume component, ‘Halo’ alfalfa mixed with CMF had numerically higher
yield in Yr 1 (2.4 vs. 1.0–1.1 Mg ha\(^{-1}\) in other mixtures). However, this numerical difference was not observed in Yr 2 as legume yields in ALF-CMF (\(p = 0.02\)) and ALF-SBG (\(p = 0.01\)) were significantly lower, likely because of the dry conditions.

Table 4. Forage dry matter yield (DMY) of ‘Halo’ alfalfa and grass mixtures in Clavet, Saskatchewan, Canada over 2 yrs (2020-2021).

| DMY          | Year | ALF-CMF† | ALF-SBG | ALF-SWG | ALF-CMF-SBG-SWG | SEM | p-Value |
|--------------|------|----------|---------|---------|-----------------|-----|---------|
| Total        | Yr 1 | 4.15     | 3.54    | 3.21    | 3.60            | 0.64| 0.78    |
|              | Yr 2 | 2.79     | 2.79    | 2.14    | 2.21            | 0.32| 0.33    |
|              | SEM  | 0.463    | 0.506   | 0.511   | 0.546           | –   | –       |
| p-value      |      | 0.08     | 0.33    | 0.19    | 0.12            | —   | —       |
| Grass        | Yr 1 | 0.76     | 1.14    | 1.53    | 1.70            | 0.37| 0.32    |
|              | Yr 2 | 0.81     | 1.05    | 0.86    | 0.96            | 0.19| 0.83    |
|              | SEM  | 0.210    | 0.360   | 0.210   | 0.356           | –   | –       |
| p-value      |      | 0.86     | 0.87    | 0.07    | 0.19            | —   | —       |
| Alfalfa      | Yr 1 | 2.35     | 1.12    | 1.09    | 0.95            | 0.45| 0.16    |
|              | Yr 2 | 0.25     | 0.41    | 0.59    | 0.13            | 0.13| 0.11    |
|              | SEM  | 0.493    | 0.135   | 0.276   | 0.326           | –   | –       |
| p-value      |      | 0.02     | 0.01    | 0.25    | 0.12            | –   | –       |
| Foxtail barley | Yr 1 | 0.58     | 0.84    | 0.37    | 0.42            | 0.47| 0.89    |
|              | Yr 2 | 0.13     | 0.28    | 0.24    | 0.59            | 0.23| 0.56    |
|              | SEM  | 0.345    | 0.548   | 0.275   | 0.238           | –   | –       |
| p-value      |      | 0.40     | 0.50    | 0.75    | 0.64            | –   | –       |
| Other        | Yr 1 | 0.46     | 0.44    | 0.22    | 0.52            | 0.18| 0.67    |
|              | Yr 2 | 1.59     | 1.05    | 0.45    | 0.49            | 0.29| 0.05    |
|              | SEM  | 0.280    | 0.213   | 0.133   | 0.302           | –   | –       |
| p-value      |      | 0.03     | 0.09    | 0.27    | 0.94            | –   | –       |

Note. † ALF, alfalfa cv. ‘Halo’; CMF, creeping meadow foxtail cv. ‘Garrison’; SBG, smooth bromegrass cv. ‘Radisson’; SWG, slender wheatgrass cv. ‘Revenue’. Plants were harvested September 2020 and August 2021. Foxtail barley, foxtail barley weed; Other, other weeds excluding foxtail barley. SEM, standard error of the mean.

At Swift Current, SK, alfalfa (cv. ‘Beaver’) in mixture with SWG contributed 71 to 82% of the yield [38], compared to which alfalfa, in the present study, made a lower contribution of 34% in Yr 1 and less, 27.6%, in Yr 2. This was not surprising as salt-tolerant grasses generally outperform legumes in moderate saline conditions. However, the legume percentages were still significant, close to the recommended level (30–40%) for grass–legume mixtures by Sanderson et al. [41]. Studies in the northern Great Plains (North Dakota) have found SBG in the mixture with alfalfa made on average about 50% of the total biomass in the third production year [42]. The yield of the grass component of first cut grass–‘Rangelander’ alfalfa mixtures averaged 33% of total yield for ‘Lincoln’ smooth bromegrass in the fifth production year [43]. In comparison, SBG yield in the current study in Yr 1 (32.2% of total DMY) was lower or comparable, whereas, in Yr 2 (37.6% of total DMY) it was lower or higher, respectively.

Higher yields have been reported for these forages grown alone in saline conditions elsewhere. When grown on saline soil at Swift Current, SK, slender wheatgrass, smooth bromegrass, and creeping foxtail yielded 4.2, 5.7, and 5.4 Mg ha\(^{-1}\), respectively, at seed set stage [44]; ‘Radisson’ smooth bromegrass has produced 5.2 and 4.2 Mg ha\(^{-1}\) at Saskatoon, SK, between 1982–1986 [17]; and high total forage yields of 13.6 Mg ha\(^{-1}\) and ranging from 24.2 to 32.7 t ha\(^{-1}\) were achieved for alfalfa grown alone in saline-alkali soil regions of Turkey [45] and north China [46], respectively.

The results in the current study showed that the ALF-CMF binary mixture produced 9 to 23% greater DMY relative to the other three forage mixtures over two years on this moderate saline soil. Concurring with our findings, others noted good performance and salt-tolerance abilities of ‘Garrison’ creeping foxtail in North Dakota, USA, in soils of EC 6.5–7.0 dS m\(^{-1}\) [11], of ‘Halo’ alfalfa that produced a high relative shoot mass at
8 dS m\(^{-1}\) [47], and slender wheatgrass characterized as a salt-tolerant grass, able to withstand EC levels from 15–25 dS m\(^{-1}\) [11], or when combined together also appear to offer yield advantages over combination with a non-salt-tolerant grass like smooth bromegrass. In addition, ALF-SBG tended \((p = 0.09)\) to have more of the weeds, which possibly explains the legume decline as due to competition in these mixtures. Specifically, ALF-CMF was invaded 71.7% more with other weeds as compared to ALF-SWG (the least weed-infested) or to other mixtures \((p = 0.05)\). Slender wheatgrass tended to decrease \((p = 0.07)\) in yield in binary mixture with Halo alfalfa in Yr 2 by almost half (by 43.7%), indicative of possibly shorter longevity (short-lived vs. long-lived) and less persistence (moderate vs. high) [48] of this grass species as compared to the other two grass species.

The results suggest that ‘Halo’ alfalfa with ‘Revenue’ SWG was less susceptible to weed invasion, whereas ‘Halo’ alfalfa with ‘Garrison’ CMF was more susceptible. In an Alberta, Canada site, where the salinity ranged from slight to moderate, green/slender wheatgrass mix and smooth bromegrass were among the forage treatments that successfully suppressed foxtail barley [49]. Steppuhn et al. [50] concluded that in controlling weeds that included foxtail barley, SWG grown alternating with green wheatgrass \((Elymus hoffmannii\) Jensen and Asay) was among the most effective treatments. However, a study with 11 grasses grown on a saline soil in southwestern Saskatchewan contradicted our findings in that slender wheatgrass (73% in botanical composition) appeared to be more susceptible to weeds than creeping foxtail (97% in botanical composition) or smooth bromegrass (91% in botanical composition) [44]. It is speculated that because of the drought conditions experienced in the spring to summer of the establishment year (2019), the poor spring moisture may have affected the treatments the most with severe weed competition.

Likewise, studying the ability of forage crops to suppress weeds at mostly saline sites of Saskatchewan and Alberta, Canada, Steppuhn et al. [51] observed that drought years seemed to favor foxtail barley growth at slightly to moderately and moderately to severely salinized sites. Wall and Steppuhn [49] concluded that the more severe the salinity, the greater the challenge for the forage to suppress the weeds, the narrower the choice of forage species that will succeed, and the more favorable environmental conditions are needed. As well, identifying problems for salt-affected sites in the northern Great Plains, Tober et al. [11] noted that the symptoms may include decreased crop yield and vigorous kochia or foxtail barley growth.

### 3.4. Forage Nutrient Composition, Yield, and Uptake

Forage mixtures did not differ \((p > 0.05)\) in nutrient composition (Table 5). However, a trend \((p = 0.09)\) existed in ALF-SWG having greater TDN than the other mixtures in Yr 2. Forages with an RFV value over 151, between 150–125, 124–103, 102–87, 86–75, and less than 75 are categorized as prime, premium, good, fair, poor, and rejected, respectively [52], based on which, forages in the present study (ranged 90.8–106.3) may be categorized as of good and fair quality.

Forage mixture treatments did not vary in the amounts of CP (CPY) and TDN (TDNY) obtainable from a hectare, nor between years; however, the quaternary mixture tended to decrease in CPY in Yr 2 \((p = 0.08)\) (Table 6).

There was no difference between treatments in nutrient uptake or NUE \((p > 0.05)\) as shown in Table 7. However, the year effect on nutrient uptake was significant \((p < 0.05)\) with decreased values in Yr 2 for some treatments, likely because of the drought condition experienced that year. Thus, in Yr 2, K uptake declined (22.7 vs. 45.3 kg ha\(^{-1}\); \(p = 0.02\)) in ALF-SWG and there were trends of lower P uptake \((p = 0.08)\) in ALF-SWG and ALF-CMF \((p = 0.10)\). As well, ALF-CMF and ALF-SBG appeared to have numerically higher K and N uptakes than the other mixtures.
Table 5. Nutrient composition of ‘Halo’ alfalfa and grass mixtures in Clavet, Saskatchewan, Canada over 2 yrs (2020–2021).

| Item         | Year | Treatment | ALF-CMF † | ALF-SBG | ALF-SWG | ALF-CMF-SBG-SWG | SEM | p-Value |
|--------------|------|-----------|-----------|---------|---------|-----------------|-----|---------|
|              |      |           | g kg⁻¹ DM |         |         |                 |     |         |
| CP           | Yr 1 | 109       | 117       | 95      | 109     | 12.0            | 0.62|         |
|              | Yr 2 | 116       | 103       | 89      | 90      | 10.7            | 0.30|         |
|              | SEM  | 7.6       | 15.9      | 12.5    | 7.1     | –               | –   |         |
| p-value      |      | 0.57      | 0.56      | 0.78    | 0.10    | –               | –   | –       |
| ADF          | Yr 1 | 391       | 365       | 412     | 387     | 17.1            | 0.34|         |
|              | Yr 2 | 378       | 379       | 366     | 388     | 7.4             | 0.28|         |
|              | SEM  | 10.9      | 15.9      | 14.2    | 11.0    | –               | –   |         |
| p-value      |      | 0.46      | 0.56      | 0.06    | 0.98    | –               | –   | –       |
| NDF          | Yr 1 | 559       | 539       | 586     | 564     | 22.6            | 0.56|         |
|              | Yr 2 | 538       | 566       | 560     | 575     | 16.9            | 0.49|         |
|              | SEM  | 15.0      | 25.5      | 21.0    | 16.7    | –               | –   |         |
| p-value      |      | 0.37      | 0.49      | 0.41    | 0.64    | –               | –   | –       |
| TDN          | Yr 1 | 549       | 563       | 537     | 550     | 10.4            | 0.42|         |
|              | Yr 2 | 572       | 574       | 601     | 579     | 8.0             | 0.09|         |
|              | SEM  | 6.5       | 8.6       | 12.9    | 7.9     | –               | –   |         |
| p-value      |      | 0.05      | 0.41      | 0.01    | 0.04    | –               | –   | –       |
| RFV          | Yr 1 | 975       | 1063      | 908     | 973     | 63.9            | 0.43|         |
|              | Yr 2 | 1030      | 980       | 1010    | 955     | 35.4            | 0.48|         |
|              | SEM  | 40.5      | 72.7      | 48.5    | 37.6    | –               | –   |         |
| p-value      |      | 0.37      | 0.45      | 0.19    | 0.75    | –               | –   | –       |
| Ca           | Yr 1 | 6.1       | 6.2       | 5.0     | 5.0     | 0.90            | 0.64|         |
|              | Yr 2 | 8.3       | 5.2       | 6.0     | 5.1     | 1.60            | 0.47|         |
|              | SEM  | 1.1       | 1.1       | 1.9     | 0.8     | –               | –   |         |
| p-value      |      | 0.22      | 0.52      | 0.72    | 0.95    | –               | –   | –       |
| P            | Yr 1 | 1.8       | 1.9       | 1.7     | 1.7     | 0.16            | 0.83|         |
|              | Yr 2 | 1.5       | 1.5       | 1.3     | 1.2     | 0.16            | 0.50|         |
|              | SEM  | 0.2       | 0.2       | 0.1     | 0.1     | –               | –   |         |
| p-value      |      | 0.33      | 0.21      | 0.03    | 0.01    | –               | –   | –       |
| K            | Yr 1 | 12.9      | 15.6      | 15.0    | 14.9    | 1.36            | 0.53|         |
|              | Yr 2 | 13.3      | 13.4      | 10.5    | 10.4    | 1.17            | 0.16|         |
|              | SEM  | 1.1       | 1.2       | 1.5     | 1.2     | –               | –   |         |
| p-value      |      | 0.79      | 0.23      | 0.08    | 0.04    | –               | –   | –       |

Note. † ALF, alfalfa cv. ‘Halo’; CMF, creeping meadow foxtail cv. ‘Garrison’; SBG, smooth bromegrass cv. ‘Radisson’; SWG, slender wheatgrass cv. ‘Revenue’. Plants were harvested September 2020 and August 2021. CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin; TDN, total digestible nutrients; RFV, relative feed value = (DDM × DMI)/1.29 [24] where DDM = digestible DM calculated as 88.9 – (0.779 × %ADF) and DMI = dry matter intake calculated as 120/ [%NDF]. SEM, standard error of the mean.

Table 6. Nutrient yield of ‘Halo’ alfalfa and grass mixtures in Clavet, Saskatchewan, Canada over 2 yrs (2020–2021).

| Item         | Year | Treatment | ALF-CMF † | ALF-SBG | ALF-SWG | ALF-SWG-SBG-CMF | SEM | p-Value |
|--------------|------|-----------|-----------|---------|---------|-----------------|-----|---------|
|              |      | Mg ha⁻¹ DM|           |         |         |                 |     |         |
| CPY          | Yr 1 | 0.463     | 0.413     | 0.301   | 0.398   | 0.084           | 0.60|         |
|              | Yr 2 | 0.327     | 0.298     | 0.192   | 0.198   | 0.052           | 0.22|         |
|              | SEM  | 0.076     | 0.0839    | 0.0500  | 0.0678  | –               | –   |         |
| p-value      |      | 0.25      | 0.37      | 0.17    | 0.08    | –               | –   | –       |
| TDNY         | Yr 1 | 2.273     | 1.990     | 1.750   | 1.971   | 361.15          | 0.79|         |
|              | Yr 2 | 1.605     | 1.599     | 1.289   | 1.280   | 188.92          | 0.45|         |
|              | SEM  | 0.2678    | 0.2760    | 0.3120  | 0.2949  | –               | –   |         |
| p-value      |      | 0.13      | 0.36      | 0.34    | 0.15    | –               | –   | –       |

Note. † ALF, alfalfa cv. ‘Halo’; CMF, creeping meadow foxtail cv. ‘Garrison’; SBG, smooth bromegrass cv. ‘Radisson’; SWG, slender wheatgrass cv. ‘Revenue’. CPY, crude protein yield; TDNY, total digestible nutrients yield; SEM, standard error of the mean.
Table 7. Nutrient uptake of ‘Halo’ alfalfa and grass mixtures in Clavet, Saskatchewan, Canada over 2 yrs (2020–2021).

| Item | Year | ALF-CMF † | ALF-SBG | ALF-SWG | ALF-SWG-SBG-CMF | SEM | p-Value |
|------|------|-----------|---------|---------|-----------------|-----|---------|
| P    | Yr 1 | 7.4       | 6.5     | 5.6     | 6.2             | 1.34| 0.83    |
|      | Yr 2 | 4.1       | 4.3     | 2.6     | 2.7             | 0.69| 0.23    |
|      | SEM  | 1.17      | 1.03    | 1.02    | 1.02            | 0.05| –       |
|      | p-value | 0.10  | 0.18    | 0.08    | 0.05            | –   | –       |
| K    | Yr 1 | 53.9      | 53.4    | 45.3    | 55.2            | 9.83| 0.89    |
|      | Yr 2 | 37.8      | 37.1    | 22.7    | 22.5            | 5.47| 0.11    |
|      | SEM  | 9.29      | 6.43    | 5.18    | 9.92            | –   | –       |
|      | p-value | 0.27  | 0.12    | 0.02    | 0.06            | –   | –       |
| N    | Yr 1 | 74.2      | 66.2    | 48.2    | 63.7            | 13.56| 0.60   |
|      | Yr 2 | 52.4      | 47.7    | 30.7    | 31.7            | 8.46| 0.22    |
|      | SEM  | 12.19     | 13.42   | 8.00    | 10.85           | –   | –       |
|      | p-value | 0.25  | 0.37    | 0.17    | 0.08            | –   | –       |
| NUE  | Yr 1 | 58.8      | 57.9    | 67.8    | 57.5            | 6.27| 0.62    |
|      | Yr 2 | 54.3      | 63.1    | 76.3    | 71.5            | 8.19| 0.29    |
|      | SEM  | 3.99      | 8.49    | 9.87    | 5.22            | –   | –       |
|      | p-value | 0.46  | 0.68    | 0.56    | 0.11            | –   | –       |

Note. † ALF, alfalfa cv. ‘Halo’; CMF, creeping meadow foxtail cv. ‘Garrison’; SBG, smooth bromegrass cv. ‘Radisson’; SWG, slender wheatgrass cv. ‘Revenue’. NUE, N use efficiency which was calculated as harvested crop DMY (kg ha$^{-1}$) divided by total N (kg N ha$^{-1}$) in the crop. SEM, standard error of the mean.

Plants that are efficient in absorption and utilization of nutrients greatly enhance the efficiency of applied fertilizers, reducing cost of inputs, and preventing losses of nutrients to ecosystems [53]. In terms of NUE, the mixtures ranged from 54.3 to 76.3 ($p > 0.05$), but ALF-SWG appeared relatively more efficient than others (67.8 vs. 58.1 in Yr 1 and 76.3 vs. 63 in Yr 2) over two production years. In addition, NUE of the quaternary mixture was higher by 24.4% (71.5 vs. 57.5; $p = 0.11$) in the second production year than in the previous year.

The NUE values of the mixtures grown on the saline soil, in the current study, were in the typical range of NUE (30–60) for cereals [54], comparable to the NUE in maize (57) in the USA [52], and greater than the average cereal NUE value (44) in the UK [54], for annual wheat (38.3) [55], and the worldwide NUE of approximately 33 percent for cereal production [56].

3.5. Cost and Returns Comparison

Economic evaluation of alfalfa–grass mixtures grown on saline soils is presented in Table 8. Costs for cultivating, seeding, fertilizer, and fertilizer application were 272 CAD/ha$^{-1}$ for each treatment. After adding in seed costs, the costs to establish each treatment averaged 491 CAD/ha$^{-1}$ for the binary treatments and 589 CAD/ha$^{-1}$ for the quaternary treatment (Table 8). The seed cost, from lowest to highest, was 164, 238, 254, and 317 CAD/ha$^{-1}$ for ALF-CMF, ALF-SWG, ALF-SBG, and ALF-SWG-SBG-CMF, respectively.

The undiscounted, two-year combined market value for the forage (DMY × 0.099 CAD/kg$^{-1}$) ranged from 369 CAD/ha$^{-1}$ for ALF-SBG to 414 CAD/ha$^{-1}$ for ALF-CMF; the average across all treatments was 390 CAD/ha$^{-1}$. After discounting the returns to a present value (PV) basis and subtracting the establishment costs, the ALF-CMF had produced enough forage (grass + legume) to recoup 89% of the treatment’s establishment costs, ALF-SWG recouped 74%, ALF-SBG 65%, and the quaternary treatment 60%. It is important to note that the cost of land was not included in this analysis. Recent cash rental rates for cultivated land in Saskatchewan were 128 CAD/ha$^{-1}$ (52 CAD/ac$^{-1}$) year$^{-1}$ [57].
Table 8. Establishment costs and estimated present value of net returns for grass-legume forages seeded into saline soil in Clavet, Saskatchewan, Canada over 2 yrs.

| Item                      | ALF-CMF† | ALF-SBG | ALF-SWG | ALF-SWG-SBG-CMF |
|---------------------------|----------|---------|---------|-----------------|
| Establishment costs       | CAD/ha⁻¹ |
| Harrowing                 | 22.23    | 22.23   | 22.23   | 22.23           |
| Seeding                   | 56.81    | 56.81   | 56.81   | 56.81           |
| Seed                      | 164.03   | 254.3   | 237.95  | 316.73          |
| Fertilizer                | 170.69   | 170.69  | 170.69  | 170.69          |
| Fertilizer application    | 22.23    | 22.23   | 22.23   | 22.23           |
| Total costs (A)           | 435.99   | 526.26  | 509.91  | 588.69          |
| Returns                   |          |         |         |                 |
| Forage market value       |          |         |         |                 |
| Yr 1 (B)                  | 410.63   | 350.77  | 317.81  | 356.27          |
| Yr 2 (C)                  | 276.16   | 276.36  | 212.26  | 219.23          |
| 2-yr returns (B+C)        | 686.79   | 627.13  | 530.07  | 575.5           |
| PV of returns (E; 5% discount) | 641.56 | 584.73  | 495.2   | 538.15          |
| PV of net returns (E-A)   | 205.57   | 58.47   | -14.71  | -50.54          |

Note. † ALF, alfalfa cv. ‘Halo’; CMF, creeping meadow foxtail cv. ‘Garrison’; SBG, smooth bromegrass cv. ‘Radisson’; SWG, slender wheatgrass cv. ‘Revenue’; PV, present value. All dollar (D) values are in Canadian dollars (CAD 1.25 = USD 1).

4. Conclusions

On a moderately saline soil in Saskatchewan, Canada, ‘Halo’ alfalfa and three grass species in binary and quaternary mixtures established similarly well, though numerically binary mixtures have established better the year after establishment, while the quaternary mixture stands did better two years after establishment. The forage mixtures did not differ significantly in dry matter yield, nutritional composition, and nutrient uptake and yield, but in the first year, ‘Halo’ alfalfa mixed with creeping meadow foxtail tended to have greater total forage and legume yields, while slender wheatgrass in binary mixture appeared to produce more grass and greater total digestible nutrients, with the latter increased from the previous year. Creeping foxtail in binary mixture with ‘Halo’ alfalfa may be more susceptible to weed infestation, especially in dryer than normal years. There is a substantial cost with establishing forages, but reclaiming unproductive land with forage production that recoups 60–89% of the forage establishment costs after only two years is appealing to producers. The results suggested that binary mixtures of ‘Halo’ alfalfa with ‘Revenue’ slender wheatgrass or ‘Garrison’ creeping meadow foxtail could be reasonable alternatives for adequate forage production and quality, high N use efficiency, and ultimately livestock gain per hectare, as well as for controlling soil salinity and improving soil fertility in this saline area in the dark brown soil zone.

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