Wheatland Conservation Area Inc.
P.O. Box 2015, Swift Current, Saskatchewan. S9H 4M7
Ph. # (306) 773-4775

Crop Rotation Benefits of Annual Forages Preceding Spring Cereals

ADOPT #20190449
Start Date: April 1, 2020
End Date: February 1, 2022

Principal Investigators: Bryan Nybo, Wheatland Conservation Area, Brianne McInnes, Northeast Agriculture Research Foundation, Garry Hnatowich, Irrigation Crop Diversification Corporation

Final Report

Written by Amber Wall
Wheatland Conservation Area Inc.
wcawall@sasktel.net
(306) 773-4775

Wheatland Conservation Area Inc.
P.O. Box 2015, Swift Current, Saskatchewan. S9H 4M7
Ph. # (306) 773-4775

Crop Rotation Benefits of Annual Forages Preceding Spring Cereals

Final Report

Abstract

In the spring of 2020 a trial was established titled, “Crop Rotation Benefits of Annual Forages preceding Spring Cereals.” This project consisted of a 4-replicate RCBD demonstration with 7 different treatments made up of a barley monoculture, and 6 multispecies mixes. In the second year of the trial (2021), spring wheat was seeded into the existing plots to complete the rotation. This demonstration is designed to provide producers an opportunity to see how polyculture crops establish in their own region compared to the barley monoculture and improve soil rotational health benefits for the cereal crop in the following year. Potential yields and forage quality were closely related to environmental growing conditions at each location, as the trial took place at Swift Current, Melfort and Outlook. Results from spring wheat yields in 2021 will determine if the effect of specific mixtures in the previous year were better suited to aiding spring wheat in the following year. This trial was brought to the attention of multiple small group tours throughout 2020 and was also promoted on a CKSW radio program titled, "Walk the Plots" which is broadcasted on a weekly basis throughout each summer. Year one preliminary results were presented by Amber Wall at a Saskatchewan Ministry of Agriculture Planning Meeting on September 22, 2020 in Humboldt, SK.

Project Objectives

This demonstration is designed to provide producers an opportunity to see how these crops establish in their own region and to introduce options for improving soil health by adding annual forages into their rotation, specifically preceding a cereal year.

Project Rationale

This project is based on work demonstrated at AAFC in Swift Current, by Dr. Jillian Bainard[1]. Most recently, research has addressed environmental stability by exploring ways to reduce herbicide and fertilizer inputs, improve forage and feed grains by assessing the nutritive value of these mixtures and determining the economic and agronomic impact of incorporating annual forage mixtures into a cropping system. Results from past and ongoing projects have found that creating polyculture mixtures (more than one

[1] Schellenberg, M.P., Bainard, J., Ren, L., Lamb, E. August 2017. Determination of appropriate species for diverse annual plantings based on their contribution to forage yield and soil improvement

species) with annual crops can result in high quality forage, increased biomass production, enhanced weed suppression, greater microbial activity and diversity, and increased soil nutrients.[2,3]

Nitrogen is commonly provided through chemical fertilizer, or by the introduction of nitrogen fixing plants, such as legumes. Although legume species were shown to vary in the amount of N they can fix, they can have a significant impact on the amount of N fertilizer needed to reach maximum crop productivity. At AAFC, Dr. Jillian Bainard is looking at mixtures where the addition of these legumes in grass-legume mixtures can improve forage quality in terms of protein content and digestibility. Multiple studies have found that as the proportion of legumes in a mixture increases, so does the forage yield and quality, and the yield of subsequent cereal crops.[4]

The inclusion of brassica species will also impact nutrient cycling as they have the potential to take up excess nitrates in the soil and store them in plant tissues. The breakdown of these tissues over time can replenish soil N levels and increase the efficiency of N cycling. Brassica species are being tested as forage crops as they provide a source of high-quality feed, as well as show considerable weed control through competition. Although forage brassicas do come with a risk, as N fertility is important to maximize forage brassica production, the timing and rate of fertilizer application can lead to levels of nitrates and sulfates in the plants, high enough to be toxic to animals.

Many producers are looking to improve soil rotational health and effects in order to create environmental stability that allows for a reduction in herbicides and fertilizers, higher quality forages, and provides multiple benefits for a monoculture in the following year. Benefits to improving soil health includes the integration of larger, and more stable aggregates occurring in soils after annual forage polycultures are grown, indicating increased microbial activity and overall soil quality compared to single seeded monoculture **(Control)**, such as barley or oats.

Although mixtures are not likely to maintain fertility over multiple years without additional inputs, legume species such as Persian Clover, Hairy Vetch, and Forage Pea **(Nitrogen- Fixing Mix)** may allow for a low input fertilizer application to be applied in both crop years due to the N fixation occurring in the soil.

Weed suppression in a cereal crop after incorporating forages into a rotation has shown to be significantly higher**.** Mixtures with higher amounts of root crops/brassica species such as Groundhog Radish, Tillage Radish and Winfred Radish, **(Weed Control Mix)** may account for some weed control, with the possibility of reducing herbicide applications in the following cereal year. Care must be taken to create a mix in which the proportion of brassica species to cereals and legumes is not too high, as brassicas are shown to contain nitrates and sulfates that can be toxic to animals at high enough levels.

Polyculture mixes are shown to create higher quality forages compared to a single monocrop. It is important to pick mixes that provide high crude protein, low non-digestible fibre (NDF) with high digestibility. As many producers are creating their own mix, they may prefer to produce something simple that will still accomplish a range of tasks, therefore includes a balance of legumes, cereals, and brassicas **(Balanced**

---

[2] AAFC Swift Current, Dr. Jillian Bainard; Ongoing SK Cattlemen's Association Project – Development of best management practices for residue and fertility management of annual polycultures

[3] AAFC Swift Current, Dr. Jillian Bainard; Ongoing BCRC Project - Assessing the impact of grazing annual forage cover crops in an integrated crop-livestock system

[4] Lithourgidis, A. & Dordas, Christos & Damalas, Christos & Vlachostergios, D. (2011). Annual intercrops: An alternative pathway for sustainable agriculture. Australian Journal of Crop Science. 5. 396-410.

Mix). Another option is a balanced mix with an additional cereal species to increase biomass **(Simple Balanced Mix).** Others may be willing, or have the means to produce a more complicated polyculture that includes more species. The more species included, the higher the likelihood to improving biomass yield and increasing the nutritional value of the forage **(Complex Balanced Mix).**

Having a cover crop that can accomplish a range of tasks, including weed control, improved forage nutrition and biomass, as well as nitrogen fixation for the following years crop will result in a number of benefits for overall soil rotational health and effects **(Complex Soil Amendment Mix).** As for a cereal monoculture in the following year, grain yield increases are shown when annual forages precede cereal crops in a rotation, especially when mixtures that include N- fixing legumes are included allowing a low input fertility system.

Methods

- Locations: Swift Current (WCA), Outlook (ICDC) and Melfort (NARF).
- No-till, continuous cropping system, harvested for forage biomass in year 1 and grain in year 2.
- Previous crop in year 1, seeding and harvest dates varied by location (Table 1).
- All plots received a base fertility of side-banded 45 lbs. N per acre in year 1, and about 75% of the recommended rate according to residual soil Nitrogen in year 2.
- A pre-seed herbicide to ensure a clean seed bed.
- 7 treatments including a cereal monoculture (control), and 6 polyculture mixes seeded with 4 replications (Table 2).
- Treatments in 2020 were seeded at the same target plant stand at each location. Advantage barley was seeded as the control at 100 lbs/ac. Polyculture seeding rates (Table 2) were calculated so that the sum of the proportional rates exceeded one hundred percent, while also taking seed size and growth pattern into consideration.[5]
- Plant species selected are adapted to grow in the agricultural region with 3-4 species being from each of the legumes (nitrogen fixing), cereals, and brassicas (root crops). These functional groups represent variation in plant traits and growth form, and consequently vary in their contribution to the agroecosystem and to forage quality.
- The following spring (2021) spring wheat was seeded into each plot, accompanied by low amounts of fertilizer, consistent across treatments in order to show differences in residual N fixed in the previous year. All fertilizer will be side-banded and spring wheat will be harvested for grain yield.
- In-crop herbicides applied in second year after a weed control rating is complete.
- Each site was statistically analyzed individually using JMP and $p<0.05$ and all values are presented in tables, whether statistically significant, or not.

Table 1. Other agronomic information

Operation	Swift Current		Outlook		Melfort	
Year	2020	2021	2020	2021	2020	2021
Previous Crop	Spring Wheat	2020 trts	Canola	2020 trts	Canola	2020 trts
Pre-emergent herbicide	RT540 + Aim	RT540 + Aim	Glyphosate540 + Heat LQ	Glyphosate540 + Heat LQ	Glyphosate 540	Glyphosate540 + Heat LQ

[5] http://northeastcovercrops.com/wp-content/uploads/2018/03/NH-340-Cover-Crop-Planting-Specification-Guide-2.pdf

Cultivar	n/a	Adamant	n/a		n/a	Brandon
Seeding Date	15-May	12-May	28-May	14-May	23-May	11-May
Row Spacing	8.25 inches		10 inches		12 inches	
Fertility lbs/ac	45N	30N-50P	40N-31P	67N-22P	45N	83N-40P-10K-7S
Plant Density	23-Jun	16-Jun	23-Jun	02-Jun	22-Jun	31-May
Visual Weed Control	23-Jun	June 7, Jul 22	23-Jun	June 10, Aug 17	21-Jul	08-Jun, n/a
Plant height (cm)	n/a	22-Jul	n/a	16-Aug	n/a	23-Jul
In-crop Herbicides	none	Buctril M + Liquid Achieve	none	Tank mix Simplicity + Buctril M	none	Prestige XC, Axial
Fungicide Application	none	none	none	Priaxor	none	Caramba
Harvest date	05-Aug	17-Aug	13-Aug	26-Aug	06-Aug	18-Aug

Table 2. Treatment List

Year One (2020) L=Legume, C=Cereal, B=Brassica									Year Two (2021)
TRT #	# of species	Proportion	Purpose of treatment	Species	lb/ac in mix				Species
1	Monoculture	1C	Control	C: Advantage Barley	100				Spring Wheat
2	3 species	1L:1C:1B	Balanced Mix	L: Persian Clover	5				Spring Wheat
				C: Advantage Barley	30				
				B: Groundhog Radish	4				
3	3 species	3L	N-Fixing Mix	L: Persian Clover, Hairy Vetch, Forage Pea (Leroy)	4	6	70		Spring Wheat
4	4 species	1L:2C:1B	Simple Balanced Mix	L: Persian Clover	4				Spring Wheat
				C: Advantage Barley, Haymaker Oats	30	26			
				B: Groundhog Radish	2				
5	6 species	1L:2C:3B	Weed Control Mix	L: Persian Clover	1.5				Spring Wheat
				C: Advantage Barley, Haymaker Oats	30	26			
				B: Groundhog Radish, Tillage Radish, Winfred Radish	1	1.2	1		
6	6 species	2L:2C:2B	Complex Balanced Mix	L: Persian Clover, Hairy Vetch	3	2			Spring Wheat
				C: Advantage Barley, Haymaker Oat	26	30			
				B: Groundhog Radish, Winfred Radish	1	0.5			
7	8 species	2L:4C:2B	Complex Soil Amendment Mix	L: Persian Clover, Hairy Vetch	1.5	2			Spring Wheat
				C: Advantage, Haymaker Oat, Corn, Millet	17	20	3	3	
				B: Groundhog Radish, Winfred Radish	1.5	0.8			

<u>Data Collection:</u>

<u>Year 1 (2020)</u>

- Soil Sample to determine stored soil nutrients (0- 6", 6-24")
- Crop Establishment (%) – using the line intercept method
- Visual Weed Control Rating (1=no control, 5=control)
- Forage Biomass Yield (kg/ha)
- Feed Analysis (Central Testing Laboratories), including Acid Detergent Fiber (ADF), ADI-CP%, ADIN%, Calcium (Ca%), Crude protein (CP%), Magnesium (Mg%), Neutral Detergent Fiber (NDF%), Phosphorus (P%), Potassium (K%), Relative Feed Value (RFV), Sodium (Na%) and Total Digestible Nutrients (TDN%).

<u>Year 2 (2021)</u>

- Residual soil nutrients & qualities – composite soil sample bulked by treatment (0- 6", 6-24")
- Spring Wheat Emergence (plants/m^2)
- Visual Weed Control Ratings (1=no control, 5=control) – prior to in-crop and prior to harvest

- Plant Height (cm) – average height at front and back of plot
- Grain Yield (kg/ha) – corrected for dockage and to 14.5% seed moisture content

General Site Conditions

Table 3. Mean monthly temperatures and precipitation amounts for the 2020-2021 growing season at each location.

Location	Year	May	June	July	August	Avg. / Total
		-----------------------*Mean Temperature (°C)* -------------------				
Swift Current	2020	10.9	16.6	18.2	19.5	16.3
	2021	9.5	18.4	21.7	18.0	16.9
	Long-term	**10.9**	**15.3**	**18.2**	**17.6**	**15.5**
Melfort	2020	10.1	14.3	18.8	17.6	15.2
	2021	9.6	18.2	20.1	16.9	16.2
	Long-term	**10.7**	**15.9**	**17.5**	**16.8**	**15.2**
Outlook	2020	11.3	15.9	19.1	18.8	16.3
	2021	10.2	18.6	21.6	17.9	17.1
	Long-term	**11.5**	**16.1**	**18.9**	**18.0**	**16.1**
		------------------------ *Precipitation (mm)* --------------------				
Swift Current	2020	36.3	80.0	62.5	6.5	185
	2021	35.0	29.6	38.9	55.8	159
	Long-term	**51.2**	**77.1**	**60.1**	**47.4**	**236**
Melfort	2020	26.7	103.7	52.4	18.5	201
	2021	31.4	37.6	0.2	69.3	139
	Long-term	**42.9**	**54.3**	**76.7**	**52.4**	**226**
Outlook (does not include ~225mm of irrigation/year)	2020	27.8	79.2	29.6	19.0	156
	2021	30.9	13.1	1.5	16.0	62
	Long-term	**42.6**	**63.9**	**56.1**	**42.8**	**205**

Results and Discussion

For the purposes of this report, feed analysis is evaluated based on cattle requirements determined by thhe National Research Council's Nutrient Requirements for Beef Cattle, & Alberta Agriculture and Forestry calculator (BCRC). Overall, treatments resulted in inadequate calcium, and magnesium, adequate phosphorus and sodium, high potassium and feed may have needed to be supplemented. High potassium, low calcium and low magnesium can all predispose animals to winter tetany leading to disease and death among cattle, therefore it is important to test feed annually.[6] The following is based on feed analysis results from 1 year of data at 3 locations (2020), of this 2-year demonstration with 7 different treatments including a barley monoculture, and 6 multispecies mixes (polycultures). Residual effects of the treatments were evaluated in the 2021 portion of analysis (tables 11-14).

Control/monoculture (Table 4)

[6] https://www.gov.mb.ca/agriculture/livestock/beef/down-cows-winter-tetany-milk-fever-pregnancy-toxaemia.html

In year one, 6 polycultures were compared to a monoculture treatment, Advantage barley (Control). As expected, the commonly grown barley variety had the highest establishment (98.5%) compared to polyculture mixtures, which ranged from 68.5% to 82.7%. However, at Outlook establishment for each treatment was 100%, likely due to plots being under irrigation and allowing for adequate and uniform moisture conditions at emergence. The barley monoculture was also rated high for visual weed control at all sites, which likely resulted from high barley establishment allowing for increased competition for weeds compared to other treatments. Overall, the barley monoculture was low in ADF (29.6%), had NDF less than 70% (48.6%) and high TDN (67%) meaning good digestibility and intake, resulting in a high energy feed source. Crude protein was acceptable and averaged 7.3%. Barley resulted in the highest RFV (127).

Overall, the barley monoculture (Control) resulted in one of the lowest yields (7460.7 kg/ha) and was not significantly different than the Weed Control mix yield (7496.1 kg/ha). However, barley yield did vary between locations and the Control treatment yielded well at Melfort (5979 kg/ha) compared to other treatments. The Control also resulted in the lowest residual N when soil tests from the following spring were averaged over 2 sites (Swift Current and Melfort, data not shown).

Table 4. Monoculture data collection and feed analysis results for each location, as well as the 3-year average (2020).

Control	Swift Current	Melfort	Outlook	3 Site Years
Acid Detergent Fibre (%)	32	29	28	**29.6**
ADI-CP (%)	4.3	4.8	3.0	**4.0**
ADIN (% Crude Protein)	55	63	46	**54.9**
Biomass Yield (kg/ha)	8,739	5,979	7,664	**7460.7**
Calcium (%)	0.19	0.30	0.24	**0.24**
Crude Protein (%)	7.8	7.5	6.4	**7.3**
Establishment (%)	98.1	97.5	100.0	**98.5**
Magnesium (%)	0.15	0.15	0.17	**0.15**
Moisture at harvest (%)	49	64	61	**57.8**
Neutral Detergent Fibre (%)	52	48	46	**48.6**
Phosphorous (%)	0.22	0.26	0.22	**0.23**
Potassium (%)	1.86	1.32	1.39	**1.52**
Relative Feed Value	115	129	138	**127**
Sodium (%)	0.14	0.04	0.18	**0.08**
Total Digestible Nutrients (%)	64	67	69	**67.0**
Visual Weed Control	3.3	4.0	4.5	**3.9**

Balanced Mix (Table 5)

A few variations of balanced mixtures were included in the trial to determine if the addition of a legume and brassica species can improve the forage quality of a mixture in terms of protein and digestibility. Multiple studies have found that as the proportion of legumes in a mixture increases, so does the forage yield and quality (Bainard, 2011), and the additional species may improve protein, quality and increase digestibility. Overall, establishment for the Balanced mix (clover, barley, and radish) averaged 77.5%, similar to the Simple Balanced mix (82.7%) and Complex Balanced Mix (78.4%). Although weed control varied by site, high weed control at Outlook (5/5) can be explained by the strong establishment at this location compared to other locations. The Balanced mix had low ADF (35.7%), NDF less than 70% (52.8%) and moderate TDN (60.5%) meaning good digestibility and intake, resulting in a high energy feed source. Crude protein was acceptable and averaged 7.9%. The Balanced mix resulted in a high RFV (109).

Overall, the Balanced mix resulted in the significantly lowest yield (6367.3 kg/ha) and was the lowest yielding treatment at each location, although not significantly different than the Control treatment at Swift Current (Table 4).

Table 5. Balanced mix data collection and feed analysis results for each location, as well as the 3-year average (2020).

Balanced Mix	**Swift Current**	**Melfort**	**Outlook**	**3 Site Years**
Acid Detergent Fibre (%)	34	36	37	**35.7**
ADI-CP (%)	3.8	6.1	3.2	**4.4**
ADIN (% Crude Protein)	46	72	47	**54.9**
Biomass Yield (kg/ha)	8,479	4,977	5,646	**6367.3**
Calcium (%)	0.20	0.54	0.63	**0.45**
Crude Protein (%)	8.5	8.3	7.0	**7.9**
Establishment (%)	73.8	58.8	100.0	**77.5**
Magnesium (%)	0.15	0.19	0.29	**0.21**
Moisture at harvest (%)	52	73	78	**67.6**
Neutral Detergent Fibre (%)	55	53	51	**52.8**
Phosphorous (%)	0.23	0.25	0.20	**0.23**
Potassium (%)	1.99	1.75	1.74	**1.83**
Relative Feed Value	106	121	124	**109**
Sodium (%)	0.14	0.03	0.13	**0.12**
Total Digestible Nutrients (%)	62	60	62	**60.5**
Visual Weed Control	1.6	2.5	5.0	**3.0**

Nitrogen Fixing Mix (Table 6)

Legume species included in this treatment consisted of Persian clover, Hairy vetch, and a forage pea (Nitrogen-Fixing mix) and was assessed for the potential of a low input fertilizer application over both consecutive crop years as a result of the N-fixation occurring in the soil in year 1. When averaged over all sites the N-fixing mix resulted in the lowest establishment (68.5%) of all treatments. Weed control for this treatment was low at all sites. The N-fixing mix had acceptable ADF (37%), NDF less than 70% (47.9%) and moderate TDN (59.1%) meaning good digestibility and intake, resulting in a high energy feed source. As expected, crude protein was very high averaging 17.1%, significantly higher than all other treatments. The N-fixing mix also resulted in a high RFV (117).

Overall the N-fixing mix yielded 7622.5 kg/ha. However, yield did vary between locations. The N-fixing treatment yielded very well at Swift Current (10,241 kg/ha) and was the highest yielding treatment at this location. This mix did not yield higher than the Control (Table 4) at either Melfort (5979 kg/ha), or Outlook (7664 kg/ha).

Table 6. N-fixing mix data collection and feed analysis results for each location, as well as the 3-year average (2020).

N-Fixing Mix	**Swift Current**	**Melfort**	**Outlook**	**3 Site Years**
Acid Detergent Fibre (%)	38	37	36	**37.0**
ADI-CP (%)	4.1	9.2	7.0	**6.7**
ADIN (% Crude Protein)	28	52	36	**38.6**
Biomass Yield (kg/ha)	10,241	5,492	7,135	**7622.5**
Calcium (%)	0.61	1.07	1.02	**0.90**
Crude Protein (%)	14.5	17.5	19.3	**17.1**
Establishment (%)	58.1	47.5	100.0	**68.5**
Magnesium (%)	0.25	0.24	0.30	**0.26**
Moisture at harvest (%)	65	77	80	**73.9**
Neutral Detergent Fibre (%)	52	46	46	**47.9**

Phosphorous (%)	0.25	0.28	0.23	**0.26**
Potassium (%)	2.74	2.64	2.42	**2.60**
Relative Feed Value	108	108	112	**117**
Sodium (%)	0.09	0.03	0.12	**0.08**
Total Digestible Nutrients (%)	58	59	62	**59.1**
Visual Weed Control	1.0	1.5	2.5	**1.7**

Simple Balanced Mix (Table 7)

While a 3-species mix may be sufficient, others may be willing, or have the means to produce a more complicated polyculture that includes more species. This Simple Balanced mix is similar to the Balanced mix, but includes an additional cereal species meant to increase biomass. Overall weed control increased, likely due to an increase in overall establishment of the mix. As a result of the additional cereal, NDF increased by 5% (57.8%), meanwhile TDN and ADF were not significantly different. Crude protein decreased slightly and averaged 7.4% and RFV decreased to 98.

However, the additional cereal did significantly increase biomass yield by 1448.6 kg/ha compared to the Balanced mix (Table 5) and this trend was consistent at each location. This was the highest yielding treatment at Melfort (6222 kg/ha) and second highest at Outlook (8207 kg/ha).

Table 7. Simple Balanced mix data collection and feed analysis results for each location, as well as the 3-year average (2020).

Simple Balanced Mix	Swift Current	Melfort	Outlook	3 Site Years
Acid Detergent Fibre (%)	35	39	35	**36.1**
ADI-CP (%)	3.7	4.5	2.3	**3.5**
ADIN (% Crude Protein)	44	59	40	**47.4**
Biomass Yield (kg/ha)	9,019	6,222	8,207	**7815.9**
Calcium (%)	0.19	0.35	0.23	**0.25**
Crude Protein (%)	8.6	7.7	5.8	**7.4**
Establishment (%)	92.5	55.5	100.0	**82.7**
Magnesium (%)	0.15	0.15	0.16	**0.15**
Moisture at harvest (%)	54	70	70	**64.3**
Neutral Detergent Fibre (%)	58	60	55	**57.8**
Phosphorous (%)	0.24	0.26	0.20	**0.23**
Potassium (%)	2.35	2.11	1.72	**2.06**
Relative Feed Value	98	95	112	**98**
Sodium (%)	0.21	0.03	0.12	**0.11**
Total Digestible Nutrients (%)	61	59	62	**60.0**
Visual Weed Control	2.3	3.5	4.8	**3.5**

Weed Control Mix (Table 8)

A mixture that includes root crops/brassica species such as Groundhog Radish, Tillage Radish and Winfred Radish make up the Weed Control mix in order to increase weed suppression. In year one, a visual weed rating was not statistically significant at all locations. The Weed Control mix showed strong establishment averaging 79.7%. However, due to strong establishment of the barley monoculture there was a tendency for that treatment to have higher weed control at the sites with less than 100% establishment. The Weed Control mix had low ADF (35.7%), NDF less than 70% (56%) and moderate TDN (60.4%) meaning high digestibility and intake, resulting in a high energy feed source. Crude protein was acceptable at 7.6%. RFV averaged 102.

Overall, the Weed Control mix resulted in one of the lowest yields (7496.1 kg/ha). However, yield did vary between locations. This mixture yielded well at Melfort (6169 kg/ha) and was not significantly different than the highest yielding treatment (Simple Balanced mix, 6222 kg/ha).

Table 8. Weed Control mix data collection and feed analysis results for each location, as well as the 3-year average (2020).

Weed Control Mix	Swift Current	Melfort	Outlook	3 Site Years
Acid Detergent Fibre (%)	35	37	36	**35.7**
ADI-CP (%)	3.3	4.6	2.7	**3.6**
ADIN (% Crude Protein)	39	61	42	**47.3**
Biomass Yield (kg/ha)	9,106	6,169	7,214	**7496.1**
Calcium (%)	0.17	0.31	0.40	**0.29**
Crude Protein (%)	8.7	7.6	6.5	**7.6**
Establishment (%)	86.9	52.3	100.0	**79.7**
Magnesium (%)	0.14	0.14	0.22	**0.17**
Moisture at harvest (%)	55	69	73	**65.6**
Neutral Detergent Fibre (%)	55	59	54	**56.0**
Phosphorous (%)	0.24	0.25	0.21	**0.23**
Potassium (%)	2.26	1.99	1.76	**2.00**
Relative Feed Value	105	92	110	**102**
Sodium (%)	0.15	0.02	0.10	**0.10**
Total Digestible Nutrients (%)	62	57	60	**60.4**
Visual Weed Control	2.5	3.8	5.0	**3.8**

Complex Balanced Mix (Table 9)

The more species included in a mix, the higher the productivity of improving biomass yield and increasing the nutritional value of the forage (Bainard, 2011). The Complex Balanced mix was a balance of legumes, cereals, and brassicas, but included 6-species; twice the amount of species as the Balanced Mix (3-species). This mix resulted in good establishment (78.4%) and overall high average weed control. The feed analyses revealed low ADF (35.9%), NDF less than 70% (56.5%) and moderate TDN (60.3%) meaning high digestibility and intake, resulting in a high energy feed source. Crude protein was an acceptable level at 8.1%, higher than a number of other mixes. RFV averaged 101.

The Complex Balanced mix resulted in the significantly highest yield (8205.1 kg/ha) and consistently yielded well at all locations. This treatment also resulted in the highest residual Nitrogen when soil samples from the following spring were averaged across 2 locations (Swift Current and Melfort, data not shown).

Table 9. Complex Balanced mix data collection and feed analysis results for each location, as well as the 3-year average (2020).

Complex Balanced Mix	Swift Current	Melfort	Outlook	3 Site Years
Acid Detergent Fibre (%)	34	39	34	**35.9**
ADI-CP (%)	3.6	5.3	3.2	**4.0**
ADIN (% Crude Protein)	43	62	45	**49.8**
Biomass Yield (kg/ha)	8,962	5,805	9,848	**8205.1**
Calcium (%)	0.20	0.37	0.33	**0.30**
Crude Protein (%)	8.4	8.6	7.2	**8.1**
Establishment (%)	90.6	44.5	100.0	**78.4**
Magnesium (%)	0.17	0.15	0.17	**0.16**
Moisture at harvest (%)	54	71	69	**64.4**
Neutral Detergent Fibre (%)	55	62	53	**56.5**
Phosphorous (%)	0.24	0.25	0.20	**0.23**
Potassium (%)	2.40	2.20	1.74	**2.11**

Relative Feed Value	106	89	105	**101**
Sodium (%)	0.22	0.02	0.10	**0.11**
Total Digestible Nutrients (%)	62	57	60	**60.3**
Visual Weed Control	2.8	3.5	5.0	**3.8**

Complex Soil Amendment Mix (Table 10)

Lastly, the Complex Soil Amendment Mix was established to accomplish a range of tasks, including weed control, high quality forage, biomass and nitrogen fixation for the following crop and ultimately provide a number of benefits to improving overall soil rotational health and effects. Establishment for this mix was lower (71%) than other treatments and did not establish well at Melfort, specifically (27.3%). This mix resulted in low ADF (36.7%), NDF less than 70% (56.3%) and moderate TDN (59.5%), therefore high digestibility and intake, resulting in a high energy feed source. Crude protein for this treatment (8.4%) was not significantly different than the Complex Balanced mix (8.1%), but higher than most mixes. RFV averaged 101.

The Complex Soil Amendment mix resulted in the second highest yield (7867.8 kg/ha), but did vary by location. This was a particularly well-suited mix at Swift Current in terms of yield (9889 kg/ha), but was not significantly different than the barley monoculture (Table 4) at Melfort and Outlook.

Table 10. Complex Soil Amendment mix data collection and feed analysis results for each location, as well as the 3-year average (2020).

Complex Soil Amendment Mix	**Swift Current**	**Melfort**	**Outlook**	**3 Site Years**
Acid Detergent Fibre (%)	37	39	35	**36.7**
ADI-CP (%)	3.8	4.7	3.8	**4.1**
ADIN (% Crude Protein)	42	55	49	**48.7**
Biomass Yield (kg/ha)	9,889	5,878	7,837	**7867.8**
Calcium (%)	0.22	0.33	0.50	**0.35**
Crude Protein (%)	8.9	8.5	7.8	**8.4**
Establishment (%)	85.6	27.3	100.0	**71.0**
Magnesium (%)	0.16	0.16	0.22	**0.18**
Moisture at harvest (%)	58	71	74	**67.4**
Neutral Detergent Fibre (%)	55	62	52	**56.3**
Phosphorous (%)	0.23	0.26	0.20	**0.23**
Potassium (%)	2.36	2.16	1.99	**2.17**
Relative Feed Value	102	88	104	**101**
Sodium (%)	0.19	0.02	0.09	**0.11**
Total Digestible Nutrients (%)	59	57	59	**59.5**
Visual Weed Control	2.3	3.0	4.8	**3.3**

In the second year of the trial (2021), spring wheat at the same seeding rate and fertility was seeded into the existing plots to complete the rotation and is designed to assess the potential residual effects of each mixture on soil rotational health for a cereal monoculture in the following year. For the purposes of this report, residual effects of each mixture are evaluated based on emergence and yield success of the 2021 crop.

Spring Wheat Density (Table 11, Fig. 1)

Across all treatments in 2021, spring wheat density was highest at Outlook (261 plants/m^2), intermediate at Swift Current (169.7 plants/m^2) and lowest at Melfort (130.9 plants/m^2). This was not surprising considering precipitation was well below the long-term average, the extreme temperatures that existed and

Outlook having irrigation to supplement the minimal rainfall and overall low moisture reserve that has resulted at other locations over the last 2 years.

At Outlook, spring wheat density resulting from the Control (236.8 plants/m^2) had significantly lower plant populations compared to the other treatments. This could be a result of low residual nitrogen from the monoculture barley (Control treatment) compared to the legume containing mixtures, or decreased soil compaction in the polyculture mixes, especially under irrigation. Plant density resulting from the Complex Soil Amendment treatment was the highest (277.5 plants/m^2), but not significantly different than the N-fixing treatment (274.8 plants/m^2), or the Complex Balanced treatment (266.5 plants/m^2), as each of these mixtures contained two to three nitrogen-fixing species. At Melfort, the N-fixing treatment resulted in the statistically lowest spring wheat density (105.8 plants/m^2), but no other treatments resulted in significant differences. This small range in plant density was not expected given the differences in number of species per treatment, or residual soil nitrogen (data not shown), but can be attributed to limited moisture and cool weather during emergence. At Swift Current, the N-fixing treatment also resulted in the lowest spring wheat density (156 plants/m^2). The Complex Balanced treatment resulted in the highest spring wheat density at Swift Current (179.3 plants/m^2), but was not significantly different from most mixes. This small range in variation at Swift Current was expected due to drought conditions for two consecutive years and little variation in residual N from the previous year (data not shown).

Table 11. 2020 treatment effects on spring wheat density in 2021 at Swift Current, Melfort and Outlook, as well the 3-site year average (Swift Current, Melfort and Outlook, 2021).

Treatment	Swift Current	Melfort	Outlook	3-site years
		--------------------Plant Density (plants/m^2)---------------------		
LSD	9.6	11.6	17.6	8.9
Grand Mean	169.7	130.9	261	187.2
CV	12.2	19.2	14.6	18.5
Treatment				
Control	172.1ab	134.5a	236.8d	181.1bc
Balanced Mix	165.5bc	139a	259.3bc	187.9ab
N-Fixing Mix	156.0c	105.8b	274.8ab	178.8c
Simple Balanced Mix	173.6ab	139.4a	254.5c	189.2ab
Weed Control Mix	166.4b	135.7a	258bc	186.7abc
Complex Balanced Mix	179.3a	132.9a	266.5abc	192.9a
Complex Soil Amendment Mix	174.7ab	128.8a	277.5a	193.7a

When combining the 3-site years, the Complex Soil Amendment treatment and Complex Balanced treatment resulted in the highest spring wheat density, significantly higher than the Control and N-fixing treatments (Fig. 1, Table 11). Spring wheat density tended to increase with the increasing number of species in the 2020 mixture, with the exception of the Nitrogen-fixing and Weed Control treatments and may be attributed to decreased soil compaction of certain species and overall increased soil health provided by Complex mixes. Although spring wheat density from the N-fixing treatment was low, residual nitrogen from this mix may be available to the plant as precipitation accumulates, rather than early in the growing season.

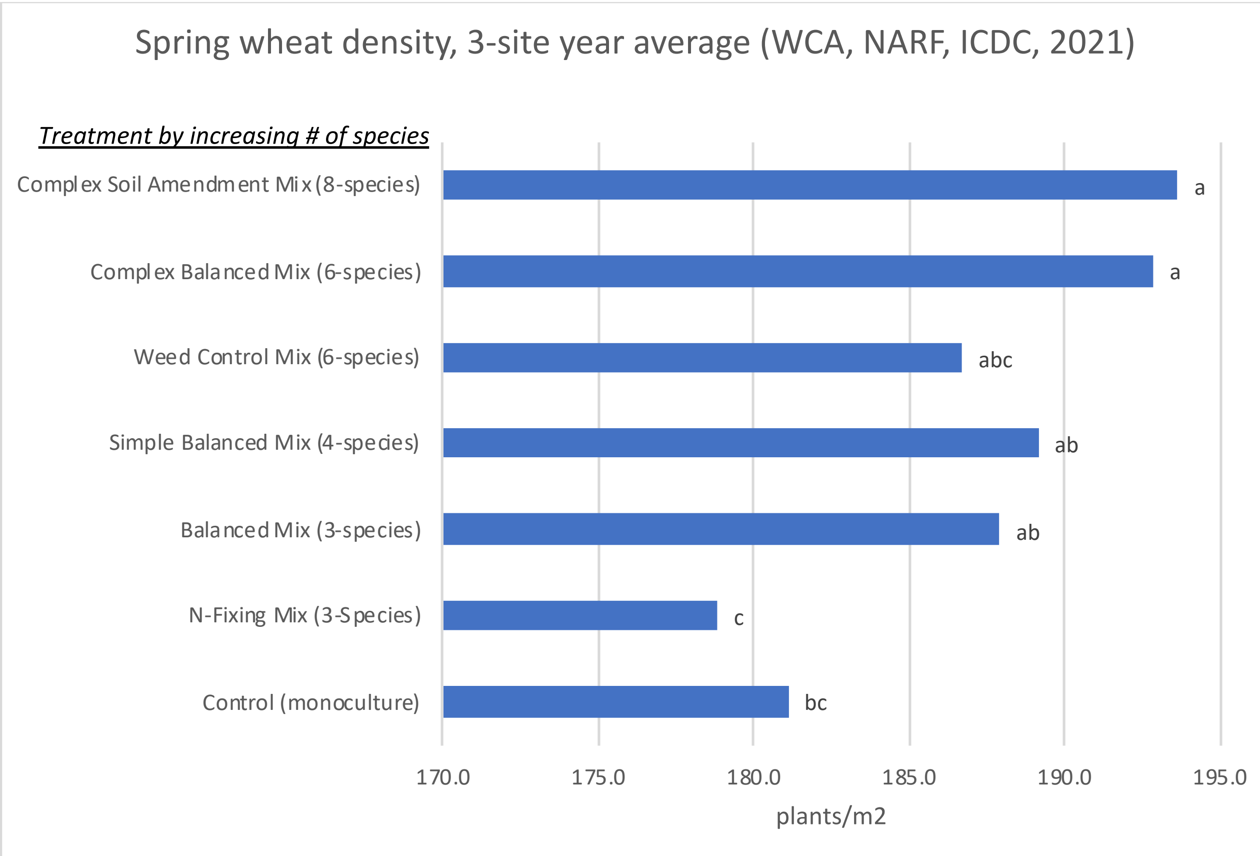

Figure 1. 2020 treatment effects on spring wheat plant density in 2021. With the exception of the Nitrogen-fixing treatment and Weed Control treatment, plant density increased with the increasing number of species in the 2020 mixture.

Weed Control (Table 12)

Across all treatments in 2021, average weed control was low. However, visual ratings are subjective, tend to vary across sites and only one rating (prior to in-crop herbicide) was completed at Melfort.

Outlook showed very little variation in weed control between treatments, and was not statistically significant, but tended to decrease with increased number of species in the 2020 treatment. At Melfort weed control was not statistically significant. However, visually had moderate weed control. At Swift Current, early weed control was high prior to the in-crop herbicide application and remained high. Averaged over the two ratings the Complex Soil Amendment mix and Control treatment had the highest visual control (4.8/5) and the N-fixing mix resulted in the least (3.8/5).

Although there was high variability between sites, the Weed Control treatment did not seem to have increased control at any location in the spring wheat year. However, overall weed pressure was low.

Table 12. 2020 treatment effects on weed control in 2021 at Swift Current, Melfort and Outlook, as well the 3-site year average (Swift Current, Melfort and Outlook, 2021).

Treatment	Swift Current	Melfort*	Outlook	3-site years
	---------------------Average Weed Control----------------------			
LSD	0.2	0.4	0.3	0.2
Grand Mean	4.4	2.4	1.6	2.8
CV	10.4	37.2	26.4	23.4
Treatment				

Control	4.8a	2.5b	1.8a	3.0a
Balanced Mix	4.4bc	3.0a	1.8a	3.0a
N-Fixing Mix	3.8d	2.5b	1.5ab	2.6c
Simple Balanced Mix	4.6ab	2.3b	1.5ab	2.8abc
Weed Control Mix	4.4bc	2.0c	1.5ab	2.6c
Complex Balanced Mix	4.3c	2.3b	1.5ab	2.7bc
Complex Soil Amendment Mix	4.8a	2.5b	1.4b	2.9ab

***Values are an average of two ratings at each location, with the exception of Melfort, where only one rating was complete.**

Plant Height (Table 13)

Across all treatments in 2021, plant height averaged 67cm at Outlook, 61.4cm at Melfort and 34.8cm at Swift Current. However, there was not a lot of variation between treatments at each site.

At Outlook, spring wheat height resulting from the Control treatment (65.3cm) and Weed Control treatment (64.5cm) were significantly shorter than the rest of the treatments, but not a lot of variation existed. At Melfort the N-fixing treatment resulted in the shortest spring wheat (57.9cm) and the Control treatment the tallest (63.1cm). At Swift Current average height of spring wheat was shorter than other sites, likely due to environmental conditions. The Complex Balanced treatment (33.5cm) and N-fixing treatment (34.4cm) were the shortest treatments and the Complex Soil Amendment treatment was the tallest (36cm) with very little variation between treatments.

Overall when all 3 sites are averaged together, the N-fixing mix was the shortest (53.3cm) and the Complex Soil Amendment treatment (55.1cm), Simple Balanced treatment (55.1cm) and Balanced treatment (55cm) were the tallest.

Table 13. 2020 treatment effects on spring wheat height in 2021 at Swift Current, Melfort and Outlook, as well the 3-site year average (Swift Current, Melfort and Outlook, 2021).

Treatment	Swift Current	Melfort	Outlook	3-site years
		-------------------------Plant Height (cm)--------------------------		
LSD	0.9	1.1	1.2	0.6
Grand Mean	34.8	61.4	67	54.0
CV	5.4	3.8	3.9	4.3
Treatment				
Control	34.5b	63.1a	65.3b	54.3b
Balanced Mix	34.9b	62.5ab	67.5a	55.0a
N-Fixing Mix	34.4bc	57.9d	67.6a	53.3c
Simple Balanced Mix	34.8b	62.5ab	68.1a	55.1a
Weed Control Mix	35.9a	61.3c	64.5b	53.9bc
Complex Balanced Mix	33.5c	61.5bc	68.0a	54.3b
Complex Soil Amendment Mix	36.0a	61.1c	68.1a	55.1a

Grain Yield (Table 14, Fig. 2)

Overall, across all treatments in 2021, spring wheat yield was highest at Outlook (4015.9 kg/ha), intermediate at Melfort (3677.9 kg/ha) and lowest at Swift Current (1033.8 kg/ha).

At Outlook, spring wheat seeded into the Control treatment resulted in the lowest yield (3619.0 kg/ha). This could be a result of increased compaction resulting from irrigation on a cereal-cereal rotation, or low residual nutrients from the previous year compared to other treatments. Spring wheat yield following the N-fixing mix (4413.2 kg/ha) and Complex Balanced mix (4366.4 kg/ha) were the highest at Outlook and could be explained by overall increased soil health from these mixtures. At Melfort, there was little variation between treatments, but spring wheat following the N-fixing mix resulted in the statistically lowest yield (3445.2 kg/ha), but no other treatments were significantly different. Yield at Melfort was limited by moisture, as indicated at plant emergence. At Swift Current, spring wheat yield resulting from the Weed Control treatment (966.3 kg/ha) and Balanced treatment (1003.9 kg/ha) were lowest and not significantly different than the Control (984.9 kg/ha). This can be explained by these treatments having species that require nitrogen, rather than species that are nitrogen-fixing. Spring wheat yield following the N-fixing treatment was the highest (1091.8 kg/ha), but was not significantly different than the Complex Soil Amendment treatment (1071.2 kg/ha), Complex Balanced treatment (1060.9 kg/ha), and Simple Balanced treatment (1057.6 kg/ha). With the exception of the N-fixing mix, which had the lowest spring wheat density (Table 11), none of these high yielding treatments significantly differed in plant density.

When combining the 3-site years, spring wheat yield averaged 2909.2 kg/ha. As expected, spring wheat following the Control treatment resulted in the lowest yield (2761.6 kg/ha) due to low residual Nitrogen available in the second year compared to other treatments that contained nitrogen fixing legumes and a decrease in overall soil health. The Control was not significantly different than yield following the Weed Control treatment, also likely due to low residual nitrogen available from the brassica species in the previous year, which are high users of Nitrogen. Overall, spring wheat yield following the Complex Balanced mix (3055.5 kg/ha), N-fixing mix (2983.4 kg/ha) and Complex Soil Amendment mix (2953.4 kg/ha) resulted in the highest yields and were not significantly different.

Table 14. 2020 treatment effects on spring wheat yield in 2021 at Swift Current, Melfort and Outlook, as well the 3-site year average (Swift Current, Melfort and Outlook, 2021).

Treatment	Swift Current	Melfort	Outlook	3-site years
	--------------------Spring Wheat Yield (kg/ha)-------------------			
LSD	50.2	176.7	233.3	107.4
Grand Mean	1033.8	3677.9	4015.9	2909.2
CV	10.5	10.4	12.5	14.3
Treatment				
Control	984.9b	3681.0a	3619.0d	2761.6d
Balanced Mix	1003.9b	3732.7a	3893.1c	2876.6bc
N-Fixing Mix	1091.8a	3445.2b	4413.2a	2983.4
Simple Balanced Mix	1057.6a	3762.4a	3843.0cd	2887.7bc
Weed Control Mix	966.3b	3757.9a	3814.0cd	2846.0cd
Complex Balanced Mix	1060.9a	3739.3a	4366.4ab	3055.5a
Complex Soil Amendment Mix	1071.2a	3626.6a	4162.5b	2953.4abc

Fig. 2 illustrates the 3-site year averages of spring wheat yield increasing with plant density, with the exception of the N-fixing treatment, which had the lowest average plant density, but the second highest yield. This was likely due to higher amounts of available nitrogen throughout the season for the N-fixing treatment, rather than all available nitrogen applied as fertilizer and the legume species included in this treatment in 2020 appear to have had large amounts of N-fixation occurring in the soil. Spring wheat yield resulting from the Complex Soil Amendment mix and Complex balanced mix were also high and can be explained by having a cover crop with six to eight species that can accomplish a range of tasks including increasing nitrogen fixation and soil rotational health and effects including decreased compaction.

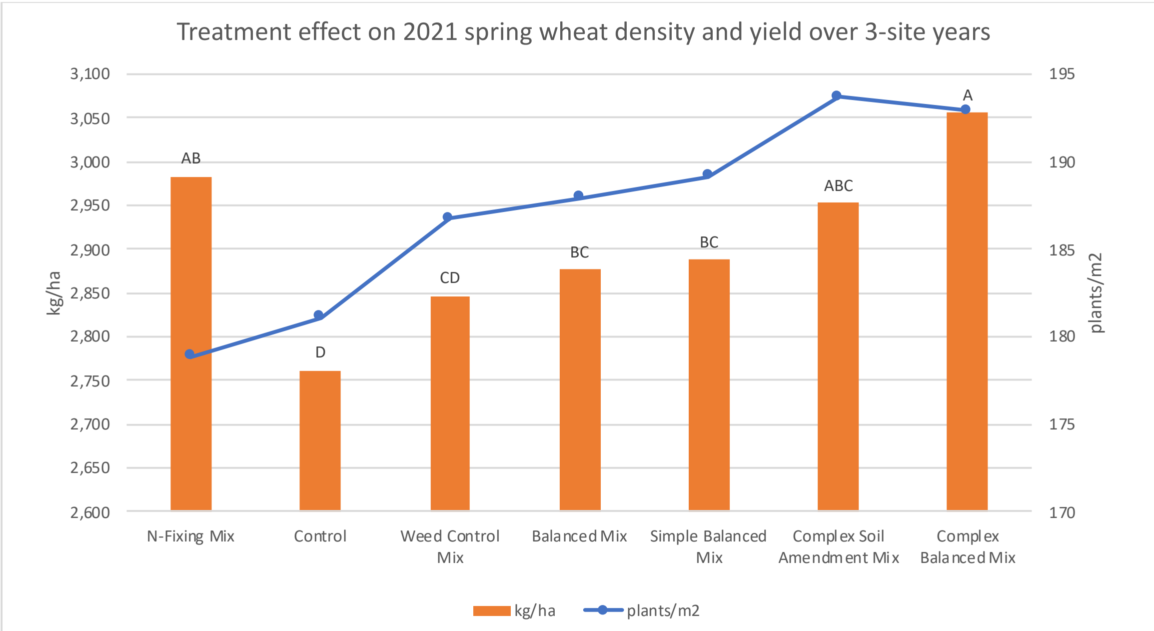

Figure 2. Treatment effects on spring wheat grain yield and plant density averages (3-site years: Swift Current, Melfort and Outlook, 2021). With the exception of the Nitrogen-fixing treatment, yield increased with plant density.

Conclusions and Recommendations

In the first year of this demonstration, producers had an opportunity to see how these crops established in their own region and to introduce options for improving soil health by adding annual forage mixes into their rotation with intent of seeding a cereal crop the following year. As expected, the cereal monoculture appeared to have the greatest establishment, but polyculture mixes were also successful, ranging in establishment from 71 to 98.5% (Tables 4-10). Feed analyses revealed that forage quality is dependent on field conditions and differs year to year according to species, stage of maturity at time of harvesting, weathering, storage conditions, plant disease and many other factors, it is important to test feed annually. Nutrients may need to be supplemented, but these results were limited by environmental conditions and more data collection is needed to make a recommendation. The Control monoculture generally had the highest visual weed control in 2020, likely due to having the highest establishment and preventing weeds from competing. However, it was noted at Outlook that the forage mixtures controlled for weeds quite well. The Complex Balanced mix did result in the highest forage yield and residual nitrogen according to soil tests, which were the average of 2/3 locations the following spring. According to the feed analysis results sent to Central Testing Laboratories, all treatments have potential to be sufficient for cattle requirements and overall 5 polyculture mixtures yielded higher than the monoculture Control.

As for the spring cereal seeded in the following year, we did observe the grain yield increases that were expected compared to the cereal-cereal rotation, specifically following mixtures that were high in nitrogen fixing legumes. The resulting yields reveal that the effect of each mixture on the following year was increased available nitrogen, decreased compaction and overall increased soil rotational health as spring wheat yield tended to increase with an increasing number of species. Fig. 3 illustrates the accumulative yield from the forage in 2020 and spring wheat yield from 2021 with the Balanced treatment resulting in lowest accumulative yield at each location. The Complex Balanced treatment at Outlook performed very well compared to other treatments, possibly due to the high number of species (six) in equal proportions of legumes, cereals and brassicas all receiving adequate moisture, increasing forage biomass and fixing larger amounts of nitrogen for the following year compared to other treatments. In Swift Current the N-fixing mix and Complex Soil Amendment mix had the highest overall accumulative yield. Not only did the number of species increase forage biomass in 2020, but also fixed larger amounts of nitrogen for the following year as shown by the spring wheat yield following legume containing mixtures.

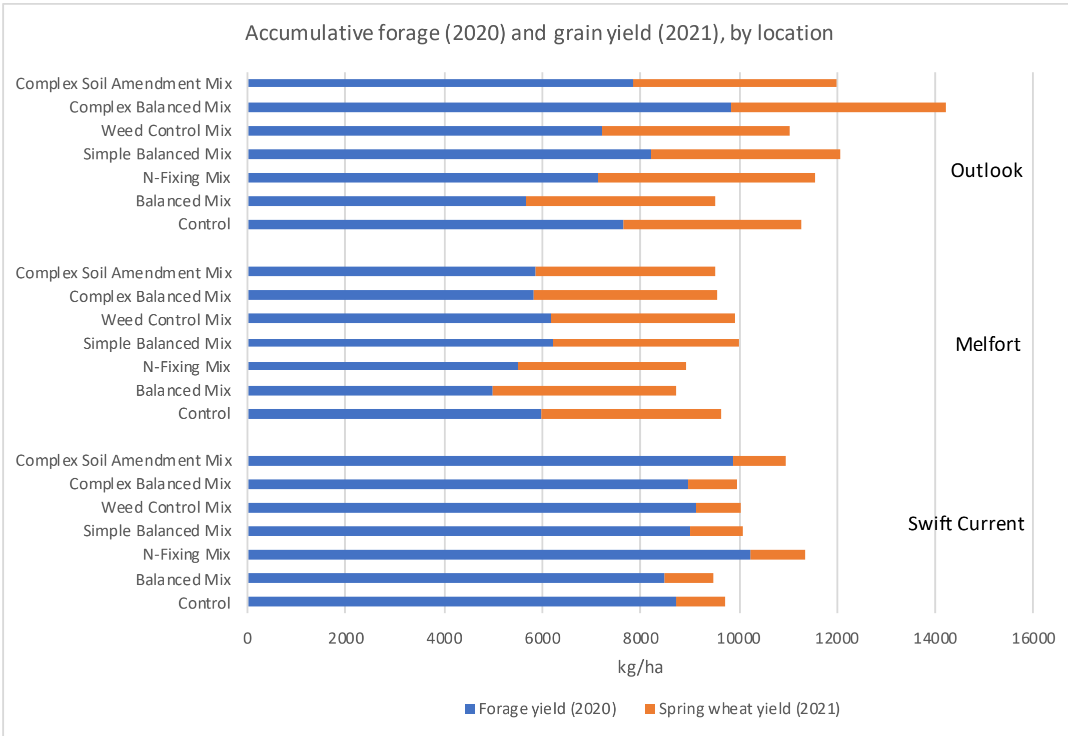

Figure 3. Treatment effects on accumulative forage (2020) and grain yield (2021) over a two-year rotation (Swift Current, Melfort and Outlook)

Acknowledgements/Extension

We thank the Ministry of Agriculture for all ADOPT projects including plot signage and verbal acknowledgement at field days and on PowerPoint slides during presentations. This will continue at each venue where an extension activity occurs. We also thank Shannon Chant with the Saskatchewan Ministry of Agriculture.

This trial was brought to the attention of multiple small group tours throughout 2020 and was also promoted on a CKSW radio program titled, "Walk the Plots" which is broadcasted on a weekly basis throughout the summer, each year. Year one results were also presented by Amber Wall at a SMA planning meeting September 22, 2020 in Humboldt, SK. Results will be also shared locally and a summary can be found on our website at www.wheatlandconservation.ca