Project Identification

1. **Project Title:** Reviving Forage Stands with Nitrogen Efficiency Products
2. **Project Number:** 20180391
3. **Producer Group Sponsoring the Project:** Conservation Learning Centre
4. **Project Location(s):** SW 20-46-26 W2 RM #461 (Prince Albert)
5. **Project Start and End Dates (Month & Year):** August 2, 2018 to February 15, 2020
6. **Project Contact Person & Contact Details:**

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Objectives and Rationale

7. Project objectives:
The objective of this demonstration was to demonstrate the effectiveness of using nitrogen enhancer products to revive old grass dominated forage stands.

8. Project Rationale:

Like any crop, forages that are harvested for hay production require fertilizer to replace the nutrients removed. While there is no benefit to applying N to a heavy N fixing forage stand like alfalfa, studies have identified that yields of old grass forage stands increase when nitrogen is added. Response to fertilizer has been documented across the province when adequate moisture is available. In both Scott and Pathlow Saskatchewan, the addition of fertilizer has doubled or even tripled production when compared to an unfertilized check (Saskatchewan Ministry of Agriculture).

While early spring application is believed to be the most effective, late fall applications may be more practical due to road bans, time constraints and wet soils. With fall applications of N, there is greater potential for N to be lost through volatilization, leaching and runoff. Enhanced efficiency products can help reduce losses to the surrounding environment by slowing down the release of plant available N in order to ensure better crop uptake. A meta analysis investigating the effectiveness of fertilizer enhancer products in New Zealand found that when there is a high risk of volatilization, there can be a 50% increase in N response with the use of a urease inhibitor producer, like Agrotain or Nitrain, when compared to urea alone. (Jenkins et al., 2018). The use of fertilizer enhancer products can increase nutrient use efficiency and could further increase yields when rejuvenating hay fields.

Enhanced efficiency fertilizer products have been proven effective for their specific purposes and are commercially available. Some of these readily available products include SuperU, Agrotain/Nitrain, and ESN. Both SuperU and Nitrain are inhibitors, while ESN is a controlled release product. SuperU uses both a urease and nitrification inhibitor that slows the conversion of urea to ammonia, which reduces volatilization losses, and the conversion of ammonium to nitrate, which reduces leaching and denitrification losses. Nitrain only uses a urease inhibitor and as a result protects against volatilization losses, but not leaching and denitrification. ESN uses a polymer coating around urea that allows moisture in. This moisture forms a N solution that moves out through the membrane at a rate controlled by soil temperature. Ideally the N solution is released when conditions are ideal for plant growth. Like SuperU, ESN reduces losses associated with denitrification, leaching and volatilization.

This study aimed to show producers that nitrogen fertilizer application can help rejuvenate old forage stands, and nitrogen enhancer products can improve nutrient use efficiency if fertilizer is applied in the fall and on the soil surface, where volatilization potential is high. This project highlights many of the 4 R principals including right rate, source and timing. Since the fertilizer placement of surface applied broadcasting and fall timing are not ideal practices, choosing the right source, such as using an efficiency product can help reduce our losses. This demonstration will reinforce the importance of nutrient stewardship principles towards sustainable farming.

References:
Jenkins, A.J., Randhawa, P., and V. Jenkins. 2018. How well do fertilizer enhancers work? Journal of Plant Nutrition. 41: 832-845

Saskatchewan Ministry of Agriculture. Fertilizing Seeded Forages in Saskatchewan. Retrieved June 2, 2018 from https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/soils-fertility-and-nutrients/fertilizing-seeded-forages-in-saskatchewan.

Methodology and Results

9. Methodology:

A large- and small-scale demo were set up on an old dominantly grass forage stand. The large-scale grass forage stand had been seeded in 2004 and contains some patches of cicer milkvetch and alfalfa. The small-scale trial was located on a grass stand that has not received any inputs for at least 10 years. There were 17 treatments (Table 1) applied comparing 4 types of nitrogen products (Nitrain, ESN, Super U, and urea) at two rates (45 and 90 lb N/ac) and two application timings (fall and early spring). The treatment list is included below. Fertilizer was broadcasted by hand for the small-scale demo and by plot seeder for the large-scale demo on October 19, 2018. Spring treatments were applied May 9, 2019.

Table 1. Treatment list applied to investigate reviving an old grass forage stand with N fertilizer.

Treatment #	Application date	Rate (lb N/ac)	Nitrogen Form
1	Fall October 19, 2018	0	None (control)
2		45	Urea
3			ESN
4			Agrotain
5			Super U
6		90	Urea
7			ESN
8			Agrotain
9			Super U
10	Spring May 9, 2019	45	Urea
11			ESN
12			Agrotain
13			Super U
14		90	Urea
15			ESN
16			Agrotain
17			Super U

The large-scale demonstration had 2 replicates. A check/control of no fertilizer was placed between every strip/plot that was a fertilized treatment, resulting in 17 checks/control per rep. Each plot had a width of 1.5 m and a length of 50 m. Although this area is not uniform and is rolling throughout, the large plot size and checks helped account for variability. To also account for any potential variability, biomass data was collected from 3 different landscape positions including upper, mid and lower slope. The small-scale trial was a randomized complete block design with 4 replicates. Plots were 1.5 m x 10 m. In this demo, there was one check/control per replication. Biomass samples were collected from 2 locations per each plot for the small-scale trial. Due to lack of drying facilities, biomass results are reported as wet weight. A set of subsamples were dried and an average % dry matter was determined to be 35%.

Soil testing was completed prior to fertilizer application. No other nutrients were added. Yield was determined at the end of July 2019. For the small-scale demonstration, ¼ m^2 biomass samples were collected from the front and back of each plot. For the large-scale trial, a ¼ m^2 biomass sample was taken at 3 locations per strip/plot, at the upper, mid and lower slope position. Attempts were made to bale the large-scale plots; however, it was too difficult to ensure the mower stayed within the plot boundaries due to the length of the plot, tall grass and the plot width not matching the size of harvest equipment. This resulted in different strips becoming mixed up with the control and not being representative of the actual treatment applied. While some plots were successfully cut and raked, miscommunication with the baler resulted in mislabelling of bales. Only 7 of 66 strips were successfully baled. Weather related conditions were recorded by the onsite SRC Climate Station.

Data did not meet the assumptions for factorial ANOVA analysis and was analysed by the non-parametric Kruskal-Wallis test. Pairwise comparison was completed using Dunn's at the p=0.05 level. Statistical analysis was not completed for the field scale trial, since the trial was only replicated twice. However, results were reported for 3 different landscape positions (Appendix). Biomass results were also presented as a percent of the closest 2 control plots that received no fertilizer. These plots were located on both sides of each fertilized plot. During biomass collection, an approximate percent of plant species present was recorded. Although both the small- and large-scale trials were located on predominantly old grass forage stands, but some broadleaf forages and weed species were present.

10. Results

<u>Soil Tests</u>

Soil testing was completed fall of 2018 prior to fertilizer application (Table 2 and 3). Based on soil test results both locations were very low in available N and were expected to show a N response. Phosphorus levels were low and very similar between plots. The small-scale demo location had higher organic matter, sulfur and salts.

Table 2. Soil test results for large scale demonstration.

Depth (cm)	N (lb/ac)	P (ppm)	K (ppm)	S (lb/ac)	OM (%)	pH	Salts (mm ho/cm)
0 – 15	2	4	221	24	3.8	6.8	0.23
15 – 30	1			16		6.6	0.15
0 – 30	3						

Table 3. Soil test results for small scale demonstration.

Depth (cm)	N (lb/ac)	P (ppm)	K (ppm)	S (lb/ac)	OM (%)	pH	Salts (mm ho/cm)
0 – 15	1	3	347	120	8.8	6.0	0.59
15 – 30	1			120		6.1	1.23
0 – 30	2						

Weather

Fall of 2018 was very cool and dry. After the fall application date of October 19, 2018, daily high temperatures did not exceed 14.1°C and night time temperatures were below freezing. There was no substantial precipitation following application until November 4, 2018. However, after this date mean temperatures were below freezing and the winter snowpack began November 5, 2018. At the end of February 2019, there was a snowpack of 53 cm, and in March the snow began to melt. The snow pack had melted by April 9th and there was minimal precipitation in both April and May 2019. Following spring application of fertilizer on May 9, 2019, there was 7 mm of precipitation on May 10 and an additional 9 mm on May 15th. Overall the spring and summer was dry (Table 4), and the CLC and producers in the area struggled with poor crop emergence due to dry soil conditions.

Table 4. Weather conditions over the 2018 and 2019 growing season at the Conservation Learning Centre.

	May	June	July	August	September	October	Average/Total
				--- Temperature (°C) ---			
2019	9.5	15.8	17.4	15.1	11.6	1.0	11.7
2018	13.3	16.3	17.4	15.7	6.5	1.4	11.8
2012-2017	11.5	16.0	18.7	17.6	12.5	3.8	13.4
				--- Precipitation (mm) ---			
2019	30.0	54.4	57.4	16.8	59.6	11.6	229.8
2018	12.5	49.8	112.4	38.4	29.3	8.6	251.0
2012-2017	69.4	85.4	93.3	49.6	25.2	26.0	348.7

Small Plot Trial

Mean biomass ranged from 5453 – 10748 kg/ha (Table 5). The addition of N fertilizer increased biomass of the forage stand, especially at the higher rate of 90 lb N/ac (p=0.0002) (Figure 1). The few outliers indicated in figure 1 are due to greater presence of cicer milkvetch and alfalfa. A description of forages present per plot can be found in the appendix.

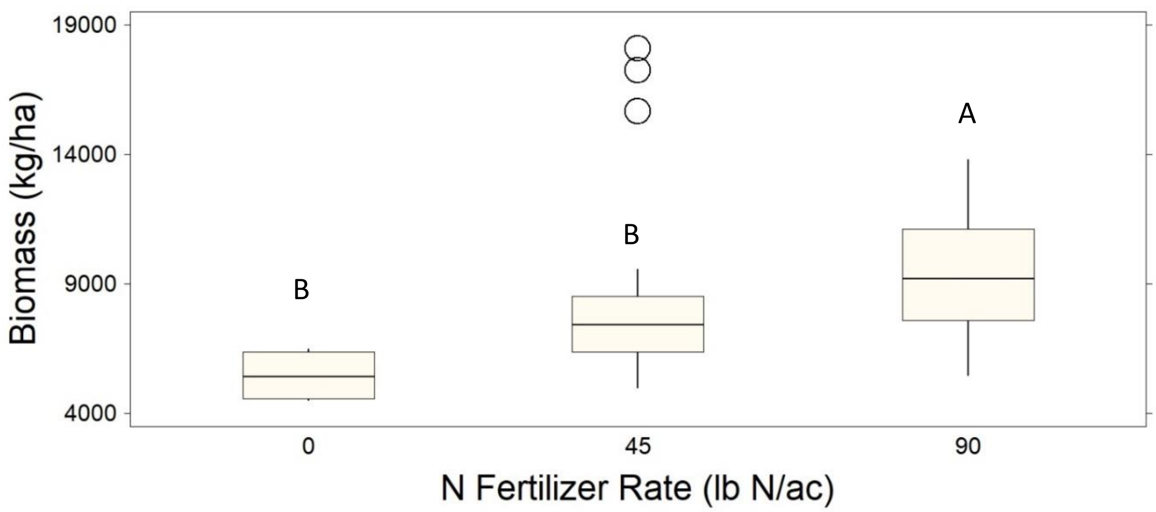

Figure 1. Mean biomass (reported as wet weight) response of a dominantly old grass forage stands to different rate of N fertilizer. Different upper-case letter indicates significant difference at the p<0.05 level.

Treatment 17 of 90 lb N/ac of spring applied Super U was the only treatment that was statistically greater than the control (p=0.0368). This treatment resulted in double the biomass compared to the control (Table 5). There was no difference in timing of fertilizer application (p=0.2460). Both the fall of 2018 and spring of 2019 were very dry. During spring application, it was possible to still see fertilizer granules on the surface of the fall applied treatments, especially the ESN treated urea. Conditions were relatively cool and dry following fall broadcasting, which was not conducive to high volatilization losses, and lack of fall precipitation reduced high leaching and denitrification potential. All three of the fertilizer products can reduce volatilization losses and SuperU contains a nitrification inhibitor that reduces losses associated with high moisture conditions. ESN can also reduce losses associated with denitrification and leaching, since the polymer coating slows down the release of urea. The environmental conditions experienced in the fall of 2018 and spring of 2019 may not have showcased the true potential of the efficiency products. However, when data was analysed based on fertilizer source, SuperU was the only fertilizer source that provided a statistically significant response (p=0.0314) compared to no N fertilizer (Figure 2). SuperU did not increase biomass when compared to the other efficiency products and urea used.

Table 5. Results from the small-scale demonstration of mean biomass (reported as wet weight) response of an old grass forage stands when N fertilizer is broadcasted at different rates, timing and with use of efficiency products (SD= standard deviation, n=4).

Trt #	Timing	Rate (lb N/ac)	N Form	Biomass kg/ha	SD
1	Fall	0	None	5453	898
2		45	Urea	7851	1074
3			ESN	9218	5517
4			Nitrain	7259	1597
5			Super U	7245	1574
6		90	Urea	9671	3414
7			ESN	9372	2935
8			Nitrain	7860	1161
9			Super U	10281	1877
10	Spring	45	Urea	6463	752
11			ESN	7673	1245
12			Nitrain	10231	5246
13			Super U	9583	4093
14		90	Urea	9270	2230
15			ESN	8193	2556
16			Nitrain	9545	1663
17			Super U	10748	1881

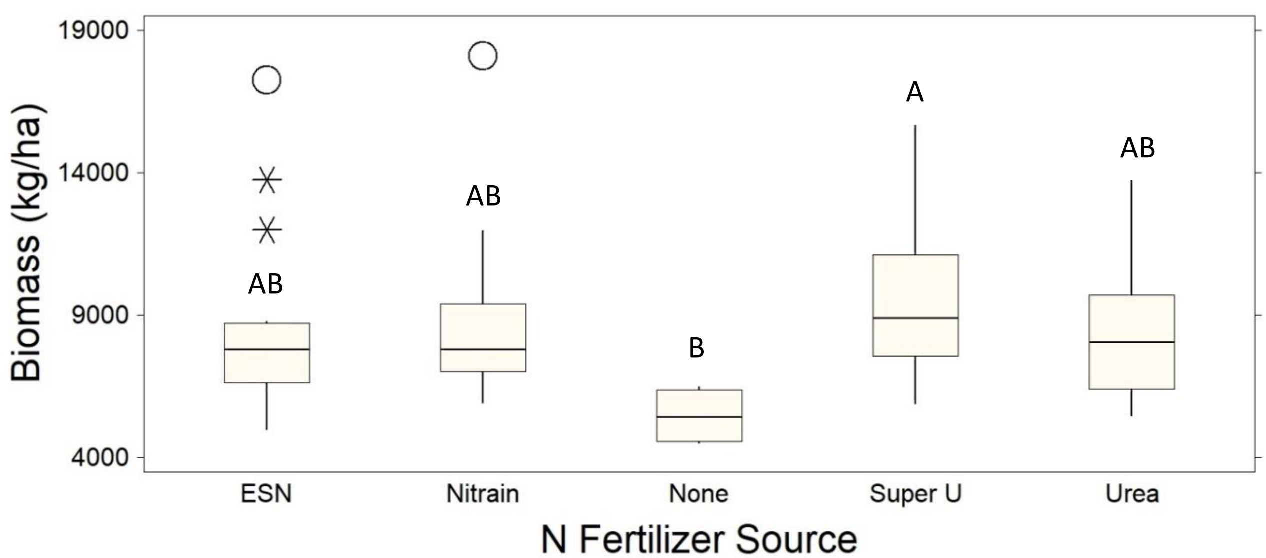

Figure 2. Mean biomass response (reported as wet weight) of a dominantly old grass forage stands to different N efficiency products and urea. Different upper-case letter indicates significant difference at the p<0.05 level.

Large Scale Trial

Mean biomass, including all three landscape positions, ranged from 7378 – 21676 kg/ha in both reps. The larger scale trial was likely better yielding due to soil quality. The larger scale trial was located on a site that had a lower salt concentration than the small-scale trial (Tables 2 and 3). The larger scale trial also appeared to have a better initial forage stand. When analysing the large-scale results, a more accurate comparison would be to compare the mean biomass with the average yield of the 2 nearest controls that received no fertilizer. This is referred to as % of check in Table 6. While the large-scale trial was relatively rolling and data collection occurred from 3 different landscape positions per plot, the whole trial was elevated in relation to the surrounding area. No clear trends were noticed across the landscape positions, so only the plot average is displayed in Table 6. Mean of the three different landscape positions can be found in the appendix. There were no indications, such as a change in vegetation or water that would imply the low slope position was a wetland or different enough from the other landscape positions to expect a different response.

Similar to the small scale replicated trial, the addition of fertilizer increased total biomass. A few treatments had % of check less than 100, which would imply a decrease in biomass; however, in most of these cases this is due to a higher percent of legume forage species present in the closest check, while the fertilized treatment contained more grass. At times the opposite occurred where the fertilized treatment had an advantage of greater legumes than the grassy checks. In these cases, the % check of biomass is higher than what would be expected. Values that are believed to have been affected by forage species present rather than the treatment effect have been indicated throughout tables in the appendix. More detail can also be found in the appendix about the approximate quantity and type of forage species found within each biomass sample. There does not appear to be any differences in the two rates of fertilizer. Similar to the small replicated study, SuperU was one of the better performing efficiency products that appears to have doubled yields in many of the plots. Nitrain also doubled biomass when applied at a rate of 90 lb/ac in fall for both reps.

When the whole plot was harvested (Table 7), fall applied urea at the low rate of 45 lb N/ac did not increase yield when compared to the 2 control treatments that had no fertilizer added. SuperU applied at a rate of 90 lb N/ac had the greatest yield response. When compared to the control that yielded 2227 kg/ha, SuperU produced almost double the yield at 4253 kg/ha. Nitrain performed similarly to Urea when applied at the higher rate. It is unfortunate that issues were encountered during baling and results were not available to be able to compare the performance of ESN, spring timing and lower rates of efficiency products.

Table 6. Results from the large-scale demonstration of mean biomass response (reported as wet weight) of an old grass forage stand when N fertilizer is broadcasted at different rates, timing and with use of efficiency products).

Trt #	Timing	Rate (lb N/ac)	N Form	Replicate 1		Replicate 2	
				Biomass kg/ha	% of check	Biomass kg/ha	% of check
1	Fall	0	None	7378	n/a	8002	n/a
2		45	Urea	8352	154	13287	185
3			ESN	8728	161	15257	177
4			Nitrain	9077	137	10371	134
5			Super U	8188	94	16396	163
6		90	Urea	13444	162	11955	131
7			ESN	8297	148	13533	155
8			Nitrain	11109	204	12520	214
9			Super U	9701	116	14952	216
10	Spring	45	Urea	7536	81	15884	143
11			ESN	10044	135	14328	168
12			Nitrain	10615	171	12857	141
13			Super U	10040	174	10241	194
14		90	Urea	10536	173	11907	129
15			ESN	11277	219	8229	146
16			Nitrain	13664	173	10005	115
17			Super U	21676	166	13229	236

Table 7. Hay yield response to added nitrogen fertilizer applied in the fall of 2018 at the Conservation Learning Centre.

Rep	Plot	TRT #	Timing	Rate (lb N/ac)	Source	Bales/plot	Yield Kg/plot	Yield Kg/ha
1	110	6	Fall	90	Urea	3	27.4	3653
1	114	8	Fall	90	Nitrain	2	25	3333
1	115	1		0	None	2	16.7	2227
2	210	9	Fall	90	SuperU	3	31.9	4253
2	214	2	Fall	45	Urea	2	17.9	2387
2	215	1		0	None	2	21.24	2832

Table 8. Economic analysis of using N efficiency products to revive an old grass forage stand at the Conservation Learning Centre (2019).

	Treatment				Small Scale			Large Scale		
	Timing	Rate (lb N/ac)	N Form	N cost† $/ha	Dry Biomass Kg/ha	Gross $/ha	Net $/ha	Dry biomass Kg/ha	Gross $/ha	Net $/ha
1	Fall	0	None	0	1909	210	101	2692	296	187
2		45	Urea	55	2748	302	138	3787	417	253
3			ESN	72	3226	355	174	4197	462	281
4			Nitrain	64	2541	279	106	3403	374	201
5			Super U	69	2536	279	101	4302	473	295
6		90	Urea	110	3385	372	153	4445	489	270
7			ESN	143	3280	361	109	3820	420	168
8			Nitrain	128	2751	303	66	4135	455	218
9			Super U	139	3598	396	148	4314	475	227
10	Spring	45	Urea	55	2262	249	85	4099	451	287
11			ESN	72	2686	295	114	4265	469	288
12			Nitrain	64	3581	394	221	4108	452	279
13			Super U	69	3354	369	191	3549	390	212
14		90	Urea	110	3245	357	138	3928	432	213
15			ESN	143	2868	315	63	3414	375	123
16			Nitrain	128	3341	367	130	4142	456	219
17			Super U	139	3762	414	166	6108	672	424

†A breakdown of the costs included in the economic analysis are: Urea = $500/t, Nitrain = $580/t, SuperU = $630/t, ESN = $625/t. Fertilizer costs were an estimate as of November 2019. Biomass results were reported as a wet weight. For the economic analysis, it was assumed the total biomass weight would be reduced to 35% of total weight, which was the average % dry matter reading determined on a subset of the collected biomass. Cost of hay is estimated at a conservative value of $0.05/lb. based on Kijiji prices for the Prince Albert area on Feb 12, 2020. Cost to bale was estimated to be $44.14/ac or $109/ha. Values presented do not consider all production costs and are estimates only.

A simplified economic analysis is provided in table 8 to provide further insight about cost benefits and should be interpreted with caution. Many assumptions were made such as biomass samples having an equal moisture content, which is very unlikely since some samples had different forage species. Hay prices also vary amongst areas and the quality of hay was not analyzed. Other production costs such as land costs were not considered. The highest net earnings in the small-scale trial was achieved with Nitrain and SuperU when applied at 45 lb N/ac in the spring. Profits were greater for the field scale trial, corresponding with the higher yields. SuperU applied at the higher rate of 90 lb N/ac during the spring was the highest earning at $424/ha. However, this value is likely high due to presence of legume forages. Under most scenarios ESN did not perform as well as SuperU, even though both are expected to offer protection from all three potential loss pathways. The low precipitation may have restricted the polymer coating from breaking down at a desirable rate for release. Although higher rates of the efficiency products increased hay production and gross profit, the increased cost of the fertilizer input was greater and net profits did not increase or even became less than applying no fertilizer or using urea alone. While efficiency products can be beneficial under high loss potential scenarios, the products can be very costly and can limit producer uptake. However, it may be possible to apply them at lower rates than the industry standard of urea and still get a similar response to urea at a higher rate. The CLC experienced a relatively cool and very dry growing conditions for the duration of this study. Results likely would have been very different under wetter conditions. Production may have been limited by moisture and efficiency products could have outperformed urea had conditions been wetter.

This demonstration was featured at the CLC Annual Field Day held July, 2019 with approximately 50 people in attendance. This demo will also be presented at WARC's Crop Opportunity Event in North Battleford on March 4, 2020.

11. Conclusions and Recommendations

When adequate moisture is available old grass forage stands respond well to the addition of N fertilizer. Efficiency products can further increase N responses when environmental conditions favor nutrient losses through volatilization or leaching and denitrification. While it is difficult to predict the weather, efficiency products offer a form of insurance and should be considered when fertilizer is being applied outside the time period of plant uptake, such as fall application and if broadcasted. Unfortunately, weather at the CLC was not conducive to excessive nutrient loss, and dry conditions may have reduced the yield potential of the forage stand. As a result, growing conditions likely were not favorable in showcasing the true potential of the efficiency products. There was no difference between fall and spring application of fertilizer due to cool dry conditions following the fall application. In both the small- and large-scale trial it was evident that the addition of N fertilizer increased yields in the first year following application. Other studies have found that the benefit of added N can continue to increase yields the second year compared to a control, but yields do decline. While the higher rate of N had a better response, depending on the product, net revenue may not increase due to the higher cost of the efficiency product. Overall, SuperU was the best performing N product used.

12.Acknowledgements:

The Conservation Learning Centre graciously acknowledged the Ministry's and Fertilizer Canada's support through signage directly in field with the project, verbally during the Field Day and on the Field Day agenda handed out to all visitors. The CLC also thanks Nutrien Ag Solutions and Koch Fertilizer for providing the efficiency products used.

13. Abstract:

The objective of this demonstration was to showcase the effectiveness of using N enhancer/efficiency products to revive old grass forage stands. Previous work throughout the province of Saskatchewan has shown that the addition of N can double or even triple production when compared to an unfertilized control. If nutrient loss potential is high, then efficiency products can further improve response to added N. Three efficiency products (ESN, Nitrain, and SuperU) and urea was broadcast in the fall of 2018 and spring of 2019 at two different rates (45 and 90 lb/ac). Yield was determined by collecting wet biomass samples and an attempt was made to bale plots of the larger-scale study. The addition of fertilizer increased yields, but there was no difference between fall and spring timing and no differences between the type of product used, with the exception of SuperU producing higher yields than the control. Unfortunately, cool and dry growing conditions following the application of fertilizer was not favorable for showcasing the true potential of the efficiency products used. Efficiency products do provide a form of insurance and are beneficial under extremely wet conditions and can reduce volatilization losses when broadcasted on the surface. However, response of higher rates may not translate into additional profit due to the higher costs associated with efficiency products. This was a single year project and the long-term benefit of added N was not determined. Other studies have identified that producers could expect to have increased yields of 1.5X in year 2 following fertilizer application. This demonstration was discussed at the CLC 2019 July Field Day with approximately 50 people in attendance.

Appendix

A2. Description of forage species present in each of the large-scale plots.

REP	Plot	TRT	Fertilizer Timing	Rate	Type	Forage species present (%)		
						Upper	Mid	Lower
1	101	1		0	None	99 grass 1 alfalfa	50 grass 50 milkvetch	100 grass
1	102	2	Fall	45	Urea	90 grass 10 alfalfa	40 alfalfa 60 grass	100 grass
1	103	1		0	None	100 grass	100 grass	100 grass
1	104	3	Fall	45	ESN	20 alfalfa 80 grass	100 grass	100 grass
1	105	1		0	None	20 alfalfa 80 grass	100 grass	100 grass
1	106	4	Fall	45	Nitrain	100 grass	60 grass 40 alfalfa	100 grass
1	107	1		0	None	30 alfalfa 70 grass	100 grass	100 grass
1	108	5	Fall	45	Super U	100 grass	100 grass	100 grass
1	109	1		0	None	40 alfalfa 60 grass	100 grass	60 grass 15 milkvetch 25 alfalfa
1	110	6	Fall	90	Urea	5 alfalfa 95 grass	100 grass	100 grass
1	111	1		0	None	100 grass	100 grass	100 grass
1	112	7	Fall	90	ESN	100 grass	100 grass	100 grass
1	113	1		0	None	100 grass	100 grass	100 grass
1	114	8	Fall	90	Nitrain	100 grass	100 grass	100 grass
1	115	1		0	None	100 grass	100 grass	100 grass
1	116	9	Fall	90	Super U	30 alfalfa 70 grass	100 grass	20 milkvetch 80 grass
1	117	1		0	None	20 alfalfa 80 grass	100 grass	90 milkvetch 10 grass
1	118	10	Spring	45	Urea	100 grass	100 grass	100 grass
1	119	1		0	None	30 alfalfa 70 grass	100 grass	100 grass
1	120	11	Spring	45	ESN	50 alfalfa 50 grass	100 grass	10 alfalfa 90 grass

1	121	1		0	None	100 grass	100 grass	60 alfalfa 40 grass
1	122	12	Spring	45	Nitrain	50 alfalfa 50 grass	100 grass	100 grass
1	123	1		0	None	100 grass	100 grass	100 grass
1	124	13	Spring	45	Super U	100 grass	100 grass	100 grass
1	125	1		0	None	25 alfalfa 75 grass	100 grass	100 grass
1	126	14	Spring	90	Urea	100 grass	40 alfalfa 60 grass	100 grass
1	127	1		0	None	25 alfalfa 75 grass	100 grass	100 grass
1	128	15	Spring	90	ESN	100 grass	100 grass	70 alfalfa 30 grass
1	129	1		0	None	20 alfalfa 80 grass	100 grass	100 grass
1	130	16	Spring	90	Nitrain	30 alfalfa 30 milkvetch 40 grass	100 grass	100 grass
1	131	1		0	None	50 milkvetch 50 grass	100 grass	100 grass
1	132	17	Spring	90	Super U	20 alfalfa 40 milkvetch 40 grass	100 grass	100 grass
1	133	1		0	None	80 milkvetch 20 grass	100 grass	5 milkvetch 95 grass
2	201	1		0	None	100 grass	100 grass	100 grass
2	202	15	Spring	90	ESN	100 grass	100 grass	100 grass
2	203	1		0	None	30 alfalfa 70 grass	100 grass	100 grass
2	204	8	Fall	90	Nitrain	60 grass 40 alfalfa	100 grass	100 grass
2	205	1		0	None	80 grass 20 alfalfa	100 grass	20 milkvetch 80 grass
2	206	13	Spring	45	Super U	50 alfalfa 50 grass	5 clover 95 grass	100 grass
2	207	1		0	None	10 alfalfa 90 grass	5 milkvetch 95 grass	100 grass
2	208	17	Spring	90	Super U	100 grass	100 grass	70 grass 30 milkvetch

2	209	1		0	None	100 grass	5 alfalfa 95 grass	100 grass
2	210	9	Fall	90	Super U	100 grass	5 alfalfa 95 grass	100 grass
2	211	1		0	None	60 alfalfa 40 grass	100 grass	100 grass
2	212	16	Spring	90	Nitrain	20 alfalfa 80 grass	100 grass	100 grass
2	213	1		0	None	100 grass	75 milkvetch 25 grass	100 grass
2	214	2	Fall	45	Urea	100 grass	60 milkvetch 40 grass	100 grass
2	215	1		0	None	100 grass	10 milkvetch 90 grass	5 milkvetch 95 grass
2	216	14	Spring	90	Urea	100 grass	50 milkvetch 50 grass	5 milkvetch 20 thistle 75 grass
2	217	1		0	None	90 milkvetch 10 grass	50 grass 50 thistle	100 grass
2	218	10	Spring	45	Urea	80 milkvetch 20 grass	80 milkvetch 20 grass	100 grass
2	219	1		0	None	100 grass	50 grass 50 milkvetch	60 grass 40 milkvetch
2	220	6	Fall	90	Urea	100 grass	90 grass 10 milkvetch	100 grass
2	221	1		0	None	100 grass	50 milkvetch 50 grass	50 milkvetch 50 grass
2	222	3	Fall	45	ESN	100 grass	90 milkvetch 10 grass	5 alfalfa 45 milkvetch 50 grass
2	223	1		0	None	100 grass	60 grass 40 milkvetch	100 grass
2	224	4	Fall	45	Nitrain	98 grass 2 thistle	50 milkvetch 50 grass	100 grass
2	225	1		0	None	100 grass	70 grass 30 milkvetch	98 grass 2 thistle
2	226	7	Fall	90	ESN	100 grass	70 grass 30 milkvetch	100 grass
2	227	1		0	None	100 grass	70 milkvetch 30 grass	100 grass

2	228	12	Spring	45	Nitrain	100 grass	60 grass 40 milkvetch	100 grass
2	229	1		0	None	100 grass	60 milkvetch 40 grass	100 grass
2	230	11	Spring	45	ESN	100 grass	70 milkvetch 30 grass	100 grass
2	231	1		0	None	100 grass	50 grass 50 milkvetch	5 milkvetch 95 grass
2	232	5	Fall	45	Super U	100 grass	50 grass 50 milkvetch	50 milkvetch 50 grass
2	233	1		0	None	10 milkvetch 90 grass	60 grass 40 milkvetch	50 grass 50 milkvetch

A3. Description of forage species present in each of the small scale replicated plots.

REP	Plot	TRT	Fertilizer Timing	Rate	Type	Forage species present (%)	
						Front	Back
1	101	1	Fall	0	None	20 alfalfa 80 grass, thistles and dandelions	20 alfalfa 80 grass
1	102	2	Fall	45	Urea	100 grass	100 grass
1	103	3	Fall	45	ESN	100 grass	20 alfalfa 80 grass
1	104	4	Fall	45	Nitrain	20 alfalfa 80 grass and dandelions	20 alfalfa 80 grass
1	105	5	Fall	45	Super U	15 alfalfa 85 grass	100 grass
1	106	6	Fall	90	Urea	5 alfalfa 95 grass	10 alfalfa 90 grass
1	107	7	Fall	90	ESN	50 milkvetch 50 grass	100 grass
1	108	8	Fall	90	Nitrain	20 alfalfa 80 grass	100 grass
1	109	9	Fall	90	Super U	100 grass	30 alfalfa 70 grass
1	110	10	Spring	45	Urea	10 alfalfa 90 grass	20 alfalfa 80 grass
1	111	11	Spring	45	ESN	100 grass	20 alfalfa

							80 grass
1	112	12	Spring	45	Nitrain	40 alfalfa 60 grass	100 grass
1	113	13	Spring	45	Super U	100 grass	100 grass
1	114	14	Spring	90	Urea	100 grass	100 grass
1	115	15	Spring	90	ESN	100 grass	100 grass
1	116	16	Spring	90	Nitrain	5 alfalfa 95 grass	100 grass
1	117	17	Spring	90	Super U	50 alfalfa 50 grass	100 grass
2	201	6	Fall	90	Urea	100 grass and dandelions	80 grass 20 broadleaf weeds
2	202	14	Spring	90	Urea	100 grass	80 grass 20 broadleaf weeds
2	203	11	Spring	45	ESN	5 clover 95 grass	90 grass 10 broadleaf weeds
2	204	7	Fall	90	ESN	100 grass	50 grass 50 prickly lettuce
2	205	12	Spring	45	Nitrain	100 grass and dandelions	90 grass 10 broadleaf weeds
2	206	9	Fall	90	Super U	100 grass	95 grass 5 alfalfa
2	207	5	Fall	45	Super U	100 grass	90 grass 5 clover 5 broadleaf weeds
2	208	16	Spring	90	Nitrain	100 grass	100 grass
2	209	3	Fall	45	ESN	100 grass	100 grass
2	210	13	Spring	45	Super U	100 grass	10 alfalfa 90 grass
2	211	1	Fall	0	None	100 thin grass	50 grass 50 broadleaf weeds
2	212	15	Spring	90	ESN	5 alfalfa 95 grass	5 weeds 95 grass 5 clover
2	213	8	Fall	90	Nitrain	100 grass	5 alfalfa 95 grass
2	214	4	Fall	45	Nitrain	10 alfalfa 90 grass	10 clover 10 broadleaf weeds 80 grass

2	215	17	Spring	90	Super U	15 alfalfa 85 grass	5 alfalfa 5 weeds 90 grass
2	216	10	Spring	45	Urea	100 grass some dandelions	100 grass
2	217	2	Fall	45	Urea	100 grass	50 alfalfa 50 grass
3	301	15	Spring	90	ESN		
3	302	8	Fall	90	Nitrain		
3	303	13	Spring	45	Super U	20 alfalfa 60 grass 20 dandelion	2 clover 96 grass 2 alfalfa
3	304	17	Spring	90	Super U	20 dandelion 80 grass	20 alfalfa 70 grass 10 dandelions
3	305	9	Fall	90	Super U	100 grass some dandelions	100 grass
3	306	16	Spring	90	Nitrain	50 alfalfa 30 grass 20 dandelions	1 alfalfa 10 dandelion 1 clover 88 grass
3	307	2	Fall	45	Urea	50 alfalfa 40 grass 10 dandelion	10 alfalfa 80 grass 10 dandelion
3	308	14	Spring	90	Urea	20 dandelion 10 other weeds 70 grass	20 dandelions 10 alfalfa 70 grass
3	309	10	Spring	45	Urea	10 weeds 90 grass	5 alfalfa 95 grass
3	310	6	Fall	90	Urea	10 alfalfa 90 grass	50 alfalfa 50 grass
3	311	3	Fall	45	ESN	15 clover 15 weeds 70 grass	20 clover 80 grass
3	312	4	Fall	45	Nitrain	15 clover 15 weeds 70 grass	30 alfalfa 70 grass
3	313	7	Fall	90	ESN	10 clover 10 weeds 80 grass	50 alfalfa 50 grass
3	314	12	Spring	45	Nitrain	20 alfalfa 80 grass	30 alfalfa 70 grass

3	315	1	Fall	0	None	10 clover 15 weeds 75 grass	80 weeds 20 grass
3	316	11	Spring	45	ESN	10 alfalfa 80 grass 10 weeds	5 weeds 10 alfalfa 85 grass
3	317	5	Fall	45	Super U	20 alfalfa 80 grass	99 grass 1 clover
4	401	10	Spring	45	Urea	85 grass 5 dandelion 10 clover	100 grass
4	402	7	Fall	90	ESN	15 alfalfa 10 dandelion 75 grass	50 alfalfa 50 grass
4	403	15	Spring	90	ESN	30 alfalfa 10 dandelion 60 grass	50 dandelion 50 grass
4	404	11	Spring	45	ESN	5 clover 95 grass	30 alfalfa 60 grass 10 dandelion
4	405	1	Fall	0	None	10 dandelion 90 grass	10 dandelion 10 alfalfa 80 grass
4	406	17	Spring	90	Super U	80 milkvetch 20 grass	50 alfalfa 20 milkvetch 30 grass
4	407	13	Spring	45	Super U	50 alfalfa 40 grass 10 milkvetch	40 milkvetch 40 alfalfa 20 grass
4	408	4	Fall	45	Nitrain	70 milkvetch 5 alfalfa 25 grass	30 alfalfa 70 grass
4	409	8	Fall	90	Nitrain	5 alfalfa 95 grass	10 alfalfa 10 dandelion 80 grass
4	410	12	Spring	45	Nitrain	1 alfalfa 99 grass	90 grass 10 alfalfa
4	411	5	Fall	45	Super U	100 grass	100 grass
4	412	2	Fall	45	Urea	100 grass	10 alfalfa 10 dandelion 80 grass
4	413	14	Spring	90	Urea	60 alfalfa 40 grass	20 alfalfa 80 grass

4	414	6	Fall	90	Urea	20 alfalfa 80 grass	30 clover 70 grass
4	415	16	Spring	90	Nitrain	95 grass 5 weeds	20 alfalfa 10 clover 70 grass
4	416	9	Fall	90	Super U	95 grass 5 weeds	50 alfalfa 50 grass
4	417	3	Fall	45	ESN	90 alfalfa 10 grass	20 dandelion 80 grass

A3. Mean biomass (reported as wet weight) of old grass forage stands when revived with N fertilizer. These results are from replicate 1 of the larger scale trial. Highlighted cells represent treatments where the forage species varied from closest controls/check. SD=standard deviation is provided for treatment 1, since % of check does not apply to this treatment.

Trt #	Timing	Rate (lb N/ac)	N Form	Upper	% of check/ SD	Mid	% of check/ SD	Low	% of check/ SD	Avg	% of check
1	Fall	0	None	8951	8286	6077	1858	7106	3784	7378	2839
2		45	Urea	7764	235	10484	143	6808	121	8352	154
3			ESN	7272	155	9940	223	8972	126	8728	161
4			Nitrain	5540	72	13448	232	8244	128	9077	137
5			Super U	5144	55	10548	135	8872	99	8188	94
6		90	Urea	8096	120	20920	257	11316	114	13444	162
7			ESN	7068	188	9840	145	7984	127	8297	148
8			Nitrain	8140	168	14240	220	10948	219	11109	204
9			Super U	8824	135	11400	158	8880	78	9701	115
10	Spring	45	Urea	7884	87	8784	123	5940	50	7536	81
11			ESN	12684	172	8204	147	9244	99	10044	135
12			Nitrain	13548	277	8804	168	9492	112	10615	171
13			Super U	10676	151	10672	211	8772	169	10040	174
14		90	Urea	8660	120	11576	234	11372	188	10536	173
15			ESN	7360	127	6980	148	19492	393	11277	218
16			Nitrain	23192	156	5760	138	12040	173	13664	173
17			Super U	42580	144	11560	247	10888	220	21676	166

A4. Mean biomass (reported as wet weight) of old grass forage stands when revived with N fertilizer. These results are from replicate 2 of the larger scale trial. Highlighted cells represent treatments where the forage species varied from closest controls/check. SD=standard deviation is provided for treatment 1, since % of check does not apply to this treatment.

Trt #	Timing	Rate (lb N/ac)	N Form	Upper	% of check	Mid	% of check	Low	% of check	Avg	% of check
1	Fall	0	None (control)	7595	4886	9604	4337	6809	2587	8002	2548
2		45	Urea	10180	235	21680	193	8000	134	13287	185
3			ESN	6140	92	22688	204	16944	211	15257	177
4			Nitrain	9440	129	11100	112	10572	177	10371	134
5			Super U	19004	255	11708	96	18476	174	16396	163
6		90	Urea	10320	205	15364	116	10180	112	11955	131
7			ESN	11820	147	19960	159	8820	156	13533	155
8			Nitrain	13580	213	11740	288	12240	173	12520	214
9			Super U	14936	175	18329	231	11600	270	14952	216
10	Spring	45	Urea	19332	133	23176	187	5144	80	15884	143
11			ESN	11940	154	21332	193	9712	142	14328	168
12			Nitrain	12992	156	15968	124	9612	157	12857	141
13			Super U	15200	252	6744	214	8780	132	10241	194
14		90	Urea	12464	87	10880	133	12376	235	11907	129
15			ESN	6920	135	9504	180	8264	127	8229	146
16			Nitrain	12232	146	10088	82	7696	141	10005	115
17			Super U	11584	209	9544	155	18560	365	13229	236