Influence of Long-Term Application of N and S Fertilizers (1980-2002) and Liming in 1992 on Dry Matter Yield of Grass and Soil Properties in a Dark Gray Chernozem in North-Central Saskatchewan

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Abstract

Most soils are deficient in plant-available N in the Prairie Provinces of Canada, and in the Parkland region, many soils are also insufficient in available S for high crop yields. Long-term field experiments, initiated in 1980 and 1996 on a Dark Gray Chernozem loam soil at Canwood in north-central Saskatchewan, were conducted to determine the effects of N, S and lime application and forage removal on forage dry matter yield (DMY) and soil properties. The results indicated that application of N or S alone had only a little effect on DMY, while application of N together with S substantially increased DMY. Decline of soil pH by annual applications of N and S fertilizers mainly happened in the 0-5 cm layer. In layers below 10 cm, soil pH tended to increase with N or NS fertilization. Surface application of granular lime increased soil pH mainly in the 0-5 cm layer, and the high pH was maintained for at least 9 years. The TOC and TN mass in the 0-7.5 cm soil layer increased with annual applications of N and S fertilizers, and the increase was more pronounced with application of N and S together. In the subsoil layers, the N treatment tended to decrease, but the NS treatment tended to increase the TOC and TN. This suggests that application of N and S together was more effective in increasing C and N sequestration in a soil deficient in both N and S.

Background

In the Prairie Provinces of Canada, most soils are deficient in plant-available N. In the Parkland region, many soils also contain insufficient amounts of plant-available S for high crop yields. When soils are lacking in one or more nutrients, plant growth is reduced, resulting in low crop yields. So, application of proper fertilizers is essential to obtain optimum yield. Application of N and/or S fertilizers can acidify soil or alter some other soil properties, but also improve soil quality. The objective of this study was to determine the effects of long-term N, S and K fertilization (from 1980 to 2002) and liming in 1992 on forage dry matter yield (DMY) and soil properties in a Dark Gray Chernozem in north-central Saskatchewan.

Materials and Methods

The field experiments were conducted on a Dark Gray Chernozem loam soil at Canwood in north-central Saskatchewan (mean annual precipitation 425 mm). The site had been cultivated for several years in 1920's or early 1930's, and then allowed to revert to grassland. The dominant grasses on the experimental site were bromegrass (*Bromus inermis* Leyss), Kentucky bluegrass (*Poa pratensis* L.) and rough hair grass (*Agrostic scabra* Wild).

Experiment 1 was established in 1980 with annual applications of: 1. no fertilizer (Nil); 2. ammonium nitrate at 112 kg N ha^{-1} (N); 3. sodium sulphate at 11 kg S ha^{-1} (S); 4. 112 kg N + 11

kg S ha^{-1} (NS); and 5. 112 kg N + 11 kg S + potassium chloride at 40 kg K ha^{-1} (NSK). The fertilizers were broadcast on the surface every year in May. Granular lime was surface-applied in 1992. There was one strip (0.91 m wide x 62 m long) for each treatment, and each strip was divided into 10 replications (6.2 m long x 0.91 m wide). The strips were separated by 1 m wide x 62 m long pathways. Grass was usually harvested once in each growing season for DMY. Soil samples in Nil, N and NS treatments were obtained from the 0-5, 5-10, 10-15 and 15-20 cm depths in 1995 and 2000 for pH, and in 2002 for C and N. The soil samples after drying and grinding were analyzed for pH, total organic C (TOC) and N (TN), and light fraction organic C (LFC) and N (LFN).

Experiment 2 was established in 1996. The fertilizer treatments Nil. N. S and NS (as in Experiment 1) were applied from 1996 to 2002. This experiment also included hay-off and hay-on treatments. Grass was harvested for DMY once in each growing season. In the hay-off treatments, all forage was removed from plots, while in the hay-on treatments after taking a representative sample for DMY the harvested grass was returned to the plots.

Results and Discussion

Experiment 1

Dry Matter Yield

Although there were exceptions in some years, mean DMYs over 11 years from 1992 to 2002 showed that application of N fertilizer increased DMY only slightly over the Nil (1285 vs 1170 kg DM ha^{-1} in unlimed, and 1517 vs 1225 kg DM ha^{-1} in limed plots) (Table 1). The DMY was significantly increased when N fertilizer was applied in combination with S fertilizer (i.e., NS treatment), which were 4944 and 5502 kg DM ha^{-1} for unlimed and limed treatments, respectively. Application of N and S fertilizer in combination with K increased DMY further compared to NS treatment (i.e., mean DMY of 5448 and 5835 kg DM ha^{-1}, respectively, for unlimed and limed plots) Compared to the Nil, the mean DMY with N, NS and NSK, respectively, was 1.1, 4.2 and 4.7 times in unlimed plots, and was 1.2, 4.3 and 4.6 times in limed plots, correspondingly. This indicated that the response of hay yield to N was impeded by S deficiency in soil, and application of N together with S is an effective way for increasing DMY. However, application of K in addition to N and S fertilizers only had little effect on increasing DMY. Surface application of granular lime increased DMY in all N, S and K treatments.

Cumulative DMY

There was a little increase in cumulative DMY with application of N alone over the Nil (12.9 vs 14.1 Mg DM ha^{-1} in unlimed plots, and 14.1 vs 16.7 Mg DM ha^{-1} in limed plots) (Table 1, Figure 1). Application of S fertilizer alone increased DMY over the Nil, but DMY was much less than the NS treatment under unlimed condition. Application of S fertilizer in combination with N produced substantial increase in cumulative DMY (54.4 and 60.5 Mg ha^{-1} for unlimed and limed treatments, respectively). Addition of K fertilizer in combination with NS (i.e., NSK) increased forage yield further to 59.9 Mg DM ha^{-1} in unlimed plots and 64.2 Mg DM ha^{-1} in limed plots. Application of lime increased DMY in all treatments, but more so in the NS or NSK treatments. The increase in cumulative DMY from liming in the Nil, N, NS and NSK treatments, respectively, was 1.2, 2.6, 6.1 and 4.3 Mg ha^{-1} compared to unlimed plots.

Soil pH

In the 0-5 cm soil layer, pH declined substantially with annual applications of N and S fertilizers for 16 (1995) or 21 (2000) years (Table 2). The decrease in soil pH was more when only N fertilizer was applied compared to N and S fertilizers together. In the 5-10 cm layer, there was some depression in soil pH but only in the N alone treatment until 1995. In the deeper subsoil layers, there was no effect of N and S fertilization on pH depression. Soil pH instead tended to

increase with N or NS fertilization in most cases (probably due to downward movement of Ca or other bases to subsoil layers). Surface application of granular lime in 1992 increased soil pH mainly in the 0-5 cm layer in all treatments, and maintained the high pH at least until 2000 when the soil was sampled.

C and N Sequestration

The total organic C and Total N in the 0-7.5 cm soil layer increased significantly with annual applications of N and S fertilizers for 23 (2002) years (Table 3). When N and S fertilizers were applied together, the increase of TOC and TN was 8.9 Mg ha^{-1} and 0.59 Mg ha^{-1}, respectively, which was more compared to only N fertilizer (the increase was 2.3 Mg ha^{-1} for TOC and 0.09 Mg ha^{-1} for TN). In the 7.5-15 cm layer, there was obvious depression in TOC and TN only when N was applied alone, compared to the Nil. In the deeper subsoil layers, the N alone treatment tended to continuously decrease TOC and TN in 15-30 cm soil layers, but markedly increased TOC in the 30-37.5 soil layer. The NS treatment tended to increase TOC and TN in the 15-37.5 cm soil layers.

The total amount of TOC in layers from 0 to 37.5 cm was 183.4, 170.7 and 202.3 Mg ha^{-1} for Nil, N and NS treatments, respectively (Table 3). The corresponding values for TN were 15.5, 14.2 and 16.8 Mg ha^{-1}. Therefore, although application of N alone could increase C and N sequestration in the top 0-7.5 cm layer, but it was not able to increase the sequestration in the entire soil profile as did the application of N and S fertilizers together.

Light Fraction Organic C and N

Annual applications of N and S fertilizers pronouncedly increased LFC and LFN in the 0-7.5 cm soil layer over 23 years (Table 4). When N and S fertilizers were applied together, the increase of LFC (9.1 Mg ha^{-1}) and TN (647 kg ha^{-1}) was more than that when only N fertilizer was applied (the increase was 4.43 Mg ha^{-1} for LFC and 344 kg ha^{-1} for LFN). However, in the 7.5-15 cm layer, LFC and LFN were markedly depressed when N was applied alone, compared to the Nil. In the subsoil, the N alone treatment decreased LFC and LFN in the 15-22.5 cm soil layers, but markedly increased LFC and LFN in the 22.5-37.5 soil layer. The NS treatment increased LFC and LFN in all layers in the 15-37.5 cm soil depth.

LFC in the total of the five layers from 0 to 37.5 cm was 19.1 22.6 and 30.2 Mg ha^{-1}, respectively for Nil, N and NS treatments, and the corresponding mass of LFN was 850, 1170 and 1638 kg ha^{-1} (Table 4). This indicated that application of N and S fertilizer could markedly increase light fraction of C and N sequestrated in soil, and the increase was more with the application of N and S fertilizers together compared to N alone.

Soil Bulk Density

In the 0-7.5 cm soil layer, soil bulk density was substantially lowered with annual applications of N and S fertilizers over 23 years (Table 5). The decrease of soil bulk density was more when N and S fertilizer were applied together compared to N fertilizer alone (0.25 vs 0.14 g cm^{-3}). In the deeper subsoil layers, there was no effect of N fertilization on soil bulk density, but it tended to decrease with NS treatment in most layers.

Experiment 2

Forage Yield

The DMY of hay was increased by application of N and S fertilizer, but the effect was different for N, S and NS treatments (Table 6). Compared to the Nil, the increase of DMY (mean of the seven years from 1996 to 2002) was 158, 361 and 3975 kg ha^{-1} respectively, for N, S and NS treatments in the hay-on plots, and 119, 355 and 3386 kg ha^{-1} for the corresponding treatments in the hay-off plots. This indicated that application of N or S alone had a little effect on the

increase of DMY, although the effect of S was slightly higher than N. Application of N together with S substantially increased the DMY.

Compared to hay-on, hay-off usually tended to produce less DMY for means of each year or over the seven years (Table 6). The DMY (mean of the seven years) was decreased by 51, 90, 57 and 640 kg ha^{-1} in hay-off plots compared to hay-on plots for Nil and N, S and NS treatments, respectively.

Cumulative DMY

In consistence with DMY, the cumulative DMY was only increased a little by N or S application, and substantially increased by application of N together with S (Table 6, Figure 2). The increase in DMY was 1.1, 2.5 and 27.8 Mg ha^{-1} for N, S and NS treatments in the hay-on plots, and 0.9, 2.5 and 23.7 Mg ha^{-1} for the corresponding treatment in the hay-off plots. The hay-off plots had lower cumulative DMY compared to hay-on plots, most likely due to less nutrient return and cycling in soil in hay-off plots.

C and N Sequestration

Over 7 years of annual N applications together with S increased TOC and TN in the 0-7.5 cm soil layer (Table 7). For TOC and TN in soil, respectively, the concentration increased by 23.35 g C kg^{-1} and 1.85 g N kg^{-1}, and equivalent mass increased by 8.8 Mg C ha^{-1} and 0.74 Mg N ha^{-1}. Like TOC and TN, the LFC and LFN in the 0-7.5 soil layer was also increased with application of N and S together (Table 7). The increase was 12.63 g C kg^{-1} for LFC and 0.96 N g kg^{-1} for LFN for concentration, and corresponding increase in LFC and LFN mass was 8.8 Mg C $ha^{-1}$and 0.74 Mg N ha^{-1}.

Conclusions

Forage DMY increased with NS fertilization and further improved when K fertilizer was also applied.

The cumulative DMY was greater in limed plots than in unlimed plots.

Soil pH declined with annual applications of N and S fertilizers mainly in the 0-5 cm layer.

TOC and LFOC increased with NS application mainly in the 0-5 cm soil layer.

There was a close relationship between DMY improvement and increase in C sequestration from appropriate fertilization.

Hay-on plots tended to produce greater DMY than hay-off plots

Table 1. Effect of long-term annual applications of N, S and K fertilizers (from 1980 to 2002) and liming in 1992 to grass on dry matter yield (DMY) (kg ha^{-1}) on a Dark Gray Chernozemic soil at Canwood, Saskatchewan (Experiment 1, established in 1980)

Year	Lime	Nil	N	NS	NSK	Mean
1992	Unlimed	645	598	3190	3418	1963
	Limed	775	453	3599	3700	2132
1993	Unlimed	783	728	4453	5258	2806
	Limed	752	931	5056	5217	2989
1994	Unlimed	910	1157	6687	6969	3931
	Limed	1094	1213	7264	8315	4472
1995	Unlimed	1293	1515	4255	4380	2861
	Limed	1290	1522	3788	4456	2764
1996	Unlimed	1477	1008	5919	7044	3862
	Limed	1442	1127	6561	6995	4031
1997	Unlimed	1176	904	5386	5986	3363
	Limed	1545	1503	6767	7257	4268
1998	Unlimed	1028	1485	4004	4124	2660
	Limed	1219	1848	4686	4666	3105
1999	Unlimed	1385	2424	5563	6257	3907
	Limed	1618	2762	5527	6264	4043
2000	Unlimed	1929	2396	6831	7208	4591
	Limed	2289	3305	8165	8214	5493
2001	Unlimed	1849	1668	7307	8067	4723
	Limed	1816	1756	8427	8202	5050
2002	Unlimed	399	252	785	1212	662
	Limed	228	263	687	897	519
Mean	Unlimed	1170	1285	4944	5448	
	Limed	1279	1517	5502	5835	
Cumulative	Unlimed	12.9	14.1	54.4	59.9	
(Mg ha^{-1})	Limed	14.1	16.7	60.5	64.2	

Table 2. Effect of long-term annual applications of N and S fertilizers (from 1980 to 2002) and liming in 1992 to grass on soil pH on a Dark Gray Chernozem at Canwood, Saskatchewan (Experiment 1, established in 1980)

Year	Lime	Fertililzer	Soil pH in 1995 at depths (cm)			
			0-5	5-10	10-15	15-20
1995	Unlimed	Nil	6.63	6.73	7.06	7.26
		N	5.08	6.32	7.21	7.59
		NS	5.39	6.82	7.40	7.63
	Limed	Nil	7.27	6.83	7.03	7.23
		N	6.59	6.39	7.33	7.54
		NS	6.56	6.63	7.21	7.52
2000	Unlimed	Nil	6.41	6.42	6.76	7.02
		N	5.40	6.41	6.98	7.23
		NS	5.82	6.35	6.81	7.12
	Limed	Nil	6.97	6.59	6.81	7.09
		N	6.31	6.61	7.14	7.37
		NS	6.47	6.51	6.88	7.22

Table 3. Effect of long-term annual applications of N and S fertilizers (from 1980 to 2002) to grass on total organic C (TOC) and total N (TN) in soil on a Dark Gray Chernozem at Canwood, Saskatchewan (Experiment 1, established in 1980)

		Soil depth (cm)					
Parameter	Treatment	0-7.5	7.5-15	15-22.5	22.5-30	30-37.5	0-37.5
TOC (Mg ha^{-1})	Nil	53.2	52.7	36.5	19.4	21.6	183.4
	N	55.5	48.4	24.9	17.7	24.2	170.7
	NS	62.1	56.0	36.9	22.8	24.5	202.3
	Mean	56.9	52.4	32.8	20.0	23.4	
TN (Mg ha^{-1})	Nil	4.15	4.23	3.16	1.93	2.07	15.5
	N	4.24	3.89	2.26	1.72	2.07	14.2
	NS	4.74	4.55	3.09	2.08	2.29	16.8
	Mean	4.38	4.23	2.84	1.91	2.15	

Table 4. Effect of long-term annual applications of N and S fertilizers (from 1980 to 2002) to grass on light fraction organic C (LFC) and N (LFN) in soil on a Dark Gray Chernozem at Canwood, Saskatchewan (Experiment 1, established in 1980)

		Soil depth (cm)					
Parameter	Treatment	0-7.5	7.5-15	15-22.5	22.5-30	30-37.5	0-37.5
LFC (Mg ha^{-1})	Nil	11.24	4.55	1.65	0.76	0.90	19.1
	N	15.67	2.96	1.51	1.01	1.48	22.6
	NS	20.34	4.68	2.34	1.22	1.59	30.2
	Mean	15.75	4.06	1.83	1.00	1.32	
LFN (kg ha^{-1})	Nil	538	180	70	30	32	851
	N	882	131	61	37	59	1170
	NS	1185	234	105	50	64	1639
	Mean	868	181	79	39	52	

Table 5. Effect of long-term annual applications of N and S fertilizers (from 1980 to 2002) to grass on soil bulk density (g cm^{-3}) on a Dark Gray Chernozem at Canwood, Saskatchewan (Experiment 1, established in 1980)

	Soil depth (cm)					
Treatment	0-7.5	7.5-15	15-22.5	22.5-30	30-37.5	Mesn
Nil	1.29	1.75	1.87	2.09	2.40	1.88
N	1.15	1.80	1.92	2.03	2.30	1.84
NS	1.04	1.69	1.84	1.98	2.26	1.76
Mean	1.16	1.75	1.88	2.03	2.32	

Table 6. Effect of annual applications of N and S fertilizers to grass on dry matter yield (DMY) (kg ha^{-1}) in hay-on and hay-off plots on a Dark Gray Chernozemic soil at Canwood, Saskatchewan (Experiment 2, established in 1996)

Year	Hay	Nil	N	S	NS	Mean
1996	Hay-on	1589	1784	2013	4626	2503
	Hay-off	1485	1588	1814	4517	2351
1997	Hay-on	1907	1518	1808	4801	2509
	Hay-off	1246	1286	1681	4759	2243
1998	Hay-on	1361	2184	1689	5444	2670
	Hay-off	1357	2080	1489	5222	2537
1999	Hay-on	1930	2388	2270	7981	3642
	Hay-off	1883	2230	2380	6062	3139
2000	Hay-on	2055	2239	3169	8268	3933
	Hay-off	2323	2340	3333	7518	3879
2001	Hay-on	1656	1560	2046	6339	2900
	Hay-off	1859	1616	2083	5152	2678
2002	Hay-on	499	432	526	1364	705
	Hay-off	484	332	345	1114	569
Mean	Hay-on	1571	1729	1932	5546	
	Hay-off	1520	1639	1875	4906	
Cumulative	Hay-on	11.0	12.1	13.5	38.8	
(Mg ha^{-1})	Hay-off	10.6	11.5	13.1	34.3	

Table 7. Effect of annual applications of N and S fertilizers on total organic C (TOC) and N (TN), and light fraction organic C (LFC) and N (LFN) in the 0-7.5cm soil layer Dark Gray Chernozem at Canwood, Saskatchewan (Experiment 1, established in 1996)

	Concentration (g kg^{-1})			Equivalent mass (Mg ha^{-1})		
	Nil	NS	Contrast Nil vs. NS	Nil	NS	Contrast Nil vs. NS
Hay-On						
TOC	56.65	80.00	0.016	37.41	46.21	0.033
TN	4.29	6.14	0.012	2.83	3.57	0.025
LFC	15.79	28.42	0.011	10.39	14.81	0.016
LFN	0.79	1.75	0.002	0.52	0.91	0.001
Hay-Off						
TOC	52.40	79.57	0.004	35.73	49.56	0.011
TN	4.10	6.07	0.004	2.79	3.81	0.013
LFC	11.31	26.76	0.005	7.65	15.35	0.011
LFN	0.51	1.56	0.002	0.35	0.89	0.004

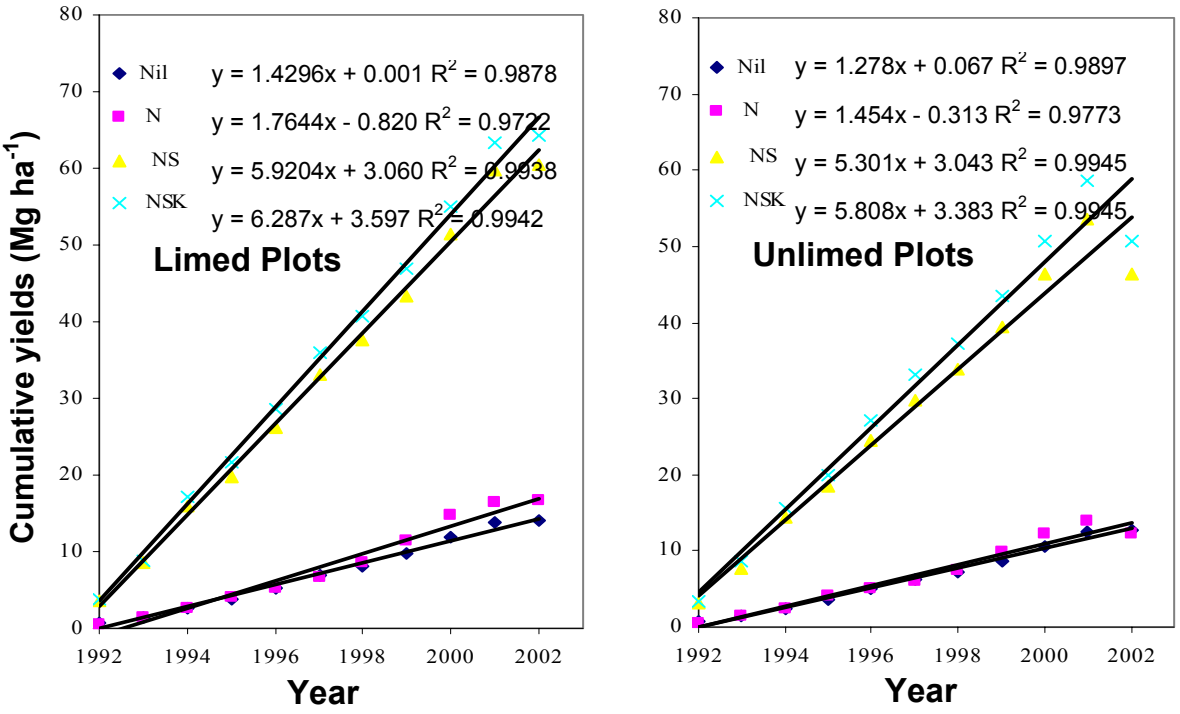

Figure 1. Effect of long-term annual N, S and K fertilizer applications to grass on dry matter yield (DMY) on a Dark Gray Chernozemic soil at Canwood, Saskatchewan (Experiment 1 was initiated in 1980).

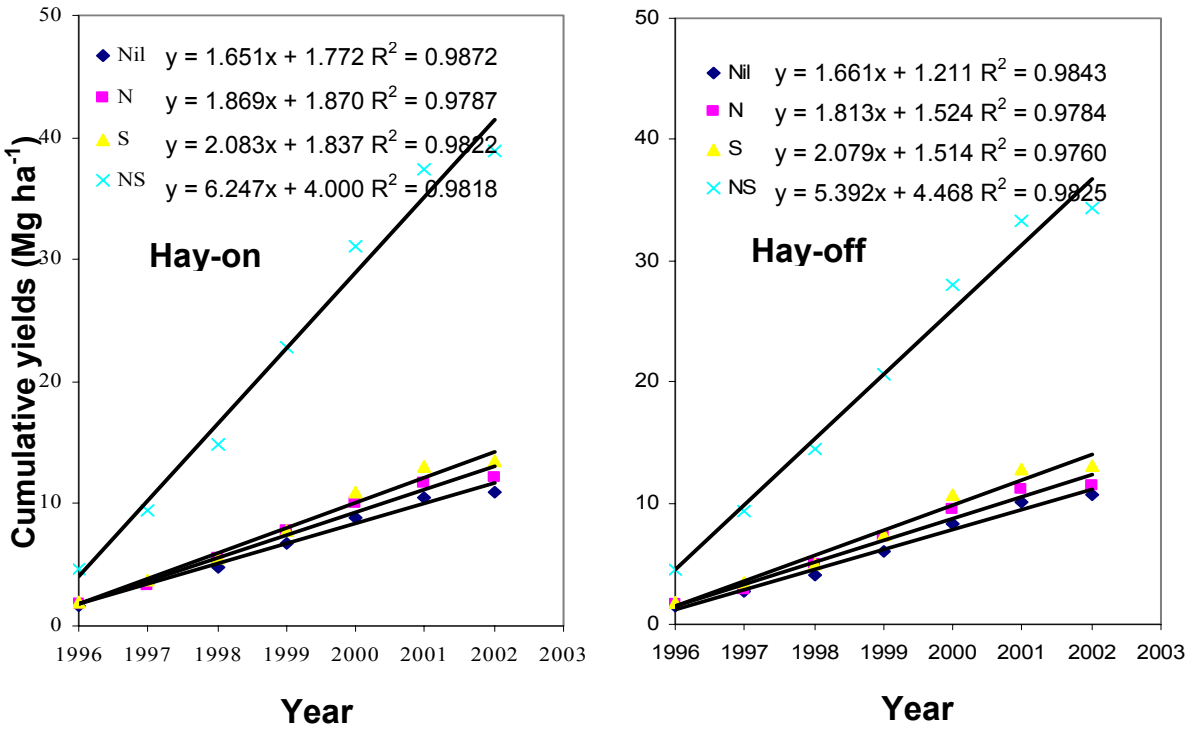

Figure 2. Effect of long-term annual N and S fertilizer applications to grass on dry matter yield (DMY) on a Dark Gray Chernozemic soil at Canwood, Saskatchewan (Experiment 2 was initiated in 1996).