Effects of Long-Term Swine Manure Application on Soil and Plant Nitrogen and Crop Yield in an East-Central Saskatchewan Gray Luvisol Soil

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Introduction

- Liquid hog manure (LHM) is an important source of essential plant nutrients, and is typically applied by injection to farm fields surrounding the intensive livestock operation (ILO).
- The impact of LHM application to agricultural land in improving crop yield is influenced by rate/frequency of application, balance of available nutrients and placement method.
- Increased soil fertility is an important benefit of LHM application that substantially increases the supplies of available N in the soil. However, LHM is often low in available S relative to N.

Study Objectives

- To evaluate the long-term effect of application of LHM on soil N, plant N uptake and crop yield.

Materials and Methods

- **Study Site:** Star City, SK., Dark Gray Luvisol belonging to the Kamsack Soil Association. Established in Fall 1999 with application of LHM and urea fertilizer treatment every year to 2013.
- **Study Design:** Randomized complete block design, replicated four times. Split into three subplots:
  - No S fertilizer (NS): 24.4 m X 4.0 m.
  - Broadcast Elemental S fertilizer (ES): 4.0 X 3.1 m.
  - Broadcast K_2SO_4 fertilizer (SS): 4.0 m X 3.1 m.
- **LHM Treatments:** 37,000 L ha^{-1} on an annual basis. 74,000 L ha^{-1} every second year. 110,000 L ha^{-1} every third year. LHM was injected at 8-10 cm depth using sweep type openers 1999-2002 and coulter type openers 2003-2014, in either Oct., prior to freeze-up or in early May, prior to seeding (Fig. 1).
- **Urea fertilizer:** (46-0-0) applied at 80 kg N ha^{-1} on an annual basis.
- **Control plots**: No LHM or commercial fertilizer applied.
- **S Subplot Treatments:** Beginning in May 2002 and repeated every three years. Broadcast ES fertilizer added at 40 kg S ha^{-1} rate beginning in May 2002. Broadcast SS added at 40 kg S ha^{-1} rate beginning in May 2002.
- **Seeding:** In May 2000 and following to 2014, plots seeded to alternating canola (*Brassica napus*) - cereal (oats, wheat or barley).
- **Sampling:** Crop samples obtained prior to swathing stage. Soil samples obtained after harvest operations.

Fig. 1. LHM application using coulter type openers (a) spaced 30.0 cm apart (b) and injection banding (c) at 8.0-10.0 cm depth.

Table 1. Amount of nitrate-N in soil in autumn after crop harvest from liquid hog manure (LHM applied every year, once in 2 years or once in 3 years) and urea (applied every tear), without and with sub-treatments of S fertilizers (elemental S [ES] and sulphate-S [SS]) at 40 kg S ha^{-1}, on a Dark Gray Luvisol at Melfort, Saskatchewan, Canada (experiment initiated in 2000 – first crop growing season)

LHM/N fertilizer rate[z]	Source /rate of S	Amounts of nitrate-N (kg N ha^{-1}) in different soil layers (cm)											
		2010				2011				2013			
		0-15	15-30	30-60	0-60	0-15	15-30	30-60	0-60	0-15	15-30	30-60	0-60
Control	No S	6.6	3.8	6.5	16.9	3.1	1.3	1.5	5.9	6.7	2.8	3.8	13.3
	ES	7.5	3.8	6.8	18.1	3.9	2.2	4.3	10.4	6.1	3.3	4.7	14.1
	SS	7.5	3.8	6.4	17.7	4.8	2.1	3.0	9.9	5.9	2.0	4.4	12.3
LHM-1X	No S	14.0	4.9	7.5	26.4	2.7	1.3	1.9	5.9	7.8	3.1	4.5	15.4
	ES	11.2	4.8	7.1	23.1	5.2	2.7	4.0	11.9	7.2	3.1	4.7	15.0
	SS	20.0	6.1	7.7	33.8	5.2	2.1	3.0	10.3	6.6	2.1	5.9	14.6
LHM-2X	No S	12.1	5.5	15.1	32.7	4.1	1.5	2.3	7.9	8.5	3.4	4.0	15.9
	ES	12.3	5.2	9.6	27.1	8.7	3.4	5.0	17.1	8.1	5.0	4.8	17.9
	SS	13.9	5.1	6.9	25.9	4.4	2.5	3.7	10.6	6.0	1.5	1.7	9.2
LHM-3X	No S	11.9	5.0	7.3	24.2	5.9	2.7	3.4	12.0	11.4	3.6	4.7	19.7
	ES	10.2	4.8	7.4	22.4	7.7	3.9	10.0	21.6	8.9	3.6	5.1	17.6
	SS	13.0	4.6	6.7	24.3	9.9	5.0	6.9	21.8	7.4	2.1	2.2	11.7
Urea	No S	16.0	8.4	13.9	38.3	3.9	1.1	1.7	6.7	7.6	2.8	4.3	14.7
	ES	18.8	16.4	32.7	67.9	5.5	2.4	2.0	9.9	7.9	2.7	4.1	14.7
	SS	18.9	6.6	10.8	36.3	3.9	1.7	9.3	14.9	7.5	1.7	1.4	10.6
SEM (Sig)													
$LSD_{0.05}$						2.1	0.9	1.5					
Control		7.2	3.8	6.6	17.6	3.9	1.9	2.9	8.7	6.2	2.7	4.3	13.2
LHM-1X		15.1	5.3	7.4	28.8	4.4	2.0	3.0	9.4	7.2	2.8	5.0	15.0
LHM-2X		12.8	5.3	10.5	28.6	5.7	2.5	3.7	11.9	7.5	3.3	3.5	14.3
LHM-3X		11.7	4.8	7.1	23.6	7.8	3.9	6.8	18.5	9.2	3.1	4.0	16.3
Urea		17.2	10.5	19.1	46.8	4.4	1.7	4.3	10.4	7.7	2.4	3.3	13.4
SEM (Sig)													
$LSD_{0.05}$													
	No S	12.1	5.5	10.1	27.7	3.9	1.6	2.2	7.7	8.4	3.1	4.7	16.2
	ES	12.0	7.0	12.7	31.7	10.3	2.9	5.0	28.2	7.6	3.5	4.7	15.8
	SS	14.7	5.2	7.7	27.6	9.4	2.7	5.2	17.3	6.7	1.9	3.1	11.7
	SEM (Sig)												
	$LSD_{0.05}$												

[z]LHM-1X = 37,000 L of LHM ha^{-1} every year; LHM-2X = 74,000 L of LHM ha^{-1} once in 2 years; LHM-3X = 111,000 L of LHM ha^{-1} once in 3 years; Urea applied every year at 80 kg N ha^{-1}.
[y]*, *, **, *** and ns refer to significant treatment effects in ANOVA at P ≤ 0.10, P ≤ 0.05, P ≤ 0.01, P ≤ 0.001 and not significant, respectively.

Table 2. Uptake of total N in seed + straw of various crops in 15 years from 2000 to 2014 from liquid hog manure (LHM applied every year, once in 2 years or once in 3 years) and urea (applied every tear), without and with sub-treatments of S fertilizers (elemental S [ES] and sulphate-S [SS]) at 40 kg S ha^{-1}, on a Dark Gray Luvisol at Melfort, Saskatchewan, Canada

LHM/N fertilizer rate[z]	Source /rate of S	Uptake of total N in seed + straw (kg N ha^{-1}) in different years															
		2000[x]	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011[x]	2012	2013	2014
Control	No S	47	46	39	23	40	18	32	53	50	42	13	27	35	35	14
	ES			53	20	42	13	36	35	29	44	13	31	52	47	16
	SS			54	26	46	16	34	43	35	36	18	33	50	48	21
LHM-1X	No S	59	93	93	80	136	66	116	158	113	114	67	75	58	66	34
	ES			133	86	116	55	91	121	90	105	59	71	77	83	47
	SS			154	87	113	66	79	129	108	106	52	56	69	87	59
LHM-2X	No S	66	54	100	58	144	54	99	68	119	66	66	99	46	72	19
	ES			160	65	133	50	98	43	69	65	67	90	58	97	32
	SS			193	69	137	51	96	2	130	68	70	69	62	91	38
LHM-3X	No S	56	60	44	122	119	33	178	70	66	162	39	109	60	59	25
	ES			59	125	92	25	112	49	52	166	43	103	67	65	26
	SS			51	121	83	24	107	59	54	133	37	90	62	63	30
Urea	No S	64	82	101	45	121	35	55	114	46	127	33	93	50	114	28
	ES			139	91	116	55	96	84	64	112	43	92	78	121	48
	SS			146	93	113	51	92	100	105	94	49	76	82	114	72
SEM (Sig)		12.4	7.6	7												
$LSD_{0.05}$		27	17	15												
Control				48	23	43	16	34	43	34	40	15	30	46	42	17
LHM-1X				127	84	122	62	95	131	104	108	60	68	68	78	47
LHM-2X				151	64	138	51	98	56	106	66	68	86	55	87	30
LHM-3X				51	123	97	27	133	60	57	153	40	100	61	62	27
Urea				129	71	117	38	82	96	72	111	42	87	70	117	49
SEM (Sig)				3												
$LSD_{0.05}$				7												
	No S			75	61	108	34	92	82	79	97	43	78	49	68	40
	ES			109	74	98	40	82	66	59	94	44	76	66	81	34
	SS			120	76	94	41	84	76	84	85	44	63	65	79	44
	SEM (Sig)			3												
	$LSD_{0.05}$			7												

[z]LHM-1X = 37,000 L of LHM ha^{-1} every year; LHM-2X = 74,000 L of LHM ha^{-1} once in 2 years; LHM-3X = 111,000 L of LHM ha^{-1} once in 3 years; Urea applied every year at 80 kg N ha^{-1}.
[y]*, *, **, *** and ns refer to significant treatment effects in ANOVA at P ≤ 0.10, P ≤ 0.05, P ≤ 0.01, P ≤ 0.001 and not significant, respectively.
[x]Total N uptake only in seed.

Table 3. Seed yield of various crops in 15 years from 2000 to 2014 from liquid hog manure (LHM applied every year, once in 2 years or once in 3 years) and urea (applied every tear), without and with sub-treatments of S fertilizers (elemental S [ES] and sulphate-S [SS]) at 40 kg S ha^{-1}, on a Dark Gray Luvisol at Melfort, Saskatchewan, Canada

LHM/N fertilizer rate[z]	Source /rate of S	Seed yield (kg ha^{-1}) in different years														
		2000 [x, y, z]	2001 [y]	2002 [x, y, z]	2003 [x, y]	2004 [x, y]	2005 [x]	2006 [x, y, z]	2007 [y]	2008 [x, y]	2009 [x, y]	2010	2011 [x, y, z]	2012 [y]	2013 [x, y, z]	2014 [x]
Control	No S	1063	1155	1265	635	2374	430	1472	1327	1509	2909	478	1670	995	2525	741
	ES			1717	570	2429	309	1527	1167	855	3039	431	1815	1597	3132	888
	SS			1682	745	2904	387	1349	1819	1035	2494	711	1725	1492	3289	1092
LHM-1X	No S	2083	1975	2359	1783	5039	1545	4959	4183	2528	6406	1951	3853	1645	4325	1541
	ES			3418	2173	5054	1436	4424	4749	1993	5827	1743	3640	2131	4896	2154
	SS			4082	1900	4656	1576	4033	4572	2391	6007	1531	2980	1879	5109	2549
LHM-2X	No S	2280	1190	2272	1388	4640	1154	4628	1741	2734	4222	1615	4668	1210	4512	907
	ES			3570	1635	5211	1120	4951	1776	1696	4243	1860	4010	1709	5613	1452
	SS			4357	1707	4736	1171	4839	2613	3342	4246	1883	3425	1745	5201	1784
LHM-3X	No S	2295	918	1397	2155	4996	826	5253	2104	1931	6565	1082	4568	1651	3868	1113
	ES			1905	2175	4566	635	5647	2165	1593	7301	1198	4378	1993	4181	1305
	SS			1582	2068	4138	593	5095	2747	1702	5824	982	3848	1779	4173	1429
Urea	No S	2428	583	2365	660	4719	0	2261	2761	209	5729	483	3755	616	5768	200
	ES			2961	1840	5048	1322	4883	4159	1381	6613	1207	4248	2172	6440	2151
	SS			3611	2030	4497	1301	4244	4249	2317	5091	1189	3775	2269	5940	2988
SEM (Sig)		334.4	257.2	233												
$LSD_{0.05}$		729	560	476	470											
Control				1555	650	2569	375	1449	1437	1133	2814	540	1737	1381	2982	907
LHM-1X				3286	1952	4918	1519	4472	4501	2304	6080	1742	3491	1885	4777	2081
LHM-2X				3400	1577	4882	1148	4806	2044	2591	4237	1786	4034	1555	5109	1381
LHM-3X				1628	2133	4567	685	5332	2339	1742	6566	1088	4265	1808	4074	1282
Urea				2979	1510	4755	875	3796	3721	1302	5811	947	3926	1686	6049	1780
SEM (Sig)				111												
$LSD_{0.05}$				242	226	470	156	404	291	216					537	
	No S			1932	1324	4354	791	3715	2423	1782	5166	1168	3703	1224	3380	900
	ES			2714	1679	4461	964	3912	2803	1503	5406	1292	3618	1920	4872	1590
	SS			3063	1690	4188	1006	3985	3199	2157	4736	1315	3151	1832	4742	1968
	SEM (Sig)			104												
	$LSD_{0.05}$			213	175	384	121	313	226	167						

[z]LHM-1X = 37,000 L of LHM ha^{-1} every year; LHM-2X = 74,000 L of LHM ha^{-1} once in 2 years; LHM-3X = 111,000 L of LHM ha^{-1} once in 3 years; Urea applied every year at 80 kg N ha^{-1}.
[y]*, *, **, *** and ns refer to significant treatment effects in ANOVA at P ≤ 0.10, P ≤ 0.05, P ≤ 0.01, P ≤ 0.001 and not significant, respectively.

Results and Discussion

- In the last three years there was little evidence of soil buildup of nitrate-N (NO_3-N) in the 0-60 cm depth from LHM or urea fertilizer application (Table 1).
- LHM applied at 37,000 L ha^{-1}, which was equivalent to ~ 80 to 100 kg N ha^{-1}, added N that was in balance with crop removal of N.
- LHM and urea application resulted in significant increase in N uptake by crops in all years (Table 2).
- The N uptake by crops in the study was greater in annual 37,000 L ha^{-1} LHM application rate compared to urea fertilizer and where manure was applied once every three years at 110,000 L ha^{-1} LHM application rate (Table 2). This suggests that a 110,000 L ha^{-1} LHM single application rate intended to last for three years is not as efficiently used as smaller applications made more frequently.
- There was significant crop yield response to 37,000 L ha^{-1} annual LHM application in all crops for the duration of the study, compared to non-amended control plots (Table 3).
- Yields in the LHM tri-annual 110,000 L ha^{-1} application rate were often not higher than control plots in 3rd year after application (Table 3).
- LHM contains low amounts of S and the supplemental application of S fertilizer aided in correcting the N:S imbalance, especially in canola crops (Table 3). Supplementing LHM with S fertilizer can help in achieving optimum crop production on S deficient soils.

Conclusions

- Application rates of LHM that supply sufficient amounts of N each year to meet crop requirements gave the best crop N recovery and did not result in soil nitrate loading. Larger single applications of LHM were less effective in increasing crop yields, N uptake and recovery over time. Yield and N use efficiency can be improved by balancing manure available N with added S fertilizer.

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