Liquid Swine Manure Application to Forage Soil: Effect on Soil Carbon and Economic Returns

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Abstract

Hog production has been on the increase in Saskatchewan for the past several years. This has lead to an increase in the environmental interest surrounding the application of liquid hog manure. The expected increase in swine production operations will lead to an increase in demand for suitable land area to properly dispose of this effluent within the economic transport distance of the collection site. Soil injection of liquid swine effluent into forage crops will produce two types of benefits: increased forage crop production and an increase in soil carbon. A three-year study was conducted to determine the effects on injecting different rates of swine effluent into three types of forage crops: alfalfa, Russian Wild Rye and brome-alfalfa The effluent treated plots were sampled to determine if there has been any significant increases in soil carbon compared to untreated control plots. The economic distance which hog manure can be transported depends on the cost of transport and application and the short-term returns to be realized from the additional yield produced by the fertilizing effect of the manure. Results showed that the yearly application of the low rate of liquid hog manure into the brome/alfalfa forage crop produced the greatest net return to the forage grower.

Introduction

Hog production has increased in Saskatchewan over the last five years and since further expansion in production is anticipated, there will be an increase in demand for land area for manure application. Due to the costs associated with transporting and applying liquid manure, there is a restriction on the distance that manure can economically be moved (Nagy et al., 2000).

Land application of swine manure effluent has long been acknowledged as a source of plant macronutrients and micronutrients and can be described as a dilute multi-nutrient fertilizer blend (Schoenau, 1997). The application of manure has both a short and long term benefit of providing nutrients to crops. Low disturbance liquid hog manure injection meets the hog operation requirement for sufficient land to apply the manure and it presents the forage crop grower with a supplementary or low cost alternate fertilizer system. The over application of hog manure can have detrimental effects including injury to crops and soil problems such as increased salinity and nutrient imbalances (Schoenau et al., 1999).

There is a need to establish the effect that application of manure has on different types of crops, including soil quality and economic returns to the grower. The recommended application method for liquid hog manure has been to inject it, rather than broadcast the effluent. This type of application reduces volatilization losses of nutrients such as nitrogen, and it also increases the crop's ability to access the nutrients in the liquid hog manure (Mooleki et al., 2001).

There is also another potential benefit to be derived from the injection of liquid hog manure into forage grassland. Any change in land management that increases soil organic carbon will aid in the removal of carbon dioxide from the atmosphere. Carbon dioxide is thought to be one of the gases that contribute to the greenhouse gas effect. The removal of carbon dioxide from the atmosphere and storage in the soil is called carbon sequestration. Every pound of soil organic carbon represents 3.7 pounds of carbon dioxide that is removed from the atmosphere (McConkey et al., 1999).

The effects of management on carbon levels in forage crops has not been examined to a large extent in Canadian prairies. Soil organic carbon is a reservoir containing carbon and changes in the soil carbon storage have important implications for atmospheric carbon dioxide. Several studies have revealed that application of nitrogen fertilizer can affect soil organic carbon content (Owensby et al., 1969; Schwab et al., 1990). Nyborg et al. (1999) applied inorganic nitrogen and sulfur fertilizers to bromegrass, Kentucky bluegrass and rough hair grass over a 13 year period to determine if SOC and LFOC would increase in a dark gray chernozem soil. They reported an increase of 3.88 Mg C ha-1 in SOC in the 0-30 cm soil depth as a result of the forage fertilization.

Owing to the content of nitrogen and other nutrients contained in manure, applications of liquid hog manure may increase organic carbon content in the upper surface layer of the soil in a forage grassland through a fertilization effect on stimulating biomass production. A three-year study was conducted in east-central Saskatchewan to determine the effects of injecting swine manure into three types of forage crops. The objectives of the study were to assess the differences in total soil organic carbon and light fraction organic carbon that would result from the application of different rates of liquid hog manure into three different forage crops (alfalfa, brome/alfalfa and Russian wildrye) at four locations in east-central Saskatchewan. A second objective examined the economic returns associated with the application of liquid hog manure on forage crops based on yield results from the three year trial.

Materials and methods

Treatments

The study was established to compare different rates of injected hog manure on three different forage crops. The experimental design for the hog manure was a randomized complete block design, replicated four times. Test plots for each treatment were 6 m wide by 30 m long. The trial layout was repeated at all four locations.

The treatments in the hog manure trials consisted of a check, a disturbed check (injector applicator passing over the plot producing soil disturbance similar to the manure treated plots, but without injecting manure), three rates of hog manure, using a low disturbance coulter injector, were applied at a depth of 10-13 cm and 30 cm spacing. The hog manure was obtained from an earthen storage unit located near each field site.

At the Burr, Valparaiso, and Star City sites, the hog manure was applied during the fall of 1997, 1998 and 1999 for each of the three years of the study. At the Lanigan site, the hog manure was applied in the spring of 1998, and fall of 1998 and 1999. The sequence of liquid hog manure application is shown in table 1.

Table 1. Liquid hog manure application rates and schedule.

Injection Rate (L $ha^{-1)}$	Kg N ha^{-1}	Fall 1997 Manure Injection	Fall 1998 Manure Injection	Fall 1999 Manure Injection
37,000	90	Yes	Yes	Yes
74,000	180	Yes	No	Yes
148,000	360	Yes	No	No

Sites

Four field sites were elected in the fall of 1997 in the Black soil zone. The first site (Burr, Saskatchewan SE-21-35-23-W2) was located on a farm field containing soil classified as Meota Association (Black Chernozem with sandy loam surface texture) and is underlain by a mixture of loamy glacial till and gravelly fluvial material of variable depth with significant subsurface salinity. The Burr site is limited by salinity and low water holding capacity. This site had been seeded to a mixture of brome grass and alfalfa several years prior, and at the time of sampling, was dominated by brome. The second site (Lanigan, Saskatchewan NE21-33-21-W2) was located on the Western Beef Development Center Farm on soil classified as Oxbow Association (Black Chernozem with a sandy loam to loamy sand surface texture) and is underlain by loamy glacial till. The Lanigan site is limited due to insufficient moisture holding capacity and unfavorable topography. The Lanigan site was in Russian Wild Rye grass.

The third site (Valparaiso, Saskatchewan NE35-44-16-W2) was located on a farm field containing soil classified as Melfort-Tisdale Association (a mixture of Black and Dark Gray Chernozem with clay loam to silty clay surface texture) and is underlain by clay lacustrine materials. The fourth site (Star City, Saskatchewan SW14-45-16-W2) was located on a farm field containing soil classified as Melfort-Tisdale Association (a mixture of Black, Thick Black and Dark Gray Chernozem with silty clay surface texture) and is underlain by clay lacustrine material). The Valparaiso and Star City sites were young stands in alfalfa for dehy production.

Individual soil samples were collected from each treatment plot by inserting a polyvinyl chloride pipe (PVC) (10 cm diameter by 15 cm length) sharpened at one end, into the surface soil. The soil core was then removed intact from the plot and stored inside a plastic bag. For each depth increment sampled, SOC content was calculated using data obtained from bulk density and SOC concentration measurements. The SOC content was then corrected for bulk density differences to obtain SOC on an equivalent mass basis. This was done as the disturbance by hog manure injection may have induced changes in soil bulk density.

The PVC soil cores were sectioned into depths of 0-7.5 and 7.5-15 cm segments. The individual segment were spread out on separate drying trays and air dried at $25^{O}C$ for 96 hours. Wet weights were recorded for each segment before air drying. The dry weights of the soil samples were recorded after air drying. The samples were then ground using a wood rolling pin and sieved to < 2mm-particle size for total organic carbon (TOC) determination. The samples were then mixed and a 25 g subsample was obtained from each sample for TOC analysis. These subsamples were further ground using a Spex model 8000 ball/mill grinder operating for 2 minutes per sample. This apparatus ground the soil sample so that it could pass a 100-mesh sieve for organic C analysis using a LECO Carbon Determinator CR-12, set at 840^{O}C (Dry Combustion Method).

The light fraction component of the organic carbon in the soil samples was determined using the method developed by Gregorich and Ellert (1993). The upper increment (0-7.5 cm) of each soil core was selected for LFOC analysis as this layer is the most sensitive to LFOC changes induced by recent additions of organic matter from forage and/or grass biomass and from additions from injected hog manure. Twenty five grams of ground soil samples were weighed into centrifuge tubes and 50 ml of sodium iodide (NaI) (USP grade) of density 1.7 g cm^{-3} was added to each tube, covered, shaken for 60 minutes, and centrifuged at 1000 rpm for 20 minutes. The light fraction from each centrifuge tube was then decanted into vacuum flasks and the light fraction and NaI were then separated. The light fraction was collected and dried for 72 hours at 45 ^{O}C to obtain the dry weight. This procedure was repeated a second time for each sample to retrieve another aliquot of light fraction from the heavy fraction. The two aliquots for each sample were combined and using a motorized mechanical grinder, were ground to pass a 0.25 mm sieve. The concentration of organic carbon in the light fraction was determined using the LECO CR-12 Carbon Analyzer.

Results and discussion

1998 plant biomass yield

The application of liquid hog manure at the rate of 74,000L ha^{-1} increased brome/alfalfa yields (Burr site) from 1650 kg ha^{-1} in the undisturbed check plot to 2760 kg ha^{-1} (Figure 1).

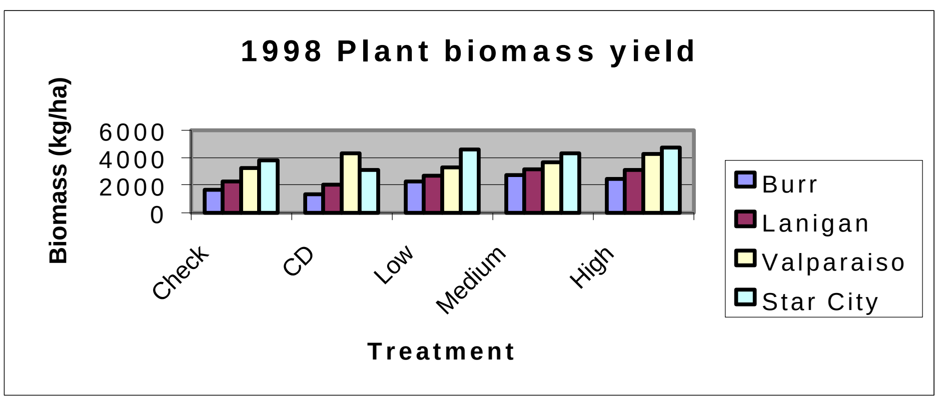

Figure 1. 1998 Plant biomass yield at Burr, Lanigan, Valparaiso and Star City, Saskatchewan (Pastl et al., 2000).

Russian wild rye yields (Lanigan site) increased from 2250 kg ha^{-1} in the undisturbed check plot to 3360 kg ha^{-1}(Figure 1) (Pastl et al., 2000). The application of liquid manure at 148,000 L ha^{-1} increased alfalfa yields (Valparaiso site) from 3256 kg ha^{-1} in the undisturbed check plot to 4282 kg ha^{-1}. The same application increased alfalfa yields at the Star City site from 3800 kg ha^{-1} in the undisturbed check plot to 4740 kg ha^{-1} (Pastl et al., 2000).

1999 plant biomass yield

The application of liquid hog manure at 37, 000L ha^{-1} increased brome/alfalfa yields (Burr site) from 5010 kg ha^{-1} in the undisturbed check plot to 10600 kg ha^{-1} (Figure 2).

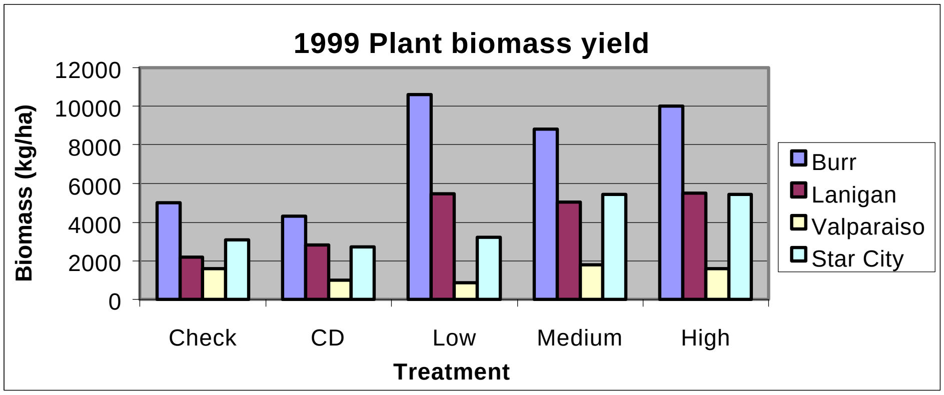

Figure 2. 1999 Plant biomass yield at Burr, Lanigan, Valparaiso and Star City, Saskatchewan (Pastl et al., 2000).

Russian wild-rye yields (Lanigan site) increased from 2170 kg ha^{-1} in the undisturbed check plot to 5460 kg ha^{-1}. There was enough residual carryover from the previous year's application of 74,000 L ha^{-1} to increase alfalfa yields (Star City site) from 3090 kg ha^{-1} in the undisturbed check plot to 5430 kg ha^{-1} (Figure 2). The same application sequence increased brome/alfalfa yields (Burr site) from 5010 kg ha^{-1} in the undisturbed check plot to 8820 kg ha^{-1} ha^{-}. There was also enough residual carryover of the previous year's application of 148,000 L ha^{-1} to increase yields from 5010 kg ha^{-1} in the check plot to 10,000 kg ha^{-1} (Figure 2). The biomass yields obtained in year two of the study were similar for both the 37,000 and 74,000 L ha^{-1} application rates (Pastl et al., 2000).

2000 plant biomass yield

The application rate of 37,000 L ha^{-1} increased brome/alfalfa yields (Burr site) from 1830 kg ha^{-1} in the undisturbed check plot to 3760 kg ha^{-1} and increased Russian wildrye yields (Lanigan site) from 1250 kg ha^{-1} in the undisturbed check plot to 2900 kg ha^{-1} (Figure 3).

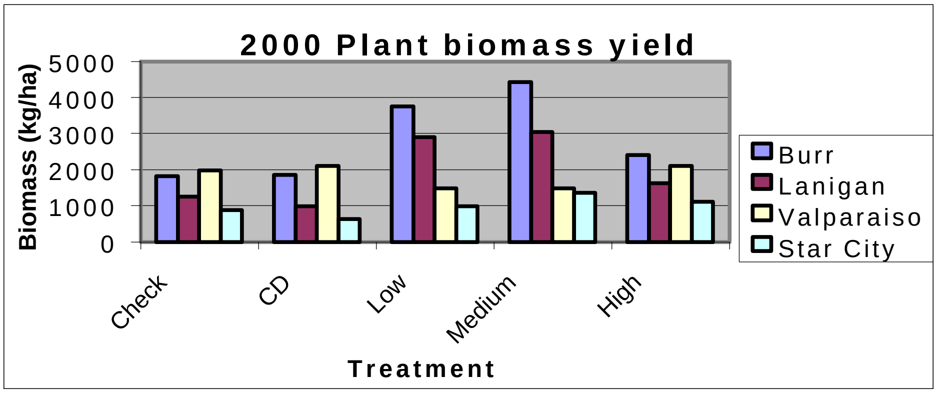

Figure 3. 2000 Plant biomass yield at Burr, Lanigan, Valparaiso and Star City, Saskatchewan (Pastl et al., 2000).

The application rate of 74,000 L ha^{-1} (applied in fall of 1999) increased brome/alfalfa yield at from 1830 kg ha^{-1} in the undisturbed check plot to 4420 kg ha^{-1} while the Russian wildrye yield (Lanigan site) increased from 1250 kg ha^{-1} to 3040 kg ha^{-1} (Figure 3). The residual carryover from the first year application of 148,000 L ha^{-1} increased alfalfa yields (Valparaiso) in year 3 from 1980 kg ha^{-1} in the undisturbed check plot to 2100 kg ha^{-1}, and increased alfalfa yields (Star City site) from 870 kg ha^{-1} in the undisturbed check plot to 1110 kg ha^{-1} (Figure 3). There was still some residual carryover from the single application rate of 148,000 L ha^{-1} two years previous; however, this residual nutrient effect was diminished by the last year of the study.

In the first year of the study when the liquid hog manure was injected at the rates of 37,000 and 74,000 L ha^{-1}, the biomass yield increased significantly when compared to the undisturbed check strip plots. In the second year of the study, there was enough carryover effect of the 74,000 and 148,000 L ha^{-1} injection rates to increase forage yields over the check plots. There was enough residual carryover of the 148,000 L ha^{-1} rate in the last year of the study to increase yields over the undisturbed check plots for all four sites (Pastl et al., 2000).

Economic analysis

The costs associated with loading and application of liquid hog manure were developed for a 20 million liter storage unit (Nagy et al., 2000). The Prairie Agricultural Machinery Institute (PAMI) developed a budget worksheet to determine tractor, pump, injector, and tank applicator costs. Application costs for the injection of liquid swine manure was valued at \$1.87 1000 L^{-1} for injection within a 2.4 kilometer transport distance plus the cost of two tractors and labor costs. The final application rate was determined to be \$2.10 1000 L^{-1} (Nagy et al., 2000). Forage prices for both the brome/alfalfa and alfalfa fields were obtained from the Saskatchewan Agriculture and Food website baled forage prices on January 28, 2002. The price for brome/alfalfa was \$122.23 1000 kg^{-1}, and the alfalfa price was \$115.85 1000 kg^{-1} (Sask. Ag & Food). Russian Wild Rye is used primarily as a forage grazing grass, and as such is not normally harvested and baled, therefore no economic analysis done on this forage at the Lanigan site. Revenues for each site and each year were determined by multiplying the forage price by the biomass yield. Injector application costs were then deducted from the gross revenue to determine a net revenue. All revenues and costs were worked out on a per hectare basis. In years where no application of liquid swine manure was made, there were no application costs deducted from the gross revenues.

1998 Forage crop returns

The injection of liquid swine manure was applied at three different rates at the beginning of this study. The application costs were as follows: 37,000 L ha^{-1} rate at $77.70, 74,000 L ha^{-1} at $155.40, and 148,000 L ha^{-1} at $310.80, for all three forage crops at all four sites. The application rate of 37,000 L ha^{-1} for the brome/alfalfa forage crop (Burr site) returned a net revenue of $186.44 which was $4.72 less than the undisturbed check plot (Table 2).

Table 2. 1998 and 1999 Net returns for brome/alfalfa forage at Burr.

Treatment (L ha^{-1})	1998 Revenue	1998 Injector Expense	1998 Net Revenue	1999 Revenue	1999 Injector Expense	1999 Net Revenue
	----------------	----------------	---------$ ha^{-1}	----------------	----------------	----------------
Check	191.16	-	**191.16**	580.42	-	**580.42**
37,000	264.14	77.70	**186.44**	1228.03	77.70	**1150.33**
74,000	319.75	155.40	**164.35**	1021.81	-	**1021.81**
148,000	285.00	310.80	**-25.80**	1158.52	-	**1158.52**

The same rate returned a net revenue for the alfalfa crop (Valparaiso site) of $329.41 versus $528.14 for the undisturbed control plot. The application rate of 74,000 L ha^{-1} returned a net revenue for the alfalfa crop (Star City site) of $372.74, which was $80.82 less than the $453.56 net return for the undisturbed check plot (Table 3).

Table 3. 1998 and 1999 Net returns for the alfalfa forage crop at Star City.

Treatment (L ha^{-1})	1998 Revenue	1998 Injector Expense	1998 Net Revenue	1999 Revenue	1999 Injector Expense	1999 Net Revenue
	----------------	----------------	---------$ ha^{-1}	----------------	----------------	----------------
Check	453.56	-	**453.56**	377.76	-	**377.76**
37,000	332.53	77.70	**254.83**	392.44	77.70	**314.74**
74,000	528.14	155.40	**372.74**	663.84	-	**663.84**
148,000	573.37	310.80	**262.57**	663.84	-	**663.84**

1999 Forage crop returns

During the second year of the study, the single 148,000 L ha^{-1} application rate made the first year returned the best net return of $1158.52 for the brome/alfalfa forage (Burr site) crop which was $578.10 higher than the check plot net return of $580.42 (Table 2). The same rate returned a net benefit of $663.84 for the alfalfa (Star City site) forage crop versus $377.76 for the undisturbed check plot (Table 3). The application rate of 74,000 L ha^{-1} returned the best net benefit for the alfalfa (Valparaiso site) forage crop of $217.61 versus $196.83 for the undisturbed check plot.

2000 Forage crop returns

The application rate of 74,000 L ha^{-1} repeated again in the fall of 1999 produced the highest net revenue for the brome/alfalfa (Burr site) forage crop at $363.62 versus $212.01 for the undisturbed control plot (Table 4).

Table 4. 2000 and total net return for the brome/alfalfa forage crop at Burr.

Treatment (L ha^{-1})	2000 Revenue	2000 Injector Expense	2000 Net Revenue	Total 3 Years Net Revenue	Total 3 Years Injector Expense	Total 3 Years Net Revenue
	---$ ha^{-1}---					
Check	212.01	-	**212.01**	983.58	-	**983.58**
37,000	435.6	77.70	**357.90**	1927.78	233.10	**1694.68**
74,000	519.02	155.40	**363.62**	1860.58	310.80	**1549.78**
148,000	278.04	-	**278.04**	1721.56	310.80	**1410.76**

The application rate of 37,000 L ha^{-1} made a similar return of $357.90 for the same forage crop. The application rate of 148,000 L ha^{-1} returned the best net benefit for both of the alfalfa forage crop sites. The net benefit at Valparaiso was $256.73, which was only $14.67 more than the undisturbed check plot net benefit of $242.06. The net revenue at Star City was $135.70 versus $106.36 return for the undisturbed check plot (Table 5).

Table 5. 2000 and total net returns for the alfalfa forage crop at Star City.

Treatment (L ha^{-1})	2000 Revenue	2000 Injector Expense	2000 Net Revenue	Total 3 Years Net Revenue	Total 3 Years Injector Expense	Total 3 Years Net Revenue
	---$ ha^{-1}---					
Check	106.36	-	**106.36**	937.69	-	**937.69**
37,000	121.03	77.70	**43.33**	846.00	233.10	**612.90**
74,000	166.27	155.40	**10.87**	1358.24	310.80	**1047.44**
148,000	135.7	-	**135.70**	1372.91	310.80	**1062.11**

Three year total net returns

The annual application rate of 37,000 L ha^{-1} had the overall best net beneficial revenue for the brome/alfalfa (Burr site) forage crop for the three years of the hog manure injection study. The total net return was $1694.68 versus a total net return of $938.58 for the undisturbed check plots (Table 4). The total net return for the alfalfa (Valparaiso site) crop revealed that the undisturbed check plot had the best overall return of $967.03 which was a higher total net return than the three different liquid manure application rates. The application rate of 148,000 L ha^{-1} returned the best total net return ($1062.11) for the alfalfa crop at Star City (Table 5). The undisturbed check plot at this site; however, returned a total net benefit of $937.69 which was only $124.42 less than the 148,000 L ha^{-1} net return.

The economic results show that application of liquid swine manure into alfalfa was not beneficial at one site (Valparaiso), while only marginally beneficial at the other site (Star City). The results show that injection of liquid hog manure into the brome/alfalfa forage crop, dominantly brome at the time of application, was economically beneficial. It should be noted that forage crop prices used were the same price across all three years. The uniquely high net revenue for 1999 at the Burr site was aided by the timely application of rainfall, which produced a very large yield response of the brome to the applied manure nutrients. The final year of the study was a cool year, with less moisture being received. These climatic conditions did not favor optimum plant biomass production.

Soil organic carbon in the 0-7.5 cm depth

Total Soil organic carbon (SOC) in the 0-7.5 cm depth was not significantly affected by treatment at three of the four sites. The only significant difference was at the alfalfa forage crop site at Valparaiso. The application of 37,000, 74,000 and 148,000 L ha^{-1} resulted in SOC values of 38.1, 35.1 and 34.5 Mg ha^{-1}, respectively, versus 28.6 Mg ha^{-1} for the disturbed check strip (Table 6). The undisturbed check plot SOC was determined to be 36.7 Mg ha^{-1} and was not significantly different from the three application rates of liquid hog manure (Table 6).

Table 6. Soil organic carbon at 0-7.5 cm and 7.5-15 cm soil depth segments at Burr, Lanigan, Valparaiso and Star City, Saskatchewan.

Treatment (L ha^{-1})	Burr		Lanigan		Valparaiso		Star City	
	--Mg ha^{-1}-------------------------------------							
Depth(cm)	0-7.5	7.5-15	0-7.5	7.5-15	0-7.5	7.5-15	0-7.5	7.5-15
Check	31.9	28.0	37.3	28.8	36.7a	27.2	19.6	17.5
CD	27.6	25.7	35.9	31.6	28.6b	28.5	18.5	16.9
37,000	32.4	30.8	33.8	30.3	38.1a	27.7	19.1	16.5
74,000	29.3	26.7	35.1	27.2	35.1ab	31.1	18.1	15.3
148,000	31.1	25.9	36.6	27.2	34.5ab	37.8	19.9	15.0
$LSD_{(0.10)}$	NS	NS	NS	NS	6.8	NS	NS	NS

*Means followed by the same letter are not significantly different at p=0.10.

Soil organic carbon in the 7.5-15 cm depth

The SOC in the 7.5-15 cm depth segment of the soil profile revealed no significant differences in SOC values among three hog manure application rates and both check plots, for all four sites. Average SOC values for each site in the 7.5-15 cm depth were lower than the average SOC values for each site at the 0-7.5 cm depth. Average SOC for the brome/alfalfa forage crop (Burr site) in the 7.5-15 cm depth was 27.4 Mg ha^{-1} versus 30.5 Mg ha^{-1} in the 0-7.5 cm depth. Average SOC for the Russian wildrye (Lanigan site) forage crop was 35.7 Mg ha^{-1} in the 0-7.5 cm segment versus 29.0 Mg ha^{-1} in the 7.5-15 cm depth segment. The average SOC values for the alfalfa at Valparaiso and Star City sites were 34.6 and 19.0 Mg ha^{-1} in the upper segment, respectively, versus 30.4 and 16.2 Mg ha^{-1}, respectively, in the lower 7.5-15 cm depth segment (Table 6). These results are expected as SOC amounts usually decrease with depth in the soil profile.

Light fraction organic carbon

The light fraction organic carbon (LFOC) analysis was conducted on the 0-7.5 cm depth segment of the soil profile at each of the four sites. Results showed that there was a significant increase in LFOC in the brome/alfalfa (Burr site) forage crop with hog manure application. Applications of 37,000, 74,000 and 148,000 L ha^{-1} resulted in LFOC values of 5.2, 5.1 and 5.6 Mg C ha^{-1}, respectively versus 3.4 Mg ha^{-1} in the undisturbed check (Table 7).

Table 7. Light fraction organic carbon at Burr, Lanigan, Valparaiso and Star City, Saskatchewan.

Treatment (L ha^{-1})	Burr	Lanigan	Valparaiso	Star City
	--------Mg C ha^{-1}--------			
Check	3.4b	6.5	2.4a	3.9a
Check-Dist.	3.9ab	6.9	1.6b	2.7b
37,000	5.2ab	6.0	2.5a	2.9b
74,000	5.1ab	5.4	2.1ab	2.5b
148,000	5.6a	5.9	2.3ab	2.9b
$LSD_{(0.10)}$*	1.8	NS	0.8	0.6

*Means followed by the same letter are not significantly different at p=0.10.

There were no significant differences between the three application rates of hog manure for the brome/alfalfa forage crop. There were no significant treatment differences in LFOC in the Russian wildrye (Lanigan site) forage crop. Results from the Valparaiso alfalfa showed a significant difference between the check disturbed plot (1.6 Mg C ha^{-1}) and the undisturbed check (2.4 Mg ha^{-1}) (Table 7). There was no significant differences in LFOC between the three hog manure application rates at this site. The results from the Star City alfalfa site showed a significant difference between the undisturbed check plot (3.9 Mg C ha^{-1}) and the three hog manure application rates and the disturbed check plot. The application rates of 37,000, 74,000, 148,000 L ha^{-1} and the disturbed check plot had 2.9, 2.5, 2.9 and 2.7 Mg C ha^{-1} as LFOC, respectively (Table 7). Overall, at this site the undisturbed check plot showed higher LFOC than all the other treatments.

One possible explanation for higher LFOC in the undisturbed check was that the disturbance by the injection equipment, had an effect on the LFOC, possibly enhancing decomposition rates of the organic biomass. This could also explain the trend at the Russian wildrye site as the hog manure application treatment LFOC were lower than the undisturbed check plot LFOC. The significant increase in LFOC in the brome/alfalfa forage crop (Burr site) could be due to this stand having a greater proportion of the stand comprised of grass (brome) as compared to alfalfa. The grass would have more effectively utilized the nitrogen from the hog manure to produce more above and below surface biomass, which in turn would have increased the LFOC values compared to the check plot.

It should be noted that although that there were no significant increases in total SOC for the 0-7.5 cm depth, the significant increase in LFOC, in the brome/alfalfa forage crop indicates that there will be an eventual increase in SOC as the LFOC represents the recent carbon additions to the soil organic matter.

Summary and conclusions

The application of liquid hog manure produced variable results across three different forage crops. The best overall response to hog manure addition in terms of soil carbon and economic benefit was in the brome/alfalfa forage grass (Burr site) at an annual application rate of 37,000 L ha^{-1}. It should be noted, however, that this was only a three year study and thus the effects from a second carryover year of the 74,000 L ha^{-1} rate were not included. Another year of study could have possibly resulted in the 74,000 L ha^{-1} application rate applied every second year being the more economical rate to apply. The injection of liquid hog manure into the alfalfa resulted in no significant economic gain when compared to the check plots. It should also be noted that some studies have found that applications of liquid hog manure over 10,000 gallons acre-1 (112,000 L ha^{-1}) can have detrimental effects on crops grown immediately following injection (Schoenau et al., 1997). This could have been the case for the Russian wildrye and alfalfa forages as the yield response to injected hog manure was more muted compared to the brome/alfalfa stand, which was predominantly brome grass and responded to the nitrogen in the manure.

The increase in LFOC at the brome/alfalfa site is indicative of potential increases in total SOC in the future. Although there was little solid matter (approximately 2-5%) in the hog manure which would directly contribute to the SOC, the nutrients present in the hog manure would have been utilized by the plants to increase plant biomass. This increase in above ground plant biomass would have also led to an increase in below ground biomass to sustain the above ground biomass production. The below ground biomass would then contribute to the LFOC, which is comprised of recent carbon additions to the organic matter in a soil. A longer time period than three years is needed to see the increase in SOC levels from the application of liquid hog manure; however, significant increases in the LFOC are predicting that this will occur.

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