Nutrient and Heavy Metal Contents of Hog Manure – Effect on Soil Quality and Productivity

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1.0 Introduction

It is well-known that the application of hog manure to land is an economical and environmentally sustainable method for the utilization of the nutrients and other components in the manure. Manure application can increase soil quality and productivity, at least in the short term, on most soils. However, soil quality and productivity can be severely reduced in the long-term unless precautions are taken with respect to the loadings and frequency of application of manures. Sustaining the hog industry, through good manure management, is one method to ensure the continued growth of the hog industry in the province.

Excessive accumulations of phosphorus, metals such as copper and zinc, sodium and other soluble salts can reduce soil quality and productivity. The loading rates and period of time a soil or parcel of land can be used for manure application depends on soil properties and the concentration of various constituents in the manure. Manures vary in the concentrations of metals (such as copper and zinc), depending on the type of hog operation (feeder, sow, nursery or farrow to finish barns) because of the varying concentrations of these minerals used in the feed. Soils with pH values of less than 6.5 are sensitive to metal loadings of copper and zinc, and crop yield and quality may be reduced if metal applications are high. Sodium and other soluble salts found in the manures, also depend on the mineral supplements in the feed, as well as the source of water used to operate the hog facility. Many soils in Manitoba are highly sensitive to sodium and salt applications. Another concern is the ratio of nitrogen to phosphorus in the manures. If the nitrogen to phosphorus ratio in the manure is much less than the ratio of nitrogen to phosphorus removed by crops, and the application rate of the manures was based only on available nitrogen, phosphorus will accumulate in the soil. The build-up of phosphorus in the long-term can result in phosphorus runoff to surface waters (a decrease in water quality) and may cause yield reductions.

This investigation was an exploratory study to determine whether or not decreases in soil quality and productivity were likely to occur due to the long-term applications of manure to Manitoba soils. Several types of hog manures produced by various hog operations in Manitoba were examined, and the effects of these manures on soil quality and productivity were assessed.

2.0 Methods

Manures were obtained from various facilities in the fall of 1998 and 1999, and analyzed for various constituents. In this investigation, a total of 145 samples from 38 different operations were studied. Each sample was identified by year, operation number, type of barn-type of storage, location of sampling and feed additives. The manure samples were taken from open earthen (open primary and earthen secondary) and slurry storage facilities. Samples were taken from either the top, middle or bottom of a storage facility during clean-out of storage facilities. Of the total samples, there were 92 samples that originated from feeder barns, 37 from sow barns, 11 from nursery barns and five from farrow-to-finish barns. The additives used in the feed were the same for each type of barn. In general, the feed additives for the nursery barns were the highest in protein, copper and zinc of the four types of barns investigated. The feed additives for the sow barns were in general the lowest in protein, copper and zinc of the four barns (Table 1).

Table 1. Feed additives for various barn types.

Feed Additives	Feeder Barn	Sow Barn	Nursery Barn	Farrow to Finish
Protein	medium	med. to low	high	** medium (1999)
Copper	high	low (1998) med to low (1999)	high	** medium (1999)
Zinc	low (1998) med. to low (1999)	medium	high (1998) med to high (1999)	** medium (1999)

**Information regarding the feed additives in the farrow to finish operation was not given in 1998.

The hog manure samples were analyzed for moisture and solids content, electrical conductivity, total nitrogen, phosphorus, potassium and sodium, inorganic and organic nitrogen, and dissolved calcium, magnesium, sodium, and chloride. The samples were also analyzed each year for the total contents of 32 elements. The two years of laboratory data were grouped and the data for the 145 hog manure samples statistically summarized. Correlation matrices relating the various hog manure constituents were prepared for all of the samples, the various barns and storage facilities.

Loadings of the various hog manure constituents were determined from the composition data based on the application of hog manure at a rate of 70 kg available nitrogen per hectare.

3.0 Properties, composition and loadings

3.1 Moisture content and percent solids

The moisture content of the hog manure samples averaged 96.6% and did not vary greatly among the different types of barns. Manure from the feeder barns, in general, had the lowest moisture content of the four types of barns, with a relatively large number of manures with moisture contents below 93%. The percent solids in the hog manure samples averaged 3.5%, and was the highest in the manures from the feeder barns.

The solids content increased with depth of sampling in most of the storage facilities. Percent solids, as expected, was higher from primary than secondary storage facilities. Percent solids was positively correlated with most manure constituents. The highest correlation of percent solids occurred with total phosphorus ($r = 0.718$, $n = 145$), reflecting an increase in phosphorus content of the manure with percent solids. The percent solids was also highly correlated with the content of many of the minor elements and/or heavy metals.

3.2 Nitrogen, phosphorus and nitrogen to phosphorus ratios

3.2.1 Concentration

The total nitrogen (N) content of the hog manure samples varied greatly within and with type of barn most likely due to the protein content of the feed (Table 2). The mean total N content of the 145 hog manure samples was 2.89 kg/1000L. Most of the samples from the feeder barns had a total N content between 2 and 3 kg/1000L, while most of the samples from the sow barns had a total N content between 1 and 2 kg/1000L. The mean total N content was the highest in the manure samples obtained from the feeder barns, followed by the samples from the farrow-to-finish and nursery barns. Manure from the sow barns had the lowest mean total N content, and in fact, the feed for the sow barns had the lowest levels of protein.

Table 2. Total nitrogen (kg/1000L) in hog manure samples.

Frequency Distribution					
Barn Type / Range	**0-1**	**1-2**	**2-3**	**3-4**	**>4**
No. of Feeder Barns	0	15	29	18	30
No. of Sow Barns	5	25	3	3	1
No. of Nursery Barns	0	3	4	2	2
No. of Farrow to Finish	0	2	0	3	0
Total No. of Samples	5	45	36	26	33
Statistical Summary					
Barn Type / Statistic	**Total**	**Maximum**	**Minimum**	**Mean**	**Std.Dev.**
Feeder Barns	92	6.40	1.50	3.38	1.26
Sow Barns	37	6.50	0.60	1.73	1.05
Nursery Barns	11	4.60	1.50	2.72	0.97
Farrow to Finish	5	4.00	1.20	2.76	1.23
Total of Samples	145	6.50	0.60	2.89	1.38

Approximately one-half of the 145 hog manure samples had a total phosphorus (P) content between 0 and 0.5 kg/1000L (Table 3). The overall mean total P content for the 145 samples was 0.92 kg/1000L. The mean total P content of manure was the highest in the samples from the nursery barns and lowest in those from the sow barns. Total P had the highest correlation ($r=0.718$) of all the elements studied with percent solids.

Table 3. Total phosphorus (kg/1000L) in hog manure samples.

Frequency Distribution					
Barn Type / Range	**0.0-0.5**	**0.5-1.0**	**1.0-1.5**	**1.5-2.0**	**>2.0**
No. of Feeder Barns	45	11	10	7	19
No. of Sow Barns	26	4	3	1	3
No. of Nursery Barns	3	1	2	4	1
No. of Farrow to Finish	2	1	0	1	1
Total No. of Samples	76	17	15	13	24
Statistical Summary					
Barn Type / Statistic	**Total**	**Maximum**	**Minimum**	**Mean**	**Std.Dev.**
Feeder Barns	92	3.54	0.05	0.99	0.95
Sow Barns	37	5.51	0.03	0.65	1.04
Nursery Barns	11	2.55	0.14	1.17	0.76
Farrow to Finish	5	2.07	0.12	1.06	0.79
Total of Samples	145	5.51	0.03	0.92	0.97

The ratio of total nitrogen to total phosphorus (N:P) is a method of assessing P fertilizer requirements and whether or not a build-up of phosphorus will occur in the soil, over the longterm, if application rates are based solely on N content. Annual crops usually take up N:P in a ratio of about 5:1 to 7:1. Thus, N:P ratios below 5:1 may indicate a possible build up of P in the soil, whereas N:P ratios above 7:1 may require the addition of P to meet crop needs, when long term application rates are based on the N content of manures.

The mean ratio of N:P was greatest in the samples from the feeder, followed by the samples from the sow barns (Table 4). The overall mean ratio of N:P was about 3.14, with about 45% of the samples having N:P ratios of 4:1 or less, and about 38% of the samples having N:P ratios greater than 8:1. In many instances, the samples with very high N:P ratios were obtained from the top of storage facilities and/or from secondary storages. Thus, for many operations, better mixing of some of the manures from the bottom of storages with manure from the top of storages would provide manure with a N:P ratio closer to crop requirements and reduce the land area treated with manures of high phosphorus content. As noted before, the mean N:P ratio was 3.14 to 1 and about 50% of the manure samples had N:P ratios less than 5 to 1. Thus phosphorus will tend to accumulate in many soils if manure application rates are based solely on nitrogen supply. Two strategies could be used to prevent excessive accumulation of phosphorus in soils.

(1) Thorough mixing of manures in storage facilities and applying manure at P rates consistent with crop uptake and/or good environmental stewardship.

(2) Separation of solids from liquids in manure and use of the solids as a P fertilizer, e.g., applying a relatively large amount of P (50 to 70 kg P/ha) to land to be seeded to permanent forage as a means of supplying P to forages for a period of two to three years. The P could be broadcast and worked into the soil prior to establishment of forage. This may be feasible since most of the P in the manure was associated with the solids portion of the manures.

Table 4. Ratio of total nitrogen to total phosphorus in hog manure samples.

Frequency Distribution					
Barn Type / Range	**<4**	**4-8**	**8-12**	**12-16**	**>16**
No. of Feeder Barns	38	18	13	8	15
No. of Sow Barns	14	8	7	5	3
No. of Nursery Barns	8	0	1	1	1
No. of Farrow to Finish	4	0	1	0	0
Total No. of Samples	64	26	22	14	19
Statistical Summary					
Barn Type / Statistic	**Total**	**Maximum**	**Minimum**	**Median**	**Mean***
Feeder Barns	92	32.00	1.27	5.61	3.41
Sow Barns	37	24.00	1.10	5.56	2.66
Nursery Barns	11	20.00	0.89	2.10	2.32
Farrow to Finish	5	10.00	1.93	3.68	2.60
Total of Samples	145	32.00	0.89	5.00	3.14

*Calculated from overall average concentrations of N and P, not from ratio of individual samples.

The total N content of the manures usually increased by approximately 25% with depth of sampling in the various storage facilities (Table 5). However, the total P content of the manures increased more than two fold with sampling depth despite attempts to mix the manure in the facilities prior to use for land application and sampling. Therefore, the ratio of N:P decreased markedly with depth of sampling.

Table 5. Nitrogen and phosphorus contents for different depths.

Sample Depth	Dry Matter %	Total N (kg/1000L)	Total P	N to P Ratio
Top (n=62)	2.3	2.59	0.61	4.20
Middle (n=30)	3.7	2.79	0.88	3.20
Bottom (n=53)	4.6	3.27	1.31	2.50

3.2.2 Loadings

It is important to know the actual amounts of elements added to soils i.e., loadings. Thus, the amounts of phosphorus added to soil was calculated based on the amounts of liquid hog manure required to add 70 kg of available nitrogen per hectare. Available nitrogen was calculated from the sum of inorganic nitrogen plus 25% of the organic nitrogen content.

Loadings of P were extremely variable and varied from 2.28 to 112 kg P/ha (Table 6). About 60% of the manures would result in loadings below 25 kg P/ha with about 37% of the manures with loadings of less than 10 kg P/ha. The median loading rate of P was 16 kg P/ha but varied from about 14 to 15 kg P/ha for the feeder and sow barns (128 samples) to about 35 kg P/ha for the nursery barns (11 samples). The median for loadings of total P for manures from the feeder and sow barns is close to that removed annually by annual crops, and only slightly higher than that added annually as commercial fertilizer to annual crops in Manitoba. Loadings of P with about 23% of the samples were in excess of 40 kg P/ha and the overall mean loading rate was 27.4 kg P/ha, considerably in excess of crop uptake by annual crops. Thus, loadings of P were less than or equal to crop removal for many samples and considerably in excess of crop removal for about 20 to 30% of the samples. As noted previously, total P content of the manures varied with barn type (feeder, nursery, etc.) and increased with depth of sampling of the storage facilities. For example, mean loadings of P for manure from the feeder barns increased with depth as follows: top one-third of storage = 16 kg P/ha, middle one-third of storage = 23 kg P/ha, bottom one-third of storage = 32 kg P/ha. Thus, the low loadings of P were usually with manure types low in P and/or with manures from the top portion of storage facilities. In contrast, the very high loadings were usually with manures high in P and/or with manures from the bottom of storage facilities. It, therefore, follows that rate of P application to a field would vary considerably during a typical clean-out of storage facilities.

3.3 Electrical conductance and sodium adsorption ratio

The electrical conductivity (measure of salt content) of hog manures can be quite high mainly because of the presence of nutrients (for example, ammonium), the use of dietary salts, and in some instances groundwater containing salts. The dominant ions that contribute to electrical conductivity in hog manures are ammonium, sodium, calcium, magnesium, chloride and sulfate.

The electrical conductivity (EC) of the hog manure samples varied with type of barn and ranged between 8.65 and 27.50 dS/m (Table 7). The mean EC of the 145 hog manure samples was 15.99 dS/m, and most of the samples had EC values between 12 and 24 dS/m. Manure samples from the farrow-to-finish and feeder barns had the highest mean EC, followed by the samples from the nursery barns. Manure samples from the sow barns had the lowest mean EC values. It is interesting to note that the manure from the sow barns also had the lowest nutrient contents. The EC did not change with sampling depth. Electrical conductivity of the manure samples was reasonably well correlated with inorganic N content of the samples (r = 0.725), and had very low correlation with ions like Na or Cl indicating that variations in EC were due in large part to variations in inorganic N.

Table 6. Total phosphorus (kg/ha) loadings based on the application of hog manure at a rate of 70 kg available nitrogen per hectare.

Frequency Distribution					
Barn Type / Range	**< 10**	**10 - 25**	**25 - 40**	**40 - 55**	**> 55**
No. of Feeder Barns	34	21	16	13	7
No. of Sow Barns	15	10	5	2	5
No. of Nursery Barns	3	0	3	2	3
No. of Farrow to Finish	1	2	1	1	0
Total No. of Samples (144)	53	33	25	18	15
Statistical Summary					
Barn Type / Statistic	**Maximum**	**Minimum**	**Mean‡**		**Median**
Feeder Barns (n=91)	78.3	2.28	25.1		14.7
Sow Barns (n=37)	112.0	3.11	33.7		13.9
Nursery Barns (n=11)	84.7	5.25	38.2		34.7
Farrow to Finish (n=5)	41.6	7.72	29.6		21.4
Total of Samples (n=144)	112.0	2.28	27.5		16.0

‡Means were calculated from average concentrations and are not means of individual samples.

The sodium adsorption ratio (SAR) of solutions is used to provide an indication of the possible harmful effects of sodium on soil structure. A build-up of excess sodium in the soil relative to calcium and magnesium can have adverse effects on soil structure, such as surface crusting. The SAR is a measure of amounts of sodium added to soil in relation to amounts of calcium and magnesium added.

Solutions with SAR values of 0 to 4 have little or no effect on soil quality, and solutions with SAR values of 4 to 9 have slight to moderate effects on soil quality. Approximately two-thirds of the hog manure samples had SAR values between 0 and 6 (Table 8). The mean SAR of the hog manure samples was 5.1. Manure from the farrow-to-finish barns had the highest SAF, followed by manure from the sow barns. The SAR of the manure from the feeder and nursery barns were similar. The SAR of manure, in general, decreased with increasing sampling depth within a particular type of storage facility. Only a few of the samples had very high SAR values, thus the majority of manures would have little or no sodicity hazard.

Table 7. Electrical conductivity (dS/m) of hog manure samples.

Frequency Distribution					
Barn Type / Range	**0-8**	**8-12**	**12-16**	**16-24**	**>24**
No. of Feeder Barns	0	1	28	59	4
No. of Sow Barns	0	25	12	0	0
No. of Nursery Barns	0	1	3	7	0
No. of Farrow to Finish	0	1	1	3	0
Total No. of Samples	0	28	44	69	4
Statistical Summary					
Barn Type / Statistic	**Total**	**Maximum**	**Minimum**	**Mean**	**Std.Dev.**
Feeder Barns	92	27.5	11.8	17.8	3.3
Sow Barns	37	15.2	8.7	11.3	1.8
Nursery Barns	11	18.5	11.7	16.1	2.1
Farrow to Finish	5	22.8	9.8	18.0	5.6
Total of Samples	145	27.5	8.7	16.0	4.1

Table 8. Sodium adsorption ratio in hog manure samples.

Frequency Distribution					
Barn Type / Range	**0-3**	**3-6**	**6-9**	**9-12**	**>12**
No. of Feeder Barns	29	42	16	2	3
No. of Sow Barns	14	7	8	5	3
No. of Nursery Barns	4	3	2	2	0
No. of Farrow to Finish	0	3	0	0	2
Total No. of Samples	47	55	26	9	8
Statistical Summary					
Barn Type / Statistic	**Total**	**Maximum**	**Minimum**	**Mean**	**Std.Dev.**
Feeder Barns	92	17.3	1.1	4.5	2.9
Sow Barns	37	17.8	0.6	5.9	4.3
Nursery Barns	11	10.6	1.6	4.8	3.1
Farrow to Finish	5	16.5	4.0	8.9	4.9
Total of Samples	145	17.8	0.6	5.1	3.5

3.4 Concentration and loadings of some major, minor and rare elements

3.4.1 Concentration

Potassium (K), calcium (Ca) and chloride (Cl) were, on average the most abundant elements in manure of the elements shown in Table 9. Magnesium (Mg), sodium (Na) and sulfur (S) were present at moderate concentrations. The contents of iron (Fe), aluminum (Al) and silicon (Si) were generally lower than magnesium, sodium or sulfur contents. Levels of copper (Cu), zinc (Zn), manganese (Mn), titanium (Ti), strontium (Sr), boron (B) and barium (Ba) were usually present at detectable levels. Vanadium (V), nickel (Ni), molybdenum (Mo), chromium (Cr), lithium (Li), tin (Sn) and selenium (Se) varied at concentrations below or just above detectable levels and had mean concentrations between 0.2 and 0.5 mg/L. The elements with the lowest concentrations were lead (Pb), arsenic (As), antimony (Sb), cobalt (Co), bismuth (Bi), cadmium (Cd), thallium (Th), beryllium (Be), tin (Sn) and silver (Ag). The percentage of samples with concentrations below detection limits was very high for antimony, arsenic, beryllium, bismuth, silver and thallium. Contents of many of the elements increased with sampling depth within storage facilities or with solids content.

The concentration of each element was extremely variable, varying several hundred fold or greater for many of the elements. Some of the manures, particularly from the nursery barns, had high levels of trace elements and/or heavy metals. Close correlations were found when relationships among the concentrations of various metals were studied. This indicates that the source of many of the metals was likely the same. Limestone and other mineral supplements are added to some hog feeds to promote growth and to prevent microbial infections. Copper, Zn, Mg and Fe are routinely added to some feeds and thus the higher concentrations of these metals are due to the inclusion of these metals in the feed. The concentrations of other metals such as Be, Cd, Ni and Pb. were also closely correlated with the metals added as nutritional supplements or for disease suppression, suggesting the Be, Cd, Pb and Ni were most likely contaminants in the mineral supplements. Since the metal content of manures is a function of the metal content of the feed it follows that the metal content of manures will reflect the source of raw materials used for manufacturing of mineral supplements, i.e. source of phosphate rock, limestone and other minerals.

3.4.2 Loadings

Loadings of the various hog manure constituents were determined from the composition data based on the application of liquid hog manure at a rate of 70 kg available nitrogen per hectare. Loadings, for elements with concentrations below detection limits, were calculated assuming that non-detectable values were equal to detection limit. This method of calculation was used to provide an estimate of the highest loadings that could occur and to provide some information on the potential risk to plant growth and soil quality. These values in Table 10 are listed as less than a particular value.

Table 9. Concentration of Some Major, Minor and Rare Elements

Element	Concentration (mg/L) MAX	MIN	MEAN	Percentage of Samples Below Detection Limit
Aluminum (Al)	825	1.15	90	0
Antimony (Sb)	0.09	<0.02	-*	88
Arsenic (As)	0.44	<0.10	-	66
Barium (Ba)	11.0	0.06	1.74	0
Beryllium (Be)	0.06	<0.005	-	50
Bismuth (Bi)	<0.07 or <0.04	<0.04	-	100
Boron (B)	11.2	0.32	2.04	0
Cadmium (Cd)	0.198	<0.005	0.044	4
Calcium (Ca)	8640	64	1036	0
Chromium (Cr)	2.17	<0.008	0.34	0.7
Chloride (Cl)	2260	97	1127	0
Cobalt (Co)	0.41	<0.007	0.06	8
Copper (Cu)	177	0.6	32	0
Iron (Fe)	988	3.9	133	0
Lead (Pb)	0.48	<0.02	-	25
Lithium (Li)	1.41	0.05	0.30	0
Magnesium (Mg)	4760	8.9	544	0
Manganese (Mn)	134	0.37	17.8	0
Molybdenum (Mo)	2.02	<0.01	0.36	1.4
Nickel (Ni)	1.88	0.04	0.41	0
Potassium (K)	3380	212	1604	0
Selenium (Se)	0.97	<0.02	0.21	6
Silicon (Si)	1520	9.5	147	0
Silver (Ag)	0.027	<0.005	-	99
Strontium (Sr)	15.8	0.13	2.24	0
Sodium (Na)	1500	180	525	0
Sulfur (S)	1220	23	234	0
Titanium (Ti)	19.3	0.05	2.77	0
Thallium (Th)	<0.02	<0.02	-	100
Vanadium (V)	2.80	<0.01	0.48	6
Tin (Sn)	2.42	<0.015	-	20
Zinc (Zn)	541	1.18	58	0

*Means are not presented where more than 20% of samples tested below detection limits.

Table 10. Loadings of Some Major, Minor and Rare Elements for Manure Applied at 70 kg Available N per hectare.

Element	Loading (kg/ha or g/ha) MAX	MIN	MEAN	MEDIAN	% of samples with Loadings < the mdl
Aluminum	24.4	0.04	2.67 (kg)	0.98	0
Antimony	4.2	<0.3	-* (g)	-	88
Arsenic	12.6	<0.8	- (g)	-	66
Barium	276	2.9	32 (g)	23	0
Beryllium	1.84	<0.06	- (g)	-	50
Bismuth	<5.8	<0.52	- (g)	-	100
Boron	203	11	61 (g)	48	0
Cadmium	6.3	<0.1	1.3 (g)	0.85	4
Calcium	200	2.7	31 (kg)	18	0
Chromium	63	<0.3	10 (kg)	5.4	0.7
Chloride	141	3.2	33.6 (kg)	32.4	0
Cobalt	13.5	<0.12	1.78 (g)	1.12	8
Copper	4.4	0.04	0.96 (kg)	0.55	0
Iron	30.6	0.15	3.95 (kg)	1.77	0
Lead	18.5	<0.33	- (g)	-	25
Lithium	39.9	1.86	8.78 (g)	7.53	0
Magnesium	75.1	0.27	16.2 (kg)	8.7	0
Manganese	2794	17	529 (g)	303	0
Molybdenum	52.9	<0.35	10.6 (g)	7.4	1.4
Nickel	58.8	1.4	12.2 (g)	8.5	0
Potassium	122	4.3	47.8 (kg)	51	0
Selenium	23.0	<1.0	6.3 (kg)	5.0	6
Silicon	28.3	0.21	4.4 (kg)	2.2	0
Silver	0.83	<0.07	-	-	99
Strontium	298	6.18	66.6 (g)	43.3	0
Sodium	67.1	5.14	15.6 (kg)	14.6	0
Sulfur	23.5	0.99	6.98 (kg)	5.25	0
Titanium	418	1.86	82.5 (g)	42.0	0
Thalium	<3.33	<0.30	- (g)	-	100
Vanadium	103	<0.26	14.2 (g)	6.06	6
Tin	54.8	<0.42	- (g)	-	20
Zinc	14.2	0.04	1.73 (kg)	0.83	0

*Means and medians are not presented where more than 20% of samples tested below detection limits.

Loadings of the various elements were extremely variable reflecting the large variations in concentration of the various elements in the various manures. The mean loadings of the various elements were usually highest for manures from the sow and nursery barns. In general the mean potential loadings of the more abundant elements such as phosphorus, potassium, calcium, sodium and chloride were the highest with manure from sow barns. The mean potential loadings of many of the essential trace elements and heavy metals were highest with manures from the nursery barns.

Loadings of potassium were similar to loadings of phosphorus and varied from 4.3 to 122 kg/ha. Loadings of sodium, calcium and magnesium varied from 5 to 62, 2 to 200 and 0.3 to 75 kg/ha, respectively. Loadings of aluminum, silicon, sulfur and iron were similar and varied from traces to about 25 kg/ha. Loadings of antimony, arsenic, beryllium, bismuth, cadmium, cobalt, lead, silver and thallium varied from traces to about 1 to 10 g/ha whereas loadings of barium, boron, chromium, lithium, molybdenum, nickel, selenium, strontium, titanium, vanadium and tin varied from traces to about 50 to 300 g/ha. Loadings of copper, manganese and zinc varied from 0.04 to 4.4, 0.017 to 2.8 and 0.04 to 14 kg/ha, respectively. The very high loadings of some metals occurred from a relatively low percentage of samples and loadings of most metals was very low for most manures.

4.0 Assessment of potential soil accumulations of various elements with repeated applications of hog manure.

4.1 Number of potential applications based on CCME and Ontario Ministries' guidelines

To date, in Canada, there are no standards or guidelines set for acceptable loadings of certain elements when hog manures are applied to agricultural soils. There are, however, many different types of guidelines (such as for soil, water, biosolids and other wastes) that may be used to assess the effect of a build-up of various element(s) through the repeated application of liquid hog manures. The soil quality guidelines for agriculture, recommended by the Canadian Council of Ministers of the Environment (CCME), is one set of guidelines that can be used to identify elemental loadings that are potentially of concern. The guideline values presented by the CCME (1997) are for "clean down to levels" at contaminated sites and not "pollute up to levels"; thus, the values are used herein to identify the elements most likely to cause a problem with respect to soil quality. The values presented by the CCME for agricultural soils (The land use of agricultural land, defined by the CCME (1997), has the primary activity of growing crops or tending livestock and includes agricultural lands providing habitat for resident and transitory wildlife as well as native flora.) are derived from toxicological data (i.e. the lowest value for either the exposure from direct soil contact, or soil and food ingestion) and were specifically made for the protection of ecological receptors in the environment or for the protection of human health. The values presented by the CCME are similar to guidelines presented by the Ontario Ministries of Environment and Agriculture, Food and Rural Affairs (1996) for the utilization of biosolids and other wastes on agricultural land, and thus are presented and discussed together.

Table 11 displays the number of applications of hog manures required to increase elemental concentrations to soil remediation levels for several elements, using the guidelines presented by the CCME (1997) and Ontario Ministries (1996). Based on the data from the 145 hog manure samples, the loadings of Sb, As, Be, Bi, Cd, Ag and Tl are extremely small. As well, based on the available data from the CCME (1997) guidelines and background soil levels, it would appear that thousands of applications of hog manures would be required to potentially exceed the CCNIE guidelines for Sb, Ba, Be, Co, Pb, Ag and V. Similarly, hundreds of applications of hog manures would be required to potentially exceed the CCME guidelines for As, Cd, Cr, Ni, Se and Tl even at the highest content found in the samples. Thus, the loadings of Sb, As, Ba, Be, Bi, Cd, Cr, Co, Ni, Pb, Ag, TI and V from hog manures would be of little concern under most situations, and would not be the elements limiting the number of hog manure applications.

In contrast, the number of applications of manure would be restricted to about 74 for manure high in Mo, and to 36 applications for manures high in Sn (Table 11). The number of applications would be limited to only about 20 applications due to the maximum reported loadings of Cu and Zn. However, the mean and median loadings for Cu and Zn would only exceed the guidelines after 100 or more applications of manure.

CCME guideline values are not given for Al, Bi, Ca, Cl, Fe, Li Mg, Mn, P, K, Si, Sr, Na, S and Ti and therefore loadings of these elements in relation to CCME guidelines could not be assessed. It should be noted that elements such as Al, Ca, Mg, Fe, and Mn are soil structural elements, being part of soil constituents and are naturally present in soils at high concentrations. These elements, added in amounts present in the manures, are of no concern since they would be precipitated in soil and represent only a small fraction of the total amounts already in soils.

The information presented above indicated that in the short term, only B, Cu and Zn, if present at high concentrations in manures, would restrict the number of applications permitted. Loadings of most metals are very low and for most manures loadings can be continued for an extremely long period of time. It should also be noted that the above calculations were conducted without accounting for crop removal and other losses from soil. If crop removal was considered, loadings could be continued for longer periods of time for many of the metals.

It should be noted that the CCME guideline for boron is given as "hot water extractable boron" (Table 11) and could not be used to assess effects of B loadings on soil quality. However, the Ontario Ministries of Environment and Agriculture, Food and Rural Affairs (1996) have established a limit for boron addition to soils: 1 kg B/ha/yr for most crops that are B intolerant, and 2 kg B/ha/yr for crops that are B tolerant, when biosolids or other wastes are added to agricultural land. The data for B reported in Table 11 showed B loadings were between 0.011 and 0.203 kg B/ha, which are much less than the 1 kg B/ha limit set by the Ontario Ministries of Environment and Agriculture, Food and Rural Affairs.

Manures with high loadings of B, Cu and Zn can act as an excellent fertilizer source for these micronutrients on soils that are deficient in these elements. Thus, one should look for opportunities for recycling trace elements on soils that are deficient in these elements. To minimize the effects of Cu and Zn, as well as other heavy metals found in the manure, manures should be used on heavier textured soils with high pH (instead of acidic sandy soils) that would reduce the plant availability of the metals. Another method of reducing the amount of Cu and Zn, as well as other elements added to soils may be to reduce the amounts in the feed, especially in the nursery barns. Rotating manure applications among several fields, i.e. to apply manures once every four to five years to the same parcel of land, will also reduce the effects of inputs of Cu, Zn and B and ensure that a rapid "build-up" of these elements in soluble forms does not occur.

The Ontario Ministries (1996) also have guidelines for sodium (Na) since wastes from food processing can contain significant levels of Na, that may affect soil quality. Table 12 displays the guidelines for the maximum annual additions of Na. The maximum allowable annual additions for Na are much greater than the Na loadings of 5 to 67 kg Na/ha determined from the addition of 70 kg available N/ha of liquid hog manure. Thus, based on the Ontario guidelines, it does not appear that Na from hog manures will limit hog manure applications for most manures.

The annual maximum Na additions outlined in the Ontario Ministries guidelines, are however, relatively high and applications at these rates may pose soil structural problems on some Manitoba soils. The cation exchange capacity (C.E.C.) of soils in Manitoba varies from about 5 to 50 cmole/kg, depending on soil texture and organic matter content. Soils with 15% or more of the C.E.C. dominated by Na are considered to be sodic, and pose soil structural limitations and limitations to crop production. For some soils, soil structure may be impaired when 7 to 8% of the C.E.C. is dominated by Na. Thus, if for example a value of 5% of the C.E.C. is selected as an upper limit for Na content of C.E.C. then about 115 to 1150 kg Na/ha could be added to soils of C.E.C. of 5 to 50 cmole/kg, respectively. This calculation assumes there is no or very little Na on the C.E.C. initially and that no remediation of the soil occurs between or after application of manure. Remediation, i.e. leaching of Na from the surface soil and/or soil profile, will occur over time due to rainfall and thus maximum loading capacities could be higher than calculated herein. However, these calculations show that it would be prudent to limit Na application to some soils and that the Na content of soils should be monitored periodically for manures with a high sodium adsorption ratio (SAR) particularly if applied to soils of a medium texture and a low C.E.C. (such as Grey Wooded and Luvisolic soils).

4.2 Number of potential applications based on Alberta wastewater sludge guidelines

Alberta Environment (1982, 2000) developed a set of guidelines that are used for the application of municipal wastewater sludges to agricultural lands. The Alberta guidelines are somewhat different than the previous sets of guidelines in that they define three classes of land suitable for the application of wastewater sludges. Table 13 defines the number of applications of hog manures that would be required to reach maximum additions of selected metals and boron according to the guidelines of Alberta Environment.

Table 11. Calculation of number of hog manure applications to reach soil levels that may require soil remediation.

Element	Soil Median* (mg/kg)	CCME (mg/kg)	Ontario Ministry (mean) (mg/kg)	Difference# (mg/kg)	HOG MANURE LOADINGS** BASED ON 145 SAMPLES Maximum (mg/kg)	Minimum (mg/kg)	Mean (Weighted) (mg/kg)	Median (mg/kg)	NUMBER OF APPLICATIONS ## TO REACH GUIDELINE LIMIT Minimum	Maximum	Mean (Weighted)	Median
Aluminum					12.5297	0.0228	1.3706	0.5048				
Antimony	1	20		19	0.0021	0.0002	0.0006	0.0006	8892	124118	32788	33818
Arsenic	5.8	12	14.00	6.2	0.0065	0.0004	0.0016	0.0016	957	15328	3977	3960
Barium	500	750		250	0.1416	0.0015	0.0266	0.0117	1765	167604	9408	21456
Beryllium	0.3	4		3.7	0.0009	0.0000	0.0002	0.0001	3915	123686	22547	31444
Bismuth	0.2				0.0030	0.0003	0.0008	0.0009				
Boron	20	2		***	0.1043	0.0057	0.0312	0.0245				
Cadmium	0.1	1.4	1.60	1.3	0.0032	0.0001	0.0007	0.0004	401	25453	1935	2973
Calcium					102.5641	1.3928	15.8114	9.0339				
Chloride					72.5974	1.6571	17.2126	16.6192				
Chromium	46	64	120.00	18	0.0321	0.0001	0.0052	0.0028	561	120343	3465	6486
Cobalt	12	40	20.00	28	0.0069	0.0001	0.0009	0.0006	4033	456300	30674	48918
Copper	18	63	100.00	45	2.2700	0.0182	0.4908	0.2835	20	2466	92	159
Iron	19600				15.7162	0.0768	2.0265	0.9057				
Lead	15	70	60.00	55	0.0095	0.0002	0.0016	0.0010	5792	323282	33833	57455
Lithium					0.0205	0.0010	0.0045	0.0039				
Magnesium					38.5063	0.1369	8.3090	4.4808				
Manganese	572				1.4327	0.0088	0.2711	0.1555				
Molybdenum	3	5	4.00	2	0.0271	0.0002	0.0054	0.0038	74	11129	369	528
Nickel	21	50	32.00	29	0.0302	0.0007	0.0063	0.0044	961	41575	4620	6619
Phosphorus					88.1762	0.6393	12.7177	5.2477				
Potassium					62.6941	2.1853	24.4904	26.3358				
Selenium	0.4	2	1.60	1.6	0.0118	0.0005	0.0032	0.0026	136	3131	493	619
Silicon					14.5021	0.1090	2.2364	1.1068				
Silver	0.2	20		19.8	0.0004	0.0000	0.0001	0.0001	46332	517374	167870	169812
Strontium	250				0.1528	0.0032	0.0342	0.0222				
Sodium					34.3851	2.6368	8.0164	7.4665				
Sulfur		500			12.0311	0.5100	3.5780	2.6908				
Titanium	5000				0.2144	0.0010	0.0423	0.0216				
Thallium	0.2	1		0.8	0.0017	0.0002	0.0005	0.0005	468	5226	1733	1715
Vanadium	76	130		54	0.0529	0.0001	0.0073	0.0031	1021	407661	7426	17373
Tin	4	5		1	0.0281	0.0002	0.0041	0.0018	36	4620	245	561
Zinc	65	200	220.00	135	7.2668	0.0212	0.8894	0.4260	19	6366	152	317

Table 11. Calculation of number of hog manure applications to reach soil levels that may require soil remediation (continued).

* Soil median values for As, Cd, Cr, Co, Cu, Fe, Pb, Mn, Mo, Ni, Se, Ag, V and Zn are from Haluschak et al (1998). Soil Median values for all other elements are from Bowen (1979).

The Difference was calculated from the difference between the CCME (1997) Guideline Limit and the Soil Median. For chromium, the Difference was calculated from the difference between the Ontario Ministry (1996) Guideline and the Soil Median.

** Loadings were converted from g/ha (or kg/ha) to mg/kg, assuming the bulk density of the soil was 1300 kg/m3 and the resultant mass of soil to a depth of 15 cm was 1950 000 kg/ha.

The number of applications was determined from the Difference divided by the Maximum, Minimum, Mean and Median Loadings of the various elements.

*** The CCME (1997) guideline for boron is given as "hot water soluble B" and cannot be compared to totals presented for soil (Bowen 1979).

Table 12. Suggested annual sodium addition to Ontario soils* (Table from Ontario Ministries (1996)).

Soil Texture	Annual Maximum Sodium Addition (kg/ha)
Sands, Sandy loams	200
Organic soils, Loams, Clay loams, and Clays	500

*Annual additions may be doubled if all of the following criteria are met. The soils must be well drained, or tile drained, and applications of high Na waste will be permitted only if soil Na and soil electrical conductivity are monitored annually. Exchangeable Na in the soil must not be allowed to exceed 5% of the soil's cation exchange capacity. Soil conductivity, measured on a saturation extract, should not exceed 2.0 mS/cm or, if measured in a 2:1 water to soil suspension, should not exceed 0.45 mS/cm.

The maximum cumulative additions for B, Cd, Cr, Cu, Pb, Ni and Zn presented by Alberta Environment (Table 13) greatly exceed the potential loadings for these elements from one application of hog manure. According to the calculations in Table 13, the maximum loadings of B, Cu and Zn would limit the number of applications of hog manures. For B, the minimum number of applications would be restricted to 25 on the least suitable (Class 3) soil, due to the sample with the maximum B loading (203 g B/ha). For Cu, the minimum number of applications would be restrict restricted to 23 on the least suitable (Class 3) soil, due to the sample with the maximum Cu loading (4427 g Cu/ha). For Zn, the manure sample with the maximum loading (14 kg Zn/ha) would restrict the number of applications to 11 on the least suitable (class 3) soil. The data for Cd and Ni show that several hundred applications of hog manure would be required to exceed the maximum cumulative addition for Cd and Ni. Thousands of applications of hog manure would be required to exceed Cr and Pb loadings on the three classes of soil.

The minimum number of applications was calculated from one sample that had the highest possible loading for an element of the 145 hog manure samples, and thus represents the most extreme situation. The median number of applications represents the data from 50% of the 145 samples, and thus illustrates a more common occurrence. According to the calculations in Table 14, the median number of applications of hog manure on the third class of soil, would be restricted to 105 applications due to the accumulation of B. For both Cu and Zn, the median loadings would restrict the number of applications to 181 on the Class 3 soil. For the other elements, the maximum accumulations of Cd, Cr, Fe, and Ni would restrict the median applications to 938, 9239, 26786 and 1405, respectively.

The results obtained in the above comparison is similar to the results obtained when loadings were compared to CCME guidelines. In both comparisons, the elements of concern were B, Cu and Zn, and restricted mainly to manures that contained high concentrations of these elements.

4.3 Removal of various elements by crops

The foregoing analysis of possible lifetime loadings (total number of applications) of hog manure did not take into account the removal by crops of the elements. Therefore, another method of identifying if there will be a build up of an element in the soil, is to calculate the difference between the amounts added and the amounts removed by crops.

Table 15 displays the content of various elements, mostly trace elements, in the grain of wheat. The removals of phosphorus versus amounts applied in hog manure was discussed in a previous section. The removal of many of the elements listed is much less than the mean or median loadings, and thus a build-up of these elements would occur under most cropping situations. It should be noted, that research has shown that although several heavy metals tend to build up in the soil from application of sewage sludges or fertilizers, these metals are not mobile or plant available, and thus do not affect soil productivity and food quality if not added above guidelines.

Table 16 displays the removal of plant nutrients by some crops grown in Manitoba. For the majority of the harvested portions of the crops listed, the removals of S, Ca and Mg are close to the median loadings of these elements from hog manures. As well B removals closely match the median B loadings. Thus, under normal conditions and for a variety of crops, 50% of the potential loadings of S, Ca, Mg and B from hog manures would not build-up in the soil. The potential median loadings of Cl exceed the removal of CI by all crops, except for alfalfa which removes somewhat more C1 than the median loading. Alfalfa also appears to remove more Fe and Mn than the median loadings of Fe and Mn. Also, alfalfa appears to remove the highest amount of Zn of all crops. listed, but the removal is somewhat less than the median loading of Zn. Other crops only remove a small portion of the median loadings of Zn. Cu loadings also exceed the removal by all crops. These data indicate that the micronutrients added to the soil in hog manures will accumulate in soils, but may be useful to crops beyond the year of application.

Table 13. Calculation of number of hog manure applications to reach maximum additions of selected elements.

	MANITOBA HOG MANURE SAMPLES LOADINGS OF VARIOUS ELEMENTS (g/ha)				ALBERTA GUIDELINES MAXIMUM CUMULATIVE ADDITIONS SLUDGE-BORNE METALS (g/ha) FOR THREE SOIL CLASSES#			NUMBER OF APPLICATIONS## OF HOG MANURE TO REACH MAXIMUM LIMIT FOR SOIL TYPE		
	Maximum	Minimum	Mean (Weighted)	Median	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3
Aluminum	24432.88	44.48	2672.60	984.44						
Antimony	4.17	0.30	1.13	1.10						
Arsenic	12.63	0.79	3.04	3.05						
Barium	276.16	2.91	51.82	22.72						
Beryllium	1.84	0.06	0.32	0.23						
Bismuth	5.83	0.52	1.62	1.75						
Boron**	203.29	11.05	60.76	47.83	10000.00	7500.00	5000.00	49-905 (209)	37-679 (157)	25-452 (105)
Cadmium	6.33	0.10	1.31	0.85	1500.00	1100.00	800.00	237 - 15000 (1759)	174-11000 (1290)	126-8000 (938)
Calcium	200000.00	2715.90	30832.18	17616.13						
Chloride	141566.00	3231.28	33564.62	32407.41						
Chromium	62.52	0.29	10.13	5.41	100000.00	75000.00	50000.00	1599-344828 (18478)	1200-258621 (13858)	800-172414 (9239)
Cobalt	13.54	0.12	1.78	1.12						
Copper	4426.57	35.58	957.05	552.84	200000.00	150000.00	100000.00	45-5621 (362)	34-4216 (271)	23-2811 (181)
Iron	30646.58	149.67	3951.59	1766.21						
Lead	18.52	0.33	3.17	1.87	100000.00	75000.00	50000.00	5400-303030 (53571)	4050-227273 (40179)	2700-151515 (26786)
Lithium	39.89	1.86	8.78	7.53						
Magnesium	75087.32	266.88	16202.56	8737.48						
Manganese	2793.69	17.17	528.73	303.21						
Molybdenum	52.91	0.35	10.58	7.39						
Nickel	58.82	1.36	12.24	8.54	25000.00	19000.00	12000.00	425-18382 (2926)	323-13971 (2224)	204-8824 (1405)
Phosphorus	171943.66	1246.70	24799.53	10233.02						
Potassium	122253.52	4261.31	47756.23	51354.88						
Selenium	22.97	1.00	6.33	5.04						
Silicon	28279.07	212.60	4360.94	2158.27						
Silver	0.83	0.07	0.23	0.23						
Strontium	297.98	6.18	66.63	43.34						
Sodium	67051.00	5141.85	15631.99	14359.73						
Sulfur	23460.67	994.58	6977.03	5247.13						
Titanium	418.08	1.86	82.50	42.03						
Thallium	3.33	0.30	0.90	0.91						
Vanadium	103.18	0.26	14.18	6.06						
Tin	54.83	0.42	7.95	3.48						
Zinc	14170.25	41.35	1734.42	830.76	300000.00	200000.00	150000.00	21-7255 (361)	14-4837 (241)	11-3628 (181)

Table 14. Calculation of number of hog manure applications to reach maximum additions of selected metals (continued).

The Alberta Guidelines for the Application of Municipal Wastewater Sludges to Agricultural Lands (2000) identify three acceptable classes of land for the application of sludges according to the table:

	Class 1	Class 2	Class 3
pH	>6.5	≥ 6.5	≥ 6.5
Soil Texture	CL, SiCL, SiL, Si, SiC, L, SCL, SC	C, HC	LS, SL
Slope (%)	0-2	2-5	5-9
Depth to Potable Aquifer (m)	>5	3-5	2-3

** The Alberta Guidelines for the Application of Municipal Wastewater Sludges to Agricultural Lands (2000) did not include boron. The previous set of Alberta Guidelines (1982) provided a value for boron.

The number of applications within a class of land is a range - the first number in the range (i.e. the minimum number of applications) is calculated from the maximum loading value and the second number (i.e. the maximum number of applications) is calculated from the minimum loading value. The number in parenthesis represents the number of applications calculated from the median loading.

Loadings of total potassium varied between 4.26 and 122.26 kg K/ha, with the majority of the samples potentially supplying between 25 and 75 kg K/ha. The mean loading of K for all of the samples was about 48 kg Kfha. The median K loadings of the samples were close to the mean K loadings for all the barns. Since the loadings of K were high, up to 122 kg K/ha, the loadings of K would greatly exceed the removal of K in the grain of cereal and oilseed crops. Only crops such as alfalfa and corn, harvested for forage or silage, would remove sufficient K to prevent the build up of exchangeable K in soils under most circumstances. Extremely high levels of exchangeable K in soil leads to high levels of K in the vegetative portions of plants. High levels of K in forage increases the incidence of milk fever and grass tetany in cows. Thus crop rotations and manure application have to be managed so that K levels in soils are maintained at levels which do not result in excess K levels in forage.

5.0 Summary

Hog manures can serve as an effective and environmentally sound fertilizer provided that loadings are consistent with crop uptake for elements and/or within acceptable guidelines for soil quality. Hog manures were extremely variable in composition, varying with type of hog operation, ration, type of storage facility, etc. Each manure sample was unique in its composition indicating that the composition of manures can only be accurately assessed by analysis. Producers should obtain routine, frequent analysis of manures for constituents such as nitrogen and phosphorus to ensure uniform and desired rates of application to land. Producers should also obtain analysis of a few samples for a large number of constituents to calculate loadings of various metals and assess whether or not a build up of elements will occur in soils. The effect of build-up of elements on soils quality and productivity and environmental quality should then be assessed on a site-specific basis. Cropping systems affect nutrient removals and thus build-up of elements. Also the effects of metals and other constituents on soil productivity and environmental quality is a function of soil type. Thus, the effect of build-up of elements on soil quality and productivity and environmental quality can only be accurately assessed on a site-specific basis considering cropping systems, soil type and surficial geology. Manures, exceptionally high in particular constituents (such as zinc, copper, boron, phosphorus), will require special management practices for long-term sustainability.

Table 15. Typical concentrations of various elements in wheat grain grown on the Canadian prairies and amounts removed by an average crop of wheat yielding 2500 kg/ha.

CONTENT OF WHEAT GRAIN	Concentration (mg/kg)			Yield = 2500 kg/ha**	Removal (g/ha)			Loadings Based on Manure Samples***	Additions (g/ha)			
	Mean	Min.	Max.		Mean	Min.	Max.		(Weighted) Mean	Median	Min.	Max.
Al	5.4			**Al**	13.50			**Al**	2672.60	984.44	44.48	24432.88
As		0.01	0.05	**As**		0.03	0.13	***As***	*3.04*	*3.05*	*0.79*	*12.63*
B	2.03			**B**	5.08			**B**	60.76	47.83	11.05	203.29
Ca	700			**Ca**	1750.00			**Ca**	30832.18	17616.13	2715.89	200000.00
Cd	0.056	0.015	0.08	**Cd**	0.14	0.04	0.20	***Cd***	*1.31*	*0.85*	*0.10*	*6.33*
Cl	700			**Cl**	1750.00			**Cl**	33564.62	32407.41	3231.00	141566.00
Co	0.02	0.005	0.01	**Co**	0.05	0.01	0.03	***Co***	*1.78*	*1.12*	*0.12*	*13.54*
Cr		0.016	0.37	**Cr**		0.04	0.93	***Cr***	*10.13*	*5.41*	*0.29*	*62.52*
Cu	4	2	7	**Cu**	10.00	5.00	17.50	**Cu**	957.05	552.84	35.58	4426.57
Fe	52	31	35	**Fe**	130.00	77.50	87.50	**Fe**	3951.59	1766.21	149.67	30646.58
Hg		0.006	0.03			0.02	0.08					
K	4500			**K**	11250.00			**K**	47756.23	51354.88	4261.31	122253.52
Mg	1600			**Mg**	4000.00			**Mg**	16202.56	8737.48	266.88	75087.32
Mn	24	19	29	**Mn**	60.00	47.50	72.50	**Mn**	528.73	303.21	17.17	2793.69
Mo	0.6	0.2	0.8	**Mo**	1.50	0.50	2.00	***Mo***	*10.58*	*7.39*	*0.35*	*52.91*
N	28070			**N**	70175.00			**N**	70000	70000	70000	70000
Na	100.00			**Na**	250.00			**Na**	15631.99	14559.73	5141.85	67051.00
Ni		0.05	0.4	**Ni**		0.13	1.00	**Ni**	12.24	8.54	1.36	58.82
P	3900			**P**	9750.00			**P**	24799.53	10233.02	1246.70	171943.66
Pb	0.035	0.01	0.04	**Pb**	0.09	0.03	0.10	***Pb***	*3.17*	*1.87*	*0.33*	*18.52*
S	1800			**S**	4500.00			**S**	6977.03	5247.13	994.58	23460.67
Se		0.1	1	**Se**		0.25	2.50	***Se***	*6.33*	*5.04*	*1.00*	*22.97*
Tl		0.02	0.08	**Tl**		0.05	0.20	**Tl**	0.90	0.91	0.30	3.33
V	0.08			**V**	0.20			***V***	*14.18*	*6.06*	*0.26*	*103.18*
Zn	41	22	100	**Zn**	102.50	55.00	250.00	***Zn***	1734.42	830.76	41.35	14170.25

* Data was combined from four sources (Norwest Labs, Winnipeg, MB; Canadian Grain Commission, Winnipeg, MB; Dilk, unpublished data: Merian (1991)).

** Wheat yield in 1999 was 2500 kg/ha (Statistics Canada 1999-2000 Summary of major crop production).

*** Elemental loadings that are italicized contain loading data that assumed non-detectable values were equal to the detection limit values.

Table 16. Nutrients removed in typical Manitoba Crops (kg/ha).

Crop and Yield	Crop Portion	N	P	K	S	Ca	Mg	Cl	B	Cu	Fe	Mn	Zn
		Nutrient removal (kg/ha)											
Spring Wheat 40 bu/ac	seed	67	11	16	4	-	-	4.5	0.04	<0.11	0.34	0.15	0.15
	straw	28	3	52	6			1.3	0.01	<0.11	0.11	0.22	0.08
	Total	95	14	78	10								
Barley 80 bu/ac	seed	87	17	23	8	2	4	9.0	0.11	<0.11	0.34	0.11	0.11
	straw	31	4	63	6	17	10	1.1	0.02	<0.11	0.01	0.78	0.11
	Total	119	21	86	13	19	15	10.1					
Oats 100 bu/ac	seed	68	13	17	6	3	4	1.1		<0.11	1.12	0.22	0.11
	straw	50	7	118	9	10	18	1.1		<0.11	0.22	0.22	0.45
	Total	119	20	135	15	13	22	2.2					
Corn 100 bu/ac	seed	109	21	26	8	1	10	1.5	0.56	<0.11	0.15	0.78	0.15
	stover	63	9	94	9	36	12	0.8	0.04	<0.11	0.78	1.23	0.22
	Total	171	30	120	17	37	22	2.2					
6t/ac	silage	175	30	188	15	37	22						
Canola 35 bu/ac	seed	76	20	20	13	10	12	-	1.01	-	-	-	-
	straw	49	8	67	11	-	-						
	Total	125	28	87	25								
Flax 24 bu/ac	seed	57	8	14	6	-	-	-	-	-	-	-	-
	straw	16	2	18	7	-	-						
	Total	73	10	32	12								
Sunflwr 2000 lb/ac	seed	59	8	11	4	-	-	-	0.16	-	-	-	-
	straw	24	5	23	4	-	-						
	Total	83	13	34	9								
Peas 50 bu/ac	seed	131	17	32	8	-	32	-	0.08	<0.11	0.78	0.56	0.11
	straw	40	4	95	7	-	-						
	Total	171	21	127	15								
Potatoes 300 cwt/ac	tubers	108	14	150	10	4	9	22.4	0.06	<0.11	0.78	0.17	0.11
	vines	84	11	57	6		25						
	Total	192	25	207	16		34						
Alfalfa 4 ton/ac	Total	258	27	223	27	138	30	47.0	0.78	0.27	2.24	0.90	0.67
Grass hay 3 ton/ac	Total	115	15	121	15	72	18	-	-	-	-	-	-

Loadings Based on Hog Manure Samples (kg/ha)

	N	P	K	S	Ca	Mg	Cl	B	Cu	Fe	Mn	Zn
Maximum	70	112	122	23	200	75	141.6	0.20	4.43	30.65	2.79	14.17
Minimum	70	2.2	4.3	1.0	2.7	0.3	3.2	0.01	0.04	0.15	0.02	0.04
Mean (Weighted)	70	27	48	7	31	16	33.6	0.06	0.96	3.95	0.53	1.73
Median	70	16	51	5	18	9	32.4	0.05	0.55	1.77	0.30	0.83

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