Impacts of Winter Spreading of Manure on Water Quality - Literature Review

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June 2000

UNIVERSITY of GUELPH

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Background

Spreading livestock manure in the winter has been a common practice in Ontario for many years. For the farmer, there are several advantages, including: a) ability to build smaller manure storages; b) ability to spread the manure at a time when there is less pressure to get to the crop in the ground; c) spreading manure on frozen ground may help to reduce soil compaction. Despite these practical reasons for spreading manure in the winter, the concern about impacts on water quality has lead to a general acceptance that spreading manure in the winter is no longer environmentally acceptable.

Depending on the condition of the soil, runoff can potentially carry manure nutrients and bacteria to nearby surface waters. It is widely believed that frozen or snow-covered soils allow less infiltration than non-frozen bare soils. This is the main reason why policies within Canada recommend avoiding the winter spreading of manure.

The objectives of this literature review are:

1. to provide a brief overview of some of the policies in Canada concerning the winter spreading of manure; and
2. to review North American research that examines the implications of spreading manure in the winter.

Canadian Recommendations and Policies

Most provinces in Canada recommend avoiding the application of manure on frozen or snow-covered ground. The policies for selected provinces are summarized in Table 1. Provinces not listed generally have recommendations similar to those outlined below. The guidelines tend to be fairly general and rely mainly on the common sense of the manure applicator.

Table 1 - Summary of selected provincial policies dealing with winter-spreading of manure

Province	**Type**	**Summary**
Prince Edward Island	guidelines	If it is necessary to spread manure in the winter, i) it should only be applied when the potential for surface runoff is minimal; ii) it be applied to stubble fields with good trash cover; and iii) the distance from watercourses and wells be increased (PEI government 2000).
Ontario	guidelines for manure; regulations for sewage biosolids	Manure should "not be spread on frozen or ice covered soil". It is acceptable to spread manure when there is snow on the ground only when the ground is not frozen. The government acknowledges that slope influences nutrient movement over a surface: they indicate that manure may be spread on frozen ground providing the field has a sustained slope of 3% or less. These recommendations also govern the use of sewage biosolids on agricultural land (Ministry of the Environment and Energy, and Ministry of Agriculture, Food and Rural Affairs 1996). Manure should only be applied in emergency situations (during those months when the land is frozen, bare or snow-covered) onto grass winter cover crops or onto fields with high crop residue where there is no danger of run-off or floods (OMAFRA and AAFC 1992).
Manitoba	regulations	Large-scale livestock operations are prohibited from spreading manure between November 10 and April 15. A large operation is defined as any livestock operation having more than 400 animal units of a given livestock type. Smaller-scale operations do not have to comply with this regulation, although they are still responsible for meeting minimum setback distance requirements from sensitive areas such as watercourses, wells, sinkholes and springs (Manitoba Agriculture and Food 2000).
Quebec	regulations	Manure spreading is prohibited between October 1 and March 31, and any other time when the ground is either frozen or snow covered. The October 1 date may be delayed if conditions permit (Quebec Ministry of the Environment 2000).

Research on Winter-Spreading of Manure

A - Winter-Spreading Studies

A number of studies have been conducted over the past several years to examine this issue. Table 2 contains a summary of the various projects. It distinguishes whether each study was small- or large-scale, the location of the study, duration of the study, manure type, and other pertinent information. Following is a brief description of each study, listed in chronological order:

1. Midgley and Dunklee (1945) carried out an extensive study (begun in 1935) in Vermont using fresh dairy manure. The field investigations were carried out at three different sites, having fairly steep slopes (i.e. 8, 10, and 20%). Manure was spread onto frozen, snow-covered ground in late December or early January. They found that all frozen soils were impervious to water, and considerable runoff therefore occurred when the soil was frozen. Steepness of slope had relatively little impact on runoff losses. Spreading manure on frozen ground resulted in large losses of N (nitrogen) in the runoff. In addition to the runoff losses, volatilization of ammonia was also considered to contribute to large N losses from the manure.

2. Hensler et al. (1970) spread fresh dairy manure onto field-scale plots. They found that runoff losses from manure applied to frozen ground were variable. During the first year of observation, they noted significant losses of N and P (phosphorus) in the runoff. They attributed these losses to a 2 cm rain that fell within 24 hours after manure application. During the subsequent year, there was very little precipitation throughout the winter months. This resulted in minimal nutrient losses in runoff. Over the two-year study, average runoff losses of N, P, and K were 10%, 6%, and 8%, respectively.

3. Converse et al. (1976) compared the nutrient run-off from fall, winter and spring treatments of solid dairy manure on ten different plots. They observed no significant difference in nutrient losses between seasonal treatments over the three year study period. However, they did find that the amount of nutrients lost varied directly with the volume of runoff. The following observations were made regarding runoff volume: 1) winter- and spring-manured plots had more runoff volume than fall-manured plots; and 2) the check plots had more runoff volume than all manured plots. These differences were attributed to variations in infiltration rates. The infiltration rates appeared to be influenced by number of earthworms present and by grass and mulch cover.

4. Klausner et al (1976) found that application rate and weather conditions played a large role in determining the amount of nutrients lost in runoff from winter-applied manure. Dairy manure was applied on frozen ground at three spreading rates for three consecutive winters. Excessive nutrient losses were seen when manure spreading occurred during active thaw periods. Minimal nutrient losses were seen when manure was applied (application rate: 35 tonnes/ha) and covered with snow, which melted at a later date. These minimal losses were comparable to the nutrient losses of plots receiving no manure.

5. In a Minnesota study, Young and Mutchler (1976) examined the effects of different

manure application times. Solid dairy manure was either applied: a) in the fall and plowed under, b) in the fall on frozen ground or c) in the spring on top of snow. Fields were plowed "up and down" the slope to represent the most severe erosion and runoff averages. The slope of the plots averaged 9%. Plots were covered with either fall-plowed corn, new alfalfa, or old alfalfa crops. The combination that created the most serious pollution potential was: manure applied onto frozen ground having alfalfa cover - up to 20% of the manure-N was lost in the spring runoff. They attributed this to two factors: 1) the plots with alfalfa provided a less rugged surface with which to slow the movement of water; and 2) the alfalfa plots remained frozen longer in the spring, thus allowing less infiltration time and more runoff for a prolonged period of time. This study pointed out the importance of measuring concentrations, as well as total volumes of runoff. The concentration of nutrients in the runoff from manured plots was much higher than that from the check plots. However, the total losses of nutrients was not much greater, because the total runoff volume was less. The researchers noted that spreading manure on top of snow, rather than before a snowfall, resulted in less soil, water and nutrient losses.

6. Young and Holt (1977) conducted an experiment based on the design of Young and Mutchler (1976). Using the same plots, solid dairy manure was again applied. They confirmed that winter-applied manure can appreciably reduce soil loss and reduce runoff and nutrient loss on plowed ground when compared to un-manured plots. Soil loss decreased because the manure acted as a mulch on the soil surface – absorbing the impact of raindrops and reducing the volume of the surface runoff. They also found that total nutrient and runoff losses were consistently less in the manured corn compared to the un-manured corn.

7. Phillips et al. (1981) conducted a six-year study aimed at finding the effects of rate and timing of manure application on nutrient loading of surface and subsurface water and on crop yields. They spread liquid dairy manure in the spring, fall and winter on a series of field plots. Winter-spreading resulted in considerably higher concentrations of N, P, and K in runoff, compared to spring and fall applications. The higher the rate of winter application, the higher the concentration of nutrients in the runoff. They concluded that manure application to areas that contribute snow-melt directly to surface water should be avoided.

8. Steenhuis et al. (1981) determined through laboratory and field experiments in Wisconsin that solid dairy manure spread on frozen ground (no snow cover) did not necessarily lead to a loss of N because not all frozen soils are impermeable. They found permeability varied with the temperature of the soil as well as the extent that pores were blocked by ice. Therefore, under some conditions, applying manure onto frozen ground may pose no more threat of contamination than fall-applied manure. They also found that the first meltwater had the highest concentration of N. It is this first meltwater after spreading that largely determines the fate of manure nitrogen. If the water infiltrates, there will be very little loss of N. However, if the water runs off, the losses will be high.

Table 2 – Summary of the main details of winter-spreading studies

Authors	Duration of Study	Location	Type of Study	# of Plots	Plot Size (m)	Soil Type	Manure Type	Slope (%)	Cover	Tillage
Midgley and Dunklee (1945)	3 to 6 yrs	Vermont	field and lab	N/A	92 m^2		fresh dairy manure	8, 10, 20		
				6			fresh dairy manure	slight		
Hensler et al. (1970)	2 yrs	Wisconsin	field	4	N/A	silt loam	fresh dairy manure	11	none	plowed on the contour
Converse et al. (1976)	3 yrs	Wisconsin	field	10	3 x 13.2	silt loam	solid dairy manure	10 – 12	alfalfa-grass mixture	N/A
Klausner et al. (1976)	3 yrs	New York	field	8	61 x 53.3	silt loam	dairy manure	2	corn trash	N/A
Young and Mutchler (1976)	3 yrs	Minnesota	field	8	4.06 x 23.35	N/A	solid dairy manure	9	4-corn, 2-new alfalfa with oat cover crop, 2- 6yr old alfalfa	corn-fall plowed
Young and Holt (1977)	3 yrs	Minnesota	field						tilled corn	up and down slope
Philips et al. (1981)	6 yrs	Ontario	field	14	75.6 x 11.6	sandy clay loam	liquid dairy	0.8	corn stubble	none
Steenhuis et al. (1981)	1 yr	Wisconsin	field	8	13 x 3	silt loam	solid dairy manure	10 – 12	none	plowed
			lab	4	N/A	2.5 cm sheet of polystyrene	solid dairy manure	2 or 12	none	
Lorimor and Melvin (1996)	2 yrs	Iowa	field	24	3.8 x 22	silt loam	liquid swine manure	2.9	12-short bean, 12-long corn stubble	
Qu et al. (1996)	—	Alberta	lab	16 (trials)	N/A	N/A	dairy manure, compost	0.4	none	
Blais and Weil (1999)	2 yrs	Ontario	field	12	N/A	clay	liquid	level	N/A	N/A

9. Lorimor and Melvin (1996) investigated N losses in snowmelt runoff from winter-applied liquid swine manure. Manure was applied on bean stubble (12 plots) and corn stalks (12 plots) over a two year period. They examined runoff from fall-incorporated manure, early winter broadcast manure on frozen soil, late-winter broadcast manure on top of snow, and spring broadcast manure. Runoff N losses were measured and expressed as a percentage of the manure-N applied. They found that, generally, there was no significant difference between treatments - with the exception of one "catastrophic" event. Average runoff losses of N (% of manure-N applied) were: fall-incorporated - 1.5; early winter broadcast - 1.4; late-winter broadcast - 10.3; and spring broadcast - 0.6. A "catastrophic" event occurred when there was a snow-melt two days after a winter application of manure. In this case, the runoff loss was 17.4% of manure-N applied. Because of the risk of high nutrient losses, they advised against applying manure in the winter altogether.

Lorimor and Melvin (1996) also found that the type of winter cover crop affected the amount of nutrients lost in runoff. Because there was a higher accumulation of snow in the taller corn stubble compared to the shorter bean stubble, the resulting volume of water lost from the corn was larger. As a result, more nutrients were carried away in the runoff from the corn stubble than from the bean stubble. Lorimor and Melvin advised that if manure must be applied in the winter, it should be applied early so as to minimize the risk of snow-melt occurring. For late-winter application, they recommended waiting until after snowmelt, when most runoff had already occurred.

10. In a lab-scale experiment, Qu et al. (1996) found that the pollution potential of snow-melt runoff from composted manure applied on top of snow was significantly lower than the pollution potential from fresh manure.

11. A recently-completed study at Alfred College – University of Guelph measured the water quality implications of liquid manure applications on a level clay soil. Manure was applied in the late fall on frozen ground, and in the spring on unfrozen ground. Preliminary results indicated that, for these soil and weather conditions, neither late fall application nor spring application caused significant N contamination of surface runoff or subsurface drainage water (Blais and Weil, 1999).

B - Pathogens

Manure contains bacteria and protozoa such as fecal coliforms, like *Escherichia coli* (*E.coli*), and *Cryptosporidium parvum*, that can cause severe gastrointestinal illness in humans. The maximum allowable concentration of *E.coli* colonies in drinking water is zero. Water is deemed unsafe for swimming if the *E.coli* levels exceeds 100 colonies per 100 mL of water (Ontario Ministry of the Environment 1984).

The survival rate of *E. coli* in manure was studied by Tamasi (1981). The results indicated that survival is greater in cooler conditions (8^{o}C) compared to warmer conditions (20^{o}C). However, freezing conditions were not considered.

Freezing conditions were considered in studies by both Stoddard et al. (1998) and Kibbey

et al. (1978). Both studies found that manure applied in freezing conditions had a higher mortality rate of fecal coliform than spring-applied manure; and that freezing conditions are usually lethal to fecal bacteria.

Cryptosporidium parvum is a protozoan parasite that is transported through the fecal-oral route in the form of oocycts. Though infective doses vary, as few as 10 oocysts can establish an infection. An infection can be lethal if the host is immunocompromised, such as an AIDS victim or a chemotherapy patient (Carrington 1995). Olson (1999) found that the most favourable conditions for *Cryptosporidium* oocyst survival were at temperatures between -4^{o} and 4^{o}C in feces and water, whereas the least favourable conditions were at 25^{o} C. In another study, Carrington and Ransome (1994) found that winter and spring stream water conditions were favourable for oocyst survival. Both of these studies illustrate that winter-spreading of manure does not guarantee oocyst die-off.

Overall, very little literature focussed on how temperature affects the survivability of pathogens following land application of manure.

C - Models

Mathematical modelling of manure application to snow-covered fields, confirmed by both lab and field studies, determined that particulate losses were minimal in snow melt, but the loss of organic nitrogen, ammonium and potassium were related to the melt rate (Steenhuis et al 1980)

D - Air Quality

While it was not the focus of this study, ammonia losses to the atmosphere are also an environmental concern. Steenhuis et al. (1979) determined that the rate of volatilization of ammonia from manure was diminished if the manure was spread in the winter. This was because of decreased wind speeds and temperature during the winter months. Lauer et al. (1976) found that when liquid dairy manure was spread onto snow and subsequently covered by a blanket of snow, the potential for ammonia volatilization was reduced to zero. Midgley and Dunklee (1945) found that even though N runoff losses were high for winter-spread manure, volatilization of N accounted for a higher proportion of the total N lost from manure (mainly due to the fact that volatilization starts as soon as the manure is produced).

E - Climate

All of the studies cited in this report have been carried out in areas where a typical winter involves a significant amount of snow cover. Several of the studies have pointed out the importance of weather conditions and snow cover on the potential for manure runoff following winter spreading. There are differences, however, from year to year for any given region, and from area to area within a state or province. Identifying areas of highest risk of runoff could involve using accurate climate data. An example of the type of mapping that is available to assist with this is included as Figure 1. It shows the average annual number of days with more than 5 cm of snow cover. Even within Southern Ontario, there is a considerable range of values. For example, Essex has typically less than 30 days, while Pembroke has greater than 120 days.

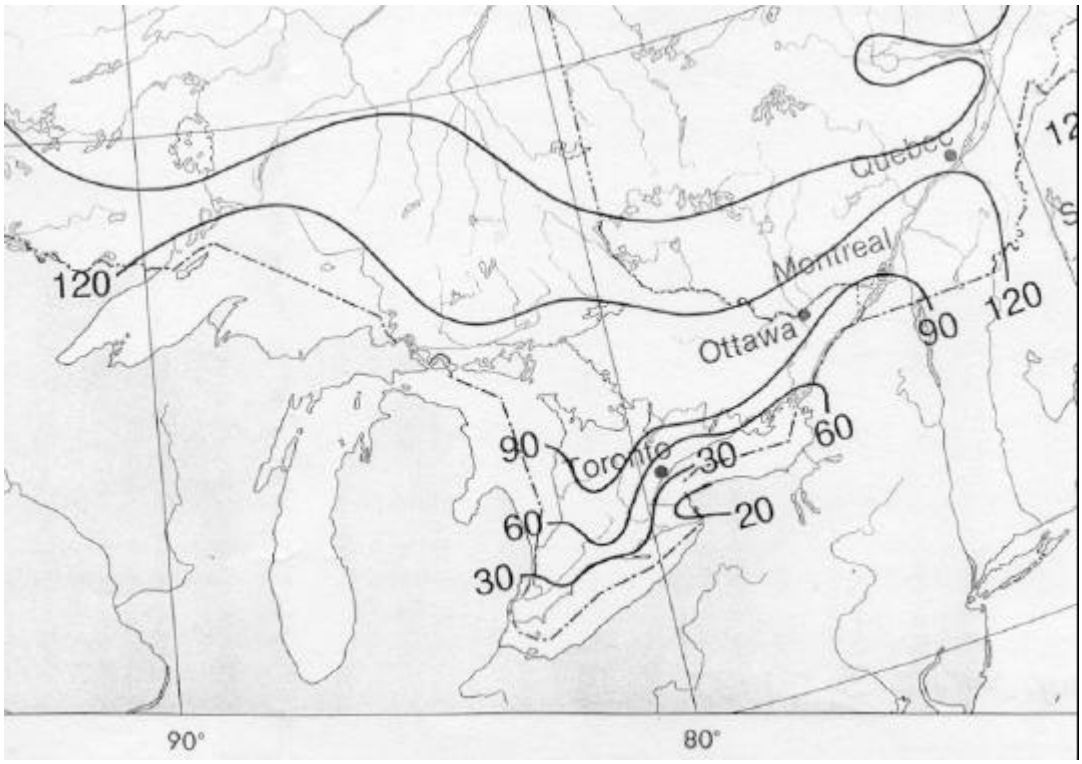

Figure 1 Mean annual number of days with more than 5 cm of snow on the ground - showing Southern Ontario (1951 to 1980) excerpted from: Climatic Atlas of Canada (Environment Canada 1987)

Summary

Of the several studies summarized in this report, it appears that there are similarities in the findings, and there are some conflicts. The following points appear to be generally true:

- Nitrogen lost in runoff following winter manure spreading can vary from negligible levels to upwards of 20% of the manure-N applied.
- The amounts of nutrients lost in runoff following winter application of manure are usually greater than from manure spread in other seasons, though this is not always the case.
- Many (not all) frozen soils are virtually impervious - there is a high likelihood that snowmelt and rainfall on manure-covered frozen ground will result in the runoff of manure constituents.
- The fate of the first meltwater or rainfall following winter manure spreading will usually determine the amount of manure runoff - if it soaks into the ground, the runoff amount will be relatively small - if the ground is frozen, the runoff amount can be relatively high.
- The risk of manure runoff appears to be similar, whether the manure is spread on frozen bare ground or on snow-covered ground.
- Spreading manure onto a cover crop in the winter does not necessarily reduce the risk of runoff.

- Spreading solid manure in the winter can actually reduce the amount of runoff and of soil erosion. It forms a mulch on the soil surface that slows down the flow of water.
- For the single study that looked at the influence of slope on manure runoff, it appeared that there was little difference for slopes of 10% and 20%. No information is available on the impact of lower slopes.
- Spreading manure in the winter provides no guarantee of pathogen die-off, though freezing conditions are usually lethal to fecal bacteria.
- The rate of volatilization of ammonia from manure is diminished for winter-spread manure, especially if the manure is covered by snow.

Recommendations

One of the goals of this literature review was to outline the various risk factors associated with winter-spreading of manure. However, the single greatest impact is "weather". Since this is a factor that is out of the control of the farmer and cannot be accurately predicted, the risk of runoff from winter-spread manure will be low some years and high in other years. Climate records may help to identify those areas where the risks are highest, though there are not likely any areas of the province where the risks are acceptable. The current Canadian standards and Best Management Practices appear to be quite reasonable and should be followed.

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