Quality of runoff water from fresh and composted manure spread on snow

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Qu, G., Leonard, J.J. and Feddes, J.J.R. 1999. **Quality of runoff water from fresh and composted manure spread on snow**. Can. Agric. Eng. **41**:099-104. An experiment was conducted to compare the quality of snow-melt runoff from fresh or composted manure that had been spread on snow. Sixteen sheet metal trays held a layer of snow and either frozen composted or fresh manure. Each tray measured 400mm x 400mm x 100mm deep and had two holes to collect runoff from the surface and bottom of the tray. Trays were mounted on racks at a slope of 20° and insulated with rigid polystyrene. Total depth of compacted snow in the trays was about 90 mm (6 kg). Composted and fresh manure was spread to give nutrient loading rates in accordance with available manure management guidelines. A factorial experimental design was used with two materials, four arrangements of snow with composted or fresh manure, two collection openings, two collecting periods, and two replicates of each. Trays were placed in a temperature-controlled room to simulate a natural freeze-thaw cycle. Daily temperatures were set at 8°C for 10 hours and -5°C for 14 hours. Runoff from the snow surface and from the bottom of trays was collected and analyzed for soluble carbon, total nitrogen, and BOD_5. The mean BOD_5 level of runoff from composted manure was 45.0 mg/L compared with 1834 mg/L from unprocessed manure. The snow-material sequence, representing application season, had a significant effect on all analysis parameters from runoff of fresh manure, but no effect on runoff quality of composted manure. Although there were no significant differences between BOD_5 levels of early and late runoff for both fresh and composted manure and total nitrogen for composted manure, nitrogen, and soluble carbon levels from fresh manure and soluble carbon from composted manure were significantly higher in the early runoff. The mean BOD_5 level and the concentrations of soluble carbon from runoff of fresh manure collected from upper opening locations were significantly higher than those from lower ones.

Une expérience a été effectuée pour comparer la qualité de l'écoulement des eaux de fonte provenant de fumier frais ou composté de la neige. Seize bacs de tôle ont été remplis d'une couche de neige et de fumier frais ou de compost gelé. Chaque bac mesurait 400 mm de côté sur 100 mm de profondeur et était doté de deux trous destinés à recueillir le ruissellement de la surface et du fond du bac. Les bacs étaient montés sur des supports inclinés à un angle de 20 ° et garnis d'un isolant rigide de polystyrène. La profondeur totale de la neige compactée dans les bacs était d'environ 90 mm (6 kg). Le fumier frais et de compost avait été étalé conformément aux lignes directrices actuelles sur les taux d'épandage visant à optimiser l'utilisation des éléments nutritifs. Un plan d'expérience factorielle a été utilisé avec deux matériaux, quatre arrangements de neige et de fumier frais ou de compost, deux ouvertures de collecte, deux périodes de collecte et deux répétitions de chaque. Les bacs ont été placés dans une pièce à température contrôlée pour simuler un cycle gel-dégel normal. Les températures quotidiennes étaient fixées à 8 °C pendant 10 heures et à -5 °C pendant 14 heures. Le ruissellement provenant de la surface de la neige et du fond des bacs a été recueilli et analysé pour déterminer la teneur en carbone soluble, l'azote total et la demande biologique en oxygène (DBO_5). La DBO_5 moyenne de l'écoulement provenant du fumier de compost était de 45,0 mg/L comparée à 1834 mg pour le fumier à l'état brut. La séquence neige-matériau, représentant la saison d'application, a eu un impact important sur tous les paramètres de l'analyse de l'écoulement provenant du fumier frais, mais aucune incidence sur la qualité de l'écoulement venant du fumier de compost. Bien qu'il n'y ait aucune différence significative entre les niveaux de DBO_5 des eaux de ruissellement recueillies au début et plus tard, et provenant de fumier frais et de compost, et l'azote total pour le fumier de compost, les taux d'azote et de carbone soluble provenant du fumier frais et le carbone soluble provenant du fumier de compost était sensiblement plus élevés au début du ruissellement. La DBO_5 moyenne et les concentrations de carbone soluble de l'eau de ruissellement du fumier frais recueillie par les ouvertures supérieures étaient grandement supérieures à celle provenant des ouvertures inférieures.

INTRODUCTION

Animal manure is a valuable resource in maintaining the fertility and productivity of agricultural soils. However, the rapid and large-scale increase in intensive animal production has created problems related both to protection of water resources and to the utilization of manure as a nutrient source (Edwards and Daniel 1994). In 1991, the populations of cattle and pigs in Alberta were 4.8 million and 1.7 million (Statistics Canada 1993), respectively. Together, these cattle and pigs would have produced over 50 million tonnes of manure per year containing approximately 200,000 tonnes of nitrogen. Animal manure cannot be spread on frozen ground directly because the snow melt runoff that contains manure components such as nitrogen, phosphorus, soluble carbon, and microorganism may degrade the quality of ground and surface water (Young and Mutchler 1976; Young and Holt 1977; Klausner et al. 1976). Due to Alberta's cold climate, only a few weeks of the year are suitable for spreading and incorporating animal manure on farmland. This represents a high work load during the application season and a management problem outside the application season. A promising method to solve the above problems may be composting of animal manure. Composting can break down animal manure into stable humic compounds, thus decreasing the concentrations of the various pollutants in runoff. If both composting and the application of compost could be conducted year round, the work load would be more evenly distributed with time, resulting in easier management of manure. Before adopting this practice, however, quantitative information is required on the nature of runoff that can be expected when composted manure is spread on snow and frozen ground.

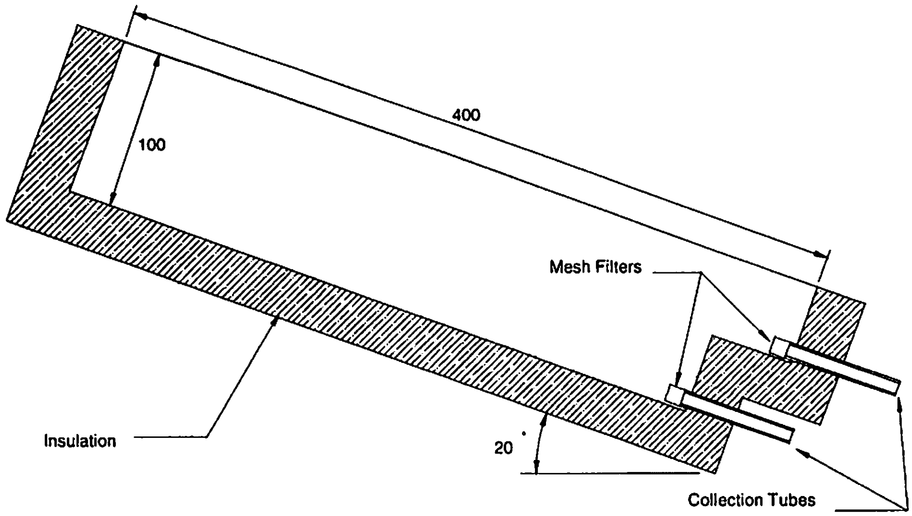

Fig. 1. Cross-section of a runoff collection tray.

The objectives of this research were:

1. To assess the effects of spreading fresh and composted manure on snow-covered, frozen ground by comparing the soluble and suspended contaminants in runoff collected from the surface and the bottom of the snow layer, and
2. To evaluate the influence of runoff collection periods, and the sequence of layers of snow and fresh or composted manure on the soluble and suspended contaminants of the runoff.

MATERIALS and METHODS

Ideally, an investigation of this nature would be carried out in the field under the actual environmental conditions in which fresh or composted manure would be applied. However, because of the difficulty of duplicating conditions between and within treatments, experiments were designed to be carried out in an artificial environment in which temperatures and climatic variables, thickness of snow packs, and slope of 'ground' surfaces could be controlled. The experimental work described here was carried out in a cold room with material held on racks of insulated metal trays. A detailed description of this facility follows.

Trays and racks

Sixteen sheet metal trays held the experimental materials: snow and either fresh or composted manure (Fig. 1). Each tray had a 0.16 m^2 (0.4 m x 0.4 m) base surrounded by a rim that was 0.1 m high. To simulate the natural environment of snow melting, the trays were insulated by 25 mm-thick, rigid polystyrene, exposing only the top surface of a tray to the ambient air. Trays were supported on racks set at a slope of 20° to the horizontal. A high slope was required in order to speed up response and to maximize sample volumes and the 20° slope was selected as being near the limit of land on which fresh or composted manure could possibly be applied under any circumstance. Each rack supported eight trays and each tray had two collection locations, fitted with coarse mesh filters, in the 'downhill' face. One point was at the bottom of the face to collect runoff from the surface of the tray and the other was at the mid-height of the face to collect runoff from the surface of the material on the trays (Fig. 1). The downhill face of each tray was stepped to prevent surface runoff getting to the lower collection point and both drainage points were connected to sampling bottles with plastic tubing. The object of the two sampling points was to try to separate melt water running off the surface of the snow from melt water percolating through the snow. The former would be more likely to end up in surface water, while the latter would end up at the soil surface and could follow a thawing front into the groundwater.

The inlet to each sampling tube was fitted with a 1-mm mesh screen to exclude coarse particles that might have blocked the tube. The area of the screens was sufficient to allow unimpeded flow, thus the collected samples contained only fine suspended solids and dissolved solids.

Fresh and composted manure

Manure was obtained from the Dairy Research Facility at the Edmonton Research Station, University of Alberta (Table I). Some of the manure was composted with chopped barley straw using a ratio of 1 kg chopped barley straw to 3 kg wet manure. This material was composted for three weeks in aerated, 200 L plastic vessels. At the end of this period the compost was not fully mature but was considered to be sufficiently processed for the purpose of this experiment. While the compost was being processed, the remainder of the collected manure was stored in a refrigerated room for later application. Fresh and composted manure was spread on the trays on the basis of their nitrogen content in accordance with the rates recommended by ILOC (1995). This resulted in 1.08 kg wet manure or 0.39 kg wet compost being applied on each tray with 6 kg of snow compacted to a depth of about 90 mm.

Table I. Chemical characteristics of manure and compost.

Material	Soluble C (g C/kg DM)	Total C (%)	Total N (%)	Moisture content (% wb)
Fresh manure	52.0	42.8	2.3	88.3
Composted manure	34.8	40.4	2.5	70.1

Experimental design and sampling procedure

A factorial experimental design was used with two materials, four spreading patterns, two runoff collection locations, two collecting periods, and two replicates of each. The two materials were fresh and composted manure. The four arrangements were based on the position of the layer of snow (s) relative

Table II. Statistical analysis of runoff from the two materials.

Material	BOD_5 (mg/L)		Soluble carbon (mg/L)		Total nitrogen (mg/L)	
	mean[1]	SD*	mean	SD	mean	SD
Fresh manure	1833.5a	1321.6	1514.4a	1061.1	377.5a	264.1
Composted manure	45.0b	33.2	257.0b	265.1	39.7b	21.5

*Standard Deviation
[1]Parameter means followed by different letters are significantly different.

to either fresh (f) or composted (c) manure in a tray. The eight different combinations (two materials times four spreading patterns) used were given the following designations: f-s, s-f-s, s-f, and f-s-f, or c-s, s-c-s, s-c, and c-s-c. The symbol "f-s" means that fresh manure was spread on top of the snow. These different arrangements were intended to simulate the effect of different times of spreading of a material, e.g., materials covered by snow represent fall spreading (s-f, s-c); materials spread over snow represent spring spreading (f-s, c-s); materials applied between two layers of snow represent mid winter spreading (s-f-s, s-c-s); and snow between two layers of material represents late fall and mid-spring spreading (f-s-f, c-s-c). Thus, with replicates, a total of 64 runoff samples was collected.

To minimize the number of samples and analysis required, while still collecting representative data, runoff samples were collected during the initial and the final snow-melting periods. The time of runoff collection was governed by the time taken to accumulate samples of approximately 200 mL from each tray.

The experiment was conducted at the Metabolic Research Facility of the Edmonton Research Station, University of Alberta. The 32 trays were placed in random order on racks in a temperature-controlled room to simulate freeze-thaw cycles typical of the spring runoff period. Daily temperatures of the ambient air in the room were set at 8°C for 10 hours from 11 PM to 9 AM and -5°C for 14 hours from 9 AM to 11 PM. In reality, temperature changes would be more gradual than in the simulation, but the freeze-thaw sequence produced by the simulation would, nevertheless be similar to actual conditions. No attempt was made to simulate the effect of solar radiation on the thawing process. The lights in the cold room were turned off at all times except when samples were being collected and their effect was considered to be negligible.

The freeze-thaw cycle used ensured that the runoff collection period ended during the normal working day and so samples could be analyzed as soon as they were collected. Each sample was analyzed in triplicate for five-day biological oxygen demand (BOD_5) (APHA 1995), soluble carbon, and total nitrogen. Although phosphorous is also an important nutrient and potential pollutant in manure, its levels were not determined.

Total soluble carbon and total nitrogen were used as factors for estimating organic content in runoff. Soluble carbon was determined using a soluble carbon analyzer (Astro 2000 System 2, Astro International Corp., League City, TX) and total nitrogen was analyzed using the micro-Kjeldahl digestion method followed by colorimetric analysis (McGill and Figueiredo 1993). Nitrogen was analyzed only as total nitrogen, and was not further separated into ammonia nitrogen and nitrate nitrogen due to limited resources. Nevertheless, the parameters that were measured were chosen to provide a reasonable representation of the pollutant potential of the runoff.

Statistical analysis

Data from the chemical analyses were analyzed using the Statistical Analysis System (SAS) software package (SAS 1988). The General Linear Models of SAS was used to conduct an analysis of variance. All statistical examinations were performed at the $\alpha = 0.05$ level of significance.

RESULTS and DISCUSSION

In general, the variability of data collected was quite high. This could have been due to non-uniform thawing, non-uniform flow of runoff, inadequacy of the filters allowing small solid particles to get into samples, and the inherent heterogeneity of fresh and composted manure. Nevertheless, some clear differences were found.

Fresh vs composted manure runoff

Table II shows the results of statistical analysis comparing the runoff from trays containing the two materials regardless of how the materials were layered with the snow or of sampling locations or periods.

As shown in Table II, there were significant differences in BOD_5 and in the concentrations of soluble carbon and total nitrogen between the runoff from fresh and composted manure. The BOD_5 levels and the concentrations of soluble carbon and total nitrogen in the runoff for fresh manure were 40.7, 5.9, and 9.5 times that of composted manure, respectively. The BOD_5 levels measured in the runoff from composted manure were such that, if receiving surface water had a BOD_5 level of 2 mg/L, the runoff would need to be diluted about 13 times to meet surface quality guidelines of 5 mg/L of dissolved oxygen (AEP 1994; Barnes et al. 1981). Runoff from the fresh manure would need to be diluted by a factor of 610 to meet the same guidelines.

The above differences between the runoff from composted and fresh manure are considered to be conservative because of the way solids were treated in this investigation. No quantitative measurements were made of suspended solids in the runoff or of the material retained by the screens on the collection outlets. However, qualitative observations indicated that runoff from the fresh manure was invariably much darker than that from compost and, in some cases, solids actually settled out. Also, the screens in the fresh manure treatments retained more coarse material than those in the composted manure treatments. These observations indicate that the solids from composted manure were less mobile than those from fresh manure and that, if all the mobile solids had been included in the runoff analyses, the differences shown in Table II would

Table III. Statistical analysis results for snow-fresh manure sequences.

Material sequence	BOD$_5$ (mg/L)		Soluble carbon (mg/L)		Total nitrogen (mg/L)	
	mean[1]	SD	mean	SD	mean	SD
F*–S*	1350.0a	908.1	1250.8a	909.0	380.1a	296.7
S–F–S	1976.4a	1373.4	1461.0a	950.3	356.6a	213.9
S–F	2185.4a	1384.7	1909.9a	1142.1	439.2a	279.7
F–S–F	1822.1a	1635.1	1445.0a	1301.4	334.0a	299.8

*F = Fresh manure; S = Snow
[1]Parameter means followed by different letters are significantly different.

Table IV. Statistical analysis results for snow-composted manure sequences.

Material sequence	BOD$_5$ (mg/L)		Soluble carbon (mg/L)		Total nitrogen (mg/L)	
	mean[1]	SD	mean	SD	mean	SD
C*–S*	59.8a	33.0	391.7a	396.0	53.8a	30.2
S–C–S	65.2b	41.0	312.6b	255.2	41.0b	13.9
S–C	22.1c	15.3	109.9c	53.4	24.7c	7.6
C–S–C	33.1d	20.2	213.8d	187.6	39.5d	20.0

*C = Composted manure; S = Snow
[1]Parameter means followed by different letters are significantly different.

Table V. Statistical analysis of runoff from two collection locations for fresh manure.

Collection location	BOD$_5$ (mg/L)		Soluble carbon (mg/L)		Total nitrogen (mg/L)	
	mean[1]	SD	mean	SD	mean	SD
Upper	2335.1a	1423.0	1876.2a	1071.1	433.7a	246.5
Lower	1331.9b	1023.7	1152.6b	948.9	321.2a	276.9

[1]Parameter means followed by different letters are significantly different.

Table VI. Statistical analysis of runoff from two collection locations for composted manure.

Collection location	BOD$_5$ (mg/L)		Soluble carbon (mg/L)		Total nitrogen (mg/L)	
	mean[1]	SD	mean	SD	mean	SD
Upper	38.4a	27.3	195.7a	179.6	35.8a	19.1
Lower	51.7a	38.0	318.2a	324.0	43.7a	23.6

[1]Parameter means followed by different letters are significantly different.

have been even greater. The results presented in Table II indicate that even incomplete composting had converted the most degradable and soluble organic components in the manure into more stable compounds and, consequently, had greatly decreased the risk of ground and surface water pollution from snow-melt runoff. Further maturing of the compost would be expected to further decrease the level of pollutants.

The mean values of all three parameters for runoff from fresh and composted manure are not of the same order of magnitude. Thus separate analysis is needed for the two materials, because the variances of the three parameters may not be homogeneous.

Snow-material sequence

The statistical analysis of results from the snow-material sequence treatments are shown for fresh and composted manure in Tables III and IV, respectively. For fresh manure, there were no statistically significant differences among the four arrangements for BOD$_5$, or the concentrations of soluble carbon and total nitrogen in the runoff. However, for composted manure, statistically significant ($\alpha > 0.05$) differences existed for all three parameters (BOD$_5$ and the concentrations of soluble carbon and total nitrogen in the runoff), with all possible snow-composted manure sequences. This suggests that the effects of material location with respect to snow layers are different between fresh and composted manure and that the quality of runoff from composted manure would be affected by the snow-material sequence while that from fresh manure would not.

Of the sequences investigated, the one representing spring application was the best for the composted manure while the worst was the sequence representing fall application. Fresh manure could be spread on snow-covered frozen lands at any time during cold weather conditions without significant difference of the runoff quality. However, as discussed above, the quality of runoff from fresh manure was uniformly poor due to the higher mobility of nutrients from this source.

Collection location

Overall, approximately one third of the total runoff collected came from the upper collection locations. Although material was caught on the screens in both fresh and composted manure trays, the surface area of the screens was great enough for runoff collection to be effectively unimpeded. Statistical data for fresh and composted manure runoff collected from different collection locations are presented in

Table VII. Results for runoff of fresh manure collected during two collection periods.

Collection period	BOD_5 (mg/L)		Soluble carbon (mg/L)		Total nitrogen (mg/L)	
	mean[1]	SD	mean	SD	mean	SD
Initial period	2150.8a	989.3	1980.0a	970.9	495.9a	252.0
End period	1516.2a	1554.4	1048.8b	960.2	259.0b	225.2

[1]Parameter means followed by different letters are significantly different.

Table VIII. Results for runoff of composted manure collected during two collection periods.

Collection period	BOD_5 (mg/L)		Soluble carbon (mg/L)		Total nitrogen (mg/L)	
	mean[1]	SD	mean	SD	mean	SD
Initial period	49.2a	37.2	348.8a	308.8	44.1a	23.8
End period	40.8a	29.4	165.2b	178.6	35.3a	18.7

[1]Parameter means followed by different letters are significantly different.

Tables V and VI. In the runoff from fresh manure, significant differences ($\alpha > 0.05$) were observed between the collection opening locations for BOD_5 and the concentrations of soluble carbon, but not for total nitrogen. BOD_5 and soluble carbon concentrations collected from the upper openings of fresh manure trays were 75.3%, and 62.8% higher, respectively, than runoff collected from the lower openings. Though not statistically significant, the concentration of total nitrogen in the runoff collected from the upper openings of fresh manure trays was 41.9% higher than that from lower openings. There were no statistically significant differences between the runoff collected from the upper and lower openings of composted manure trays, for BOD_5, or the concentrations of soluble carbon and total nitrogen.

Runoff collected from the upper collection locations in the fresh manure trays would be more likely to find its way, via overland flow, to surface water while that collected from the lower points would have greater potential to percolate through the thawing soil and end up in groundwater. Although this reasoning is rather over-simplified, these results suggest that the potential of the fresh manure snow-melt runoff to pollute surface water might be larger than the potential to pollute groundwater.

Collection periods

The time to collect 200 mL samples during the initial thawing period varied from four to eight days with a mean of 6.5 days. During the final thawing period, the time to collect samples was reduced to one to two days with a mean of 1.8 days. The initial period was longer due to absorption of water by the fresh and composted manure. Also, during the initial thaw, melt water filled up pore spaces in the snow before running off.

The initial snow-melt runoff of fresh manure, as shown in Table VII, had significantly higher concentrations of both soluble carbon and total nitrogen, while, with composted manure (Table VIII) the initial runoff had significantly higher concentrations of soluble carbon than the snow-melt runoff at the end of thaw cycle. Concentrations of soluble carbon and total nitrogen in the runoff of fresh manure and the concentrations of soluble carbon in the runoff of composted manure collected during the initial snow melting period were 88.8%, 91.5%, and 111.1 % higher than that collected during the end period. While not statistically different, BOD_5 in the fresh manure runoff and BOD_5 and total nitrogen in the composted manure runoff also tended to be greater during the initial snow-melting period than during the end period. This agrees with the research of Edwards and Daniel (1994) who found that the concentrations of all pollutants were highest in the first runoff and then declined rapidly. This variation of the measured parameters with time could also account for some of the high variability in the data for the various treatments.

CONCLUSIONS

A comparison of applying fresh or composted manure on snow covered frozen soil shows that composted manure has a lower potential pollution. The mean level of BOD_5, the concentrations of soluble carbon, and total nitrogen from runoff of composted manure were 45.0, 257.0, and 39.7 mg/L, respectively, compared with 1833.5, 1514.4, and 377.5 mg/L from fresh manure. The application season of composted manure had significant effects on BOD_5, and the concentrations of soluble carbon and total nitrogen in runoff, the best season is spring and the worst is fall. The quality of runoff from fresh manure was uniformly poor under all cold weather conditions. Although there were no significant differences between BOD_5 levels of early and late runoff from both fresh and composted manure and total nitrogen from composted manure, nitrogen and soluble carbon levels from fresh manure and soluble carbon from composted manure were significantly higher in the early runoff. Runoff from the surface of snow constituted about one third of the total and had significantly higher BOD_5 and soluble carbon from fresh manure and soluble carbon from composted manure than runoff from the bottom of the snow layer

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