Fall spreading of fertilizing residuals – environmental risks and preventive measures

Marc Hébert, agronome, M. Sc.[1]

Originally published in French, in Agrosol June 2005, 16(1):61-68, under the title "Épandage automnal des MRF – risques environnementaux et mesures préventives". Translated by Elisabeth Groeneveld.

Abstract

Fertilizing residuals (FR) and composts are often beneficially used post-harvest, at the end of the summer or the fall, both for practical reasons and to reduce odour problems. However, this practice is questioned due to the risk of water contamination. This article examines the main parameters (contaminants) that must be considered, based on a review of the pertinent Québec literature. These parameters are examined as a function of their environmental pressure as determined by the quantities and characteristics of the FR, the state of the environment in terms of water, air, soil and food, and the level of protection offered by the current government standards (the Pressure-State-Response). Studies show that the environmental and human health risks from spreading FR in the fall are low and generally less than those of farm manures. This is particularly true for composts and paper mill biosolids with a C/N > 20, even more so considering that most FR do not contain pathogens. Fall spreading of FR is also preferable to a spring or summer spreading in terms of odours and bioaerosols. Spreading FR high in organic matter and compost in the fall, rather than discarding them, would permit, either directly or indirectly, to reduce : soil erosion of the receiving soil, contamination of surface waters (suspended solids) and greenhouse gas emissions (CH_4 and possibly N_2O for FR with a high C/N ratio). Simple preventive measures are proposed to minimize losses of nitrogen to the environment, as a function of the C/N ratio and the $N\text{-}NH_4/N_{total}$ of FR, and to reduce risks of surface water contamination by pathogens.

Key words: Biosolids, composts, fall application, post-harvest, residuals, sludge.

[1] Ministère du Développement durable, de l'Environnement et des Parcs, Direction des politiques en milieu terrestre, Service agricole, 675, boul. René-Lévesque Est, 9e étage (boîte 71), Québec (Québec) G1R 5V7
Télécopieur : (418) 528-1035, Téléphone : (418) 521-3950 # 4826, Courriel : marc.hebert@mddep.gouv.qc.ca

Introduction

In June 2002, the Québec government adopted the Regulation Respecting Agricultural Operations (RRAO), whose main objective is: "*to protect the environment, particularly water and soil against pollution caused by certain agricultural activities.*" Article 31 of the RRAO further says that "*fertilizers may be spread after 1 October on ground that is not frozen or covered with snow if the agrologist who designed the agro-environmental fertilization plan specifies a new prohibition period*."

To guide the agronomists relative to the spreading of fertilising materials, especially post-harvest, the Ordre des agronomes du Québec published guidelines (OAQ 2004), based mainly on their experience in dealing with farm fertilizers, and mostly in relation to nitrogen risks. However, fertilizing residuals and composts have characteristics which are sometimes similar and sometimes quite difference from animal waste, notably relating to odour, pathogens and levels of ammonia nitrogen. A different approach is therefore needed to evaluate the overall environmental risk and to formulate agronomic recommendations.

This article will identify the parameters (contaminants), based on a literature review, that must be considered. As needed, simple preventive measures to be taken during the fall spreading of FR and composts will be proposed.

Materials and methods

The information will be presented using the Pressure-State-Response, often used in agro-environment (MDDEP 2003). Emphasis will be placed on farm-level risks, but also on a wider scale, based on the type of contaminant and specific risks which are presented. For example, levels of ammonium in water will be considered on the scale of individuals fields and on the scale of water courses (watersheds), but the issue of odours and bioaerosols will be limited to the scale of the farm and its immediate surroundings. Risks relating to metals will be examined over time, both short and long term.

Risk estimation integrates the contamination level of a given fertilizer, and the level of exposure of a population, according to the following simplified concept:

Risk = *f* (contamination level; exposure)

Therefore, a FR which contains few contaminants presents low environmental risk. A more highly contaminated residual will require additional spreading constraints (dose, setback distances, etc.) to limit exposure, and thus the overall risk.

To quantify the risk, we will refer to regulatory standards and environmental quality criteria (for example the nitrate standard for drinking water). The risk posed by different FR will be compared to that of farm fertilisers, both qualitatively and quantitatively, to determine the relative importance of the various risks and environmental issues, for example phosphorus surpluses.

Many scientific publications on the fall spreading of farm fertilizers in Québec were consulted. This allows us to fill certain gaps in the scientific literature pertaining to FR, specifically the risk of surface water contamination by ammonium and the production of greenhouse gases. However, this article does not compare the relative risk of various farm fertilizers - this would require a separate study.

For simplicity, the term "fall spreading" means all post-harvest spreading practices, even those which occur before September 21st.

Table 1. Main types of FR spread on agricultural soils in 2001-2002. Adapted from MDDEP (2004) and Potvin (2003).

Types de MRF	Tonnes humides
Biosolides papetiers	720 000
Biosolides municipaux	70 000
Biosolides d'abattoirs	45 000
Biosolides agroalimentaires autres	20 000
Composts commerciaux	55 000
Cendres	60 000
Poussières de cimenteries	50 000
Résidus alcalins de papetières	37 000
Résidus magnésiens	25 000
Autres ACM	25 000
Total	1 107 000

Environmental pressures

Quantities of FR

More than one millions tonnes of FR of industrial or municipal origin are spread each year on Québec's agricultural soils (MDDEP 2004).Main FR spread are biosolids (organic sludges), liming materials and composts (Table 1). This represents a significant tonnage diverted from landfills, with consequent reductions in methane emissions (a greenhouse gas), and landfill leachate loaded with organic matter.

However, the quantity of FR beneficially used in agriculture is relatively low (Figure 1) when compared to the yearly spreading of 31 millions tons of farm manures (Charbonneau *et al.* 2000). The proportion of FR spread in agriculture (3% of fertilizing materials) remains relatively stable, because the increase in FR use over the last few years has been matched by a significant increase in the volumes of liquid manures (MDDEP 2004; BPR 2005). FR are spread on approximately 2.5% of the cultivated land (Charbonneau et al. 2000), but only 1% of the soils in regions with a manure surplus (BPR-GREPA 2000). The FR are divided among 1100 farms (MDDEP, unpublished data), which account for 3.7% of the 30 000 farms in Québec.

Province-wide, nitrogen (N) and phosphorus (P) from FR account for approximately 2% of the soil nutrient loadings, much lower than farm fertilizers or mineral fertilizers (Figures 2a and 2b). In regions with a manure surplus, such as Montérégie, FR account

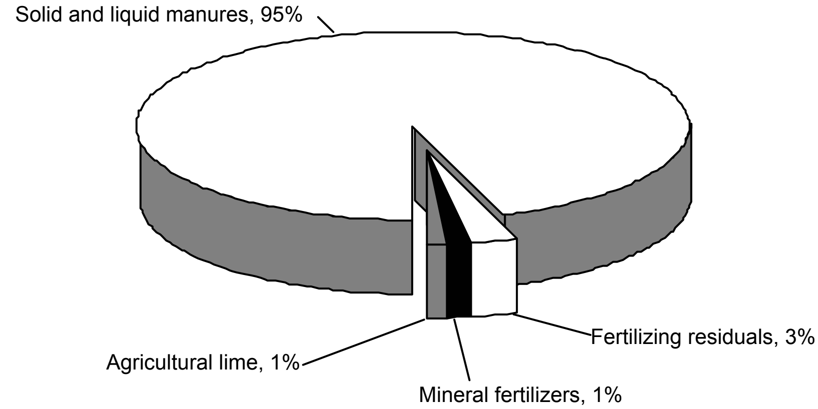

Figure 1. Contribution of FR to the tonnage of fertilizing materials spread in agriculture (Charbonneau et al. 2000)

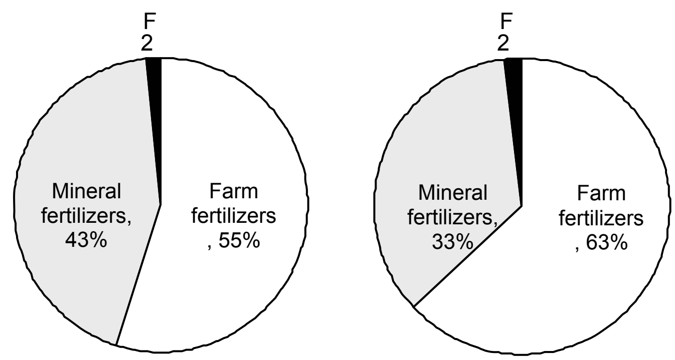

Figure 2. Relative distribution of (a) nitrogen loadings, (b) phosphorus loadings on Québec agricultural soils (adapted from Beaudet 2003, BPR 2005 and Charbonneau et al. 2000.)

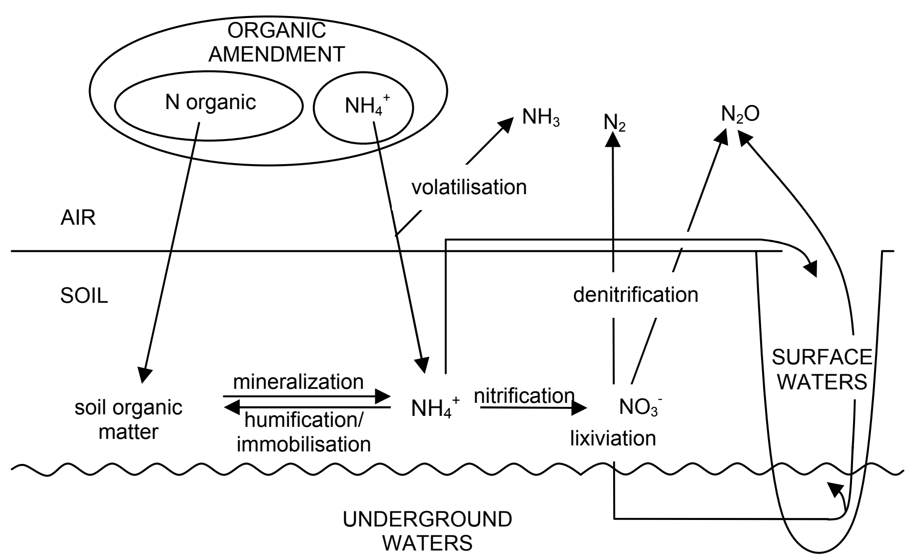

Figure 3. Nitrogen dynamics and losses to the environment (adapted from Nicolardot et al. 2003)

Table 2. Average levels in FR and farm fertilizers of various agri-environmental parameters.

FR/Farm fertilizer	Dry matter	C/N	N-NTK		$N\text{-}NH_4$		$N\text{-}NH_4$/ N-NTK	P_2O_5	
	(% d.w.[7])		mg/kg (d.w.)[7]	kg/w.w. ton	mg/kg (d.w.)	kg/w.w on	%	mg/kg (d.w.)	kg/w.w. ton
Mixed paper mill biosolids[1]	26	21	23 700	6.2	1 024	0.3	4%	9 611	2.5
Primary paper mill biosolids[1, 2]	44	281	1 500	0.7	29	0.0	2%	782	0.3
Municipals biosolides[1,3]	23	11	30 000	6.9	3 194	0.7	11%	26 757	6.2
Abattoir biosolides and residuals[1]	9	6	61 000	5.2	10 189	0.9	17%	32 482	2.8
Other biosolids and agri-food residuals[1]	13	8	40 500	5.4	7 605	1.0	19%	51 296	6.8
Commercial composts[1]	54	17	12 000	6.5	121	0.1	1%	16 045	8.6
Magnesium residuals (SPD)[1]	50							11 214	5.6
Ash[1]	79	165						12 514	9.9
Cement kiln dust[1]	91							740	0.7
Liquid hog manure – feeder[4]	4	4	100 000	4.0	57 500	2.3	58%	57 500	2.3
Solid cattle manure with straw[5]	22	18	26 000	5.6	5 761	1.2	22%	17 593	3.8
Liquid cattle manure[5]	7	11	40 000	2.9	24 306	1.8	60%	20 833	1.5
Chicken manure[5]	53	13	41 000	21.5	9 630	5.1	24%	43 238	22.7
Farm composts[6]	29	15	25000	7.3	951	0.3	4%	33000	9.6

(1) From Charbonneau *et al*. (2001) and MDDEP (unpublished data) for fresh samples. Levels of $N\text{-}NH_4$ in mixed paper mill biosolids may significantly increase during storage, refer to the text. The NO_3/NO_2 are generally found in trace concentrations, with a few exceptions such as very mature composts.

(2) Including primary deinking biosolids.

(3) Including septic tank biosolids

(4) From Seydoux *et al*. (2004). The $N\text{-}NH_4/N_{tota}$ ratio for liquid hog manure may reach 80% (Rochette et al., 2001).

(5) Adapted from Trudelle et al. (1996)

(6) From Gagnon *et al*. (2004). Composting generally implies 1 to 2 mixings of the heaps.

(7) w.w. = wet weigh basis; d.w. = dry weight basis

for only 1% of the P loading on agricultural soil (MDDEP 2002).

Quantitatively, “2-4%” represents the tonnage, the N and P loadings, and the receiving acreage for the beneficial use of FR in agriculture. Most FR are spread in a solid state, in contrast with animal waste which is typically managed in liquid form (BPR 2005).

Nitrogen dynamics

Nitrogen (total) from organic amendments may be in organic or mineral forms, the latter being mainly in the form of ammonia. Figure 3 illustrates the fate of nitrogen applied during a spreading event, and demonstrates that the losses are mostly related to the ammonium ion (NH_4^+) present in the amendment. The $N\text{-}NH_4/N_{total}$ of FR is highly variable, but generally low and much lower than that of liquid manures (Table 2). However, storage increases the $N\text{-}NH_4$ level of mixed paper mill biosolids, due to microbial activity (Envir-Eau 2001). When papermill biosolids with a C/N ≤ 20 are stored for a few weeks, the $N\text{-}NH_4/N_{total}$ can reach 32% (Rioux 2002; N’Dayegamiye *et al.* 2004a), a value comparable to that of solid cattle manure (N'Dayegamiye *et al.* 2004a). Ratios of 40% have been observed after 10 weeks of storage for biosolids with a C/N < 15 (Granger, personal communication). These $N-NH_4/N_{total}$ ratios following storage are however around two times lower than those of liquid manure, which average 60% (Seydoux *et al.* 2004) but may reach 70-80% (Rochette *et al*. 2001; Chantigny *et al*. 2004).

Soil incubation tests carried out in Québec with paper mill biosolids and a granulated municipal biosolid demonstrated that nitrogen is not immobilized in the soil with C/N < 20, and that the nitrification of the added nitrogen begins within a week (Watt 2001). N'Dayegamiye *et al.* (2004a), who worked in experimental plots showed that NO_3 remaining in the soil following the fall spreading of paper mill biosolids or solid manures is correlated to the $N-NH_4/N_{total}$ (r=0.67) and the C/N (r= -0.80) of the amendment. These authors conclude that the fall spreading (October 1st) of an amendment with a C/N > 20 does not significantly contaminate water with nitrates (NO_3). Even though the trial was not repeated over many years, nor with a large variety of amendments, some of the observations were corroborated by Nicolardot *et al.* (2003) with incubations of soils amended with manures, municipal sludges or agro-industrial residuals (r=0.87 between the mineralized N and the $N_{organic}/C_{organic}$ ratio of the amendments).

Following a literature review of different test plots, Chabot *et al.* (2000) highlighted the risk of soil nitrogen immobilization following springtime spreadings of paper mill biosolids with a C/N > 30. The risk of nitrogen loss is systematic for paper mill biosolids with a C/N > 43 (Chabot *et al*. 2000; Hébert & Gagné 2003). Field trials by Chantigny *et al.* (1999) demonstrated that the immobilisation process may last many months with primary deinking residuals (C/N > 200). The length of net nitrogen immobilisation in the soil (period during which the quantity of immobilized nitrogen exceeds the quantity mineralized) is proportional to the C/N ratio of biosolids (van Ham & Henry 1995). The length of the immobilisation process is strongly influenced by the soil temperature (Chantigny *et al.* 1999).

As for composts, even though the C/N is generally < 20, and often less than 15, these humified amendments mineralized their nitrogen much slower than manures (Gagnon *et al.* 1997; Hébert & Gagné 2003; Nicolardot *et al.* 2003). Farm compost (produced at the farm, generally with manures) contain less than 10% of their nitrogen in mineral form, that is less than 2000 mg/kg of $N-NH_4$ or of nitrates ($N-NO_3$), according to the dominant mineral form (Gagnon *et al*. 2004).

The fate of nitrogen is strongly influenced by soil temperature. When the soil is < 5°C, microbial activity is limited, according to certain authors (Clément & N'Dayegamiye 2003). This temperature is generally reached around the beginning of November in many Québec agricultural areas (Environment Canada 1984). However, recent research has shown that a late fall spreading of farm fertilizers can stimulate soil microbiological activity, beneath snow cover, when the soil temperature is near 0°C. The ammonification of the added organic nitrogen may be significant (Chantigny *et al.* 2002), as can the nitrification of the produced ammonium (Chantigny 2005) and the denitrification of accumulated nitrates (Chantigny *et al.* 2002).

Gangbazo *et al.* (1993; 1995; 1997) stated that the spreading period (soil temperature) is the main factor determining which water quality parameter will be most highly impacted following the spreading of liquid hog manure; NO_3 for underground water, or NH_4 for surface water. The liquid manure dose and type of soil incorporation determine the potential contamination intensity. These generalized observations were corroborated by a group of experts (MAPAQ, MDDEP, UPA, MSSS & MAM 1998).

Phosphorus (P) and other chemical contaminants

Phosphorus levels in FR are also highly variable (Table 2), but mixed paper mill biosolids contain on average 2 times less P than cattle manure, and 6 times less P than liquid hog manure, on a dry weight basis. Therefore, these biosolids are a source of organic matter having less impact on the P enrichment of agricultural soils. However, the differences are less striking on a wet weight basis.

Fertilizing residuals contain other nutrients and chemical contaminants in varying amounts (Charbonneau et al. 2001), including heavy metals such as copper, zinc or cadmium, from natural or anthropogenic sources. Average levels in biosolids are variable, but often relatively low compared to the maximal amounts allowed by the Ministère du Développement durable, de l'Environnement et des Parcs (MDDEP 2004) for C1 and C2 fertilizing residuals. Levels of copper and zinc in FR are often lower than those in animal manures, with the exception of municipal biosolids (CRIQ 1994; Hébert 1998; Seydoux *et al.* 2003).

Pathogens

The MDDEP (2004) uses the presence of *Salmonella* and thermotolerant fecal coliforms (*E. coli*) in fertilizing residuals as indicators of real or likely pathogens of fecal origin. These analyses and other parameters are used to determine the pathogen category for each fertilizing residuals (categories P1, P2 or P3). According to Ministry records for certificates of authorisation (CA) issued in 2004 (unpublished data) 70% of the fertilizing residuals spread were in the P1 category, that is, virtually exempt of fecal pathogens. When we consider that fertilizing residuals certified by the Bureau de normalisation du Québec (BNQ), not governed by CA are also in the P1 category, we can state that over 80% of the FR spread in agriculture are virtually exempt of fecal pathogens. This sharply contrasts with manures and liquid manures (Table 3), which often contain *Salmonella* as well as large numbers of *E. coli* (Hébert *et al.* 2003; Majdoub *et al.* 2004). However, there is a certain disagreement in the literature concerning bacterial counts in farm manures: Giroux *et al.* (2003) report finding *Salmonella* only in 20 to 35% of the farm manures sampled, whereas Letellier *et al.* (1999, cited by Chevalier *et al.* 2004) report *Salmonella* in 10% of cattle manures and 71% of hog manures. Some of this variability may be due to differences in analytical methods.

Odours

The MDDEP (2004) established odours categories for fertilizing residuals based on a survey of odour perceptions carried out by Groeneveld & Hébert (2002). Residuals in the O1 category have very low odours; those in the O2 category have odours analogous to that of solid dairy cattle manure; those in the O3 odour category smell more strongly than solid dairy cattle manure, but less strongly than liquid hog manure. The spreading constraints increase with increasing odour category. The spreading of fertilizing residuals with odour levels exceeding the O3 category is prohibited.

According to Ministry data (unpublished data, 2004) the fertilizing residuals spread in Québec under a CA are evenly divided amongst the three odour categories: O1, O2 and O3. Products certified by the BNQ are exclusively in the O1 category. Furthermore, only about 10% of the farms receiving strongly smelling O2/O3 fertilizing residuals spread them during the period most likely to generate complaints, that is from 15 June to 15 August. In fact, about 50% are spread post-harvest (Groeneveld & Hébert 2003), in contrast with animal manures, of which about 30% are spread post-harvest (BPR 2005).

Environmental state

Overview

Knowing the environmental state is the second step in the Pressure-State-Response flow-chart. Although citizens have made complaints regarding the odours of fertilizing residuals, and there have been cases of errors made by agronomists (soil pH unbalanced, nitrogen deficiency, etc.), the MDDEP is not aware of any known cases in Québec where water or soil use has been compromised, or food has been contaminated following beneficial use in agriculture of FR. A similar conclusion has been reached in the United States (NAS 2003) and Ontario (Smith 2005) regarding municipal biosolids, when used according to applicable

Table 3. Levels of *E. coli* and *Salmonella* in farm fertilizers, and the quality criteria for FR (from Hébert *et al.* 2003).

	E. coli (MPN/ g d.w.)¹	*Salmonella* (MPN/ 4 g d.w.)¹
P1 FR criteria – all purpose	< 1 000	absence
P2/P3 FR criteria – restricted use	< 2 000 000	n/a
Cow manure (n=5)²	64 000; (min=235; max =285 000)	Detected in 100% of the cases
Liquid hog manure (n=6) ²	15 000 000 ; (min=5 x 10^5; max =5 x 10^7)	Detected in 67% of the cases

(1) MPN : Most probable number; d.w.. : dry weight basis. Note that the analysis for total *E. coli* does not reveal toxic serotypes such as *E. coli* O157:H7, which was responsible for the water contamination in Walkerton (Ontario).

(2) n : number of samples analysed.

standards.

This observation can be explained by the following:

- Relatively few fertilizing residuals are beneficially used, as compared to farm manures (the 2-4% rule);
- Most of the fertilizing residuals spread in Québec are exempt of fecal pathogens and contain relatively few chemical contaminants;
- Fertilizing residuals which contain pathogens may only be spread under a CA delivered by the MDDEP;
- The limit criteria for metallic trace elements and the usage constraints for FR by the MDDEP are among the strictest in the Wold (Désilets 2003; Van Coïllie & Laquerre 2003);
- Epidemiological studies establishing a cause and effect link between the spreading of a given fertilizing (farm fertilizer or fertilizing residual) and a microbial pollution or human illnesses are limited (Chevalier *et al*. 2004);
- The most risky activities are the illegal ones, which are not controlled, such as mixing non-stabilized septic tank sludge in a liquid manure lagoon, followed by spreading in agriculture (MDDEP 2004). By their very nature, these activities are difficult to document.

The following sections will focus on the environmental parameters generally considered for the control of pollution in an agricultural setting. These parameters will be used to predict at which level the fall spreading of fertilizing residuals can alter or improve environmental quality or human health as a function of the surroundings (water-air-soil-food) and the end use being protected (drinking water, swimming, aquatic life, etc.).

Well water

The main parameters to considered in the *Regulation respecting groundwater catchment* (RRGC, Québec 2004) are *E. coli* and nitrates. In a recent study analysing the water quality of groundwater in seven agricultural watersheds, the Government of Québec (2004) concluded that:

"The study of household wells demonstrated that in terms of ***microbiological*** *parameters, the quality of groundwater in intensive agricultural zones is comparable to that of control zones... A risk assessment which took into consideration the water consumption of both children and adults as well as the level of nitrates in the water revealed that the risk level for populations in areas of intensive agriculture is very low. This result is supported by the low percent of samples (2.6%) which exceeded the 10 mg/L-N standard for the concentration of nitrates in household wells."* [translation]

Considering that all the activities in zones of intensive agriculture result in few or no loses of groundwater use as compared to non agricultural zones, we can logically deduce that FR have essentially no negative impact on groundwater use in Québec, regardless of the spreading season. In fact, 80% of the FR which are spread are virtually exempt of pathogens, and they represent only 2% of the N spread in agricultural areas (Figure 2a).

Various studies have shown that the residual soil nitrates in soil from the fall spreading of paper mill biosolids likely to migrate towards the water table, is relatively low when compared to the residual amount typically observed following the cultivation of corn (Table 4). According to Tran *et al*. (1996), nitrate losses are influenced by a combination of practices which influence nitrate losses, specifically the choice of crop and the accompanying fertilization, according to the following risk sequence (Giroux *et al*. 2003):

Potatoes > grain-maize > cereals = canola > soy >>>> hay fields

Surface water

The MDDEP regularly evaluates the water quality of the province's rivers, in order to observe trends and determine problematic parameters in terms of exceedances of quality criteria or benchmark values. According to Simard (2004), the most highly affected parameters of rivers in southern Québec, from May to October, from 2000 to 2002 are suspended matter and turbidity (Table 5). In second place were total phosphorus, total chlorophyll a and to a lesser degree, nitrates and nitrites as well as fecal coliforms. Ammonia nitrogen was the least worrisome parameter during this period in terms of the frequency of exceedances of the criteria or benchmark values. Similar results were reported by the Ministry (MDDEP 2003) for the period spanning 1998 to 2000.

The impact of agricultural activities on suspended matter and turbidity of surface water is mainly due to soil erosion. This erosion is influenced by soil management practices, many of which are directly related to corn cropping (MDDEP 2003). Spreading FR rich in organic matter will theoretically limit erosion (see the section on soil quality). However, the time of

Table 4. Residual soil nitrogen in the fall as a function of the preceding crop or the fall spreading of paper mill biosolids.

Preceding crop	Biosolids application			Spreading date	Soil levels (kg/ha)		Reference
	C/N	t/ha	kg N-NH_4/ha		N-NH_4	N-NO_3	
Corn	-	0	-	-	n.a.[1]	23-175	Tran *et al.* (1992)
Corn	-	0	-	-	n.a.	18-145	5 studies cited by Giroux *et. al*. (2003)
Potatoes	-	0	-	-	n.a.	23-40	1 study cited by Giroux *et. al.* (2003)
Wheat	-	0	-	-	n.a.	23-75	Tran *et al.* (1992)
Barley or canola	-	0	-	-	n.a.	11-42	2 studies cited by Giroux *et. al*. (2003)
Hay fields	-	0	-	-	n.a.	7-9	1 study cited by Giroux *et. al*. (2003)
n.a.[1]	20	30	48	1 October	0^2	33^2	N'Dayegamiye *et al.* (2004)
n.a.[1]	24	30	6	1 October	0^2	20^2	N'Dayegamiye *et al.* (2004)
n.a.[1]	21	40	n.a.[1]	23 October	8^2	52^2	Cormier & Dauphin (1998)
n.a.[1]	18	40	19	31 October	n.a.	0^2	Pouliot *et al*. (1998)

(1) n.a. = not available

(2) Excess soil N-NO_3 or N-NH_4 as compared to the control plots without biosolids ($N_{treatment} – N_{control}$), analysed in November-December.

spreading (spring, summer or fall) has essentially no direct impact on erosion, although indirect impacts may result from working the soil in ways that increase erosion (ploughing, heavy machinery, compaction etc.).

As for total phosphorus, a literature review by Larocque *et al*. (2002) indicated that losses from a cultivated parcel are influenced by many factors including soil P, P added by an amendment, the incorporation of the added P, the spreading period, the soil tillage practices and the crop. According to Bédard *et al*. (1999), erosion is the main factor in P losses. The risk from spreading a soil amendment during a given season is thus neither the only nor the most important factor influencing P losses to surface waters. Furthermore, incorporating soil amendments, although effective for reducing losses under certain conditions (Giroux *et al*. 2003) can be incompatible with certain agro-environmental practices designed to limit soil tilling, thus increasing erosion risks, and consequently suspended matter and turbidity in watercourses. Low till cultivation methods are practised on close to half the acreage devoted to annual crops (BRP 2005).

Total chlorophyll a is mainly correlated to the P levels in surface water; for this reason it is not further discussed in this article.

Fecal coliforms in water are used as an indication of fecal contamination from agricultural of municipal sources. This parameter does not reflect the actual content of pathogenic organisms. In fact, although fecal coliforms appear to pose fewer problems than suspended matter, turbidity and P (Simard 2004), Barthe & Brassard (1996, cited by Chevalier *et al*. 2004) report that more than 40% of the surface waters sampled in Québec had parasitic protozoans belonging to *Cryptosporidium* and *Giardia* genera. Although the causality between agricultural activities and infections in humans following the ingestion of drinking water is hard to establish, the case of Walkerton demonstrated that this risk is not negligible for bacteria (Chevalier *et al*. 2004) considering that 2300 people required medical care and 7 died (Unc *et al*. 2003).

Pathogen risks runoff to surface waters following spreading is higher for liquid manures than solid manures, but is reduced in soils with a higher proportion of macropores, as is the case of certain soils where conservation cropping methods are employed (Unc *et al*. 2003).

Bacterial runoff risks for liquid manure is higher during and immediately following spreading, due to an increase in soil humidity (Topp & Scott 2003) and the formation of a waterproof layer that reduces liquid infiltration rates (Unc *et al*. 2003). Incorporation of the liquid manure into the soil does not accelerate the destruction of *E. coli* as compared to liquid manure left on the soil surface, under laboratory conditions (Topp & Scott 2003). Transposing these results to fertilizing residuals containing pathogens, it seems likely that surface water contamination risks by runoff are less for solid residuals, as compared to liquid residuals. Risks would also be

Table 5. Parameters and river water quality for the summer 2000-2002 (adapted from Simard 2004)

Parameter	Description	Main impacts/uses	Criteria/Reference value	Level of concern[1]
Suspended solids (SS)	Organic or inorganic particles found in water.	Problems related to sedimentation. See also turbidity.	R.V.[2] : 13 mg/L	1
Turbidity	Cloudiness of water caused by various substances, including SS.	Aesthetic problems. Also limits drinking water disinfection capacity.	Criteria : 5 UNT[3]	1
Total phosphorus	Nutrient. In excess, it alters eutrophication..	Various uses impacted (drinking water, recreational activities, aquatic organisms).	Criteria :0.03 mg/L	2
Total chlorophyll a	Phyto-plankton pigment. Eutrophication indicator.	See total phosphorus.	R.V. : 8.6 mg/m^3	2
Fecal coliforms	Bacterial group used as indicators of fecal contamination.	Various uses (drinking water, recreational activities).	Criteria : 200 CFU/100 ml (contact)	3
Nitrates/nitrites	Mineral form of nitrogen naturally present in low concentrations.	Drinking water (methemoglobinemia of newborns and possibly a cancer causing agent)	Standard : 10 mg N-NO_3/L R.V. : 1 mg/l	3
Ammonia nitrogen (NH_3 or NH_4)	Mineral form of nitrogen naturally present in low concentrations. Nitrate precursor.	Hinders drinking water disinfections. Toxic to fish.	Criteria : 0.5 mg/L R.V. : 1.5 mg/L[4]	4

(1) The level of concern is expressed relative to their exceedance of the criteria or reference values chosen, and not weighted by the importance of the use to protect or the impact of an exceedance on human or ecosystem health.

(2) R.V. = Reference value

(3) Nephelometric turbidity units.

(4) The value varies according to the pH and water temperature (Guay 2003)

lower in soils having many macropores, such as hayfields and fields where soil conservation methods are practiced. The incorporation of residuals into the soil has shown mixed results, and further study is required.

Overall, approximately 100 000 tonnes of category P2 and P3 residuals which may contain fecal pathogens are spread in the fall on agricultural soils, as compared to 10 million tonnes of farm fertilizers spread over the same period (calculated with partial data for 2003 (BPR 2005)). This is a 1 to 100 ratio of fertilizing residuals to manures. Considering this proportion on a watershed scale, it is unlikely that the fall spreading of a limited amount of P2/P3 fertilizing residuals will have a measurable impact on surface water quality. This is supported by the fact that most fertilizing residuals are solid, which reduces runoff risks as compared to liquid manures.

Even if a significant episode of surface water contamination occurred in a localised area, a fall or winter microbial contamination is less likely to have a negative impact on recreational activities than with a spring of summer spreading, due to cold water. Regulatory requirements to disinfect surface water used for human consumption are an additional “safety net” for human health.

As for the contamination of surface water by **nitrates/nitrites**, we rarely observe exceedances of the 10 mg/L standard for water quality (Gangbazo & Babin 2000; Simard 2004). Rivers in agricultural areas generally have median concentrations below 2 mg N-NO_3/L (Gangbazo & Babin 2000). Thus, although surface waters may be enriched in nitrates as compared to pristine levels, they are rarely polluted by nitrates (that is, exceedances of regulatory standards).

Ammonia nitrogen poses few water contamination problems from May to October (Table 5) (Simard 2004). However, Cabana (2000) showed that untreated water used for human consumption in Repentigny, Assomption and Épiphany, three municipalities of the Assomption river watershed, regularly exceed the 0.5 mg N-NH_4/L quality criteria, especially between December and February. Contamination peaks were shown to generally follow rain or winter snow melts in this area which has increasing pork production. This agrees with observations made by Gangbazo *et al*. (1997) for plots which received liquid manure, or on a watershed scale (Gangbazo *et al*. 2003). The authors attribute this high contamination to runoff from plots which received high doses of liquid hog manure, rich in ammonia nitrogen, late in the fall. In fact, when the soil is cold (late spreading), ammonia nitrification is slowed (Rochette *et al*. 2004a). In contrast, Chantigny (2005) reports that all of the ammonia nitrogen of a liquid manure spread in December than can nitrified in less than 100 days, under certain conditions.

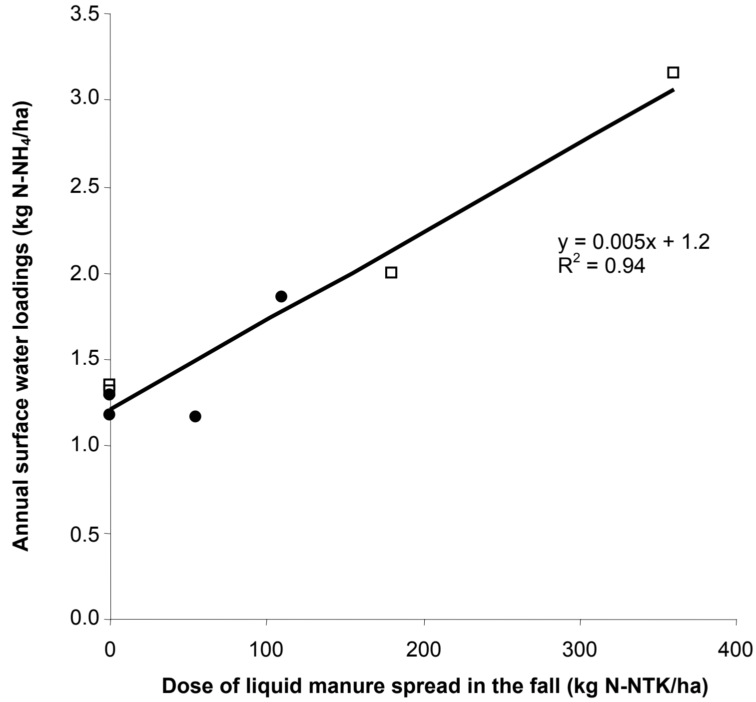

Figure 4. Average annual N-NH_4 losses to surface water as a function of the quantities of liquid hog manure spread between the 1st and 30th of October, for two crops, on a silty loam soil with a 6% slope, over 5 years (adapted from Gangbazo *et al.* 1997).

Ammonia nitrogen can also be toxic to the aquatic fauna in ditches and small water courses in agricultural zones, in concentrations varying between 0.13 and 2.1 mg N-NH_4/L, according to the pH and water temperature (Guay *et al*. 2002), but little data is available for these low flow habitats. However, Gangbazo *et al*. (1997; 1999) observed that plots which received large doses of liquid hog manure in the fall over a five year period had NH_4 concentrations which reached 2.2 mg N-NH_4/L, thus exceeding chronic toxicity criteria.

The field trials by Gangbazo *et al*. (1997; 1999) may overestimate the true environmental risk, because some of the doses studied were excessively high. Several other counter arguments must also be considered. First, the spreading dates studied, from the 1st to the 30th October according to the year, favoured nitrification, thus reducing soil NH_4 prone to runoff, from the fall to the spring snow melt. An almost complete disappearance of the added ammonia was observed by N'Dayegamiye *et al*. (2004a), less than 6 weeks following the spreading of solid manures and paper mill biosolids on October 1st (Table 4). Chantigny (2005) reports that even the ammonium from a liquid manure spread in December may be completely nitrified during the winter, under snow cover. Second, a 24 hour delay before incorporation allowed a non-negligible loss of NH_3 though volatilisation, because most of the volatilisation occurred in less than 12 hours (Rochette *et al*. 2001, 2004; Chantigny *et al*. 2004). This is confirmed by Nicolardot *et al*. (2003) for fertilizing residuals, notably those with a pH ≥ 7.8. Third, incorporating the liquid manure into corn fields, as was done by Ganbazo *et al*., reduces the risk that residual NH_4 will runoff. Fourth, the extremely high water levels of N-NH_4 measured for experimental plots correspond to the extreme levels observed in a watershed with a high density of pork production (Gangbazo *et al*. 2003). Fifth, a strong linear relation between fall doses of liquid hog manure and N-NH_4 loses is observed, regardless of the crop being studied (Figure 4). Therefore, it is reasonable to use data from Ganbazo *et al*. (1997, 1999) to conservatively estimate NH_4 losses to surface water, for a given plot, as a function of the actual total nitrogen (or ammonia nitrogen) loading (Figure 4). Moreover, these results can reasonably be applied to other amendments rich in ammonia nitrogen, although equally complete studies for other farm fertilizers and fertilizing residuals have not been carried out.

Air quality

Three parameters are considered; odours, bioaerosols, and greenhouse gases. Recent public consultations through the BAPE on the sustainable development of hog production revealed important cohabitation problems in rural areas, relating to **odours** (MDDEP 2003). The mental health of individuals living the rural areas may have been affected. In fact, a significant increase in psychological distress for the population in the spring was observed in municipalities with a large number of pigs (MDDEP 2003). Although cause and effect has not been rigorously demonstrated, these possible impacts of pig production cannot be ignored. Due to the malodorous and repulsive smell of some fertilizing residuals (Fortin 2000; Thériault 2001; Groeneveld & Hébert 2002, 2004), caused by the volatilization of various gases (Kodski *et al*. 1992; Rochette *et al*. 2004b), spreading these malodours fertilizing residuals in the spring and in the summer may impact the mental health of neighbours. Fall spreading would reduce these risks as the population is more likely be indoors, thus reducing their exposure to malodours.

According to Goyer *et al*. (2001, cited by Forcier 2002), bioaerosols are airborne particles, composed of microorganisms (bacteria, viruses, fungi) or their derivatives such as metabolites, toxins or fragments. These particles come from organic matter, plants, soil, animals and humans. Fresh and humid organic matter, such as farm fertilizers and biosolids are a favourable substrate for microbial presence and growth, and thus the emission of bioaerosols. Although the risks relating to bioaerosols is controversial, mainly with regards to municipal biosolids, there is no evidence that fertilizing residuals beneficially used according to regulation present a health risk (Forcier 2003). This statement takes into account the fact that only some of the fertilizing residuals contain pathogens (P2/P3 categories), and that these are subject to spreading setback distances (MDDEP 2004). The fall spreading of fertilizing residuals may actually be an additional protection factor by reducing population exposure.

Nitrous oxide (N_2O), also known as dinitrogen oxide or dinitrogen monoxide is a greenhouse gas 310 times more powerful than CO_2. It represents 11% of Canadian greenhouse gas emission, half of which come from agriculture (Rochette 2004), this in spite of the fact that only 1 to 2 % of the nitrogen added to soils is volatilized as N_2O (Chantigny, personal communication). The N_2O results from the denitrification of nitrates accumulated in the soils, especially under humid conditions (Rochette 2004). Losses of N_2O in winter under snow cover are significant (van Bochove *et al*. 1996, cited by Chantigny *et al*. 2002) and evidence suggests that N_2O emissions are greater during thawing, when soils are water saturated (Chantigny, personal communication). The fall spreading of nitrogen containing organic matter is therefore more likely to generate N_2O emission than spring spreading. However, the reverse phenomena may also be observed, according to pedo-climatic conditions which vary between years (Rochette *et al*. 2004a).

Because fertilizing residuals contain less mineral nitrogen than liquid manures, the risk of N_2O emissions in the soil (or rivers) following a fall spreading is theoretically reduced, especially for biosolids with a high C/N ratio, which immobilise soil nitrates. However, little data exists to confirm this statement.

More generally, in terms of greenhouse gas reduction, the fall spreading of biosolids permits an indirect reduction of methane emissions, if the landfilling of organic residuals is reduced. However, this has been poorly studied to date.

Soil quality

One of the main **soil degradation** problems for Québec agricultural soils is linked to a deterioration of the soil structure, which, by the end of the 1980's was affecting nearly 25% of the cultivated areas (Tabi *et al*. 1990, cited by MDDEP 2003). This loss of structure results mainly from monocultures and predisposes the soils to water erosion, resulting in surface water contamination by suspended matter and phosphorus (MDDEP 2003). However, amending with certain organic fertilising residuals, especially those with plant fibres, improves soil structure (Angers *et al*. 1998; Chantigny *et al*. 1999; N'Dayegamiye *et al*. 2001; Watt 2001; Chantigny *et al*. 2005) or other soil properties such as porosity and organic matter levels (Beauchamp & Thériault 1998; Chantigny *et al*. 1999; N'Dayegamiye *et al*. 2004b) or earthworm populations (N'Dayegamiye *et al*. 2004b). Less data exists for soil amended with municipal biosolids, but we can assume that the addition of organic matter also tends to improve soil structure, in addition to possible positive effects due to the presence of anionic polyacrylamides added during the wastewater treatment. (Unc *et al*. 2003).

Enhanced soil quality following the spreading of biosolids may therefore reduce surface water contamination due to the erosion of soil particles, dissolved phosphorus and nitrogen ammonia runoff. The beneficial use of biosolids on a degraded soil, regardless of the spreading period, may thus aid reduce the environmental pressures of agricultural activities, in particular those associated with growing corn.

As for **trace metallic and organic elements** present in fertilizing residuals, many studies have shown that short term risks to the soil are low or negligible (Caron *et al*. 1998; chasse *et al*. 2003). This takes into account that limited fertilizing residual loadings does not significantly modify levels of heavy metals or trace elements in the soil. This has been well documented for paper mill biosolids (Beauchamp & Thériault 1998; Gagnon *et al*. 2004). The time of spreading (spring or fall) therefore has little impact on the risk management.

Possible risks from trace elements are more related to repeated long-term spreadings of fertilizing residuals containing high levels of persistent substances such as copper, cadmium and dioxins. Studies by the IRDA (Giroux *et al*. 2004) showed that repeated amendments of farm fertilizers over 10 years could significantly increase the extractible soil fraction (Mehlich 3) of copper and zinc, even if total soil levels remained essentially the same. These authors suggest preventive measures to reduce loadings, notably from chicken and liquid hog manures. For fertilizing residuals, preventive measures have been in place for many years (MDDEP 2004). Based on risks analyses performed mainly in the USA with municipal biosolids, the likelihood of a significant environmental contamination due to trace elements in fertilizing residuals appears low, even long term (Hébert 1998; van Coïllie & Laquerre 2003; Hébert 2003; MDDEP 2004).

Food quality

Impacts on human or animal health due to the consumption of crops fertilized with human or animal fecal matter is poorly documented. However, the fall spreading of farm fertilizers can be recommended, because it may hasten the destruction of bacteria and pathogens, due to the long delay between spreading and harvesting and exposure to harsh freeze-thaw cycles (Giroux *et al*. 2003). Although no regulation restricts the use of farm fertilizers with regards to pathogens, P2/P3 fertilizing residuals are subject to spreading restrictions for certain crops (MDDEP 2004).

Response

This is the last step in the Pressure-State-response sequence. Because the legal and administrative framework for the beneficial use of fertilizing residuals is very complex (MDDEP 2004), we limit the remaining discussion to a summary of the key players. We will then highlight main the environmental parameters, which should be considered for modification, regarding the fall spreading of fertilizing residuals.

Canadian Food Inspection Agency (CFIA)

The CFIA administers the Fertilizers Acts (CFIA 1996). Products sold or imported as fertilizers or soil amendments must conform to federal labelling and safety standards. The criteria and reference values relating to chemical contaminants and pathogens are very similar to those of the MDDEP (2004). The CFIA does not directly oversee spreading practices, in contrast with the MDDEP.

Bureau de normalisation du Québec (BNQ)

The BNQ develops commercial standards for fertilizing substances in Canada, and certifies conformity with regards to these standards. In 2003, 10 commercial products were certified by the BNQ including 4 composts, 5 liming amendments and granulated municipal biosolids (MDDEP 2004). This represents around 150 000 tonnes/year, and approximately 10% of the volume of fertilizing residuals and commercial composts beneficially used in Québec (MMDEP 2004). The products certified by the BNQ are pathogen-free, with low odour, and generally contain little mineral nitrogen. They may beneficially used in agriculture without a certificate of authorisation from the MDDEP.

Ministère du Développement durable, de l'Environnement et des Parcs du Québec (MDDEP)

Within a context of sustainable development, and to help attain the environmental goals of the *Québec Residual Materials Management Policy* (Québec, 2000), the MDDEP encourages the beneficial use of fertilizing residuals, while ensuring that these activities are carried out in a manner that respects the environment and human health.

The MDDEP controls beneficial use activities both *a priori* and *a posteriori* to ensure that the Environment Quality Act, the regulatory standards and requirements relating to certificates of authorisation (CA), are respected. The *Guidelines for the Beneficial Use of Fertilizing Residuals* (MDDEP 2004) brings together the regulatory standards, including the setback distances of the *Agricultural Operations Regulation* and the *Regulation Respecting Groundwater Catchment*, in addition to supplemental criteria relating to certificates of authorisation. When fertilizing residuals have non negligible levels of trace elements (C2 category), pathogens (P2 or P3 categories), or are malodorous (O2 or O3 categories), additional spreading constraints are applicable (MDDEP 2004) to reduce exposure. Fertilizing residuals which do not meet the basic requirements may not be spread.

Farms which receive fertilizing residuals must prove to the MDDEP that they have the capacity to receive the fertilizing residuals (phosphorus assessment), even if the N and P spreading doses for each field is determined by the agronomist. However, for spreading after October 1st, the agronomist must supply additional information (Article 31 of the *Agricultural Operations Regulation*).

Field inspections by the Ministry revealed that the beneficial use of fertilizing residuals carried out under a certificate of authorisation largely respected the quality criteria with regards to metals and pathogens (Hébert *et al*. 2002; 2003). Requirements relating to field storage are also respected on most of the farms (Groeneveld & Hébert 2003).

Ordre des agronomes du Québec (OAQ)

The OAQ monitors the public's protection relating to the *Loi sur les agronomes*. In this respect, the OAQ is responsible for ensuring the competency of the agronomists. The *Ligne directrice sur la gestion des matières fertilisantes* specifies, among other things, that the agronomist must "*recommend a dose of approximately 55 kg/ha potentially available nitrogen supplied by the fertilizing residuals, when the target spreading period is recognized as having a "moderate to high" environmental risk*" [translation]. This loading limit was considered for the first time in 1998 (MAPAW, MDDEP, UPDA, MSSS & MAM 1998) and is derived from work done by Gangbazo *et al*. (1997, 1999). Figure 4 shows that at doses of 55 kg N_{total}/ha liquid pig manure on hayfields in the fall, losses of $N\text{-}NH_4$ to surface water are of the same order of magnitude as those obtained with a spring spreading of liquid manure or mineral fertilizer.

Municipalities

Municipalities and counties have the power to forbid spreading on certain dates due to minimize odour impacts, by virtue of the *Municipal Code* and the *Cities and Towns Act* (maximum of 12 days prohibition per year). Setback distances for odours of fertilizing residuals in agricultural areas are determined by the MDDEP (2004).

Synthesis of the information and preventive measures

Table 6 present a synthesis of the information drawn from a Pressure-State-response analysis. We can conclude that there is no evidence that fall or post-harvest spreading of fertilizing residuals, when done according to the current standards and criteria pose a significant environmental problem. This observation results from a consideration of the quantities used, levels of contaminants, and the strictness of the current regulatory framework. Post-harvest spreading of fertilizing residuals may even be advantageous for managing odours and bioaerosols, while facilitating the farmer's work.

However, to minimize nitrogen loses to water, or its transformation into nitrous oxide, a powerful greenhouse gas, some preventive measures must be considered, according to the type of fertilizing residual and their relative risk. These measures are grouped in Table 7, and essentially imply restricting fertilizing residual doses as a function of the C:N ratio and the level of ammonia nitrogen. These parameters are related to the nitrification potential. Certain additional measures are also applicable to P2/P3 liquid fertilizing residuals to reduce the risk of contaminating surface water. Because P levels in fertilizing residuals are generally correlated, limiting the doses as outlined in Table 7 will indirectly reduce soil P loadings.

With these preventive measures, which imply low doses of mineral nitrogen, and other measures required by the regulations and criteria of the MDDEP (2004), it does not seem necessary, from an environmental point of view, to always require the immediate incorporation of fertilizing residuals into the soil following a fall spreading. Incorporation may even be incompatible with soil conservation practices (direct seeding, hayfields) which limit losses of P and suspended matter in degraded watersheds (Gangbazo *et al*. 2002), in addition to risks of pathogen runoff (Unc *et al*. 2003). On the other hand, the MDDEP (2004) requires incorporation for certain specific situations in order to reduce the attraction of pathogen vectors (flies, mosquitoes, etc.) or to limit exposure to odours.

Finally, even if the generalized risk evaluation used in the present article is applicable to farm fertilizers, we cannot directly transpose the measures imposed on fertilizing residuals. Their contaminant levels (Pressure) and

Table 6. Summary of the Pressure-State-Response approach

Environment/ resource to protect	Environmental indicator	Degradation level of the environment/ resource	FR fall spreading risks	Status of current measures taken by the MDDEP for FR	Extra measures for fall spreading
Underground water (drinking)	Nitrates	Low, except for specific aquifers (2.6% of wells exceed the 10 mg/L standard)	Low to none is the residuals C/N > 30, or for composts Higher if the N-NH_4/N ratio is high and spreading is done in warm soil (early spreading)	Satisfactory (doses according to the needs of plants, setback distances).	Limit loadings for biosolids with a C/N < 30.
	E.coli	Low except for specific aquifers	Probably no difference with regards to catchment works	Sufficient (RRGC, FR Guide)	None
Surface waters (rivers)	Turbidity and SS	Very high	No direct causality link. Indirect advantages (soils, erosion)	Sufficient	None
	Total phosphorus	High to very high	Higher than for a spring spreading	Parameter already highly managed (RRAO)	Dose limits. Use of existing management tools (LoPhos, etc.)
	Fecal coliforms	Moderate to very high (Cf. Walkerton)	Low probability of an impact (few P2/P3 FR as compared to manures, setback distances)	Sufficient	Injection/ incorporation of liquid P2/P3 residuals on bare soil, if this does not increase erosion risks
	Ammonium (NH_4)	Variable (low in the summer, but higher in the winter in certain watersheds). Unknown for small water courses	Higher if the total N- NH_4/N ration is high, with a late spreading	Insufficient	Limit doses when the soil is cold. Superficial injection/ incorporation on bare soil, if this does not increase erosion risks
	Nitrates (NO_3)	Low	Higher if C/N < 30	Sufficient	None. Indirect limitation via N-NH_4
Air	Odours – psychological distress	Not determined, but possibly very high (spreading manure in the spring and in the summer)	Much lower than in the spring and summer (lower exposure)	Possibly sufficient (odour categories, setback distances, prohibition dates by municipalities)	None
	Bioaerosols	Not determined	Lower (less exposure as compared to spring and summer)	Possibly sufficient (setback distances)	None
	Greenhouse gases	Very high	Probably higher as compared to spring/summer if high levels of NH_4. Lower is the residual has C/N ratio > 30, or for composts	Insufficient	Limit NH_4 doses (see NH_4). Limit landfilling (methane)
Soil	Trace elements in fertilizing residuals	Low (comparing actual levels versus toxicological criteria.	No causality link with the spreading time.	Sufficient for the short term. Probably sufficient long term (C2 limits)	None
	Erosion	Very high (see SS and soil degradation study (Tabi *et al.*, 1990).	No direct causality. However fall spreadings increase soil organic matter, indirectly reducing erosion risks.	Sufficient.	Avoid working the soil (incorporation) on hay fields or direct seeding.
Food for humans/ livestock	Pathogens	Not determined	Lower (longer delay between spreading and harvest).	Sufficient (prohibitions, delays).	None

Table 7. Preventive measures for the spreading of FR and compost post-harvest to minimize nitrogen losses and the contamination of surface waters by pathogens.

FR type	Additional measures[1]	Justification	Notes
Composts	None	Composts have very little mineral nitrogen ($N_{mineral}/N_{total}$ ratio of 4% for farm composts). They contain little or many fewer pathogens than animal manure.	A farm compost is partially deodorized and have $N\text{-}NH_4$ levels < 2000 mg/kg, d.w. (Gagnon *et al.*, 2004), otherwise itmust be managed like a solid manure. Commercial composts are generally more mature and contain little ammonia nitrogen.
Biosolids, C/N ≥ 30	None	These biosolids are likely to reduce losses by causing temporary mineral nitrogen immobilization in the soil (Chabot *et al*.. 2000). They also contain little phosphorus.	On an agronomic basis, biosolids with C/N ratio > 43 can harm crops due to immobilisation. Beauchamp and Thériault (1998) suggest adding a mineral nitrogen supplement in the spring, in the order of 1 to 3 kg N/ton wet weight for primary deinking residuals (C/N very high, ≥ 200). The nitrogen supplement dose will vary according to the C/N ratio of the FR, the spreading rate, the residual soil nitrogen in the fall, and the soil temperature (spreading date). Because deinking residuals may contain up to 40% $CaCO_3$ (dry weight basis), the spreading dose will be limited to avoid over-liming. This will indirectly reduce the nitrogen immobilisation intensity. The additional nitrogen may not be necessary for legumes (Chantigny *et al*. 1999; Machrafi *et al*. 2003).
Biosolids, C/N ≥ 20 and < 30	≤ 40 tons/ha (wet weight basis)[1]	A C/N > 20 was suggested by Giroux *et al*. (2003) to strongly limit risks of nitrogen loss. With a spreading rate of 30 to 40 t/ha (wet weight basis) for paper mill biosolids, Cormier & Dauphin (1998), Pouliot *et al*. (1998) and N'Dayegamiye *et al*. (2004) obtained an ammonia nitrogen soil loading of 17 kg $N\text{-}NH_4$/ha (max.: 48 kg $N\text{-}NH_4$/ha). The authors also measured a relatively low nitrate accumulation in the soil profile in December (Table 4).	This spreading dose is compatible with acceptable agronomic crop yields (Gagnon *et al.* 2004) and is technically feasible (Charbonneau *et al*. 2000).
Biosolids, C/N <20	≤ 35 kg $N\text{-}NH_4$/ha[1]	These biosolids may have a significant proportion of their nitrogen as ammonia, which makes them more similar to solid and liquid manures. The $N\text{-}NH_4$ loading is less or comparable to 55 kg Ntotal/ha for liquid hog manure (which adds 30 to 40 kg $N\text{-}NH_4$/ha). This loading corresponds to a relatively low contamination risk (Figure 4).	This unique preventive measure is simple to apply compared to most of the measures of the OAQ (2004). However, it implies analyzing NH_4 in the FR following storage at the farm to determine actual content. In absence of specific analyses, a conservative $N\text{-}NH_4/N_{total}$ ratio of 30% (40% if the biosolid have a C/N < 15). However, if the biosolid has a pH >11, or a dryness > 90%, the level of NH_4 will not increase during storage, because protein ammonification is stopped. Analysis at the production plant may therefore be sufficient. Almost all municipal and agri-food biosolids have a C/N < 20.
Liquid FR	≤ 35 kg $N\text{-}NH_4$/ha. Soil injection/ incorporation for P2/P3 if this does not increase soil erosion risks[1]	Idem.	This ammonium loading implies doses > 20 m^3/ha, achievable with liquid manure spreaders, but care must be taken to minimize runoff. From an agronomic point of view, liquids containing most of their nitrogen in mineral form ($N\text{-}NH_4/N_{total}$ > 50%) should not be spread post-harvest if the main objective is nitrogen fertilization, as a significant proportion may be lost the following spring.
Liming amendments	None	These FR (wood ash, cement kiln dust, etc.) have little or no nitrogen.	

(1) Soil incorporation may reduce ammonia nitrogen losses, but contributes to increasing erosion and surface water pollution risks by suspended matter. It is thus not recommended for hayfields and annual crops with soil conservation practices. Additionally, as soil ammonium loadings are strongly limited, significant surface water contamination risks are low, based on studies by Gangbazo *et al.* (1997).

the regulatory framework (Response) differ on many levels.

Acknowledgements

The author would like to thank the following people: Richard Beaulieu, agr., M.Sc., Martin Chantigny, Ph.D.; Georges Gangbazo, Ph.D., ing.; François Granger, ing. and agr.; Jocelyn Magnan, agr., and Louis Robert, agr. who commented an early draft of this article. A special thanks goes to Elisabeth Groeneveld, M. Sc., who helped with the preparation of the manuscript.

References cited

Angers, D., J. Caron, M. Chantigny, R. Nemati and L. Trépanier. 1998. Structure du sol et rétention en eau. In: La valorisation agricole des résidus papetiers – le cas Daïshowa inc – Document synthèse (1992-1998).

Beauchamp, C.J. and G. Thériault. 1998. General conclusion. In: “La valorisation agricole des résidus papetiers – le cas Daïshowa inc – Document synthèse (1992-1998)”.

Beaudet, P. and J. Champagne. 2003. Les surplus d’engrais de ferme, état de la situation. In: La gestion des engrais organiques dans les régions de fortes concentrations animales. Colloque en agroenvironnement. IRDA, November 2003. Pages 29-44.

Bédard, J., R. L. Granger and F. Granger. 1999. Revue des études sur l’évaluation des pertes de phosphore en milieu agricole. UDA inc. Report presented to l’INRS-Eau.

BPR inc. 2005. Suivi 2003 du Portrait agroenvironnemental des fermes du Québec. Final report. http://www.mapaq.gouv.qc.ca/NR/rdonlyres/D11217A3-F6E8-45C6-BFCC-E3D4E22613D6/0/PAESuivi_2003_rap_final.pdf

BPR-GREPA. 2000. Le portrait agroenvironnemental des fermes du Québec – rapports régionaux. Presented to l’Union des Producteurs agricoles, au MAPAQ and to l’Institut de recherche et développement en agro-environnement inc.

Cabana, Y. 2000. Suivi de la qualité des eaux dans le bassin versant de la rivière l’Assomption : cas de l’azote ammoniacal. Ministère de l’environnement du Québec. Direction régionale de Lanaudière.

Caron, J., G. Thériault and L. Tépanier.1998. Impact environnemental des résidus papetiers. In: La valorisation agricole des résidus papetiers – Le cas Daïshowa inc. – document synthèse 1992-1998. Université Laval.

CFIA. 1996. Guide d’interprétation du Règlement sur les engrais. Canadian Food Inspection Agency. http://www.inspection.gc.ca/francais/plaveg/fereng/1996regsf.shtml#7

Chabot, R., G. Gagné and M.H. Charest. 2000. Évaluation de la disponibilité de l’azote des résidus papetiers : revue de littérature. In: “Actes du 1er colloque sur les biosolides : Les biosolides, une richesse pour les sols”. Pages 132-152. Centre de Référence en agriculture et agroalimentaire du Québec.

Chantigny, M., D.A. Angers and C.J. Beauchamp. 1999. Aggregation and organic matter decomposition in soils amended with de-inking paper sludge. Soil Sci. Soc. Am. J. 63: 1214-1221.

Chantigny, M., D.A. Angers and P. Rochette. 2002. Fate of carbon and nitrogen from animal manure and crop residues in wet and cold soils. Soil biology and biochemistry 34:509-517.

Chantigny, M.H., P. Rochette, D.A. Angers, D. Massé and D. Côté. 2004. Ammonia volatilisation and selected soil characteristics following application of anaerobically digested pig slurry. Soil Science Society of America Journal 68:306-312.

Chantigny, M.H. and D. Angers. 2005. Activité microbiologique et qualité des sols : quoi de neuf sous nos pieds? In: “Colloque en agro-environnement : des outils à notre échelle”. CRAAQ 2005.

Chantigny, M. 2005. Les émissions de GES lors de l’épandage des déjections animales et méthodes de réduction. Presentation given during the conference “La gestion des fumiers et les émissions de gaz à effet de serre en production bovine”. Held in Drummondville, Québec at the Best Western Hotel, 23 March 2005.

Charbonneau, H., M. Hébert and A. Jaouich. 2000. Portrait de la valorisation agricole des MRF au Québec. Partie 1 : Aspects quantitatifs. Vecteur Environnement 33(6):30-32, 41-

51.

Charbonneau, H., M. Hébert and A. Jaouich. 2001.Portrait de la valorisation agricole des MRF au Québec. Partie 2 : Contenu en éléments fertilisants et qualité environnementale. Vecteur Environnement 34(1):56-60.

Chassé, R., M. Hébert and S. Delbean. 2003. Toxicological characterisation of fertilizing residuals for the development of quality criteria. In: “Proceedings of the 2nd Canadian Organic Residuals Recycling Conference”. Held in Penticton, British Columbia, April 24 and 25th 2003. Pages 169-180.

Clément, M.-F. 1996. Stratégie ou démarches pour une valorisation optimale des engrais de ferme. In: “Colloque sur la fertilisation intégrée des sols”. Centre de référence en agriculture et agro-alimentaire du Québec. Pages 139-152.

Clément, M.F. and A. N’Dayegamiye. 2003. Estimation de la contribution en azote de la matière organique du sol. In: “CRAAQ, 2003. Guide de référence en fertilisation”, section 2.2.4. Centre de Référence en agriculture et agroalimentaire du Québec, 1st edition.

Cormier, E. and R. Dauphin. 1998. Minéralisation de l’azote après un épandage d’automne de résidus primaires et secondaires de papetières. Fertival inc.

CRAAQ, 2003. Guide de référence en fertilisation. Centre de Référence en agriculture et agroalimentaire du Québec, 1st edition.

Désilets, L. 2003. Qu'advient-il des boues de traitement des papetières?. Vecteur Environnement 36(1):47-53.

Envir-Eau. 2001. *Modélisation actualisée, Entreposage au champ d'amas de biosolides non couverts*, version finale. Prepared for the Association des industries forestières du Québec and the ministère de l'Environnement du Québec, by Envir-Eau, QB475. 54 pages and appendices.

Environnement Canada, 1984. Normales Climatiques au Canada. Volume 9 – Température du sol, évaporation à la surface des lacs … 1951-1980. Service de l’environnement atmosphérique.

Forcier, F. 2002. Biosolides et bioaérosols: état de la situation.Vecteur Environnement 35(5):21-31

Fortin, S.H . 2000. Rapport préliminaire d’enquête sur les problèmes de santé secondaires à l’entreposage de boues d’abattoir en zone rurale à St-Didace. Direction de santé publique de Lanaudière.

Gagnon, B. 2004. Détermination en incubation contrôlée de la disponibilité des éléments nutritifs des composts produits à la ferme. Agrosol 15(1): 10-17.

Gagnon, B., N. Ziadi and J. Lafont, 2004. Valorisation des boues mixtes de papetières en grandes cultures et en production horticoles : Leur impact sur le rendement, les propriétés du sol et l’environnement. Agriculture et agroalimentaire Canada. Agrosol, 15(1):4-9.

Gagnon, B., R. Simard and R. Robitaille. 1997. Impacts de l’utilisation de différents types de composts agricoles et commerciaux sur la plante, le sol et l’eau. Colloque sur l’agriculture durable : un virage bien amorcé. Saint-Hyacinthe, 26 November 1997.

Gangbazo, G., D. Couillard, A.R. Pesant and D. Cluis. 1993. Effets du lisier de porc sur la charge d’azote et de phosphore dans l’eau de ruissellement sous des pluies simulées. Canadian Agricultural Engineering 35(2): 97-103.

Gangbazo, G., A.R. Pesant, D. Cluis, D. Couillard and G.M. Barnett. 1995. Winter and early spring losses of nitrogen following late fall application of hog manure. Canadian Agricultural Engineering 37(2):73-79.

Gangbazo, G., A.R. Pesant and G.M. Barnett, 1997. Effets de l’épandage des engrais minéraux et des grandes quantités de lisier de porc sur l’eau, le sol et les cultures. Ministère de l’Environnement et de la Faune du Québec.

Gangbazo, G., G.M. Barnett, A.R. Pesant and D. Cluis. 1999. Disposing hog manure on inorganically fertilized corn and forage fields in southeastern Québec. Canadian Agricultural Engineering 41(1):1-12

Gangbazo, G. and F. Babin. 2000. Pollution de l’eau des rivières dans les basins versants agricoles. Vecteur Environnement 33(4):47-57.

Gangbazo, G., D. Cluis and E. Buon. 2002. Transport des sédiments en suspension et du phosphore dans un basin versant agricole. Vecteur Environnement 35(1):43-53.

Gangbazo, G., D. Cluis and E. Buon. 2003. Comportement de l'azote dans une rivière drainant un bassin versant agricole excessivement fertilisé. Vecteur Environnement 36(1):58-67.

Giroux, M., A.R. Michaud, C. Côté, N. Ziasdi, S.P. Guertin and S. Quessy. 2003. Stratégies de réduction à la ferme des risques environnementaux liés à la fertilisation avec des engrais de ferme. In "La gestion des engrais organiques dans les régions de fortes concentrations animales". Agroenvironment symposium, IRDA, November 2003, pages 73-99.

Giroux, M., L. Deschênes and R. Chassé. 2004. Bilan de transfert des éléments traces métalliques dans une prairie et un champ de maïs-grain fertilisés avec des engrais minéraux et des engrais de ferme. Cahiers de l'Observatoire de la qualité des sols. IRDA.

Groeneveld, E. and M. Hébert. 2002. Perceptions d'odeur des matières résiduelles fertilisantes en comparaison avec les engrais de ferme. Vecteur Environnement 35(3):22-26 http://www.menv.gouv.qc.ca/chronique/2002/avril-juin/020523_mrf.htm

Groeneveld, E. and M. Hébert. 2003. MRF - respect des critères d'utilisation sur les fermes. Vecteur Environnement 36(5):48-55. http://www.MENV.gouv.qc.ca/matieres/articles/index.htm

Guay, I *et al*. 2002. Critères de qualité de l'eau de surface au Québec. Ministère de l'environnement du Québec. http://www.MENV.gouv.qc.ca/eau/criteres_eau/index.htm

Hébert, M. 1998. Contamination des sols agricoles du Québec par les éléments traces. Situation actuelle et perspectives. Agrosol 10(2):87-95.

Hébert, M. 2003. Teneurs limites en cadmium et dioxines et furannes des MRF – position du MDDEP. Vecteur Environnement 36(4):80-81.

Hébert, M., V. Rioux and E. Gagnon. 2002. Contrôle de qualité indépendant des MRF par le MDDEP - Partie 1. Vecteur Environnement 35(5):33-37.

Hébert, M., V. Rioux and E. Gagnon. 2003. Contrôle de qualité indépendant des MRF par le MDDEP - Partie 2 : pathogènes et paramètres agronomiques. Vecteur Environnement 36(1):34-40.

Hébert, M. and G. Gagné. 2003. Composts et matières résiduelles fertilisantes – aspects agronomiques. In : "Guide de référence en fertilisation". Centre de Référence en agriculture et agroalimentaire du Québec, 1st edition.

Kodsi, E. and M. S. Cournoyer. 1992. Chaulage et valorisation agricole de boues d'abattoirs - Étude de faisabilité. Final report, prepared for the Ministère de l'Environnement du Québec, Environnement Canada (Centre Saint-Laurent) and Abattoir Bienvenue (Olymel), by Urgel Delisle & Associés, Report 2250-02, 93 pages plus appendices.

Larocque, M., M. Patoine, O. Banton, N. Rousseau and P. Lafrance. 2002. Quantification des pertes de phosphore en milieu agricole – Outil LoPhos. Vecteur Environnement 35(5):43-56.

Machrafi, Y., J. Wamegni, F.-P. Chalifour, G. D. Leroux, G. Tremblay and C. J. Beauchamp. 2003. Use of de-inking paper sludge for sustainable corn and soybean Production. In: "Proceedings of the 2nd Canadian Organic Residuals Recycling Conference". Tenu in Penticton, British Columbia, April 24 and 25 2003, pages 300-312.

Majdoub, R., C. Côté and M. Duchemin. 2004. Risques de contamination microbiologique des eaux souterraines et mesures préventives à adopter. Vecteur Environnement 3(2):61-66.

MAPAQ, MDDEP, UPA, MSSS and MAM, 1998. Rapport au groupe de travail interministériel relatif à l'interdiction d'épandre des fumiers après le 1er octobre. Document de travail. Groupe technique sur la date limite d'épandage du 1er octobre. 8 May 1998.

MDDEP. 2002. Questions et réponses sur la valorisation agricole des matières résiduelles fertilisantes. http://www.MENV.gouv.qc.ca/matieres/mat_res/fertilisantes/faq.htm

MDDEP. 2003. Synthèse des informations environnementales disponibles en matière agricole au Québec. Ministère du

Développement durable, de l'Environnement et des Parcs du Québec. http://www.MENV.gouv.qc.ca/milieu_agri/agricole/synthese-info/index.htm

MDDEP. 2004. Guide sur la valorisation des matières résiduelles fertilisantes. Ministère du Développement durable, de l'Environnement et des Parcs du Québec. http://www.MENV.gouv.qc.ca/matieres/mat_res/fertilisantes/critere/index.htm

N'Dayegamiye, A., S. Huard and Y. Thibault. 2001. Valeur fertilisante des boues mixtes de papetières (biosolides) dans des sols cultivés en maïs-grain, soya et orge. IRDA. Agrosol 12(1):25-34.

N'Dayegamiye, A., M. Giroux and R. Royer. 2004a. Épandages d'automne et de printemps de divers fumiers et boues mixtes de papetières : coefficients d'efficacité et nitrates dans le sol. Agrosol 15(2):97-106.

N'Dayegamiye, A. Drapeau, S. Huard and Y. Thibault. 2004b. Intégration de boues mixtes et de fumiers dans des rotations de cultures : réponse des cultures et interactions avec les propriétés du sol. Agrosol 15(2):83-90.

National Academy Of Sciences. 2002. *Biosolids Applied To Land : Advancing Standards and Practice*s. Prepublication copy. Committee on Toxicants and Pathogens in Biosolids Applied to Land; Board on Environmental Studies and Toxicology; Division on Earth and Life Studies; National Research Council. National Academy Press, Washington D.C., 266 pages.

Nicolardot, B., V. Parnaudeau, S. Guénermont and al. 2003. Disponibilité en azote des effluents urbains, agro-industriels et issus d'élevage. In: "Agriculture et épandage de déchets urbains et agro-industriels". Dossier de l'environnement de l'IRDA no 25. Pages 15-26.

OAQ. 2004. Ligne directrice de l'Ordre des agronomes du Québec (OAQ) sur la gestion des matières fertilisantes. Ordre des agronomes du Québec. http://www.oaq.qc.ca/Lignes_Grilles_Avis/Ligne_gestion_matieres_fertilisantes.pdf

Potvin, D. 2003. Compostage Au Québec - Enquête 2002. 4e Colloque québécois sur la gestion des matières résiduelles. Held 21-22 October 2003 in Saint-Hyacinthe, Québec. Association Québécoise des Industriels du Compostage.

Pouliot, M.-A., R. Landry and J. Vigneux. 1998. Épandage automnal de boues primaires et secondaires de papetières. GSI Environnement.

Québec. 2000. Politique québécoise de gestion des matières résiduelles 1998-2008. Gazette Officielle du Québec, partie I, n^{o} 39, 30 septembre 2000, 132^{e} année, pages 968-974.

Québec. 2004. Étude sur la qualité de l'eau potable dans sept bassins versants en surplus de fumier et impacts potentiels sur la santé - Résultats et plan d'action. Press release http://www.MENV.gouv.qc.ca/Infuseur/communique.asp?no=644

Québec. 2004a. Règlement sur les exploitations agricoles. http://www.MENV.gouv.qc.ca/publications/lois_reglem.htm

Québec. 2002b. Règlement sur le captage des eaux souterraines.

Québec. 2003. Loi sur la qualité de l'environnement, L.R.Q., c. Q-2.

Rioux, V. 2002. Contrôle de la qualité des matières résiduelles fertilisantes (MRF) valorisées en agriculture. Essay presented to the Faculté des sciences, in partial fulfillment of the requirements for a master's in environment. Université de Sherbrooke. Mars 2002. 102 pages.

Rochette, P. 2004. Les sources agricoles de gaz à effet de serre (GES) au Canada. Agriculture et agro-alimentaire Canada, Sainte-Foy.

Rochette, P., M.H. Chantigny, D.A. Angers, N. Bertrand and D. Côté. 2001. Ammonia volatilisation and soil nitrogen dynamics following fall application of pig slurry on canola crop residues. Canadian Journal of Soil Science, pages 515-523.

Rochette. P., D.A. Angers, M.H. Chantigny, N. Bertrand and D. Côté. 2004a. Carbon Dioxide and Nitrous Emissions following Fall and Spring Applications of Pig Slurry to an Agricultural Soil. Soil Science Society of America Journal 68:1410-1420.

Rochette, P., M. Chantigny, D. Angers and A. Vanasse. 2004b. Gestion de l'azote des fumiers : comment réduire les pertes?

Agriculture et agro-alimentaire Canada., Sainte-Foy.

Seydoux, S., D. Cöté and M. Grenier. 2004. Caractérisation des volumes et des concentrations en éléments fertilisants des déjections animales liquides en Chaudière-Appalaches. Institut de recherche et de développement en agroenvironnement.

Simard, A., 2004. Portrait global de la qualité de l'eau des principales rivières du Québec. Sur le site-web du Ministère du Développement durable, de l'environnement et des Parcs du Québec www.menv.gouv.qc.ca/eau/sys-image/global/index

Smith, E. 2005. Ontario's approach to biosolids. In: "First Canadian national wastewaster forum". Held in Montréal, 3-5 April 2005. Canadian water and wastewater association.

Thériault, G. 2001. Épandage non conforme de matières résiduelles fertilisantes dans la région du Pontiac, Direction de la santé publique de l'Outaouais.

Topp, E. and A. Scott. 2003. Persistence of pathogenic and indicator bacteria in agricultural Soils. In: "Proceedings of the 2nd Canadian Organic Residuals Recycling Conference". Held in Penticton, British Columbia, 24-25 April 2003. Pages 313-322.

Tran, T.S., M. Giroux and A. N'Dayegamiye. 1992. Utilisation rationnelle des fumures azotées minérales : aspects agronomiques et environnementaux. Agrosol 5(2):18-24.

Tran, T.S., D. Isfan, F. Chalifour, A. Mailloux and S.P. Guertin. 1996. Utilisation rationnelle de l'azote en agriculture. In: "Colloque sur la fertilisation intégrée des sols". Held in Québec, 24 January 1996. Centre de référence en agiculture et agro-alimentaire du Québec. Pages 19-47.

Trudelle, M., M-F. Clément, M. Lavoie and D. Côté. 1996. Engrais et amendements organiques. In: "Colloque sur la fertilisation intégrée des sols". Held in Québec, 24 janvier 1996. Centre de référence en agiculture et agro-alimentaire du Québec. Pages 135-160

Unc, A., M.J. Goss and S. Springthorpe. 2003. Factors important for the transport and survival of microbes from materials (manure/biosolids) applied to land. In: "Proceedings of the 2nd Canadian Organic Residuals Recycling Conference". Held in Penticton, British Columbia, 25-25 April 2003. Pages 181-199.

USEPA. 1999. Control of Pathogens And Vector Attraction In Sewage Sludge (Including Domestic Septage) Under 40 CFR Part 503. Environmental regulations and technology. EPA/625/R-92/013, December 1992, revised October 1999. 154 pages.

Van Coillie, R. and M. Laquerre. 2003. Critères de qualité et risques du cadmium et des dioxines et furannes chlorés des matières résiduelles fertilisantes au Québec. Vecteur Environnement 36(1):22-33.

Van Ham, M.and C. Henry. 1995. Carey Island Nitrogen Leaching Study. Unpublished report to Greater Vancouver Regional District, Vancouver, B.C., Canada.

Watt, S. 2001. Étude comparative des effets de différents résidus organiques sur les propriétés physico-chimiques et biologiques reliées à la qualité des sols. Master's thesis. Université Laval.