Fall spreading of fertilizing residuals
– environmental risks
and preventive measures

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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 (CH₄ and possibly N₂O 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-NH₄/Ntotal of FR, and to reduce risks of surface water contamination by pathogens.

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

\[
\text{Risk} = f(\text{contamination level}; \text{exposure})
\]

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>
<thead>
<tr>
<th>Types de MRF</th>
<th>Tonnes humides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biosolides papetiers</td>
<td>720 000</td>
</tr>
<tr>
<td>Biosolides municipaux</td>
<td>70 000</td>
</tr>
<tr>
<td>Biosolides d'abattoirs</td>
<td>45 000</td>
</tr>
<tr>
<td>Biosolides agroalimentaires autres</td>
<td>20 000</td>
</tr>
<tr>
<td>Composts commerciaux</td>
<td>55 000</td>
</tr>
<tr>
<td>Cendres</td>
<td>60 000</td>
</tr>
<tr>
<td>Poussières de cimenteries</td>
<td>50 000</td>
</tr>
<tr>
<td>Résidus alcalins de papetières</td>
<td>37 000</td>
</tr>
<tr>
<td>Résidus magnésiens</td>
<td>25 000</td>
</tr>
<tr>
<td>Autres ACM</td>
<td>25 000</td>
</tr>
<tr>
<td>Total</td>
<td>1 107 000</td>
</tr>
</tbody>
</table>
Environmental pressures

Quantities of FR

More than one million 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 million 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)
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-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-NH$_4$ level of mixed paper mill biosolids, due to microbial activity (Envir-Eau 2001). When papermill biosolids with a C/N $\leq$ 20 are stored for a few weeks, the N-NH$_4$/N$_{total}$ can reach 32% (Rioux 2002; N’Dayegamiye

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

<table>
<thead>
<tr>
<th>FR/Farm fertilizer</th>
<th>Dry matter C/N</th>
<th>N-NTK mg/kg (d.w.)</th>
<th>N-NH$_4$ mg/kg (d.w.)</th>
<th>N-NH$<em>4$/N$</em>{total}$%</th>
<th>P$_2$O$_5$ mg/kg (d.w.)</th>
<th>kg/w.w. ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed paper mill biosolids$^1$</td>
<td>26</td>
<td>23 700</td>
<td>6.2</td>
<td>1 024</td>
<td>4%</td>
<td>9 611</td>
</tr>
<tr>
<td>Primary paper mill biosolids$^{1,2}$</td>
<td>44</td>
<td>1 500</td>
<td>0.7</td>
<td>29</td>
<td>2%</td>
<td>782</td>
</tr>
<tr>
<td>Municipals biosolides$^{1,3}$</td>
<td>23</td>
<td>30 000</td>
<td>6.9</td>
<td>194</td>
<td>11%</td>
<td>26 757</td>
</tr>
<tr>
<td>Abattoir biosolides and residuals$^1$</td>
<td>9</td>
<td>61 000</td>
<td>5.2</td>
<td>10 189</td>
<td>17%</td>
<td>32 482</td>
</tr>
<tr>
<td>Other biosolids and agri-food residuals$^1$</td>
<td>13</td>
<td>40 500</td>
<td>5.4</td>
<td>7 605</td>
<td>19%</td>
<td>51 296</td>
</tr>
<tr>
<td>Commercial composites$^1$</td>
<td>54</td>
<td>12 000</td>
<td>6.5</td>
<td>121</td>
<td>1%</td>
<td>16 045</td>
</tr>
<tr>
<td>Magnesium residuals (SPD)$^1$</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11 214</td>
</tr>
<tr>
<td>Ash$^1$</td>
<td>79</td>
<td>165</td>
<td></td>
<td></td>
<td></td>
<td>12 514</td>
</tr>
<tr>
<td>Cement kiln dust$^1$</td>
<td>91</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>740</td>
</tr>
<tr>
<td>Liquid hog manure – feeder$^4$</td>
<td>4</td>
<td>100 000</td>
<td>4.0</td>
<td>57 500</td>
<td>58%</td>
<td>57 500</td>
</tr>
<tr>
<td>Solid cattle manure with straw$^5$</td>
<td>22</td>
<td>26 000</td>
<td>5.6</td>
<td>5 761</td>
<td>12%</td>
<td>17 593</td>
</tr>
<tr>
<td>Liquid cattle manure$^5$</td>
<td>7</td>
<td>40 000</td>
<td>2.9</td>
<td>24 306</td>
<td>60%</td>
<td>20 833</td>
</tr>
<tr>
<td>Chicken manure$^5$</td>
<td>53</td>
<td>41 000</td>
<td>21.5</td>
<td>9 630</td>
<td>24%</td>
<td>43 238</td>
</tr>
<tr>
<td>Farm composts$^6$</td>
<td>29</td>
<td>25000</td>
<td>7.3</td>
<td>951</td>
<td>4%</td>
<td>33 000</td>
</tr>
</tbody>
</table>

(1) From Charbonneau et al. (2001) and MDDEP (unpublished data) for fresh samples. Levels of N-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-NH$_4$/N$_{total}$ ratio for liquid hog manure may reach 80% (Rochette et al., 2001).

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


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

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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 odor 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>
<thead>
<tr>
<th></th>
<th><em>E. coli</em> (MPN/g dry wt.)¹</th>
<th><em>Salmonella</em> (MPN/4 g dry wt.)¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 FR criteria – all purpose</td>
<td>&lt; 1 000</td>
<td>absence</td>
</tr>
<tr>
<td>P2/P3 FR criteria – restricted use</td>
<td>&lt; 2 000 000</td>
<td>n/a</td>
</tr>
<tr>
<td>Cow manure (n=5)²</td>
<td>64 000; (min=235; max =285 000)</td>
<td>Detected in 100% of the cases</td>
</tr>
<tr>
<td>Liquid hog manure (n=6)²</td>
<td>15 000 000; (min=5 x 10⁵; max =5 x 10⁷)</td>
<td>Detected in 67% of the cases</td>
</tr>
</tbody>
</table>

(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.

Table 3. Levels of *E. coli* and *Salmonella* in farm fertilizers, and the quality criteria for FR (from Hébert et al. 2003).
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
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 4. Residual soil nitrogen in the fall as a function of the preceding crop or the fall spreading of paper mill biosolids.

<table>
<thead>
<tr>
<th>Preceding crop</th>
<th>Biosolids application</th>
<th>Spreading date</th>
<th>Soil levels (kg/ha)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C/N t/ha kg-N-H₄/ha</td>
<td></td>
<td>N-NH₄ N-NO₂</td>
<td></td>
</tr>
<tr>
<td>Corn</td>
<td>-  0 - -</td>
<td>n.a.¹</td>
<td>23-175</td>
<td>Tran et al. (1992)</td>
</tr>
<tr>
<td>Corn</td>
<td>-  0 - -</td>
<td>n.a.</td>
<td>18-145</td>
<td>5 studies cited by Giroux et al. (2003)</td>
</tr>
<tr>
<td>Potatoes</td>
<td>-  0 - -</td>
<td>n.a.³</td>
<td>23-40</td>
<td>1 study cited by Giroux et al. (2003)</td>
</tr>
<tr>
<td>Wheat</td>
<td>-  0 - -</td>
<td>n.a.³</td>
<td>23-75</td>
<td>Tran et al. (1992)</td>
</tr>
<tr>
<td>Barley or canola</td>
<td>-  0 - -</td>
<td>n.a.³</td>
<td>11-42</td>
<td>2 studies cited by Giroux et al. (2003)</td>
</tr>
<tr>
<td>Hay fields</td>
<td>-  0 - -</td>
<td>n.a.³</td>
<td>7-9</td>
<td>1 study cited by Giroux et al. (2003)</td>
</tr>
<tr>
<td>n.a.¹</td>
<td>20 30 48 1 October</td>
<td>n.a.³</td>
<td>0² 33²</td>
<td>N'Dayegamiye et al. (2004)</td>
</tr>
<tr>
<td>n.a.¹</td>
<td>24 30 6 1 October</td>
<td>n.a.³</td>
<td>0² 20²</td>
<td>N'Dayegamiye et al. (2004)</td>
</tr>
<tr>
<td>n.a.¹</td>
<td>21 40 n.a.¹ 23 October</td>
<td>8² 52²</td>
<td>n.a.</td>
<td>Cormier &amp; Dauphin (1998)</td>
</tr>
<tr>
<td>n.a.¹</td>
<td>18 40 19 31 October</td>
<td>n.a.³</td>
<td>0²</td>
<td>Poulit et al. (1998)</td>
</tr>
</tbody>
</table>

(1) n.a. = not available
(2) Excess soil N-NO₂ or N-NH₄ as compared to the control plots without biosolids (Nₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑₑ水肿
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.

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Main impacts/uses</th>
<th>Criteria/Reference value</th>
<th>Level of concern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspended solids (SS)</td>
<td>Organic or inorganic particles found in water.</td>
<td>Problems related to sedimentation. See also turbidity.</td>
<td>R.V.(^2) : 13 mg/L</td>
<td>1</td>
</tr>
<tr>
<td>Turbidity</td>
<td>Cloudiness of water caused by various substances, including SS.</td>
<td>Aesthetic problems. Also limits drinking water disinfection capacity.</td>
<td>Criteria : 5 UNT(^3)</td>
<td>1</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>Nutrient. In excess, it alters eutrophication.</td>
<td>Various uses impacted (drinking water, recreational activities, aquatic organisms).</td>
<td>Criteria : 0.03 mg/L</td>
<td>2</td>
</tr>
<tr>
<td>Total chlorophyll a</td>
<td>Phyto-plankton pigment. Eutrophication indicator.</td>
<td>See total phosphorus.</td>
<td>R.V. : 8.6 mg/m(^3)</td>
<td>2</td>
</tr>
<tr>
<td>Fecal coliforms</td>
<td>Bacterial group used as indicators of fecal contamination.</td>
<td>Various uses (drinking water, recreational activities).</td>
<td>Criteria : 200 CFU/100 ml (contact)</td>
<td>3</td>
</tr>
<tr>
<td>Nitrates/nitrites</td>
<td>Mineral form of nitrogen naturally present in low concentrations.</td>
<td>Drinking water (methemoglobinemia of newborns and possibly a cancer causing agent)</td>
<td>Standard : 10 mg N-NO(_3)/L R.V. : 1 mg/l</td>
<td>3</td>
</tr>
<tr>
<td>Ammonia nitrogen (NH(_3) or NH(_4))</td>
<td>Mineral form of nitrogen naturally present in low concentrations. Nitrate precursor.</td>
<td>Hinders drinking water disinfections. Toxic to fish.</td>
<td>Criteria : 0.5 mg/L R.V. : 1.5 mg/L(^4)</td>
<td>4</td>
</tr>
</tbody>
</table>

(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)

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 to pristine levels, they are rarely polluted by nitrates (that is, exceedances of regulatory standards).
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.

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-NH₄/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 NH₄ concentrations which reached 2.2 mg N-NH₄/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 NH₄ 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 NH₃ 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 NH₄ will runoff. Fourth, the extremely high water levels of N-NH₄ 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-NH₄ 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 NH₄ 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 (N₂O),** also known as dinitrogen oxide or dinitrogen monoxide is a greenhouse gas 310 times more powerful than CO₂. 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 N₂O (Chantigny, personal communication). The N₂O results from the denitrification of nitrates accumulated in the soils, especially under humid conditions (Rochette 2004). Losses of N₂O in winter under snow cover are significant (van Bochove et al. 1996, cited by Chantigny et al. 2002) and evidence suggests that N₂O 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 N₂O emission than spring spreading. However, the reverse phenomena may also be observed, according to pedoclimatic conditions which vary between years (Rochette et al. 2004a).

Because fertilizing residuals contain less mineral nitrogen than liquid manures, the risk of N₂O 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 landfillsing 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 \textit{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 \textit{et al.} 1998; chasse \textit{et al.} 2003). This takes into account that limited fertilizing residual loadings do 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 \textit{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 \textit{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 Cottile & 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 \textit{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 (MDDEP 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 \textit{a priori} and \textit{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 are 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).

**Ordonnance des agriculteurs 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 agriculturists. 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<sub>total</sub>/ha liquid pig manure on hayfields in the fall, losses of N-NH₄ 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 losses 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

<table>
<thead>
<tr>
<th>Environment/resource to protect</th>
<th>Environmental indicator</th>
<th>Degradation level of the environment/resource</th>
<th>FR fall spreading risks</th>
<th>Status of current measures taken by the MDDEP for FR</th>
<th>Extra measures for fall spreading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underground water (drinking)</td>
<td>Nitrates</td>
<td>Low, except for specific aquifers (2.6% of wells exceed the 10 mg/L standard)</td>
<td>Low to none is the residuals C/N &gt; 30, or for composts Higher if the N-NH₄/N ratio is high and spreading is done in warm soil (early spreading)</td>
<td>Satisfactory (doses according to the needs of plants, setback distances).</td>
<td>Limit loadings for biosolids with a C/N &lt; 30.</td>
</tr>
<tr>
<td>E.coli</td>
<td>Low except for specific aquifers</td>
<td>Probably no difference with regards to catchment works</td>
<td>Sufficient (RRGC, FR Guide)</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Turbidity and SS</td>
<td>Very high</td>
<td>No direct causality link. Indirect advantages (soils, erosion)</td>
<td>Sufficient</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>High to very high</td>
<td>Higher than for a spring spreading</td>
<td>Parameter already highly managed (RRAO)</td>
<td>Dose limits. Use of existing management tools (LoPhos, etc.)</td>
<td></td>
</tr>
<tr>
<td>Fecal coliforms</td>
<td>Moderate to very high (Cf. Walkerton)</td>
<td>Low probability of an impact (few P2/P3 FR as compared to manures, setback distances)</td>
<td>Sufficient</td>
<td>Injection/ incorporation of liquid P2/P3 residuals on bare soil, if this does not increase erosion risks</td>
<td></td>
</tr>
<tr>
<td>Ammonium (NH₄)</td>
<td>Variable (low in the summer, but higher in the winter in certain watersheds). Unknown for small water courses</td>
<td>Higher if the total N- NH₄/N ration is high, with a late spreading</td>
<td>Insufficient</td>
<td>Limit doses when the soil is cold. Superficial injection/ incorporation on bare soil, if this does not increase erosion risks</td>
<td></td>
</tr>
<tr>
<td>Nitrates (NO₃)</td>
<td>Low</td>
<td>Higher if C/N &lt; 30</td>
<td>Sufficient</td>
<td>None. Indirect limitation via N- NH₄</td>
<td></td>
</tr>
<tr>
<td>Odours – psychological distress</td>
<td>Not determined, but possibly very high (spreading manure in the spring and in the summer)</td>
<td>Much lower than in the spring and summer (lower exposure)</td>
<td>Possibly sufficient (odour categories, setback distances, prohibition dates by municipalities)</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Bioaerosols</td>
<td>Not determined</td>
<td>Lower (less exposure as compared to spring and summer)</td>
<td>Possibly sufficient (setback distances)</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Greenhouse gases</td>
<td>Very high</td>
<td>Probably higher as compared to spring/summer if high levels of NH₄. Lower is the residual has C/N ratio &gt; 30, or for composts</td>
<td>Insufficient</td>
<td>Limit NH₄ doses (see NH₄). Limit landfilling (methane)</td>
<td></td>
</tr>
<tr>
<td>Trace elements in fertilizing residuals</td>
<td>Low (comparing actual levels versus toxicological criteria.)</td>
<td>No causality link with the spreading time.</td>
<td>Sufficient for the short term. Probably sufficient long term (C2 limits)</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Erosion</td>
<td>Very high (see SS and soil degradation study (Tabi et al., 1990).</td>
<td>No direct causality. However fall spreadings increase soil organic matter, indirectly reducing erosion risks.</td>
<td>Sufficient.</td>
<td>Avoid working the soil (incorporation) on hay fields or direct seeding.</td>
<td></td>
</tr>
<tr>
<td>Pathogens</td>
<td>Not determined</td>
<td>Lower (longer delay between spreading and harvest).</td>
<td>Sufficient (prohibitions, delays).</td>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>

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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.

<table>
<thead>
<tr>
<th>FR type</th>
<th>Additional measures¹</th>
<th>Justification</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composts</td>
<td>None</td>
<td>Composts have very little mineral nitrogen ($N_{\text{mineral}}/N_{\text{total}}$ ratio of 4% for farm composts). They contain little or many fewer pathogens than animal manure.</td>
<td>A farm compost is partially deodorized and have $N_{\text{NH}_4}$ levels &lt; 2000 mg/kg, d.w. (Gagnon et al., 2004); otherwise it must be managed like a solid manure. Commercial composites are generally more mature and contain little ammonia nitrogen.</td>
</tr>
<tr>
<td>Biosolids, C/N ≥ 30</td>
<td>None</td>
<td>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.</td>
<td>On an agronomic basis, biosolids with C/N ratio &gt; 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).</td>
</tr>
<tr>
<td>Biosolids, C/N ≥ 20 and &lt; 30</td>
<td>≤ 40 tons/ha (wet weight basis)¹</td>
<td>A C/N &gt; 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 &amp; Dauphin (1998), Pouliot et al. (1998) and N'Dayegamiye et al. (2004) obtained an ammonia nitrogen soil loading of 17 kg N-NH$_4$/ha (max.: 48 kg N-NH$_4$/ha). The authors also measured a relatively low nitrate accumulation in the soil profile in December (Table 4).</td>
<td>This spreading dose is compatible with acceptable agronomic crop yields (Gagnon et al. 2004) and is technically feasible (Charbonneau et al. 2000).</td>
</tr>
<tr>
<td>Biosolids, C/N &lt; 20</td>
<td>≤ 35 kg N-NH$_4$/ha¹</td>
<td>These biosolids may have a significant proportion of their nitrogen as ammonia, which makes them more similar to solid and liquid manures. The N-NH$<em>4$ loading is less or comparable to 55 kg N$</em>{\text{total}}$/ha for liquid hog manure (which adds 30 to 40 kg N-NH$_4$/ha). This loading corresponds to a relatively low contamination risk (Figure 4).</td>
<td>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-NH$<em>4$/N$</em>{\text{total}}$ ratio of 30% (40% if the biosolid have a C/N &lt; 15). However, if the biosolid has a pH &gt;11, or a dryness &gt; 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 &lt; 20.</td>
</tr>
<tr>
<td>Liquid FR</td>
<td>≤ 35 kg N-NH$_4$/ha.</td>
<td>Soil injection/ incorporation for P2/P3 if this does not increase soil erosion risks¹</td>
<td>This ammonium loading implies doses &gt; 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-NH$<em>4$/N$</em>{\text{total}}$ &gt; 50%) should not be spread post-harvest if the main objective is nitrogen fertilization, as a significant proportion may be lost the following spring.</td>
</tr>
<tr>
<td>Liming amendments</td>
<td>None</td>
<td>These FR (wood ash, cement kiln dust, etc.) have little or no nitrogen.</td>
<td>(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).</td>
</tr>
</tbody>
</table>
the regulatory framework (Response) differ on many levels.

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