# TECHNOLOGIES TO ADDRESS ENVIRONMENTAL ISSUES

**Suzelle Barrington**
**Department of Agricultural and Biosystems Engineering,**
**Macdonald Campus of McGill University**

## THE ISSUES

In Canada, environmental issues are the only reasons used by the news media to discuss the livestock industry, when for most other industries, economic issue are of much greater interest. The controversy in this fact, is that the Canadian livestock industry grosses annually over $15 billion which is as much if not more than many other industries. Furthermore, its environmental impact has not been worse than that of other industries, such as the pulp and paper industry using our major rivers to transport its logs, and the electronic industry sending annually to landfills, tons of obsolete systems rich in heavy metals.

The Canadian livestock industry has therefore been quite successful in resolving its environmental issues, improving the quality of our soil, water and air resources. Although modern intensified livestock operations do concentrate wastes and offer a large point source of waste, their manure management is more cost effective. The large quantities of manure justify the purchase and operation of equipment concentrating manure nutrients and reducing odours.

The present paper will therefore review the technologies that have been developed to handle the manure produced by intensive livestock operations, with minimum impact on our resources, soil, air and water. Intensive livestock operations can be found under two circumstances:

1. those enterprises surpassing the size of the average farm by a factor of 5 or more, and
2. regions where livestock intensify exceeds 1 large animal unit (AU)/tillable ha.

## THE LIVESTOCK INDUSTRY

The North American livestock industry has not grown significantly in numbers but rather in enterprise size and in production level (Table 1), and this over the past 30 years. Cattle and sheep numbers have dropped by 17% while hog and chicken numbers have increased by 7.5% and 34%, respectively. Nevertheless, net production has greatly increased, especially for milk and eggs, (20% and 30%), indicating that yield per animal has increased even more as a consequence of heavier feeding regimes with higher feed protein and mineral content. The quantity of manure produced has increased exponentially with higher feed nutrient, because of the low digestion capability of most livestock.

As a result, livestock manure accounts for 69% of the total dry mass of organic waste produced on an annual basis in Québec (Table 2), which also reflects the North American situation. In Canada alone, livestock manure contains some 1 080, 675 and 1 120 million tons of nitrogen, phosphorous and potassium, respectively. Although some of this nitrogen is lost through handling, all the phosphorous and potassium remain (Garcia Moreno 1993).

**Table 1. Evolution of livestock numbers and animal production in North America from 1975 to 1995 (Encyclopedia Britannica inc., 1989 and 1999).**

| Livestock | 1975 | 1985 | 1995 |
|---|---|---|---|
| Cattle and sheep, 1 000 head | 143,2 | 127,7 | 122,8 |
| Hogs, 1 000 head | 58,9 | 63,0 | 67,7 |
| Milk, 1 000 tons | 62,0 | 73,4 | 79,3 |
| Eggs, 1 000 tons | 4 115 | 4 369 | 4 907 |
| Chickens, 1 000 head | 1 006 | 1260 | 1692 |

**Table 2. Organic waste production in Québec (dry matter basis) ( CQVB 1991).**

| Source | Organic waste production, Dry 1000 tons/yr | Percentage (dry mass basis) % |
|---|---|---|
| Domestic waste | | |
| - food waste | 550 | 1,6 |
| - cardboard | 660 | 1,9 |
| - garden waste | 220 | 0,6 |
| - total | 1 430 | 4,1 |
| Institutional and commercial waste | 2 000 | 5,8 |
| Wastewater sludge | 5 100 | 14,7 |
| Pulp and paper | | |
| - bark | 930 | 2,7 |
| - sludge | 1 070 | 3,0 |
| - ashes | 70 | 0,2 |
| - floating residues | 125 | 0,4 |
| - total | 2 195 | 6,3 |
| Livestock | 24 000 | 69,1% |
| Total | 34 725 | 100% |

## 1. Problems of Localised Waste Surpluses

The intensification of the livestock industry has created manure surpluses in some regions of Canada: the B.C. Fraser Valley; the region of Lethbridge, Alberta; and the regions of St Hyacinthe, L'Assomption and Beauce in Québec. Québec is the Canadian Province with the highest livestock density per tilled surface.

Nevertheless, Canada is not the country with the highest average livestock (Animal Unit = AU) density. Among the countries with the highest livestock densities are China, Denmark, The Netherlands, and Japan (Table 3). In these countries, average livestock densities exceed 1 AU per ha, when the average density in Canada is 0.19 AU/ha. In some regions of Canada, though, average livestock densities exceed or come close to exceeding 1 AU/ha. For example, in the Provinces of Ontario and Québec, such livestock densities are found in the Southern region of Ontario and in the Regions of Lanaudière (North East of Montréal), Estrie (Eastern Townships) and Chaudière-Appalaches (South of Québec City) (Table 4).

**Table 3. World livestock densities (1990) expressed in large animal units (AU) ( Statistics Canada 1990; Encyclopedia Britannica inc. 1999).**

| Province or Country | Cattle $10^3$ AU | Hog $10^3$ AU | Sheep $10^3$ AU | Poultry $10^3$ AU | Total $10^3$ AU | Tilled land $10^3$ ha | Density AU/ ha |
|---|---|---|---|---|---|---|---|
| | Cattle | Hogs | Sheep | Poultry | Total | | |
| Canada | 6145.9 | 2106.4 | 95.0 | 170.7 | 8518 | 45485 | 0.19 |
| - Maritime | 169.4 | 70.4 | 6.9 | 15.2 | 261.9 | 520 | 0.50 |
| - Québec | 706.5 | 595.0 | 14.8 | 29.1 | 1345.4 | 2115 | 0.64 |
| - Ontario | 1125 | 636.2 | 26.9 | 63.7 | 1851.8 | 4050 | 0.46 |
| - Prairies | 3775 | 758.0 | 39.1 | 41.6 | 4611.2 | 37910 | 0.12 |
| - B.C. | 370 | 46.8 | 7.3 | 21.1 | 445.2 | 890 | 0.50 |
| China | 58 230 | 93 611 | 16 586 | 24 084 | 19 551 | 166 902 | 1.17 |
| Denmark | 1015 | 2220 | 21 | 154 | 3410 | 2 728 | 1.25 |
| France | 10 332 | 2 993 | 1 308 | 1 852 | 16 485 | 30 060 | 0.55 |
| Germany | 7 880 | 4 857 | 291 | 822 | 13 850 | 17 344 | 0.80 |
| Japan | 2 375 | 1 962 | 2 | 2 472 | 6 811 | 5 038 | 1.35 |
| Spain | 2 957 | 3 854 | 2 998 | 1 008 | 10 817 | 30 816 | 0.35 |
| USA | 50 730 | 11 234 | 992 | 12 424 | 75 380 | 393 471 | 0.19 |
| Argentina | 27 300 | 640 | 2 050 | 440 | 30 430 | 177 440 | 0.17 |
| Brazil | 80 500 | 6 280 | 2 300 | 7 200 | 96 300 | 376 300 | 0.26 |
| Chili | 1 880 | 350 | 470 | 560 | 3 260 | 8 746 | 0.37 |
| Peru | 2 350 | 510 | 1 700 | 640 | 5 200 | 14 900 | 0.35 |

These high livestock densities lead to excess amounts of manure nutrients for the tilled land base. Thus, applying this amount of manure to the regional land base leads to the accumulation of excessive amounts of nutrients (nitrogen (N), phosphorus (P) and potassium (K)) and the pollution of soils, which in turn produce sediments and drainage contaminating our water resources. The only solution out of this situation is to concentrate the manure nutrients to export them to outer regions, with no manure surpluses or to transform the manure into a by-product. This last solution has produced much controversy especially since the incident of mad cow disease, which developed in the United Kingdom.

The impact of high livestock densities on manure application rates is illustrated in Table 5. To further demonstrate the level of livestock manure applied, the N, P and K requirements for corn and cereals are added at the bottom of the Table. In Canada and the USA, manure application rates are well under that required by corn, the main crop. In Europe, where cereals are the main crop, manure N, P and K levels exceed that up-taken by the plant. In such a case, manure nutrients accumulation in the soil and eventually leach with drainage to contaminate water resources.

**Table 4. Livestock densities in Ontario and Québec (1995) expressed in large animal units (Statistics Canada 1995).**

| Region | Cattle $10^3$ AU | Hog $10^3$ AU | Sheep $10^3$ AU | Poultry $10^3$ AU | Total $10^3$ AU | Land $10^3$ ha | Density AU/ ha |
|---|---|---|---|---|---|---|---|
| **Ontario** | | | | | | | |
| Niagara | 248.9 | 259.8 | 6.8 | 15.9 | 531.3 | 1191 | 0.46 |
| South | 619.5 | 378.3 | 16.4 | 15.9 | 1030.1 | 1073 | 0.96 |
| West | 226.2 | 19.1 | 6.2 | 15.9 | 267.3 | 379 | 0.71 |
| Central | 285.6 | 22.7 | 7.3 | 15.9 | 331.4 | 487 | 0.68 |
| East | 85.9 | 2.8 | 1,6 | - | 90.3 | 123 | 0.73 |
| **Québec** | | | | | | | |
| Montérégie | 184.4 | 129.3 | 2.7 | 63.0 | 379.7 | 527.8 | 0.72 |
| Mauricie Bois Franc | 176.3 | 53.9 | 3.2 | 27.5 | 260.9 | 314.1 | 0.83 |
| Laurentides | 31.4 | 2.6 | 0.3 | 3.8 | 38.1 | 69.8 | 0.55 |
| Estrie | 101.9 | 16.2 | 4.6 | 3.4 | 126.1 | 128.7 | 0.98 |
| Lanaudière | 37.4 | 23.6 | 1.6 | 70.1 | 132.7 | 107.8 | 1.23 |
| Gaspésie | 8.0 | 0.024 | 1.0 | 0.036 | 9.1 | 18.7 | 0.49 |
| Chaudière Appalaches | | | | | 300.0 | 230.2 | 1.30 |
| Bas St Laurent | | | | | 99.1 | 184.3 | 0.54 |
| Québec | 28.3 | 2.3 | 0.55 | 9.1 | 41.3 | 60.6 | 0.68 |
| Lac St Jean | 53.2 | 0.7 | 1.07 | 4.2 | 59.7 | 119.1 | 0.50 |
| Outaouais | 55.7 | 0.04 | 0.62 | 0.12 | 58.8 | 80.75 | 0.73 |

## 2. Characteristics of Livestock Manures

Along with an increase in production, livestock enterprises have been specialising and consolidating to remain competitive with the opening of world markets. Livestock enterprises now house a greater number of head under the same roof and, to facilitate manure management, it is diluted to a water content exceeding 92%. Typical swine and dairy manure water levels out of the barn are 93 and 95% whereas handled as a solid, the water content of this manure would exceed 80%. Once stored over the winter in an open outdoor pit, this manure has a water content of 95 and 97%. This additional water dilutes the manure nutrient concentrations and increases transportation costs during land spreading, by as much as 25 to 30% (Barrington 2000). The value of manures, as produced on the farm, is summarised in Table 6.

**Table 5. Manure nutrient loading of world tillable land (1990) (Statistics Canada 1990; Encyclopedia Britannica inc. 1999).**

| Province or Country | N Kg/ha/yr | P Kg/ha/yr | K Kg/ha/yr |
|---|---|---|---|
| Canada | 9.4 | 2.4 | 7.9 |
| - Maritime | 25.6 | 6.6 | 20.2 |
| - Québec | 31.6 | 8.4 | 23.6 |
| - Ontario | 23.0 | 6.0 | 18.0 |
| - Prairies | 6.2 | 1.5 | 5.4 |
| - B.C. | 25.7 | 6.3 | 22.5 |
| China | 57.2 | 16.2 | 35.8 |
| Denmark | 49.5 | 14.0 | 31.2 |
| France | 27.8 | 7.2 | 21.6 |
| Germany | 40.4 | 10.6 | 30.5 |
| Japan | 78.5 | 23.2 | 43.1 |
| Spain | 15.4 | 4.2 | 10.5 |
| USA | 10.3 | 2.7 | 7.8 |
| Argentina | 8.5 | 2.0 | 8.0 |
| Brazil | 13.3 | 3.3 | 11.5 |
| Chili | 18.8 | 5.0 | 14.1 |
| Peru | 15.4 | 4.0 | 12.0 |
| Corn requirements | 100-150 | 20 | 50 |
| Cereal requirements | 50-100 | 15 | 30 |

**Table 6. Typical manure nutrient values and management costs.**

| Manure | Storage cost | Handling Cost | Spreading Cost | Total Cost | Nutrient value[1] |
|---|---|---|---|---|---|
| Dairy cow | $55.00 | $25.00 | $55.00 | $135.00 | $80.00 |
| Grower hog | $2.60 | $0.50 | $2.50 | $5.60 | $ 4.25 |
| Laying hen | $0.80 | $0.25 | $0.45 | $1.50 | $ 0.50 |

[1]The manure nutrient value assumes that 80% of the nitrogen is conserved during land spreading. The manure is transported over a distance of 1 to 2 km. Costs and values are expressed per animal.

To minimise the costs of spreading manure, enterprises have been using two techniques:

1. use equipment which minimises the spoilage of water in the barn and produce manures of lower water content in the range of 88 to 90%, for swine and cattle respectively;
2. concentrate manure solids by removing water;
3. removing some of the volatile elements such as carbon and nitrogen.

These intensive enterprises generate gases know to produce odours (Sweeten 1995), greenhouse effects and acid rain (Oosthoek and Kroodman 1990). Several of the 300 or so gases emitted by manure are detectable at concentrations of one part per billion. Therefore, large distances are required to dilute these below their detection threshold at the property lines

(O'Neil and Philip 1992). But, most system concentrating manure nutrients also reduce manure odour emission. Nevertheless, manure odours induce a psychological response from human beings and completely attenuating odours may still leave complaining neighbours. The livestock industry must therefore improve its public image now that it has the technology to environmentally manage its manures.

## CONCENTRATING MANURE NUTRIENTS AND REDUCING ODOURS

Large volumes of manure can be environmentally managed by disposing of them on a land base where all nutrients will be up-taken by the crop within the growing season. To achieve this, manure nutrients must be concentrated as most manures are handled under a liquid form, indicating that their water content is at least 90%. Several solutions have been introduced to concentrate manure nutrients:

1. mechanical separators consisting of a screen, a press or a centrifuge, removing the large particles of solids from the manure slurry;
2. chemical systems adding a flocculent to the manure, preferably after being mechanically separated. The chemicals agglomerate the manure solids which can then be removed by either gravitational precipitation, by pressurising into a filter press or by centrifuging;
3. aerobic (biological) treatment where microbes degrade the manure solids, volatilise some of its carbon and nitrogen, and form a sludge concentrated in phosphorous;
4. anaerobic treatment where the microbes volatilise mostly carbon and produce a sludge rich in nitrogen and phosphorous;
5. ultra filtration where membranes are used to remove solids and salts from manure slurries once mechanically separated;
6. drying where the water content of the manure is reduced to 5% or less.

## THE EUROPEAN TECHNOLOGIES

Such modern treatment systems are emerging in Europe, where livestock densities are high and phosphorous must be spread under limited rates. Membrane filtration accompanies the anaerobic and aerobic treatment of the systems to complete manure separation, and the liquid produced from the treatment is clean enough to be dumped directly into a watercourse. A Denmark group (BIOSCAN A/S inc., Table 7) is presently promoting such a system offering a minimum capacity of 41 $m^3$ per day, a capacity equivalent to the manure production of 5000 grower hogs. To resolve the complex problem of operating such a system, they promote the purchase of a such a system by a group of farm enterprises along with a service contract. This system is said to treat swine manure at a net cost of $8/$m^3$. This net cost involves subtracting the system's capitalisation and operating costs from the benefits equated to the lower transportation costs and the conservation of manure nutrients.

**Table 7.** **Efficiency of BIOSCAN A/S Separation Technology (BIOSCAN A/S 2000)[1].**

| Fraction | Mass | N | P | K | Solids |
|---|---|---|---|---|---|
| Solids (compost) | 2.9% (1.2 tons) | 41.0% (83 kg) | 10.0% (6.2 kg) | 2.6% (3.1kg) | 17.2% (0.42 t) |
| N concentrate | 5.1% (2.1 tons) | 82% (168kg) | -- | -- | -- |
| P concentrate | 16.2% (6.6 tons) | -- | 33% (19.8 kg) | 84% (99 kg) | -- |
| Water | 68.6% (28.0 tons) | 0.03% (0.06kg) | 0.3% (0.5kg) | 2.7% (2.24kg) | -- |
| Biogas | | | | | 840 $m^3$ |
| Total Output (over input) | 92.8% (37.9 tons) | 123% (251 kg) | 43.3% (26.5 kg) | 89.3% ( 104.3kg) | -- |

[1]Input daily : 40.8 tons at 6% TS, with N, P and k content of 5, 1.5 and 2.9 kg/ton. Percentages calculated from process description (BIOSCAN A/S, Odense, Denmark)

In France, the accent is still focused on nitrogen pollution. The government has therefore encouraged the development of treatments scrubbing nitrogen and separating the solid and liquid fractions. To achieve this objective, several consulting groups have applied municipal wastewater systems to manure treatment. These systems are producing, unfortunately, three by-products, which for the typical livestock enterprise, complicate the handling of their manure (Table 8): a solid fraction to store inside a building, which can be composted; a thick sludge stored in an exterior concrete tank; and a separated liquid with a high salt content, but poor in N and P (Barrington 1998). Such systems use techniques of primary separation and of aeration to achieve their means, at a cost of $8 to $10/m$^3$.

**Table 8.** **Efficiency of French Separation Technologies (Barrington 1998).**

| Fraction[1] | Volume | N | P | K |
|---|---|---|---|---|
| Solids | 6% | 8% | 15% | 6% |
| Sludge | 25% | 20% | 70% | 26% |
| Remaining liquid | 62% | 2% | 15% | 62% |

[1]Fraction extracted by municipal systems developed for the treatment of swine manure.

Another French group has developed a treatment using flocculation and mechanical pressure separation. It produces a cake containing the solids (14% of the volume; 50% of total N (TN); 90% of total P (TP) and 10% of total K (TK)) and, a liquid fraction (96% of the volume; 50% of the N; 10% of the TP and 90% of the TK). This liquid fraction is still too concentrated be released directly into a watercourse. Again, the cost ranges from $8 to $10/m$^3$. Finally, a third French technology uses lime to precipitate manure solids and produce a sludge as well as a separated liquid. This system also costs $8 to $10/m$^3$ of manure treated.

Because no water reducing techniques are encouraged in the barn, the separated liquid fractions contain a very large portion of the TK, which removes some of the transportation advantages of the separation.

## THE CANADIAN TECHNOLOGIES

Since the early 1970s, manure treatment systems have been developed and tested in British Columbia, Québec and Ontario. Such investigation was triggered by the rapid expansion of the swine and poultry industry. At that time, manure nitrogen scrubbing was the main objective as nitrogen was the primary element limiting the land application of manure. British Columbia researchers (Lo and colleagues at UBC since 1980) have been innovative in introducing the sequential batch reactor. In Ontario and Québec, mesophilic anaerobic treatments and oxygen ditches have been tested (Ogilvie and colleagues at the McGill and Guelph University, from 1975 to 1985). The Québec Ministry of Environment tested a municipal wastewater treatment facility in the Beauce County in the early 1980s to abandon it three years later because of the cost and complexity of operating such a system. These first systems where generally as efficient as those found today in France. They were not widely accepted because of their high operating costs.

Manure treatment was not a pre-occupation in Canada from 1980 to 1995, because the livestock population had stabilised. In 1995, many swine producers saw interesting and large market opportunities in Asia and the renewed expansion of the swine industry, for the second time, had to re-address manure treatment. This time, manure odour and phosphorous were of prime interest. Soils being richer in phosphorous, manure application rates were now limited by this element. Agriculture Canada (Massé and colleagues since 1995) promoted the use of two psychrophilic anaerobic sequential batch reactor operated in sequence for the treatment of livestock manures on the farm. The system is presently under trial on two Canadian farms. Such installation can treat swine slurries at a cost of approximately $\$5/m^3$, for an operation with an annual capacity of at least 3 600 finished grower hogs. The operational costs are low, energy being required for the transfer of manure only. Nevertheless, a technician visits the livestock operation once every two weeks to feed the digesters and verify the performance of the system. The treatment is effective in reducing manure odour during storage and in producing a sludge with concentrated levels of N and P.

This concept had been previously investigated by many American researchers who demonstrated that the use of aerobic and anaerobic treatments, in sequence, can reduce fecal coliform levels by a factor of 1000, COD and suspended solids (SS) by 93 and 98%, and nitrogen by 99%.

The CRIQ (Centre de Recherche Industriel du Québec) developed a swine manure treatment facility called BIOSOR inc. (Table 9) consisting of:

1. a separator removing the large manure solids;
2. an anaerobic tank for the primary settling of more manure solids;
3. a bio-filter for the treatment of the digested liquid which is also used to reduce the odours produced by the piggery;

4. a membrane filtration system for the final scrubbing of the manure liquids and their disposal into a water course.

**Table 9. Efficiency of BioSor inc. Separation Technology (BioSor inc., 2001).**

| Fraction[1] | Volume | N | P | K | Solids |
|---|---|---|---|---|---|
| Solids Sludge | N/A | 3.8% (4.3 kg/ton) | 2.1% (2.4kg/ton) | 0.9% (1.0 kg/ton) | (11%) |
| Discharged Liquid | N/A | (365mg/l) | (52 mg/l) | N/A | (225mg/l) |

[1]Fraction extracted by municipal systems developed for the treatment of swine manure.

BIOSOR inc. is presented especially as a biofilter that treats manure liquids treated by settling in an anaerobic tank. Such a system requires an investment of $7.50/m$^3$ for an operation finishing at least 5 000 hogs annually. The operation of the system represents an additional cost of at least $2.50/m$^3$ and the expertise of a technician on a regular basis to verify the performance of the complex pumping and control systems. The long-term maintenance of the bio-filtration system is also questioned.

Atrium is another treatment plant located near Farnham, in the Province of Québec. It uses high efficiency dryers to convert manure slurries into dry organic fertiliser. It will be in full operation by spring 2001. Livestock producers can deliver their manure to the plant and paying a tipping fee of $4.50/m$^3$. Atrium plans to sell this dry fertiliser at a cost valued at $10.00/m$^3$ of raw manure slurry delivered. Atrium claims that there is an important market for such dried organic waste.

Purin-Pur is another Québec system (Table 10) using membrane filtration and operating on a farm. The system consists of initially removing all large particles using a mechanical separator. Then, the liquid is treated through the membrane system, where the pressure is automatically controlled to regularly start the membrane flushing operation. The system represents an investment of $5.00/m$^3$ for an operation producing between 3 000 and 4 000 finished hogs annually. The operation costs of $2.50/m$^3$ must be added to this investment cost, for a total cost of $7.50/m$^3$. This system does not control odours.

**Table 10. Efficiency of Purin-Pur 2500 Separation Technology (Consumaj 2001).**

| Fraction[1] | Volume | N | P | K | Solids |
|---|---|---|---|---|---|
| Solids | 2.0% | 29.3% (2.2g/l) | 12.8% (6.6g/l) | 4.9% (7 g/l) | 14.3% (22.7% dm) |
| Sludge | 53.8% | 68.6% (0.6mg/l) | 87.2% (2.2 g/l) | 94.9% (4mg/l) | 85.5% (5.2%) |
| Discharged Liquid | 44.4% | 2.1% (87mg/l) | 0.01% (0.7g/l) | 0.2% (12.6mg/l) | 0.2% (181mg/l) |

[1]Fraction extracted by municipal systems developed for the treatment of swine manure.

## LOW COST TECHNOLOGIES

Canadian livestock enterprises are located in regions where manure is not produced in surpluses. Thus, many livestock enterprises can benefit from simple solutions such as a preliminary separation. For agricultural purposes, such separators should not require an important level of energy to dry out the separated solids. Increasing the dry matter content over 15% does not change the volume to transport, only the weight. Barrington (1999) found that the solids' dry matter content influenced their bulk density as follows, for swine manure:

$$\text{Bulk density } (10^3 \text{ kg/m}^3) = 1.44 - 0.031 \text{ (dry matter content, \%)}$$

For a cost effective separation system, the enterprise must treat the manure from an annual hog finishing operation of at least 5 000 hogs, or the equivalent. The cost of separating is on the order of $\$1.50/m^3$ while the separation effectiveness depends on the feed type and wastage, the dilution level of the manure and the separator screen size. Generally, 30 to 40% of the solids can be removed, while reducing the volume of manure by 10%.

## CONCLUSION

Present intensive livestock operations are adopting new technologies allowing them to manage their manure with minimum environmental impact. These technologies consist of concentrating manure nutrients while, in many instances, reducing manure odour emissions. Nevertheless, these new technologies have increased the management cost of the operations, and this cost depends on the size of the enterprise. Large intensive enterprises are in better position to use such technologies more effectively and economically. The cost of improving manure management in regions of high livestock densities or for intensive livestock operations range from \$1.50 to \$10.00/finished hog or per $m^3$ of manure produced.

## LITERATURE CITED

Barrington, S. 1998. Member of a study delegation visiting North Western France. Department of Agricultural and Biosystems Engineering, McGill University, Montréal, Canada.

Barrington, S. 1999. Personnal encounter with a hog producer of the Fraser Valley. Department of Agricultural and Biosystems Engineering, McGill University, Montréal, Canada.

Barrington, S. 2000. Manure separation and aeration efficiencies. Report prepared for Agri-Brome Sales, Cowansville (Québec).

Biosor inc. 2001. Web site on Biosor technologies. Centre de recherché Industriel du Québec, Québec, Canada.

Bioscan A/S. 2000. Biorek, a total solution for organic waste. Odense, Denmark.

Consumaj. 2001. Purin Pur data supplied by Denis Choinière of Consumaj, Consultants in wastewater treatment. St Hyacinthe, Québec.

Garcia Moreno, M. 1993. Sphagnum moss for swine manure nitrogen conservation. M. Sc. Thesis, Department of Civil Engineering and Applied Mechanics, McGill University, Montréal, Canada.
Enclyclopedia Britannica inc. 1989 and 1999. Book of the year. London, England.
CQVB. 1991. Politique intégrée de gestion des déchets solides. D. Potvin et R. Cloutier, Dans: Le compostage au Québec, problématique, technique et inventaire des matériaux. Centre québécois de valorisation de la biomasse. Ste Foy, Québec.
O'Neil, D.H. and V.R. Philip. 1992. A review of control of odour nuisance from livestock buildings: Part 3, properties of odorous substances which have been identified in livestock wastes or in the air around them. Journal of Agric. Engng. Res. 53. 23-50.
Oosthoek, J. and V. Kroodsma. 1990. Ammonia emissions from cowsheds. Proceedings of the sixth international symposium on agricultural and food processing waste. American Society of Agricultural Engineering, St Joseph, Michigan, USA. p442-448.
Sweeten, J.M. 1995. Odour measurement technology and applications: a state of the art review. Seventh International Symposium on Agricultural and Food Processing wastes. American Society of Agricultural Engineering, St Joseph, Michigan, USA. p214-229.