Biological Wastes **34** (1990) 323-333.

Static Pile, Passive Aeration Composting of Manure Slurries Using Peat as a Bulking Agent*

S.P. Mathur [a]‡ N.K. Patni [b] & M.P. Levesque [a]

[a] Land Resource Research Centre, and [b] Animal Research Centre,
Research Branch, Agriculture Canada, Ottawa, Ontario, K1A 0C6, Canada

(Received 23 February 1990; revised version received 1 May 1990;
accepted 25 June 1990)

ABSTRACT

The feasibility of composting high-moisture manure slurries in combination with hydrophilic peat moss was examined. Horticultural grade peat, with or without lime (1% Ca in peat), was mixed with manure slurries from dairy cows, poultry, or sheep, in a feed-mixer. The mixtures were discharged on to a bed of peat (10 cm), overlain by horizontal perforated pipes open to the atmosphere, to construct small windrows which were then covered by a 5-cm layer of deodorizing and hygienic peat. The amphoteric peat of acidic pH adsorbed the NH_3 and any other malodorous compounds, and its fibrosity (bulk density 0.06 g cm^{-3}) supported aerobic thermophilic decomposition in which neither malodorous amines nor sulphides were produced significantly. No detectable NH_3 or H_2S emanated from the compost piles. Temperatures greater than 45°C were reached in the composts within 1-3 days and maintained above 45°C for 2-5 weeks without further mixing of the composts, or any mechanical aeration. When the composts were remixed and reheaped, 7 weeks after initial formulation, no reheating occurred - suggesting that the composts were ‘biostable', as is peat. Germination tests confirmed the 'biostability'. The mature composts had water-holding capacities nearly equal to that of the original peat, suggesting that the air-dried peat-manure composts can be recharged with manure slurries. The properties of the composts suggested that they could be marketed and used as a substitute or supplement for the limed and fertilized peat generally used in gardening, landscaping and greenhouse culture.

* LRRC Contribution No. 90-05, ARC Contribution No. 1658. To whom correspondence should be addressed.

Biological Wastes 0269-7483/90503.50

INTRODUCTION

Current high-density husbanding of farm animals in shelters with little or no use of litter is generally associated with collection and storage of animal excreta as slurries. The slurry management systems with their open or covered outdoor lagoons or storage tanks were evolved in N America and W. Europe primarily to substitute mechanical power for manual labour when energy was inexpensive, and animal farms were adequately separated from residential areas. Now, the adverse environmental impact of the slurry storage and disposal practices has led to restrictions from agencies and litigation from non-agricultural neighbours (Viets, 1974; Loehr, 1977; Voorburg, 1980; Jewell *et al.,* 1984).

The C/N ratios in the urine-containing slurries are often so low that during decomposition much of the N is lost, as it exceeds the requirement for all the microbial biomass synthesis possible from the C present (Witter & Lopez-Real, 1987). Also much of the N is in forms readily degraded by exothermic enzymatic hydrolysis. The microbial proteins, urea and uric acid thus yield foul-smelling aliphatic amines, sulphides and NH_3, even under conditions suboptimal for microbial activity (Miner & Hazen, 1969, 1977; Elliott *et al.,* 1971). The aerobic microbial activity that transforms the malodorous compounds into NO_3^-, SO_4^{-2}, CO_2 and H_2O is impaired by lack of oxygen and by low temperature. The microbial activity that does occur anaerobically produces CH_4, amines, NH_3, CO_2, and the toxic and malodorous sulphides including H_2S. High concentrations of CO_2 promote retention of the NH_3 as $(NH_4)_2CO_3$ even at neutral to slightly alkaline pH. However, the high viscosity needed to occlude and maintain CO_2 at high concentrations curtails the slurry's capacity to retain amines, H_2S and other sulphides in aqueous solution, thus heightening the problem of malodours (Vogtmann & Besson, 1978). On the other hand, the NH_3 lost from manures, and the nitrogen oxides from partly aerated systems, tend to promote eutrophication of water bodies and the acidification of soils in more than the immediate vicinity as the NH_3 is oxidized to nitrite and nitrate in soil and water (Voorburg, 1980; Schroder, 1985). When dissolved in water, the nitrous oxide and nitrate ion yield nitrous and nitric acids, respectively. Even the highly viscous and malodorous slurries would lose ammonia rapidly during handling and application to soil, as the CO_2 is degassed to the atmosphere from the slurry. The less odorous, dilute, NH_3-poor slurries, on the other hand, are costly to transport and apply.

Consequently, the available treatment systems for animal slurries probably do not eliminate all adverse environmental impacts as they cannot both conserve the N and contain the malodours at all stages. Many attempts have been made to mitigate the problems, with little or no success (Vogtmann & Besson, 1978; Jewell *et al.,* 1984; Gray *et al.,* 1987; Voorburg, 1988; Mathur *et al.,* 1989).

A need was therefore felt for testing the feasibility of composting liquid manure with a material that deodorizes (e.g. peat biofilters, Furusawa *et al.,* 1984); absorbs high proportions of water; is rich enough in exchangeable H^+ ions to neutralize the ammonia and then the cations released by decomposition, thus preventing the loss of ammonia by remaining slightly acidic throughout the composting process; has capacity for adsorbing anions, thus retarding the leaching of NO_3^- and PO_4^{-3} when added to soil (Moore *et al.,* 1981); is fluffy enough to provide thermal insulation, and enough replaceable air to prevent anaerobic production of malodours; can also be used as a litter, and/or a floating cap on the slurries; is biodegradable but, unlike straw and wood wastes, not capable of sustaining thermophilic microbial activity by itself, so that the compost can mature early in a short Canadian summer; and is devoid of pathogens and weed seeds so that an outer layer of the material does not have to be subjected to sanitizing heat, thus obviating the need for turning the composts inside out while still hot, which would require energy and permit loss of NH_3.

Horticultural (blonde) sphagnum peat meets these requirements. In addition, peat is attractive, even at high price, to home gardeners, landscapers, turf agronomists and nurserymen, for its physical properties. Peat also has an exceptionally high capacity (four to eight times that of straw) for enhancing soil organic matter (Janssen, 1984).

Sphagnum peats have bulk densities of about 0.06 g cm^{-3}, cation exchange capacities of nearly 130 meq 100 g^{-1}, pH between 3 and 4, and can absorb up to 20 times their weight in water, and adsorb NH_3 up to 3% of their weight, even in an air-dry state (Bulganina *et al.,* 1983; Mathur & Farnham 1985).

Mathur *et al.* (1985, 1986, 1988), Preston *et al.* (1986) and Mathur and Johnson (1987) have shown that peat is effective as a medium of unodorous composting of seafood wastes in a passively aerated windrow system, at both small and commercial scales. The peat-based seafood-waste composts are prepared commercially within a short Canadian summer.

The objective of this study was to determine the feasibility of composting winter-stored manure slurries from poultry, dairy cattle and sheep, to make a readily utilizable by-product.

METHODS

Materials

Properties of the peat and the manure slurries used in this study are presented in Table1 . The manures had been collected from confined animals at the Animal

TABLE 1. Properties of the Peat and Animal Manure Slurries Used.

Properties [a]	*Poultry manure*	*Dairy cow manure*	*Sheep manure*	*Peat*
Moisture (% of DM)	2870	1186	1566	100.0
Dry matter (% moist wt)	3.4	7.8	6.0	50.0
Organic matter (%)	68.4	80.7	63.9	96.0
Carbon (%)	34.6	40.0	31.3	43.7
Total nitrogen (%)	3.52	2.09	2.27	0.8
NH_4-N (mg kg^{-1})	5050	740	2650	300
NO_3-N (mg kg^{-1})	118	51	252	67
pH	6.52	8.35	7.41	3.0
C/N ratio	9.8	19.1	13.8	53.3
Phosphorus (%)	2.90	1.08	0.59	0.04
Potassium *(%)*	2.89	3.40	2.28	0.05
Calcium (%)	5.9	1.7	4.2	0.1
Magnesium (%)	0.74	0.53	0.63	0.1
Copper (mg kg^{-1})	50.4	52.9	23.4	2.8
Iron (%)	0.43	0.15	0.25	0.1
Manganese (mg kg^{-1})	380	120	115	78
Zinc (mg kg^{-1})	970	210	440	9

[a] On dry matter basis, unless indicated otherwise.

Research Centre Farm, near Ottawa, and stored in roofed tanks from December 1986 to June 1987. The water-holding capacity of the peat, at ⅓ bar suction, was 535% of dry weight.

Formulation

One part of peat (with 50% moisture) was mixed with ten parts of a manure slurry, on weight/weight basis, in a feed mixer (Butler Model 320 Feed Mixer of 320 cu. ft capacity, Butler Manufacturing Co. Ft Atkinson, Wisconsin, USA). In one set of treatments, the peat was enriched with Ca, as $Ca(OH)_2$, to the level of 1% Ca in peat on a dry-weight basis. Limed and unlimed peat were used as controls. All the eight treatments were triplicated giving 24 compost piles in all.

Compost piles

The compost piles were 1 m high, trapezoidal in cross-section, with base and top planes of 3 m x 2 m, and 2 m x 0.3 m, respectively, as described earlier by Mathur *et al* (1986, 1988).

To build a compost pile, a basal 10-cm thick layer of untreated peat was laid loosely as a rectangle of 3 m x 2 m on the gravelly shoulder of a farm road. Two 13-m long ABS pipes of 10 cm diameter with two rows of perforations (each 1.2 cm in diameter) were placed lengthwise on the basal layer, about 0.3 m from the margins. Both rows of perforations were on the top sides of the pipes to allow movement of air from the outside upwards and sideways into the compost, as a result of the convection currents induced by the heat generated in the pile. The pipes used were the same as those employed for spreading effluents from septic tanks and sewage lagoons into treatment fields.

The mixtures of peat and manure slurries were discharged from the side chute of the feed mixer on the bed of peat, above the horizontal pipes and shaped in the form of a small windrow of the dimensions noted above. A covering layer of peat, about 5 cm thick, was placed on the manure plus peat mixture as an envelope to curtail ammonia and odour emissions and attraction of flies to the piles. In the case of the piles studied here, the amount of peat used as base and covering was about 25% of the peat used in the mixture with the slurries. A canopy of transparent polyethylene sheet was used above the piles to protect them from rainfall.

Monitoring

A portable pH meter and a temperature probe were used to measure the pH of the outer 5 cm of the piles, and the temperatures and pH of the interior of the piles. The presence of NH_3 and H_2S on the exterior of the piles and in the aeration pipes was tested by placing, for 30 min, sticks with cotton swab tips soaked in phenolphthalein or lead acetate solutions, respectively, at appropriate locations (Mathur *et al.,* 1986).

Compost maturity

The absence of phyto-inhibitory substances that reflect compost maturity was tested by seed germination. The tests were performed with radish *Raphanus saliva* and lettuce *Lactuca saliva* seeds in 60-ml petri dishes containing 20 ml of peat, or water, or the composts; filter paper disks, and sufficient moisture to wet the seeds thoroughly (Mathur *et al.,* 1986). The peat and water served as controls.

Compost analysis

The methods followed were the same as those used by Mathur *et al.* (1986) for organic soils and seafood-waste composts.

RESULTS AND DISCUSSION

The near-neutral and alkaline pH of the slurries (Table 1) suggests that some ammonia may have been lost from the slurries during storage and when the manures were mixed, and pumped from the tanker to the mixer in the open air. Consequently ammonia-N content was not the expected 50% of the total Kjeldahl-N in the manures after the winter storage. Also, the slurries used contained less dry matter than the usual 9-12% at the farm, perhaps due to insufficient mixing (Table 1), and due to some loss of dry matter during storage. It is noteworthy that the compost-pile moisture content was about 90% initially compared to the generally recommended value of 60%. This relatively high initial moisture content did not appear to affect the composting process where the bulking agent was peat, which has a high retention-capacity for water.

TABLE 2. Average pH of the Outer Surface and Middle of the Compost Piles, at Time Zero and 1 Week Later.

Treatments	*Outer surface*		*Middle of the pile*	
	Time-0	*1 week*	*Time-0*	*1 week*
Peat alone	3.2 + 0.1	3.2 ± 0.1	3.3 ± 0.1	3.3 ± 0.0
Peat + lime	4.2 ± 0.1	4.3 ± 0.1	4.3 ± 0.1	4.3 ± 0.0
Peat + sheep manure	3.2 ± 0.0	4.2 ± 0.1	5.4 ± 0.1	5.4 ± 0.0
Peat + sheep manure+lime	3.2 ± 0.0	4.4 ± 0.1	5.4 ± 01	5.6 ± 0.0
Peat + cow manure	3.2 ± 0.0	4.3 ± 0.1	5.9 ± 0.1	6.1 ± 0.0
Peat + cow manure+lime	3.2 ± 0.1	4.5 ± 0.1	6.3 ± 01	6.4 ± 0.0
Peat + poultry manure	3.2 ± 0.1	5.8 ± 0.1	6.9 ± 0.1	7.0 ± 0.0
Peat + poultry manure + lime	3.3 ± 0.1	6.5 ± 0.1	7.6 ± 0.1	7.8 ± 0.0

The pH in the outer 5 cm of the compost piles all over, with the exception of poultry manure, remained between 3.2 and 4.5, indicating that little, if any, NH_3 escaped even when the pH inside the heaps increased due to ammonification (Table3.2. Ammonia and H_2S were also not detected over the piles and in the ventilation pipes. No malodours detectable by the human nose were present near the composts, after one day.

The temperatures of the compost pile interiors (deeper than 20 cm) increased to the thermophilic range within 1 day in all the manure compost piles (Table 3). Temperatures of the limed and unlimed composts of each manure were similar all through the composting. All manures probably contained sufficient bioavailable Ca.

TABLE 3. Periods (in days) of Temperature Regimes of Interior of Composts.

Temperature regimes	*Source of manures in the composts*		
	Sheep	*Dairy cows*	*Poultry*
Warming to 45°C	1	1	1
Warming to above 55°C	4	4	4
Maintained between 45°C and 65°C	14	22	36
Cooling to 30°C	19	15	8
Cooling to control peat temperature (20°C ± 3)	13	6	4
Total composting period	46	43	48

The usual inhibition of microbial activity by soluble metals at low pH (Dumontet & Mathur, 1989) may have been prevented by the high capacity of peat for complexing any metals present in the manure composts (Mathur & Farnham, 1985).

As temperatures were maintained between 55 and 65°C for 8-12 days, both animal and plant pathogens should have been eliminated as that requires only 3-4 days in composts of 55°C (Lopez-Real & Foster, 1985). As the outer layers of the composts were made of sanitary peat, these did not have to be subjected to high temperatures by being turned into the middle. When the turning was done at the end of 48 days, no reheating occurred, indicating that the composts were 'biostable'. The percentages of seeds germinating in the composts varied between 88 and 96% without significant differences between the composts and the control water and limed peat. Both observations regarding maturity were in accord with the experience with the peat-based composts of seafood wastes in both short and long static windrows (Mathur *et al.,* 1985, 1986, 1988; Preston *et al.,* 1986; Mathur & Johnson, 1987).

The finished composts were acidic, pleasantly earthy in smell, and dark brown. They felt like, and appeared to be, peat. These attributes command a price far higher than that corresponding to their nutrient value (e.g. Fieldson, 1985).

Properties of the finished composts are given in Table 4. Except for the limed poultry manure composts, which inadvertently gained some gravel and sand during handling, the water-holding capacity of the composts was similar to that of the original peat (535%). This is understandable as the peat decomposes little while the bio-resistant fibres in manures are as hydrophilic as peat (Raviv *et al.,* 1987).

The fact that the finished composts were acidic and likely to become more

TABLE 4. Properties of the Composts prepared from Mixtures of Animal Slurries and Peat, with or without Lime Addition (± Standard Error of Means), on Dry Weight Basis.

Properties	*Poultry manure + peat*		*Dairy manure + peat*		*Sheep manure + peat*	
	Without lime	*With lime*	*Without lime*	*With lime*	*Without lime*	*With lime*
pH value	5.67 ± 0.05	5.83 + 0.06	5.25 ± 0.19	5.26 ± 0.06	4.73 ± 0.05	5.81 ± 0.18
WHC [a]	420 ± 15	360 ± 30	540 ± 30	480 ± 25	630 ± 30	560 ± 40
Moisture (% DM)	245 ± 16	175 ± 19	304 ± 21	281 ± 13	340 ± 20	343 ± 19
Organic matter (%)	63.5 ± 2.4	59.9 ± 1.9	74.7 ± 0.3	65.0 ± 2.1	77.7 ± 1.5	76.9 ± 1.6
Carbon (%)	28.7± 1.4	28.1 ± 34.6	34.6 ± 0.1	30.9 ± 0.6	36.1 ± 1.2	36.4 ± 0.8
Total N (%)	1.71 ± 0.05	1.75 ± 0.10	1.83 ± 0.01	1.79 ± 0.20	1.71 ± 0.05	1.57 ± 0.06
NH_4-N (*µg g*$^{-1}$)	4259 ± 85	4114 ± 243	4393 ± 85	1690 ± 253	2697 ± 119	227 ± 135
NO_3-N (*µg g*$^{-1}$)	1054 ± 142	1800 ± 145	822 ± 45	1745 ± 320	2271 ± 119	3225 ± 198
Total P (%)	1.18 ± 0.10	1.20 ± 0.21	0.87 ± 0.10	0.89 ± 0.11	0.41 ±0.05	0.40 ± 0.05
HCl-Sol-P (*µg g*$^{-1}$)	9372 ± 200	9508 ± 190	2901 ± 170	2516 ± 190	2927 ± 111	3133 ± 180
C/N ratio	16.8 ± 1.8	16.1 ± 1.1	18.9 ± 0.1	17.2 ± 0.4	21.1 ± 0.9	23.1 ± 0.6
Potassium (%)	1.38 ±.9.1	1.48 ± 0.0	1.70 ± 0.10	1.69 ± 0.1	1.55 ± 0.9	1.58 ± 0.1
Calcium (%)	3.9 ± 0.3	4.8 ± 0.2	1.7 ± 0.2	2.9 ± 0.1	1.80 ± 0.1	2.3 ± 0.1
Magnesium (%)	0.87 ± 0.06	1.14 ± 0.01	0.62 ± 0.01	0.81 ± 0.05	0.59 ± 0.05	0.47 ± 0.01
Copper (*µg g*$^{-1}$)	28.1 ± 0.5	27.1 ± 0.1	242 ± 0.4	23.1 ± 0.6	12.8 ± 0.1	11.1 ± 0.1
Iron (%)	1.08 ± 0.08	0.95 ± 0.05	0.59 ± 0.10	0.60 ± 0.01	0.71 ± 0.01	0.69 ± 0.01
Manganese (*µg g*$^{-1}$)	360 ± 21	410 ± 10	190 ± 10	230 ± 20	145± 12	130 ± 10
Zinc (*µg g*$^{-1}$)	150 ± 11	170 ± 9	130 ± 9	120 ± 11	79 ± 10	82 ± 10

[a] Water-holding capacity at ⅓ bar suction, % of dry weight.

acidic on nitrification during further maturation, hydrophilic, and had C/N ratios far above the 8-12 attainable by humification, suggest that air-dried composts could be used as a base and covering for further composting. More importantly, the compost could be recharged with manure slurries. Further studies are needed to investigate the possibility of repeated use of the peat in the composts for composting more manure. Additions of straw or other carbonaceous materials such as paper-mill wastes could further extend the repeated use of the peat.

APPLICATIONS

The results of this study show the feasibility of composting manure slurries with peat in passively aerated, small static windrows in which the heat generated is utilized to cause aeration, the N is conserved, and the output is a product which is similar to limed and fertilized peat sold in the market at high prices for use in landscaping, home gardening, indoor-plant growth media, nurseries and greenhouse production of vegetables and flowers. Even though the windrows tested in this study were small, based on the experience with similar methods for composting of seafood wastes (Mathur *et al.,* 1988) the proposed composting system is also expected to be effective for large-scale windrows. The economic viability of commercial-scale composting of manure slurries would depend on ready availability of peat, land-base availability and advisability of direct spreading of slurries, markets for the compost product, and other factors. It is worth noting that peat-based composting of seafood waste is commercially viable and expanding (Mathur *et al.,* 1988).

ACKNOWLEDGEMENTS

Technical assistance of Bruce Sanderson, Henri Dinel, Robert Allen and other staff of LRRC and ARC is gratefully acknowledged.

REFERENCES

Bulganina, V. N., Kuznetsova, L. M., Mandelbaum, L. M. & Nemchinova, A. A. (1983). Researches on the waterless ammonia application in the production of peat fertilizers. In *Recent Technologies in the Use of Peat,* ed. G. W. Luttig. E. Schweizerbart Sche Verlagsbuchhandlung (Nagele U. Obermiller), Stuttgart, pp. 51-4.

Dumontet, S. & Mathur, S. P. (1989). Evaluation of respiration-based methods of determining microbial biomass in metal-contaminated acidic mineral and organic soils. *Soil Biol. & Biochem.,* 21, 431-6.

Elliott, L. F., Schuman, G. E. & Viets, F. G. Jr (1971). Volatilization of nitrogen-containing compounds from beef cattle areas. *Soil Sci. Soc. Amer. Proc.,* 35, 752-5.

Fieldson, R. S. (1985). The economic feasibility of earthworm culture on animal wastes. In *Composting of Agricultural and Other Wastes,* ed. J. K. R. Gasser. Elsevier Applied Science, London, pp. 243-54.

Furusawa, N., Togashi, I., Hirai, M., Shoda, M. & Kubota, H. (1984). Removal of hydrogen sulphide by a biofilter with a fibrous peat. *J. Ferment. Technol.,* 62, 589-94.

Gray, K. R., Biddlestone, A. J., Garner, P. J. & Vere, A. E. (1987). Straw matrices for composting organic wastes. In *Proc. Int. Conf. on Straw-a Valuable Raw Material, Cambridge, UK,* 1, 227-59.

Janssen, B. H. (1984). A simple method for calculating decomposition and accumulation of 'young' soil organic matter. *Plant & Soil,* 76, 297-304.

Jewell, W. J., Dondero, N. C., Van Soest, P. J., Cummings, R. J., Vergara, W. W. & Linkenheil, R. (1984). High temperature stabilization and moisture removal from animal wastes for by-product recovery. Report for the Co-operative State Research Service, US Department of Agriculture, under Project No. SEA/CR 616-15-168.

Loehr, R. C. (1977). *Pollution Control for Agriculture.* Academic Press. New York, NY, pp. 383.

Lopez-Real, J. & Foster, M. (1985). Plant pathogen survival during the composting of agricultural wastes. In *Composting of Agricultural and Other Wastes,* ed. J. K. R. Gasser. Elsevier Applied Science Publishers, London, pp. 291-302.

Mathur, S. P., Farnham, R. S. (1985). Geochemistry of humic substances in natural and cultivated peat lands. In *Humic Substances in Soil, Sediment and Water,* ed. G. R. Aiken, D. M. McKnights, R. L. Warshaw & P. MacCarthy. John Wiley, New York, pp. 53-85.

Mathur, S. P. & Johnson, W. M. (1987). Tissue-culture and suckling mouse tests of toxigenicity in peat-based composts of fish and crab wastes. *Biol. Agric. & Hortic.,* 4, 235-42.

Mathur, S. P., Levesque, M. P., Dinel, H. & Daigle, J.-Y. (1985). Peat as a medium for composting fish and crab wastes. *Proc. IPS Symposium 85, a Technical and Scientific Conference on Peat and Peatlands, Riviere-du-Loup, Que,* pp. 279-90.

Mathur, S. P., Daigle, J.-Y., Levesque, M., & Dinel, H. (1986). The feasibility of preparing high quality composts from fish scrap and peat with seaweeds or crab scrap. *Bio. Agric. & Hortic.,* 4, 27-38.

Mathur, S. P., Daigle, J.-Y., Brooks, J.L., Levesque, M. & Arsenault, J. (1988). Composting seafood wastes-avoiding disposal problems. *Biocycle,* 29, 44-9.

Mathur, S. P., Proulx, J. G. & Daigle, J.-Y. (1989). The use of sphagnum peat for deodorizing and composting manure slurries without energized aeration. In *Proc. 1989 Peat Symposium, Quebec City,* ed. R.P. Overend & J. K. Jeglum. International Peat Society, Helsinki.

Miner, J. R. & Hazen, T. E. (1969). Ammonia and amines: components of swine-building odor. *Trans. Amer. Soc. Agric. Engng,* 12, 772-4.

Miner, J. R. & Hazen, T. E. (1977). Transportation and application of organic wastes to land. In *Soils for Management of Organic Wastes and Waste Waters.* ed. L. F. Elliott & F. J. Stevenson. American Society of Agronomy, Madison, Wis., pp. 379-428.

Moore, J. J., Fahy, L. & Harrington, A. (1981). A possible application of the ion exchange properties of sphagnum moss in the treatment of nutrient-rich animal wastes. *Irish J. Environ. Sci.,* 1, 71-5.

Preston, C. M., Ripmeester, J. A., Mathur, S. P. & Levesque, M. (1986). Application of solution and solid-state multinuclear NMR to a peat-based composting system for fish and crab scrap. *Can. J. Spectroscop.,* 31, 63-9.

Raviv, M., Medina, S., Chen, Y., Inbar, Y. & Geler, Z. (1987). Changes in the chemical and horticultural properties during composting of slurry produced by methanogenic fermentation of dairy cow manure. In *Compost: Production, Quality and Use,* ed. M. De Bertoldi, M. P. Ferranti, P. L'Hermite & F. Zucconi. Elsevier, London, pp. 377-82.

Schroder, H. (1985). Nitrogen losses from Danish agriculture—trends and consequences. *Agric., Ecosyst. & Environ.,* 14, 279-89.

Viets, F. G. (1974). Fate of nitrogen under intensive animal feeding. *Fedn Proc.,* 33, 1178-83.

Vogtmann, H. & Besson, J. M., (1978). European composting methods: treatment and use of farm yard manure and slurry. *Compost Sci.,* Jan.-Feb. 1978,15-19. Voorburg, J. H. (1980). Pig production and environment. Institute of Agricultural Engineering, Wageningen, The Netherlands, Xnr 11890,14 pp.

Witter, E. & Lopez-Real, J. M., (1987). The potential of sewage sludge and composting in a nitrogen recycling strategy for agriculture. *Biol. Agric. & Hortic.,* 5, 1-23.