Medium and long-term effects of animal waste application on soil N storage and mineralisation

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Abstract
Animal manure is the main source of organic matter (OM) spread on agricultural areas in France. Information from medium- and long-term experiments is still needed to accurately predict the behaviour of manures in soil and their effects on carbon and nutrient cycles. A network of 12 medium- (8-15 years) and long-term (>15 years) experiments, was used to assess the effects of different types of animal waste on the accumulation of organic matter and N mineralisation.
For most trials and treatments, C and N contents were significantly higher for soil receiving animal manure than for control soils. Stored OM was distributed into the 50-200µ and < 50µ fractions, with a predominance for storage of OM in the fine fraction.

Measurements of mineralisation in controlled laboratory conditions revealed a significant increase in N mineralisation (P=0.05), from 10 to 30 % higher than that for control soils. The results obtained by monitoring bare soil allowed estimation of a linear relation between extra mineralisation and manure-induced N, with an increase in mineralisation rate which could be estimated as 2.4 $kg.ha^{-1}.year^{-1}$ per 100 kg of organic N stored. Manure-induced N, expressed as a proportion of N input, strongly varied among sites. This variability could not be elucidated with available results.

Introduction
Animal manure is the main source of organic matter spread on agricultural areas in France, with 275 Mt corresponding to 83% of the total national supply of organic products. These organic products are an important source of nitrogen (N), approximately 60% of the nitrogen applied in mineral fertilisers, and their fertilising value in the medium- and long-term is related to the mineralisation of the organic N remaining in the soil at the end of the year of application. Multi-year trials show an increase in soil N mineralisation due to the application of livestock waste, compared to a control situation ([1], [2], [3]). But information from medium- and long-term experiments is still needed to accurately predict the behaviour of manures in soil and their effects on carbon and nutrient cycles. A network of 12 medium- (8-15 years) and long-term (>15 years) experiments, mainly located in western France, was used to assess the effects of different types of animal wastes (slurries, farmyard manures and composted manures from cattle, pigs or poultry) on the accumulation of organic matter and N mineralisation.

2 Material and Methods
2.1 Network presentation
The location of the 12 experiments, period of manure application, crop rotation, rates and frequency of application are presented in Table 1. Most of the 8 experimental sites were located in western France, except for the St. Hilaire and Feucherolles sites. Experiments had 3 or 4 replicates. Manure was applied yearly or every two years on crop rotations, except at Derval and La Jaillière 2, where applications were spread on grass. The soils were loam or sandy loam, with the silt contents varying from 43-72% and the clay contents remaining relatively stable (15-19%). The soil C content ranged from 0.9-2.8%.

Table 1. Presentation of the experiment network, with crop rotations, types of manure, frequency of manure application and Time Between Last manure Application and soil Sampling (TBLAS). (FYM : cattle farmyard manure, CFYM : composted cattle farmyard manure, Cat-S : cattle slurry, Pig-M : pig manure, CPig-M : composted pig manure, Pig-S : pig slurry, Poultry-M : poultry manure, CPoultry-M : composted poultry manure)

Trial	Manure application period	Crop rotation*	Spreading frequency	Manure type	TBLAS (y)
Crécom 1	1984-2003	m	once per y	FYM	0.6
Crécom 2	1987-2005	m/w	every 2 y	FYM	1.7
Derval	1998-2005	gr/m/w	once per y	FYM, Cat-S	3.3
Feucherolles	1998-2008	m/w	every 2 y	FYM	1.5
La Jaillière 1	1995-2005	m/w	once per y	FYM, CFYM, Pig-M, CPig-M,Poultry-M, CPoultry-M	0.9
La Jaillière 2	1995-2005	gr	once per y	FYM, CFYM, Pig-M, CPig-M,Poultry-M, CPoultry-M	1.4
Rennes	1995-2007	m/w	every 2 y	FYM, CFYM, Pig-S	1.8
Rheu 1	1995-2005	m	once per y	FYM, CFYM	0.8
Rheu 2	1996-2005	m	once per y	Pig-M, CPig-M	0.8
St Hilaire 1	1994-2003	r/w	once per y	FYM	4.6
S Hilaire 2	1994-2003	m/w	once per y	FYM	4.4
Trévarez	1987-2006	m/w	every 2 y	FYM, Pig-M	1.7

* m: forage maize; w: wheat ; r: rapeseed; gr: grassland

2.2 Measurements and analysis

Different measurements were made to assess C and N storage and N mineralisation:

- The upper soil layer was sampled 7 months to 4.5 years after the last manure application, depending on the experiment (Table 1):
  - Total C and N contents of the soils were determined by elemental analysis. A fractionation method was used to determine the distribution of coarse (200-2000 µ), intermediate (50-200 µ) and fine (< 50 µ) soil organic matter (SOM) fractions.
  - Soil N mineralisation was measured under controlled laboratory conditions at 15°C, and soil moisture content was adjusted and maintained at -0.05 MPa for 240 days, corresponding on average to one year under field climatic conditions.
- Nitrogen mineralisation was also measured under field conditions, at least one year after the year of the last application:
  - by monthly measurements of soil mineral N content under bare soil. Soil was sampled by taking soil cores from the experimental plots; each core was divided into 3 soil layers (0-30, 30-60 and 60-90 cm), and the samples of each soil layer were then pooled for water content measurement and mineral-N analysis. Amounts of evaporated water, drained water, mineralised N and leached N were calculated using the LIXIM model ([4]), and
  - by mineral N balance under a non-fertilised crop (maize or wheat). Soil was sampled at the end of the winter and after crop harvest for mineral N analysis, and the yield and N content of the crop were determined. Soil N leaching that might occur in early spring was predicted with LIXIM, and the N balance was estimated.

Soil N mineralisation measured in field conditions was expressed as a potential rate of mineralisation Vp (kg mineralised N ha^{-1}normalized d^{-1}) applying the temperature and moisture functions used in LIXIM.

The effects of animal waste applications on SOM and N mineralisation were measured by comparison with a control treatment fertilised with mineral N (MIN). Manure-induced C (MI-C) and manure-induced N (MI-N) were calculated as the difference between the soil C and N contents under the manure treatment and the control. Extra N mineralisation (EN-Min) was calculated as the difference between the manure and control N mineralisation.

3 Results

3.1 Effects of animal manure application on soil C and N contents and their distribution in the fractions

For most trials and treatments, 10-20 years of annual or biannual supply, a total application of 1000-3000 kg $N.ha^{-1}$, resulted in C and N contents significantly higher for soil receiving animal manure than for control soils. This difference is generally significant for N when it is for C.

A highly significant correlation (P= 0.001) is observed between MI-C and MI-N, all trials combined, and by type of product (MI-N = 0.0816.MI-C, r^2 = 0.83 for cattle manure; MI-N = 0.1195.MI-C, r^2 = 0.92 for pig manure). This result reveals homogenisation of the C and N composition of the OM of manure during its evolution in the soil, because the initial mean C to N ratio of the wastes differed greatly between the trials.

Trial-by-trial comparisons confirm that the increase in N contents, compared to that of C contents, differs according to the type of product, with the relative increase decreasing from poultry manure to pig manure and to cattle manure.

Measurement of OM distribution of organic products into fractions leads to the same observations for all trials and treatments:

- manure applications do not significantly influence the size of the 200-2000µ fraction,
- stored OM is distributed into the 50-200µ and < 50µ (fine) fractions, with a predominance for storage of OM in the fine fraction (66 % on average). The incorporation of manure OM in the moderate to weak turnover compartments is confirmed by the work of [5]. The consequence of this result is that effect on the mineralisation of this stored OM will appear over the long-term.

For each type of manure, N storage in soil was correlated with the amount of N applied for a given trial but differed widely among sites, the rate of storage of organic N of cattle manure ranging from 19-70% according to the trial. This variability is not explained by the application scenarios (rates and application over time, length of the trial; modelling approach not presented), but can be related to differences in climate and soil conditions and to the biochemical composition of the manure applied.

3.2 Effects of manure application on soil N mineralisation

Soil incubation

Measurements of mineralisation in controlled laboratory conditions revealed a significant increase in N mineralisation (P=0.05), from 10 to 30 % higher than that for control soils, even for the products with low MI-N values (poultry slurry and manure). Extra mineralisation is high and significant (P=0.05) even when the last application of waste product was performed more than 4 years before the sampling (trials of St. Hilaire, Trevarez and Crecom).

Modelling of mineralisation dynamics allowed quantification of the contribution of rapid and slow turnover compartments to mineralisation. This approach shows that the increase in mineralisation in the soils receiving waste applications is explained mainly by the contribution of the slow-turnover compartment.

Field measurements

Figure 1 shows the relation between manure-induced N (MI-N, kg N ha^{-1}) and extra mineralisation (EN-Min, kg N mineralised ha^{-1} normalized day^{-1}) calculated with the 2 methods for monitoring field mineralisation.

The results obtained by monitoring bare soil allowed estimation of a linear relation between extra mineralisation and MI-N, all manure types combined (Fig. 1). The type of product applied seemed to have little influence on this relation (EN-Min= 0.0002 MI-N + 0.0726, R^2= 0.64, n=21 for cattle-derived products, EN-Min= 0.0002 MI-N + 0.0872, R^2 = 0.52, n=7, for pig-derived products). Compared to mineral fertilisation, the increase in mineralisation rate linked to the input of organic products for the same field can be estimated as 2.4 $kg.ha^{-1}.year^{-1}$ per 100 kg of organic N stored.

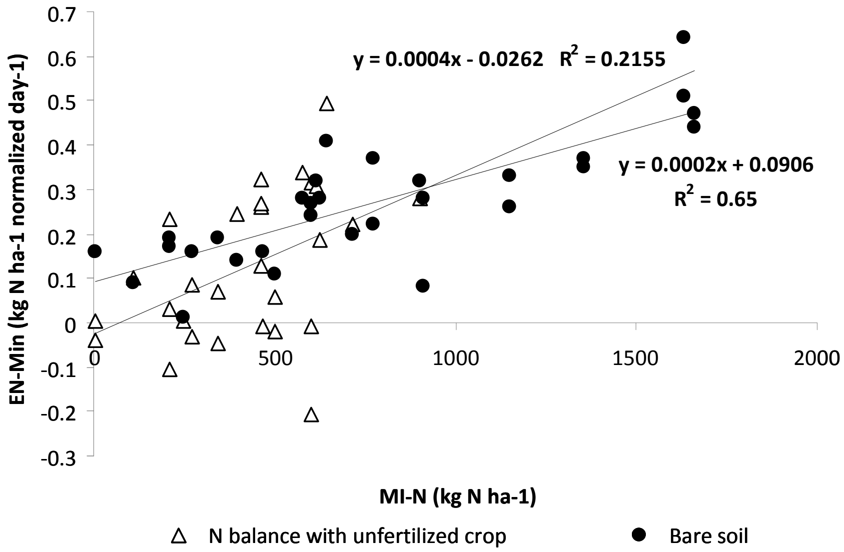

Figure 1. Relationship between manure-induced N (MI-N) and extra N mineralisation (EN-Min) observed with the bare soil method and the N balance with unfertilized crop method

The results given by N balances under unfertilised crops agree with the results of bare-soil monitoring in the Saint Hilaire, Trévarez, and Le Rheu trials but, in contrast, give clearly lower EN-Min values in the La Jallière and Crécom trials. Nonetheless, the 2 methods reveal an effect of the quantity applied to a given site: the relation between EN-Min and MI-N has an R^2 of 0.83 with bare-soil measurements and 0.79 with measurements of unfertilised forage maize in the Le Rheu trial.

Finally, the EN-Min values calculated from laboratory measurements are consistently lower than those measured in the field. This can be partially explained by the lack of response to the dose effect in the laboratory measurements of the Saint Hilaire and Le Rheu trials. The underestimation of mineralisation fluxes by this method was also observed by [6] but not explained.

Conclusion

The medium- and long-term measurements taken from this trial network reveal significant effects of animal waste applications on soil organic-matter state, the distribution of OM among size fractions, and N mineralisation. Extra mineralisation is significantly correlated with manure-induced N, regardless of the type of organic product applied. However, manure-induced N, expressed as a proportion of N input, strongly varies among sites. This variability could not be elucidated with available results.

This work was supported by the CASDAR program “Gestion durable des sols” funded by the French Ministry of Food, Agriculture, and Fisheries.

References

[1] Chang C, Janzen HH, 1996. Long-term fate of nitrogen from annual feedlot manure applications. J. Environ. Qual., 25, 785-790
[2] Schröder J.J., Jansen A.G., Hilhorst G.J., 2005. Long-term supply from cattle slurry. Soil Use Manag. 21, 196-204
[3] Cusick PR, Kelling KA, Powell JM, Munoz GR, 2006. Estimates of Residual Dairy Manure Nitrogen Availability Using Various Techniques. J. Environ. Qual. 35, 2170–2177

[4] Mary B, Beaudoin N, Justes E, Machet JM., 1999. Calculation of nitrogen mineralization and leaching in fallow soil using a simple dynamic model. Eur. J. . Soil Sci. 50: 549-566

[5] Huang S, Rui W, Peng X, Huang Q, Zhang W, 2010.Organic carbon fractions affected by long-term fertilization in a subtropical paddy soil. Nutr. Cycl. Agroecosyst., 86, 153–160

[6] Valé M, 2006. Quantification et prédiction de la minéralisation nette de l’azote du sol *in situ,* sous divers pédoclimats et systèmes de culture français. Thèse INP Toulouse, 182 p