Potential mineralization of nitrogen from organic wastes to ryegrass and wheat crops

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Abstract

Two-pot experiments with ryegrass and wheat plants were conducted in a Cambic Arenosol to test the reliability of N fate predicted by incubation experiments previously performed, with the same soil, to assess potentially mineralizable nitrogen from six organic wastes (municipal solid waste compost, secondary pulp mill sludge, horn meal, poultry manure, solid phase from pig slurry and composted pig manure). Two treatments, corresponding to 80 and 160 kg N/ha were tested, with or without mineral N fertilization. Experimental data obtained in the pot trials was consistent with nitrogen net mineralization trend observed in the aerobic incubations with all the wastes tested. Values of potentially mineralizable nitrogen (N₀) from the equations obtained by model fitting, to the incubation data, were well correlated to ryegrass and wheat N uptake. Poultry manure was the most efficient N supplier to crops.

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1. Introduction

Prime agricultural land is rapidly being taken up either for more crop production or urban expansion. Overuse and erosion are responsible for the existence of large areas of poor quality soils, namely sandy soils. Sandy soils are generally poor in available nitrogen (N). Furthermore, as they are well drained, they have a large potential for nitrate leaching, as well as limited adsorption capacity for cations including ammonium (NH₄⁺). Moreover, soil degradation and failure to replace adequately the N exported in crop production, results in large N deficits that lead to a diminution of the N supplying capacity of these soils and increased need for N fertilization. This element is often a limiting factor in the growth of many species. For this reason, excessive amounts of low cost mineral fertilizers have been used for decades to meet crops needs, resulting both in an economic disadvantage to the farmer and an environmental cost to society, in Western Europe (EEA, 2004).

On the other hand, the production of on- and off-farm wastes has increased at a very high rate, making urgent to find an environmental friendly alternative use. Land spreading can, therefore, represent an economical and environmentally safe way to recover value from a wide variety of on-farm and off-farm wastes. Soil application represents, in fact, an effective outlet for animal manure and other organic wastes and allows their organic matter and nutrient content to be used to supply crop needs and maintain soil fertility (Chambers et al., 1999). Adding organic wastes to the soil can increase total N, organic matter, microbial population, enzyme activity, moisture retention, pH buffering capacity and crop yields can be increased (Dick and Christ, 1995). The most immediate impact of organic waste application is on the availability of nitrogen to the subsequent crop, as a consequence of mineralization–immobilization processes (Hadas et al., 2004). Other authors have tested the release of N from organic wastes mineralization, to ryegrass, maize and wheat (Evers, 2002; Vagstad et al.,...
2. Methods

Two-pot experiments were carried out using the upper layer (0–25 cm) of a Cambic Arenosol (FAO, 1998). The soil, from an experimental farm in Pego˜nes, at 38°04′0N and 8°37′0W, with a particle size distribution of 872 g kg⁻¹ sand, 99 g kg⁻¹ silt and 29 g kg⁻¹ clay, and a WHC of 160 ml kg⁻¹, was air dried at room temperature, and sieved to pass a 2 mm mesh. Six organic wastes, previously ground, to pass a 0.75 mm sieve, and dried at 35 °C for 48 h were individually mixed with the soil. The organic wastes were composted municipal solid waste (M), secondary pulp mill sludge (S), horn meal (H), poultry manure (P), solid phase from pig slurry (SP) and composted pig manure (C). The soil and each waste were characterized chemically (Table 1).

2.1. Aerobic incubation

The same soil has been incubated before, using a modification of the procedure described by Gordillo and Cabrera (1997), fully described by Cordovil et al. (2005). During a period of approximately 8 months, contents of NH₄-N and NO₃-N were determined by molecular absorption spectrophotometry after extraction with a 2 M KCl solution (Mulvaney, 1996). The Stanford and Smith (1972) one pool kinetic model (\(N_m = N_0(1 - \exp(-kt))\)) was fitted to the incubation data. \(N_m\) represents the mineral N accumulated along time \(t\), \(N_0\) the potentially mineralizable N and \(k\) the mineralization rate constant.

2.2. Pot experiments

Two-pot experiments with ryegrass (Lolium perenne L. cv. Billion) and wheat (Triticum aestivum L. cv. Fitti) were conducted, in Kick-Brauchmann pots under controlled conditions. Two doses, equivalent to an addition of 80 or 160 kg TKN ha⁻¹, respectively treatments A and B, were tested with three replicates. Control – treatment A – and half of the pots received, in both cases, a total of 120 kg N ha⁻¹ as NH₄NO₃. Plants were also grown in plain soil – treatment B. The remaining pots received only waste as N supply. All pots received a mineral basal fertilization, via a nutrient solution, except N. Soil was kept at 70% water holding capacity.

Wheat and ryegrass were cultivated for approximately 4 months, and ryegrass was cut three times. The plant herbage was harvested by cutting to 2 cm above the soil surface. At both final harvests, the stubble components were obtained by further cutting to the soil surface. Plant material from each crop was analysed for nitrogen content.

Statistical analysis was performed by one-way and two-way ANOVA and significant differences were pointed out by LSD test, with 95% probability (Zar, 1996). Control means were compared to sample means by Dunnett test (Zar, 1996). Pot experimental data was correlated with data from the equations fitted with the incubation results.

3. Results and discussion

3.1. Some considerations about the incubation assay

Results from the incubation study were very well adapted to the one pool kinetic model proposed by Stanford and Smith (Cordovil et al., 2005). The kinetics of the mineralization of each waste, except for solid phase from pig slurry, can be observed in Fig. 1.

The sandy soil itself, contrary to expected, reflected a large value of mineralization rate constant \((k)\) (Cordovil et al., 2005). In fact, this soil initially underwent an intense mineralization, followed by a slower rate after less than a month. Therefore, this soil was likely to supply an important amount of N to the crops grown. The same pattern was observed before by other authors (El Gharous et al., 1990; Sousa et al., 2002).

3.2. Pot experiments

Concerning data from pot experiments, it can be drawn out that every treatment without mineral nitrogen fertilization promoted lower plant growth than control. Biomass
production was well correlated with N uptake by ryegrass and wheat ($0.99 < r < 1.00$), reflecting growth dependence from N supply to the crops.

The most efficient waste in terms of plant N nutrition, for both crops, was poultry manure (Fig. 2). This waste was also the one that showed a greater potential for N mineralization, according to the results obtained by Cordovil et al. (2005) in the incubation experiment. This is due to the fact that poultry manure has a high active N fraction ($\sim 37\%$) \( (\text{ANF} = (N_0/N_{Kj}) \times 100) \). Concerning all the wastes tested, and as reported by the former authors, the active nitrogen fraction was higher in the poultry manure and lower in the composted municipal solid waste and secondary pulp mill sludge (Cordovil et al., 2001, 2005). In fact, waste characteristics determine its behaviour in the soil, as well as the amount of N that becomes phytoavailable through mineralization.

The solid phase from pig slurry and horn meal also contributed to ryegrass N nutrition. Wheat plants also benefited from composted pig manure and horn meal application to soil. These wastes showed a quick initial N mineralization when incubated aerobically, and high proportions of ANF (25–33\%) (Cordovil et al., 2005). On the contrary, the less efficient wastes to plant nutrition, proved to be the composted MSW and pulp mill sludge, the ones with a higher proportion of recalcitrant N compounds (75\% and 72\%, respectively). The main characteristics of the composted MSW and of the pulp mill sludge, as well as the composted pig manure, were a fast initial mineralization followed by the stabilization of the mineral N content in the soil, revealing the presence of a high proportion of recalcitrant N compounds and an easily mineralizable fraction. On the other hand, wastes from animal origin had a higher active N fraction and therefore mineralised more N and for a longer period. Actually, Qian and Schoenau (2002) refer that the amount and type of compounds containing N, present in the wastes, give rise to a different ability to release mineral N. Moreover, C:N ratio is usually pointed out as one of the most important characteristics regulating N mineralization from organic wastes. Except for solid phase from pig slurry and composted pig manure, all the others showed low C:N ratios, revealing that they are potentially easily mineralised and that immobilization is not likely to occur (Cordovil et al., 2005).

The results obtained in the biological pot experiments strengthen the conclusions of the former incubation experiments.
This is proved by the good fitting of the Stanford and Smith (1972) model results and the results obtained in these experiments. Values of $N_0$ from the equations obtained by model fitting were well correlated to plant $N$ uptake by ryegrass and wheat, as can be seen in Fig. 3. The model tested was able to predict, with a high degree of confidence, the availability of $N$ to ryegrass and wheat crops.

4. Conclusions

Experimental data obtained in the pot trials was consistent with net nitrogen mineralization trend observed in the aerobic incubations with all the wastes tested. In fact, all data sets were well correlated, revealing that the Stanford and Smith model is also well fitted to organic wastes mineralization prediction, and not only to soil organic matter, thus allowing the estimate of $N$ release for plant nutrition. Among the wastes tested, poultry manure was the most efficient $N$ supplier to both crops tested, and presents a larger fraction of labile $N$ than the other organic wastes used. Municipal solid waste and secondary pulp mill sludge were the less efficient of nitrogen suppliers to crops, probably because they presented the highest proportion of nitrogen recalcitrant compounds.

Further research is needed to confirm the behaviour of organic wastes nitrogen mineralization, namely through field experiments, as compared to laboratory conditions.

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References


