SHORT TERM EVOLUTION OF PIG SLURRY MACRONUTRIENTS (N, P, K) ACCUMULATED INTO AN OVER AMENDED LYSIMETER (SOLEPUR)

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ABSTRACT

A 3280 m² lysimeter in integral drainage (SOLEPUR) received high rates (1000 $m^3.ha^{-1}.y^{-1}$) of pig slurry during five consecutive years. This application resulted in a nutrient load of 24 $t.ha^{-1}$ of total nitrogen, 8 $t.ha^{-1}$ of total phosphorus and 16 $t.ha^{-1}$ of total potassium. Consequently, the total nitrogen concentrations of the top soil increased from 1.7 $gN.kg^{-1}$ to 3.5 $gN.kg^{-1}$ which increased the soil nitrogen stock by more than 6 $t.ha^{-1}$. Six years after the end of spreadings, part of the accumulated nitrogen was mineralised, the total nitrogen content in the first horizon decreasing from 3.5 $gN.kg^{-1}$ to 2.5 $gN.kg^{-1}$. Over six years, the apparent mineralised nitrogen stock was estimated to be 2.5 $t.ha^{-1}$. During the same period, the nitrogen leaching losses accounted for 38 % of the soil-N released. Using this set of data, a rather crude predictive model for the fate of soil nitrogen was developed and used to calculate the time necessary for soil nitrogen to recess to original content. For phosphorus, soil analyses showed an accumulation of more than 6.6 $t.ha^{-1}$ of extractable Dyer phosphorus during the over application period, which represents a recovery of more than 82 % of the phosphorus applied. A large part (80%) of pig slurry phosphorus applied was recovered in the top surface layer (0-20 cm). After the applications ceased, the extractable Dyer phosphorus contents hinted a possible migration from the top soil layer down to lower ones. No significant phosphorus concentrations in the drainage water were measured, which confirmed the strong phosphorus retention capacity of the soil. Potassium applied through pig slurry seemed to be equally distributed throughout the soil profile. Six years after the applications ceased, the amount of soil exchangeable potassium decreased, while potassium concentrations in drainage water remained high.
Keywords: *pig slurry, lysimeter, nutrient fate.*

INTRODUCTION

As it is stipulated in the 6th Environment Action Programme of the EU, a new framework will be develop to promote soil protection and sustainable use. This European Soil Thematic Strategy lists eight major threats including erosion, decline in organic matter content, compaction, contamination, loss of biodiversity, sealing, landslides and flooding. Development of this new EU soil protection policy involves a wide range of consultations and experimental data set (Quevauviller and Olazabal, 2003).

In intensive livestock production areas, especially pig production, traditional manure management is realised using soil as a support for nutrient recycling. However, these routine applications of animal manure in excess of crop removal have resulted in a build up of soil macronutrient concentrations (Leinweber et *al*., 1997). As it is defined by the European Soil Thematic Strategy, this soil recycling improves the sustainability of these agricultural systems. In order to develop sustainable pig slurry fertilisation strategies, it is important to better understand and predict the fate of nutrients applied to soil with animal manure.

MATERIALS AND METHODS

Solepur field treatment plant is described in a previous paper (Martinez, 1997). A brief description is given below. The Solepur process uses a reconstructed agricultural soil (macrolysimeter) as a reactor where pig slurry is the input and drainage water is the output. Drainage water collected by artificial drains is then temporarily stored in a denitrification pond before it is finally spread on a separate field. The macrolysimeter consists of a managed field 3280 m² in size, hydrologically isolated, which allows for the total recovery of all the water leaching through the soil profile on which ryegrass (*Lolium perenne)* is grown. From 1991 to 1995, 4931 $m^3.ha^{-1}$ of raw pig slurry was applied to the managed field, which represents an annual load of 986 $m^3.ha^{-1}.yr^{-1}$. Pig slurry was applied through a spray boom 38 m wide. Samples of the applied slurry were taken for subsequent analysis especially for total Kjeldahl nitrogen, total ammoniacal nitrogen, total phosphorus and total potassium. Since 1996 this experimental treatment plant was stopped and no more applications were done while the ryegrass sward was maintained.

The main plot was sampled at 0-20, 20-40 and 40-60 cm depth. Soil samples were then mixed and sieved through a 6 mm mesh. A sub-sample of about 1 kg of fresh soil was taken for each depth. Soil samples were taken at the beginning of the experiment on 19 March 1991 (prior to intensive and repeated pig slurry applications) and approximately six months after the last slurry application on 4 April 1996. Three years after the last pig slurry application, soils were sampled on 15 March 1999 and a last sample was taken on 5 may 2002. Oven-dried at 45°C, the soil samples were finely ground before analyses for Total Kjeldahl nitrogen, Dyer extractable phosphorus, exchangeable potassium using standard methods (Baize, 1988).

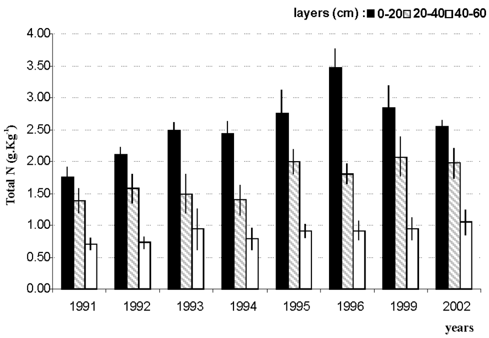
Throughout the drainage season, a daily drainage water sample was taken and analyzed for nitrate (NO_3^-) concentration. A composite sample was prepared each week for total phosphorus and potassium. This procedure was initiated during the drainage season 1993 /94 and continued on to date.

RESULTS AND DISCUSSION

Nitrogen

From 1991 to 1996, 24.5 $t.ha^{-1}$ of total nitrogen were applied onto the Solepur macrolysimeter. Total nitrogen concentration measured in soil increased from 1.8 to 3.5 $g.kg^{-1}$ for the top layer (0-20 cm), from 1.4 to 2.0 $g.kg^{-1}$ for the 20 to 40 cm layer while only a negligible increase could be detected for the 40-60 cm layer (Figure1). In total, 6084 kg of total nitrogen were estimated to be retained in the 0 to 60 cm profile, which is about a quarter of the total N applied. A tentative N balance shows that a large part (66%) of total pig slurry nitrogen was in the ammoniacal form and could be volatilised as ammonia gas after pig slurry application, the remainder being rapidly oxidised into nitrate (Martinez, 1997). The resulting nitrate was either taken up by ray-grass or lost through leaching. Nitrate concentration of the drainage water leaving the soil treatment system increased progressively with successive slurry applications. Cumulating over the 1991-1997 period, more than 400 kg $NO_3^-N.yr^{-1}$ were lost through drainage representing about 10 % of the total slurry nitrogen applied. Previous nitrogen balances from the Solepur experiment emphasised the importance of gaseous emissions. Soil denitrification appears to be an important component in the nitrogen budget, removing 30 to 40% of the total nitrogen applied. It also appears that the system emits significant amounts of nitrous oxide (Chadwick et *al*., 1998). Further investigations demonstrated that all nitrogen accumulated in the soil was in the organic form and probably originated from organic nitrogen pig slurry. Over the accumulation step, more than 8 t.ha^{-1} of organic nitrogen was spread with successive effluent applications.

After the applications ceased, soil total nitrogen concentration for the top layer decreased from 3.5 g.kg^{-1} in 1996 to 2.8 g.kg^{-1} in 1999 and to 2.5 g.kg^{-1} in 2002 (Figure 1). No significant trend was measured in the other layers (20-40, 40-60 cm). This evolution most likely results from mineralization of the organic nitrogen. Calculated mineralization rates (calculated by difference in soil total N content) were strongest during the three first years after spreadings (about 500 kgN.ha^{-1}.y^{-1}) and decreased significantly over the three following ones (260 kgN.ha^{-1}.y^{-1}). Over six years, the mineralised nitrogen stock was estimated to be 2.5 t.ha^{-1}. During the same period, nitrogen lost in drainage water amounted to 1 t.ha^{-1}, or 170 kg.ha^{-1}.yr^{-1} on average. This accounts for 38 % of the apparent nitrogen mineralized. The apparent nitrogen mineralisation could be modeled using a first-order (exponential) reaction inspired from Stanford and Smith (1972). With this model soil N stock and mineralization rates could be calculated and predicted. Our simulation results suggest that soil total nitrogen concentration would return to initial values (1.7 gN.kg^{-1}) 13 years after the end of slurry application, which corresponds to nearly three times the time taken to build total nitrogen content during the spreading period.



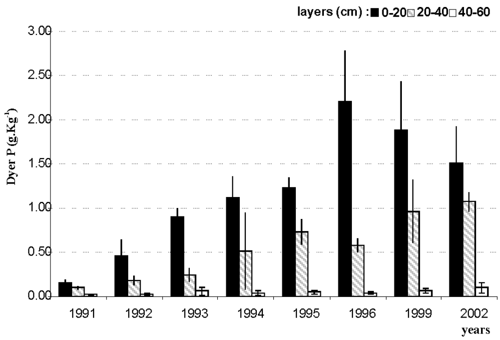


Figure 1 & 2*. Temporal evolution of total nitrogen and Dyer phosphorus concentrations in Solepur soil.*

Phosphorus

From 1991 to 1996, 8.2 t.ha^{-1} of total phosphorus were applied. Extractable Dyer phosphorus concentration measured in the soil increased from 0.1 to 2.2 g.kg^{-1} for the top layer (0-20 cm), from 0.1 to 0.6 g.kg^{-1} at 20-40 cm and only negligibly at 40-60 cm (Figure 2). More than 80 % of the total phosphorus applied was recovered with Dyer extraction in the 0-60 cm profile, which represents 6602 kg. The top layer accumulated more than 5 t.ha^{-1} of Dyer-P, which represents more than 80 % of the amount of phosphorus retained as Dyer-P in the whole soil profile.

After the end of spreading, soil Dyer-P concentration decreased in the top layer from 2.2 g.kg^{-1} in 1996 to 1.8 g.kg^{-1} in 1999 g.kg^{-1} and reached 1.5 g.kg^{-1} in 2002. An opposite trend was measured in the 20-40 cm layer: soil Dyer-P concentrations increased from 0.6 g.kg^{-1} in 1996 to 0.9 g.kg^{-1} in 1999 and to 1.0 g.kg^{-1} in 2002. For the lowest layer no significant change was observed. These results highlight that significant amounts of Dyer-P moved downward from 0-20 cm to 20-40 cm ; an estimated 300 kg.y^{-1}of phosphorus moved per year from the top to the intermediate layer. However, in our study, we found low phosphorus concentrations in the drainage water which always remained lower than 10 to 20 µg.l^{-1} P and remained unchanged during the 9 seasons monitored. The amount of P lost by leaching was estimated at a maximum of 0.3 kg from the beginning up to now, which is extremely small compared with the load of total P applied.

Potassium

Total potassium applications amounted to 16.5 t.ha^{-1}. The soil exchangeable potassium concentration increased rapidly after the applications potassium in all layers, reaching a maximum of 1.4, 1.2 and 0.9 g.kg^{-1} in 1996 for the 0-20, 20-40 and 40-60cm layers respectively (Figure 3). In 1996, the percentage recovery in the exchangeable fraction of the potassium applied to the soil was estimated to be about 43%. The potassium applied with the slurry was fairly leachable and a substantial increase of potassium concentration in drainage water was measured during the trial period. On average over the last nine drainage seasons, about 450 kg.ha^{-1}.y^{-1} potassium were leached, which represents more than 25 % of the pig slurry potassium application. This shows a much greater mobility of potassium than phosphorus in the soil profile, as one would expect. At the end of the spreading period, soil exchangeable K concentration decreased rapidly to reach about 0.6 g.kg^{-1} in 2002 for all the three layers. The substantial proportion of applied potassium (about 32% of pig slurry potassium) which was not recovered in the exchangeable fraction or in the drainage water was most certainly fixed as nonexchangeable potassium by soil clay minerals.

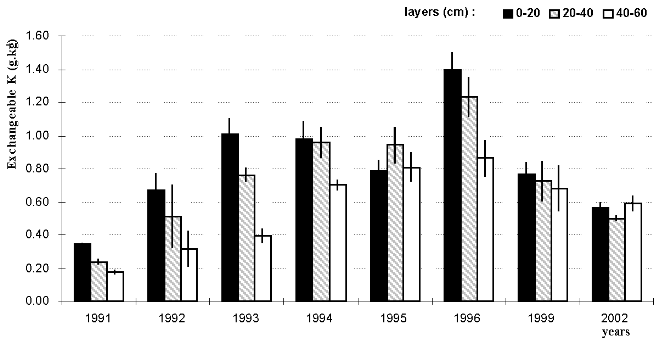


***Figure 3**. Temporal evolution of exchangeable potassium concentrations in Solepur soil.*

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