Management of pig slurry for nitrogen fertilization of corn

Gestion du lisier de porc pour une fertilisation azotée du maïs

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Abstract

A five-year lysimeter experiment was carried on a one meter deep loamy soil, pH 6,1 , to test the effect of pig slurry management on crop production and water quality. The optimum nitrogen fertilizer rate (X_{min}) was calculated annually using the balance sheet method ; X_{min} varied from 60 to 124 kg N ha^{-1}. Pig slurry was annually applied i) in late spring, at three rates,: X_{slu}, $X_{slu + 75}$, $X_{slu + 150}$ kg N ha^{-1}, and ii) in mid autumn (S_{DCD}), at the rate of 3 l m^{-2} (corresponding to 180-200 kg N ha^{-1}), mixed with a denitrification inhibitor (DCD, 25 l ha^{-1}). The slurry was manually incorporated , immediately after spreading. This five-year experiment suggests that :i) the optimum nitrogen fertilizer rate calculated according to the balance sheet method seems to strike an acceptable balance between high crop production and low level of water pollution, ii) this level of fertilization can be achieved with « repeated » and exclusive fertilization with pig slurry, iii) the two methods of slurry management (late spring or mid autumn, with DCD) gave similar results.

Keywords : slurry, fertilization, lysimeter, leaching

Résumé

Une expérimentation a été menée pendant cinq ans sur un dispositif lysimétrique, pour étudier les effets sur la production et la qualité de l'eau de différents modes de conduite de la fertilisation du maïs avec du lisier de porc. La dose optimale d'azote (X_{min}) a été calculée chaque année par la méthode du bilan prévisionnel, et a varié de 60 à 124 kg N ha^{-1}. Le lisier de porc a été apporté chaque année : i) en juin, à 3 doses : Xslu, Xslu + 75, Xslu + 150 kg N ha^{-1}, et ii) en novembre (SDCD), à la dose de 3 l m^{-2} (correspondant à un apport d'azote de 180-200 kg N ha^{-1}), mélangé à un inhibiteur de nitrification (DCD, 25 l ha^{-1}). Le lisier a été incorporé immédiatement après épandage. Cette expérimentation pluri-annuelle montre que i) la méthode du bilan prévisionnel et la valeur du coefficient d'équivalence engrais du lisier s'avèrent robustes, et conduisent à un compromis correct entre l'exigence de rendements élevés et d'un niveau bas de pollution, ii) la fertilisation du maïs exclusivement par du lisier de porc donne des résultats similaires à ceux obtenus avec l'engrais minéral, iii) des résultats proches sont obtenus avec deux modes de gestion du lisier (apport de printemps, ou d'automne, avec addition de DCD).

Mots-clés : lisier, fertilisation, lysimétrie, lessivage.

Introduction

The intensification of livestock production in Brittany over the past 30 years has led to the production of high quantities of animal waste, of which approximately 75 % are slurries (Chadwick et al, 1998). The cheapest solution for disposing of these effluents is often to spread them on cultivated soils and pasture land, as this allows recycling of the nutrients. However, environmental problems related to livestock land use are rapidly leading to increasing nitrates concentration.
Nitrate contamination of surface and groundwater due to the excessive application of animal wastes has been well established. Spallacci (1981) showed in a four-year lysimeter trial, on different soils manured with pig slurry, that nitrogen losses were influenced by soil type, slurry rates, and by the timing of slurry dressing. The N leached varied from 20 to 50 kg N ha^{-1} at moderate rates of slurry application (200-400 kg N ha^{-1}), but strongly increased at higher rates, rising to 250 kg N ha^{-1} on a sandy loam soil. Carey et al (1997) in their investigation into the behaviour of ^{15}N-labelled pig slurry spread on a cut sward, pointed out that the N leached was significantly higher at an application rate of 400 kg N ha^{-1}, compared to one of 200 kg N ha^{-1} .

Liquid manure has a high yield effect due to its high ammonia content and the low C:N ratio of its organic fraction (Tietjen, 1981, Boschi et al, 1981), but its nitrogen efficiency is lower than that obtained with mineral nitrogen. Apparent N efficiencies, obtained by comparison with mineral nitrogen fertilization, ranged from 40 to 80 % after application of pig or cattle slurry (Duthion, 1981, Chambers and Smith, 1992, Morvan et al, 1995). The N efficiency of slurry N depends mainly on : i) slurry chemical composition, particularly the dry matter content, as indicated by Chambers and Smith (1992), ii) soil characteristics (Smit and Chambers, 1992), and iii) application techniques (Wouters, 1995). The usual operational models of manure availability to plants (Pratt et al, 1973, Sluijsmans and Kolenbrander, 1977) are very simple, and assume that the N efficiency of nitrogen manure is constant over a wide range of situations : for example, manure type is taken into account, but the variability of the composition of a given manure type is not considered. These simple models despite their imperfections are often used as operational models, but we note that the soundness of the reasoning underlying fertiliser application has been poorly studied.

A five-year lysimeter trial was carried out in order to test the accuracy of a simple operational model of manure N availability, as regards satisfying plant requirement and water quality, and two different application times were compared.

Material and method

<u>Soil and lysimeter description</u> :

The study was conducted in Brittany (France) on a loamy soil. The lysimeters were built in 1991 and five trials were carried out from 1993 to 1997. Lysimeters were of closed type and consisted of concrete tanks (1,5 m x 1,34 m x 1.10 m deep) filled with : i) a layer of gravel placed at the base of each lysimeter to facilitate drainage, and ii) successive layers of soil, each 10 cm deep. The space surrounding the lysimeter was also filled with soil, so that the upper part of each lysimeter was at ground level. Each lysimeter was surrounded by a 150 m² experimental field area, subjected to the same technical itinerary. Leachates were collected at varying intervals according to the amounts of drainage water.

The characteristics of the upper layer of the soil were as follows: organic C : 1.04%; total N : 0.123 % ; C:N : 8.5 ; pH : 6.1 ; clay :15 % ; loam : 71 % ; sand : 14 %.

<u>Climatic conditions</u> :

Daily measurements of rainfall were obtained on site and of air temperature from a weather station located near the experimental site.

The mean rainfall during these five years was 701 mm, and was close to the average rainfall (714 mm) over 16 years ; 50 to 60% of the total rainfall occurred during autumn and winter, although the last two winters were not very wet.The summer rain fell essentially as storms (June to August) ; such events led to drainage only once, in 1993.

A severe drought in 1996 resulted in poor yields, whereas a storm in June 1997 retarded the development of the water deficit, and allowed high yields.

The mean air temperature during these five years was 11.8 °C, and was higher than the average air temperature over 16 years (10.2 °C).

<u>Experimental design</u> :

Different treatments were applied since 1993 to the 6 lysimeters and to the 150 m² area surrrounding each lysimeter, cultivated with corn (DEA). Except for the control treatment, the rates of nitrogen application varied from year to year as follows :

- the mineral nitrogen rate (X_{min}) was calculated according to the nitrogen requirement of the crop to be grown, using the balance sheet method (Remy and Hebert ,1977, Machet et al, 1990) :

$$R_f - R_i = Mn + X_{min} - L - bY$$

where
bY = plant population requirement (under the hypothesis that b = 13 kg N t^{-1} DM for corn).
R_i = mineral nitrogen available at the beginnig of the analysis (mid March in our case)
R_f = mineral nitrogen at harvest
Mn = net mineralization of three organic pools : soil humus, crop residues and

organic manure
X_{min} = mineral fertilizer rate
L = Nitrogen leaching between R_i and R_f (hypothesis that L=0)
R_i was measured at the end of the winter ; other parameters were estimated, so that X_{min} could be calculated . It was considered that a reasonable way of estimating Y was to take the average of the two highest DM yields during the past 5 years ; the value of 16 t DM ha^{-1} was considered, according to local references, except in 1996, because problems at emergence clearly led us to lower the objective yield. The X_{min} rate varied from 60 to 124 kg N ha^{-1} over the five years.

- the « equivalent » rate of slurry X_{slu} was calculated by assuming that 70 % of the total nitrogen of the slurry was available as mineral nitrogen (Desvignes, 1995). But as determination of the total nitrogen content of the slurry required a laboratory chemical analysis, we preferred a more operational way of determining the nitrogen content, which consisted of: i) determining the ammonia content with a rapid method analysis (Agros or Quantofix apparatus) used by farmers, just before spreading ; this method gives accurate values of ammonia content (Bertrand, 1985), and ii) assuming that the N_{tot}:NH_4 ratio is equal to 1.43. The main assumptions that were adopted in calculating the rates of mineral and slurry nitrogen are summarized in figure 1.

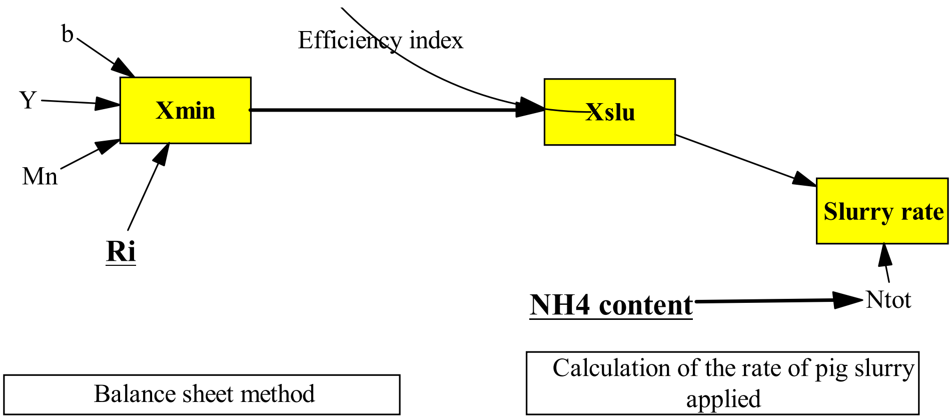

Figure 1.
Diagram representing the calculation of X_{min} and X_{slu} rates (in kg N ha^{-1}) and slurry rate (m^3 ha^{-1}) (underlined parameters were measured)

- two slurry treatments were also added : $X_{slu\ +75}$ kg N ha^{-1}, $X_{slu\ +150}$ kg N ha^{-1} ; the additional amounts of slurry were calculated on an ammoniacal nitrogen basis.

A final slurry treatment was made in autumn on bare soil at a rate of 3 l m^{-2} (corresponding to 180- 200 kg ha^{-1}). A nitrification inhibitor (DCD) was added to the slurry at a rate of 25 l ha^{-1}, because earlier studies, confirmed by the results of Morvan et al (1996) had shown that nitrification of slurry ammonium occured too rapidly to prevent a risk of nitrate leaching during winter, under our climatic conditions. The slurry was spread during the ten days before November 15 th because slurry spreading is not allowed by law in Brittany after this date.

The slurry was incorporated manually immediately after spreading, for all treatments, to prevent ammonia losses.

Calculations :

The efficiency of use of N from slurry or mineral fertilizer was calculated from the apparent nitrogen recovery (ANR_{sl}), which was the increase of the amount of N contained in the whole plant at harvest (obtained by difference with the control treatment), expressed as a percentage of the N applied in the slurry or fertilizer. Slurry ANR (ANR_{sl}) may also be related to the ANR obtained with mineral nitrogen (ANR_{min}), and can be considered as an « efficiency index » of the slurry nitrogen.

Results and discussion

Dry matter yields and nitrogen absorption :

Poor emergence of maize and drought stress in 1996 strongly depressed yields at all N rates. In contrast favourable climatic conditions in 1997 led to very high dry matter yields. The average of the two highest dry matter yields on X_{min} treatment was close to the 16 t DM ha^{-1} yield objective used for the balance sheet method calculations, and confirmed that the yield objective was realistic. The dry matter yields were however highly variable, even when the 1996 yields were not considered. Corn was responsive to increasing slurry N until the rate X_{slu+75} (table 1) ; dry matter yields at X_{slu+75} and $X_{slu+150}$ were in fact on average 2.6 and 1.6 t DM ha^{-1} year $^{-1}$ higher than the yields obtained at the X_{min} and X_{slu} rates respectively. The results therefore suggest that the X_{min} rate underestimated the optimum.

	Dry matter yield (t DM ha-1)	Total N uptake (kg N ha-1)	b (kg N / t DM)	% N recovery *
Control	10.6	100	9.43	-
X_{min}	12.9	136	10.54	65.7
X_{slu}	13.9	151	10.86	52
S_{DCD}	14.4	153	10.62	42.6**
X_{slu+75}	15.4	182	11.81	39.1
$X_{slu+150}$	15.6	185	11.85	26.3

* : mean value on years 1994,1995,1997
** : mean value on years1994,1995,1996,1997.

Table 1.
Mean values over five years of dry matter yield and total N
(total Nuptake = 1.1 x Nuptake aerial biomass) for the 6 treatments.

Despite the wide range of their value over the five years, dry matter yields between the X_{min} and X_{slu} treatments were similar, slightly higher amounts of nitrogen being taken up under the X_{slu} treatment, except in 1997 when the nitrogen uptake was 22 % higher with the slurry , compared to the mineral treatment (fig 2). These results therefore conferred a soundness to the very simple method used to calculate the slurry dose under our experimental conditions, where ammonia volatilization was limited by slurry incorporation. ANR values ranged from 49 to 81 % for X_{min} treatment, and from 31 to 67 % for X_{slu} treatment.

- Despite the long residence time of the autumn spread slurry, similar yields and N uptake, were obtained between the slurry added with DCD applied in autumn and the slurry spread in spring, over all five years (fig 2). Our results are in agreement with those of Schröder et al (1993) ; these authors obtained similar dry matter yields and ANR values, when cattle slurry was applied with DCD in autumn or without DCD in spring, whereas lower yields were observed when cattle slurry was applied without DCD in the autumn. The mid autumn treatment gave higher yields in 1996, compared to X_{min} and X_{slu}, which could be explained by a better distribution of mineral nitrogen in the soil profile, during the period of active nitrogen absorption by the crop.

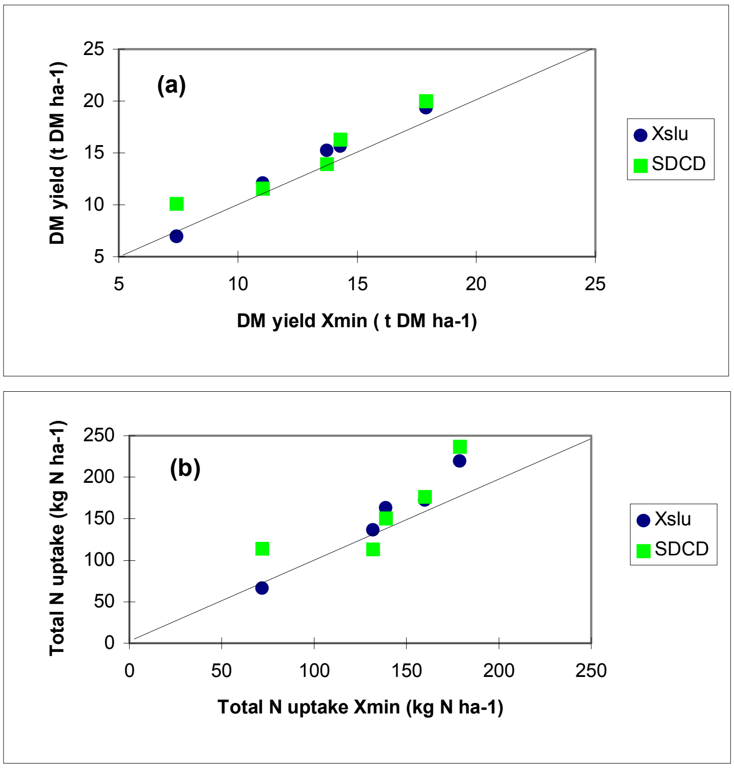

Figure 2
Comparison of dry matter yield (a) and N uptake (b) between X_{min} treatment and X_{slu} and S_{DCD} treatments, over the five years.

Drainage and N leaching :

The cumulative amounts of nitrogen measured in the leachates are reported in figure3.

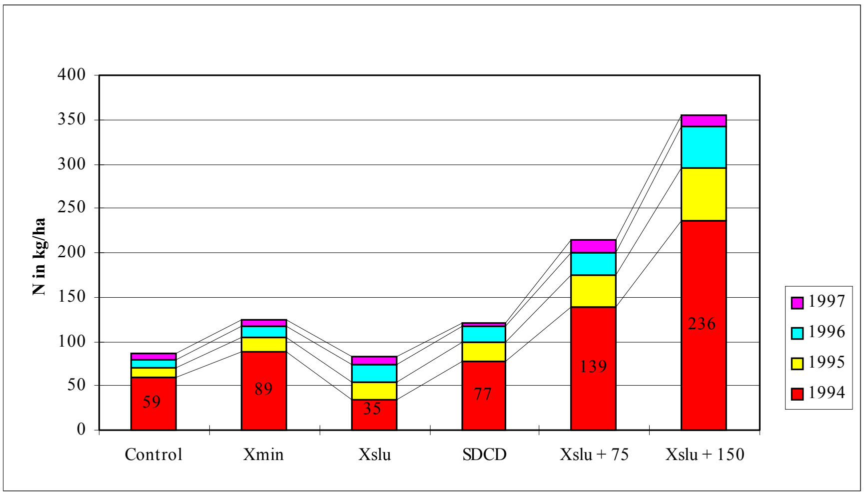

Figure 3.
Cumulative amounts of nitrogen lost in the leachates, for all treatments (information on leaching in 1993 could not be used because watertightness of lysimeters wasn't perfect)

The nitrogen lost in the leachate varied considerably between the different treatments and the different years ; the last two winter periods were drier than normal (the water percolated was 70 mm in 1997 and 105 mm in 1995, compared to 280 mm in 1994). Weak nitrogen losses occurred during these « dry » winters on control, X_{min}, X_{slu} and S_{DCD} treatments, whereas they remained much higher for the $X_{slu\ +\ 75}$, $X_{slu\ +\ 150}$ treatments. High N losses in 1994 were related to strong rainfall during the winter ; the lower N losses observed on X_{slu} compared to X_{min} treatment in 1994 could not be explained either by nitrogen quantity or by nitrogen distribution in the profile ; the N losses measured in X_{min} and X_{slu} after 1994 were quite similar.

The N leached from the X_{min} and S_{DCD} treatments was very similar for the four years, suggesting that no leaching of the slurry nitrogen added with DCD occurred during winter after spreading.

The N losses cumulated over four years attained 125 and 121 kg N ha^{-1} for the X_{min} and S_{DCD} treatments respectively, implying that the « apparent additional pollution », obtained from the difference with the control treatment, was only 37 kg N ha^{-1}. This « additional pollution » was low, representing 11.5 % and 4.4 % of the applied nitrogen for Xmin and S_{DCD} respectively ; no additional pollution was recorded with the X_{slu} treatment, because of the low leaching in 1994.

On the other hand, nitrogen leaching greatly increased at the X_{lis+75} (by 70 %)and $X_{lis+150}$ rates (by 190 %), compared to the X_{min} rate.

Conclusion

This five-year lysimeter experiment enabled us to show that exclusive and « repeated » fertilization of corn with pig slurry was quite « sustainable », as it gave similar dry matter yields, compared to mineral nitrogen fertilization, and resulted in low levels of nitrogen losses. The results also suggest that the method used to calculate the nitrogen fertilizer rate seemed to strike an acceptable balance between high crop production and water quality. This method of agronomic management permitted valorization of spring and autumn applications of pig slurry over five years without any increase in water pollution, compared with the pollution obtained with mineral nitrogen fertilization.

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