Proposal of an integrated approach to characterize « the nitrogen value » of organic products spread in agriculture.

Approches expérimentales utilisables pour caractériser la valeur azotée des produits organiques épandus en agriculture.

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Abstract

An integrated approach is proposed to study the behaviour or organic products in soil and their N availability. In field, N dynamics of organic products is studied using periodic inorganic N determinations in the soil profiles of plots maintained bare during the experiments. Net mineralization of organic products is then estimated by taking into account net mineralization in soil with and without organic residues and using a model which calculates N leaching and mineralization. In laboratory, N mineralization kinetics are measured during soil incubations under controlled conditions. Comparison with field data is rendered possible by using a normalized time scale which takes into account the effect of soil moisture and temperature on soil biological processes. Finally, organic products are characterized using chemical or biochemical determinations (e.g. water solubility at different temperatures). This methods would allow to differentiate products from different origins, first results being correlated to incubation data. Final objectives are to provide data which will be used to parameterize soil C and N transformations models and decision making tools and propose some chemical or biochemical tests which rapidly characterize the various organic products used in agriculture.

Résumé

Différentes approches ont été utilisées pour caractériser le devenir de résidus organiques dans le sol et déterminer leur valeur azotée. Etant donné la diversité des produits organiques utilisés en agriculture, il est nécessaire de proposer des tests de laboratoire qui permettent de rendre compte du comportement des produits dans le sol et de leur valeur agronomique, en s'affranchissant de la mise en place de longues ou lourdes expérimentations au champ ou au laboratoire.

Au champ, la dynamique de l'azote après apport de produits organiques a été suivie au moyen de mesures fréquentes d'azote minéral effectuées sur le profil de sols maintenus nus pendant l'expérimentation. La minéralisation nette de l'azote organique des résidus est ensuite estimée avec un modèle de calcul du lessivage et de la minéralisation LIXIM et en prenant en compte les résultats obtenus pour un sol témoin sans épandage.

Au laboratoire la cinétique de minéralisation potentielle du carbone et de l'azote des produits a été mesurée au cours d'incubations de sol en conditions contrôlées. Les résultats sont bien corrélés aux données de minéralisation nette mesurées sur le terrain, la comparaison ayant été rendue possible grâce à l'utilisation d'une échelle de temps exprimée en « jours normalisés » qui prend en compt les lois d'action de la température et de l'humidité sur les processus biologiques.

Les produits ont été également caractérisés au moyen d'analyses chimiques ou biochimiques (par exemple solubilité à l'eau à différentes températures). Cette approche permettrait de relativement bien différencier des produits d'origines variées, les premiers résultats étant bien corrélés aux données acquises en incubation.

Toutes ces méthodes sont enfin discutées en considérant la typologie et la nature des produits pris en compte.

Mots-clés : produits organiques, décomposition, minéralisation nette, tests de laboratoire.

1. Introduction

The diversity of organic products spread on agricultural areas is very important. These organic products include effluents from cattle breeding (manure, slurries,...), sewage sludge and waste waters from agro-industries (starch potato factory, sugar refinery, cannery, distillery, dairy, paper mill,..). Urban wastes (sewage sludge, refuse composts, vegetable wastes...) are also spread on agricultural fields. In addition, some of these organic products can be mixed together or co-composted. Agronomical value of these organic products consists in bringing to soil organic matter or nutrients (essentially N, P, K...).

Nevertheless, this agronomical value is generally imprecise or not well known due to the lack of knowledge on the behaviour of these organic products in soil and on the dynamics of nutrients (N, P...) after spreading. This is reinforced by the considerable number of different organic products used in agriculture. For organic products coming from agro-industry, this diversity is mainly related to the origin and nature of agricultural products, and the numerous processes of transformation of agricultural products. For a given organic product, characterics may change equally with time (e.g. starch factories which process different potatoes varieties along the season). In addition, some other factors may influence this variability as for example the physical, chemical and biological treatments applied to effluents or wastes and the conditions of storage.

Thus, there is a need to establish a classification or a typology based on different criteria as, for example, origin, nature, type or physical appearance of products in order to better predict the behaviour and N dynamics of organic products incorporated in soils. Those criteria require the implementation of analytical tests or methods of characterization, which must be simple, rapid and of a low cost. Main objective of our work is to propose an integrated approach to characterize the N value of organic products and afterwards simple methods to predict their behaviour under field conditions.

2. Existing methods to measure N availability of organic products

Different experimental approaches have been proposed to assess N availability of agricultural soils and organic products used in agriculture as organic amendments or fertilizers. These methods include field trials, greenhouse experiments, laboratory incubation and chemical extraction (Bundy and Meisinger, 1994; Bourgeois *et al.*, 1996; Chaussod *et al.*, 1997).

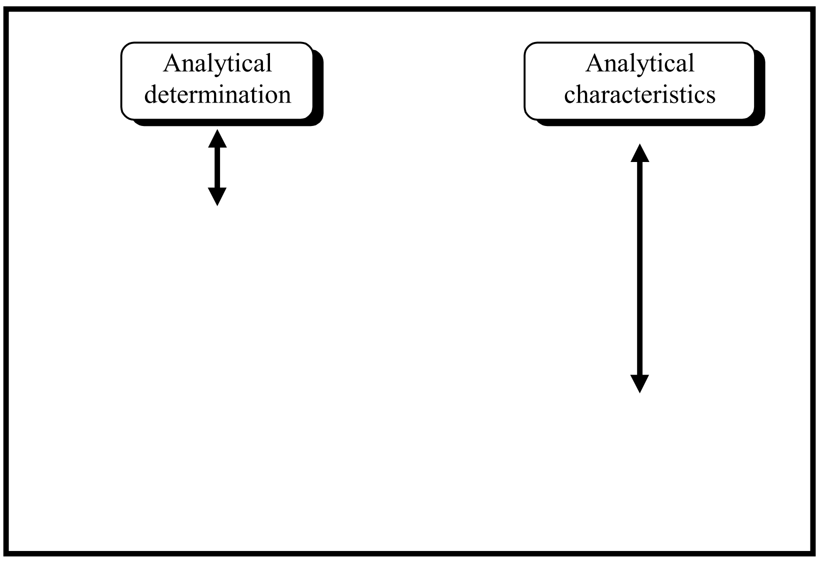
Field trials provide N values measured in real conditions considering various pedoclimatic conditions and different cultures. N values are usually evaluated using two experimental methods: i) calculation of the apparent utilization coefficient (AUC), which corresponds to the ratio between N of organic products recovered in plants (N recovered in plants growing on soil + organic products minus N recovered in plants growing on control soil without organic products) expressed in % of N from organic products; ii) use of N response curves where N of organic products recovered in plants for a defined rate is compared to plant N obtained for different increasing N fertilizer rates. N values are equally evaluated during the cultivation of plants grown in controlled growth chambers or glasshouses (Bould, 1948; Chaussod *et al.*, 1981) using comparable methods.

N values can be assessed using laboratory soil incubations where the evolution of C and/or N of organic products mixed with soil are measured during more or less long periods under optimal soil moisture and temperature (Premi and Cornfield, 1971; Chèneby and Nicolardot, 1992). Soil incubations provide information both on N mineralization kinetics and N quantities which are released during the decomposition of organic products. N mineralization kinetics are then interpreted to define N availability using simple mathematical equations (Yadvinder *et al.*, 1988; Chèneby *et al.*, 1994) derived from those proposed by Stanford and Smith (1972) to assess N mineralization potential of soils. N released during soil incubations appears well correlated with crop N uptake in pot studies, but relationships are poor when considering field studies (Jarvis *et al.*, 1996).

Numerous chemical indexes have been proposed to estimate soil organic N availability (Stanford, 1982). These methods determine amounts of N rendered soluble by chemical extracting agents which simulate mineralization activity of the soil microflora: they include more or less concentrated acid or alkaline reagents associated or not with oxidizing agents, extraction being performed at more or less high temperature. Some of these methods have been used to differentiate and characterize N availability of different organic products (Chaussod *et al.*, 1981; Castellanos and Pratt, 1981; Douglas and Magdoff, 1991). All these chemical indexes have not been tested on a broad range of organic products and field conditions (Jarvis *et al.*, 1996), thus they can be used with difficulty for the moment in decision making tools to predict N released by organic products (Chaussod *et al.*, 1997).

3. Proposal of an integrated approach to measure N availability

The three approaches described above have almost never be used simultaneously on a broad range of conditions. Elsewhere coefficients or rules to link results obtained with these approaches have not been systematically determined. The integrated approach proposed to characterize the N value of residues is described in Fig. 1. During a first step the objective will consist to establish relationships between the 3 approaches for a wide range of organic products and field conditions. Characterization and incubation can be easily performed on numerous products whereas field experiments using selected organic products will allow us to validate results obtained with laboratory methods. During a second step, results of chemical or biochemical tests will be used in models or making decision tools to predict behaviour of organic products in soil.



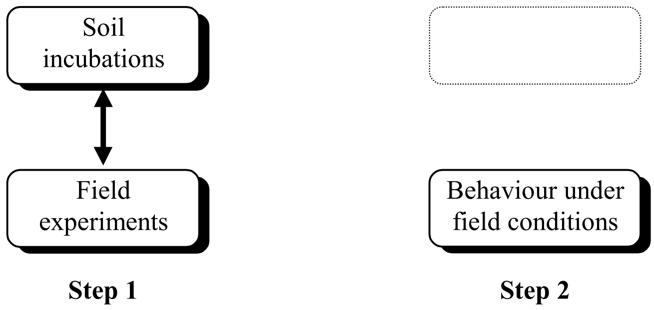


Figure 1
Proposed approach to predict the behaviour of organic products in field conditions.

Residual inorganic N in soil

Fig. 2 shows the approach used in field experiments to evaluate net N mineralization from potatoes starch industry waste water (Justes *et al.*, 1998). Two treatments were compared: bare soil with or without (control soil) waste water. Spreading amounts were about 500 m^3 ha^{-1}. Soil inorganic N and moisture were measured in the soil profile (0-120 cm, 4 layers) every 2 or 4 weeks during a 9-month period. Net N mineralization in the different treatments was calculated using a simple N mineralization and leaching model LIXIM (Mary, 1996). This model takes into account water and nitrate movements and N mineralization in bare soils. The description of nitrate movement is based on Burn's algorithm (1976), but takes also into account the daily rainfall and soil evaporation, the actual initial nitrate N profile, the atmospheric inputs and N mineralization. Then cumulated net mineralization and nitrification coming from waste water was calculated by difference with the control soil (Fig. 2).

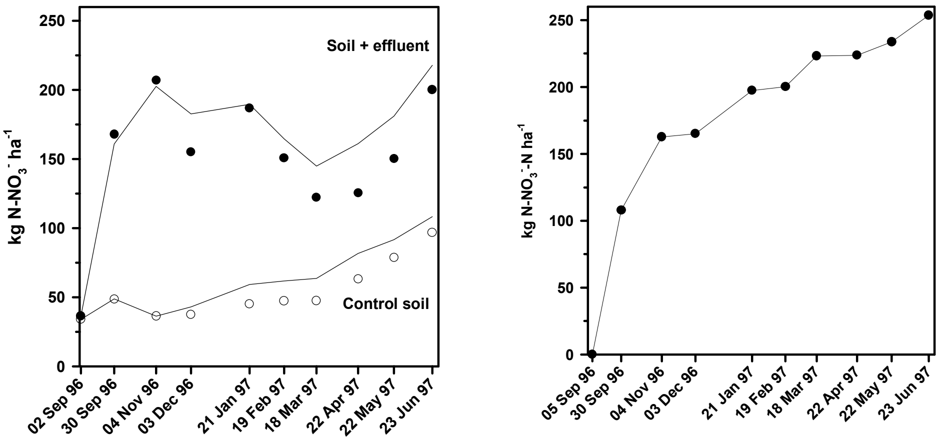


Figure 2

N mineralization of potatoes starch factory waste water under field conditions. Left: measured (symbols) and simulated (lines) data of nitrates amounts in the soil profile. Right: cumulative nitrification and mineralization from waste water N (from Justes et al., 1998).

This approach which determines N mineralization of organic products in field conditions, gives information both on amounts and kinetics comparing to N balance or cropping data. Nevertheless, this method considers only bare soil, results being largely influenced by agricultural practices and soil or climatic conditions. In addition, field measurements are time-consuming and expensive.

Soil laboratory incubation

Fig. 3 presents C and N mineralization kinetics obtained during a soil incubation in presence of different organic products whose main characteristics are summarized in Table 1.

The organic products (applied at a rate corresponding to 100 mg N kg^{-1} dry soil) were incorporated to a sieved loamy soil (clay = 17 %, loam = 77 %) and incubated in controlled conditions (20° C, soil moisture = 20 % near field capacity). Carbon dioxyde emissions and soil inorganic N were monitored as described by Recous *et al.* (1995) in soils with or without addition (control soil) of organic products. Then cumulated net mineralization of C and N coming from organic product was calculated by difference with the control soil. This incubation method allows to discriminate different organic products in terms of N availability according to their characteristics (Fig. 3).

	Dry Matter (%)	C (%)	N (%)	C/N ratio
Compost from different agro-industrial co-products	31.6	11.3	1.5	7.5
Concentrated vinasse	57.1	18.4	3.3	5.6

Dried agro-industrial sludge	94.7	31.1	6.3	5.0
Sludge of paper mill	57.5	13.3	0.7	19.0

Table 1
Main characteristics of organic products studied during soil incubations.

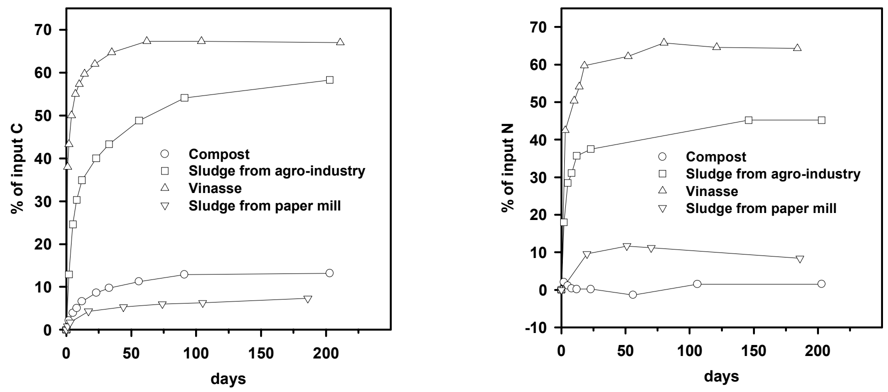


Figure 3
C mineralization (left) and N mineralization (right) of different organic products studied during a soil incubation under controlled conditions.

Incubation methods provide information on both C and N kinetics and potential mineralization. In addition, precise estimations of C and N fluxes involved during decomposition are obtained when isotopic tracers (^{15}N, ^{13}C or ^{14}C) are used. Comparing to field experiments, they allow the study of numerous organic products in a short period of time. On the other hand, data are obtained in artificial conditions (optimal temperature and soil moisture), incubated organic products being probably different from those studied in field (organic products dried and crushed for incubation methods). Nevertheless relationships between field and incubation data are relatively well established as it is shown on Fig. 4. Results obtained for potatoes starch factory waste water (see above §) in field (temperature and soil moisture variable) or during soil incubation (28°C, soil moisture at field capacity) were compared using functions describing the effects of temperature and soil moisture on soil N mineralization (Recous, 1994; Rodrigo *et al.*, 1997). Considering these effects, it is then possible to calculate climatic factors and convert days with variable soil moisture and temperature to days (normalized days) with reference soil moisture and temperature. Finally, “normalized days” allow the comparison and validation of incubation results with data obtained under field conditions.

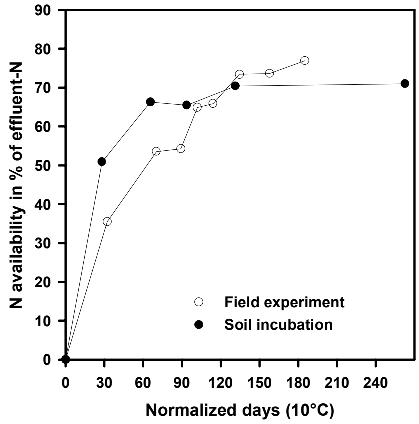


Figure 4
Comparison of N released from potatoes starch factory waste water measured under field conditions and during soil incubations using a normalized time scale at 10°C (from Justes et al., 1998).

Chemical indexes

One available approach to characterize organic products consists to differentiate fractions using an adaptation of solubility methods as the ones used to characterize the fertilizers of organic synthesis (Afnor, 1988). Water extraction at different temperatures (20°C and 100°C) allows to obtain fractions in which nitrogen is analyzed by the Kjeldahl method: N fraction soluble N at 20°C, N fraction insoluble at 20°C and soluble at 100°C, and N fraction insoluble at 100°C.

The separation of the different fractions was performed on organic products which were partially dried and crushed at 200 µm. Table 2 shows results obtained with some of these organic products. In that case, there is a close relationship between the N fraction which is soluble at 20°C or the N fraction insoluble at 100°C and N mineralized during a 180 day period soil incubation (see above §). Nevertheless, this relationship must be validated on a wide range of organic products. Moreover a similar approach should be used to separate different C fractions.

	Soluble N at 20°C	Insoluble N at 100°C	Mineralized N during incubation
Compost from agro-industrial co-products	11	84	2
Concentrated vinasse	94	5	64
Dried agro-industrial sludge	34	55	45
Sludge of paper mill	6	82	8

Table 2
N fractions obtained by water solubility at different temperatures and N mineralized during soil incubation for some organic products (expressed in % of organic products N).

However this approach is relatively static by providing chemical indexes which characterize a given organic product. No information is provided on N mineralization kinetics and the variability of the product is not taken into account. By another way, it may be wondered about the agronomical significance of the defined fractions considering N availability or behaviour of organic products under field conditions. Nevertheless, these analytical determinations are rapid, simple and easy to perform for a routine analysis laboratory. They will be very useful if chemical tests data are in good agreement with N mineralization data obtained with soil incubation methods.

4. Conclusions

All data collected with methods described previously are necessary for the parametrization of different kind of models. It includes mechanistic models which are used to describe C and N transformations in soil and which require the description of residues with different fractions, decomposition and assimilation rates. Decision making tools which are used to manage N fertilization (e.g. Azobil, published by Machet *et al*., 1990) will directly integrate immediate N values and longer effects on soil N mineralization. Data will be also taken into account by functional crop simulation models (e.g. STICS, published by Brisson *et al*., 1998) which simulates the behaviour of the soil-crop-system and are used to evaluate agronomic scenarios.

Data can be equally necessary to elaborate decision making tools which will be used by agro-industry to manage spreading areas. At the present time, management of the input of liquid effluents in the soil only takes into account amounts of water and approximative N values. Incorporating, precise N values, kinetics of mineralization and long term effects will improve N management in these areas.

Finally, data will be essential to propose some simple chemical indexes which may be used by laboratories to analyze rapidly and at a low cost N availability of organic products. Nevertheless proposed methods will probably have to take into account nature and type of organic products.

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