

# Assessment of nutrient availability from organic wastes use in agriculture. A review.

## Invited Paper

*Estimation de la biodisponibilité des éléments nutritifs présents dans les produits organiques résiduaux.*

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## Abstract

*Organic wastes are products which, firstly, are wastes and secondly contain organic compounds, i.e. organic C and N. Except for some special organic industrial by-products, these wastes, which are farmyard manure, poultry manure, pig and cattle slurries, sewage sludges, compost and mixtures of these by-products, are derived from living processes. Therefore they contain all elements that are found in living organisms, i. e. not only C and N but also P, K, Ca, Mg and most of the microelements essential for life. Further, they also sometimes contain elements, accidentally added, which have to be considered as potentially toxic (PTEs) for life.*

*Two reasons can explain the transfer of such compounds in agricultural soils. The first is the mythic role of organic matter in soil. This mythic aspect come from the past when the farmyard manure was the only source of nutrients for crops and when it was assumed that plant growth depended on organic compounds. The second reason is that the increasing urban population wish to dispose their wastes far from their houses and so explain, to the farmers, that wastes would be very good, even essential, for crop production, as it use to be in the past. Whatever the explanations given, organic wastes return, for a part, to farmer fields which are their origin at a statistic scale.*

*An essential question concerns the effect of such compounds on crop production and the behaviour of each element of these wastes. Therefore it is of first importance to be able to characterize and quantify the availability, for crops, of each nutrient contained in the organic wastes. The main question becomes: how to characterize the availability of a given element among a lot of other elements which are added together. One of the most efficient way is the use of an isotope of the element under study. As a matter of fact, when a crop takes an element in two sources (soil and wastes), labeling of one of the nutritive sources provides, in*

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*crops, the origin and the contribution to crop nutrition of the element. Experiments have been carried out with  $^{15}\text{N}$ ,  $^{32}\text{P}$  or  $^{33}\text{P}$ ,  $^{45}\text{Ca}$ ,  $^{56}\text{Fe}$ ,  $^{65}\text{Zn}$ ,  $^{109}\text{Cd}$ ,  $^{63}\text{Ni}$ , and some other tracers. Moreover, such isotopes can inform either on immediate effect of organic wastes on crops or on the residual effect of organic wastes on available nutrients in soil-plant systems.*

*In this review, examples shown concern mainly phosphorus applied as farmyard manure, slurries sewage sludges and composts whose P availability of P has been determined using isotopes. The availability of P from farmyard manure and slurries is of the same order of magnitude than that of water soluble P fertilizers. The availability of phosphorus in sewage sludges depends firstly on the industrial processes applied to polluted waters. More the water is cleaned, more the phosphorus in sludges becomes unavailable for crops. Examples are also given for other elements as zinc.*

Key-words: Organic wastes, bioavaibility, isotopes, phosphorus

## **Résumé**

Les résidus organiques sont d'abord des résidus et ensuite des produits contenant des composés organiques, c'est-à-dire contenant du C et du N. A l'exception de certains sous-produits organiques industriels, les autres, tels le fumier de bovins et de volailles, les lisiers de bovins et porcins, les boues résiduaires de station d'épuration, les composts et les mélanges de tous ces produits, ont pour origine première la vie. C'est pourquoi ils contiennent l'ensemble des constituants nécessaire au fonctionnement de la vie. Mais parfois, du fait d'une addition accidentelle, ils recèlent des éléments qui doivent être considérés comme toxiques pour les organismes vivants.

Deux raisons conduisent à transférer de tels composés vers les sols agricoles. Tout d'abord le rôle mythique de la matière organique. Cet aspect mythique a pour origine l'époque où le fumier était l'unique source de restitutions des éléments nutritifs aux champs cultivés et où certains soutenaient que la matière organique était absolument indispensable à la nutrition des plantes. La seconde raison est beaucoup plus simple. Les citoyens poussent leurs déchets loin de leurs habitations et expliquent aux agriculteurs que cette matière organique est bonne, voire indispensable, pour la production agricole. Quelles que soient les raisons évoquées, des composés organiques résiduaires rejoignent les champs.

La question majeure concerne l'effet des divers éléments contenus dans ces résidus. Il est de la première importance de disposer d'outils permettant de caractériser et quantifier la biodisponibilité pour les cultures des différents éléments présents dans ces résidus. Une des méthodes les plus efficaces consiste à utiliser des isotopes traceurs des éléments. En effet, quand une culture prélève des

éléments dans deux sources nutritives, le sol et le résidu, le marquage de l'une ou l'autre des sources permet de connaître, dans la plante, l'origine de l'élément. Des expériences peuvent être réalisées avec  $^{15}\text{N}$ ,  $^{32}\text{P}$ ,  $^{45}\text{Ca}$ ,  $^{56}\text{Fe}$ ,  $^{65}\text{Zn}$ ,  $^{109}\text{Cd}$  et  $^{63}\text{Ni}$ , voire avec quelques autres isotopes.

On présente, dans cette revue, des exemples concernant principalement le phosphore. La biodisponibilité du phosphore du fumier de ferme et des lisiers est très proche de celle du phosphore des engrais phosphatés solubles dans l'eau. La biodisponibilité du phosphore des boues résiduaires dépend du processus industriel de purification de l'eau : plus est « nettoyée », moins le phosphore est biodisponible pour les plantes. On présente également un exemple relatif au devenir du zinc contenu dans les lisiers.

Mots clé : résidus organiques, biodisponibilité, isotopes, phosphore.

## 1. Introduction

This conference is devoted to management strategies for **organic waste** use in order to recycle, **in agriculture**, agricultural, municipal and industrial residues. This paper is focused on assessments of nutrient bioavailability when applying organic wastes in/on soils. The words: bioavailability, nutrient, organic wastes, recycling and management structure this review.

The mythic aspect of organic matter was so strong in human subconscious that even the Vatican took time and money to organize a symposium on « Organic matter and soil fertility » (Anonymous, 1968). Nevertheless, whatever the historic, mythic and pertaining to the passions role of organic matter, it was shown by Liebig, 150 years ago that there is no need of organic matter for plant growth. Plants grow, without organic compounds, from inorganic nutrients and  $\text{CO}_2$  and they create, through photosynthetic processes, organic matter containing mineral nutrients taken in the soil as ions, the only chemical form which is metabolized; further, this organic matter as plant, or crop residue, goes back in the environment.

At the opposite, animals, and among them Man, cannot grow, and live, without organic compounds. They even cannot live without rejecting in the environment a part of the organic compounds they eat and transform by metabolic processes. There is no possible animal life without a production of organic residues. These unavoidable residues are, for example, manure, slurries, municipal residues, compost and sewage sludges. To avoid increasing amounts of organic residues near our life place, some of them go back to their departure point: the farmer fields. But organic compounds, and inorganic nutrients included in organic compounds or in organic structures as crop residues or bacterial cells in sewage sludges, are unavailable for plants. Inorganic nutrients have to be released and made available for plants by mineralization of organic matter. Soils contain a diversity of micro-organisms (Elliott and Coleman, 1988; Beare *et al.*, 1995; Brussard *et al.*, 1997) known for their ability to mineralize organic matter and, as a consequence, to release nutrients in their ionic form, i.e. available for plants (Coleman *et al.*, 1983).

Therefore organic wastes can be applied on soils to be mineralized. This property of soils, with their microorganisms, was called in the past « purifying power » (Catroux *et al.*, 1974). This expression, probably imagined by a town man to justify the reject of its residues far from its home, was ambiguous and too optimistic: soil microorganisms have only a capability to transform some elements from a chemical form unavailable, potentially toxic, towards another chemical form, theoretically neutral for the environment. The too optimistic view has sometimes contributed to make the soils of farmer fields or forests a bin. When these organic wastes are transferred from towns to farmers fields concurrently to transfer of foods from fields to towns, they contribute, for a part, to the recycling of non renewable nutrients, as phosphorus or potassium, and thus to go towards a more sustainable development (Biswas, 1994).

## 2. Bioavailability and mobility of nutrients or elements concepts

Definition of bioavailability and the concept on which it is based are considered as unclear for most of the scientists of soils or agronomy (Naidu *et al.*, 1997) and still more for the regulatory authorities. **Bioavailability is the property for a nutrient to be available.** A bioavailable compound, or element, is one that can enter, whatever the mechanism of entry, into a biological cycle and whatever its contribution, or not, to the metabolism. Thus, in the context of this conference, bioavailability corresponds to the mechanisms supplying nutrients to living organisms, mainly to plants. Therefore, according to Barber (1995), an available, or bioavailable or phytoavailable, nutrient, is one that is present in a pool of ions in the soil and can move to the plant root during plant growth if root is close enough. Mobility is the ability of an element to be transferred from one compartment to another compartment of the soil-solution-plant system when bioavailability is only the property of an element to be transferred from soil compartment into the plant compartment.

Confusion between the concept of bioavailability and the measurement of bioavailability is frequent (Naidu *et al.*, 1997) and has to be avoided. Bioavailability, as shown by « ity » , indicates a potentiality, a capability for a nutrient to enter into the roots, and that, irrespective of the realization, i.e. of its extraction from soil by a plant. C as CO<sub>2</sub>, N, P K, S, Ca, Mg and the 13 micronutrients considered as essential for plant growth, according to Marschner (1995), are fully included in the definition *sensu stricto*.. Nevertheless, bioavailability has to be considered as the property of an element, essential or not, to enter into the roots. Therefore this review is focused not only on nutrients but also on elements, such as Ni, Zn, Cr ..., potentially toxic (PTEs) for plants, animals or humans (Smith, 1996; Morel, 1997).

A soil bioavailable element has to be characterized using, at least, three factors: an intensity factor,  $I_x$  ; a quantity factor:  $Q_x$  and a capacity factor  $Cap_x$ . (White and Beckett, 1964; Barber, 1995). These factors are generally quantified using parameters derived from soil analysis. The intensity factor is the chemical potential of the element which illustrates, in the soil-plant system, the « pressure » of elements on the roots. Therefore the concentration of elements, or ions, in the soil

solution is the experimental parameter generally taken as intensity factor. Concentration is the first factor accounting for the uptake of nutrients by plants roots (Barber, 1995). The quantity factor is the amount of the element which is present in the soil-solution-plant system at the chemical potential of the element in the soil solution. The capacity factor has to describe the variations of the quantity factor when the intensity factor is modified either by an uptake by roots or by an application of the element in soil.

Bioavailability concept referring to plant uptake and growth, bioavailability is a time depending characteristic. The three factors, intensity, quantity and capacity proposed in the past, do not document on release, with time, of the element from soil, i.e. on the kinetic of release. Thus, a gap, more a lack, appear between the definition taking into account time and factors utilized to characterize and quantify the nutrient bioavailability.

### **3. Bioavailability of elements. Its assessment**

A full and right assessment of bioavailability would require understanding all mechanisms governing the flux of nutrients from soil particles or components towards soil solution and further to roots (Barber, 1995). Unfortunately, at the present time, only some of these mechanisms are known (Loneragan, 1997). In soil plant systems, nutrients, and probably other elements, enter into the plants as ions. Ions exist only in water: soil solution is the obligatory way for nutrients between soil particles and roots. Therefore analysis of particular properties of elements in the soil solution can document on the behavior and the bioavailability of nutrients.

#### **3.1. Where and when assess the nutrient availability with organic wastes ?**

When applying, on/in soils, an organic waste containing available elements, plants take the element from the two sources available for plants: that of the native soil and that of the organic waste. In such case, bioavailability of an element can be assessed in: (i) the waste, (ii) the soil, (iii) the soil-waste mixture. Two reasons justify that there is no universal response face these three possibilities. Firstly parameters describing bioavailability are not additive; secondly, whatever the waste applied to soil, most of the components added react with soil particles and components. These reactions can modify simultaneously the bioavailability of the added nutrient and that of the native nutrient. Therefore, the most efficient choice is often the analysis of bioavailability of elements in the soil-waste mixture and to compare further this availability to that of the element in the soil alone.

#### **3.2. Bioavailability : methods of assessment**

Whatever the element, there is no significant correlation between the total content of an element in the soil and the amount taken up by crops during a growing season: uptake depends, for a part, on the bioavailability of the element. This fact shows that each element is present in soils with many physico-chemical forms, many species, and justifies research need on element speciation. The most exiting,

and promising, speciation is that allowing to distinguish between available and unavailable forms of element.

To choose, and to continuously improve, methods of assessment of bioavailability, the following established mechanisms have to be kept in mind:

1. Nutrients enter into plant roots only as ions.
2. Nutrient uptake depends on time.
3. Excepted for C, N and S, behavior of inorganic nutrients and elements depends on physical processes as adsorption-desorption and on chemical mechanisms as precipitation-dissolution and organic synthesis.
4. Behavior of nutrient as C via CO<sub>2</sub>, N and S, depends especially on soil microorganisms activity. Thus, mechanisms by which organic compounds are transformed into inorganic compounds are biological processes and are controlled by all the factors modifying metabolism and growth of soil microorganisms. These soil factors are water and oxygen content, temperature, content in energy sources, i.e. in organic compounds available for microorganisms.

#### ***a) Chemical, or physical, extraction***

This approach, the most common to assess bioavailability, is that of routine analysis. It was imagined in 1845 (Daubeny). Such approach is based on successive assumptions: (i) a chemical reactant could extract specifically a define physico-chemical form; (ii) the form extracted is available, or unavailable; (iii) there is a significant correlation between the quantity of element taken up by a crop and the quantity of P extracted by the chemical. The conceptual limits of such approach are well known: (i) only one factor among the three required, the quantity factor, is determined using extraction methods; (ii) chemical extractions modified the adsorption properties of soil particles and thus modified the behavior of the element during the extraction procedure, resulting in various pitfalls (Nirel and Morel, 1990); (iii) chemical extractions are less selective than expected. For example, when using a basic extractant, the simultaneous extraction of the element and organic matter is a well known problem ; (iv) Such speciation is a « photography » of the status of the element at a given time; a photography is a static representation and can never document on the evolution, with time, of the system. Nevertheless, chemical extractions continue to be utilized in soil routine analyses for almost all the elements.

#### ***b) The isotopic exchange method***

1. ***Theory.*** As extraction procedures significantly modify the adsorption properties of soil components, they give, finally, wrong conclusions concerning the amounts of available nutrients. Thus it was of first interest to develop, for bioavailability assessment, experimental procedures without extraction procedure. This can be reached using **isotopic exchange kinetic method.**

The aim of this method is to determine size and kinetic properties of a pool, or compartment, of an element in a pluricompartamental system without extracting compartments (Shibley and Clark, 1972; Frossard and Sinaj, 1997). Schematically, the method consists, taking into account some theoretical and practical constraints to maintain the system under analysis in steady state, in applying an isotopic tracer in a given pool and to measure, **with time**, how it leaves the pool. The mathematical analysis of the kinetic of the isotope transfer, i.e. the decrease with time of the amount of radioactivity in the pool where the radioactivity was introduced, documents on the organization of exchangeable ions and on their ability to move from one pool to another pool (Shibley and Clark, 1972).

**2. Results.** Such a procedure was performed for phosphate ions in soil solution systems in steady state or in soil-soil solution-plant systems. The following conclusions were obtained :

⇒ Analysis of isotopically exchangeable phosphate ion kinetics shows that isotopically exchangeable P is made of many compartments. Each compartment of phosphate ions is characterized by its ability, its mean mathematical time, to be released from the soil particles into the soil solution. The compartments are organized as a mamillary system: a central pool, made for a part of the ions in the soil solution, exchange phosphate ions with all the other pools, each with a kinetic rate of transfer towards the soil solution (Fardeau *et al.*, 1996)

⇒ Thus, isotopically exchangeable P can be described using its intensity factor: the concentration of orthophosphate ions in the soil solution expressed in  $\text{mgP L}^{-1}$  and its quantity factor: the amount of instantaneously isotopically exchangeable P, expressed in  $\text{mgP kg}^{-1}$ , and determined in routine analysis as the amount of P which is isotopically exchangeable in 1 minute. As a consequence, the capacity factor, which is the ratio of the quantity factor to the intensity factor, is expressed in  $\text{L kg}^{-1}$  : it documents on the maximum volume of solution which can be added to soil without variations of the concentration. It was shown that, for a given soil, there is a stable relation between the quantity factor, Q, and the intensity factor, I (Morel *et al.*, 1995). The general equation linking Q to I is a power function:  $Q = \alpha I^\beta$

⇒ More, comparing the isotopic composition of phosphate ions in the soil solution and that of P in crops grown on soils where the isotopically exchangeable phosphate ions were labeled, it was shown that the soil isotopically exchangeable P is the only P source for plant nutrition, i.e. is the available soil P (Morel and Plenchette, 1994). Thus parameters characterizing isotopically exchangeable P can also be utilized in order to characterize available soil P.

⇒ Finally, the isotopic exchange kinetic method allows to reach the three required factors. It add a supplementary factor, the time factor, which is essential for plant nutrition. This time factor can be expressed either in terms of compartments whose the ability to leave the solid phase in order to enter into the soil solution is time depending, either in terms of a mean rate of transfer from soil to soil solution expressed in  $\text{mgP mn}^{-1} \text{kg}^{-1}$ . Thus it is shown that there is no true border between

available and unavailable nutrient: there is a continuum between instantaneously available soil P and really slowly available soil P.

**3. Extension of the method and the concept to other elements.** The same procedure was applied, in soil-solution systems and in soil-soil solution-plant systems, to potassium, iron, nickel and zinc ions (Frossard and Sinaj, 1997; Echevarria *et al.*, 1997). Conclusions derived from experiments were similar to that obtained for soil phosphate.

**4. Conclusion on isotopic exchange procedure.** At the opposite to the extraction methods which know borders, the isotopic exchange method which is based on an universal and unavoidable physical process, the **Brownian motion**, had no border. At the present time, there is no experimental and theoretical evidence that these results can be extended to all nutrients and elements whose behavior in soil-plant systems is mainly controlled by physico-chemical processes. Nevertheless, there is also no reason which can proof the opposite. This approach can be considered as a universal one (Naidu *et al.*, 1997) and thus a reference method which could be utilized to test the capability of extraction methods to extract, from soils, really available soil elements.

### **3.3. Assessment of the contribution of organic wastes to availability of a given nutrient**

Organic by-products as sewage sludges, farmyard manures or pig slurries applied in soils can increase bioavailability of elements because they contain available nutrients or nutrient which can be made available following organic compound mineralization. But organic compounds can also modify availability because some of them, and sometimes mineral compounds as calcium oxide added to wastes, modify mineralization rates and processes (Thien and Myers, 1992) or the ability of soils to fix, or to release, the native nutrients. In such situations the contribution of each source to the total element uptake cannot be determined with field, or pot, experiments and measuring element uptake. The only way to determine the contribution of each source, wastes or soil, is the labeling of one of the two available sources: that of the soil or that of the wastes (Fardeau *et al.*, 1996). As isotopically exchangeable ions in a soil-plant system are the available soil ions, the labeling can be made using isotopic exchange (Fardeau *et al.*, 1996). In order to avoid pot experiments with isotopes, which are always time and money consuming, the contribution of the two source can be obtained, after labeling of one of the two sources, analyzing the isotopic composition of the element in the soil solution. This method can be applied to forecast the contribution of P applied to a soil to the P nutrition of crops (Morel and Fardeau, 1991).

### **3.4. Case studies**

Organic wastes are the main scope of this conference. Due to their very large varieties, as they are issued: (i) from agriculture as crop residues, farmyard manure, slurries, (ii) from towns as rough residues compost or sewage sludges derived from a lot of different treatments, (iii) from industry as ashes of wood, and



to the number of essential nutrients, about 20 (Loneragan, 1997), an exhaustive list of results is impossible (Sharpley and Smith, 1995 ; Bril and Salomons, 1990). Some examples are presented below.

**a) Potassium.**

Potassium ions never link with organic compounds, except for example with an organic chemical reactant called tetraphenylboron. Thus, potassium is present as its ionic form in most of organic wastes, as crop residues, composts, sewage sludges, slurries (Bernal *et al.*, 1993a; Martinez, 1994) urine and farmyard manure. Thus, when the wall cell of living organisms become porous at death, potassium is released in the soil solution (Japenga and Harmsen, 1990). Therefore potassium applied with organic wastes has to be considered as a K fertilizer (Castillon, 1994), and can be, for a part, leached (Martinez, 1994) when applications are significantly greater than the needs of plants. It has to be also repeated to farmers that straw, or crop residues as sugar beet leaves, are the first K fertilizer for the following crop which has to be taken into account in the balance of the agrosystem.

**b) Phosphorus**

P can be a limiting factor for crop yields on soils and, at the opposite, P is also involved in eutrophication processes in surface water. P is a non renewable resource and has to be recycled. Therefore P is one nutrient which has been intensively studied. The main results are summarized as follows:

- *P in crop residues*: The percentage of utilization of P included in crops residues is of the same order or slightly higher than that of water-soluble P fertilizers. Thus the amount of P in crop residues has to be taken into account in balances of nutrients at field, farm or country scales.
- *P in animal wastes*: P contained in animal wastes is due to feeds which contain inorganic phosphate and Ca-Mg phytate, an organic compound (Cromwell, 1992). The major part of P absorbed by animals is rejected on the same chemical form. Nevertheless, in soils which received animal organic wastes, only inorganic phosphate content increases (Robinson *et al.*, 1995). Phytate is often quickly hydrolyzed by soil microorganisms with exo-enzymes and inorganic phosphate is released. As a consequence, availability of P in animal wastes is of the same order of magnitude as that of P in water-soluble P fertilizers (Bernal *et al.*, 1993b). Thus the amount of P to be applied, as animal wastes, for crop production has to be, at year scale, no greater than that applied as P fertilizer. When P is applied, as animal wastes, in amounts significantly higher than that taken up by crop, the content of available soil P increases drastically, whatever the soil type (Coppinet *et al.*, 1993; Fardeau et Martinez, 1996).
- *P in sewage sludges*: P availability in sewage sludges depends on the industrial processes of obtaining sludges. In biological sludges, P which is included in bacterial cells, is available as phosphorus in all residue derived from living organisms. When successive treatments as iron or aluminum chloride addition, and/or heating for sterilization, occur the concentration of phosphate ions in sludge solution decreases; and simultaneously P bioavailability in sewage sludges decreases: P can become almost unavailable for plants. There is, for 10 years,, an increase

of P content in sludges which results of increasing dephosphatation processes using chemicals; but simultaneously P availability for plant decreases. At the present time, we have to choose between a water clean after sludge production where the risk of eutrophisation is really limited with a decreasing P availability in sludges with less interest for its recycling and, at the opposite, a high P availability in sludges and a high risk of water eutrophisation. This case shows the struggle of interests between surface waters and cropped fields.

- *P in composts and municipal refuses.* P availability in composts is generally lower than that of P in sewage sludges (Faïsse, 1996).
- *P in industrial wastes.* Wood is sometimes utilized to produce heat and/or energy, for example in paper paste industry. In such case, P, and K, are found in ashes. P availability, due to the heating which transform free phosphate ions into little soluble P, is very low.
- *P in bones.* Bones are also derived from living organisms and have been the first P fertilizer recognized. But the availability of P in bones is very low: phosphate ions are included in very well crystallized apatite. Further bones were collected to be dissolved with sulfuric acid. It was the birth of water soluble phosphate fertilizer industry.

However that may be, P availability decreases when the time of contact between soil components and P applied as organic wastes increases, similarly to inorganic P fertilizers (Larsen, 1974).

### **c) Nitrogen**

Nitrogen of organic wastes is unavailable for plants; but **it becomes phytoavailable following microbial mineralization**. The rate of mineralization, which depends on a lot of factors, controls the behavior of organic nitrogen in soils and its transformation into phytoavailable N. <sup>15</sup>N-isotope was sometimes utilized in order to follow the behavior of organic nitrogen derived from sludges and other organic residues (Fardeau *et al.*, 1976; Béline *et al.*, 1998). Recently, this isotope was utilized in order to determine, with pig slurry, the contribution of two very important processes, ammonia volatilization and denitrification, to the biogeochemical cycle of nitrogen (Chadwick *et al.*, 1998): applying « N pig slurry » on soils in June and October, about 6 % were volatilized, 23 % became in N<sub>2</sub>O, a pollutant gas and 12 % turned into N<sub>2</sub>.

### **d) Microelements**

The fate of micronutrients, and some of microelements, the potentially toxic elements (PTEs), is studied due to potential risks for living organisms (Morel *et al.*, 1997). It was explained that organic matter either fixes heavy metals and make them unavailable or, at the opposite, that microelements are released more easily than without addition organic compounds (Smith, 1996). It was shown, for example that applications of biosolids as sludge (Sloan *et al.*, 1997) and heavy applications of pig slurries increased significantly Cd, Zn and Cu which are extractable using various chemicals (Coppenet *et al.*, 1993; L'Herroux *et al.*, 1997). But even when amounts of microelements extracted by a chemical increases, the element uptakes can be unvarying (Cabral *et al.*, 1998). But, with such an experimental procedure,

there was no mean to assess the contribution of sludges to the variations of availability of elements and to determine the causes and the origin of such increases: increasing mobility and availability of native elements in soils or uptake of these elements from applied pig slurries.

Isotopes were also utilized to study the fate of PTEs (Fardeau *et al.*, 1976). Whatever regulation difficulties, often more difficult to solve than safety precautions ! to carry out experiments with gamma-emitter isotopes, the isotopic exchange method could quickly provide knowledge on the fate of such elements whose chemical speciations and measurements are always difficult and time consuming (Echevarria, 1996; Echevarria *et al.*, 1997). Thus, when applying this isotopic method in soil samples taken in experimental field which received heavy applications of slurries, it was shown that the amounts of directly available Zn increased (Frossard and Sinaj, 1997). Generally the capacity factor of soil for a given ion decreases when the amount of instantaneously available nutrient increases. But, in this soil the capacity factor for Zn ions increased though amount of available Zn increased. In this long term field experiment a liming increased more the capacity factor for Zn than the Zn application with slurry decreased the capacity factor. Finally, as for P (Morel *et al.*, 1994), some agricultural management practices can modify the fate of microelements more than an application or an uptake of these microelements.

#### 4. Management strategies and needs for the future

In the past, the « town Man » move away its organic wastes and its personal residues, balance of his metabolism, sometimes towards the farmer fields, sometimes towards the rivers ! firstly far from its home. This ancestral management practice was the first « natural » recycling. At the present time at the earth scale, resources necessary for food production have shown a disquieting deterioration (Biswas, 1994). Some of these resources, as phosphorus, are non renewable element at the Man life scale. Therefore, a recycling, through soils, of most of our organic wastes, which contain more of the inorganic nutrient taken in soil with food harvests, has to be recommended. Interesting fact: this « disposal and removal » method has the lower cost ! But for some elements, as most of the PTEs, their contents in waste dry matter are higher than in soils. In such case, their total contents in soil increase.

Assessment of phytoavailability of elements would required understanding of mechanisms involved in transfer from soil components to roots (Barber, 1995)..Applying this comment to organic wastes, the problem could be summarized as follows :

1. These wastes contain organic and inorganic components.
2. The behavior of inorganic compounds is the same than that of mineral fertilizers and depends on the result of the competition between soil and plants for the nutrients.
3. In the context of this symposium only organic part of wastes is examined. Able to transform organic compounds into inorganic nutrients, **soil microorganisms are the key for recycling** (Coleman *et al.*, 1983; Elliott

and Coleman, 1988; Kucey *et al.*, 1989; Thien and Myers, 1992; Brussard *et al.*, 1997). To become available, elements present in organic wastes have to be firstly released from biological structures, as cells, or/and hydrolyzed. This step can be, at the first year scale following the application, a limiting factor for nitrogen release but most of the other inorganic elements remain finally most available for crops than those applied as mineral fertilizers.

Could an accurate availability assessment of nutrient and microelements improve management policies of organic wastes ? We have to said: YES. The bioavailability concept is now well known and the isotopic exchange method gives life to the concept and makes the knowledge on nutrient bioavailability increases. It was shown that there is a continuum from available to unavailable nutrient. Nevertheless : (i), methods of soil routine analysis utilized to transform the bioavailability concept into reality are scarce; (ii) there is a continuous difficulty for Man to modify its thinking habit: its is easier to speak on a quantity that to speak on ability for an element to be released from soil, with time. An evolution of methods applied to document on bioavailable elements, using new concept and knowledge have to be introduced in the routine analysis methods, is now required to improve fertilizer and wastes management. This is the first need for the future.

Have organic wastes, because they contain plant nutrients known as non renewable resources, to be applied in soils when the amounts and the availability of nutrients in soils can easily satisfy the plant needs ? The better response could be probably: NO. In such cases, such management practices result, for example, in nitrate pollution by leaching (Cheverry, 1992) in ground waters and in nitrogen and phosphate pollution in surface waters by run-off (Robinson *et al.*, 1995). These facts mean that management policies of organic wastes, whatever their origins, have to take into account, not only availability of nutrients in the wastes, but also their availability in soils. This could be a second need which concerns mainly developed countries.

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