1 INTRODUCTION

1.1 Soil N mineralization

Mineralization of organic materials in soils is one of the key processes that enables plant growth and therefore crop production because, as consequence of the mineralization process, readily available nutrients are released. Organic N is the main form of N in soils, hence mineralization, which is performed by the soil microbial population, acquires special importance in the N dynamics of the soil.

Nitrogen mineralization process consists mainly in three steps: The first step is ammonification, implying degradation of the organic materials by a wide group of heterotrophic microorganisms. These organisms use the organic matter C for their own growth and as energy source, while part of the organic N present in decomposed organic materials is incorporated to the biomass and part is released. Although most of N in soil organic matter (SOM) has not been identified yet, and it is believed to be integrated to humic substances, it is known that a significant portion of organic N is in amino-N form (Castrou and Schnitzer, 1987). Mineralization involves a sequence of enzymatic processes, the most important enzyme types being proteases and deaminases for the subtract peptide, and O-glycosidases, deaminases and acetyl hydrolases for the polymers of various amino sugars (Mengel, 1996). The ammonification process leads to NH_4^+ release, however not all the N present in decomposed organic matter is mineralized because the soil microorganisms assimilate a fraction of this N (Janssen, 1996). The N assimilation depends on the C flow and the C:N ratio of the microorganisms (Recous et al., 1996). Under field conditions decomposition of soil organic matter is limited by readily available C, while decomposition of plant residues is frequently limited by N availability (Paustian and Schnürer, 1987).

The following steps of N transformation consist in oxidation of the N compounds, producing nitrite (NO_2^-) and, through a further incorporation of oxygen, nitrification with the final product NO_3^-. These processes are performed by a small group of strictly aerobic autotrophic microorganisms, which derive their energy from the oxidation of either NH_4^+ or NO_2^-. It has been reported that nitrification is also performed by heterotrophic microorganisms, but the amounts of N involved are irrelevant compared to the former (Haynes, 1986). In most soils and environmental conditions nitrification pace is faster than ammonification, in consequence low amounts of NH_4^+ are generally present, being NO_3^- the dominant form of soil mineral N (Rosswall, 1982).

1.2 Gross and net N mineralization

Net mineralization is the result of two opposite processes: gross mineralization (N release) and immobilization (N assimilation) by the microbial population. Gross mineralization and immobilization can be measured using ^{15}N tracers that enable to separate the portion of N, either in biomass or in the mineral pool, coming from the organic material (Bjarnason, 1988; Jensen, 1993; Shindo and Nishio, 2005). When gross mineralization exceeds assimilation a net gain of soil mineral N occurs, on the contrary when the biomass growth requires more N than the released amount, a net immobilization of soil mineral N is observed (Rosswall, 1982). In most soils C availability determines microbial growth; in consequence since most soils are C limited, the mineralization of native SOM produces net N mineralization (Agren and Bosatta, 1998; Shindo and Nishio, 2005). In contrast the net result of the N mineralization of plant materials in soil depends on their composition (Reinertsen, et al. 1983; Frankenberger and Abdelmagid, 1985; Kirchmann and Bergqvist, 1988; Vigil and Kissel, 1991a).

1.3 Soil N mineralization potential

In hypothetical terms the entire pool of soil organic N is potentially mineralizable, however this extreme case is irrelevant from the agronomic point of view. On the contrary, only 1 to 3% of the organic soil N is mineralized each year (Bremner, 1965). Moreover the soils differ in their ability to provide mineral N to crops, and this ability is not always directly related to the total amount of N (Warren and Whitehead, 1988; Campbell et al., 1991). The capacity of the soils to release N has been studied in order to assess the N mineralization potential which is meaningful in terms of N supply to plants.

Studies from Stanford and Smith (1972) were aimed to establish the N mineralization capacity through long-term incubation procedures. From their studies they proposed an asymptotic model of time course of N mineralization, making it possible to calculate the N mineralization potential of the soils. Nitrogen mineralization potential has been used for assessing the effect of management practices on the soil mineralizable N pool

(Doran, 1980; Campbell and Souster, 1982). Nevertheless the Standford model is not always applicable to mineralization data sets, in consequence models considering more than one pool of mineralizable organic N, with different mineralization rates have been proposed (Nuske and Richter, 1981; Ellert and Bettany, 1988).

1.4 Factors affecting soil N mineralization

Nitrogen mineralization, like all biological processes, is affected by environmental factors especially temperature and soil water content, which affect the growth and activity of the microbial population (Harris 1981; Haynes, 1986).

A positive effect of temperature increase on N mineralization is generally acknowledged (Alexander, 1977; Ellert and Bettany, 1992; Zak et al, 1999), however the optimum temperature as well as the effect of temperature on mineralization kinetics seems to be different in different soils and environments (MacDonald et al., 1995; Zogg et al., 1997; Kirschbaum, 1994). On the other hand it has been observed that temperature changes promote changes in microbial population, with predominance of the microorganisms better adapted to the new conditions (Zogg et al., 1997). The effect of temperature fluctuations on N mineralization is a controversial aspect. Some experiments have showed an enhancing effect of these fluctuations (Carlyle, 1988), while Lochmann et al., (1989) concluded that normal temperature fluctuations in the field have a very low impact on soil N mineralization.

There effect of soil moisture on N mineralization indicates that water availability not only has a positive effect on microbial growth and nutrition, but also increases the ability of the microorganisms to reach the substrate (Killham et al. 1993). The water shortage on the other hand produces negative impacts due to increase in osmotic pressure, which in turn increases the energy requirements of the microorganisms for osmoregulation (Harris, 1981). Drying soils also affect soil microbial biomass, through restriction of bacterial movement (Wong and Griffin, 1976). On the other hand differences in microbial tolerance to low moisture potentials have been reported (Howard and Howard, 1983). It has been observed that repeated drying and rewetting of the soil promote strong increases in SOM mineralization after rewetting (Jager and Bruins, 1975; Orchard and Cook, 1983; Cabrera, 1993). According to Magid et al, (1999), the principal reasons for this effect are increasing solubilization of humic substances, the weakening of aggregates, exposing physically protected SOM and microbial death during the drying process, with consequent remineralization. The importance of this enhanced mineralization is however matter of discussion, since some studies show that the mineralization flush after rewetting is counteracted by the decreasing mineralization during the drying period (Mikka et al., 2005).

Soil acidity and high salt content of the soil solution are factors that affect organic matter mineralization. The optimal pH for soil biomass growth has been established near neutrality, being mineralization restricted at low pH levels (Haynes, 1986; Appel and Mengel, 1990). Nevertheless a significant N mineralization has been detected in soils with pH values between 4 and 5, indicating that the microorganisms can be adapted to acid conditions (Dancer et al. 1973; Shah et al., 1990). According to Beck (1983) while soil pH has a strong influence on nitrification its effect on ammonification is rather small. The high salt content of the soil solution has been also reported as negatively affecting biomass growth, and in consequence N mineralization (Laura, 1977; Haynes, 1996). The cause of this negative effect is related to the required osmorregulation of the microbial tissue as a response against external high salt concentration.

From the point of view of the organic matter as substrate for microorganisms, the amount and characteristics of native SOM and the plant materials incorporated to the soil strongly influence the mineralization process. When residues of harvested crops, which are frequently rich in C, are incorporated to the soil, their decomposition process imply the incorporation of soil mineral N to the microbial biomass, hence net N immobilization. Conversely, residues from N rich crops, like legumes (low C:N ratio), lead to net N mineralization. In consequence one of the parameters used for the assessment of net mineralization of plant materials is the C:N ratio (Janzen and Kucey, 1988; Jama and Nair, 1995). The quality of the carbonaceous compounds influences the kinetics of the decomposition process (Janssen, 1996), being decomposition of lignin rich organic materials slower than decomposition of young tissues (Jawson and Elliot, 1986). Also polyphenol content has been found to produce a retarding effect of residue decomposition (Constantinides and Fownes, 1993).

The study of the effect of inorganic N availability on mineralization rate has produced contradictory results. It has been found that soil mineral N shortage can slow the pace of decomposition of crop residues with high C:N ratio (Recous et al., 1996). On the other hand negative effects of high soil mineral N levels on microbial activity, and consequently SOM and residues mineralization have also been reported (Fog, 1988). Possible explanations for this behaviour are decrease in soil pH and increase in salt concentration of the soil solution caused by N fertilization (Kowalenko et al., 1978, Huntjens et al., 1981) and inhibition of lignin decomposition by high N concentrations (Fog, 1988).

It is difficult to determine the relative importance of the previously mentioned factors that affect mineralization. Laboratory studies indicate that soil moisture content and temperature have a greater effect during the first steps of plant material decomposition, when organic labile compounds are available, while in the final stages of decomposition the limiting factors are C and N availability (Knapp et al., 1983).

1.5 Indexes of N mineralization

Considering that N mineralization occurs during the crop development it is important to be able to forecast the net effect of mineralization in order to evaluate the capacity of the soil to provide the N required by the crop, and the need of fertilizer application when this amount is insufficient. With this aim a number of chemical indexes have been developed (Bremner, 1965; Fox and Piekelek, 1978a). These indexes are aimed to extract the portion of N which will be more easily decomposed, being therefore directly related to the N mineralized during the growth of the crop (Wang et al., 2001). The chemical indexes are in general empirical, and in consequence do not ensure a selective extraction of the labile SOM (Khan et al., 2001). Although no one of these indexes has been extensively used, they have proved to be adequate for specific areas and production systems. As an example the electroultrafiltration method has been extensively used in Germany for N fertilizer assessment. Other researchers suggested that the pool of N likely to be mineralized can be assessed by the organic matter physical fractionation, being the particulate organic matter directly related to the available portion of soil organic matter (Janzen et al., 1992).

On the other hand it is possible that the factors that affect SOM decomposition influence the success of soil N assessment indexes. Jenkinson, (1968) suggests that probably these methods show a good behavior only when the immobilization process is not very important. According to this author the behavior of the chemical methods will improve when the sampling is made long after the crop residues are incorporated to the soils, rather than when residues with a high C:N ratio were recently incorporated. From the practical point of view, however, this fact represents a disadvantage, because the use of the chemical indexes, instead of the measurements of the mineral N content of the soil, is intended to provide time for planning of the fertilizer recommendation and application. Hence the adoption of the indexes, which usually imply more complex analysis than mineral N, is only justified in advance of sowing.

1.6 Objectives

In this study the evaluation of different soil N availability indexes in soils of Lower Saxony was aimed to find parameters that characterize the mineralization potential of soils. The objective of the study in Uruguay was the evaluation of different factors (crop residue incorporation, N availability, temperature and soil moisture) that influence soil N mineralization in agricultural soils.

For the first objective a number of soil N availability indexes were compared to net N mineralized, and N absorbed by crops in 8 soils of Lower Saxony, varying in soil type and management (Chapter 2). For the second objective the effect of quality and amount of crop residues, the effect of fertilizer addition and the effect of soil temperature and moisture on net N mineralization were studied. The effect of amounts of wheat straw on the mineralization-immobilization process, as affected by soil mineral N and fertilizer N addition are presented in chapter 3. Patterns of residue decomposition, as depending on chemical composition and N availability are presented in chapter 4. The effects of temperature and moisture on soil organic matter (C and N) mineralization patterns of Uruguayan soils were also examined (chapter 5).

2 NITROGEN MINERALIZATION CAPACITY OF AGRICULTURAL SOILS OF LOWER SAXONY - RELATIONSHIP WITH SOIL N AVAILABILITY INDEXES

2.1 INTRODUCTION

The application of N fertilisers is necessary for agricultural crops in the vast majority of the production systems, however there are still uncertainties about the amount of N required to reach high yields. Moreover the potential environmental damage that the excess of fertilizer can cause should be considered. These two points highlight the need of improvement of the tools for the decision regarding the N fertilizer recommendation.

The principal cause of these problems rely on the difficulties for the assessment of the amount of mineral N that the soil is capable to release during the growing season, since most of the soil N is in stable forms and thus do not contribute to the N mineral pool (Standford and Smith, 1972). There are two main approaches to this problem: The first is the development of N availability indexes. Different chemical procedures that extract part of the organic N from the soil have been developed with the objective to estimate the pool of N susceptible to mineralization of the soil. These methods in general represent an empirical approach, without causal relationship with the mineralization process (Gallagher and Bartolomew, 1964). The hypothesis behind these procedures is that the extracted pool will be more easily attacked by microorganisms (Serna and Pomares, 1992), being therefore directly related to the mineralized N during the growth of the crop. Other researchers suggested that this pool can be assessed by the organic matter physical fractionation, being the particulate organic matter directly related to the available portion of soil organic matter (Warren and Whitehead, 1988).

The different indexes of soil N availability should be tested in order to evaluate their adequacy for N mineralization forecast. The references for N assessment can be the N accumulated after a given incubation period (aerobic or anaerobic incubation) or N uptake by plants grown in greenhouse or field experiments (Keeney, 1982). The use of field experiments for this purpose has been however criticised, because the index can not take into account the mineral N already present in the soil at the beginning of the evaluation (Wang et al., 2001), while other authors warned about the possibility that the crops extract N accumulated in deep soil layers (Bundy and Meisenger, 1994). The other problem related to the use of crop N uptake as reference is the fact that other factors, for example water availability and temperature, which cannot be standardized, affect crop growth and N mineralization (Wang et al., 2001).

Mineralized N through aerobic and anaerobic incubation has been used as index (classified as biological index) and as reference of N mineralization Examples of the mineralized N as index can be found in Gallagher and Bartolomew, (1964) as well as in Serna and Pomares (1992) work. On the other hand Smith and Standford, (1971); Gianello and Bremner, (1986); Groot and Houba, (1995); Jalil et al., (1996) used results from incubations for chemical tests evaluation. Surprisingly Gallagher and Bartolomew, (1964) reported that chemical indexes correlated better than biological indexes respect to N absorbed by crops in a greenhouse experiment. In general the incubation methods, as indexes of soil N mineralization, are considered superior to other methods, however difficulties arise for their use as routine laboratory methods, especially due to the necessary long term of the incubation (Groot and Houba, 1995; Mulvaney and Hoef, 2001). In addition Keeney and Bremner, (1966) warned about the effect of treatment of the soil samples previous to the incubation, which can affect the results of the biological indexes. Chemical methods on the other hand are seen as quick and simple methods, hence better adapted as routine tests for recommendation of N fertilization (Fox and Piekielek, 1978b).

Even though many indexes have shown good relationships with the potential of N mineralization, they are still unable to forecast the amount of mineral N effectively released, because it depends not only on soil organic matter proportion and composition, but also on weather conditions, specially temperature and water content of the soil. The second approach thus, proposes the use of simulation models, which include parameters of temperature and water content as well as estimation of N losses, in order to overcome this problem (De Willigen and Neetson, 1985; Duivenbooden, 1996; Richter and Benbi, 1996).

In order to evaluate different chemical and physical indexes of soil N availability soil samples were taken from eight field trials varying in soil type as well as long term N fertilizer additions and soil management. Each soil sample was analyzed for the different soil tests. The methodology of evaluation implies the comparison of the results