IMMOBILIZATION AND FIXATION OF N^{15}-LABELLED AMMONIUM SULPHATE AS AFFECTED BY STRAW APPLICATION AND METHOD OF FERTILIZER PLACMENT

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ABSTRACT

The extent of biological immobilization and fixation of fertilizer nitrogen as affected by method of placement was studied in a Newdale clay loam soil. Two laboratory incubation experiments were conducted in which N^{15}-labelled ammonium sulphate was either mixed with the soil or banded in the soil. The effects of amount of nitrogen added, presence of straw and its mode of placement (mixing with the soil or banding in the soil) and the effect of a nitrification inhibitor (N-Serve) were studied.

Immobilization or fixation of nitrogen as measured by percent recovery of mineral nitrogen (ammonium, nitrate and nitrite) was increased when straw was added. Fertilizer placement, mode of straw placement, amount of nitrogen mixed with the soil and addition of N-Serve did not affect percent recovery of added mineral nitrogen.

Immobilization or fixation of N^{15} banded in the soil was about one half of that when the nitrogen was mixed with the soil. Straw application at 1% of soil weight doubled immobilization for both nitrogen mixed with the soil and for nitrogen banded in the soil although percent nitrogen immobilized was greater in all instances where the nitrogen was mixed with the soil. Straw placement did not alter percent nitrogen immobilized. N-Serve increased immobilization.

Immobilization as measured by recovery of mineral nitrogen was not consistent with the results obtained from N^{15} data. Soil-fertilizer interactions which may have been responsible for this discrepancy are discussed.

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1. INTRODUCTION

1.1 General

The most important forms of nitrogen readily absorbed by plant roots are the mineral forms: nitrate (NO_3^-) ammonium (NH_4^+) and to a very little extent, nitrite (NO_2^-). Yet only a very small fraction of the total soil nitrogen occurs in the inorganic available form. The greater portion of soil nitrogen occurs in the organic form. This organic form can only be used by plants after it is broken down by heterotrophic microorganisms to release the nitrogen in inorganic form, a process called mineralization. But only about 2 to 4 percent of the organic nitrogen is mineralized each year. As a result of this slow rate of mineralization, modern agriculture cannot depend on this supply of nitrogen only. Yet nitrogen is the soil nutrient which plants require in greatest quantity. Therefore, in order to attain high crop yields, there must be a liberal addition of nitrogen to the soil to supplement the supply from mineralization and the amounts already present in the inorganic form.

The purpose of nitrogen fertilizer addition is to increase the supply of nitrogen to the plant. Nitrogen fertilizer applications have to be made at the proper stage of plant growth and placed such that plant roots can easily absorb it in order to attain efficient use of the fertilizer.

The efficiency of utilization of nitrogen fertilizers by crops depends not only on the method and time of application but also on the nitrogen requirement of the crop and its rooting habit, the chemical form in which the fertilizer is applied (NH_4^+-N or NO_3^--N), the amount of potentially mineralizeable nitrogen in the soil and amounts of inorganic nitrogen in the soil profile. Only about 40 to 60 percent of the fertilizer nitrogen added to a nitrogen-deficient soil is recovered by crops. The remainder is rendered unavailable or lost from the soil environment by some physical, chemical and biological processes. The addition of carbonaceous crop residues and the method of fertilizer application influence such losses.

1.2 Problem Analysis

Studies on fertilizer placement conducted by the Department of Soil Science, University of Manitoba, indicated that placing nitrogen fertilizers in a band (35 cm. spacing and 6 to 7 cm. depth) was superior, as measured by grain yields, to equal amounts of fertilizer mixed throughout the surface 5 to 7 cm. depth of soil. This indicated relatively more fertilizer nitrogen was lost from the soil or rendered unavailable when it was mixed throughout the soil as compared to nitrogen placed in a band. There are various ways by which nitrogen is rendered unavailable to crops. These include:

(a) Immobilization of nitrate and ammonium forms of nitrogen by soil microorganisms during the decomposition of crop residues low in nitrogen content. Immobilized nitrogen is temporarily unavailable to plants.

(b) Entrapment in between lattices of expanding silicate clays. (Ammonium fixation).

(c) Loss of the nitrate form of nitrogen in drainage water when it rains or when soil is irrigated, a process called leaching.

(d) Volatilization of gaseous products such as ammonia when ammonium fertilizers are placed on the soil surface or not properly incorporated.

(e) Loss of gaseous products such as molecular nitrogen or oxides of nitrogen in poorly drained soils, or in conditions that favour nitrite accumulation (denitrification).

1.3 Objectives

This study was conducted to determine the proportion of applied nitrogen which is rendered unavailable by ammonium fixation and microbial immobilization when ammonium sulphate fertilizer is mixed throughout the soil as compared to placed in a band. A nitrification inhibitor, 2-chloro-6-(trichloromethyl) pyridine (N-Serve) was included in some of the treatments to study the extent of ammonium fixation and microbial immobilization when nitrogen is retained in the ammonium form for a long period of time. The effect of crop residues (wheat straw) and the method of placement of the straw in the soil on biological immobilization was also studied. This study consisted of two laboratory experiments in which the treated soils were incubated at field capacity moisture content for periods up to 12 weeks at 20 to 25 C. The stable isotope N^{15} was used to enrich the ammonium sulphate fertilizer in order to determine the fate of the nitrogen fertilizer.

II. LITERATURE REVIEW

2.1 Fate of Chemical Sources of Nitrogen in the Soil

Inorganic sources of nitrogen are by far the most important of fertilizer nitrogen compounds. Most inorganic nitrogen fertilizers are ammonia derivatives such as anhydrous ammonia, aqua ammonia, ammonium chloride, ammonium nitrate, ammonium sulphate and urea. Nitrate sources are used to a lesser extent than ammoniacal fertilizers. Since all the ammoniacal nitrogen fertilizers provide the ammonium ion (NH_4^+) as the main initial product in the soil and since these are important sources of fertilizer nitrogen, most chemical, physical and biological interactions in the soil begin with the ammonium ion. The reactions which determine the fate of fertilizer nitrogen are discussed in the following sections.

(A) Crop Uptake

When nitrogen fertilizer is introduced into the soil it is exposed to plant roots for absorption. This is the intended fate for which the fertilizer is added. However, soil constituents (inorganic and organic fractions or the soil microflora) also react with fertilizer nitrogen. This has a great influence on the availability of the added fertilizer to plants. Usually considerable loss occurs. Unpublished data (Dept. of Soil Science, University of Manitoba) showed that annual crops recovered about 20 to 60 percent of fertilizer nitrogen applied. Allison (1966), in his review of work on the fate of nitrogen in soils, showed fertilizer recoveries in crops varied widely with growth conditions and cropping systems, but were not likely to be greater than 50 to 70 percent even under the best field conditions. Zamyatina (1969) using N^{15}- labelled fertilizer, showed that only about 30 to 70 percent of applied nitrogen was taken up by plants. Seven to 45 percent was immobilized and the rest was unaccounted for. Chalk *et al.* (1975) in their study of crop recovery and nitrification of fall and spring-applied anhydrous ammonia showed that although crop recovery of applied nitrogen depended on soil type and rate of application, at most 40 percent was recovered. Thus, the findings of these researchers, among others, indicated that it is almost inevitable that some fraction of fertilizer nitrogen is rendered unavailable to crop plants. Only by proper agronomic practices can these losses be minimized.

(B) Biological Immobilization of Inorganic Nitrogen

(1) The immobilization-mineralization cycle

Microorganisms and higher plants absorb and assimilate inorganic nitrogen into cellular organic nitrogenous compounds. Under normal soil conditions, inorganic nitrogen is formed from organic nitrogen also. So, the processes of immobilization and mineralization occur simultaneously (Biological interchange of nitrogen). The net effect of these processes depends on the energy supplied to the microorganisms among other soil factors. In the presence of an abundant energy supply in the form of carbonaceous material, microorganisms multiply rapidly with a consequent vigorous synthesis of protoplasm. This process requires nitrogen. Microbial protoplasm contains from 3 to 12 percent nitrogen (Harmsen and Kolenbrander 1965). This is usually higher than the nitrogen content of most decomposing substrates. It is common practice to leave crop residues on the soil after harvest which are exposed to microbial decomposition. In their decomposition, the nitrogen they contain is released and re-absorbed by the decomposing microflora. If the nitrogen content of the decomposing residue is less than microbial demand, the additional nitrogen must be supplied by the soil reserves of inorganic nitrogen. Therefore, there will be a net immobilization of inorganic nitrogen initially present in the native soil, or, applied as fertilizer. Net mineralization occurs if the decomposing substrate contains more nitrogen than the microbial demand in which case inorganic nitrogen accumulates in the soil.

Net immobilization and mineralization can sometimes be predicted from the C:N (carbon to nitrogen) ratio of the residue added. Net mineralization usually occurs when the C:N ratio of the decomposing residue is below 20 to 25. At ratios greater than this in the residue net immobilization usually occurs, (Pinck *et al.* 1946; Allison and Klein 1962). However, some substrates which are highly lignified are resistant to microbial breakdown and despite their wide C:N ratio, may not cause net nitrogen immobilization. On the other hand, stable humus, whose C:N ratio has been reduced to 10 to 15 will not degrade any further and therefore its narrow C:N ratio does not imply a ready release of nitrogen (Harmesen and Kolenbrander 1965). The degradability of a substrate rather than its C:N ratio *per se* is important in predicting the fate of mineral nitrogen in the soil. Allison and Klein (1961), studied the comparative rates of decomposition of wood and bark of ten different species of softwoods incubated in the soil at two levels of nitrogen for 53 to 800 days, and measured CO_2 evolution as an index of decomposition. They showed that these substrates were resistant to decomposition, the resistance varying for different tree species. Due to the slow rates of decompostion, the soil itself was able to furnish adequate available nitrogen for maximum rates of decomposition and supplemental nitrogen was not needed. Supplemental nitrogen at times reduced the decomposition rate. The authors suspected the supplemental nitrogen was in excess of microbial demand and inhibited microbial activity by the salt effect.

Iritani and Arnold (1960) studied the release of nitrogen during the incubation of 11 vegetable crop residues as related to their chemical composition. Multiple and simple correlation and regression analysis were conducted between the chemical composition of the residue and the accumulation of mineral nitrogen in the soil. The authors showed that although the amount and decomposability of the carbon and nitrogen was important in affecting nitrogen release, the characteristics of the nitrogen were also important. For example, total nitrogen in the residue influenced mineralization but water-soluble nitrogen in the residue was twice as effective as the insoluble fraction in affecting nitrogen release. Net mineralization of nitrogen occured when the residue contained at least 1.66 to 1.89 percent nitrogen. Total nitrogen plus water-soluble nitrogen was more highly correlated with the accumulation of mineral nitrogen than just total nitrogen and total carbon.

Pinck *et al.* (1946) indicated that organic substances high in lignin were likely to have a lower nitrogen requirement per unit dry weight than materials low in lignin. In connection with this Agarwal *et al.* (1972) studied the effects of different carbon sources on nitrogen transformations. In all 5 soils studied, mineral nitrogen was found to decrease with the addition of carbon substrates. Sucrose, a readily available energy source accelerated immobilization of added and native nitrogen more than