A STUDY OF THE QUANTITY OF NITROGEN MINERALIZED DURING THE GROWING SEASON, ITS EFFECT ON CROP GROWTH, AND FACTORS AFFECTING THE NITROGEN MINERALIZATION - IMMOBILIZATION RELATIONSHIP.

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ABSTRACT

Net nitrogen mineralization was measured in seeded and fallow portions of four plots on two Manitoba soils during the summer of 1967. The main flush in net nitrogen mineralization occured during July and August. Nitrogen uptake by the wheat crop was greatest during June and July. Mineralized nitrogen was important in completing the growth and development of the crop but did not appear to control yield.

Net nitrogen mineralization in the fallow portions of the plots exceeded that in the seeded portions. Twenty-five pounds of nitrogen per acre were mineralized in the seeded portion of three plots. Mineralized nitrogen in the seeded portion of the fourth plot totalled sixteen pounds per acre. In the fallow portions, the net quantity of nitrogen mineralized was equivalent to 1.7 to 2.0 percent of the organic nitrogen in the top six inches of soil.

Results of a greenhouse experiment indicated that yield reductions due to straw amendments to soil were greater at 60°F. than at 75°F. This was attributed to greater efficiency of nitrogen utilization at the lower temperature. Nitrification, relative to immobilization, appeared to be greater at 75°F. than at 60°F.

Chapter I

INTRODUCTION

A growing cereal crop obtains almost all of its nitrogen from soluble mineral nitrogen stored in the soil at seeding, from nitrogen mineralized during the growing season, or from fertilizer nitrogen. Nitrogen added in rainfall or irrigation water, absorbed from the atmosphere, or supplied through fixation processes accounts for only a minor portion of the nitrogen required by a growing crop(10,83).

The quantity of nitrogen mineralized during the growing season is generally considered to be the major factor in controlling the quantity of fertilizer nitrogen required (30, 42, 43, 44). However, research in Manitoba, in connection with the development of a comprehensive soil testing program, has indicated that at least 50 per cent of the variation in cereal yield can be accounted for on the basis of nitrate-nitrogen in the soil at seeding time. Soper(73)in 1960 observed that the available nitrogen at seeding time was a major factor in controlling the response of barley to nitrogen fertilizer. He also reported that the initial mineral nitrogen content of the soils he studied was a better criterion for predicting nitrogen requirements than were incubation methods. Ferguson[1], in summarizing studies conducted at Brandon, Manitoba from 1954 to 1963, observed a strong correlation between the nitrate-nitrogen content of the soil at seeding time and nitrogen uptake by cereals. Young _et al_. (89) observed a better correlation between the quantity of nitrate-nitrogen to two feet at seeding time and response to fertilizer nitrogen than between response to nitrogen fertilizer and the quantity of notrogen mineralized during laboratory incubation. These reports indicate that the quantity of nitrogen mineralized during the crop year is probably of only minor importance in determining yield response to nitrogen fertilizer. However, it was not possible, on the basis of reports in the literature, to assess the relative importance of the quantity of available mineral nitrogen at seeding time and the quantity of nitrogen mineralized during the growing season in determining response to nitrogen fertilizer. It was suggested by Ferguson[1] that the quantity of nitrogen mineralized during the growing season may possibly be related to the quantity of stored mineral nitrogen and therefore determination of the quantity of mineral nitrogen available at seeding time would result in a measure of the relative quantity of nitrogen mineralized during the growing season. He also suggested that the quantity of nitrogen mineralized may be constant among soils and years.

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[1] Data presented at the seventh annual Manitoba Soil Science Meeting , 1963.

Without a direct measurement of the quantity of nitrogen mineralized during the growing season it was not possible to determine which of the above two explanations, if either, was correct.

The present study was initiated in an attempt to determine the relative importance of the quantity of nitrogen mineralized during the growing season and the quantity of nitrogen available at seeding time in controlling yield and nitrogen uptake. This investigation consisted of a field study during the summer and fall of 1967 in which the quantities of nitrogen mineralized at various dates during the growing season and the quantities of mineral nitrogen available at seeding time were measured. The quantities of nitrogen mineralized between seeding and the various sampling dates were compared with nitrogen uptake during the same period. During the winter of 1967-1968 a greenhouse investigation was conducted in an attempt to determine the factors affecting the quantity of nitrogen mineralized and made available to the growing crop.

Chapter II

LITERATURE REVIEW

Nitrogen in soil is largely in organic combination. However, in some soils considerable quantities of nitrogen may be in the form of unexchangeably fixed ammonium-nitrogen in the clay mineral fraction of the soil (19,59). Plants, however, require nitrogen in the mineral form as either nitrate or ammonium ions. The biological conversion of nitrogen from the organic form to the mineral form is termed nitrogen mineralization and renders the nitrogen mobile, available to plants, and vulnerable to large losses (15). Organic material in the soil undergoes decomposition by soil micro-organisms. The carbon in the substrate serves as an energy source and the nitrogen contained therein is utilized in the synthesis of proteins. Some materials contain nitrogen in excess of that required by the organisms, resulting in the excretion of nitrogen as waste in the form of ammonia. The nitrogen contained in other materials, relative to the quantity of carbon, is insufficient to meet the requirements of the microorganisms. This often results in the assimilation of mineral nitrogen from the soil by heterotrophic bacteria capable of utilizing this form of nitrogen in protein synthesis. This microbiological conversion of nitrogen from the mineral form to the organic form will herein be termed nitrogen immobilization. The quantity of nitrogen mineralized or immobilized depends on the relative proportion of carbon and nitrogen in the substrate material, the availability of these elements to microbial attacks, environmental factors, and the length of time that the organisms are operating on the material.

Plants growing in a soil have a pronounced effect on the numbers and activities of bacteria in the soil in the immediate vicinity of the root. Plant roots exude amino compounds and cell wall materials during growth (51, 67, 74). These materials serve as a readily available substrate material for the bacteria on and immediately adjacent to the root, resulting in an increased potential for both nitrogen mineralization and immobilization. Plants, therefore, through their removal of mineral nitrogen from the soil and their effect on microbial numbers and activities, influence the balance between the mineralization and immobilization of nitrogen.

The complete mineralization process consists of ammonification -- the production of NH_3 from organic nitrogen; and nitrification -- the oxidation of NH_3 to NO_3. The mineralization of nitrogen depends on factors such as total nitrogen content of the soil, C/N ratio, previous history of the soil, soil aggregate size, effect of partial sterilization of the soil and the accelerated rate of decomposition of stable humus due to the addition of easily decomposed residues supplying a readily available source of carbon and nitrogen to the organisms. Factors such as pH, temperature and moisture have varying effects on ammonification and nitrification. These factors will be considered separately. The rhizosphere effect on mineralization and immobilization will also be considered separately.

2.1 Internal Nitrogen Cycle

Jansson (see ref. 42) has proposed an internal nitrogen cycle (fig. 1) consisting of active (NH_3 and fresh organic residues) and passive fractions (NO_3 and humic N) in which conversions between organic and inorganic nitrogen proceed. Each revolution of the cycle reduces the carbon available to the microbial population since a considerable quantity (50 per cent) of the carbon is lost as CO_2 (9). Eventually an equilibrium is reached at which time no more mineral nitrogen is converted to organic nitrogen and inorganic nitrogen will tend to accumulate if there is still a sufficient quantity of carbon left to support bacterial development. The substrate material must contain carbon and nitrogen in a readily decomposable form, and losses of mineral nitrogen must not be great in order for the accumulation of mineral nitrogen to occur.

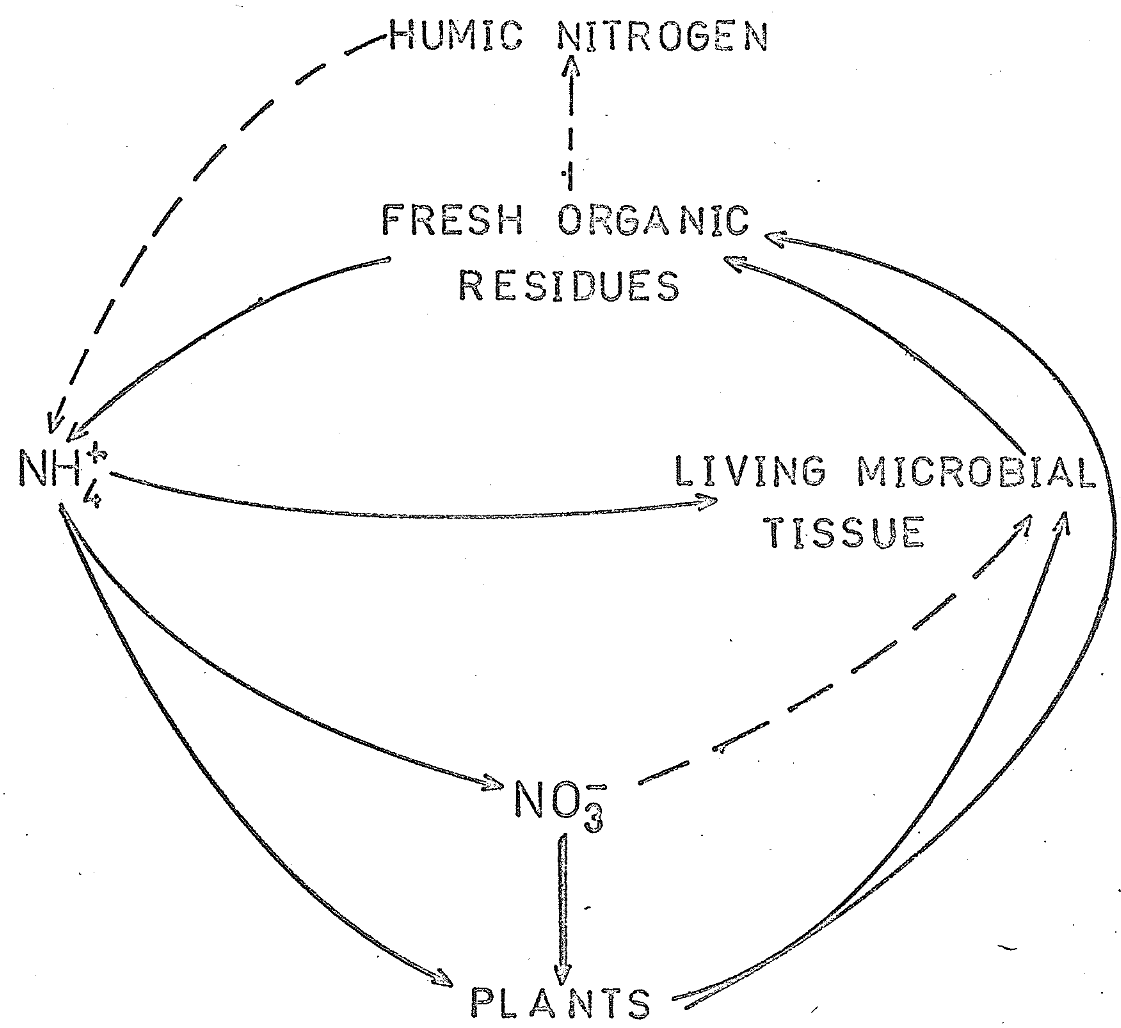

FIG. 1 INTERNAL NITROGEN CYCLE

2.2 Factors Affecting Mineralization

a) Total Nitrogen Content of Soil

The total quantity of nitrogen in a soil is determined by climate, vegetation, topography, parent material, and age. Stevenson (78) reports that climate is the most important single factor in controlling the total nitrogen content of virgin grassland soils. The total nitrogen content follows the Van't Hoff temperature rule and increases two or three times for every ten degree drop in temperature (78). Vegetation controls to some extent the quantity of nitrogen in a soil in that soils developed under legumes contain a greater quantity of nitrogen than soils developed under non leguminous plants (78). The total nitrogen content of soils developed under plants with an extensive root system is generally greater than in soils developed under plants with a more restricted root system. Topography controls the total nitrogen content of soil through its effect on climate, runoff, evaporation, and transpiration. Increasing age of a soil is generally associated with an increased total nitrogen content of the soil until an equilibrium is reached, at which point, no further increases in total nitrogen can be expected with increasing age (78).

Generally the quantity of nitrogen mineralized in a given period increases with an increase in the total quantity of organic nitrogen in the soil. It is estimated that in most arable soils between one per cent and ten per cent of the total nitrogen of a soil is mineralized per year, however, the mineralization of more than three per cent of the total organic nitrogen could be expected in only a very few soils (2, 15, 19). The quantity of nitrogen mineralized in a given time correlates very well with total nitrogen content (0.988) when soils are grouped according to total nitrogen content of the soil, and groups of soil compared. The correlation is very poor (0.368) when individual soils are considered (72). Therefore, factors other than total nitrogen also influence the quantity of nitrogen mineralized in a given period.

Many workers consider the quantity of nitrogen mineralized to be more intimately assoiciated with the characteristics of a portion of the total nitrogen than with all of it (8, 44, 52). An active fraction of the organic nitrogen of the soil has been postulated and it is felt that the quantity of nitrogen in this fraction determines the quantity of nitrogen mineralized. Attempts to characterize the mineralizeable nitrogen fraction in soils have met with only limited success. Keeney and Bremner (52) found that an index of soil nitrogen availability based solely on determination of hydrolysable and non hydrolysable nitrogen was not satisfactory. They also reported that the fraction of the organic nitrogen contributing most to the accumulation of mineral nitrogen during incubation varied with different soils.

Organic nitrogen in soils exhibits a remarkable stability toward microbial attack, resulting in the mineralization of only a limited quantity of nitrogen each year. Reasons for this stability are not immediately evident since the substances from which the soil organic matter is derived are relatively easily and quickly attacked (19). Considerable effort has been directed toward explaining this stability and several theories proposed. In a review by Bremner (19), it is reported that as early as 1892 Hebert and Déherain postulated a protien-lignin complex to account for this stability. This theory has been revived by several workers since then but does not appear to completely explain the phenomenon. Ensminger and Gieseking (33) postulated the adsorption of organic compounds by clay minerals. They found that the enzymatic hydrolysis of protein was inhibited by the presence of clay and that the degree of inhibition varied directly with the base exchange capacity of the clay. Ensminger and Gieseking (33) suggested that the inhibitory effect of clay was due to either absorption and inactivation of enzymes by clay, or the absorption of protein by clays orients it in such a way as to make it inaccessible to enzymatic attack.

A third theory is that the quantity of carbon available to the soil microflora is insufficient to supply the needs of an active microbial population (19, 44). Accelerated decomposition of consolidated humus has been reported due to the additions of fresh green manure (16, 44). Cropped land with its dense microbial population around the roots is reported to exhibit a more rapid breakdown of stable humus than uncropped soil (16, 44). This theory postulates that the stability of organic nitrogen in soil is more apparent than real and that additions of a readily available energy source results in accelerated decomposition of stable humus.

Probably no one theory adequately accounts for the stability (or apparent stability) of organic nitrogen in soil. Since there is ample evidence to support all the theories advanced it is likely that the stability of organic matter in soil is the result of a combination of several factors acting concurrently.

b) Carbon: Nitrogen Ratios

The microbial material in the soil has a characteristic ratio of carbon to nitrogen. A portion of the carbon in soil organic material is oxidized to CO_2 to supply energy for the metabolism of the microorganisms and a portion is utilized in the synthesis of cell wall material and other cellular components. The nitrogen contained in the organic substrate is utilized in the synthesis of proteins, nucleic acid, and other nitrogenous constituents of microbial cells. Since the enzymatic hydrolysis of the organic substrate releases carbon and nitrogen in definite proportions, and since carbon and nitrogen must be utilized in fixed proportions with a portion of the carbon escaping as CO_2, excess nitrogen in the substrate relative to the supply of carbon results in the exudation of nitrogen from the microbial bodies as a waste material (8). However, if the quantity of nitrogen in the substrate material, relative to the quantity of carbon were inadequate for the synthesis of microbial tissue of the proper C:N ratio, then either microbial activity would be curtailed or nitrogen in the mineral form would have to be utilized. It would be expected, therefore, that some critical ratio of carbon to nitrogen should exist, below which nitrogen would be exuded as a waste product and above which nitrogen would be removed from the pool of mineral nitrogen in the soil, i.e. net nitrogen mineralization should occur at C:N ratios below a critical level and nitrogen immobilization would be expected at C:N ratios above this level.

Critical C:N ratios have been established as a result of both experimental observations and theoretical calculations. Net nitrogen mineralization is generally considered to result from the microbial degradation of residues with a C:N ratio of less than 20. Between a C:N ratio of 20 and 30 nitrogen mineralization may or may not occur depending on environmental conditions and type of substrate. Residues with C:N ratios greater than 30 are generally considered to induce immobilization of nitrogen (8, 15, 29, 44).

Only if an equal percentage of the total carbon and nitrogen of a residue is available will the C:N ratio be a valid indication of the potential for either the mineralization or immobilization of nitrogen. If such is not the case then the C:N ratio as determined by total carbon and total nitrogen methods will not be equivalent to the effective ratio of C:N available to the microbial population. If the ratio of available carbon to available nitrogen is not equivalent to the ratio of total carbon to total nitrogen then the ratio of these elements calculated on the basis of their total quantities in an organic material will be meaningless. The critical C:N ratio also varies with qualitative variations in the soil microflora since the C:N ratios of different groups of organisms may be quite dissimilar. Alexander (4) states that "As a rule for mixed populations, 5 - 10% of substrate carbon is assimilated by bacteria, 30 - 40% by fungi, and 15 - 30% by actinomycetes. C:N ratios of 5:1, 10:1, and 5:1 may be proposed for the cellular components of bacteria, fungi, and actinomycetes respectively." It would be very dangerous, therefore, to over emphasise