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THE NITROGEN SHORT CYCLE FROM PLANT TO PLANT: MEASUREMENTS, MODELS AND IN SITU VALIDATIONS

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The paper deals with the process of nitrogen recycling from its organic forms released by vegetation to its assimilation by plants. This process has been studied, using ^{15}N, with three types of models.

- conceptual models, called *diagrams*, to order hypothetical pathways and to express research strategies

- physical models, called *microcosms*, to simulate potential pathways with soil and organisms (plants, microorganisms and earthworms)

- computerized models, called *infomodels*, to make data fittings and to calculate fluxes by derivation.

Validations of results has been made, at least on some compartments, directly in natural grasslands.

This study has been developped for seventeen years and various papers are devoted to it. Nevertheless, recent advances enlighted the need to precise the **spaciotemporal organization** of nitrogen pathways.

The main pathway presents four steps: (1) the decomposition- ammonification called here **mineralization**, (2) the **nitrification**, (3) the **reorganication** of ammonia and nitrate by microorganisms and (4) the **plant assimilation** of nitrate and/or ammonia.

Speaking about the spatiotemporal organization pathways, we have avoided here the misuse of "organization" (or reorganization) to point out the reverse process of mineralization. The synthesis of organic nitrogen compounds from mineral forms (nitrate or ammonia) is called here **organication** (in plants) or **reorganication** (by microorganisms).

The main pathway is regulated by (1) the quality of plant remains, (2) microorganisms and animals activities and (3) pedoclimatic conditions regulating plant, microorganisms and earthworm activities almost at the same rythm.

The main pathway is more or less slow and presents four variants:

- slowness of mineralization typified by a **necromass accumulation**

- **sequestration** of nitrogen in **microbial** products resulting from reorganication

- **dermo-rhyzospheric transfer** resulting from the earthworm skin excretion directly on root microsites

- earthworm **cast sequestration** coming from intestinal excretion and soil gut comminution.

The **necromass accumulation** is well known since the XIX_{th} century describing humus types. Mors and moders are characterized by organic layers on top soils, lack of anecic and endogeic earthworms, situation in poor soils (acid soils, cold soils...) and hard or resistant plant remains. On the contrary, the mull type, with a crumb structure moulded by earthworms, does not present such nitrogen blockings by plant remains. The same phenomenom occurs when tillage oxydizes soil organic matter.

The **microbial sequestration** is also well known by agronomists, particularly when ploughing mix straw in soil, which favors microbial growth and decreases mineral nitrogen in soil.

Dermo-rhizospheric transfer and **cast sequestration** are practically unknown because the lack of knowledges about intimate nitrogen ways in mull soils. While some authors, extrapoling laboratory data, assume that earthworms could play some rôle in mineralization, most of them attribute to animals a mechanical rôle of mixing and comminution increasing microbial activity.

Direct observations of ^{14}C plant remains and ^{15}N from plant to plant assimilation demonstrate that animals (earthworms = 80% of soil zoomass) play a major rôle in mineralization. This process is mutualistic; earthworms and microorganisms are synergetic, but the direct catabolic rôle of earthworms in nitrogen mineralization is important. Earthworms depend on quality of plant remains and on a primary microbial pre-digestion. They eat, digest, assimilate (or not) nitrogen and then they excreate it in two forms and by two ways.

Labelled litter and/or labelled earthworms demonstrate a very short cycle from eated plant remains to plant roots through a dermo-rhizospheric transfer. In this way, earthworm excretes nitrogen at skin level in two forms: (1) a quickly assimilable form, probably ammonia and/or urea from nephridia (assimilation in 1 to 3 days) and (2) a delay-nitrogen form, probably mucopolysaccharides from skin mucus (assimilation about 10 days later). This variant is exemplified by the dominant anecic *Nicodrilus longus* (Ude) which excretes most nitrogen in field by this channel (estimation for one field is about 460 $kg.ha^{-1}.year^{-1}$ or 46 $g.m^{-2}$).

At least for one other species (*Lumbricus terrestris* L.), an other channel is used simultaneously. In this variant of the main pathway, excretion is made into the gut when nitrogen is mixed with soil and grinded with digested organic matters. Then, casted faeces are incubated in soil and mineral nitrogen is used by reorganication in cast-crumbs. The cast sequestration is rather short (3 to 5 months) after maturation because (1) earthworm re-ingests their casts after maturation and (2) roots invade those cast-crumbs.

In all instances, *Nicodrilus longus* or *Lumbricus terrestris*, in field or in laboratory, the body's nitrogen turnover is high (i.e. 10% per day at 8°C) and follows a Q_{10} of 1.65.

In all those processes, roots colonize pedozoostructure made by earthworms as cast-crumbs and burrows, and a close spatial connexion occurs between mineralization and plant assimilation. Seasonal and regular activities of organisms are also closely synchronizated in such that leachable nitrogen forms are not available. While tillage creates oxydation and leachable nitrate accumulation, the soil "ploughed by earthworms" (Darwin) prevents it.