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Nitrogen Cycling in West African Ecosystems

REPORT OF THE WORK GROUP ON AGROECOSYSTEMS IN THE WET HUMID TROPICS

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Introduction

The nitrogen cycle is described for agrosystems on ferralitic soils subject to average desaturation with rainfall between 1400 and 1800 mm.

The concept of an agrosystem is not used here, as is generally the case, to describe an area geographically limited by definite borders. In fact, considering the scarcity of information available on the repartition of different rotation crops, it seemed preferable to consider the sequence in time of crops on one plot of land. Consequently the agrosystem is defined with respect to crop rotation.

In most cultivation systems in use, the rotation comprises two phases:

- a cropping phase
- a regeneration phase or fallow.

The relative importance and nature of each phase vary significantly according to production systems and their level of intensification. Therefore, it was considered appropriate to describe two types of agrosystems illustrating respectively:

- traditional systems
- improved systems

For each of these, only the cropping phase was the subject of a quantification essay.

Characterization of the agrosystems

Traditional systems

These systems range from intensive cropping systems where fallows are absent or very short in compound farms and areas of high population density to more itinerant long bush or forest fallow systems. The nitrogen content of the soil tends towards an equilibrium which is determined by the relation between the losses occurring for the most part during the cropping phase, and the additions mainly during the fallow phase.

No application of fertilizer is generally made but on compound farms, in areas of more or less permanent cultivation, much use is made of household refuse, small animals pen manure, mulch and sometimes compost. The supply of nitrogen to plants is mainly dependent on the mineralization cycle of the organic reserves of the soil, which is itself related to the climatic cycle.

The planting of associated crops allows a better use of the environmental potentials (water, mineral elements and light energy) and limits the effects of climatic uncertainties and other factors threatening the crops.

The productivity of these systems, although not generally high, is essentially dependent on the length of the period of fallow, which determines the extent of replenishment of fertility lost during the cropping phase.

Improved systems

In these systems, the productivity increase is obtained through the simultaneous improvement of a whole set of farming techniques which, apart from the use of fertilizers, affect essentially:

- the choice of selected plant varieties
- the timing and density of the sowing
- the tillage of the soil
- the battle with predators.

The intensification of production factors aims at an economic optimization of the input/output relationships.

Method of presenting the results

The method used is the one defined by Frissel (1977). The systems studies were restricted to two compartments:

- a plant compartment (P)
- a soil compartment (S)

each characterized by the following fluxes which traverse it:

- inputs → X
- outputs Y →
- transfers Y → X

These fluxes, grouped on one side as supplies and on the other side as removals, allow the calculation of a balance and the characterisation of the system's state. They are expressed in kg ha^{-1} and represent a yearly average.

In most cases, in order to integrate the variability of the data from the literature, it was judged preferable to give a range of values rather than an average. This implies a certain lack of precision in the calculation of the balances.

List of fluxes studied

In the plant compartment

- Supplies
  - (i) inputs by seed or seedling → P
  - (ii) transfer by net uptake from soil S → P
  - (iii) input by uptake from the atmosphere → P

– Removals
  (i) transfer by seed for sowing P → S
  (ii) output by primary product P →
  (iii) transfer by plant residues P → S
  (iv) output by burning P →

In the soil compartment

– Supplies
  (i) input by waste → S
  (ii) input by addition of fertilizer → S
  (iii) input by non-symbiotic N-fixation → S
  (iv) input by dry and wet deposition → S
  (v) transfer from plant residues P → S

– Removals
  (i) output by denitrification and volatilization S →
  (ii) output by leaching S →
  (iii) output by erosion and run off S →
  (iv) transfer by plant uptake S → P

Significance of the extreme values

In the case of traditional systems, the highest values correspond to the cultivation phase immediately after the reclamation of the land. This period is characterized by an excess of supply over demand. This excess is partly lost due to the inadequacy of the farming techniques used. The lowest values correspond to crops grown several years after the reclamation of the land, when the fertility decreases.

In the case of improved systems, the range of values represent different levels of intensification. The lower values correspond to the implementation of the agricultural practices most commonly popularized and spread in rural areas, whereas the higher values relate to results obtained at experimental farms where the whole set of farming methods can be applied in conditions of maximal efficiency.

Results

The results are summarized in Table 1.

Comments on the plant compartment

The average quantity of nitrogen used yearly by plants has been estimated to:

– 40 to 80 kg ha^{-1} in traditional systems,
– 100 to 200 kg ha^{-1} in improved systems.

This nitrogen originates generally from the soil with the exception of leguminous species

Table 1. Example of nitrogen balance for a tropical agrosystem (kg ha^{-1} yr^{-1}). The figures mentioned are based either on: compilation from the literature, extrapolations or calculations.

Identification of fluxes	Traditional systems		Improved systems	
Plant compartment				
Supplies				
input by seed or seedlings	2 to 5		2 to 5	
transfer by net uptake from soil	33 to 66	40 to 80	83 to 166	100 to 200
input by uptake from the atmosphere	7 to 14		17 to 34	
Total supplies	42 to 85		102 to 205	
Removals				
transfer by seed for sowing	2 to 5		2 to 5	
output by primary product	24 to 48	40 to 80	60 to 120	100 to 200
transfer by plant residues	5 to 10		40 to 80	
output by burning	11 to 22		– –	
Total removals	42 to 85		102 to 205	
Balance	0		0	
Soil compartment				
Supplies				
input by waste	<5		<5	
input by addition of fertilizer	0		50 to 100	
input by non-symbiotic N-fixation	<10		<10	
input by dry and wet deposition	10 to 20		10 to 20	
transfer from plant residues	5 to 10		40 to 80	
Total supplies	15 to 45		100 to 265	
Removals				
output by denitrification and volatilization	<20		<50	
output by erosion and run-off	<60		<60	
output by leaching	5 to 50		50 to 150	
transfer by plant uptake	33 to 66		83 to 166	
Total removals	38 to 196		133 to 426	
Balance	-23 to -151		-33 to -161	

which partly use atmospheric nitrogen. The quantity thus fixed through symbiotic fixation has been estimated to:

- 20 to 40 kg ha^{-1} in traditional systems. The quantity is of less importance when the soil is well provided with mineral nitrogen, as a high content of the latter has a lowering effect on the efficiency of symbiotic fixation.
- 40 to 80 kg ha^{-1} in improved systems, for which the increase of fixation when the level of intensification is raised originates partly from the use of selected species with high fixation ability, and partly from the suppression of other limiting factors than nitrogen.

At the rotation level, the relative importance of nitrogen originating the soil compared to nitrogen from the atmosphere depends thus on the relative importance of the leguminous crop in comparison to other crops.

The results mentioned in the table above were calculated assuming the relation to be 1/2, i.e., assuming a succession of three crops, one of them being leguminous.

As to the relative importance of the fractions removed through harvest and the fractions that can be transferred by plant residues, they have been estimated to be 60 % and 40 % respectively of the total quantity used by the plants.

In traditional systems the recovery can be limited by the practice of burning, which can affect up to 70 % of the total residues from farming.

Comments on the soil compartment

Fertilizers are used only in improved systems. The rates most frequently recommended are in the magnitude of 50 kg ha^{-1}. As mentioned above, the aim is to obtain an economic optimum. In less advanced systems inputs are preferably reserved primarily for cash crops, and secondly for cereals.

In more intensive systems the rates can be significantly raised and reach 100 to 200 kg ha^{-1}. The cumulative effect of large inputs, most frequently in the form of ammonia sulphate, causes an acidification of the soil.

The coefficient of fertilizer uptake by plants, which is higher at low rates than at high rates, does not exceed 50 %.

The recovery of plant residues constitutes an essential practice for the maintenance of fertility and the equilibrium of humus balance. Moreover, it allows the reincorporation into the soil of a fraction of the nitrogen taken up from the atmosphere.

The table shows that in the soil compartment, the total inputs remain insufficient to compensate for the losses. In traditional systems the inputs are inferior to the amounts absorbed by plants alone. The deficit results in an impoverishment of the soil that could only be slowed down by the introduction of a sufficiently long period of fallow, which would allow fixation and transfer to the surface of a fraction of the subsoil nitrogen.

Conversely, in improved systems, the supplies are in excess compared to the absorption by plants. Nevertheless, they are necessary for the maintenance of the system's productivity as they result in a significant increase of losses, mainly through leaching, and hence a deficit which increases with increasing supplies.

The maintenance of these systems is dependent on the adoption and use of farming techniques apt to increase the efficiency of fertilizers by reducing losses (e.g., by splitting up the inputs). Besides, the introduction of an improved fallow or a rotation cultivation of fodder based on leguminous crops may constitute a possible solution to the maintenance of a satisfactory nitrogen balance.

Discussion

The method of presentation adopted, which exhibits each compartment as a "black box" illustrates inadequately the whole set of interactions that rule the dynamics of a soil-plant system as well as the processes set in action. For instance, little information is available on the prospection of soil profiles of plant rooting and on profiles of root activity "in situ". The role of deep roots remains to be defined. This is all the more important as erosion phenomena are intensive.

Regarding the plant compartment, which is the best known, some uncertainties remain. In particular, the contribution from biological fixation to the nitrogen cycle is only measured under particular circumstances which makes it difficult to extrapolate and evaluate its significance in the field. The emphasis was placed on these shortcomings, and research focused on their removal must be given priority.

In the soil compartment little information has been assembled concerning the internal nitrogen cycle (mineralization – immobilization). The knowledge of the impact of farming techniques on this cycle constitutes, however, an essential element of a better control of the conditions for nitrogen balance. The use of ^{15}N could be a fruitful method for these studies.

On the other hand, if the intensification results in an opening of the nitrogen cycle, the available data are, at the current state of knowledge, insufficient for an exhaustive and reliable evaluation. In particular, for losses, the variability as well as the number of data cause difficulties. There are several reasons for this. Some are of methodological nature (differences in experimental measurement devices), while others are probably due to inadequate identification of the processes.

Therefore, if the data obtained by different authors should be used for the setting up of a complete balance, it seems indispensable to have access to a certain number of references which take into account the whole complex (climate – soil – plant – farming techniques). For this reason, it is recommended that a network of reference information regarding measurement results can be created.

Finally, it is advisable to once more state that the undertaken quantification essay relates to a single plot and does not take into consideration the redistributions which may occur in the atmosphere. The consequence of this is that deficiences are overestimated in the balance. Therefore, measurements ought to be made on the level of whole geographical units such as, e.g., basin slopes.

References

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