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Nitrification and acidification induced by urea in a venezuelan tropical alfisol
Nitrification et acidification induite par l'urée dans une alfisol tropical du Vénézuela

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Repeated supplies of urea are generally considered to be acidifying mainly due to nitrate leaching. It is the reason why, the rhythm of nitrification and the amount of lixiviation and gaseous losses were analyzed in the Barinas alfisol (Kandic Paleustalf) under maize and permanent pasture between 1986 and 1994.
The study of nitrification was based on experiments including ^{15}N urea budgets, soil sampling during field Maize and permanent pasture crops, water sampling under monolithic lysimeters, soil incubations, green-house cultivations (Rye-grass)
Nett nitrification was normal below maize, and nearly null below permanent pasture (Digitaria decumbens) Nitrate concentrations increased for three to six weeks after fertilization (depending on temperature) then dropped back to their initial level which was similar to that found for ammonium.
In the field, measured losses by leaching were on the average 2 kmolN.ha^{-1} year^{1}. These nitrates were mainly derived from soil. Gaseous losses of nitrogen which represented twice more nitrogen than leached nitrates, were mainly derived from fertilizer and occured immediately after the urea input on maize and permanent pasture.
In incubations, the time necessary to obtain nitrates as labelled as ammonium may vary between 6 to 14 weeks in relation with the temperature. Nitrate production was about 1mg kg-1 d-1 at 20 **C and almost 2mg kg-1 d-1 at 30 C.**
Even in presence of excessive quantities of ammonium which may occur after banded inputs of urea, nitrification was not inhibited ant a test plant was able to actively absorb nitrates. On the contrary, the same plant is able to actively absorb newly formed ammonium in presence of great quantities of accumulated nitrates.
The common practice of modellers who considers that nitrogen is equally absorbed under both forms sould be improved by an adaptation taking in account the unbalanced composition of the soil solution after fertilization and the selectivity of the plant for the form of nitrogen actually absorbed during the differents steps of its developpement.

Keywords : Nitrogen, nitrate, ammonium, Urea, Maize, Pasture, Savanna
Mots clés : Azote, nitrates, ammonium, Urée, Maïs, Fourrage, Savane

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Introduction:

Urea is the most commonly used nitrogen fertilizer in the tropics. Even when large amounts of N fertilizer are added, N is primarily taken up from soil N (Ganry, 1990; Hétier et al, 1989). Nevertheless, the form of mineral nitrogen derived from urea which is finally absorbed by the plant was never clearly described. On one hand, it would be important for modelling purposes, to know wether the fertilizer is mainly absorbed by the plant as ammonium and wether the nitrogen derived from the soil is mainly absorbed as nitrates. On the other hand, an increase of leaching will only occur when the plant cannot immediatly absorb the newly formed nitrates. It was the reason why the study of nitrification and acidification had to be linked, repeated supplies of urea being often considered to be acidifying primarily because of an increased nitrate leaching (Moody & Aitken 1997).

Data used in the present work were firstly compiled from periodical soil sampling performed in Barinas under maize and pasture field crops.

Weekly to monthly water sampling using monolithic lysimeters for eight years (1986-1991 and 1993,1994) yielded an estimate of leached nitric nitrogen under both crop cultures.

Finally, laboratory incubations and plant test cultivations of rye-grass were organized to simulate the effect of the high concentration of urea produced by banded inputs.

MATERIALS AND METHODS

All the results were performed in the Botanical Garden of the Unellez at Barinas (8°37’N, 70°12’W, altitude: 180m). The climate was typical of seasonal savannas with a constant temperature and variable precipitation around a ten-year average, which was 1600 mm (1975-1986).The soil on which the maize was grown was an acidic alfisol low in organic matter (C: 7 mg kg^{-1} N: 0.6 mg kg^{-1}).

Crops

After soil preparation including P, K, inputs (100 units P and K ha^{-1} as KCl and $Ca_3(PO_4)_2$) maize was sowed with a density of 55 000 plants ha^{-1}. Three weeks after sowing, urea was applied in solution by lateral banding (1988 and 1990) or uniformly spread on the surface between rows spaced 0.9 m apart (1993 and 1994).

Sampling

For all years, the first samples were taken at sowing PO, 30 days later, i.e. 8 days after urea application P1, one month afterwards (60 days after planting (« DAP ») P2, at 101 DAP P3, and at final harvest,130 DAP P4. Soil sampling under pasture was at the same dates. At each point a total of approximately 5 kg of fresh soil, was mixed and sieved to form a representative composite sample.

Spatial variability was measured using twelve samples taken the same day (C.V. about 20% for $N\text{-}NH_4^+$ and 30% for $N\text{-}NO_3^-$ above 5 mg kg^{-1}).

Lysimetry and volatilization

From may 1986 to october 1991 six lysimeters of 0,25 m2 and 110 cm high of undisturbed soil (Roose 1981) were used to collect water samples under maize (1 plant by lysimeter) and pasture to quantify drainage and nitrates leaching. During 1993 and 1994, the six lysimeters were cultivated with maize.

Immediatly after the 1988 fertlization, acid tramps were used in a field device to obtain an evaluation of the quantity and almost of labelling of evolved ammonium.

Incubations

Ten kg of dry soil was thoroughly mixed after sifting (2mm) and moistened to 80% of field capacity either with distilled water (control) or with a solution of labelled urea (E = 0,8%) adjusted to simulate a banded input (150 mg kg^{-1}). Three sub-samples of 100 g were taken at each sampling time (1,3,6, 9 and 15 weeks after labelling) for N mineral extraction. The soil was re-mixed and re-moistened after each sampling.

Rye grass cultivation

Twenty kg of dry soil were mixed, moistened and fertilized as above and distributed in 20 pots. A first set of ten pots was immediatly sown with 250 rye-grass seeds (Treatment S). The second set was sown six weeks later (Treatment D). The green parts of rye-grass were harvested four times (3,5,9,15 weeks after seedling) for the first set and three times (3, 6, 9 weeks after seedling) for the second set.

Analysis

Total nitrogen in plant and soil samples was determined by Kjeldahl method. Mineral nitrogen was extracted for 2 hours stirring fresh soil using a soil/solution ratio of 1/3, then measured by vapor distillation and recovered as $(NH4)_2SO_4$ for ^{15}N atomic excess determination by optical or mass spectrometry according to the expected excess value.

RESULTS AND DISCUSSION

Evolution of mineral nitrogen in the field (Fig 1)

Two examples are given to demonstrate that nitrate was generally the dominant specie under maize except immediatly after urea input. Subsoil nitrate content was much higher than that under pasture, indicating a possible nitrate leaching which was confirmed by lysimetry (Hétier et Silva 1992).

As in the original savannah soil, ammonium is always dominant under permanent pasture. This observation does not only indicates that nitrification was reduced but also that the nitrates were immediatly absorbed by a root biomass which was twice more abundant than under maize. The relatively high ammonium content under pasture should be related to a more active MIT (Mineralization-Immobilization Turnover) (Chaussod et al. 1992) than under maize.

Nitrogen derived from the fertilizer (Ndff %) indicated a rapid dilution of the fertilizer due to an active gross mineralization under both crops. Thus, one week after fertilization, only 30% of mineral nitrogen was derived from the fertilizer compared of 57% under maize. At the end of the first crop cycle and throughout the second cycle, the previously immobilized nitrogen in the top soil was partially re-mineralized whith a Ndff varying around 2%.

The first partial conclusion drawn from these results was that the fertilizer was rapidly diluted in the mineral compartment by newly formed ammonium and nitrates derived from the soil. Therefore, this dilution should be taken into account when attributing the deficit in fertilizer recovery, which is always observed both under pasture and under maize, to gaseous losses from the soil solution .

The second conclusion was that nitrification was activated by tillage, especially at the beginning of the rainy season in 94. If these nitrates are preferentially leached, acidification will increase while if they are prefentially absorbed by maize, the acidification will be reduced.

Lysimetry and gaseous losses (Tab 1 & 2)

Table 1 summarizes all the results from lysimetry obtained from 1986 to 1994. Despite a high interannual variability, the diference between nitrogen (mainly nitric) leaching under maize and under permanent pasture is clearly shown. Drainage was one third lower under pasture, and nitrogen leaching ten times lower than under maize. Of this leached nitrogen (average 23 kg N.ha^{-1} year-^{1}), only 4 or 5 kg may be attributed to the fertilizer introduced in 1986 or 1993

One indirect consequence of lysimetry measurements was that the main losses of nitrogen (50 to 100 kg ha-1 yearly) were gaseous losses. To be compatible with the observed steady state of total nitrogen, these losses were presumed to be primarily derived from fertilizer and to occur immediately after urea input on maize and permanent pasture. In fact, the results of a tentative direct evaluation of gaseous losses were very low. However, the losses occured only during the first 4 days after fertilization and were mainly derived from the fertilizer. The static tramps used highly underestimate the real amount of volatilized ammonium (Ganry 1990) but give a good idea of its dynamics and origin.

Incubations (Fig. 2)

The first goal of laboratory incubations was to know if nitrification was inhibited by the high concentrations of ammonium. The second goal was to measure how much time was required to obtain nitrates which were as labelled as ammonium in the field conditions of banded inputs.

No inhibition of nitrification was observed. The time required to obtain nitrates which were as labelled as ammonium varied between 6 to 14 weeks depending on the temperature. Nitrate production was about 1mg kg-1 d-1 at 20°C and almost 2mg kg-1 d-1 at 30°C. In the second incubation, the warmer temperature made it possible to

observe that the accumulated nitrates may reach a higher labelling rate than ammonium which was constantly diluted by the mineralization flow.
Potential nitrification rate of Barinas alfisol was measured in the laboratory (L.Jocteur Monrozier pers. comm.) Nitrificant population had a rather slow developpement but normal and tolerated acid conditions. In fact, the observed nitrification in the incubations was near of measured potential.

Plant test cultivations: Fig 3
At the end of both experiments, no losses appeared, and total N and 15N budgets were close to 100%. On the contrary, nitrogen budgets generated at the end of all field cultivations always demonstrated losses.
When seedling occured immediatly after the fertilization, 70% of the absorbed nitrogen was derived from the fertilizer in the three first harvests, while only 55% was in the forth. Aerial dry matter production was relatively low (4,4 g) and N concentration was relatively high (N%=5,7-3,3-1,7-0,7). The roots were coarser and more developped than usual (2,5 g). It would appear that this absorbed nitrogen was primarily amoniacal, ammonium being the dominant specie before nitrates during the first weeks.
When seedling was six week delayed, 58% of the absorbed nitrrogen derived from the fertilizer in the three harvests. Aerial dry matter production was very strong (6,1g) but nitrogen concentration normal (N%=4,9-1,7-1,1) and roots also (1,2g). It looks probable that this absorbed nitrogen was mainly nitric because after six weeks ammonium was quite null. However, after the first harvest, the existing nitrates remained constant in quantity and labelling until the end of the experiment and were more labelled than the absorbed nitrogen. Therefore, they could not have been the only source of absorbed nitrogen.
A joint conclusion can be drawn from these two experiments. The plant could actively absorb nitrates or ammonium to compensate the dominant form. When a high amount of highly labelled nitrates was present, the plant actively selected ammonium and vice-versa.
If the compensation mechanisms were still functionning under these extreme conditions, it means that they are probably more efficient in the field. If amoniacal form of nitrogen was initially used, the plant will probably preferentially use nitrates during the following stages of its developpement.
This type of experiment has to be repeated with maize and other plants to be sure that modelling adequately reflects an initial absorption of amoniacal nitrogen mainly derived from urea followed by an additional absorption of nitrates mainly derived from the soil.

CONCLUSION

Drainage and Nitrification are activated by tillage. Losses of nitrates mainly occured before cultivations in the first month of the rainy season. These measured losses by leaching concur with a moderate or null acidification but not with the calculated deficit in the nitrogen budgets.
The observed nitrification rate in vitro is normal but sufficiently slow to explain that nitrates formed after fertilization are more absorbed by the plants than deeply leached in the sub-soil during cultivation.
Even in presence of excessive quantities of ammonium resulting of banded inputs of urea, nitrification was not inhibited ant a test plant could actively absorb nitrates. However,

the same plant could actively absorb newly formed ammonium when large quantities of accumulated nitrates were present.

Model designers, who generally considers that mineral nitrogen is equally absorbed under both forms, can improve their models by including a consideration of the unbalanced composition of the soil solution after fertilization and of the plant selectivity for ammonium or nitrates during its developpement.

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Tab. 1: Lysimetry under maize				**Under pasture**		
Year	Drainage mm	N leached kg ha-1	Ndff %	Drainage mm	N leached kg ha-1	Ndff %
1986* Labelling	698	5	16	437	1	2,25
1987	327	16	20	275	2	0,4
1988	508	25	3	403	2	0
1989	232	22	1	159	1,7	0
1990	583	49	0	452	2,8	0
1991	705	27	0	695	1,2	0
1993*Labelling	844	10	3,5			
1994	998	31	7,8			
Mean 8 Years	612	23		404	2	
C.V. %	*39*	*55*		*41*	*33*	

Tab 2: Volatilization from 4 to 72 Days after fertilization (B.Silva 1989)

Sample	N mg	E%	Ndff%	Fert. recovery %
P 1: 4 Daf	98	0,61	84,7	3,27
P 2: 8 Daf	1,994	0,1	13,9	0,07
P. 3: 14 Daf	0,63	0,2	27,8	0,02
P. 4: 23 Daf	0,22	0,07	9,7	0,01
P. 5: 37 Daf	0,37	0,1	13,9	0,01
P.6: 56 Daf	0,19	0,03	4,2	0,01
P.7: 72 Daf	0,11	0,04	5,6	0,00
Total	**101,51**			**3,38**