Journal of Animal & Plant Sciences, 2009. Vol. 4, Issue 3: 384 - 398.
Publication date: 19 October 2009, *http://www.biosciences.elewa.org/JAPS*; **ISSN 2071 - 7024**

Native soil N mineralization in major rice based cropping systems

Jean-Pierre Bognonkpe[1*] and Mathias Becker[2]

[1] UFR SN - University of Abobo-Adjame – Abidjan, 02 BP 801 Abidjan 02, Cote d'Ivoire – Tél: +225 09729882, Fax:+225-20304256; [2] Institute for Plant Nutrition, University of Bonn, Karlrobert-kreitenstr 13, 53115 Bonn, Germany

**Corresponding author Email: j.bognonkpe@gmx.de*

Keywords
Denitrification, leaching, mineralization, nitrogen, rice-based, systems.

1 SUMMARY

A laboratory and field study was conducted in Côte d'Ivoire during the dry-to-wet season transition period (DWT) of 1996 and 1997 with the objective of quantifying native soil nitrogen (N) mineralization dynamics in the major rice based system. It comprised of (1) an incubation study under controlled conditions in the laboratory in 1996 to determine soil N mineralization potential using soil samples from the 10 major rice based systems of Côte d'Ivoire, (2) a detail soil survey in 1997 to quantify *in situ* soil N dynamics in 6 rice based systems of Gagnoa (bimodal forest zone) with weekly soil samples being analyzed for ammonium and nitrate. Results indicated that the amounts of the mineral soil N (N_{min}) strongly varied by system as well as in space and time. Nitrogen mineralization trends in time were similar for both ammonium and nitrate. Extensive systems showed higher N mineralization than intensive systems. Peak levels of soil N_{min} were observed under upland conditions, reaching up to 42 kg N ha^{-1} in the humid forest zone. The dry-to-wet season transition period was composed of successive increases and decreases in soil N_{min}, following the fluctuating soil moisture content. Soil mineral N declined throughout the cropping season as rainfall intensity increased. Plant N uptake can partially explain this decrease, but it is likely that large losses from the soil-plant system resulted from the action of surface runoff (nitrate leaching) and lowland moisture saturation (denitrification). The largest decline in mineral soil N (highest N losses) was observed in the period between land clearing and rice crop establishment. Technical options aiming at increasing the use efficiency of native soil N should target this transition period.

2 INTRODUCTION

Nitrogen (N) is subject to intense chemical and microbiological transformation processes (hydrolysis, oxidation, reduction) and is, therefore a very mobile nutrient element in the soil – plant – atmosphere continuum (DeDatta & Buresh, 1989; Phongpan & Mosier, 2003; Stahl *et al.*, 2002). Most tropical soils are deficient in N, and this N deficiency is the most prominent constraint to food production in the inland valleys of Cote d'Ivoire. N deficiency is severe in upland soils, particularly in the sandy Alfisols of the savanna agroecological zone, than in the valley bottom lands, where soils tend to have high soil organic matter content. The amount of mineral and therefore plant-available native soil N is determined by the soils' content in organic matter and the ecological conditions favoring its mineralization (George *et al.*, 1993; Smith *et al.*, 1998), transformation and mobilization. Among these ecological conditions is the water availability and therefore, a strong seasonality in sub-humid tropical climates (Mazzarino *et al.*, 1998).

Before the onset of the rainy season, soil contains mostly organic N, as well as some ammonium and little nitrate (Ikerra *et al.*, 1999; Aulakh *et al.*, 2000). With the wetting of the soil at the onset of the rainy season, a flush of inorganic N occurs (Birch, 1960). This N_{min} flush (Birch-effect) is usually of short duration (Warren *et al.*, 1997) due to N_{min} losses by leaching/bypass flows (Wild, 1972; Andreini & Steenhuis, 1990; Barraclough *et al.*, 1992), denitrification (Schnabel & Stout, 1994), volatilization if soil pH $\geq$ 7.0 (Koelliker & Kissel, 1988) but also due to the N uptake by plants (Greenland, 1958). The magnitude of the Birch-effect depends on the length of the dry period (Semb & Robinson, 1969), the quality and quantity of organic matter (Franzluebbers *et al.*, 1995; Wong & Nortcliff, 1995) and climatic parameters such as the intensity and the quantity of the rainfall (Narain *et al.*, 1997). With the establishment of the rains, soils get saturated and the downward flow of water and dissolved nutrients in the soil profile sets in.

If nitrate is not absorbed by a growing vegetative cover, massive nitrate-N losses can occur at this stage. These losses have been reported to range from 25 to as high as 109 kg N ha-1 in lowland fields of Southeast and South Asia (George *et al.*, 1993; Pande & Becker, 2003). However, crop demand for N during the early growth stage at the beginning of the wet season is low (Sanginga *et al.*, 1995) and consequently N losses are generally high. The extent of the prevailing loss mechanism will depend on the amount of nitrate, the intensity of the rain and the flow of water in the soil profile. Such losses are likely to be dominated by leaching in well-drained sandy soils on valley slopes and by denitrification in saturated heavy-textured soils of the valley bottomlands (Hadegorn *et al.*, 1997).

The subsistence-oriented farming systems in the inland valleys of Côte d'Ivoire are in the hands of small farmers. The current intensification of the production is achieved by clearing of new land, a decrease of the length of fallow periods on upland-slopes and the expansion of cultivations in adjacent lowlands. The extent of slope use is likely to intensify water and nitrogen mineralization and fluxes and thus to differentially impact fertility and crop productivity in both ecologies.

The overall objective of this study was to generate a quantitative understanding of the soil N dynamics in the major rice based cropping systems of Côte d'Ivoire with different land uses in order to improve the spatial targeting of technical options aimed at conserving soil fertility and maximizing water/nutrients use efficiency. Specifically, the objectives were: (1) to quantify seasonal N mineralization potential in major rice-based production systems of Côte d'Ivoire during the dry-to-wet season transition period, and (2) to estimate N losses in relation to rainfall intensity.

3 MATERIALS AND METHODS

3.1 Study sites and experimental description: Côte d'Ivoire is part of the humid zone of West Africa, located between 4° to 11° N latitude and 3° to 9° W longitude. The northern half of the country is characterized by the moist savanna agro-ecological zone with monomodal rainfall distribution (mean annual precipitation around 1100 mm), while the south lies in the equatorial forest zone with a monomodal rainfall distribution in the west and a bimodal rainfall distribution in the center and the east (annual mean precipitation of 1600 mm). Between these two major agroecological zones, lies a transition zone (derived savanna) with a pseudo-bimodal rainfall regime. Only small portions of the country are characterized by high mountains, namely the western part bordering Guinea and Liberia, or by extended river floodplain, namely the north and the coastal floodplains in the south.

The overriding majority of Côte d'Ivoire is characterized by the gently undulating landscape of the inland valleys, which are the main sites of rice production. Regional climatic and vegetation characteristics determine the general distribution of soil types in Côte d'Ivoire. In the forest zone, Oxisols and Ultisols occupy the upper end of the toposequence, while Ultisols and Inceptisols are found in lower portions and valley bottoms. In the western mountains, soils are strongly acidic (pH 4 - 5) and consequently deficient in phosphorus. Under the dry climate of the transitional zone and the savanna, Alfisols and Inceptisols are most common. Physical and chemical characteristics of the soils are shown in Table 2.

When not under cash crops, food crops occupy the toposequence and are dominated by rice cropped from the strictly rainfed upland to the flooded lowland. Shifting-cultivation, with slash-and-burn practices and dibble seeding of rice, dominates in the upland zones. Rice is sometimes intercropped with cassava or maize. Bush fallow, for soil regeneration, has long been an integral part of the system.

3.2. Plant material: Planting material used in the various experiments is rice. The modern high-yielding 120 day rice (*Oryza sativa* L.) variety IDSA 8 was obtained from the rice germplasm collection of the International Network of Germplasm Evaluation of Rice (INGER – Africa), Bouaké – Côte d'Ivoire. Under upland conditions, rice was dibble seeded at 15 x 15 cm spacing. In the lowland, 25 day-old seedlings were transplanted at 20 x 20 cm spacing.

3.3. Measurements and data recorded: The daily rainfall events were manually recorded with rain gauges and complemented with data obtained from meteorological station located in the nearest town to the field site.

Composites of 2-3 soil samples were collected from three depths (0 – 20, 20 – 40 and 40 – 60 cm) using a gravimetric auger.

Bulk density was determined in the course of a physical evaluation of the soils in order to translate gravimetric into volumetric values according to the method described by Schlichting *et al.* (1995) using a soil volume of 100 cm^3. The volume-samples were carefully removed from the profile using 100 cm^3 metal rings, dried at 105°C to a constant weight and weighed. Bulk density values presented are the mean of two samples taken at the onset of the dry and the rainy season. Soil moisture was measured using Time Domain Reflectometry (TDR). The TDR equipment used was a Trime FM 2 (IMCO GmbH, Ettlingen, Germany) with unmovable probe rods of 25 cm length. Measurements were taken at each soil sampling date and expressed as volumetric soil moisture (% water volume per soil volume). The pH was measured in 10 g air-dried soil (Ø < 2 mm) samples, in H_2O and 1.0 M KCl, using a soil: solution ratio of 1:2.5 according to the procedure of Hendershot *et al.* (1993) using a digital pH meter (HI 9214 / HANNA Instruments, Frankfurt, Germany). Dispersion of soil aggregates was performed by chemical and ultrasonic means with the separation of particles according to size limits through sieving and sedimentation. The procedure of Schlichting *et al.* (1995) was employed in the soil laboratory of WARDA.

Soil N mineralization potential was determined by anaerobic incubation following the modified method by Standford and Smith (1972). Four replications of 20 g air-dried soil samples were tightly enclosed in glass tubes with 30 ml H_2O (no shaking) and incubated in the dark at 26°C. Tubes were extracted with 0.5 M KCl after 2, 4, 6 and 8 weeks. The extracts were filtered and distilled following the Kjeldhal procedure (Page *et al.*, 1982). To determine mineral ammonium and nitrate content in field samples, soil was ground, extracted with 0.5 M KCl and processed on a distillation unit with the addition of 0.2 g of MgO for ammonium and 0.2 g of Devarda's metal for nitrate determination. The resulting condensate was titrated with 0.01 N H_2SO_4. Total N content in soil was determined by distillation after heat digestion (370 °C) of air-dried samples in concentrated sulfuric acid with a catalyst (selenium), following the Kjeldhal procedure (Page *et al.*, 1982).

Soil mineral N concentration was adapted with bulk density and calculated as follows:

$$\frac{((v1 - v2) \times mN \times Vo)}{V1 \times Pe} \times (h \times Da) = NH_4^+ or NO_3^- (kgN/ha)$$

For 20 cm depth.v1: acid volume used for titration of measured sample (ml); v2: acid volume used for control sample (ml); mN: atomic mass of nitrogen (14 g); Vo: volume of extraction solution (80 ml); V1: extract used for distillation (20 ml); Pe: dry weight of extracted sample (g); h: considered depth (20 cm); Da: bulk density of the considered soil (g / cm^3)

Journal of Animal & Plant Sciences, 2009. Vol. 4, Issue 3: 384 - 398.
Publication date: 19 October 2009, *http://www.biosciences.elewa.org/JAPS*; **ISSN 2071 - 7024**

Table 1. Rice-based cropping systems of Côte d'Ivoire.

	Forest zone				Savanna zone					
Systems	**Krou**	**Yacouba**	**Dioula**	**Irrigated**	**Rainfed upland**	**Till mechanized or CIDT**	**Fully mechanized**	**Lowland**	**Floodplane**	**Swamp**
Rainfall pattern	bimodal	monomodal	bimodal	bimodal / monomodal	monomodal	monomodal	monomodal	monomodal	monomodal	monomodal
Ecology and moisture regime	upland/ rainfed	from upland to valley bottom Rainfed	from upland to valley bottom Rainfed	valley - bottom irrigated	upland Rainfed	upland Rainfed	upland Rainfed	valley bottom irrigated	plane alluvial	valley bottom irrigated
Labour	non-existent	manual	manual	manual and tractor	manual	animal traction and tractor	tractor	manual and animal traction	tractor	manual
Associated crops	maize	cassava	maize	none	maize, yam	maize, sorghum	none	none	none	none
Surface area (%)	**22**	**10**	**29**	**5**	**6**	**15**	**2**	**4**	**3**	**3**

Source: Becker and Diallo (1992)

Changes in soil N between 2 sampling dates were used to stepwise calculate N mineralization gains and N losses for each time. Organic carbon in soil was determined by the titration method of Walkley-Black (Page *et al*., 1982). Wet-ashing of samples was done with potassium-bi-chromate ($K_2Cr_2O_7N$) and sulfuric acid (H_2SO_4), after which iron sulfate ($FeSO_4$, $7H_2O$) was added. Organic matter content was calculated from the organic C values multiplied with 1.72 (value for cultivated area).

2.4. Plant sampling and analysis

Above ground plant biomass was sampled on 2 m² sampling areas. Total N in the plant biomass was determined after drying and grinding 100 g of fresh biomass after 24 hours air-drying (60 °C) (Tecator Cyclotec 1093 Sample Mill with 1 mm sieve) using the Micro-Kjeldhal method (Page *et al*., 1982).

Journal of Animal & Plant Sciences, 2009. Vol. 4, Issue 3: 384 - 398.
Publication date: 19 October 2009, *http://www.biosciences.elewa.org/JAPS*; **ISSN 2071 - 7024**

2.5. Experimental design and treatment application

2.5.1. Soil N supply potential in major rice-based systems of Côte d'Ivoire

A soil survey was conducted during the dry to wet transition period (DWT) of 1996, in the rice-based cropping systems, to investigate potential soil N mineralization and the extent of N losses. The field sites chosen for the diagnostic survey were smallholder farms representing the major rice-based cropping systems where more than 90% of the rice in Côte d'Ivoire is grown (Becker & Diallo, 1992). They are spread across the different rainfall regimes and are differentiated by parent rock / soil types and position along the toposequence.

One farmers' rice field was selected in each of the 11 production systems. The systems differed by agroecological zones with regard to cropping intensity in uplands (short fallow less than 5 years and long fallow, from 6 years onward) and to water management in the lowlands (bunded vs. unbunded plots). Total and net-N mineralization were determined by anaerobic incubation for 6 weeks and subjected to ANOVA and multi-regression analysis. Accordingly, the N supplying capacity was classified by independent variables and differentiated into forest and savanna agro-ecological zones (AEZ), upland and lowland ecologies (TOP), light- and heavy-textures soils (STX), and extensive and intensive land use (LUI).

Table 2. Physical and chemical characteristics of soils at the moist savanna, derived savanna and humid forest sites (Source: Becker and Diallo (1992)

Location / Geology	Toposequence level	Horizon	Clay content	CEC (meq 100 g^{-1})	Base saturation (%)	pH	Observations
Moist savanna / transition schist - granite	Crest	A1	22.5	4.84	74	6.6	red gravelled clay
		B2	55.3	4.78	78	6.3	
		B3	29.3	1.29	42	5.7	
	Slope	A1	10.8	2.06	60	5.8	ligth gray sand and ochre sandy
		B2	39.2	2.42	54	4.7	
	Bottom land	A1	18.2	1.36	32	4.6	gray sandy clay with gley
		A3	31.5	0.59	17	5.1	
Derived savanna / Granitoide	Crest	A1	8.9	2.48	35	6.1	ochre sandy clay
		A2	18.6	0.82	16	5.7	
	Slope	A1	4.9	3.01	48	6.5	gray ochre sandy clay
		A3	11.9	2.95	41	5.7	
	Bottom land	A1	7.2	2.84	59	6.6	belge sandy with little clay
		BC	19.9	2.98	52	6.6	
Humid forest / Gneiss	Crest	A1	18	10.7	85	5.9	Ochre gravelled clay surface
		B2	53.3	2.45	30	4.8	
	Upper slope	A1	13.7	1.75	23	4.8	beige yellow sandy clay
		B21	60	0.81	12	5	
	Lower slope	A1	6.8	2.5	38	5	
		A3	19.5	1.01	24	5.3	
	Bottom land	A1	13.7	3.78	29	4.5	gray beige sand loam & gley
		B2g	18.7	1.94	35	5.4	

Soils were sampled at 0 – 20 cm in each of the selected field sites, in the DWT, immediately after the first rain after the dry season and two to three weeks later when the rainy season was established because it was hypothesized that mass leaching happen at this time. The soil samples were translocated to an incubator at WARDA and were individually incubated in 3 replications per sample to evaluate the soil N supply capacity. Sample tubes were extracted for exchangeable NH_4-N at bi-weekly intervals for a duration of 8 weeks. Net N mineralization was calculated by subtracting the initial NH_4-N from samples' N content and the cumulative net N mineralization was determined as the sum of all successive N_{min} increases. The bulk density was used to express sample N content on a per unit area basis.

Journal of Animal & Plant Sciences, 2009. Vol. 4, Issue 3: 384 - 398.
Publication date: 19 October 2009, *http://www.biosciences.elewa.org/JAPS*; **ISSN 2071 - 7024**

Table 3. Environmental and production system descriptors used as independent variables in a multiple regression analyses of soil N supplying capacity.

Agro-ecological zone (AEZ)	Toposequence level (TOP)	Soil texture (STX)	Land Use Intensity (LUI)
Forest: >270 days LGP (length of growing period – FAO, 1982).	**Upland** with a mean annual groundwater table below 1.2 m	**Sand**: comprising textural classes S, lS and sL;	**Extensive**: >4 years of fallow, 1 year of cropping (forest); <4 consecutive years of cropping before fallow (savanna)
Savanna: 180 – 270 days LGP; sites with both monomodal and bimodal rainfall distribution patterns	**Lowland** with seasonally flooded valley bottom land	**Clay**: comprising textural classes L, sC, lC and C	**Intensive**: <3 years of fallow, 1-2 years of cropping (forest); >4 consecutive years of cropping before fallow (savanna)

2.5.2. Soil N dynamics in major production systems of the forest zone

A detailed investigation of soil N dynamics was conducted in 1997 in the bimodal forest zone, near the village of Guessihio–Gagnoa (Equatorial forest), to quantify N mineralization and losses at various toposequence levels in two production systems differentiated by their cropping intensity. One site was located on a toposequence which had been cropped two years before (intensively), the other site had been under 14 years of secondary forest fallow. In the field, six subplots of 2 x 4 m were installed in the upland, hydromorphic zone and lowland at each site. The experimental design was a strip-split-plot, using 5 replications. After land clearing by slash-and-burn, subplots were either kept bare or dribble seeded to rice at 15 x 15 cm spacing Soils were sampled for N_{min} and bulk density and soil moisture at weekly intervals, from the 24th of January to the 4th of April, and on monthly intervals (May to August) after land clearing. Rice biomass samples were taken at monthly intervals on 0,25m^2 and analyzed for N uptake.

4. RESULTS AND DISCUSSION

4.1 Soil N mineralization potential

The soil N mineralization from incubation studies is commonly used as an indicator of soil mineral N supplying capacity (Stanford & Smith, 1972). In different experiments, widely differing depths, weights of soil, and sizes of incubation container have been used (Egelkraut *et al.*, 2003). A review of publications on incubation studies showed large variability in the mineralization potential of rice soils across the world (Khera *et al.*, 1999). In this study, the predominant factor which influenced soil N mineralization was soil particle size, which was agro-ecology dependent. Forest rice soils (mostly sandy) showed the highest N mineralization; and the largest part of this soil N was supplied earlier in forest soil than in savanna soils, particularly in the upland ecosystem (**Error! Reference source not found.**). This is likely to be due to the appreciable soil-aeration in this environment, as organic matter transformation via ammonium into nitrate is an aerobic process. Upland soils are usually better aerated than other segments of the toposequence, namely the hydromorphic zone and the lowland. Egelkraut et al. (2003) found that the clay concentration in surface soil was positively correlated with aerobic N mineralization in a Georgia coastal plain field (Carbon sequestration by clay). Thus, the large ammonification found in rainfed lowland soils of the savanna is probably the result of a combination of high organic matter content and a relatively good aeration. It appears that the organic matter content of the soil is the main factor contributing to the intensity of N_{min} turn-over, provided there is good aeration. Gigou, (1995) related this higher N mineralization in the

Journal of Animal & Plant Sciences, 2009. Vol. 4, Issue 3: 384 - 398.
Publication date: 19 October 2009, http://www.biosciences.elewa.org/JAPS; **ISSN 2071 - 7024**

forest than in the savanna zone to the higher organic matter content, resulting from the density of biomass and reduced lixiviation processes. Intensively used lowland soils mineralized less N than upland soils. This could be the result of a deficiency of the substrate (organic matter), the absence of actors (micro-organisms) and/or the presence of another bio-physical factor which reduced the mineralization in lowland soils.

Table 4. Net N mineralization of upland sandy soils and lowland clay soils under different intensities of land use irrespective of agroecological zone.

Toposequence (texture)	**Land use intensity**	**Net N mineralization ($mg.kg^{-1}$)**	
		2 weeks	6 weeks
Upland (sand)	Intensive	5	8
	Extensive	5.1	10.7
		ns	**
Lowland (clay)	Intensive	2.2	3.6
	Extensive	6.9	12.3
		*	*

The acid pH of Ivorian forest soils may have protected the organic matter from microbial decomposition and reduced the N_{min} supply. Consequently, pH variations resulting from the flooding of the soil have probably created favorable conditions for N mineralization. Flooding is known to be a suitable method for the establishment of a bicarbonate buffer which will neutralize the pH of the soil solution (Ponnamperuma, 1978). Sahrawat (1982) reported low mineralization in tropical soils with pH below 6 but, on the other hand, N mineralization was described at pH 5.3 in sandy soil poor in humus by Bruin *et al.* (1989) during an incubation study with alternative phases of moistening. Bruin *et al.* (1989) also showed that under laboratory conditions the C/N ratio of over 13 in an unfertilized Sahelian soil can lead to a lag in N mineralization.

Soil exhaustion as a result of intensified land use in different agro-ecological zones significantly reduced net N mineralization. The intensive use of land for crop production decreases the soil organic N content, thus the net N supply capacity (Buresh *et al.*, 1993b). Van Reuler and Janssen (1993) found a decrease of nutrient fluxes, particularly soil mineral nitrogen, in shifting cultivation of the Ivorian forest zone where mineralizable N reserve in soil was low because of intensive land-use. Krul *et al.*, (1982) previously reported that a low net N mineralization was the result of a low mineralizable N content in soils. As soil nutrient mineralization rates are also controlled by the specific character of the vegetation occupying a site, plant-soil-plant feedback loops in agricultural systems will influence the N dynamics over time.

3.2. Soil N mineralization and dynamics in the major rice based cropping systems

A soil N_{min} peak was found during the DWT (shaded in gray), approximately 2 – 3 weeks after the first rainfall event of the rainy season (Birch, 1958) – (**Error! Reference source not found.**). This flush was of short duration as reported elsewhere (Warren *et al.*, 1997) probably due to N losses by leaching, denitrification, volatilization and uptake by plants (Greenland, 1958; Wild, 1972; Ikerra *et al.*, 1999). Soil moisture is an important factor in the mineralization and loss of soil N_{min} (Aulakh *et al.*, 2000). Wetting of the soil after the dry season results in an increase in available N as earlier reported by several researchers (Semb & Robinson, 1969; Wong & Nortcliff, 1995; Warren *et al.*, 1997). This is attributed to an increase in net N mineralization upon moistening of dry soils (Birch, 1960). According to Ikerra *et al.* (1999), the magnitude of this N flush depends on the organic matter content of the soils and the length of the preceding dry period. The N mineralization peak occurred later in the savanna agro-ecological zone as compared to the forest zone, and depended on the N supply capacity of the soil and the rainfall intensity.

Journal of Animal & Plant Sciences, 2009. Vol. 4, Issue 3: 384 - 398.
Publication date: 19 October 2009, http://www.biosciences.elewa.org/JAPS; **ISSN 2071 - 7024**

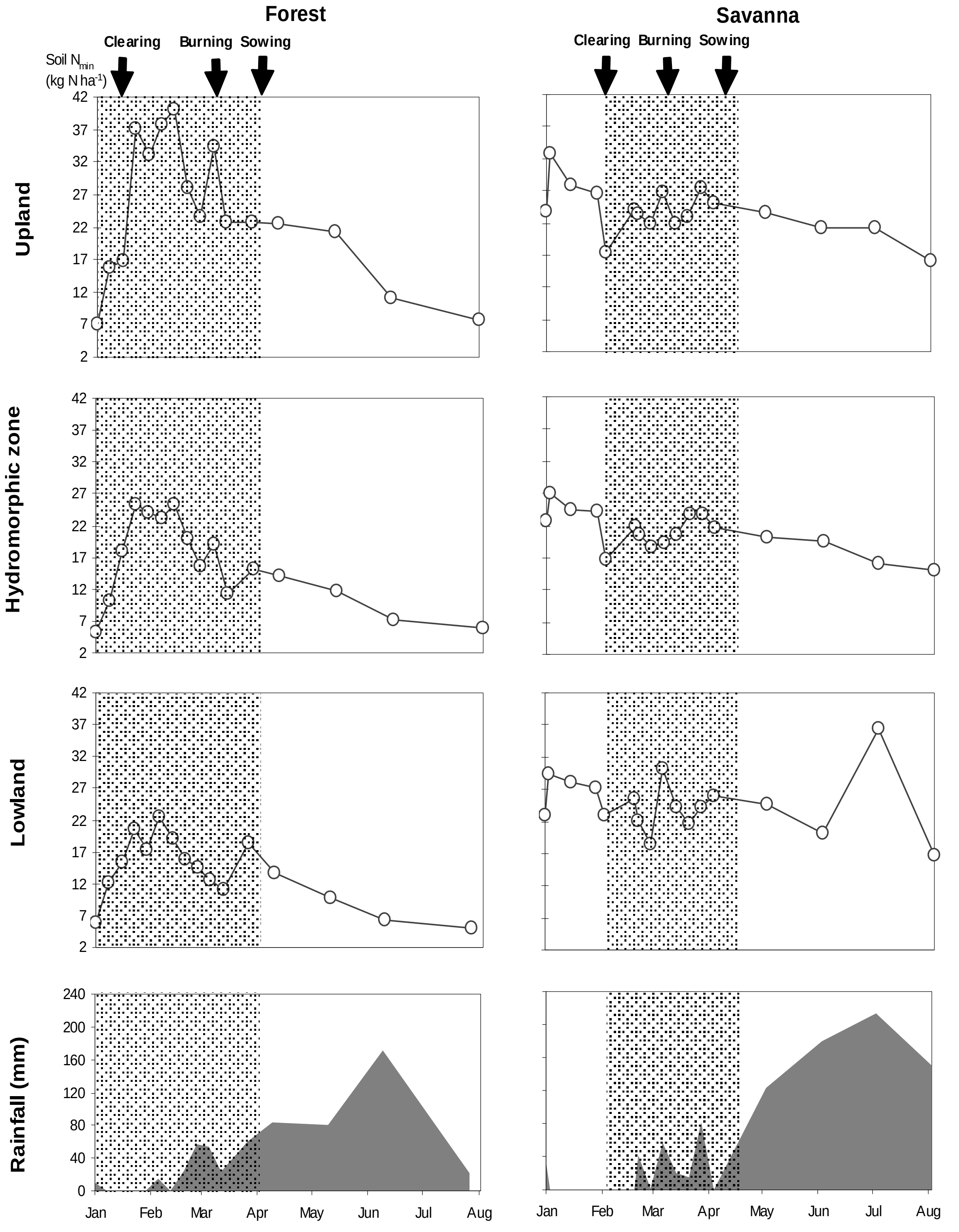

Figure 1. Soil N_{min} (ammonium + nitrate) dynamics from the onset of the rainy season to the end of the cropping period in upland, hydromorphic zone and lowland of the forest and the savanna agroecological zones of Côte d'Ivoire. The Dry –wet season transition is shaded in gray.

Journal of Animal & Plant Sciences, 2009. Vol. 4, Issue 3: 384 - 398.
Publication date: 19 October 2009, *http://www.biosciences.elewa.org/JAPS*; **ISSN 2071 - 7024**

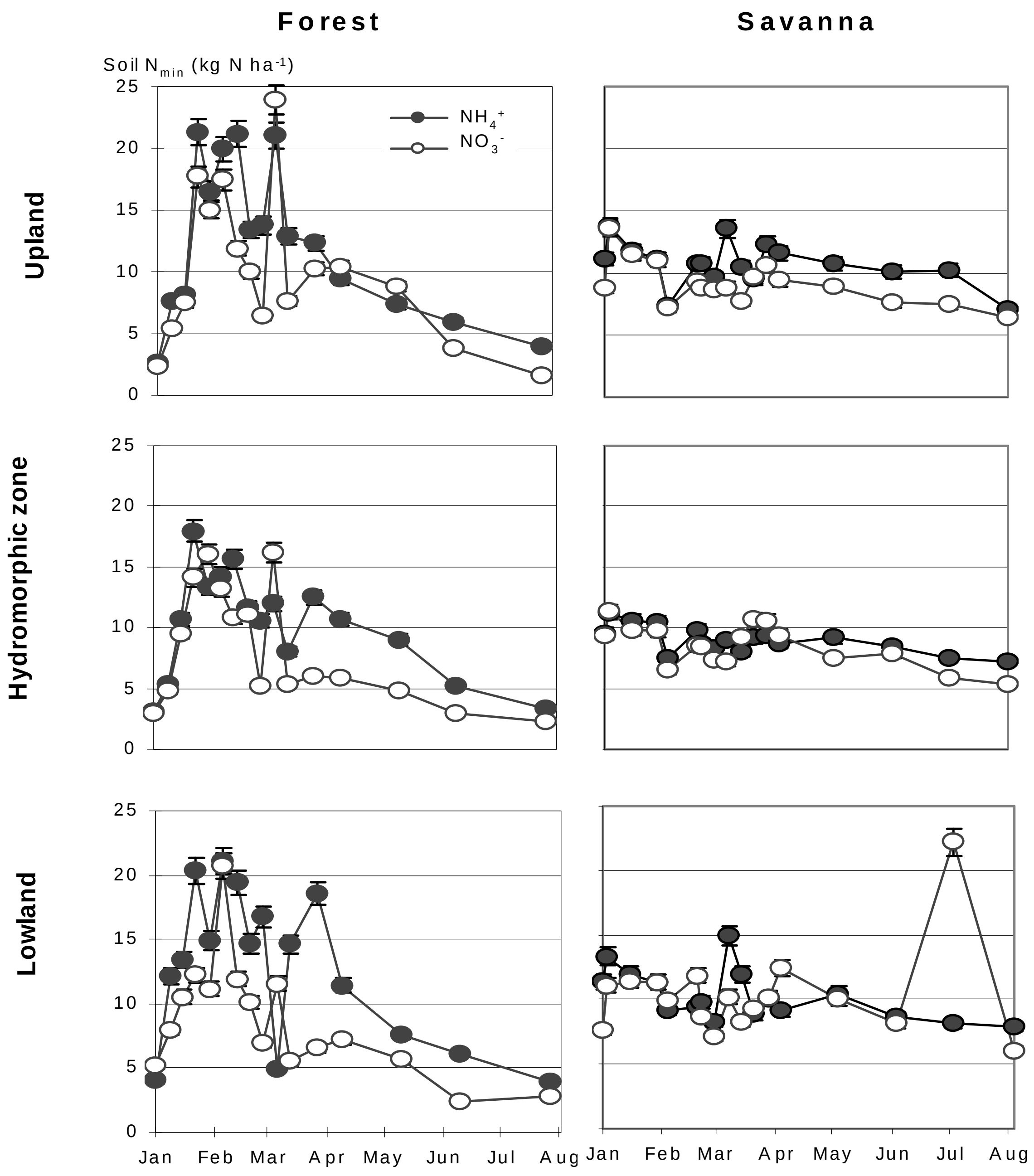

Figure 2: Soil N_{min} dynamics differentiated into ammonium and nitrate at the three toposequence positions of the forest and the savanna agroecological zones of Côte d'Ivoire.

Journal of Animal & Plant Sciences, 2009. Vol. 4, Issue 3: 384 - 398.
Publication date: 19 October 2009, http://www.biosciences.elewa.org/JAPS; **ISSN 2071 - 7024**

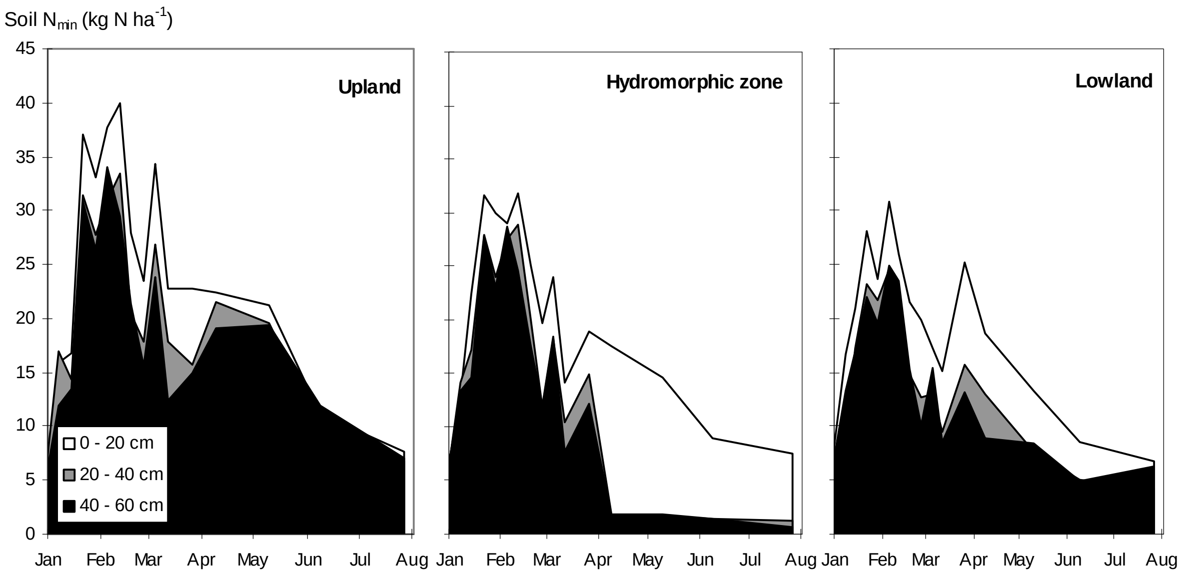

Figure 3: Dynamics of soil N_{min} (NH_4-N + NO_3-N) in different soil profile depths (0-20; 20-40; 40-60 cm) in upland, hydromorphic and lowland soils of the forest zone during the dry-to-wet season transition period (Côte d'Ivoire).

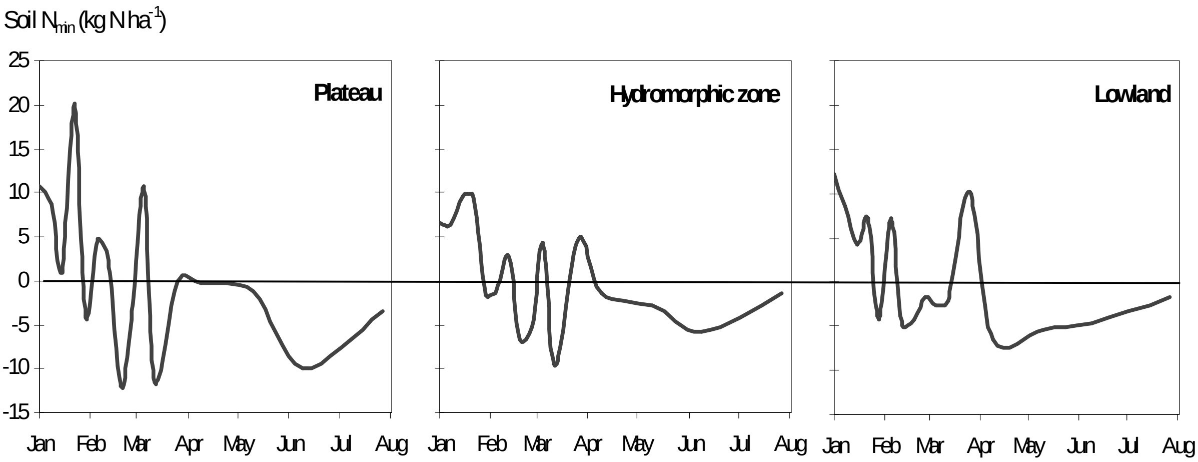

Figure 4. Changes in soil N_{min} (ammonium and nitrate) based on subtraction of measured values at weekly intervals.

The *on-farm* N mineralization in the present study was highest in the forest zone, confirming the results obtained in the incubation study described in the previous section. Pieri (1992) and Gigou (1992) have acknowledged the low N fertility of savanna soils compared to forest soils in characterization studies implemented in the north of Côte d'Ivoire.

Ammonium and nitrate accumulations in soils are successive results of the oxidation of organic matter. The two forms of N were found in relatively equal proportions in the soils of the different agro-ecological zones covered by this study (Figure 2). Contrary to the findings of Engels *et al.* (1996) and Phongpan and Mosier (2003) showing that nitrate (NO_3-N) is the dominant form of mineral N in soil during the dry season, ammonium was the predominant N form in our experiments during both the dry and the subsequent wet season

(Figure 2). The reductive conditions of the rainy season were favorable for the accumulation of ammonium (NH_4-N) which was the predominant N-form in the lowland soils of the forest zone. This may be because this form of N is sorbed onto soil particles and, therefore less mobile than nitrate.
Humus-rich topsoil is known to be the center of microbial activity and therefore N mineralization (Alexander, 1971; Delmas *et al*., 1997). Engels *et al.* (1996) reported that an N flush occurs during DWT in sandy Alfisols with highest quantities of N being observed initially in the topsoil (0-20 cm) – (Figure 3). The rapid decline of inorganic N observed early in the topsoil of both agroecological zones in the rainy season may be due to N movement down the slope and the soil profile, denitrification and microbial immobilization rather than plant N uptake since the crop demand for N at this time is low (Sigunga *et al*., 2002). This soil horizon is shallow in the lowlands of the study sites, where the deep B and C horizons with low organic matter contents are found in only a few centimeters depth. This poor availability of organic matter may explain the low N mineralization in the lowland soils, particularly of the forest zone.

Cissé (1982) reported that the N mineralization in soils continues until the exhaustion of the available N reserve. Field activities (plowing, slash and burn, sowing) boosted the N mineralization in soils, particularly in the lowland ecosystems. The clearing of natural vegetation to open new land for food crop production exacerbates N movements and losses (Buddenhagen, 1978). Therefore, N mineralization showed alternate increases (with field activity) and decreases with rain (Figure 4).

3.3. N_{min} losses from agricultural soils

The appreciable amounts of soil Nitrate (NO_3-N) which accumulated at the onset of the rainy season are prone to losses by lixiviation and/or denitrification before the onset of the cropping period. The high apparent losses of NO_3-N are attributable to denitrification and bypass flow. The resulting decrease in soil N_{min} was related to rainfall intensity and was predominant during the period before crop establishment. In the present experiments, approximately 2/3 of the total measured N_{min} was lost from the soil during DWT. In India, Sadanandan and Mahapatra (1973) found N losses under different land management ranging from 77 to 308 kg N ha^{-1} before the start of the cropping activities with N losses being largest in the lowland ecosystem. Bognonkpe and Becker (2000) and Pande and Becker (2003) found that N losses are likely to be dominated by nitrate leaching in well-draining sandy soils and by denitrification in saturated heavy-textured lowland soils. Buresh and DeDatta (1991) and Wulf *et al.* (1999) reported that the extent of N losses and the prevailing loss mechanisms depend on the amount of soil nitrate, the intensity of the rain and the flow of water in the soil profile which are generally high at the onset of the rainy season. It is, therefore suggested that N losses from flooded lowland soils may be at least partly due to denitrification of NO_3-N produced by nitrification of ammonium NH_4-N, particularly during periods of alternating drying and wetting of the soil (Buresh *et al*., 1993a; Sigunga *et al*., 2002). Pande *et al*. (2003) described an initial nitrate accumulation and the subsequent nitrate loss under field conditions in Nepal to a gradual rising of the soil moisture during DWT. We found that this relation between the increase in soil moisture and the decrease in N is highest in the hydromorphic zone of the valley (sandy soil texture). Only small quantities of N_2 and N_2O are reportedly emitted from upland soils (Schwarz, 1994), where lixiviation seems to be the major N loss mechanism (Engels *et al*., 1996).

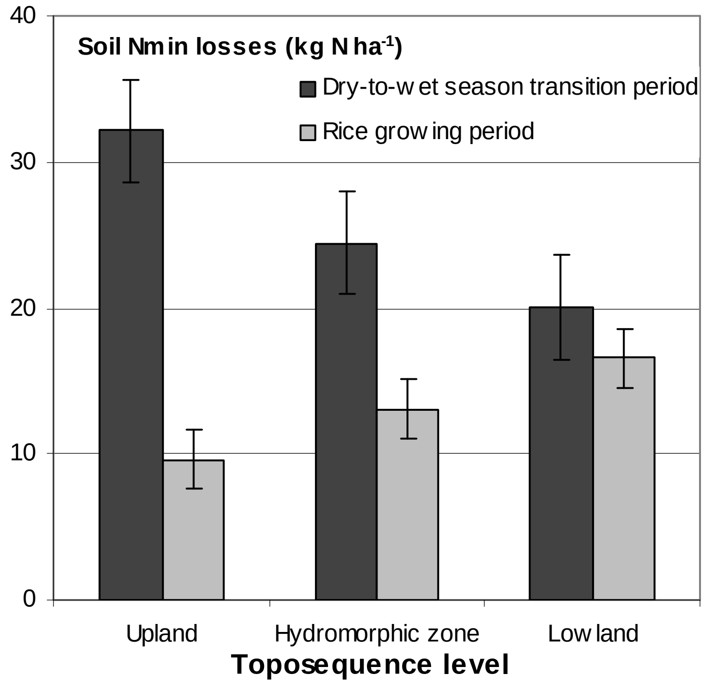

Figure 5: Cumulative soil N_{min} losses (integral of the negative soil N_{min} values from as differentiated by season (DWT and rice growing period) and toposequence position (upland, hydromorphic zone and lowland).

5 CONCLUSION

Studying soil mineral N dynamics in tropical soil of the humid zone of West Africa has highlighted the mineralization potential of the soil and the high seasonality of this nutrient. N_{min} content increased at the end of the transition period and rapidly decreased with the establishment of the rainy season before crop installation. This work confirmed an inherent problem in managing soil native N originating from mineralization of organic materials as it normally accumulates at the beginning of the season, well before peak demand by crops. This situation has strong implications on N management in small systems in which external N supplies are limited in quantity and crops often rely on native soil fertility. The downslope movement of nitrates with water may benefit lowland crops. In that case, promising options in increasing native N use by food crop may include (1) improved fallow cover crop on the slope during the transition period, (2) retention of N at the valley fringe with deep rooting strip of trees, and (3) pre-rice "nitrate catch crop" in the rice niche of lowland during the transition period.

Acknowledgements: We gratefully acknowledge WARDA-Côte d'Ivoire for logistical support and allowing use of its key sites for survey and measurements reported in this paper. We thank Alexander Engels for the soil analysis and most helpful advice. The work is an output of the Nitrogen project funded by GTZ foundation - Germany.

6 REFERENCES

Alexander M: 1971. Microbial ecology. Wiley. New York.

Andreini MS and Steenhuis TS: 1990. Preferential paths of flow under conventional and conservation tillage. Geoderma 46: 85-102.

Aulakh MS, Tejinder SK and John WD: 2000. Mineralization and denitrification in upland, nearly saturated and flooded subtropical soil. Biol. Fertil. of Soils 31: 162-167.

Barraclough D, Jarvis SC, Davies GP and William J: 1992. The relation between fertilizer nitrogen applications and nitrate leaching from grazed grassland. Soil Use and Management 8: 51-56.

Becker L and Diallo R: 1992. Characterization and classification of rice agro-ecosystems in Côte d'Ivoire. WARDA. Bouaké, Côte d'Ivoire.

Birch HF: 1958. The effect of soil drying on humus decomposition and nitrogen availability. Plant and Soil 10: 9-31.

Birch HF: 1960. Nitrification in soils after different periods of dryness. Plant and Soil 12: 81-96.

Bognonkpe JPI and Becker M: 2000. Native soil N dynamics and use efficiency by lowland rice as a function of slope management. in Deutscher Tropentag. Müllerbader Press. University of Hohenheim.

Bruin Bd, Vries FWTPd, Broekhoven LWV, Vertregt N and Geijn SCVd: 1989. Net nitrogen mineralization, nitrification and CO_2 production in alternating moisture conditions in an unfertilized low-humus sandy soil from Sahel. Plant and Soil 113: 69-78.

Buddenhagen IW: 1978. Rice ecosystems in West Africa. in Buddenhagen I.W. and Persley G.J. (eds.). Rice in Africa. Academic Press, London, U.K.

Buresh RJ, Castillo EG and Dedatta SK: 1993a. Nitrogen Losses in Puddled Soils as Affected by Timing of Water-Deficit and Nitrogen-Fertilization. Plant and Soil 157: 197-206.

Buresh RJ and DeDatta SK: 1991. Nitrogen dynamics and management of rice-legume cropping systems. Advances in Agronomy 45: 1-59.

Buresh RJ, Garrity DP, Castillo EG and Chua TT: 1993b. Fallow and Sesbania Effects on Response of Transplanted Lowland Rice to Urea. Agronomy Journal 85: 801-808.

Cissé IB: 1982. La regénération des terrains dégradés. in Vries F.W.T.P.d. and Djitèye M.A. (eds.). La productivité des pâturages sahéliens. Agronomy Research Report. Pudoc, Wageningen. pp. 440-449.

DeDatta SK and Buresh RJ: 1989. Integrated nitrogen management in irrigated rice. Advances in Soil Sciences 10: 143-169.

Delmas R, Serça D and Jambert C: 1997. Global inventory of NOx sources. Nutrient Cycling in Agroecosystems 48: 51-60.

Egelkraut TM, Kissel DE, Cabrera ML and Adkins W: 2003. Predicting N mineralized in a Georgia Coastal Plain field. Nutrient Cycling in Agroecosystems 66: 1-12.

Engels A, Becker M and Giesen NVd: 1996. Managing native soil nitrogen on the continuum toposequence. WARDA. Bouaké, Côte d'Ivoire. pp. 51-52.

Franzluebbers AJ, Hons FM and Zuberer DA: 1995. Tillage and Crop Effects on Seasonal Dynamics of Soil Co2 Evolution, Water-Content, Temperature, and Bulk-Density. Applied Soil Ecology 2: 95-109.

George T, Ladha JK, Buresh RJ and Garrity DP: 1993. Nitrate Dynamics During the Aerobic Soil Phase in Lowland Rice-Based Cropping Systems. Soil Science Society of America Journal 57: 1526-1532.

Gigou J: 1992. L'azote dans les systèmes de culture du nord et du centre de la Côte d'Ivoire. in Mulongoy K., Gueye M. and Spencer D.S.C. (eds.). Biological nitrogen fixation and sustainability of tropical agriculture. IITA. Ibadan. pp. 377-393.

Gigou J: 1995. La dynamique de la matière organique et de l'azote dans les sols tropicaux des zones humides et tres humides. in CIRAD and Coopération M.d.l. (eds.). Fertilité du milieu et stratégies paysannes sous les tropiques humides. France. pp. 194-206.

Greenland DJ: 1958. Nitrate fluctuations in tropical soils. Journal of Agricultural Science 50: 82-92.

Hadegorn F, Steiner KG, Sekayange L and Zech W: 1997. Effect of rainfall pattern on nitrogen mineralization and leaching in a green manure experiment in south Rwanda. Plant and Soil 195: 365-375.

Hendershot W, Lalande H and Duquette M: 1993. Soil reaction and exchangeable acidity. in Carter M. (ed.). Soil sampling and methods of analysis. Lewis Publishers. Ann Arbor. pp. 141-145.

Ikerra ST, Maghembe JA, Smithson PC and Buresh RJ: 1999. Soil nitrogen dynamics and relationships with maize yields in a gliricidia-maize intercrop in Malawi. Plant and Soil 211: 155-164.

Khera TS, Aulakh MS and Doran JW: 1999. Significance of soil depth on nitrogen transformations in flooded and nonflooded systems under laboratory conditions. Nutrient Cycling in Agroecosystems 54: 209-213.

Koelliker JK and Kissel DE: 1988. Chemical equilibria affecting ammonia volatilization. in Bock B.R. and Kissel D.E. (eds.). Ammonia volatilization from urea fertilizers. NDFC, TVA, Muscle Shoals. AL. pp. 37-52.

Krul JM, Vries FWTPd and Traoré K: 1982. Les processus du bilan d'azote. in Vries F.W.T.P.d. and Djitèye M.A. (eds.). La productivité des pâturages sahéliens. Pudoc. Wageningen, The Netherlands. pp. 226-246.

Mazzarino MJ, Bertiller MB, Sain C, Satti P and Coronato F: 1998. Soil nitrogen dynamics in northeastern Patagonia steppe under different precipitation regimes. Plant and Soil 202: 125-131.

Narain P, Singh RK, Sindhwal NS and Joshie P: 1997. Agroforestry for soil and water conservation in the western Himalayan Valley Region of India 1. Runoff, soil and nutrient losses. Agroforestry Systems 39: 175-189.

Page AL, Miller RH and Keeney DR: 1982. Methods of soil analysis. ASA, SSSA Publisher. Madison, Wis. p. 1159.

Pande KR and Becker M: 2003. Seasonal soil nitrogen dynamics in rice-wheat cropping systems of Nepal. Journal of Plant Nutrition and Soil Science 166: 499-506.

Pande KR, Shah SC and Becker M: 2003. Managing seasonal soil N Dynamics in rice-wheat cropping systems of Nepal. in International Research on Food Security, Natural Resource Management and Rural Development. Centre for Tropical and Subtropical Agriculture and Forestry (CeTSAF). University of Göttingen. p. 258.

Phongpan S and Mosier AR: 2003. Effect of crop residue management on nitrogen dynamics and balance in a lowland rice cropping system. Nutrient Cycling in Agroecosystems 66: 133-142.

Pieri CJMG: 1992. Fertility of soils. A future for farming in the West African savanna. Springer-Verlag. Berlin Heidelberg, New York. p. 348.

Ponnamperuma FN: 1978. Electrochemical changes in submerged soils and the grooth of rice. in IRRI (ed.). Soils and rice. IRRI. Manilla. pp. 421-441.

Sadanandan N and Mahapatra IC: 1973. Studies in multiple cropping - balance sheet of nitrogen in various cropping patterns. Indian Journal of Agronomy 18: 323-327.

Sahrawat KL: 1982. Nitrification in some tropical soils. Plant and Soil 65: 281-286.

Sanginga N, Vanlauwe B and Danso SKA: 1995. Management of Biological N-2 Fixation in Alley Cropping Systems - Estimation and Contribution to N Balance. Plant and Soil 174: 119-141.

Schlichting E, Blume HP and Stahr K: 1995. Bodenkundliches Praktikum. Blackwell. Wien. p. 295 p.

Schnabel RR and Stout WL: 1994. Denitrification Loss from 2 Pennsylvania Floodplain Soils. Journal of Environmental Quality 23: 344-348.

Schwarz J: 1994. quantitative Erfassung von Denitrifikationsverlusten auf einer mehrjährig güllegedügten Weidelgrasfläche (*Lolium perenne* L.) mit Hilfe der Acetylen-Inhibierungstechnik (AIT). Giessen. Giessen.

Semb G and Robinson JBD: 1969. The natural nitrogen flush in different arable soils and climates in East Africa. East African Agriculture and Forest Journal 34: 350-370.

Sigunga DO, Janssen BH and Oenema O: 2002. Effects of improved drainage and nitrogen source on yields, nutrient uptake and utilization efficiencies by maize (*Zea mays* L.) on Vertisols in sub-humid environments. Nutrient Cycling in Agroecosystems 62: 263-275.

Smith CK, Gholz HL and Oliveira FD: 1998. Soil nitrogen dynamics and plant-induced soil changes under plantations and primary forest in lowland Amazonia, Brazil. Plant and Soil 200: 193-204.

Stahl L, Nyberg G, Hogberg P and Buresh RJ: 2002. Effects of planted tree fallows on soil nitrogen dynamics, above-ground and root biomass, N-2-fixation and subsequent maize crop productivity in Kenya. Plant and Soil 243: 103-117.

Stanford G and Smith SJ: 1972. Nitrogen mineralisation potentials of soils. Soil Sci. Soc. Am. Proc. 36: 465-472.

Van Reuler H and Janssen BH: 1993. Nutrient Fluxes in the Shifting Cultivation System of South-West Côte d'Ivoire. Plant and Soil 154: 169-177.

Warren GP, Atwal SS and Irungu JW: 1997. Soil nitrate variations under grass, sorghum and bare fallow in semi-arid Kenya. Experimental Agriculture 33: 321-333.

Wild A: 1972. Nitrate leaching under bare fallow at site in northern Nigeria. Journal of Soil Science 23: 315-324.

Wong MTF and Nortcliff S: 1995. Seasonal fluctuations of native available N and soil management implications. Fertilizer Research 42: 3-26.

Wulf S, Lehmann J and Zech W: 1999. Emissions of nitrous oxide from runoff-irrigated and rainfed soils in semiarid north-west Kenya. Agriculture Ecosystems & Environment 72: 201-205.