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Diagnostic of mineral deficiencies and interactions in upland rice yield declining on foot slope soil in a humid forest zone

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Key words: Rice yield stabilization, soil nutrient deficiency, rice mineral nutrition, phosphorus, humid forest.

Abstract

Haphazardly fertilization can impaired rice production inducing yield declining in continuous cropping even with high input management. To sustain upland rice production on foot slope ferralsol in a humid forest zone of West Africa, soil deficient nutrients were identified in omission trial concerning N, P, K, Ca, Mg and Zn –fertilizers in Côte d'Ivoire from 2003 to 2005. The relationship between rice grain yield and nutrient contents in soil and above ground organs were also determined. Significant (P = 0.05) yield depressions were observed for P and K exclusion treatments as deficient nutrients in the first (P) and second (PK) years. Chaminade index revealed also secondary soil deficiency for Mg and N in the subsequent year with a decreasing trend from 2003 to 2005 [N (85%, 104%, 78%), P (63%, 51%, 56%), K (95%, 44%, 62%) and Mg (87%, 85%, 64%)] likely to grain yield declining. Antagonistic relationships in rice mineral nutrition, soil leaching and acidification as well as increasing of Mn availability and soil nutrient deficiencies were main factors of yield declining. These processes were discussed to be depending on the initial soil fertility level that was somewhat differing in savanna ecology. Application of P, PK and PKNMg fertilizers were recommended for three years cropping respectively. Practice of minimum tillage and maintaining high ratio of Ca: Mg was suggested for reinforcing the yield stabilization.

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Introduction

Rice (*Oryza sativa* L.) is one of the major food crops in the farming systems of sub-Sahara Africa, with an estimated area of about 6.4 million hectares. The production was 10 million tons annually accounting for 62 % from West Africa (Jones, 1999). About 80 % of rice production surface in West Africa accounted for upland rainfed rice cultivation, especially in humid forest ecology (Audebert *et al.*, 1999).

Most of the upland rice in West Africa is produced in slash-and-burn systems inthe humid forest zone (WARDA, 1999). With increasing land shortages, the length of fallow between periods of cultivation has declined from 12 years in the 1980s to less than three years at present, with permanent cultivation emerging in some high population areas (Becker and Assigbe, 1995). This intensification of land use in the low-input systems causes declining yield levels, which are associated with a reduced soil N supplying capacity, more weed pressure and widespread P deficiency on the predominant acid Ultisols (Becker and Johnson, 1998, Becker and Johnson, 2001). Thus, the yield declining in continuous cropping is a consequence of soil fertility depletion for about 51% of associated factors but, it also occurred even after applying inorganic fertilizers in high input management as well (Pieri, 1986). This observation could be related to the effect of unknown limiting factor and/or unbalanced soil nutrient contents resulting to haphazardly practice of fertilization. Thus, we suggested the diagnostic of soil nutrient levels and mineral interactions in a site specific fertilizer management concept to overcome yield declining in intensive rice cropping.

In sub-humid ecology of West Africa (Senegal), NPK and Ca associated to legume cultivation were recommended to prevent yield declining in intensified rice cropping (Fauck, 1956) likewise the recommendation of NPK and Zn in the derived savanna of West Africa (Koné et al., 2009a). In the humid forest zone of West Africa,

the used of phosphate rock and legume were recommended to maintain rice yield of about 3 tha^{-1} in continuous cropping (Cuero, 2006). Therefore, up to date, no fixed fertilizer strategy was identified for rice yield stabilization in West Africa. The lack of consideration of the effect of topographic variation in soil fertility can account for this. Indeed, topographic variation can influenced considerably the soil fertility, especially, in ferralsol environment (Bognonkpe and Becker, 2009, Moormann *et al.*, 1977, Koné *et al.*, 2009b). Furthermore, except for N and P deficiencies (Takow *et al.*, 1991), few was known about K, Ca, Mg, and Zn effects in upland rice production of the humid forest zone in Africa. Although, these nutrients are also required for rice production (Roy *et al.,* 2006). Therefore, the study of soil nutrient deficiencies including N, P, K, Ca, Mg and Zn at least, is need in different topographic sections to generate efficient strategy of fertilizer management for continuous rice cropping. The knowledge of nutrients removal by rice plant is also needed for this purpose.

The present study was conducted on ferralsol of foot slope in the humid forest zone of Côte d'Ivoire, to assess the effects of N, P, K, Ca, Mg and Zn deficiencies on rainfed rice grain and straw yields as well as nutrient concentration in rice leaf, straw and grain. The aim was i) to identify deficient nutrients in soil for rice production, ii) how nutrient deficiency can affect rice mineral nutrition and iii) how to stabilize rice grain yield in intensive cropping? The overall goal is to improve the sustainability of upland rice cropping in humid forest ecosystem of West Africa, especially in the foot slope position that is less exposed to drought stress.

Materials and methods

Experimental site

The experiment was an on-farm study carried out at Guéssihio (6°06 N, 6° 00 W, 180 m elevation) in the Centre Western part of Côte d'Ivoire, about ten kilometers from Gagnoa. It is a humid forest zone with a bimodal rainfall pattern.

The recorded annual rainfall amounts were 1555 mm, 1349.9 mm and 1656.6 mm in 2003, 2004 and 2005 respectively (Fig. 1). During the cropping period (March – June), the rainfall of 849.8 mm (2003), 778.4 mm (2004) and733.1 mm (2005) were recorded. The experiment was laid on a three years bush fallow land previously dominated by *Chromoleana Odorata*. Studied soil was Hyper Dystric Ferralsol (High weathered soil rich in iron oxide and hydroxide) located on the foot slope of a plateau. It was a deep (> 1m) sandy-clayed soil having a moderate gravel content of less than 30 % within the 60 cm depth. The pH (water) was 5.70±0.47 and the exchangeable cation capacity-ECC was 3.20±2.44 cmol. kg^{-1}. The landscape has gentle slope estimated to 2% – 5 %.

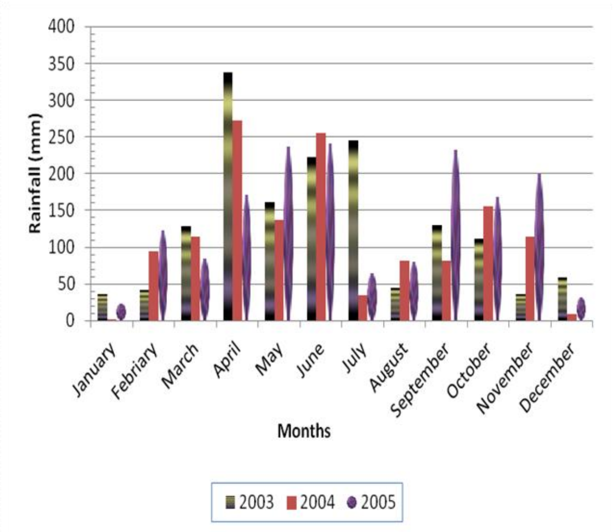

Fig. 1. Rainfall recorded in 2003, 2004 and 2005.

Experiment layout

The land was cleaned and tilled manually every year (2003, 2004 and 2005) in March. Fertilizer composed of nitrogen-N (urea), phosphorus-P (super triple phosphorus), potassium-K (potassium chloride), calcium-Ca (calcium sulfite), magnesium-Mg (magnesium sulfite) and zinc-Zn (zinc sulfite) were applied as complete fertilizer (Fc) treatment and a specific nutrient was excluded from Fc for the other treatments (Fc-N, Fc-P, Fc-K, Fc-Mg, Fc-Ca and Fc-Zn). A zero fertilizer treatment (0) was set as the control treatment (check).

As basal fertilizers, the rates of 30 kg N ha^{-1}, 100 kg P ha^{-1}, 50 kg K ha^{-1}, 50 kg Ca ha^{-1}, 50 kg Mg ha^{-1} and 10 kg Zn ha^{-1} were applied depending on treatment. The rice variety WAB 56-104 (*Oryza sativa* L.) was sown per hill of three grains spaced by 20 cm in a randomized complete blocks design. Each treatment was set in a micro-plot of 3 m × 5 m with 0.5 m as inter-plot space in a block (replication). Four replications spaced by 1.5 m were considered for a total of 32 micro-plots. At rice tillering and panicle initiation stages, additional applications of 35 kg N ha^{-1} were applied in all treatments except for treatment-0. Two manual weeding were done at 21 and 45 days after rice emergence.

Soil and plant sampling and analyses

Before the experiment, in 2003 and 2004, the soil was sampled in 0 – 20 cm and 20 – 40 cm depths of each micro plot using an augur. The samples were sun-dried, broken and sieved (2mm) before laboratory analyses. Soil pH(water) and its contents in organic carbon-C (Walkley-Black), total nitrogen-N (Kjeldahl) and available-P (Bray I) were determined. Furthermore, 1 N NH4OAc (pH 7.0) was use for K, Ca, and Mg analysis and Zn (perchloric acid), Mn (hydroquinone extraction) as well as Fe (EDTA) contents were determined. In the first year of cropping (2003), two/third of the matured leaves was sampled by plant in a $1m^2$ at flowering period. Samples of grain and straw were also taken in 2003 after harvest. Leaf, straw and grain concentrations in N, P, K, and Mg were analyzed. Laboratory analyses were done following the methods described by TSBF (Anderson and Ingram, 1993).

Yield data collection

At grain maturity stage (about 100 days after emergence), rice was harvested in 8 m^2 of each micro-plot excluding the two seeding lines from the border. After threshing, the grains were sun-dry and sieved. Then, grain moisture content was measured before weighting. The grain yield (GY) was determined for corresponding weight for standard moisture of 14%.

The straw was directly weighted after drying and the straw yield (SY) was determined as it was. The harvest indice (HI) was also calculated as follows:

$$HI = [GY/(GY + SY)] \times 100 \qquad (1)$$

Chaminade index-CI (1960) was calculated for each treatment (Fc-x) in relation to the complete fertilizer treatment (Fc) as the ratio of the respective grain yields (GY):

$CI=[GY_{(Fc-x)}/GY_{Fc}]*100$ (2)

Statistical analysis

Mean values of grain yield-GY, straw yield-SY, and harvest index-HI as well as for nutrient contents in plant organs (leaf, straw and grain) were generated and separated by Fischer least significant difference test (lsd) with α defined at 0.05, by analyze of variance-ANOVA procedure. Nutrient balance in soil was calculated by mixed model analysis using the difference of the mean value between 2003 and 2004. A regression test was also performed to generate the characteristic of the yield trend across years and Pearson correlation analysis was used to determine the relationship between Grain yield and nutrient concentration in leaf, straw and grain as well as with soil nutrient contents (α was defined at 0.10 for latest analysis). All statistical analyses were performed using the SAS software (Version 10).

Results and discussion

Soil suitability for sustainable rice production

The studied soil was acid (pH= 5.6-5.5) with low content of C (8.75 – 5.6 g kg^{-1}) and Bray I-P (4.94 – 4.03 mg kg^{-1}) in 0 – 20 cm and 20 – 40 cm depths (Table 1). N contents (0.9 g kg^{-1}) were slightly below the threshold value (1 g kg^{-1}) in both soil depths. Soil Zn content (0.88 mg kg^{-1}) was also low in 0 – 20 cm depth but high (1.40 mg kg^{-1}) in the subsoil (20-40 cm). In opposite, soil content in K was high in topsoil (0 – 20 cm) and fall at critical value of 0.14 cmol kg^{-1} in 20 – 40 cm depth. Soil Ca (0.70 cmol kg^{-1}/ 5.40 cmol kg^{-1}), Mg (0.31 cmol kg^{-1}/ 0.21 cmol kg^{-1}), Mn (1.12 cmol kg^{-1}/ 6.59 cmol kg^{-1}) and Fe (133.5 mg kg^{-1}/ 90.16 mg kg^{-1}) contents were suitable respectively in 0 – 20 cm and 20 – 40 cm of soil depth.

However, Mg content in 20 – 40 cm was close to the critical value of 0.20 cmol kg^{-1}. The Exchangeable Cation Capacity-ECC (3.7 cmol kg^{-1} / 2.43 cmol kg^{-1}) values were low in 0 – 20 cm and 20 – 40 cm depths (Table 1). Regarding to these results, soil P and N deficiencies can be suspected with minor attention to K and Zn in continuous rice cropping. However, significant depression of rice grain yield was observed only in treatment Fc-P (1.65 tha^{-1}) below the one of the control-0 (1.94 tha^{-1}) in the first year of the experiment (Table 2). Later in 2004, grain yield was also significantly depressed in treatment Fc-K like it was in Fc-P. These effects were confirmed by the across year mean values of GY. Then, the presuming soil N, K and Zn deficiencies were not reflected by the rice grain yield in 2003, attesting that soil contents for these nutrients were at suitable levels for one year cropping but not enough for soil K, in continuous cropping. Thus, P and K deficiencies appeared to be main soil fertility factors of grain yield declining in the studied agro-ecology while, soil N and P-deficiencies were mentioned by Christianson and Vlek (1991) in savannah ecology. It appears an ecological difference in soil fertility effect affecting the sustainability of agriculture in addition to the species (K, S, Zn and B) specificities as reported by Friessen (1991) and Hanson (1992).

Table 1. Chemical characters in the composite sample of 0 – 20 and 20 – 40 cm depths of soil in 2003.

Chemical characteristics	Value in soil	
	0 – 20 cm	20 – 40 cm
pH water	5.6	5.5
pH_{KCl}	4.5	4.5
C (g kg^{-1})	8.75	5.6
N (g kg^{-1})	0.87	0.90
P (mg kg^{-1})	4.94	4.03
K (cmol kg^{-1})	0.23	0.14
Ca (cmol kg^{-1})	0.70	5.40
Mg (cmol kg^{-1})	0.31	0.21
Zn (mg kg^{-1})	0.88	1.40
Fe (mg kg^{-1})	133.5	90.19
Mn (cmol kg^{-1})	10.12	6.59
ECC (cmol kg^{-1})	3.7	2.43

The depletion of soil organic matter, Ca, and Mg contents as factor of yield depreciation in continuous cropping (Adepetu *et al.*, 1979, Juo and Wilding, 1996, Mokwunye *et al.*, 1996) seems to be function of the soil fertility (treatments) according to nutrient balances (Table 3) as observed in our study. In contrast, significant positive balance of Zn content was observed in 0 – 20 cm for Fc-P (1.40 cmol kg^{-1})

and Fc-K (2.20 cmol kg^{-1}). But no significant change was observed in 20 – 40 cm for Fc-P while, negative and positive balances were accounted for soil Mn (-1.25 cmol kg^{-1}) and Mg (0.09 cmol kg^{-1}) in treatment Fc-K respectively. In fact, continuous cropping can increase soil acidity consecutive to leaching of exchangeable cations (K^+, Ca^{++}, Mg^{++}, Zn^{++}) according to Juo *et al.* (1995). Therefore, inducing the depletion of soil leached nutrient contents resulting a positive balance compared with the precedent cropping year. Whereas, the increasing of soil acidity can enhanced soil extractable-Mn content (negative balance), that can impairs crop growth at certain level (Rorison, 1971).

Therefore, we attest that P and K fertilizers are requested for sustainable upland rice production with limiting tillage in order to reduce nutrient leaching and consequently, the acidification of soil.

Table 2. Grain (GY) and straw (SY) Yields and harvest indice (HI) by treatment in 2003, 2004 and 2005.

	2003			2004			2005			Means		
	GY (t ha^{-1})	SY (t ha^{-1})	HI (%)	GY (t ha^{-1})	SY (t ha^{-1})	HI (%)	GY (t ha^{-1})	SY (t ha^{-1})	HI (%)	GY (t ha^{-1})	SY (t ha^{-1})	HI (%)
Fc	2.62ab	3.47ab	43a	1.66a	1.55b	66a	2.03a	3.23a	38a	2.11a	2.75ab	49a
Fc-N	2.25abc	3.27ab	41a	1.74a	2.49ab	42a	1.59a	2.22bc	41a	1.86ab	2.66ab	41ab
Fc-P	1.65c	3.15ab	34a	0.84bc	2.28ab	26a	1.14a	1.78c	39a	1.21c	2.40bc	33b
Fc-K	2.49abc	3.29ab	44a	0.74c	2.53ab	23b	1.27a	1.86c	41a	1.50bc	2.56ab	36b
Fc-Ca	2.83ab	3.92a	42a	2.07a	2.39ab	48ab	1.71a	3.17a	33a	2.20a	3.16ab	41ab
Fc-Mg	2.29abc	3.35ab	41a	1.33abc	2.72ab	33b	1.30a	2.83ab	32a	1.64abc	2.97ab	35b
Fc-Zn	3.07a	3.58ab	46a	1.63ab	3.42a	32b	1.99a	2.74ab	40a	2.23a	3.25a	39ab
0	1.94bc	2.31b	44a	0.85bc	1.23b	47ab	1.23a	1.65c	42a	1.34bc	1.73c	45ab
Lsd.05	0.91	1.49	12	0.80	1.59	33	0.96	0.63	12	0.61	0.81	12
CV (%)	26	31	20	40	47	57	43	18	23	42	37	38

a, b, c and d are indicating mean values significantly different.

Potential of rice production

According to Chaminade index calculated with the overall grain yield mean values (3 years), the yield was at 57% , 71% , 77% and 88% of the yield obtained in treatment Fc for Fc-P, Fc-K, Fc-Mg and Fc-N respectively (Table 2). Thus, there was moderate P-deficiency while N, K and Mg were at secondary deficiency levels for three years cropping. There was also increasing of Chaminade index from 2003 to 2005 in Fc-N (85%, 104%, 78%), Fc-P (63%, 51%, 56%), Fc-K (95%, 44%, 62%) and Fc-Mg (87%, 85%, 64%) attesting the requirement of P in 2003 while PK and +Mg fertilizer were for 2004 and the subsequent year respectively. Addition of N-fertilizer was necessary only in the third years of cropping. However, nitrogen should be applied at top dressing and panicle initiation stages in minimize N-loss (Agnusdei *et al.*, 2010).

It appeared an increasing of the deficient nutrients spectrum in the course of the study as consequence of leaching and nutrient removal by plant.

In opposite, highest mean values of grain yield were observed for Fc (2.11 tha^{-1}), Fc-Ca (2.20 tha^{-1}) and Fc-Zn (2.23 tha^{-1}) with no significant difference between these treatments. This result imply that Ca and Zn are not necessary for rice cropping in the studied environment while Zn-deficiency in rice production was reported by Koné *et al.* (2011) in West Africa derived savanna zone while PKMg are required in the basal fertilizer.

Our finding reveals Mg-fertilizer as an important component of basal fertilizer for rice production on acidic soil of foot slope regardless to previous knowledge (Sahrawat *et al.*, 1999).

The long-term study in the same ecology with Mali rock phosphate (41- 50% P, 9% - 14% Ca and 1.4% S), including N and K fertilizations, has induced yield declining below three years duration (Koné *et al.*, 2010) below that observed in treatments Fc-Ca, Fc-Zn and Fc in the actual study.

The lack of Mg-fertilizer and the strongest soil acidity (pH = 4.9 vs. 5.6) in the previous study can explained this gap confirming the requirement of Mg for rice production as well as soil acidity management.

Nevertheless, only the treatment Fc-P has significantly affected the straw yield among the treatments involved in grain yield depression (Table 2). No significant effect of Fc-N was also observed for straw yield-SY and the harvest indice-HI.

While, treatments Fc-P, Fc-Mg and Fc-K have reduced significantly the HI up to 33%, 35% and 36% respectively.

Therefore, we attest that P, K, Mg (basal) and N are the important nutrients for rice production on foot-slope soil in humid forest zone of West Africa in that order. As Site Specific Fertility Management data for rice production in the ecology, our result also conforms for the foot slope soil, the recommendation done by WARDA and FAO (2002).

Table 3. Soil nutrient contents balance in 0 – 20 cm and 20 – 40 cm depths after one year (2003) cropping according to treatment.

Soil depth	Treat.	C^{g}	N^{g}	P^{mg}	K^{cmol}	Ca^{cmol}	Mg^{cmol}	Zn^{cmol}	Fe^{mg}	Mn^{cmol}
0-20 cm	Fc	-4	0.14	-2.80	-0.04	-0.67	-0.03	-0.47	-81.2*	-13.25
	Fc-N	2.50*	0.11	2.25	-0.18	-0.22*	0.02	1.38**	-53*	-4*
	Fc-P	-0.08	0.33	-1.50	-0.45	-0.16	0.07	1.40*	-24	-3
	Fc-K	-0.78	-0.01	-0.50	-0.07	-0.13	0.09	2.20*	-28	-9.25
	Fc-Ca	1.14	-0.29	3.75	0.18	-0.35*	0.06	1.10	-52*	-4.3*
	Fc-Mg	0.17	0.17	1	0.04	-0.11	0.08*	1.25	-10	-1.75*
	Fc-Zn	-0.48	-0.12	-13.2	-0.29	-0.40	-0.08	0.25	-27	-1.50
	0	-0.90	-0.14	-2.50	-0.03	-0.42	-0.01	0.38*	-18	-6.75
20 – 40 cm	Fc	-2.10	-0.13	-2.5*	-0.84	-0.28	0.005	0.15	-30.00	-4.75
	Fc-N	-1.10	0.01	-0.50	-0.37	-0.11	-0.08	0.03	-31.50	-0.25
	Fc-P	-0.09	-0.15	-3.25	-0.08	0.28	0.12	0.23	-2.50	-0.25
	Fc-K	-1.50	-0.14	0.25	-0.01	-0.05	0.09*	-0.4	5.50	-1.25**
	Fc-Ca	-1.60	-0.16	-6.00	0.04	-0.23	0.01	0.58	-22.70	-3.25
	Fc-Mg	-0.80	0.007	-0.50	0.04	0	0.06	0.78*	-26.00	-0.50
	Fc-Zn	-0.90	0.03	-6.00	0.01	-0.07	0.02	-0.10	-59.00	-1.75
	0	-1.80*	-0.02	0	0.01	-0.15	0.06	-0.12	-10.50	-0.50

*and ** indicate significant and highly significant values; Treat: treatment; g = g kg^{-1}; mg = mg kg^{-1}; cmol = cmol kg^{-1}

Soil and rice relationship

Significant positive C-balance (2.5 gkg^{-1}) was observed in treatment Fc-N while negative balance (-1.80 g kg^{-1}) occurred in the control-0 (Table 3). Each of these scenarios was known in previous works (Julio *et al.* 1995; Bhandari *et al.,* 2002). The positive balance obtained may have resulted from the weeding operations including cleaning by residues taking out of the plots. Thus, the source of organic matter was negligible during rice growing. However, dead roots in rice rhyzosphere can occurred as source of organic matter in some treatments, especially, in the control-0. Indeed, root system needs maintenance by applying fertilizer (Huber, 1980), otherwise, the senescence can occurred.

Table 4. Concentrations of major nutrients (N, P, K and Mg) in rice grain, leaf and straw after the first year of the experimentation.

Treatments	Leaf (g kg^{-1})				Straw (g kg^{-1})				Grain (g kg^{-1})			
	N	P	K	Mg	N	P	K	Mg	N	P	K	Mg
Fc	20.0a	1.62b	17.0a	4.6a	8.52a	8.25ab	28.57a	2.10bcd	12.4a	1.87ab	3.3a	0.42a
Fc-N	15.6a	2.65a	19.5a	2.7b	6.97a	1.12a	30.15a	1.47d	10.5a	2.23a	3.6a	0.45a
Fc-P	21.1a	1.25b	17.0a	3.4ab	8.15a	0.92ab	27.47a	2.90a	11.4a	1.20c	3.3a	0.22b
Fc-K	19.8a	1.65b	17.0a	4.0ab	6.27a	0.42b	27.52a	1.57bcd	11.5a	2.10ab	2.7a	0.47a
Fc-Ca	20.7a	1.47b	18.1a	4.4a	8.32a	0.95a	25.67ab	2.17abcd	12.7a	1.92ab	3.2a	0.47a
Fc-Mg	20.2a	1.62b	17.1a	3.5ab	8.92a	0.82ab	20.70b	2.25abc	10.8a	2.17a	3.0a	0.42a
Fc-Zn	20.5a	1.82ab	16.8a	4.5a	8.42a	0.87ab	27.65a	2.30ab	10.6a	2.07ab	3.0a	0.52a
0	19.0a	1.37b	19.2a	2.7b	7.22a	0.62ab	26.80a	1.52cd	11.1a	1.50bc	2.8a	0.25b
Lsd.05	6.01	0.83	3.3	1.70	3.31	0.511	6.05	0.733	2.41	0.63	0.94	0.11
P>F	0.620	0.061	0.425	0.08	0.708	0.220	0.131	0.006	0.748	0.035	0.772	0.003

a, b and c are indicating mean values significantly different.

No significant change in soil N and K contents was observed while significant depletion of soil Mg contents occurred in 0 – 20 cm for Fc-Mg and Fc-K (20 – 40 cm) in Table 3. Except the negative balance in 20 – 40 cm soil depth of the treatment Fc, the balance in soil P content was not significant. These observations are contrasting with the yield trends observed in Table 2 and Fig. 2, especially for Fc-P. However, in our study, significant balances observed for soil Zn, Fe, Mg and Mn contents attested the depletion in Zn (Fc-N, Fc-P, and Fc-K) and Mg (Fc-Mg) while soil Fe (Fc-N) and Mn (Fc-Mg) contents were increased after a year of cropping. Thus we suspect some specific nutrient interactions according to studied treatments. These interactions can occur as antagonistic or synergistic relationship (Rice, 2007) between rice mineral nutrition and yield: in table 4, treatment Fc-N did not affect N concentration in rice organs while but Mg concentrations in leaf and straw were significantly depressed. In opposite, the treatment Fc-P has significantly depressed P content in all the studied plant organs as well as for Mg in rice grain. Straw concentrations in Mg and K were respectively depressed in Fc-K and Fc-Mg also affecting P concentration in leaf. It appeared (Table 5) that P concentration in leaf was negatively correlated with rice production in Fc-Mg while this picture was observed for Mg concentration in grain as well as for P in grain when considering Fc and Fc-Zn respectively. But, K concentration in grain was significantly and positively correlated with grain yield in the treatment Fc-Zn.

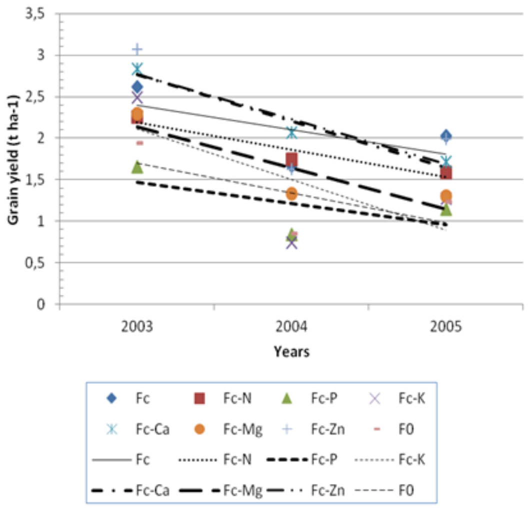

Fig. 2. Rice grain yield declining in three years cropping from 2003 to 2005.

Table 5. Relationship between N, P, K and Mg concentrations in above ground organs (Leaf, straw and grain) and rice yield as obtained in 2003.

Treat ments	Coefficient of correlations (R) and its probability (*, **)											
	Leaf				Straw				Grain			
	N	P	K	Mg	N	P	K	Mg	N	P	K	Mg
Fc	0.26	0.68	0.78	0.25	-0.29	0.24	0.96	-0.97**	-0.10	0.66	-0.86	-0.18
Fc-N	0.80	-0.27	-0.28	0.83	0.67	0.44	-0.50	0.99	-0.12	-0.45	-0.08	-0.49
Fc-P	0.59	0.67	0.75	0.99	-0.58	-0.67	0.00	-0.55	0.61	-0.98	0.56	-0.50
Fc-K	-0.00	-0.95	-0.45	0.86	0.13	0.91	-0.34	0.67	-0.09	-0.87	0.39	0.30
Fc-Ca	0.32	-0.74	-0.46	-0.43	0.00	0.88	0.24	0.52	-0.91	0.45	0.00	0.74
Fc-Mg	-0.19	-0.91*	0.08	-0.79	-0.52	-0.68	-0.75	0.77	0.84	0.06	0.65	0.77
Fc-Zn	0.28	-0.63	-0.26	0.45	0.26	0.07	0.49	0.89	0.25	-0.91*	0.96**	-0.54
0	0.15	-0.43	0.66	0.42	-0.72	-0.47	0.00	0.18	0.25	-0.28	0.40	0.00

** is *P*< 0.05; * is *P*< 0.10

Table 6. Rice grain yield as influenced (*r*, *P*= *; **) by soil nutrient contents in 0 – 20 cm per treatment in 2003 and 2005.

Treat ments	Correlation coefficient-r and its probability-P													
	P		K		Ca		Mg		Zn		Fe		Mn	
	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
Fc	0.84	0.30	0.28	0.87	0.83	0.55	0.84	0.76	0.42	0.58	-0.42	0.99	0.33	0.85
Fc-N	0.74	-0.65	0.19	-0.07	0.74	0.89	0.77	0.93*	0.37	0.38	-0.42	0.99	0.33	0.85
Fc-P	0.47	0.18	0.39	-0.45	0.38	0.96*	0.52	0.79	0.38	0.87	0.73	0.99	0.76	0.88
Fc-K	-0.13	0.03	-0.16	0.77	-0.67	0.89	0.59	-0.33	0.34	0.65	-0.81	-0.71	0.92*	0.56
Fc-Ca	-0.81	0.10**	-0.87	-0.14	-0.81	0.76	-0.92*	0.97*	-0.18	0.85	0.42	-0.55	-0.78	0.98*
Fc-Mg	-0.02	-0.94*	-0.40	-0.84	0.75	-0.89	0.90*	-0.87	0.60	-0.98*	0.27	-0.73	0.40	-0.83
Fc-Zn	-0.54	-0.31	-0.53	0.82	0.83	0.22	0.14	0.007	-0.36	----	-0.07	0.83	0.42	-0.28
0	0.44	-0.55	0.78	0.05	0.34	0.66	0.18	0.60	-0.26	----	-0.49	-0.62	-0.28	-0.58

----: no value; ** is for *P*< 0.05; * is for *P*< 0.10

Thereby, these results underline rice grain quality improvement in N, P, K and Mg concentrations (Table 4) when excluding Ca and Zn from fertilizer as recommended in our study. The grain yield can also increase by applying P in these conditions, especially when excluding Ca (Table 6). However, yield declining from 2003 to 2005 was also important in Fc-Zn (P = 0.09) with R^2 and slope of 0.52 and -0.54 respectively (Fig. 2). Therefore, the exclusion of Zn should be done with attention to Ca: Mg ratio that should be maintained higher than 1: 1 in order to improve availability of soil indigenous Zn in concordance with the theory developed by Scharpenseel *et al.*(1983) attesting Zn deficiency in a soil with low ratio of Ca: Mg (< 1).

Conclusion

Soil P, K, Mg and N deficiencies in that order were indentified for rice production on ferralsol of foot slope in humid forest of West Africa. Leaching, soil acidification with increasing of Mn-availability and antagonistic relationships in rice mineral nutrition according to soil nutrient status were deemed to be responsible of yield declining in continuous rice cropping somewhat differing with the picture observed in savanna ecology.

Time scheduled fertilization method was identified including P in the first year. In the second year and the subsequent cropping season, the combination of P and K as well as P, K and Mg were suggested respectively in the basal fertilizer while N fertilizer is required at top dressing and panicle initiation stages. The practices of minimum tillage and maintaining high ratio of Ca:Mg were also recommended to avoid yield declining.

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