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Chemical Technology Series

FERTILIZER TECHNOLOGY II

Biofertilizers

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About the Series

American Institute of Chemical Engineers (AIChE) gives following definition of chemical engineering/technology: "*A multidisciplinary science that deals with the development and implementation of the processes by which their chemical structures, energy contents, or physical states undergo changes and a science that performs to a large extent the conversion of raw materials and chemicals into useful and valuable products and it is based on the fundamental principles and approaches of mathematics, physics, chemistry and life sciences*".

The chemical engineering discipline includes the design, development, construction and operation of industrial processes for the production of a diverse range of products. Modern chemical engineering is also concerned with valuable new materials and techniques such as biomedical engineering and nanotechnology. The chemical engineering profession today is a key contributor to any country's economic growth. The field is so wide and important that it finds its applications in almost all walks of life, be it food and nourishment (fertilizers, insecticides, herbicides, oils and fats), clothing and housing (synthetic fibres, plastics and polymers, plywood and hardboards, paints and varnishes, rubber), healthcare (artificial organs, drugs and pharmaceuticals), cosmetics (soaps, shampoos, perfumes), energy (oil and natural gas, synthetic fuels, solar energy, wind energy, biomass, energy from wastes, fuel cells, batteries, nuclear energy), communication (papers, pencils, printing inks, magnetic tapes and records), defence (explosives, bullet proof jackets, high performance materials) and protection of environment (catalytic converters, effluent treatment facilities), *etc*. Nearly all industries producing consumer goods directly or indirectly need the products of chemical industry.

Since the beginning of its operation in India, Studium Press LLC USA has been publishing the high quality academic books and edited series from senior researchers and academicians for young brains of Asia and other continents in economic range. The present *Chemical Technology Series* is another assiduous effort from the experts to bring latest cutting-edge and converging technologies of a highly competitive and rapidly changing field to educate and inform students, researchers and academicians of latest developments. Studium Press LLC USA plans to bring multiple volumes on all aspects of chemical engineering including Synthetic fertilizers, biofertilizers, petroleum refining, petrochemicals, lubricants and additives, fluidization engineering, safety in chemical process industries, oil and fats, paint technology, food technology, biochemical engineering, polymers and plastics and many more.

The first four volumes of the *Chemical Technology Series* are concerned with Fertilizer and Petroleum industry. The global fertilizer demand for 2013-14 is estimated to be at 180.5 million metric tonnes. Fertilizers are important chemical compounds to quench the *hunger of the soil* in order to have enough food for all. The fertilizer industry helps ensure that farmers have the nutrients they need to grow enough crops to meet the world's requirements for food, feed, fibre and energy. Petroleum is perhaps the most significant chemical compound on earth today. Although it is a feedstock for thousands of petrochemicals, but its major application is as an energy source which runs the wheels of the world economy. Studium Press LLC USA and the series editors do hope that the *Chemical Technology Series* will fulfill the long felt need for a source book on chemical industries and will be a valuable addition to the technical literature on this discipline.

Dr. Shishir Sinha
Dr. K.K. Pant
S. Bajpai
Dr. J.N. Govil

Preface

A biofertilizer is a substance which makes use of living microorganisms to fertile the soil. When a biofertilizer is applied to seed, plant surfaces, or soil, it colonizes the rhizosphere or the interior of the plant and promotes growth by increasing the reserve of primary nutrients and growth stimulants to the host plant. The exaggerated use of synthetic fertilizers and pesticides causes substantial harm to the soil and environment. Although, it is not possible to completely replace synthetic fertilizers as they provide nitrogen (N), phosphorous (P), potassium (K) and other essential nutrients to plants, but the use of biofertilizers along with synthetic fertilizers can help to maintain soil fertility for enhanced crop production. This second volume of the series principally deals with the biofertilizers.

The chapter 1 reviews the role of different microorganisms in the nutrient uptake of crop plants and presents the strategies for developing effective biofertilizers. The chapter 2 again looks into the preparation and uses of biofertilizers. The chapter 3 takes into account the biofilmed biofertilizers which have shown their consistent potential in reducing the use of chemical fertilizers with numerous ecological benefits. Hope, hype and reality of biofertilizers are analyzed in chapter 4 with specific examples. The chapter 5 describes the role of biofertilizers and their influence on plant growth and health. The chapter 6 raises the ethical issue of use of bacteria in agriculture, as the opinion of scientists and farmers is still divided on this subject. The chapter 7 concentrates around the evaluation of soil fertility for plant growth based on bacterial biomass and material cycle in soil environment. The chapter 8 is directed toward nitrogen and phosphate inputs by salt-tolerant bacteria because of their proven ability and their contribution to integral agricultural production systems under salt stress. The chapter 9 comprises a discussion on biofertilization in tropical soils with mycorrhizal fungi and microorganisms capable of dissolving phosphate compounds to enhance effectiveness of phosphate fertilizers. The chapter 10 covers the microbiological, biochemical and molecular tools that can unravel the complex dynamics of composting process. The chapter 11 unlocks the utility of biogenic waste compost as biofertilizer. The chapter 12 advocates the use of mix of mineral fertilizers, organic amendments, biofertilizers and plant growth-promoting rhizobacteria as source of plant nutrients, choosing the most appropriate for specific situations. The chapter 13 takes an overview of genomic approaches for identification of genes from plant growth promoting rhizobacteria involved in plant growth and antibiosis. The chapter 14 studies the effect of moisture content on bio-mineralisation of nutrients, release of heavy metals and microbial characteristics of liquid, solid and semi-solid organic fertilizers. The chapter 15 assesses the impact of fertilization on productivity by estimating crop responses to nutrient application in Pampean region of Argentina taking into account soil fertility and crop response functions locally developed.

The chapters 17, 18 and 19 discuss the effect of soil nutrient deficiency and fertilization practice on root density and declining grain yield in rainfed rice cultivation in West Africa. The chapter 19 investigates the fertility aspects of municipal wastewater on rice cultivation and soil health in Bangladesh. The chapter 20 proposes a new organic fertilizer composition containing calcium lignosulfonate and silicic acid, as an alternative to inorganic fertilizers, to prevent the problem of caking and degradation in inorganic fertilizers during the storage process. The chapter 21 explores the plant growth properties of innovative biostimulants obtained from seaweed biomass and waste feathers. These biostimulants can be applied in sustainable agriculture as environment friendly and efficient biopreparations. The chapter 22 evaluates the influence of foliar application of various complex foliar fertilizers on vegetative and generative behaviors, economic productivity and quality of zucchinis fruits in order to enhance the effectiveness of early field production. The chapter 23 focuses on the importance of micronutrients for crops growth and development. The authors suggest the use of nanoparticles as a vehicle for micronutrients to solve the both nutritional and environmental problems in farming. The biomass containing high levels of micronutrients bound by the ion-exchange mechanism can be used as natural component of fertilizers. The chapter 24 examines the biosorption process in context of enrichment of the biomass with fertilizer micronutrients. The chapter 25 explains the site-specific and need based management strategies for nitrogen fertilizers in cereals based on gadgets like chlorophyll meters, leaf colour charts and optical sensors as developed in India.

The 25 articles of this volume are authored by 67 senior academicians, researchers and/or experienced industry professionals from 20 nations (Argentina, Bangladesh, Belgium, Benin, Bulgaria, Colombia, Côte d'Ivoire, Hungary, India, Iran, Italy, Japan, Mexico, Nigeria, Poland, Spain, Sri Lanka, Taiwan, Turkey and Ukraine) of the world. The series editors and publishers Studium Press, LLC USA do hope that this scholarly series will prove to be a valuable resource to students, researchers, academicians and industry professionals involved in this vast field.

Dr. Shishir Sinha
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Dr. J.N. Govil

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Effects of Soil Nutrient Deficiencies and Fertilizer Practice on the Decline of Rainfed Rice yield in the Humid forest zone of West Africa

BRAHIMA KONE[1], ALIOU SAIDOU[2], JEAN-BAPTISTE ETTIEN[1] AND MAMERY CAMARA[3]

ABSTRACT

Nutrient depletion in soils depending to nutrient removal and fertilizer practice is adversely affecting soil quality and stabilization of crop yield as a threat to global food security. To identify soil deficient nutrients and the related amount of nutrient uptakes by rice, an omission trial was conducted from 2003 to 2005. There was increasing soil nutrient deficiency along the study involving soil P (2003), P and K (2004) while yield reduction occurred for N, P, K and Mg in 2005. The highest yield of 3-4 tha^{-1} recorded in 2003 was decreased three times in 2005 mainly, as consequence of low Mg-uptake in K and Mg exclusion treatments. Furthermore, yield declining occurred in Zn exclusion treatment as consequence of unbalanced ratio of K:Mg that could disturbed P-nutrition. Applying these nutrients was recommended as basal fertilizer and 20kgha^{-1} and 150kgha^{-1} was suggested for the rates of P and K respectively.

Key words: Rainfed rice cultivation, Foot slope, Yield stabilization, Soil fertility, Humid forest zone, Côte d'Ivoire.

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INTRODUCTION

Yield declining in cereal-based cropping have been extensively reported (Beets, 1989; George *et al.*, 2002; Bhandari *et al.*, 2002; Koné *et al.*, 2010a) and soil fertility depletion was accounted for 51% of factors involved (Pieri, 1986) even when chemical fertilizer was applied. Sequential cropping including legume-rice technology (Melendez *et al.*, 2003; Assigbé *et al.*, 2012) was advised, but the variability observed in legume net benefit to soil fertility is limiting the success of this strategy (Sanginga *et al.*, 2000). Furthermore, legume-based technology also requires chemical fertilizer (Assigbé *et al.*, 2012). Therefore, there is a need of fertilizer recommendation for intensification of rice production.

Diagnostic of soil nutrient deficiency effects on rice yield and nutrient uptake in a site specific fertilizer management concept (Bationo *et al.*, 2007) might generate knowledge for fertilizer best management practice (Dobermann, 2007) in order to build up efficiently the capital of soil fertility (Stoorvogel and Smaling, 1990).

Three years omission trial was initiated in the humid forest zone of Côte d'Ivoire (West Africa) to identify deficient nutrients in the soil and their effects on rice yield and nutrient uptake. The aim was to recommend a composition of basal fertilizer for sustainable rice production in this agro-ecology.

MATERIAL AND METHODS

Site Characterization

An agronomic trial was carried out in 2003, 2004 and 2005 at Guéssihio (6º06 N, 6º00 W, 180 m asl), located in the Centre Western part of Côte d'Ivoire. It is a humid forest zone with a bimodal rainfall pattern of about 1200 mm annually (Fig. 1). Rainfall amount was 849.8 mm, 778.4 mm and 733.1 mm during the cropping season of 2003, 2004 and 2005 respectively. Average annual temperature was about 28ˆC for a total ET (Penman) of 43 mm. The study was preceded by a three years bush fallow dominated by *Chromolaena odorata* on a Hyper Dystric Ferralsol of foot slope position of a plateau with a hillside of 2–5%. It was a deep (> 1m) sandy-clayed soil having a moderate gravel content of less than 30 % within 60 cm.

Experiment Layout

During the cropping season (March–June) of 2003, 2004 and 2005, 1500 m^2 of bush fallow was cleaned and tilled manually. Simple fertilizers composed of nitrogen-N (urea-46% N), phosphorus-P (super triple phosphorus-22% P), potassium-K (potassium chloride-50% K), calcium-Ca (calcium sulfite-40% Ca), magnesium-Mg (magnesium sulfite-17% Mg) and zinc-Zn (zinc sulfite-36% Zn) 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). Blank treatment (0) with no fertilizer application was used as control. The rice (*Oryza sativa* L.) variety named WAB 56-104 was sown per hill of three grains spaced by 20 cm × 20 cm in a randomized complete blocks design. The micro-plot size for each treatment was 3 m × 5 m and they were spaced by 0.5 m in a block (replication). Four replications spaced by 1.5 m were laid for a total of 32 micro-plots. Fertilizers were applied at respective 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} as basal fertilizer. At rice tillering and panicle initiation stages, additional applications of 35 kg N ha^{-1} were applied respectively. Two hand weeding were done at 21 and 45 days after rice sowing. No irrigation was applied during the experiment which was depending exclusively to the rainfall.

Soil and Plant Sampling

Five soil samples (four corners and the centre) were taken in 0–20 cm and 20–40 cm depths for each micro-plot before the experiment in 2003 using hand auger. Then, a composite sample was done per micro-plot. These samples were dried, broken and sieved (2 mm) before laboratory analysis. Soil pH–H_2O (1:2.5), organic carbon-C, total nitrogen-N, available phosphorus-P (Bray-I), exchangeable potassium-K, calcium-Ca, magnesium-Mg and Zinc-Zn content were determined based on methods described by Page *et al*. (1996). After the harvest in 2003, about 200 g of paddy rice grain and a sample of straw were taken for the analyses of N, P, K, Ca, Mg and Zn concentrations using methods described by Tropical Soil Biology and Fertility (TSBF) (Anderson and Ingram, 1993).

Plant Data Collection at Rice Maturity

At rice maturity, the numbers of rice tillers and panicles were counted per square meter in each micro-plot as well as for plant height measurement. Then, the rice was harvested in 8 m^2 of each treatment plot leaving two border lines. After threshing and drying, the straw and grains were separated and weighed before calculating the grain yield (GY) in basis of moisture correction at 14%. The straw yield (SY) was calculated as it was. Then, the total dry mater (TDM) was calculated based on formula below (Equation 1):

$$TDM = GY + SY \qquad ...(1)$$

The nutrient concentrations in grain [x] and straw [y] were used to calculate nutrient uptake (EX) using the TDM as describe in Equation 2:

$$EX = TDM \times ([x] + [y]) \qquad ...(2)$$

Statistical Analysis

Analyze of variance was done to generate mean values of plant height, the numbers of tillers and panicles as well as the grain yield per treatment for every year of experiment. The mean values were separated by the test of least significant difference for $\alpha = 0.05$. Analyze of linear regression of grain yield across years was also performed. These analyses were carried out using Statistical Analysis System (SAS) software version 10. Furthermore, yield trend during the three years of experimentation was determined by regression using Excel.

RESULTS

Soil Nutrient Contents per Treatment

In general the chemical properties of the soil of the experimental site are significantly similar independently to soil depths (Table 1). However, soil nutrient deficiency can be noticed according to their respective critical level in a given soil depth and treatment: N-deficiency (< 1 g kg^{-1}) is observed in all of the plots except for the treatments Fc, Fc–K and the control plot in the 0–20 cm depth while, an exception was observed with Fc-P and Fc–K plots in 20–40 cm depth. Soil available P-BrayI content is also low (< 10 mg kg^{-1}) in all the plots contrasting with that of treatment Fc–Zn in 0–20 cm depth. It was observed K-deficiency (< 0.10 cmol kg^{-1}) in 0-20 cm and 20–40 cm depth for Fc–K and Fc–Zn plots respectively, contrasting with most of the other treatments with soil K content close to the critical level of 0.10 cmol kg^{-1}. A part from the high exchangeable Ca content (5.64 cmolkg^{-1}) noticed in 20–40 cm depth in the control plot, Ca concentration in the soil is low (< 2 cmol kg^{-1}) in all the studied micro-plots. In opposite, soil exchangeable Mg content is sufficient (> 0.20 cmol kg^{-1}) in 0–20 cm depth whatever the treatment while, it is low in the Fc–P, Fc–Mg and Fc–Zn plots within 20–40 cm depth. Zn-deficiency (< 1mgkg^{-1}) was also noticed in all the micro-plots in subsoil (20–40 cm) except in treatments Fc and Fc–N while its deficiency occurred only in the treatment Fc–Mg and the control plot for the topsoil (0–20 cm).

Table 1: Soil N, P, K, Ca, Mg and Zn contents in 0–20 and 20–40 cm depths of each micro-plot before the experiment in 2003

	0 – 20 cm					
	N^{g}	P^{mg}	K^{cmol}	Ca^{cmol}	Mg^{cmol}	Zn^{mg}
Fc	1.12a	6.62a	0.13a	0.77a	0.40a	3.43a
Fc–N	0.94a	4.37a	0.19a	0.62ab	0.32ab	2.30a
Fc–P	0.79b	3.50a	0.32a	0.42b	0.24b	1.23a

Table 1: (*Contd...*)

Table 1: (*Contd...*)

	0 – 20 cm					
	N^{g}	***P***^{mg}	***K***^{cmol}	***Ca***^{cmol}	***Mg***^{cmol}	***Zn***^{mg}
Fc–K	1.00ab	6.25a	0.09a	0.68ab	0.33ab	1.90a
Fc–Ca	0.87ab	5.87a	0.15a	0.64ab	0.36ab	1.82a
Fc–Mg	0.83ab	5.00a	0.10a	0.51ab	0.22b	0.78a
Fc–Zn	0.83ab	11.87a	0.26a	0.59ab	0.28ab	3.20a
0	1.00ab	3.25a	0.13a	0.72a	0.40a	0.83a
	20 – 40 cm					
	N^{g}	***P***^{mg}	***K***^{cmol}	***Ca***^{cmol}	***Mg***^{cmol}	***Zn***^{mg}
Fc	0.63a	2.25a	0.11a	0.56a	0.27a	7.52a
Fc–N	0.55a	2.25a	0.28a	0.44a	0.21a	1.70a
Fc–P	1.45a	3.12a	0.10a	0.39a	0.14a	0.40a
Fc–K	1.26a	1.87a	0.16a	0.44a	0.36a	0.30a
Fc–Ca	0.66a	4.37a	0.12a	0.44a	0.26a	0.55a
Fc–Mg	0.51a	2.50a	0.10a	0.30a	0.19a	0.45a
Fc–Zn	0.62a	5.00a	0.09a	0.42a	0.17a	0.40a
0	0.58a	1.75a	0.10a	5.64a	0.28a	0.40a

^{g} = g kg^{-1} ; ^{mg} = mg kg^{-1} ; ^{cmol} = cmol kg^{-1}

Effect of Type of Fertilizer on Rice Growth and Yield Parameters

Figure 1 presents the overall mean of the numbers of rice tillers and panicles per square meter as well as the plant height recorded for the three years trial according to the different treatments. It is observed significant decrease effects of the treatments Fc–P and Fc–N on plant height, numbers of tillers and panicles. Similar trend is observed with treatment Fc–Mg but it not affects significantly the number of tillers produced. Only the plant height is significantly affected by the treatments Fc–K and Fc–Zn likewise for the treatment Fc–Ca which is also recording a significant reduction of the number of panicles for highest tillers number.

There are almost similar effects of the treatments Fc and Fc–Zn on the studied parameters whereas; the control plot has induced the lowest plant growth similarly with that of Fc–P. Consequently, the lowest grain yields (GY) are observed with the treatment Fc–P along the study while, significant decreasing effect of treatment Fc–K is observed only from the second cropping year resulting a decreasing effect on the overall mean of the grain yield (Table 2). Although, the effect of the treatment Fc–Mg is not significant annually, it has significantly decreased the overall mean value of grain yield. Furthermore, about 47% of yield reduction is observed with treatment Fc–N.

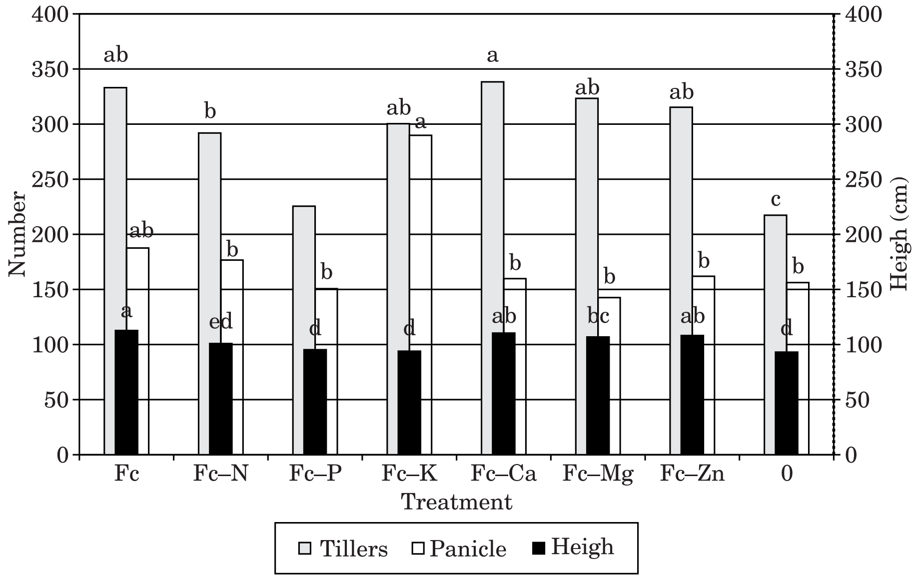

Fig. 1: Overall mean of the three years data of the numbers of tillers and panicles per square meter as well as the plant height regarding the treatments

Table 2: Rice grain yield regarding the different treatments in 2003, 2004 and 2005 as well as the overall mean value

	Grain yield ($t\ ha^{-1}$)			
Treatments	***2003***	***2004***	***2005***	***Mean***
Fc	2.63ab	1.66ab	2.03a	2.11ab
Fc–Zn	3.07a	1.63ab	1.99ab	2.23a
Fc–Mg	2.29abc	1.33abc	1.30ab	1.64bcd
Fc–Ca	2.83ab	2.07a	1.71ab	2.20a
Fc–N	2.25abc	1.75a	1.59ab	1.86abc
Fc–K	2.49abc	0.74c	1.27ab	1.50cd
Fc–P	1.65c	0.84bc	1.14b	1.21d
0	1.94bc	0.85bc	1.23ab	1.34d
$Lsd_{.05}$	0.957	0.830	0.885	0.493

a, b, c, d indicate the mean values with significant difference

Rice Yield Trend and Mineral Nutrition

Figure 2 presents the overall annual yield range and yield trend across years. In general, rice grain yield was ranging between 0.71 and 3.65 tha^{-1} in 2003 while the lowest values observed in 2004 and 2005 were 0.43 and 0.64 tha^{-1} respectively. However, 3.94 tha^{-1} and 3.42 tha^{-1} were recorded as maximum yields in 2004 and 2005 respectively. Nevertheless, there is three times decrease of the annual average grain yield from the beginning to the end of the study. Details of this trend of the grain yield are given in Table 3 showing negative values of the slope in all the linear regressions of grain yield as determined for all the treatments respectively. Highest significant decreasing trend of rice grain along the study is observed with treatments Fc–K (P = 0.001) and Fc–Mg (P = 0.007). The treatment Fc–Zn has also induced a significant (P < 0.10) decreasing trend of grain yield. However, there is significant reduction of the uptake of almost the studied nutrients (K, N, Mg and Zn) in treatment Fc–P whereas; treatments Fc–K and Fc–Mg have only induced reduction of Mg–uptake similarly with treatment Fc–N. Meanwhile, only the uptake of Zn was reduced in treatment Fc–Zn (Table 4).

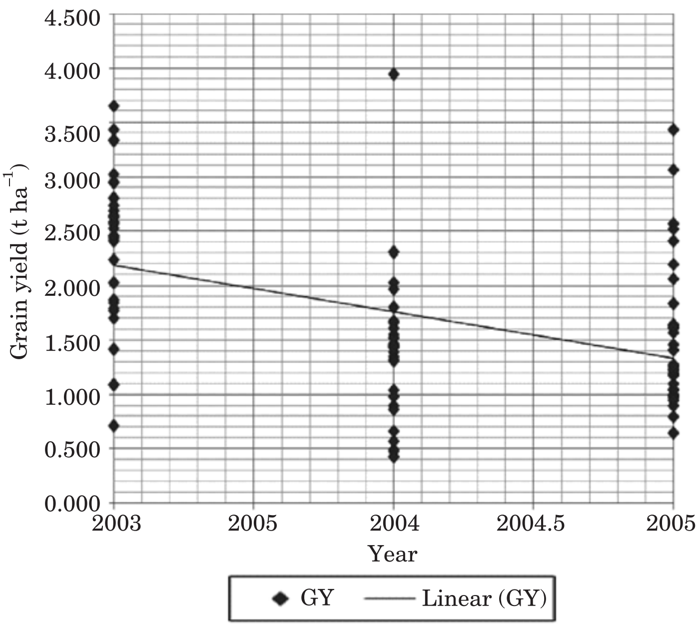

Fig. 2: Annual yield range and yield trend across years

Table 3: Pearson correlation value of the linear regression grain yield across years during the experiment according to the treatments

	Slope	*P>´ t ´*
Fc	–0.296	0.286
Fc–Ca	–0.562	0.106
Fc–K	–0.611	0.019
Fc–Mg	–0.490	0.007
Fc–N	–0.330	0.172
Fc–P	–0.254	0.157
Fc–Zn	–0.543	0.092

Table 4: Nutrient uptake by rice regarding the treatments

	Ca (***kg ha***$^{-1}$)	***P*** (***kg ha***$^{-1}$)	***K*** (***kg ha***$^{-1}$)	***N*** (***kg ha***$^{-1}$)	***Mg*** (***kg ha***$^{-1}$)	***Zn*** (***g ha***$^{-1}$)
Fc	6.91 a	7.21 a	84.7 ab	54.80 ab	6.45 abc	5.75 ab
Fc–N	8.36 a	7.55 a	75.04 ab	40.35 abc	4.73 cd	4.58 abc
Fc–P	6.14 a	3.44 a	51.20 b	32.48 c	5.24 cd	3 bc
Fc–K	8.95 a	6.21 a	75.35 ab	44.35 abc	5.10 cd	5.60 ab
Fc–Ca	9.63 a	8.10 a	71.00 ab	59.55 a	3.31 ab	6.74 a
Fc–Mg	7.22 a	7.00 a	63.00 ab	44.60 abc	5.50 bcd	5.22 abc
Fc–Zn	9.84 a	8.95 a	95.36 a	58.95 a	8.80 a	2.94 bc
0	6.52 a	22.95 a	57.70 b	35.60 bc	3.43 d	2.57 c
GM	7.95	8.93	71.63	46.36	5.95	4.55
P>F	0.46	0.64	0.23	0.09	0.009	0.05

a, b, c and d are indicating mean values with significant difference in column

DISCUSSION

Nutrient Limitation for Upland Rice Cropping

Our study confirms P-deficiency in acid soil of the humid forest zone in West Africa (Koné *et al.*, 2010b) affecting rice height, tiller and panicle numbers as well as the grain yield that was significantly reduced every cropping year. Although, the level of soil exchangeable K concentration (0.09 cmol kg^{-1}) was deficient in 0–20 cm depth, the treatment Fc-K did not significantly reduced the grain yield in the first cropping year probably because of the suitable K content in the sub-soil (20–40 cm) which could supply sufficient-K to the rhizosphere including about 90% of upland rice root density (Koné *et al.*, 2011). However, K-deficient was observed in the second cropping year roughly due to a low compensation of the amount taken up by the plant (75.5 kg K ha^{-1}) in the treatment Fc–K. In fact, K uptake was ranging between 51.20 kg ha^{-1} and 95.4 according to the treatments (Table 4) and about 47 kg K/ha/year are lost in agricultural soil of Africa by leaching (Stoorvogel and Smaling, 1990) whereas, only 50 kg K ha^{-1} was applied during the study. Therefore, soil K content was partially compensated, inducing chemical degradation of the soil (Connor, 2006) as consequence of a cumulative depletion of this nutrient content in the soil during the trial. Rationally, the rate of K-fertilizer may be increased up to 150 kg ha^{-1} in rice cultivation in the studied ecology as recommended elsewhere by Buresh *et al.* (1997) and Wang *et al.* (2001). Successfully, the rates applied for N, P and Mg were sufficient for the compensation of their uptake respectively. However, the rate of P-fertilizer can be reduced to 20 kg P ha^{-1} for rational compensations of its uptake and leaching (20 kg P_2O_5/ha/year).

Soil total N content (0.94 g kg^{-1}) in the 0–20 cm depth of Fc–N treatment did not reflected N-deficiency during the cropping year of 2003 regarding grain yield recorded. However, this value was closed to the critical level of 1 g kg^{-1}, and it was reduced by the annual amount of 40.4 kg N ha^{-1} taken up by the plant in this treatment. This situation has resulted in soil N-deficiency for the subsequent crops as consequence we noticed 47% of the overall mean value yield reduction. Similar analysis can also explain the interference of soil Mg content and rice grain yield as observed with Fc–Mg treatment during the trial.

Consequently, basal fertilizers composed of P, P and K as well as NPKMg is required for successive cropping years respectively for upland rice production in the studied ecology. Similar annual increasing of soil nutrient deficient concerning N, N and P as well as NPKSZn respectively, was observed for the declining of rice yield in agro-ecological zones of Bangladesh (Rijpma and Fokhrul Islam, 2003). However, the actual study did not revealed soil Zn-deficiency effect in rice grain yield which could justify site specific fertility management strategy dealing with rice yield declining.

The topsoil removal by erosion was found to be the most important process in the variability of soil fertility and productivity in sub-Sahara Africa (Lal, 1995; USDA SEA-AR, 1981; Saïdou *et al.*, 2003) while our study reveals great contribution of the amount of nutrient uptake in cultivated land, depending on soil inherent fertility and fertilizer practice. Based on the variability of soil inherent fertility along a toposéquence (Koné *et al.*, 2009a), nutrient uptake and fertilizer requirement for sustaining rice production could be different with the actual results (foot slope) according to topographic positions in a farm side.

Yield Stabilization

Soil nutrient depletion is an important concern directly linked to food insecurity in developing countries due to the intensification of land use system for agricultural production without proper application of external inputs (Henao and Baanante, 1999; Keatinge *et al*., 2001). The continued lack of required replenishment of nutrient in depleted soils as well as nutrient losses through erosion are not only exacerbating soil degradation, but also jeopardizing agricultural sustainability (Ayoub, 1999; Sheldrick *et al.*, 2002). However, more reliable data of human-induced soil nutrient depletion can help in addressing solution for yield gap (Tan *et al.*, 2005).

The grain yield recorded in the process of the present experiment ranged up to 3 – 4 t ha^{-1} during the first two cropping years (Fig. 2). This result seems interesting for rainfed rice production in the studied ecology where the average yield is about 1 t ha^{-1} (Koné *et al.*, 2009b). However, only the treatments Fc, Fc–Zn and Fc–Ca have induced more than 2 t ha^{-1} as overall average grain yield during the experiment (Table 2). This low performance of the crop was related to soil nutrient deficiency mineral nutrition disorder. Soil P and K deficiencies occurred along successive cropping seasons respectively while important yield reduction was observed for treatments Fc–N and Fc–Mg regarding the overall mean yield in concordance with lowest Mg uptake. Nevertheless, the significant yield decline was noticed with treatments Fc–K, Fc–Mg and Fc–Zn whereas, treatment Fc–P has affected the uptake of almost all the nutrients. Therefore, the total nutrient uptake cannot entirely explain the yield declining alone. However, the low compensation of exported K by rice, can increase unbalance of K:Mg ratio in the treatments Fc–K and Fc–Mg, which could affect P-nutrition (Yates, 1964). Furthermore, application of optimum rate of Zn-fertilizer is required for increasing the uptake of P and K (Ranade-Malvi, 2011) while, Zn-deficiency was noticed in the subsoil (20–40 cm depth) of the Fc–Zn treatment, supplying limited amount of Zn to deepest rooting zone.

Thereby, we suggest the improvement of K-fertilizer strategy for the maintenance of rice grain yield in the studied ecology as recommended by Regmi *et al.* (2002) in continuous wheat cropping system. The improvement of P and K fertilizer application with a rational rate of 20 kg P ha^{-1} in the first cropping year combined with 150 kg K ha^{-1} in the second cropping season while maintaining the rates of N and Mg for the subsequent year may strengthen rice yield stabilization on Ferralsol located in the foot slope landscape in the humid forest zone of West Africa. Soil test and nutrient uptake are likely to be the key strategies to deal with crop yield declining for recommendation of best fertilizer management.

CONCLUSIONS

The present study revealed a widespread of soil P-deficiency in the humid forest soil follow by a secondary K, Mg and N deficiencies. In this context, K-fertilizer management and K nutrient use efficiency would be the key matters that induce rice grain yield declining in continuous upland rice cropping system as observed with the omission of K, Mg and Zn during the experiment. It was recommended basal fertilizer application composed of N, P, K and Mg for sustaining intensive upland rice production in the humid forest of West Africa at a rate of 100 kg ha^{-1}, 20 kg ha^{-1}, 150 kg ha^{-1} and 50 kg ha^{-1} respectively.

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