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Rainfed upland rice production on a derived savannah soil in West Africa

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1 SUMMARY

To generate knowledge on rainfed upland rice production and to identify the existing nutrient constraints in a derived savannah soil of West Africa, trials were conducted in 2005 and 2006 on three major soils in central and southern parts of Benin. An acrisol, a ferralsol and a plinthisol were investigated at Avokanzou and Cana in the South and at Sowe in central Benin, respectively. The trial was duplicated at Sowe and conducted in one year (2006) only while one trial was conducted per year at the other sites. A randomized complete block design with four replications of eight treatments was used. The rice variety used was NERICA 4 grown in plots of size 3 x 5m, and a spacing of 20 cm within and between plants. The complete fertilizer treatment (Fc) was composed of N, P, K, Ca, Mg and Zn and a specific nutrient was excluded from Fc in the other treatments (Fc-N, Fc-P, Fc-K, Fc-Ca, Fc-Mg and Fc-Zn). The zero fertilizer treatment (0) was used as the check. Respective fertilizer rates were 100 kg N ha^{-1} (urea), 100 kg P ha^{-1} (super triple phosphate), 50 kg K ha^{-1} (potassium chlorite), 50 kg Ca ha^{-1} (calcium sulfite), 50 kg Mg ha^{-1} (magnesium sulfite) and 10 kg Zn ha^{-1} (zinc sulfite). The pH, soil particle sizes, C, N, Ca, Mg and K contents were measured before the establishment of the trials. Rainfall data was also recorded as well as rice grain yield. Linear model analysis and analyses of variance of grain yield was done using SAS software. Results indicated the importance of soil texture and rainfall regularity during the cropping season. A significant (*$P<0.05$*) decreasing effect of Fc-N, Fc-K, Fc-Zn treatments was observed on rice grain yield in the southern part of Benin while additional effect of Fc-P was observed in Sowe. N, P, K and Zn fertilizers are therefore recommended for increased rice production in the derived savannah of West Africa. Areas with similar ecologies to Sowe would be more suitable when applying 100 kg ha^{-1} N and P, 50 kg K ha^{-1} and 10 kg Zn ha^{-1} for a target yield of about 4 t ha^{-1}.

2 INTRODUCTION

The most widespread limiting nutrients to food production in Africa are nitrogen (N), phosphorous (P) and potassium (K) in that order (Ssali *et al.*, 1986; Sanchez & Palm, 1996).

However, calcium (Ca), magnesium (Mg) and sulphur (S) deficiencies can also occur under conditions of high weathered acid soil with low organic matter content (Smaling *et al*., 1997). Moreover, zinc (Zn) deficiency and aluminum (Al) toxicity often associated with manganese (Mn) toxicity are identified in upland soils of West Africa (Kang & Osiname, 1985; Mutsaer *et al*., 1997).

For suitable crop production good nutrient content and balance in the soil is necessary, especially for rice (Doberman & Fairhust, 2000). Therefore, indigenous soil fertility knowledge especially regarding N, P, K, Ca, Mg, S, Zn, Al and Mn soil replenishment is essential for rice production in West Africa. WARDA (1990) has already identified P and N deficiencies as major constraints to rice production in the humid forest zone of West Africa. Soil iron deficiency was also identified as a constraint to rice production in Nigeria (Moormann *et al*., 1977). However, there is limited knowledge regarding nutrient deficiencies in relationship to rice production in the savannah zone of West Africa. Large areas of several countries including Ghana, Togo, Benin and Nigeria are essentially under a derived savannah and Guinea savannah (Kang, 1980). Due to the high cost of rice importation, these countries are developing strategies for local rice production and need to be supported with the necessary technologies and information.

In Benin, rice is becoming a cash crop even though there is limited knowledge of rice production (Obilana & Okumu, 2005) especially for upland rice in the southern parts of the country. Major soil mineral nutrient constraints need to be addressed for sustainable rainfed upland rice production to be achieved.

The actual objective of this study was to assess the potential of producing upland rice on the dominant soils of the derived savannah zone in Benin and to identify deficient nutrients that need to be corrected to improve rice production.

3 MATERIALS AND METHODS

3.1 Experimental sites: The experiment was conducted in Cana (7º10 N, 2º 04 E, 158 m above sea level [asl]) and Avokanzou (7º10N, 2,03E, 165masl) in the southern part of Benin. Avokanzou is situated in the North, about 10 km from Cana. In the central part of Benin, a third site named Sowe (7º94 N, 2º08 E, 171 masl) was selected. All the selected sites received rainfall in a bimodal pattern with an average annual amount of 1200 mm. The vegetation was a derived savannah composed of secondary forest and grass vegetation.

A ferralsol plinthic was identified in Cana. It was graveled (>30%) soil especially below 20 cm depth and an ironstone hardpan often appeared below 80 cm depth. In Avokanzou, a deep (>10 m) and red soil locally named *terre de barre* was identified. It is an Acrisol with neither gravel nor ironstone hardpan. The soil at Sowe was a ferralsol ferric. It was a graveled (>30%) soil within 80 cm and ironstone hardpan was often occurring within 40 cm depth.

The experiments were established on the upper slope of a plateau in Cana and Avokanzou was located on the summit of the Cana landscape.

3.2 Experiment design and layout: In 2005 and 2006, the experiment was conducted in Cana and Avokanzou. In 2006, two more trials (Trial 1 and Trial 2) were also conducted in Sowe in addition to those of Cana and Avokanzou. The trial sites at Cana and Avokanzou had been fallowed for three and five years, respectively. A three years old bush fallow preceded trial 1 in Sowe while a one year old yam farm was existing in the location of trial 2.

The land was cleared and tilled manually in June of every year. Treatments included N, P, K, Ca, Mg and Zn applied as the complete fertilizer (Fc); while other treatments had a specific nutrient excluded from Fc (Fc-N, Fc-P, Fc-K, Fc-Mg, Fc-Ca and Fc-Zn). A zero fertilizer treatment was used as a check. The rice variety NERICA4 (New Rice for Africa 4) was sown in a randomized complete design composed of micro-plots of 3 m x 5 m dimensions and spaced by 0.5 m between plots. An alley was left between the four blocks of 1.5m. The fertilizers were applied at respective rates of 30kg N ha^{-1} (urea), 100 kg K ha^{-1} (potassium chloride), 50 kg Ca ha^{-1} (calcium sulfite), 50 kg Mg ha^{-1} (magnesium sulfite) and 10 kg Zn ha^{-1} (zinc sulfite) as basal fertilizer. Urea was applied two times at the rate of

35 kg N ha^{-1} as top dressing at tillering and panicle initiation, respectively.

3.3 Soil sampling and analysis: Before tilling the land, soil was sampled from the 0 – 20 cm depth of each micro plot using an augur. Samples were taken from the four corners and at the center of a micro plot, and combined to make an elementary composite sample. Thus, 32 elementary samples were used to collect the composite sample of the soil in the experimental area.

The samples were dried, broken and sieved (2mm) before the laboratory analysis was carried out. Soil particle size, soil pH and soil contents in C, N, P, K, Ca and Mg were determined as described by the American Society of Agronomy (ASA) and Soil Sciences Society of America (SSSA) (1982, 1986).

3.4 **Data collection:** At maturity, the plot size harvested was 8 m^2 after eliminating two lines from each side of the plot. After threshing, the grains were dried under sunlight, sieved and weighed after determining the moisture content. The grain yield (GY) moisture content was determined at 14%.

3.5 Statistical analysis: Linear model was processed by site and year to determine grain yield mean value for each treatment at Cana and Avokanzou. Another linear model was run by trial to generate GY mean value per treatment at Sowe. Further analyses of variance (ANOVA) were processed by site to determine the average mean value of GY per treatment at Cana and Avokanzou. The average mean value of GY in Sowe was generated by the same method combining the two trials. Least significant difference was used to separate the mean values and α was considered at 0.05. SAS software (Version 8, 2000) was used for the statistical analysis.

4 RESULTS AND DISCUSSION

4.1 Soil and rainfall factors: The soils in south Benin (Avokanzou and Cana) were more acid and clayed than the soils at Sowe in central Benin (table 1). However, fine particles (clay + silt) content was higher in the soils in central Benin than the southern acrisol (Avokanzou) and ferralsol (Cana). A difference was also observed in the soils at Sowe between trials 1 and 2, with increased acidity and sand content in the soil at the trial 2 site. This observation could be related to land use before the experiment, possibly leading to depletion of soil organic matter content and probable soil nutrient leaching as well as erosion as described by Brams (1971) and (Bationo, 1984). Except C content in the soil at Cana and N content in the soil of the trial 1 site at Sowe, these nutrient contents are low (<10 g kg^{-1}). Highest P contents (>20 cmol kg^{-1}) were obtained in southern soils inspite of their lower pH. However, the cation ratios (Ca: Mg and K:Mg) are unbalanced in the range that can inhibit P uptake by plants (Yates, 1964; Doll & Lucas 1973). The lowest K contents (0.08 cmol kg^{-1}) and P (<10 mg kg^{-1}) were observed in soils of the two trial sites at Sowe. These results indicated a possible deficiency of N, P and K contents in the soil during the actual experimentation, confirming the general knowledge of African soil fertility (Stoorvogel & Smaling, 1990).

A lower monthly rainfall of less than 100 mm was realized at Avokanzou and Cana (South region) from July to August (figure 1). This drought period known as the midseason drought was reduced to the month of August in 2005 at Cana and 2006 at Avokanzou. Thus, there was inter-annual variability of the rainfall distribution during the midseason drought in southern Benin, increasing the climatic risk for rainfed crops. Early rice seeding in May could have resulted in a coincidence of the rice reproductive stage (70 - 90 days after seeding) and the drought period leading to loss of grain yield as observed by Laffitte (2002). Thus, there is a limited flexibility of rice sowing date in southern Benin. Moreover, the higher sand content in the soil at Cana and Avokanzou implies a reduced water holding capacity, which leads to more drought stress on the crop.

In central Benin, the midseason drought was observed in June 2006. Before May, there was a high variability of monthly rainfall. Thus, the more appropriate seeding period at Sowe would be in June according to the data collected in 2006. Sowing in June would allow mitigation of midseason drought effects because the rice is at the vegetative stage. In fact, crop water demand is low at this period compared to the need during the reproductive stage (Snyder *et al*., 2001). In contrast to the soils in the south, there is high content of fine particles in the soils at Sowe, which can improve the water holding capacity. It appears that Sowe has more potential for rice growing than the sites in southern Benin. The acidity, soil texture and soil nitrogen content at Sowe contribute to the more favorable situation, in addition to higher probability of more regular rainfall during the cropping season.

4.2 Rice yield and nutrient deficiencies: Lower yields (<1 t ha^{-1}) were realized at Avokanzou with a significant (*P = 0.01*) decreasing effect of Fc-N treatment in year 1 (table 2). The average mean values confirm this effect and reveal a slight decreasing effect (14%) of Fc-K treatment on rice grain yield. The grand means were low and varied from 80 kg ha^{-1} in year 1 to 510 kg ha^{-1} in year 2. The rainfall variability, especially during the midseason drought associated with rice growth stages could have contributed to these results.

Table 1: Results of physico-chemical analysis of the soil from 0 – 20 cm depth in Avokanzou, Cana and Sowé trial sites.

	South		Centre	
	Avokanzou	Cana	Sowé1	Sowé2
pH water	5.6	5.8	6.4	5.9
Clay (g kg^{-1})	82.5	156	30	23
Silt (g kg^{-1})	15	64	300	276
Sand (g kg^{-1})	902.5	780	670	701
C (g kg^{-1})	2.5	11.7	6.1	3
N (g kg^{-1})	0.2	0.9	11.5	0.31
C :N	12.5	13	11.5	
P (mg kg^{-1})	20.2	20	8	3
Ca (cmol kg^{-1})	17.8	1.85	0.9	1
Mg (cmol kg^{-1})	4.3	0.90	----	----
K (cmol kg^{-1})	0.81	0.72	0.08	0.08
Ca : Mg	4.1 :1	2 :1	----	----
K : Mg	0.2 :1	4 :5	----	----
Soils	Acrisol	Ferralsol plinthic	Ferralsol ferric	Ferralsol ferric

----: not analysed.

Table 2: Rice grain yield at Avokanzou and Cana in year1 (2005) and year2 (2006) and at Sowe (trial 1 and 2 in 2006).

	Grain yield (t ha^{-1})								
	Avokanzou			Cana			Sowé		
	Year1	Year2	Mean	Year1	Year2	Mean	Trial1	Trial2	Mean
Fc	0.09a	0.60a	0.35a	1.10a	1.27a	1.20a	4.36ab	2.83a	3.60ab
Fc-P	0.10a	0.59a	0.35a	1.08a	1.20a	1.15a	4.18ab	2.25b	3.22b
Fc-Mg	0.08a	0.55ab	0.32a	1abc	1.27a	1.15a	4.77a	2.87a	3.82a
Fc-Ca	0.10a	0.55ab	0.32a	1abc	1.21a	1.10a	3.86bc	2.65a	3.25b
Fc-Zn	0.11a	0.54ab	0.33a	1abc	0.78b	0.87b	3.85bc	2.67a	3.25b
Fc-K	0.10a	0.50ab	0.30ab	0.89abc	0.93ab	0.90ab	4.10ab	2.56ab	3.33b
Fc-N	0.04b	0.37b	0.21c	0.68c	0.83b	0.80b	3.06cd	1.68c	3.40c
0	0.04b	0.38b	0.21bc	0.71bc	0.81b	0.77b	2.80d	1.33c	2.05c
GM	0.08	0.51	0.30	0.95	1.06	1.01	3.87	2.36	3.11
$Lsd_{.05}$	0.04	0.18	0.09	0.37	0.42	0.27	0.83	0.35	0.93
P>F	0.01	0.12	0.01	0.12	0.06	0.004	0.001	<.00001	0.005

At Avokanzou in 2005, the monthly rainfall was lower than 50 mm (July) when the rice was entering the reproductive stage. In 2006, the drought occurred later in August with a lower severity (rainfall>50 mm) coinciding with the end of the rice reproductive stage. Thus, the reproductive stage of rice was less stressed by the midseason drought during 2006. Since drought occurrence during crop reproduction can induce the highest yield decrease (Castillo *et al.*, 2006), the rainfall pattern must have been one of the major factors inducing yield decrease and variability in Avokanzou as observed in 2005 and 2006.

However, rice grain filling could have been affected by drought stress in 2006, reducing NERICA 4 yield from a potential of 4 – 5 t ha^{-1} (WARDA, 2006) to 510 kg ha^{-1} . This result is concordant with work done by Fujii *et al.* (2004) showing poor drought tolerance of NERICA 4. Moreover, the soil of Avokanzou is particularly richer in sand particles and poor in organic matter content (C x 1.73). Therefore, water stress could have been enhanced by a low water holding capacity of the soil and the deficiencies of nitrogen and potassium. In fact, nutrient deficiency is known to reduce crop tolerance to water stress (Onken & Wendt, 1989).

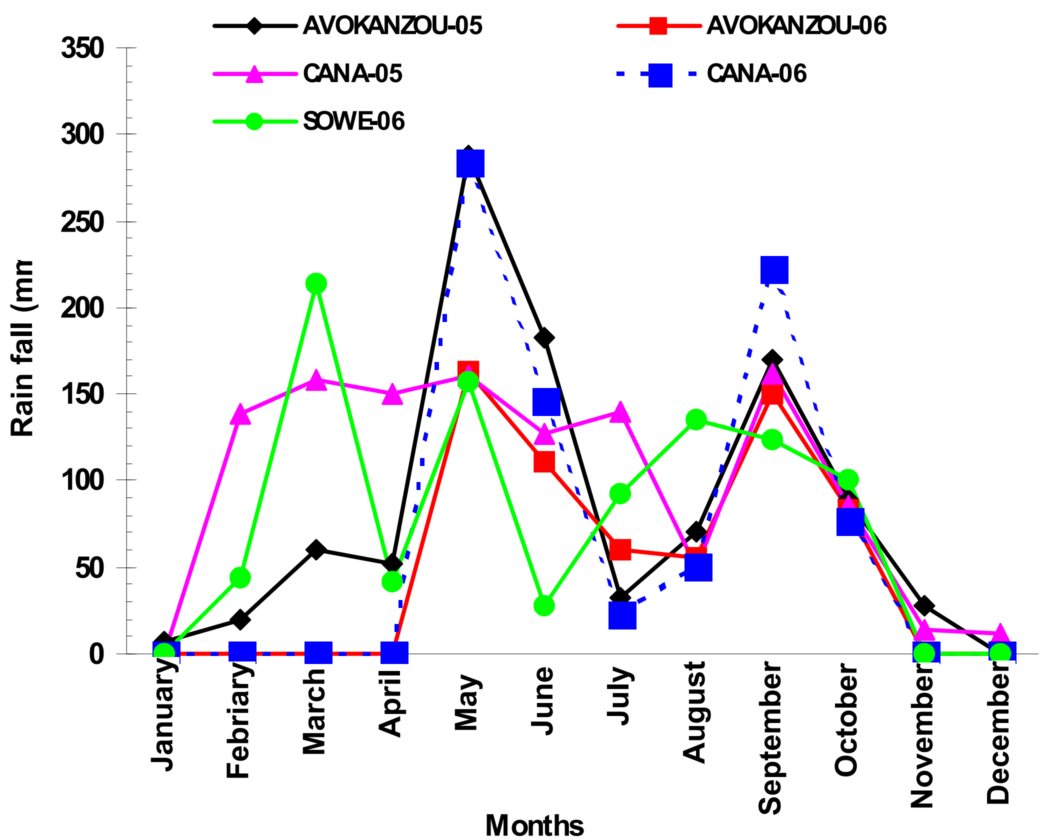

Figure 1: Distribution of annual rainfall at Avokanzou, Cana in 2005 and 2006 as well as 2006 at Sowé.

There was also a significant (P = 0.004) decreasing effect of Zn (28%), N (34%) and K (36%) exclusion on the mean grain yield at Cana. These results attest to the existence of Zn, N and K deficiencies in the ferralsol plinthic soils of Cana, which need to be corrected to ensure sustainable upland rice production. In addition to these nutrient deficiencies, P exclusion also induced significant (P <0.05) decreasing effects on rice grain yield at Sowe.

We can deduce that N and K deficiencies limit rice cultivation on *terre de barre* (Acrisol) in southern Benin while Zn deficiency is also observed on ferralsol plinthic soil at Cana in addition to N and K deficiencies. More nutrient (N, P, K and Zn) deficiencies are observed at Sowe on ferralsol ferric. However, the highest grain yield was obtained at Sowe, probably because of early occurrence (June) of the midseason drought and more regular rainfall showing that NERICA 4 is more tolerant to early drought than the later one (Cana and Avokanzou) during the cropping period. Infact, soil moisture is required for nutrient uptake and efficient use (Koné, 1998; Castillo *et al.*, 2006).

The observed effect of K and P deficiencies on rice production at Sowe confirm the soil tests results (Table 1) but there is a contrast with soil analysis in Avokanzou and Cana especially for K. The critical content of this nutrient in tropical soils ranges from 0.15 to 0.20 cmol kg^{-1} (Juo & Grimme, 1980; Juo & Franzluebbers, 2003). Comparing these values to K content in the soil sample of 0 – 20 cm in Avokanzou (0.71 cmol kg^{-1}) and Cana (0.8 cmol kg^{-1}), K deficiency could not occur. However, upland rice rooting depth can reach 60 cm (Chopart, 1980). Therefore, we can presume that K deficiency have been induced by a lower (<0.15 cmol kg^{-1}) K content in the deepest (>20 cm) soil horizon during rice growth in K exclusion treatments. Applying 100 kg K ha^{-1} can correct this deficiency as observed during this study.

Our results corroborate the work done by Dabin (1956) on *terre de barre* in Togo concerning K deficiency and also confirm the Zn deficiency mapped in West Africa by Kang and Osiname (1985). The zinc deficiency observed is a significant contribution to rice production knowledge improvement for Africa. Except a few cases observed on Brazilian Ultisol (De Datta & Vergara, 1975) zinc deficiency has not yet been reported as constraint to rice cultivation in Africa.

Based on these analyses, we recommend N, P, K and Zn fertilizer application for rice cultivation in central Benin while N, K and Zn fertilizers are required in the south. Organic matter use can be a suitable alternative to application of inorganic fertilisers. Besides nutrients, upland rice production seems to be limited also by rainfall irregularity and soil physical characteristic in southern Benin. This observation can largely explain why Sowe is a traditional rice cultivation area in the country.

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