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The Role of Pulses in the Management of the Fertility of the Soils in Intensive Irrigated Rice

M. Bagayoko
Niono Regional Agronomic Research Center, Institute of Rural Economy (Mali)

Abstract - In the year 2003 and 2004, two rotational experiments were initiated to determine the effects of preceding legume crops on yields of irrigated rice in the Office du Niger. The first experiment was a split plot design with three legume species (rice, cowpea and groundnut) as main plot treatments and 4 levels of nitrogen as secondary plot treatments. The second experiment had 4 treatments which were composed of (T1) rice following rice (T2) rice following cowpea, (T3) rice following groundnut and (T4) rice following soybean. Yield increase with rice after pulses ranged from 28 % for cowpea and groundnut to 48 % for soybean when compared with rice after rice. Nitrogen use efficiency was altered by previous crops. In general, nitrogen use efficiency decreased with increasing N application in all cropping systems except continuous rice.

Key Words: **Rotation, Cowpea, Groundnut, Soybean, Rice, Nutrient Use Efficiency, Yields**

I. INTRODUCTION

There is a general agreement that the sustainability of crop production in West Africa is often severely limited by the rapid loss of soil productivity after only a few years of cultivation. This is because soil nutrients are removed from the soil through crop uptake, erosion, leaching and immobilization. Because of the low fertility status of most West African soils, nutrients need to be added for the productivity to be sustainable. Fertility restoration can be achieved through application of chemical fertilizers and or soil organic amendments. However, most smallholder farmers have limited resources to purchase fertilizers or have limited access to enough organic amendment materials. In these contexts, exploring management strategies to use low inorganic N with suitable grain legumes would help to sustain crop productivity. It is surprising how little is known about the contribution of grain legumes to crop production by subsistence farmers in Africa (Mapfumo and Giller, 2001; Twomlow, 2004) especially in rice (*Oriza Sativa L*) based system even if N -fixing legumes have been repeatedly shown to have positive impact on soil fertility by enhancing N and P availability and by reducing nematodes infestation (Bagayoko et al., 2000; Sanginga, 2003).

In West Africa, rice is grown under both upland and lowland conditions and about 100 million people depend on it for their livelihoods (Nwanze et al., 2006).In irrigated rice system with full water control, nitrogen is one of the most important nutrients that is badly needed. Recent studies by Wopereis et al. (1999) indicated that the effectiveness of the applied nitrogen fertilizer is very low because of several factors that include the timing and the method of application.

Legumes have the capability to fix atmospheric nitrogen and to have beneficial effects on the growth and yields of crops that follow. The N fertilizer replacement values of 40 kg to 80 kg N ha^{-1} were reported by Bagayoko et al. (2000) in cowpea (*Vigna unguiculate L))*/millet (*Pennisetum glaucum L*) or groundnut (*Arachis hypogaea*)/millet rotational systems.

Incorporating mucuna (*Mucuna utilis* L) and soybean (*Glycine Max*) before sowing rice increased grain yield by > 30% compared to the control and ranked among the highest in added benefits (0.8–0.9 t ha^{-1} grain yield) in Northern Nigeria (Okeleye, Kehinde, 2009). A similar advantage of mucuna had earlier been reported in mucuna-maize (*Zea mays L.*) rotation systems and in soybean-upland rice systems by Oikeh et al. (2008).

Van Noordwijk et al. (1995) estimated mucuna-N made available to a subsequent crop at 83%. This could have been the reason why mucuna plots preceding rice provided the highest (33%) rice yields in his study. Adigbo and Okeleye (2006) also reported that mucuna incorporation enhanced upland rice yield as observed in his trial.

Intensive rice monoculture in the Office du Niger has resulted in excessive application of chemical fertilizers (PRI, 2005). The quantity of applied nitrogen on rice was estimated to be between 250 and 300 kg ha^{-1} urea per year for a simple cropping and 518 kg ha^{-1} urea per year for the double cropping systems (PRI, 2005). Such level of nitrogen fertilizer would rapidly lead to the pollution of ground water which is already near the soil surface. Therefore, rational use of legumes as diversification crops will improve the soil fertility and consequently the nutritional status of plants, animals and humans and break the cycle of rice monoculture. The present study was initiated to determine the combined effects of preceding grain legume crops and inorganic N rates on yields of irrigated rice in the Office du Niger. The main objective was to determine the role of groundnut, cowpea and soybean in the improvement of soil fertility and rice yield in the context of crop intensification.

II. MATERIALS AND METHODS

A. Site of Experimentation

In the year 2003 and 2004, two rotational experiments were initiated to determine the effects of preceding legume crops on yields of irrigated rice in the Office du Niger zone in Mali. The office du Niger is situated in Segou region, in the interior delta of the Niger River which extends in the North-eastern direction (between 13° and 15° latitudes North and 4°-6° Western longitudes). The climate is of Soudano-Sahélienne type, characterized by one rainy season (mid-June to October), one cold season (mid-November to mid-February) and one hot season (mid-February mid-June). The average annual rainfall varies between 450 and 600 mm depending on the years. With the climate change, the tendency takes shape towards the lower limit 450 mm per annum. The average temperature varies between 14° and 40°C (with the minimum in January-February and the maximum in April-May). The prevailing winds are harmattan (wind blowing north to south between November and April) and the monsoon which is a fresh wind (blowing south-north) from May to October. The experimentation was installed on a vertisol with weak internal and external drainage. The soils are formed on old alluvium of the Niger. The vernacular name gives them the name "Danga", which are soils formed on silty loam or silty materials based on clay. The rate of organic matter is low (0.4%), pH (Kcl) is between 5.40 and 5.77; the rate of available phosphorus (Bray P) in the 0-60 cm horizon ranges between 1.06 and 1.14 mg P kg^{-1}. The soil physical and chemical characteristics estimated before the onset of the experiments are reported in Table 1.

Table 1 Physical and Chemical Characteristics of Soil from the Site of Experimentation

Measured parameters	Soil depth	
	0-30 cm	30-60 cm
Total sand (%)	38,60	36,70
Silt loam (%)	27,05	28,80
Clay (%)	34,35	34,50
pH (H_2O)	7,05	6,77
pH (Kcl)	5,77	5,40
Organic matter (%)	0,41	0,37
Total Nitrogen (%)	0,05	0,02
Bray 1 P mg Kg^{-1}	1,06	1,14
Exchangeable K (meq/100g)	0,23	0,19

B. Method of experimentation

Before the onset of the experiment in 2002, a blank trial was conducted using pure stand rice. On this trial only rice was grown with no fertilizer application. Yield response to this trial was plotted in contour graph to determine the fertility gradient (Fig. 1). This homogenization trial helped to better design the orientation of the experimental block layout in the field.

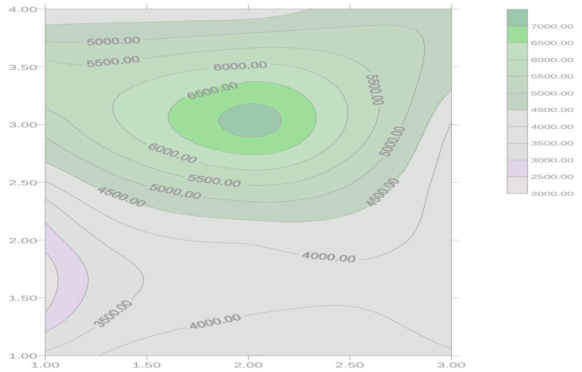

Fig. 1. Rice Yield Response to Soil Fertility Gradients in the Homogenization Trial In 2002
(Source: personal data 2002)

C. Rice/Legume Rotation Trial

During the off season of the year 2003, a rotation experiment including rice (*Oriza Sativa*), groundnut (*arachis hypogaea* L.) and cowpea *(Vigna unguiculata* Walp.) was initiated with 4 levels of mineral fertilization. The experiment design was a split plot with crop species as main plots and fertility levels as secondary plots. Fertility treatments were T0 (a control plot with no N-fertilizer) T1 (120 N ha^{-1} which corresponded to recommended N), T2 (96 N ha^{-1} which is half of the recommended N) and T3 (72 N ha^{-1}, 60% of the recommended N). The rice variety used was Kogoni 91-1 and cowpea and groundnut were local genotypes. Each treatment was replicated 3 times. The experiment had a unit plot size of 100 m² (10m x 10m). The nitrogen was applied in the form of urea.

During the rainy season in 2003 (June to November), rice was grown uniformly on all plots to evaluate the previous legumes (grown from February to May) effects on rice. The rice crop received only 100 kg ha^{-1} di-ammonium phosphate (DAP) and 100 kg ha^{-1} potassium chloride (KCL). No urea was added as so to account for previous legume N contribution on rice. All fertilizers were manually applied. This experiment was conducted in 2003 and 2004.

During the off season 2004, a more simplified experiment was set up using Groundnut, cowpea and soybean. The experiment design consisted of 4 treatments including a rice plot (T1), a groundnut plot (T2) a cowpea plot (T3) and a soybean plot (T4). These 4 treatments were setup in randomized complete bloc design (RCBD). During the rainy season 2004 all plots were uniformly grown with rice.
Fertilization was as follow:

Rice: 46 kg P2O5 + 60 kg K2O + 120 kg N (applied as DAP, KCL and Urea)

Groundnut, cowpea and soybean: 23 kg P2O5 (applied as triple super phosphate: TSP)

D. Cultural Practices

For tillage practice, the land was plowed with animal traction (using oxen drawn plow) after pre-irrigation and when excess water was completely infiltrated within the soil profile. Then, individual plots were harrowed and the seed beds were carefully prepared through manual leveling processes before sowing pulses or transplant rice seedlings.

E. Raising rice seedlings in nursery

The seedling bed was carefully prepared before sowing. The plot was hand plowed using traditional “hoe” and then manually harrowed and leveled. The seedbed was kept moist for two days then seeds were soaked overnight and planted in the nursery. The nursery was kept moist until full germination then regularly irrigated as needed without flooding. Seedlings were raised for 21 days before transplanting.

F. Transplanting process

Seedlings were transplanted in cluster of 3 to 4 plants at 21 days after sowing in nursery. After transplanting, the plots were kept flooded throughout the growing period.

1. Weed management

Weeding was done manually. During the growing period, two manual weeding were necessary.

2. Data collection and sampling

Soil samples prior to installation of the crops were taken in the study area to characterize the study site. During the course of the experiment, the soil pH and the electrical conductivity (EC) of the water layer were measured. For agronomic parameter, collected data concerned yield and yield parameters. For rice, plant population and productive tillers/m² were recorded by counting the average of ten pockets taken randomly from each treatment in each plots. Plant height, grain per panicle and 1000 grains weight were recorded. For pulses, data collected concerned pods, straw and total biomass.

3. Nutrient use efficiency analysis

The nitrogen use efficiency analysis was based on the partial factor productivity (PFP) and the agronomic efficiency (AE). These parameters were calculated as follow:

$$\mathrm{PFP} = \frac{\text{Rice grain yield}}{\text{Amount of fertilizer nutrients}}$$

$$\mathrm{AE} = \frac{\text{yield in N plots} - \text{yield in control plot } (kg)}{\text{quantity of N fertilizer applied}}$$

4. Statistical analysis

Analysis of variance was performed with the GENSTAT 5 release 3 (Lawes Agricultural Trust, 1993). Analysis of variance was carried out on all parameters. Means were compared by using the Least Significant Difference (LSD) at 5% probability level. The LSD was calculated as follow:

$\mathrm{LSD} = \sqrt{(2VE/\mathrm{Nrep})} \times t_{5\%}$

Where: VE = variance error

Nrep = number of replication

$t_{5\%}$ = t value from the t table at 5%

III. RESULTS AND DISCUSSION

A. Growth and Yields of Leguminous Crops

The first year (2003), legume germination was severely affected by water logging. The few germinated legume plants grew very poorly. Therefore, straw and pod yields of groundnut and cowpea were very low (Table 2).

Table 2. Straw and pod yield of groundnut and cowpea in 2003

N rates (kg ha^{-1})	Groundnut		Cowpea	
	Pods kg ha^{-1}	staw kg ha^{-1}	Pods kg ha^{-1}	staw kg ha^{-1}
0 N	88	100	-	50
72 N	63	100	-	85
96 N	150	88	-	63
120 N	100	88	-	85
P>F	0.446	0.844	-	0.559
LSD	119	44	-	65
CV %	75	30	-	58

In 2004, the growth and development of legume crops were much better than 2003 because the drainage system of the plots was improved and cultural practices were optimized. Although yields of legume crops were high no significant differences were observed between N rate treatments.

B. Rice Growth and Yields after Leguminous Crops

1. Growth parameter and yield response

In 2003, rice germination and growth were severely affected by the prolonged cool season (November to March). Rice plants in continuous rice plots remained stunted and yellowish. Several patches of affected areas were visible. The top leaves of the affected plants looked dry. Application of phosphorus, nitrogen and potassium did not improve much the growth. This suggested the presence of a growth limiting factor other than N, P and K. Application of different rates on nitrogen showed significant differences between treatments on straw yield, but not on paddy yield. Also, Tiller and panicle numbers were not significantly affected (Table 3). Average rice yield was less than 3 t ha^{-1}, which is far below the annual average of the Office du Niger, estimated at about 5 t ha^{-1}.

Table 3. Continuous plot yields and yield components during the off-season 2003 at Niono agronomic research station.

Nitrogen rates (kg ha^{-1})	Tiller number m^{-2}	Panicle number m^{-2}	Straw yield kg ha^{-1}	Paddy yield kg ha^{-1}	Ratio Paddy /Straw
0 N	546	560	1654	1650	1,00
72 N	566	549	3611	2875	0,80
96 N	621	620	2380	2475	1,04
120 N	645	596	2596	2550	0,98
P>F	0.692	0.499	0.016	0.095	0.326
LSD	211	184	1057	985	0.3559
CV	22	20	26	26	21

During the rainy season of 2003, there was no interaction between previous crop treatments and nitrogen rates. Previous crop main effect was significant on straw yield (P>F = 0.003) and paddy yield (P>F = 0.005). In general, rice following legume crop had better yield than rice following rice (Table 4). Rice following groundnut and rice following cowpea had similar yields (not significantly different from each other). During the rainy season, there was significant interaction between crop history and nitrogen level (Table 4)

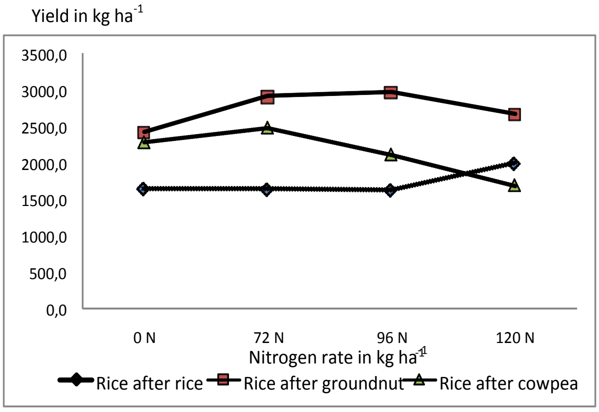

Fig. 2. Previous crop effects on rice yield during the wet season 2003 at the agronomic research station of Niono

Nitrogen application resulted in high significant differences between the different treatments (Table 4) but the magnitude of the differences depended on previous crop (Fig 2). As it could be expected, there was a linear relationship between the increasing rates of nitrogen and the yield response. Continuous rice yield responded steadily to high N application while rice yield after cowpea tented to decrease with increasing N. Maximum rice yields were recorded with rice/groundnut rotation whatever the N level is.

Table 4. Rice yield after previous legume crops during the rainy season of 2003 at Niono agronomic research station.

	Paddy yield Kg ha^{-1}	Straw yield Kg ha^{-1}	Total biomass yield kg ha^{-1}
Cropping system			
Rice after rice	3104	2853	5957
Rice after cowpea	3553	3216	6769
Rice after groundnut	3793	3447	7241
LSD	360.7	250.3	596.0
CV	6	5	5
Nitrogen rates			
0 N	2907	2637	5543
72 N	3092	2807	5898
96 N	3986	3624	7610
120 N	3950	3620	7571
LSD	571.8	539.2	1106.5
CV	20	20	20
Test F			
Previous crops (Prc.)	0.009	0.003	0.005
Nitrogen	<.001	<.001	<.001
Prc. x nitrogen	0.022	0.212	0.214
CV	20	20	20

In 2004, previous crop effects were significant on straw (P>F = 0.035) and paddy (P>F = 0.045) yields (Table 5) but not on tiller and panicle.

Table 5. Tiller and panicle numbers in rice / legume rotation trial at Niono agronomic research station in 2004

Previous	Tiller number per m²	Panicle number per m²	Paddy yield kg ha^{-1}	Straw yield kg ha^{-1}
Rice after groundnut	255	330	3550	4700
Rice after cowpea	256	296	3560	4960
Rice after rice	268	298	2780	3380
Rice after soybean	299	301	3990	4010
P>F	0.075	0.125	0.045	0.035
LSD	25	76	155	92
CV (%)	15	20	45	33

Rice yields after previous legumes were much higher than rice after rice. The magnitude of yield increase due to previous legume was 28 % for cowpea and groundnut and 48% for soybean.

2. Nitrogen use efficiencies

With the monoculture of rice (rice after rice) nitrogen use efficiency was low at low N rate (almost 0 kg paddy kg^{-1} N) and high (4 kg paddy kg^{-1} N) with high N rate. However, with rotation plots, N use efficiency decreased with increasing rates of N application (Fig. 2). Increase in N used efficiency with the monoculture of rice was not expected in this study and the reason is not clear.

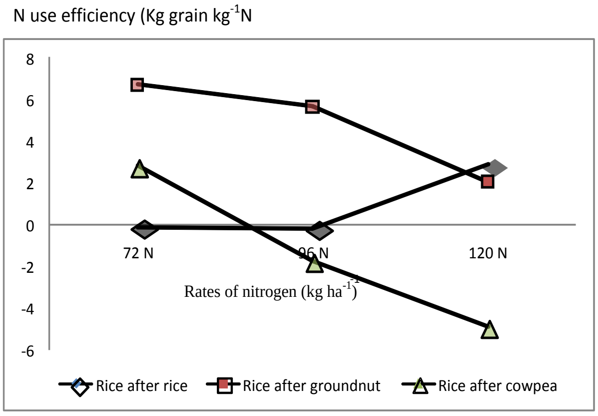

Fig. 3. Agronomic Efficiency of Applied Nitrogen on Rice Yield In 2003

Discussion

The results of the present study indicated that the soils of the study area had some nutritional disorders. In 2003, the poor growth of legume crops was related to water logging due to the bad drainage system of the experimental plots. Rice plants remained stunted throughout the active growth period despite the application of phosphorus and nitrogen fertilizers. It was suspected that the experimental plots had some problem of iron toxicity as this phenomenon could be observed from place to place as patches of stunted growth with leaves color turning to yellow and brown were visible. In some places leave tips appeared completely dry. Iron toxicity problems in upland lowland rice are steadily reported throughout West Africa (Audebert, 2006, Bernardin, 2006; Mamadou, 2006, Amadou et al., 2006). Yield reductions of 12 to 100% due to iron toxicity were reported depending on the prevailing soils iron toxicity level (Massojo et al., 1986, Audebert, 2006, Bernardin, 2006).

It was noticed that when the growth conditions are favorable, rotating pulses with rice can contribute to significant rice yield enhancement. However, water logging can hamper rice growth and inhibit nitrogen fixation of legume. One of the reasons of introducing legume crops in rotational system is their ability to fix di-nitrogen. In agricultural soils, there is a symbiosis of legumes and bacteria of the genera Rhizobium, which are responsible for fixing nitrogen. Water logging will alter this relationship and cause reduction in root growth and nodule formation (Curt Jude Riche, 2004,; Jong-Tag Youn, 2008). In the year, 2004 when cultural practices were improved to suit legume crops, the growth was better than the first year and yields were much higher.

IV. CONCLUSION

From the present study, it can be concluded that when the growth conditions are favorable, rotating pulses with rice can contribute to significant rice yield enhancement. Despite the assumption of iron toxicity problem in the study area, legume effects on rice were significant. Yield increase with rice after pulses ranged from 28 % for cowpea and groundnut to 48 % for soybean when compared with rice after rice. Nitrogen use efficiency was altered by previous crop. In general, nitrogen use efficiency decreased with increasing N application in all cropping system except continuous rice.

Although the assumption of iron toxicity was made to explain the poor growth of rice plant and the low yield response to added mineral fertilizers in the study area, other factors may have been involved such as plant disease pathogens particularly nematodes. Therefore, further investigation is needed to clarify the low yield level of irrigated rice.

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REFERENCES

[1] R. I. Ali, T. H. Awan, M. Ahmad, M. U. Saleem and M. Akhtar, “Diversification of rice-based cropping systems to improve soil fertility, sustainable productivity and economics diversification of rice-based cropping systems to improve soil,” Journal of Animal & Plant Sciences, 22(1): 108-112, 2012.

[2] S.O. Adigbo, K.A. Okeleye, “Green manuring and nitrogen fertilization effects on soil chemical properties, agronomic traits and grain yield of upland rice,” Moore Journal of Agricultural Research. 7 (1):1-8, 2006.

[3] A. Audebert, “Iron toxicity in rice. Environmental conditions and symptoms,” In A. Audebert, L.T. Narteh, P. Kiepe, D. Millar and B. Beks (editors). Iron Toxicity in Rice-based Systems in West Africa – Africa Rice Center 2006. Pp 25-33, 2006.

[4] Curt Jude Riche, “Identification Of Soybean Cultivars Tolerance To Waterlogging Through Analyses Of Leaf Nitrogen Concentration”. A Thesis research. 42p, 2004.

[5] Jong-Tag Youn “Water logging Effects on Nitrogen Accumulation and N2 Fixation of Supernodulating Soybean Mutants.” J. Crop Sci. Biotech. (11) 111-118, 2008.

[6] L.T. Narteh and K.L. Sahrawat, “Influence of flooding on electrochemical and chemical properties of West African soilsGeoderma 87: 179-207, 1999.

[7] L. Bernardin “Evaluation of iron toxicity on rice production in Lotodenou in Southern Benin,” In A.Audebert, L.T. Narteh, P. Kiepe, D. Millar and B. Beks (editors). Iron Toxicity in Rice-based Systems in West Africa – Africa Rice Center 2006. Pp 25-33, 2006.

[8] K. Mamadou, “An outline of iron toxicity in the soils of Casamance rice fields,”. In A.Audebert, L.T. Narteh, P. Kiepe, D. Millar and B. Beks (editors). Iron Toxicity in Rice-based Systems in West Africa – Africa Rice Center 2006. Pp 25-33, 2006.

[9] C. Mamadou, F. Mamadou, A. Audebert, Z. Michel, “Iron Toxicity in Rice-based Systems in West Africa,” In A. Audebert, L.T. Narteh, P. Kiepe, D. Millar and B. Beks (editors).– Africa Rice Center 2006. Pp 25-33.

[10] T.M. Masajo, K. Alluri, A.O. Abifarin and D. Janakiram, “Breeding for high and stable yields in Africa,” In: ASR Juo and J.A Lowe (Eds). The Wetlands in sub-Saharan Africa. Proceedings of the International Conference on Wetland Utilization for Rice Production in sub-Saharan Africa, 4-8 November 1985. Ibadan, Nigeria. pp 107-114.

[11] A.O. Abifarin, “Grain yield loss due to iron toxicity,” WARDA Technical Newletter 8 (1):1-4. , 1988.

[12] A.O. Abifarin, “Progress in Breeding Rice for Tolerance to Iron toxicity” WARDA Annual Report: 34-39, 1989.

[13] K. A. Okeleye, “Influence of Legume/rice Sequence and Nitrogen on NERICA rice in Rainfed Upland and Lowland Ecologies of West Africa. The proceedings of International.

[14] M. Bagayoko, A. Buerkert, G. Lung, A. Bationo and V. RömheldCereal/legume rotation effects on cereal growth in Sudano-Sahelian West Africa: soil mineral nitrogen, mycorrhizae and nematodes. Plant and Soil 218, 103-116 , 2000.

[15] M. Bagayoko, E. George, V. Roemheld and A. Buerkert “Effects of mycorrhizae and phosphorus on growth and nutrient uptake of pearl millet, cowpea and sorghum on a West African soil,”. Journal of Agricultural Science 135, 399-407, 2000.

[16] P. Mapfumo, K.E. Giller "Soil Fertility and Management Strategies and Practices by Smallholder Farmers in Semi-arid Areas of Zimbabwe". ICRISAT report 2001.

[17] N. Sanginga, "Role of biological nitrogen fixation in legume-based cropping systems," Plant Soil. 252:25–39, 2003.

[18] PRI (Programmed Riz Irrigué), annual report 2005.

[19] S. J. Twomlow "Increasing the Role of Legumes in Smallholder Farming System– The Future Challenge,". In Serraj R, ed. Symbiotic Nitrogen Fixation: Prospects for Application in Tropical Agro ecosystems. Science Publishers, USA; 29-46, 2004.

[20] Nwanze K F Mohapatra S Kormawa PM Keya S Bruce-Oliver S 2006. Rice development in sub-Saharan African. Perspective. J. Sc. Food and Agric. 86:675–677.

[21] M. Van Noordwijk, S.M. Sitompul, K. Hairiah, E. Listyarini, "Nitrogen supply from rotation of spatially zoned inclusion of leguminous for sustainable maize production on an acid soil in Indonesia,". In: plant soil interaction at low pH, by Date RA et al. ed. Kluwer Press. 779– 784, 1995.

[22] S.O. Oikeh, P. Houngnandan, R.C. Abaidoo, I. Rahimou, A. Touré, A. Niang, I. kintayo, "Integrated soil fertility management involving promiscuous dual-purpose soybean and upland NERICA enhanced rice productivity in the savannas,". Nutr Cycl Agroecosyst, 2008.