VOL. 7, NO. 8, AUGUST 2012 ISSN 1990-6145
ARPN Journal of Agricultural and Biological Science

EFFECTS OF PLANT DENSITY, ORGANIC MATTER AND NITROGEN RATES ON RICE YIELDS IN THE SYSTEM OF RICE INTENSIFICATION (SRI) IN THE "OFFICE DU NIGER" IN MALI

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ABSTRACT

A study was conducted to determine influence of combined application of farmyard manure and different levels of inorganic fertilizer on growth, yield and yield components in the System of Rice Intensification in Mali. Three types of experiments were conducted at the agronomic research station of the Regional Centre of Agronomic Research of Niono (CRRA-N) in the Office du Niger zone, which extends in the North-eastern direction (between 13° and 15° latitudes North and 4°-6° Western longitudes). The materials used comprised a rice variety, mineral fertilizers and organic matter. The rice variety used was Kogoni 91-1 also called (*Gambiaka Suruni*) which is an improved variety with a cycle of 120 days. The mineral fertilizers used were, triple superphosphate (TSP), Di-Ammonium Phosphate (DAP, urea and potassium chloride. The potassium chloride was uniformly applied to all plots, while the rate of application of TSP, urea and DAP depended on the treatments described in the research protocol. The organic matter (OM) source was animal manure coming from the animal park of the research station. This manure was characterized by low content of nitrogen (0, 34 %N), phosphorus (0.16% P) and potassium (0.65% K). The results indicated significant yield benefit of the SRI system although the drainage system not efficient. Significant interaction between row spacing and soil fertility level occurred showing that row spacing as wide as 30cm x 30cm can be used in SRI system when soil fertility is high. However, when soil fertility level is low, it is reasonable to use row spacing of 25cm x 25cm or narrower as certain studies have already shown it. Although good yield can be obtained using farmyard manure, addition of mineral fertilizer still increase rice yield showing that combination of organic and inorganic fertilizer should be considered to sustain rice yield.

Keywords: system of rice intensification, row spacing, manure, mineral fertilizer, yield, agronomic efficiency.

INTRODUCTION

Rice is a major staple in Mali, particularly in urban areas. Per capita rice consumption in Mali is estimated at 57 kg, making rice the third significant among the cereals after millet and sorghum (Diarra *et al*., 2000; Initiative Riz, 2008). Since the year 2000, rice imports in Mali have reached 200,000 tons per year (PRI 2006). Supply short ages or rising prices produce inflammatory pressure on wages and have a potential of creating political instability. Because of this strategic importance, the Government of Mali has been deeply involved in rice production and marketing. Although imports are expected to be a solution for food shortage, massive rice importation may cause negative effects on national production, because of differences in prices. The impact of subsidized cheap rice on local markets can jeopardize local rice production and profitability due to high input costs. In 2008, rice production in the Office du Niger was estimated to be 560,000 tons with a yield average of 5.6 t/ha. Although this yield range may be considered as high, it is still far below the yield potential that can be generated by high yielding varieties and improved cultural practices (Malian government rice initiative project 2008). Among yield limiting factors are land preparation methods, careless transplanting of old rice seedlings, unbalance use of fertilizers, planting densities, scarcity and high cost of labor leading to delay in transplanting time etc.

In the Office du Niger, land preparation is usually done with oxen drawn plow. At the start of the rice growing period, the animals do not have enough energy to pull the plow, and this leads to shallow and insufficient transplanting bed preparation. Shallow land preparation leads to transplanting difficulties and delay in seedling recovery from transplanting stress. This affects productive tiller number and crop yield at harvest. Another production constraint is careless transplanting by hired labor. This is usually due to the rarity and the high cost of labor which do not allow producers to transplant when seedlings are at the right transplanting age. Delay in transplanting is a known factor that cause low yield (Santhi *et al*., 1998,; Dicko, 2005).

Fertilizer use efficiency is a measure of maximum returns per unit of fertilizer applied (Mortvedt *et al*., 2001). Unbalanced fertilizer use in terms of N and P ratio has created concern in agricultural productivity (FAO, 2007). Unbalance fertilizer use and practice of inappropriate production technologies are common among farmers. These comprise low rates of some nutrients such as phosphorus and potassium, timing, method and excessive nitrogen application. Judicious use of nitrogen is a key factor in rice based production system. In general N use in relation in relation to P and K use is excessive (Bum *et al*., 1996). This reduces the efficiencies of all nutrients and results from the tendency of farmers to save on costs (P and K fertilizers being significantly reduced or neglected). This reduces return on investment in N fertilizer (Amanullah and Lal, 2009) and leads to degradation of soil and causes environmental problems (Cisse and Amar, 2000).

Soils usually have low organic matter content and unbalanced fertilizer applications at improper time can severely affect nutrient uptake further reduce crop production. Organic materials such as green manure, compost and farmyard manure have demonstrated positive impact on yield and yield parameters in rice growing areas trough the world. However, there is a concern about the sustainability of sole application of these materials because of their low nutrient content which may not be enough to cover plant nutrient needs. For this reason, integrated nutrient management strategies have been proposed to include simultaneous use of both inorganic and organic materials as the most effective method to maintain a healthy and sustainable soil/plant system while increasing the productivity (Bado, 1997; Dembele, 2007; Raman *et al*., 1996; Singh *et al*., 1999). While synthetic fertilizer is applied to feed the plant on short term, organic compound are use to feed the soil system that feed the plant (Amir *et al*., 2011) making the combination a sustainable strategy for long term run.

In the recent decade, the new “System of Rice Intensification (SRI)”, developed through empirical method in Madagascar, is seen to be a solution for food security and therefore, getting its way in developing countries especially in Africa because this system, under most circumstances can significantly increase the productivity of land, water, seeds, capital and labor use for irrigated rice (Kassam *et al*., 2011; Sathia and Sathya, 2009; Ceesay, 2011). This SRI has its own methodologies that include transplanting of very young seedling (8-15 days old), transplanting single seedling per hill at square pattern of 25cm x 25cm, 30cm x 30cm (or wider spacing), use of mechanical weeder to aerate the soil/plant system, alternate wetting and drying the soil (soil not flooded during the vegetation period), use of organic manure as nutrient source.

The present research was conducted to study influence of combined application of farmyard manure and different levels of inorganic fertilizer on growth, yield and yield components in the System of Rice Intensification in Mali.

MATERIALS AND METHODS

Experimental site

In 2009 and 2002, three types of experiments were conducted at the agronomic research station of the Regional Rentre of Agronomic Research of Niono (CRRA-N) in Office du Niger zone. The Office du Niger is situated 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 (November-semi-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 characterized by a coarse structure and termed by the vernacular name “dian”.

Plots history

The experimental design was installed on a plot having a cropping history of 5 years after 2 years fallow period. Before installing the experiment, a homogenization trial was setup using a rice crop. During this period, no mineral fertilization or organic nutrient source was applied.

Materials used in the study

The materials used in this study comprise a rice variety, mineral fertilizers and organic matter. The rice variety used was Kogoni 91-1 also called (*Gambiaka Suruni*) which is an improved variety with a cycle of 120 days. The yield potential of this variety is estimated to be 10 T/ha. It is the most common variety used by farmers in the Office du Niger zone. This variety is highly appreciated by consumers.

The mineral fertilizers used were Di-Ammonium Phosphate (DAP) and Urea and potassium chloride. The potassium chloride was uniformly applied to all plots, while the rate of application of urea and DAP depended on the treatments described in the research protocol.

The organic matter (OM) source was animal manure coming from the animal park of the research station. This manure was characterized by low content of nitrogen (0, 34% N), phosphorus (0.16% P) and potassium (0.65% K).

Experimental setup

First experiment

Treatments used

Factorial combination of 3 rates organic fertilizer, 2 row spacing and 3 mineral fertilizers.

Row spacing (Rs):
Rs1 = 25 x 25 cm
Rs2 = 30 x 30 cm

Organic fertilizer
FO1 = 5 T/ha of farmyard manure
FO2 = 10 T/ha of farmyard manure
FO3 = 15 T/ha of farmyard manure

Mineral fertilizer
FM1 = control (No fertilizer)
FM2 = 100 kg/ha Urea and 50 kg/ha DAP (half of the recommended fertilizer)

FM3 = 200 kg/ha Urea and 100 kg/ha DAP (recommended fertilizer for the area).

Experimental layout

The experimental design was a split plot with 3 rates of manure for main plots treatments and the combination of 2 densities and 3 rates of mineral fertilizers for secondary plot treatments. Secondary treatment combinations were randomly distributed within main plots. Each treatment was replicated 4 times.

Second experiment

Treatment design

The treatment design was a factorial combination of 3 rates of farmyard manure and 6 rates of nitrogen. The manure came from the animal park of the research station while nitrogen was applied in the form of urea. The treatment description is shown in Table-1.

Table-1. Description of the treatments

Organic fertilizer	Nitrogen levels
FO1 = 5 T/ha manure	N1 = 0 kg/ha N
FO2 = 10 T/ha manure	N2 = 40 kg/ha N
FO3 = 15 T/ha manure	N3 = 80 kg/ha N
	N4 = 120 kg/ha N
	N5 = 160 kg/ha N
	N6 = 200 kg/ha N

Experimental layout

The 18 treatments were distributed within a randomized complete bloc design (RCBD) with 4 replications.

Third experiment

Treatment design

The treatment design was a factorial combination of 4 rates of phosphorus and 6 rates of nitrogen. The phosphorus source was triple super phosphate (TSP) while nitrogen was applied in the form of urea. The treatment description is shown in Table-2.

Table-2. Description of the treatments.

Phosphorus levels	Nitrogen rates
P1 = 0 kg/ha P	N1 = 0 kg/ha N
P1 = 10 kg/ha P	N2 = 40 kg/ha N
P2 = 20 kg/ha P	N3 = 80 kg/ha N
P4 = 30 kg/ha P	N4 = 120 kg/ha N
	N5 = 160 kg/ha N
	N6 = 200 kg/ha N

Experimental layout

The 24 treatments were distributed within a randomized complete bloc design (RCBD) with 4 replications.

Cultural practices

The cultural practices were similar for all experiments. The land was submersed overnight and deeply plowed with animal traction after excess water was completely infiltrated within the soil profile. Then, subplot sizes of 5m×4m were laid out to receive treatments. All plots were surrounded by consolidated bunds. Main plot treatments were first installed then organic matter treatments were applied and thoroughly mixed up through the harrowing process. The seed beds were carefully prepared before transplant rice seedlings.

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.

Transplanting the seedlings

Seedlings were transplanted (one seedling per hill) at 15 days after sowing in nursery. Transplanting spacing between hills depended on treatment description (25cm × 25cm for D1 and 30cm × 30cm for D2). SRI plots were supposed to be kept saturated until flowering, but the rainfall pattern did not always allow this practice. Frequent rains occurred in 2009 and 2010 and drainage was not always possible. Consequently, plots were sometimes maintained with standing water for 3-7 days (depending on rainfall intensify and frequency).

Weed management

The plots were kept weed free throughout the growing period. Weeding was done manually 2 weeks after transplanting then mechanically after on. A hand pushing rotavator was used twice each year with 10 days interval.

Data collection and sampling

Collected data concerned yield and yield parameters. 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, sterility % and 1000 grains weight were recorded.

Nutrient use efficiency analysis

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

$$AE = \frac{\text{Rice yield in fertilizer plot} - \text{Rice yield in control plot (kg)}}{\text{Quantity of fertilizer nutrient applied}}$$

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

Economic analysis

The economic analysis was based on the value cost ratio (VCR) analysis calculated as fallow:

$$VCR = \frac{\textit{Value of the additional yield}}{\textbf{Value of fertilizer used}}$$

Statistical analysis

Analysis of variance was performed with the GENSTAT 5 release 3 (Lawes Agricultural Trust, 1993) the split-plot designs with manure applications as the main factor and the combination of planting density x N rates as the sub-factor in each year. Means were compared by using the standard error of the difference of the means (Sed). Analysis of variance was carried out on all parameters for the two-year period.

RESULTS

Influence of planting density, manure and mineral fertilizer on yield and yield components

The data presented in Tables 3 and 4 showed significant interactions between row spacing and mineral fertilizer and between mineral fertilizers and manure in years 2009 and 2010. These interactions were illustrated in Figure-1 and Figure-2.

Row spacing and mineral fertilizer interaction effects on rice paddy yield

Figure-1 shows that with no fertilizer application, rice yield was lower at with wide row spacing (30cm x 30cm) than narrow row spacing (25cm x 25cm). With ½ recommended fertilizer applications, rice yield was similar for both row spacing. At recommended fertilizer rate, rice yield increased with wider row spacing compared with narrower one (P = 0.05).

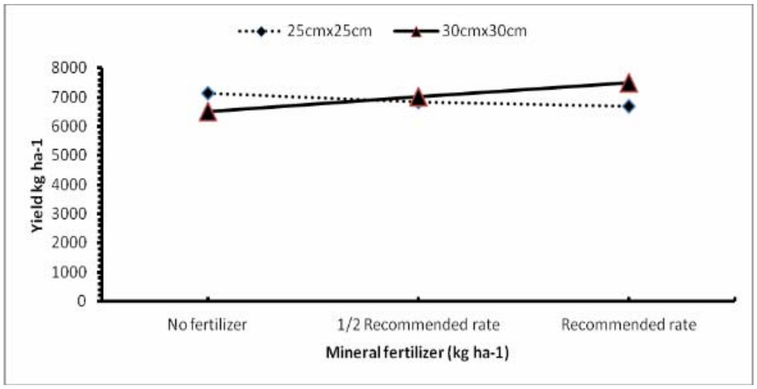

Figure-1. Interaction between row spacing and mineral fertilizer application rates.

Figure-2 shows that paddy yields were lower when no mineral fertilizer was applied. Addition of recommended or ½ recommended fertilizer increased rice yield by 32% at 5T ha^{-1} manure, 32% to 55% at 10T ha^{-1} manure and 25-26% at 15T ha^{-1} manure. These show a synergic effect between mineral fertilizer applications and manure.

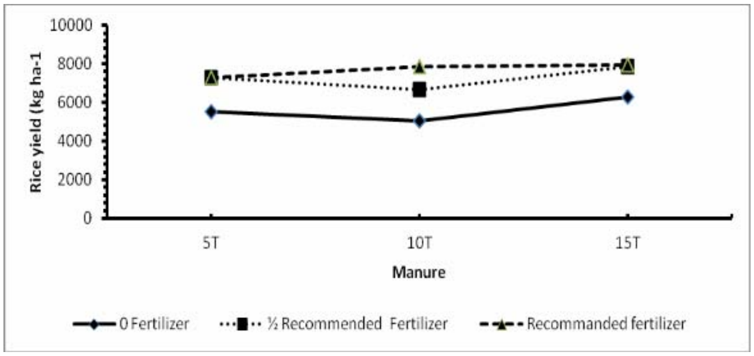

Figure-2. Interaction effects of manure and mineral fertilizer on rice yield in the SRI system at Niono research station in 2009.

Table-3. Row spacing, mineral fertilizer and manure effects on yield and yield component in Niono research station in 2009.

	Plant height (cm)	**Tiller number per m²**	**Panicles number per m²**	**Thousand grains weight (g)**	**Paddy yield kg/ha**
Row spacing (Rowsp)					
25cm x 25cm	84.03	173, 12	157,12	23, 8	6860
30cm x 30cm	83.28	213, 28	194,4	24.0	6890
P>F	0.533	0, 004	0,003	0, 552	0,96
Sed	1.067	4, 896	4,016	0, 303	606,5
Rates of manure					
5 T/ha manure	83.62	189, 28	175,2	24, 52	6810
10 T/ha manure	83.50	200, 64	180,16	23, 24	6780
T/ha manure	83.83	189, 6	172	23, 94	7035
Mineral fertilizer (MineralF)					
0 Mineral fertilization	82.42	184, 96	170,08	24, 17	6820
½Recommended rate fertilizer	83.04	192, 8	173,6	24, 07	6840
Complete recommended fertilizer	85.50	201, 92	183,52	23, 47	6970
Sed	1.328	7, 728	6,768	0, 708	186, 5
	P>F				
MineralF	0.058	0.099	0.130	0.570	0.683
Manure	0.968	0.262	0.473	0.201	0.335
Rowspac. MineralF	0.856	0.834	0.394	0.452	0.005
Rowspac. Manure	0.963	0.982	0.962	0.647	0.026
MineralF. Manure	0.721	0.153	0.080	0.543	0.019
Rowspac. MineralF. Manure	0.332	0.275	0.236	0.961	0.587
CV%	5.5	13.9	13.3	10.3	9.4

Table-4. Row spacing, mineral fertilizer and manure effects on yield and yield component in Niono research station in 2010.

	Plant height (cm)	**Tiller number per m²**	**Panicles Number per m²**	**Thousand grains weight (g)**	**Paddy yield kg/ha**
Row spacing					
25cm x 25cm	85.89	135.68	175.2	23.78	6917
30cm x 30cm	84.47	135.12	202.3	23.87	7125
P>F	0.336	0.654	0.024	0.725	0.754
Sed	1.238	1.127	6.40	0.217	606.2
Mineral fertilizer					
0 Fertilization	84.92	131.90	172.0	24.15	6819
½Recommended rate fertilizer	84.33	135.96	186.2	24.06	7025
Complete recommended fertilizer	86.29	138.34	208.1	23.27	7219
Sed	1.175	1.787	10.24	0.663	192.9
Rates of manure					
5 T/ha manure	85.12	135.98	179.7	24.30	6954
10 T/ha manure	84.33	134.95	195.7	23.24	6927
T/ha manure	86.08	135.27	190.9	23.94	7181
Sed	1.175	1.787	10.24	0.663	192.9
	P>F				
MineralF	0.337	0.003	0.004	0.352	0.127
Manure	0.242	0.841	0.285	0.273	0.359
Rowspac. MineralF	0.833	0.692	0.235	0.335	<.001
Rowspac. Manure	0.139	0.873	0.838	0.540	0.548
MineralF. Manure	0.408	0.696	0.334	0.489	0.025
Rowspac. MineralF. Manure	0.562	0.356	0.695	0.996	0.618
CV%	4.8	4.6	18.8	9.6	9.5

Effects on other yield parameters

In general row spacing had some significant influence on tiller number and panicle number (Table-3). With wider row spacing, tiller number (P = 0.004) and panicle number (P = 0.003) increased in 2009. In 2010, differences were not significant for tiller number, but panicle numbers increased significantly (P = 0.024). The combined analysis of variances of the two year experiments indicated year interaction with row spacing (Table-5).

Table-5. Degree of freedom and F probability of yield and yield components (averaged over two years 2009-2010) in row spacing x manure x mineral fertilizer experiment at Niono research station.

Variate		**Plant height**	**Tiller number**	**Panicle number**	**1000 grains weight (g)**	**Paddy yield (kg)**
Source of variation	d.f.	F pr.				
Rep stratum	3					
Rep.Yr stratum						
Yr	1	0.014	0.001	0.035	0.337	0.015
Residual	3					
Rep.Yr.Rowspac stratum						
Rowspac	1	0.233	<.001	<.001	0.471	0.788
Yr.Rowspac	1	0.698	<.001	0.221	0.761	0.845
Residual	6					
Rep. Yr. Rowspac.*Units* stratum						
MineralF	2	0.028	0.016	<.001	0.199	0.115
Manure	2	0.409	0.324	0.219	0.049	0.110
Yr.MineralF	2	0.467	0.409	0.181	0.974	0.614
Rowspac. MineralF	2	0.711	0.755	0.107	0.148	<.001
Yr.Manure	2	0.633	0.237	0.467	0.965	1.000
Rowspac. Manure	2	0.296	0.994	0.920	0.346	0.274
MineralF. Manure	4	0.222	0.215	0.031	0.159	<.001
Yr.Rowspac. MineralF	2	0.997	0.907	0.653	0.968	0.839
Yr.Rowspac. Manure	2	0.514	0.959	0.825	0.977	1.000
Yr.MineralF. Manure	4	0.991	0.120	0.889	0.999	1.000
Rowspac. MineralF. Manure	4	0.142	0.262	0.303	0.947	0.227
Residual	100					
Total	143					

Increasing rates of nitrogen fertilizer and manure on yield and yield components of rice

The results of experiment two on increasing rates of nitrogen and manure, presented in Table-6 did not show any significant interaction between factors. Also, no significant differences were observed with manure rates. Manure effects were very heterogeneous and high rates did not necessarily increase crop yield. Application of different rates of nitrogen had some influence on grain number per panicle (P = 0.019) and grain yield (P<0.001). In general the responses to nitrogen rates were linear with $R^2 = 0.777$ for grain per panicle and $R^2 = 0, 926$ for grain yield per ha (Figure-3a and Figure-3b).

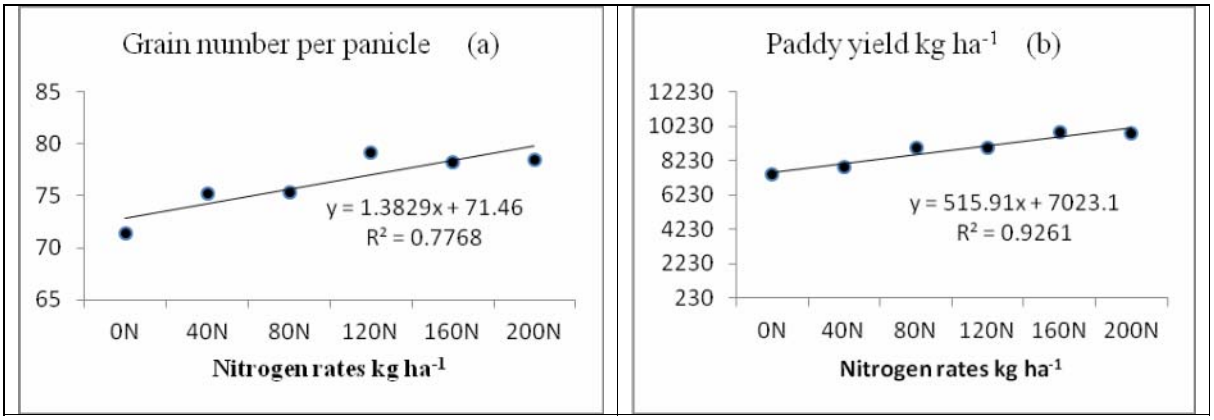

Figure-3. Influence of different rates of nitrogen on yield and yield parameters.

Table-6. Influence of manure and nitrogen rates on yield and yield parameters in the system of rice intensification (SRI), Niono, 2010.

	Tiller number per m^2 60 DAP	**Grain number per panicle**	**Number of panicle per m^2**	**Paddy yield kg/ha**
Rate of phosphorus				
FO1 = 5 T/ha manure	319.2	76.6	291.04	8644
FO2 = 10 T/ha manure	311.3	75.9	294.3	9071
FO3 = 15 T/ha manure	305.4	76.5	287.2	8771
S.e.d.	24.896	6.41	22.16	551.2
Rate of nitrogen				
0N	303.3	71.4	281.6	7451
40N	311.2	75.2	285.6	7850
80N	302.2	75.3	290.51	8953
120N	321.4	79.2	291.6	8999
160N	312.2	78.2	298.56	9892
200N	321.5	78.5	297.21	9828
S.e.d.	30.496	7.86	27.136	779.6
	P>F			
Manure	0.408	0.677	0.616	0.601
Nitrogen	0.214	0.019	0.159	<0.001
Manure x nitrogen	0.867	0.252	0.77	0.997
S.e.d. manure x nitrogen	38.11	15.71	33.92	1350.3
CV%	20	21.6	19.4	21.6

Table-7. Phosphorus and nitrogen interaction effects on yield parameters in 2010

	Tiller number per m^2 60 DAP	Grain number per panicle	Number of panicle per m^2	Paddy yield kg/ha
Rate of phosphorus				
0P	323.52	71.6	291.04	6613
10P	302.88	69.9	283.2	6794
20P	309.44	71.6	284	6917
30P	281.12	77.3	262.72	6972
SED	24.896	6.41	22.16	312.1
Rate of nitrogen				
0N	278.24	62.3	258.56	6310
40N	281.28	82.5	254.56	5954
80N	284.8	84.4	267.36	7166
120N	310.24	62.1	277.76	7639
160N	339.36	78.1	313.6	6925
200N	331.36	66.2	309.44	6950
SED	30.496	7.86	27.136	382.3
	P>F			
Dose P	0.408	0.677	0.616	0.67
Dose N	0.214	0.029	0.159	0.011
Dose N x P	0.867	0.252	0.77	0.985
SED	38.11	15.71	33.92	764.6
CV (%)	20	21.6	19.4	15.8

Table-8. Phosphorus and nitrogen interaction effects on yield parameters in 2011

	Tiller number per m^2 60 DAP	Grain number per panicle	Number of panicle per m^2	Paddy yield kg/ha
Rate of phosphorus				
0P	304.52	81.6	279.0	6901
10P	321.88	79.9	296.2	7263
20P	300.44	81.6	297.0	7372
30P	291.12	87.3	295.7	7384
SED	24.896	6.41	292.0	312.1
Rate of nitrogen				
0N	274.21	72.3	270.55	6110
40N	285.28	92.5	270.68	7152
80N	285.8	94.4	270.36	7160
120N	311.11	92.1	311.49	7527
160N	339.2	78.1	316.25	7781
200N	331.36	66.2	312.55	7650
SED	30.496	7.88	391.98	282.3
	P>F			
Dose P	0.308	0.572	0.518	0.671
Dose N	0.234	0.019	0.259	<.001
Dose N x P	0.768	0.352	0.75	0.985
SED	39.41	14.62	36.92	764.6
CV (%)	20	25.6	19.4	19.8

Effects of phosphorus and nitrogen (experiment 3)

The two years results did not show any significant differences between phosphate and nitrogen rates (Table-7). Also, no significant effects of phosphate rates were observed. As in the previous experiment nitrogen application affected linearly the number of grain per panicle and the grain yield. The response curve had similar trend as for experiment 2. The yields always increase with the addition of nitrogen up to 200 kg N ha^{-1}. However, economic level should be considered when using increasing rates of N.

Partial factor productivity of nutrients applied

The partial factor productivity of applied nutrients expressed as the ratio of rice yield per unit fertilizer (N+P) varied greatly from 12 to 105 kg depending on the treatment (Table-9). In general the partial factor productivity declined with increasing level of NxP application. The highest value (105.5 kg) was observed with minimum P application at O N level (P1xN0) and the lowest value (12.3 kg) with the highest fertilizer rate (P3xN5). The values for the other treatments were within these two extremes.

Agronomic efficiency

The agronomic efficiencies calculated as the ratio of yield increments due to nitrogen and phosphorus per unit of nutrient applied (Table-9) varied according to treatments. Agronomic efficiencies varied from 3.73 kg to 15.80 kg grain per kg of nutrient applied. Agronomic efficiency due to nitrogen rates (N rates with no P) was the highest with minimum N application and the lowest, with the higher rate. Agronomic efficiency due to phosphorus application at zero N level ranged from 4.7 to 5.5 kg grain with no significant differences between rates.

Table-9. Interactive impact of nitrogen and phosphorus supply on partial factor productivity, agronomic efficiency and cost value ratio of rice in the Office du Niger zone.

Fertilizer applied	Amount of fertilizer (kg ha^{-1})	Cost of fertilizer (CFA)	Grain yield Kg ha^{-1}	Yield increase over control	Value of increased yield	Partial factor productivity	Agronomic efficiency	Value cost ration (VCR)
P0 x N0	-	-	4825	-	-	-	-	-
P0 x N1	87	21750	6200	1375	206250	71,3	15,80	9,5
P0 x N2	174	43500	7089	2264	339600	40,7	13,01	7,8
P0 x N3	261	65250	7734	2909	436350	29,6	11,15	6,7
P0 x N4	348	87000	6789	1964	294600	19,5	5,64	3,4
P0 x N5	435	108750	6591	1766	264900	15,2	4,06	2,4
P1 x N0	50	12500	5274	449	67350	105,5	8,98	5,4
P1 x N1	137	34250	6550	1725	258750	47,8	12,59	7,6
P1 x N2	224	56000	7611	2786	417900	34,0	12,44	7,5
P1 x N3	311	77750	8059	3234	485100	25,9	10,40	6,2
P1 x N4	398	99500	7086	2261	339150	17,8	5,68	3,4
P1 x N5	485	121250	6634	1809	271350	13,7	3,73	2,2
P2 x N0	100	25000	5614	789	118350	56,1	7,89	4,7
P2 x N1	187	46750	6586	1761	264150	35,2	9,42	5,7
P2 x N2	274	68500	7082	2257	338550	25,8	8,24	4,9
P2 x N3	361	90250	7827	3002	450300	21,7	8,32	5,0
P2 x N4	448	112000	7039	2214	332100	15,7	4,94	3,0
P2 x N5	535	133750	7353	2528	379200	13,7	4,73	2,8
P3 x N0	150	37500	6201	1376	206400	41,3	9,17	5,5
P3 x N1	237	59250	7014	2189	328350	29,6	9,24	5,5
P3 x N2	324	81000	7074	2249	337350	21,8	6,94	4,2
P3 x N3	411	102750	7538	2713	406950	18,3	6,60	4,0
P3 x N4	498	124500	6785	1960	294000	13,6	3,94	2,4
P3 x N5	585	146250	7220	2395	359250	12,3	4,09	2,5

Fertilizer applied	
N0 = 0 kg N ha^{-1}	P0 = 0 kg P ha^{-1}
N1 = 40 kg N ha^{-1}	P1 = 10 kg P ha^{-1}
N2 = 80 kg N ha^{-1}	P2 = 20 kg P ha^{-1}
N3 = 120 kg N ha^{-1}	P3 = 30 kg P ha^{-1}
N4 = 160 kg N ha^{-1}	
N5 = 200 kg N ha^{-1}	

Economic analysis of production factors

The value cost ratio of different rates of N and P revealed that it ranged from 2.2 to 9.5. The highest ratio was observed with minimum N application at 0 P level and the lowest values with maximum N application (Table-9). Value cost ratio for all treatments was more than 2.0.

DISCUSSIONS

During the three years, the yields in this study ranged from 6 to 9 tons per ha in average. Many reports on SRI studies have shown yields range of 10 to 15 t ha^{-1}. Such yield level could not be obtained in the present study. Probably the most limiting factor was water control which could not be optimized because the seasonal raining pattern and the drainage system of the plot which was not efficient. In 2009, and 2010, heavy and frequent rains occurred almost every days maintaining the plot flooded throughout the vegetation period. Therefore, benefit from the alternated wetting and drying, an important component of SRI, along with soil oxygenation through mechanical weeding, could not be achieved.

Influence of planting density, manure and mineral fertilizer applications on yield and yield components

Row spacing effects on yield and yield components

The interaction effects presented in this study (Figure-1) indicated that row spacing effects on yield and yield components depend largely on soil fertilization. With no fertilization, rice yield was lower with wide row spacing, equal when ½ of recommended fertilizer was used and higher when recommended rate of fertilizer was applied. This was related to greater tiller and panicle numbers per square meter which increased with fertility status and the adverse effects on grain yield due to competition between tillers for growth factors in low fertile soils (Tables 3 and 4). Balasubramaniyan and Palaniappan (1991) attributed higher tiller numbers per plant to greater space available for individual plant to put forth more tillers. When soil fertility is high, larger row spacing will promote production of healthier and more panicle bearing tillers. In contrast, with limited soil fertility, crowded plant population will produce lest panicle fertile tillers. Veeramani (2011) reported significant higher number of filled grains per panicle and lower spikelet sterility percentage at wider row spacing of 30cm x 25cm compared with closer pacing of 25cm x 25cm. However, in his study, the marked increase in yield components was not sufficient to explain yield differences.

Manure main effects on yield and yield components

The results of this study did not show any significant manure main effects on rice yields. Hi rate of manure did not necessarily increase rice yield. This is because farmyard manure is a heterogeneous compound and the availability of nutrients depends largely on the state of its decomposition. Dembele (2007) reported that soil amendments with cow and donkey manures had C/N ratio>25 and mineralization rates were very low and reported as insufficient to cover plant needs the first year. He reported high synergic effect between soil amendment and mineral fertilizer application. Addition of 5t and 10t ha^{-1} to recommended fertilizer resulted in 20 to 40% yield increase as compared to the control treatment. While significant differences were not always seen on yield and yield component with manure the first year, soil nutrient balance showed significant changes in sol characteristics. In previous studies, soil analysis data in the same soils (data not presented) clearly showed an increase in soil organic matter, mineralized nitrogen, phosphorus and potassium with continuous application of manure on previous crops. This indicates that manure effect should be considered in longer run.

Interaction effects of manure x mineral fertilizer on yield and yield components

Interaction graph (Figure-2) showed synergic benefic of manure and mineral fertilizer application. This is in agreement with other studies where combined application of organic and inorganic fertilizer increased productivity of rice (Pendey *et al*., 1999; Ghosh *et al*., 1999; Dembele, 2007). In India, research in farmer field on the combined effect of manure and fertilizer showed long-term yield benefit which was attributed to the maintenance of soil organic carbon and microbial activities (Ghoshal and Singh, 1995).

Increasing rates of nitrogen fertilizer and manure on yield and yield components of rice

Increasing rates of nitrogen had some influence on grain number per panicle ($P=0.019$) and grain yield ($P<0.001$). The linear response of rice yield to nitrogen application (Figure-3a and Figure-3b) showed the importance of this element in the production system. Although no interaction occurred in this study, a combined use of mineral N and manure have been proved to conserve soil N by forming organic and mineral complex and thus ensure continuous N availability to rice plants and greater yields (Sharma *et al*., 1988).

Nitrogen and phosphorus interaction effects on yield and yield components

No significant interaction between N and P indicates that the response to N was not dependent to P. The lack of significant effects of phosphate rates implies that P was not limited in the soil (Tables 7 and 8). Two years prior the application of N x P treatments, the experimental site received a uniform application of manure at the rate of 10 tons ha^{-1} manure which may have contributed largely to the availability of P in the soil and consequently set off the treatment effects. Dembele (2007) found an increase in soil P balance when a tomato crop that received 10 tons manure per ha was rotated with rice on farmer's field in the Office du Niger.

As in the previous experiment nitrogen application affected linearly the number of grain per panicle and the grain yield. The yields always increase with the addition of nitrogen up to 200 kg N ha^{-1}. This implies that nitrogen is very important in the rice system, and that care should be taken to use this element at economical level.

Partial factor productivity of nutrients applied

The partial factor productivity of applied nutrients is a useful measure of nutrient use efficiency because it provides an integrative index that quantifies total economic output relative to utilization of all nutrient sources in the system (Jagadeeswaran *et al*., 2005). The reduction in the partial factor productivity with increasing level of NxP application may indicate an unbalance in the uptake ratio of the two elements. According to Cassman *et al*. (1996), the partial factor productivity can be improved by increasing the uptake and utilization of indigenous nutrients. In the present situation, since phosphorus was not showing any increase in rice yield, it may be assumed that P should not be used at higher rate than recommended. Fertilizer use is declared economical if the value of the increase in yield du to the quantity of fertilizer added is greater than the cost of the fertilizer used. If a unit of fertilizer does not increase the yield enough to cover its cost, its application becomes uneconomical (Singh, 2004). The highest value (105.5 kg) was observed with minimum P application at O N level (P1xN0) and the lowest value (12.3 kg) with the highest fertilizer rate (P3xN5). This indicates that fertilizer application should be associated with good farming practices because fertilizer is not the only factor that can improve yield.

Economic analysis of production factors

The VCR is a measure of the risk factor involved in agricultural. The VCR of 2 is recommended for farmers using high technology in Pakistan (Bhatti, 2006). The VCR of 2 represents 100% return on the money invested on fertilizer. According to Amunullah (2009) for farmer using low technology with limited resources, a fertilizer rate giving a VCR greater than 2 is highly recommended. In the present study, data show that the value cost ratio of different rates of N and P were between 2.2 and 9.5. Value cost ratio for all treatments was more than 2.0. To improve yield and profits, fertilizer use should be accompanied with the best management practices.

CONCLUSIONS

The results indicated significant yield benefit of the SRI system although the drainage system was not efficient. Significant interaction between row spacing and soil fertility level occurred showing that row spacing as wide as 30cm x 30cm can be used in SRI system when soil fertility is high. However, when soil fertility level is low, it is reasonable to use row spacing of 25cm x 25cm or narrower as certain studies have already shown it.

Although good yield can be obtained using farmyard manure, addition of mineral fertilizer still increase rice yield showing that combination of organic and inorganic fertilizer should be considered to sustain yield rice yield.

The partial factor productivity of applied nutrients expressed as the ratio of rice yield per unit fertilizer (N+P) varied from 12 to 105 kg indicating yield increase per unit of fertilizer added. The economic analysis of the production factors indicated that all treatments had VCR of more than 2.0 indicating more than 100% return on all money invested in fertilizer. As partial factor productivity and VCR values decrease with increasing level of fertilizers, their use should be accompanied with the best management practices for optimal profit.

ACKNOWLEDGEMENTS

This research was supported by Syngenta Foundation for Sustainable Agriculture. I would like to thank Dr. Oumar NIANGADO, delegate of Foundation for West Africa for his believe and willingness to support this project. Acknowledgement is also due to Mr. Brehima Traoré, Souleymane Coulibaly and Seydou Cissé for their assistance in field work.

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