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Full Length Research Paper

Combination of flushing, organic amendment and soil tillage as an effective technical package for reclamation of saline/alkaline soils of the Office du Niger in Mali

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A study was conducted at Niegue seed farm (Near Niono) in the Office du Nieger to determine the combination effects of flushing, organic amendment and soil preparation practices (deep tillage and puddling) on yield and yield components of rice paddy. Treatments comprised (T1) a control plot with recommended fertilization practices, (T2) a technological package comprising manure amendment, deep tillage, flushing after pre-irrigation and puddling, (T3) the technical package without manure and (T4) the technical package without flushing. Irrigation water pH and EC were followed throughout the growing periods during the three-year experimentation. There was high spatial variability in water pH and EC. The pH measurement and EC values indicated the alkalinity status of the experimental site. The tested technological package (T2) had significant impact on paddy yield (5.3, 5.2 and 5.5 t ha^{-1}respctively in yr1, yr2 and yr3) as compared with the control treatment where paddy yields were 4.3, 4.0, and 3.7 t ha^{-1} respectively the same years which correspond to 23 to 52% yield increase. Removal of both manure amendment and flushing resulted in yield reduction (21 to 35% for manure and 9 to 28 % for flushing). These results showed that manure amendment and flushing were important components of the technological package.

Keywords: Salinity, Alkalinity**,** Office du Niger, irrigation, flushing, amendment, tillage.

INTRODUCTION

Soil salinity and alkalinity are common problems that occur with irrigation in most semi-arid regions where large irrigation schemes are established. Salt related soil degradation due to irrigation activities is considered to be a major threat to the sustainability of rice cropping under semi-arid conditions of West Africa (van Asten et al., 2002). Salinity and alkalinity problems related to topographic position of the plots were observed in Mauritanie (van Asten et al., 2002), Senegal (Wopereis et al., 1998), Niger (Marlet et al. 1998) and Mali (Bertrand et al., 1993; N'Diaye et al., 1999, Marlet et al. 1998). In the recent two decades, salinity problems have been pointed out as a serious threat in the sustainability of rice production in West Africa, and the causes have been investigated by a consortium of research group in Mali, Senegal, Niger and Mauritania from 1995 to 1999 (N'Diaye et al., 1999, Marlet et al. 1998; PSI, 1999). Causes were attributed to bad drainage system of the irrigation scheme, excessive concentration of salt on the soil surface through high evaporative demand of the Sahelianhot climate and the positive residual calcite alkalinity ($RA_{calcite}$ = Alcalinity-Ca in mol ha^{-1}) of irrigation water (Valles et al., 1992; Bertrand et al., 1993).The study results by the consortium of research group which acted under the acronym of PSI (in French Pôle Systèmes Irrigués) in Mali, Senegal, Mauritania and Niger indicated that salinity in these areas was not increased by rice cropping but gardening was reported to increase the salinity problems. In the Office du Niger rice yields significantly increased over the past 20 years as the results of improved management practices while soil

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Alkalinity slightly decreased on the clay-eye areas where rice is grown while in contrast, in sandier areas and in areas where vegetable crops are grown, soil alkalinity increased (Marlet, 1999).

Flooding rice field can reduce soil salinity by solubilizing and leaching soluble salts below the root zone and rice can grow using this advantage. However, the salinity in irrigation water may vary from place to place and affect rice growth, nutrition, and yield. Results of greenhouse studies showed that the application of saline water can decrease growth of rice (Kumar and Bajwa, 1997). It was observed that salinity strongly reduced spikelet number per panicle, 1000 grain weight and increase panicle sterility, regardless of stage of rice. The strongest salinity effects on rice yield were observed around panicle initiation (Asch and Wopereis, 2001).

The development of management options to improve salinity problems requires and analysis of agronomic parameters which affect the interaction between salinity and crop yield. For rice the parameters such as cultural practices, irrigation, water depth and fertilization practices are important agronomic factors among others that require special attention. Water depth is important agronomic parameter that may influence salinity/alkalinity effects on the growth and yield of irrigated rice. Standing water is usually maintained in paddy rice field to control weed pressure. Variation in water level in the paddy field is generally observed if the land preparation is not adequate resulting to irregular leveling (Zeng et al., 2003) and this generally affects rice growth and yield (Anbumozhi et al., 1998). Excessive standing water tends to reduce photosynthetic leaf area (Yoshida, 1981), increase oxygen deficiency on soil surface (IRRI, 1964, 1979), inhibit tiller development (Williams et al., 1990) and decrease water use efficiency (Tuong and Bhuiyan, 1999).

It has been well established that salinity affects rice seedling growth and development (Shannon et al., 12998). Soil salinity inhibits plant growth through several complex factors that include osmotic effect, specific ion toxicity and nutritional imbalance (Wyn Jones, 1981).

Gypsum (CaSO4 2H20) is widely used on saline sodic and sodic soils to displace the sodium in order to reclaim the soil (Mianand Ali, 1980; Kerenand Shainberg, 1981; Bahriand Amami, 1986; Hussain et al., 1986). The gypsum application is generally followed by heavy irrigations to dissolve the applied amendment to leach down the replaced sodium and to remove the soluble reaction products from the root zone. The technique involves mixing of gypsum with soil in standing water with cultivator followed by horizontal flushing of standing water to a nearby drain. In general two or three flushing is necessary to get good results. However, the technology is site specific because the drainage system must be good enough to make it work (Qadir et al., 1998). A study by “Pole System Irrigué (PSI)” in 1999 indicated that flushing 24 hours after plot submersion with irrigation water can permit to evacuate 150 kg ha^{-1} of salt from the salt affected soils (PSI, 1999). Research results indicated that organic fertilization increased salt tolerance of some vegetable crops under saline conditions (El-Missery, 2003 on cabbage and spinach; Saleh et al., 2003 on onion).

In the present study it was hypothesized that the combination of flushing, soil tillage and use of organic matter compound will alleviate the adverse effects of soil salinity/alkalinity level of the salt affected soils of the Office du Niger and improve rice yield. Therefore, the objective was to determine the interactive effects of these proposed factors on the yield and yield components of paddy rice in the Office du Niger zone.

MATERIALS AND METHODS

Experimental site

From 2003 to 2006, an experiment was conducted at the seed multiplication farm of Niegué an area situated in the Office du Niger of Mali (Figure 1). The Office du Niger is located 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℃ (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 seed multiplication farm of Niegue is situated on the diverter KL4-bis of Kolodougou the locker area of rice production in Niono. This site was selected for this study, because of its state of degradation through salinization / alkalization processes. The experimentation was installed on a vertisol with weak internal and external drainage. Initial characterization made on this site gives a pH variation ranging between 6.4 and 9.3 and EC (100 to 500 µS cm^{-1}).

Materials used in the study

The equipment used to till the soil was oxen drawn plow and the rolling harrow. The rice variety used was Kogoni 91-1 also called «Gambiaka Suruni» which is an improved

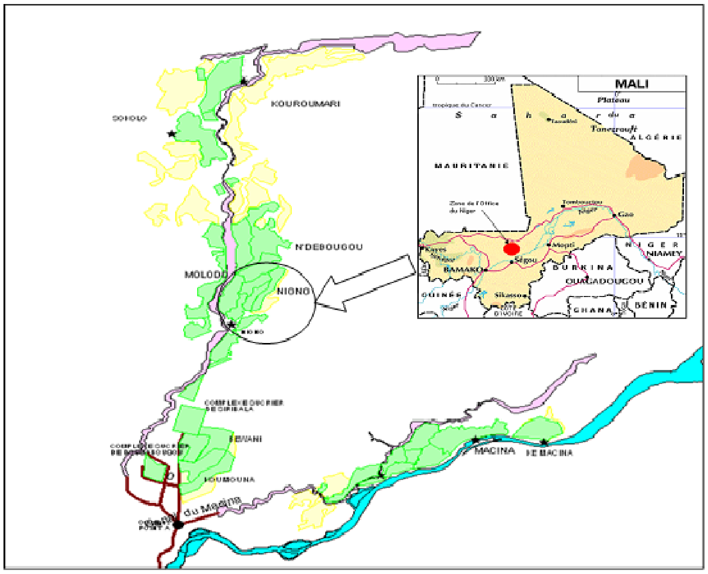

Figure 1. Map of the Office du Niger zone

variety with a cycle of 120 days. The yield potential of this variety is estimated to be 10 tons ha^{-1}. 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). (Figure 1)

Experimental setup

After conclusive results (proving the effectiveness of flushing in controlling alkalinity) from previous study conducted by PSI (1999), an experiment comporting four treatments was established in the seed farm plots of Niegué from 2003 to 2006. The treatments comprised: (T1) a control treatment consisting of the popularized fertilization package (100 kg DAP + 200 kg ha^{-1} urea)

T2 = complete technological package:

- *Flushing after 24 hours pre-irrigation and puddling*
- *Mineral fertilization (120 kg N ha^{-1} + 46 kg P2O5 ha^{-1}+ 100 kg ha^{-1} KCL*
- *Farmyard manure = (5 tons per hectare)*
- *Tillage practice = Deep tillage + puddling*

T3 = T2 without manure

T4 = T2 without flushing

Experimental layout

The experimental design was a randomized complete bloc design replicated 3 times. The 4 treatments were randomly distributed within individual plot size of 20m x 20m. All plots were surrounded by consolidated bunds.

Cultural practices

For tillage practice, the land was submersed overnight and deeply plowed with animal traction after excess water was completely infiltrated within the soil profile. Then, the plots were submersed again and harrowed using the rolling harrow. Several passages of the rolling harrow permitted an efficient puddling of the plots and then the excess water was flushed out through drainage. After that, the seed beds were carefully prepared through manual leveling processes 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 gradually irrigated as needed until plants could support flooding with thin water layer. Seedlings were raised for 21 days before transplanting.

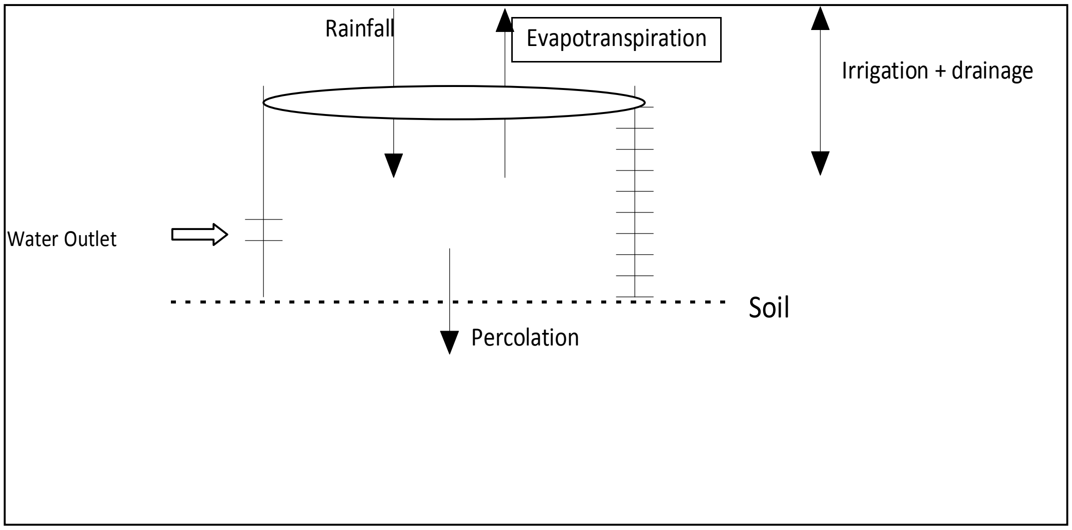

Figure 2. Design of an infiltrometer for water measurement

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.

Weed management

Weeding was done manually. During the growing period, two manual weeding were necessary. Maintaining standing water in the plots throughout the growing period also helped in reducing weed pressure.

Data collection and sampling

Soil samples were taken in the study area to characterize the study site prior crop installation. During the course of the experiment, soil pH and EC of the water layer were measured. The quantity of applied water and excess soluble salt in drainage water were measured. For agronomic parameter, collected data concerned yield and yield parameters. Plant population and productive tillers/m² were recorded by counting the average of ten planting hills taken randomly from each treatment in each plots. Plant height, grain per panicle and 1000 grains weight were recorded.

Measurement Of irrigation water

Monitoring technique for water data collection was based on the methodology of a device comprising a ring infiltrometer (cylinder equipped with a graduated scale internally and externally (Figure 2). For instance, it was possible to follow the evolution of the water layer in the four treatments (T1, T2, T3, and T4) of each of three blocks (BI, BII and BIII) of the experimental design.

The quantity of water in irrigation and drainage was calculated for each treatment in each block. Between day j and day j+1, the quantity of water supplied is:

$V_{(j/j+1)} = (H_{extj}+1 - H_{extj}) - (H_{intj}+1 - H_{intj})$

where:

$V_{(j/j+1)}$= quantity of water applied between day j and day j+1

H_{extj+1} = water level (mm) outside the cylinder in day j+1

H_{extj}= water level (mm) outside the cylinder in day j

H_{intj+1} = water level (mm) inside the cylinder in day j+1

H_{intj}= water level (mm) inside the cylinder in day j

Water levels were measured daily. If the water level is positive, there was irrigation, otherwise it was lost by drainage. The accumulation of positive values is useful for irrigation (evapotranspiration, percolation, stock variation in the soil) and the cumulative negative values correspond to losses by surface drainage.

Measurement of excess salts from water drainage

A conductivity meter was used to measure daily and weekly the electrical conductivity (EC) of the water layer in each treatment. The amount of salt mobilized (removed or stored) was measured. Knowing the Electrical conductivity expressed in µS cm^{-1} and knowing that 1 µS cm^{-1} corresponds to 1.09 mg L^{-1}, the amount of salt (kg ha^{-1}) in water layer was determined by

Figure 3. Salt affected area in the seed farm of Niegue

the following equation:

Quantity of salt (kg/ha) = water layer (cm)*1,09.10^{-1}*CE

Statistical analysis

The analysis of variance was performed on all parameters using the GENSTAT 5 release 3 (Lawes Agricultural Trust, 1993). The design was a Randomized Complete Block Design (RCBD). Means between treatments were compared by using the standard error of the difference of the means.
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RESULTS AND DISCUSSION

Results

General observations of rice growth in Niegue seed farm

The seed multiplication farm of Niegue is usually characterized by large salt affected areas where plant growth is severely reduced (Figure 3). Results of sample analysis of the affected areas show a high pH level (>8.5) and an electrical conductivity varying from 100 to 500 µS cm^{-1}. Compared to non-affected areas, salinity effects of the affected areas can results in 50 to 80% yield reduction.

The water pH and electrical conductivity measurements, reported in figure 1 indicate high variability from place to place. During the transplanting period, the water pH ranged between 6.8 and 8.3 and the electrical conductivity (EC) between 400 and 700 µS cm^{-1} for EC (Figure 4)**.**

After transplanting, plant recovery was very irregular.

Several patches of affected areas were visible. The top leaves of the affected plants looked dry. Rice grew very poorly and plants in affected areas remained stunted and sparse. Application of phosphorus, nitrogen and potassium did not improve much the growth. This suggested that the growth was probably limited salt ions. Average rice yield of affected was less than 1.5 t ha^{-1}, which is far below the annual average of the Office du Niger, estimated at about 5 t ha^{-1}.

The pH and electrical conductivity measurements before the onset of the experiments are reported in figure 1. Initial pH values ranged between 6.8 and 8.5 and EC between 250 and 800 µS cm^{-1} with an average value of 437 µS cm^{-1}.

Water pH and electrical conductivity of the affected areas

During the active vegetation period, the pH and the EC were intensively followed each year. The results presented in figure 4 showed high spatial variability. The analysis of variance performed on the raw data did not show any significant differences between treatments for any of the sampling period. Specific measurement made in salt affected areas revealed higher pH and EC (Table 1) compared to non-affected ones.

Treatment effects on plant growth parameters

In general, rice plants grew very poorly in all treatments although T2 had more healthy plants than the other treatments. The analysis of variance, performed on tiller number, empty grain weight of 10 planting hills, thousand grain weights did not show any significant difference

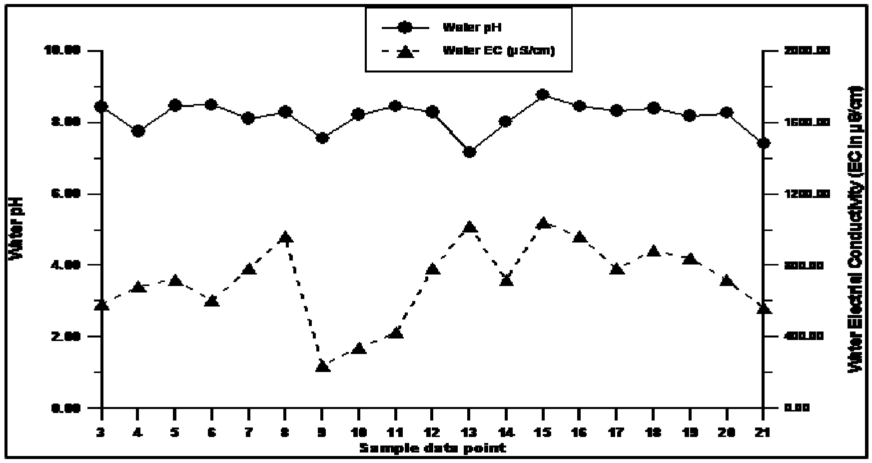

Figure 4. Spatial variability of water pH and electrical conductivity observed at the onset of the experiments in 2003 at Niegue seed multiplication farm.

Table 1. Measurement of soil pH and soil electrical conductivity in stunted and non-stunted growth areas at the seed multiplication farm of Nieguein 2003.

Treatments	Soil pH		Electrical conductivity (E C) of standing water	
	Non stunted growth area	Stunted growth area	Non stunted growth area	Stunted growth area
T1	7.88	8.55	520	2720
T2	7.85	8.23	520	2720
T3	7.19	8.56	630	2850
T4	8.51	7.56	410	2590
F test	NS*	NS	NS	NS

*NS = Non significant

Table 2.Agronomic parameters of the flushing experiment at Niegue seed farm in 2005

Treatments	Tiller number	Plant height (cm)	Total grain weight from 10 planting hills (g)	Empty weight grain from 10 planting hills (g)	Weight of 1000 grains (g)	Grain Yield in kg ha^{-1}
T1	116.0	70.0	134.7	5.1	6.1	3650
T2	136.7	73.3	169.6	6.7	5.2	5549
T3	127.7	69.3	109.4	6.3	5.8	3595
T4	125.3	70.7	155.7	6.2	6.2	3975
P>F	0.811	0.061	0.050	0.328	0.237	0.050
SED	21.2	1.2	17.4	0.8	0.5	275.5
CV%	21	2	15	16	10	25

between treatments in any year (Table 2). However, plant height (p>F = 0.06), total grain weight from 10 planting hills (p>F = 0.052) and paddy yield per ha (P>F =0.05) were improved with the complete technical package (T2).

Rice yields were significantly affected (P>F =0.007 and 0.050) by treatment differences in all year except in 2003 (Table 3). In general T2, the complete technical package which is composed of flushing, deep tillage and manure, gave the highest yields (5300, 5168 and 5549 kg ha^{-1}) respectively in 2003, 2004 and 2005 while the lowest yields (4200, 3733 and 3595 kg ha^{-1}) were recorded the same years in T3 which is the complete technical package without manure application (Table 3). When comparing yield of T2 and T3, it can be seen that

Table 3. Yields response to different treatments in the flushing experiment at Niegue seed multiplication farm from 2003 to 2005

	Grain yield in kg ha^{-1}		
Treatments	**2003**	**2004**	**2005**
T1	4300	3993	3650
T2	5300	5168	5549
T3	4200	3733	3595
T4	4800	4610	3975
P>F	0.0850	0.007	0.050
SED	-	260.4	275.5
CV%	-	7	25

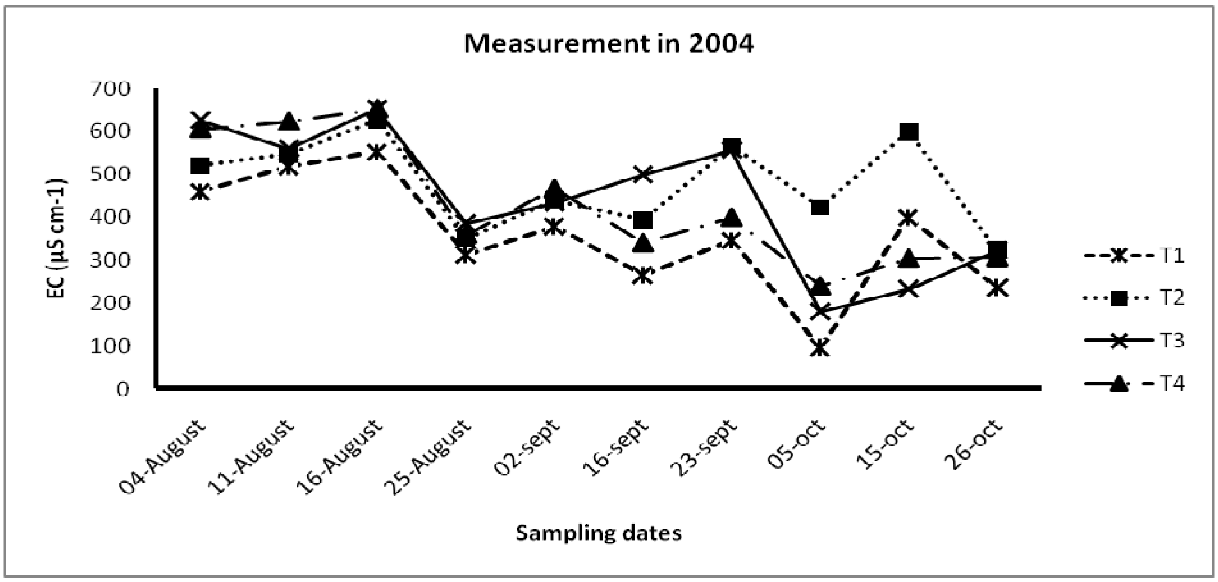

Figure 5. Electrical conductivity measurements during the course of the experiment i n 2004

removal of manure from the package resulted in 21%, 28% and 35% yield reduction respectively in 2003, 2004 and 2005 (Table 3). Removal of flushing from the technological package (T4) gave paddy yield of 4.8, 4.6 and 4.0 t ha^{-1} respectiveley in year 2003, 2004 and 2005 which correspond to 9%, 11% and 28% yield reduction. Although T4 was not statistically different from T1, the arithmetic value of T4 was higher indicating combined positive effects of flushing and improved cultural practices.

Evolution of water pH and electrical conductivity during the growing period

Water pH and electrical conductivity were monitored throughout the course of the experiment in 2004 and 2005 (Figure 5 and 6). Spatial measurement of soil pH across plots showed values ranging from 6.8 to 9.3 indicating the experimental site is going under the process of alkalization. The EC across inter-and intra-plot water layer also indicate high spatial variability.

Although water pH was high at transplanting time, it decreased with the level of flooding as plant got older. In October and November, the pH was stabilized between 6 and 7. Similarly water Electrical conductivity was high at transplanting time but progressively decreased with the level of flooding indicating that the salt concentration of irrigation water decreased with time (Figure 5 and 6).

Measurement of irrigation water and salt concentration

The summary data of the total amount of irrigation and

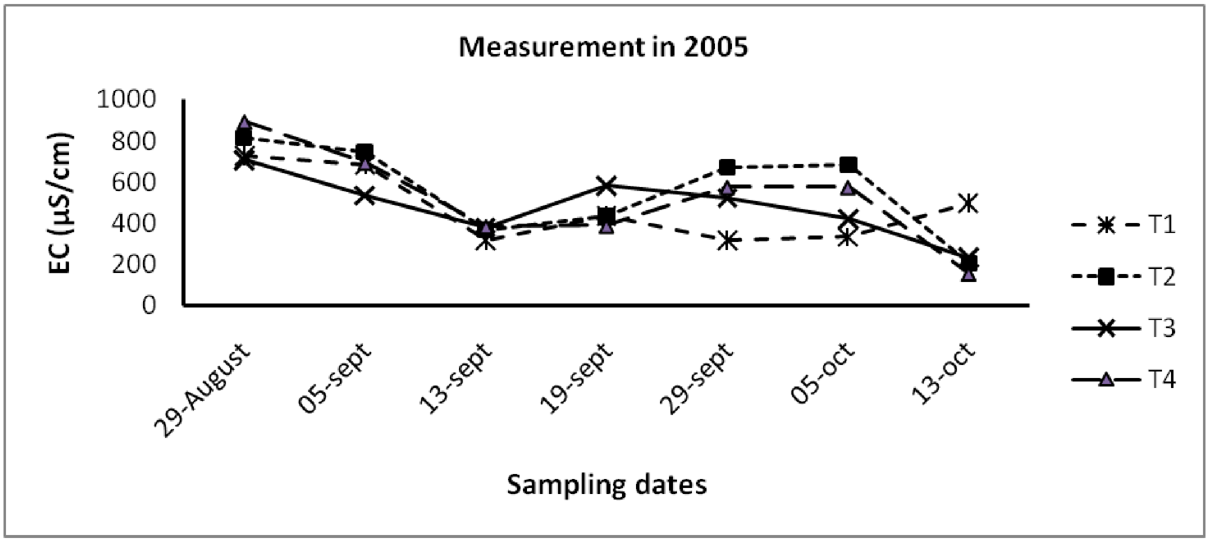

Figure 6. Electrical conductivity measurements during the course of the experiment i n 2005

Table 4. Summary result after rice transplanting

Treatm-ents	Average water entry (mm)	Average water irrigation (mm)	Average water natural drainage (mm)	Average quantity of salt evacuated (kg ha^{-1})		Total salt evacuate through the technology (kg ha^{-1})
				Pre-irrigation	Pudding	
T1	3932	3381	2254	_	_	-
T2	**3043**	**2491**	**1020**	**736**	**580**	**1316**
T3	**5572**	**5020**	**4378**	**681**	**468**	**1149**
T4	3404	2853	2378	_	_	

drainage water and the total amount of salt mobilized during the cycle of the rice plants are reported tin Table 4. Detailed calculation for each treatment in each block can be observed in Table 5. Effective water consumption ranged from 1060 to 7229 mm. The electrical conductivity was between 250 and 300 µS/cm at pre-irrigation, 200 and 720 µS cm^{-1} at puddling and 200 and 820 µS cm^{-1} during the rest of the cycle (Table 5). The total amount of salt evacuated at pre-irrigation and puddling was estimated to be 1316 kg ha^{-1} for T2 and 1149 kg ha^{-1} for T3 (Table 4).

DISCUSSION

Understanding plant growth pattern in response to the changes in water salt content is important for water management when dealing with salinity/alkalinity problems in salt affected soils. The relationship between salt concentration and crop yield can be better understood when following the evolution of salt level throughout the growing period. In the present study, the electrical conductivity data presented in Table 1 showed salt concentration as high as 2850 µS cm^{-1} (2.85 dS L^{-1}) which is near the threshold level estimated to be 3 dS m^{-1} for rice (Dehayr et al., 1997). Figure 2 and 3 indicated a gradual decrease in water pH and EC from transplanting in August to late growth period in October November. This was probably the response to large water irrigation entry in the system, because of the poor drainage system of the seed farm.

Effects of the technical package on paddy yield

Rice yield in Niegue seed farm is usually below the average 5 tons per ha reported for by Office du Niger. Application of the complete technical package resulted in 5,30, 5,17 and 5,55 kg t^{-1}) respectively in 2003, 2004 and 2005 which correspond to 23, 28 and 52% increase when compared with the control (T1) plot yields in the same years. These yields increases indicated the performance of the package used. Flushing and manure applications seem to be the most important components of the technology package because removing manure from the package resulted in 21% to 35% yield reduction and

Table 5. Quantity of water and salt mobilized in 2003 Rainfall in 2003 :551.5 mm ; Pre-irrigation at 17/07/2003 : 250 mm ; pudding at 04/08/2003 ; Transplanting at 11 to 13/08/2003

Blocs	Treatments	Quantity of water at pudding (mm)	Irrigation (mm)	Total water entry Irrigation + rainfall (mm)	Number of irrigation	Absolut value of drainage water (mm)	Effective water consumption (mm)	Electrical conductivity CE (µS cm^{-1})			Quantity of salt evacuated at pre irrigation (kg ha^{-1})	Quantity of salt evacuated at pudding (kg ha^{-1})	Quantity of salt évacuated throughout the cycle (kg ha^{-1})
								Pre-irrigation	pudding	Rest of the cycle			
BI	T1	_	3802	4353	7	1363	2990	_	390	558	null	null	8289
BI	T2	140	2931	3482	11	344	3138	300	500	829	818	763	**3111**
BI	T3	90	**10617**	11168	9	3939	7229	250	500	663	681	491	**28480**
BI	T4	_	3269	3820	7	1505	2314	_	500	660	null	null	10828
BII	T1	_	3038	3589	7	559	3029	_	200	564	null	null	3441
BII	T2	150	3618	4169	9	505	3664	250	200	491	681	327	**2703**
BII	T3	90	2800	3351	8	307	3044	250	220	411	681	216	**1376**
BII	T4	_	4579	5130	9	670	4459	_	200	533	null	null	3897
BIII	T1	_	3303	3854	11	331	3523	_	720	416	null	null	1500
BIII	T2	85	926	1477	7	171	1306	260	700	574	709	649	**1071**
BIII	T3	100	1645	2196	7	132	2064	250	640	642	681	698	**922**
BIII	T4	_	**711**	1262	8	202	1060	_	720	496	null	null	1093

T1 = Control treatment
T2 = Complete technical package
T3 = Technical package without manure
T4 = Technical package without flushing

removing flushing from the package reduced yield by 9% to 28%. When comparing T1 and T4, there is still an increase in paddy yields indicating a synergic action between all components of the technological package (tillage practice, flushing and manure application). These results are in agreement with previous studies in Mali which indicated that flushing 24 hours after plot submersion with irrigation water can permit to evacuate 150 kg ha^{-1} of salt from the salt affected soils (PSI, 1999). Also positive effects of organic fertilization on salt tolerance of some vegetable crops under saline conditions were reported by El-Missery in 2003 (for cabbage and spinach) and by Saleh et al., in 2003 (for onion).

Flushing effect on irrigation salt removal

The pH measurements and the SAR calculation form previous studies in the same experiment site (Dicko, 2005) indicated high values for these parameters (pH>8 and SAR >15). This indicated that the experimental site was going under alkalinisation processes although the electrical conductivity values were far below the threshold level of 3 dS m^{-1} for rice (Lopez, 1997, DeHayr et al., 1997). Intra and inter-plot measurements of water pH and EC indicated high spatial variability of the phenomenon. Because of the degradation status of the seed multiplication farm, farmers usually apply large quantity of irrigation water (up 10620 mm) to attenuate the depressive effects of salt ions in the root zone.

In view of the results in Table 4, although the mean values of water supply for irrigation, drainage, and amount of salt discharged during the remainder of the growth cycle of rice are important for the flushing treatments (T2 and T3) compared with the non-flushing (T1 and T4), the differences are not significant. However, it is still important to note that a large amount of salts was evacuated treatments T2 and T3 at pre-irrigations (709 kg ha^{-1}) and puddling (524 kg ha^{-1}). During these phases cultivation, the treatments T1 and T4 have stored almost the same amount of salt. Similar washing efficiency of flushing to evacuate salts outside the plots was also reported by F.Ouvry et al, (1999). In the present study, the values calculated are far larger than those reported by F.Ouvry et al, (1999) and is easily explained by the fact that the EC values recorded in the treatments are much higher.

CONCLUSION

The results of the present study indicated the efficiency of the technological package comprising deep tillage, flushing after 24 hours of pre-irrigation and after puddling, and application of manure. With this package, rice yield increased by 23 to 52% when compared with the recommended practice. Removal of both manure amendment and flushing resulted in yield reduction (21 to 35% for manure and 9 to 28 % for flushing). These results showed that manure amendment and flushing were important components of the tested technological package.

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