The Proceedings of the International Plant Nutrition Colloquium XVI

Title

Reducing the effect of iron toxicity in lowland rice through bunding and fertilizer application

Permalink

https://escholarship.org/uc/item/4tx2455z

Authors

Srivastava, Amit K
Kanninkpo, Claude
Gaiser, Thomas

Publication Date

2009-03-28

Introduction

To produce sufficient food to feed a growing population remains a most prior objective on the African continent in general and in sub-saharan region in particular. Faced with this situation, the use of ecosystems once regarded as marginal or wasteland as the inland valleys has emerged as a most appropriate alternative. In sub-Saharan Africa, the bottoms of the inland valleys occupy a total of 85 million hectares, or 7% of total cultivable land and can therefore play a vital role in the development process and intensification of agricultural production. As such, soil erosion and nutrient depletion threaten agricultural productivity and food security in Sub-Saharan Africa. Additionally, iron toxicity is also recognised as one of the major constraints to rice production in the lowlands of West Africa and is linked to water logging and only occurs under anoxic soil conditions (*Ponnamperuma* et.al.,1967).Therefore, it is necessary to test different management practices to maintain or enhance the productivity of these ecosystems. Keeping this in mind the current study intends to analyse the potential of lowland rice production in relation to slope positions, bunding and fertilization in an inland valley of the sub-humid Savannah in Benin Republic.

2. Materials and methods

2.1 Site Description and soil characterisation

The experiments were carried out for three years from 2006 to 2008 at the village of Dogue (Southern Donga) in North west of Benin Republic (West Africa).
The region is occupied by ferruginous tropical soils in the well drained areas. Hydromorphic soils are located at the bottoms. According to FAO soil classification the soils on the experimental plots are characterised as Lixisols (upper slope) and Gleysols (down slope).

Table 1 : Selected soil chemical parameters of the experimental soils on the valley fringe and the valley center of an inland valley in Benin.

Parameters	**Valley fringe**		**Valley center**	
	Mean	**Standard deviation**	**Mean**	**Standard deviation**
Total N(mg g^{-1})	0.39	±0.07	0.67	±0.1
Organic C (%)	0.6	±0.08	0.9	±0.2
C/N ratio	17	±2.2	13	±3.7
Available P (Olsen) (ppm)	5	±3	8	±5
pH (H_2O)	5.6	±0.3	5.3	±0.2
CEC (Cmol kg^{-1})	4.1	±0.5	5.3	±1.4

2.2 Study Methodology

2.2.1 Planting material

In order to cover the potential of rice production, this study used the variety Sahel 108 in the first year of the experiment (2006) and switched over to NERICAL-26 in the year 2007 and 2008 bacause of the unavailability of Sahel 108 rice seeds. NERICAL-26 is a variety of rice which has been recently developed for lowland condition in inland valleys with an average yield of about 5.5 t ha^{-1} and a production cycle of approximately 105 days (WARDA, 2006).

2.2.2 Experimental design and treatments

The experimental design was a split-split plot. Overall, there were 8 treatments with 4 replication. The plot size was 5m × 5m. A total of three factors were studied :

(i) Topographical position : 2 levels (upper slope and down slope) were tested ;

(ii) Bunding : Level 0, i.e without bunds on the border of plots (without any impediments to the flow of water) and level 1, i.e with bunds on the border of the plots (0.5m wide and 40cm in height).

(iii) Mineral fertilizer : Two treatments of mineral fertilizer were tested : The first treatment, control (without mineral fertilizer application) which corresponds to the farmer's practice in the study area. The second treatment was application of 60 kg N and 40 kg P_2O_5 per hectare.

2.3 Plant sample and data analysis

In 2007 and 2008 rice tissue was sampled on for nitrogen and iron content analysis. Samples were oven-dried at 70°C to constant weight, weighed, and analysed for tissue Fe content by atomic-absorption spectrometry (Perkin-ELMER AAS 1100B, Überlingen, Germany) following a hot pressure digestion with saturated ammonium nitrate solution at 180°C for 7 hours and a subsequent filtering and standard dilution to 100 mL. For nitrogen analysis Kjeldhal method was carried out. Treatment effects were determined by analysis of variance by (ANOVA) using the computer package SPSS, Version11(SPSS Inc.©2002, Chicago, Illinois, USA). Mixed procedure was used for mean separation by SAS, Version 9.0. Significance was regarded at $p \leq 0.05$.

3. Results and Discussion

(i) Effect of fertilizer application on grain yield

In 2006, grain yield of 2.0 Mg ha^{-1} was observed with fertilizer application (Figure 1). This was 20% less than the control (without fertilizer) . As 2006 was relatively dry, the observed decline may have been caused by water stress at panicle initiation, which delays anthesis and maturity, reduces growth rate and N uptake and affects rice grain yield (*Castillo* et al., 1992 ; *Yambao* and *Ingram*, 1988). In 2006, drought stress during the reproductive phase hampered floret and spikelet formation (*De Dutta*, 1981 ; *Yambao and Ingram*, 1988 ; *Tuong* et al., 2000).

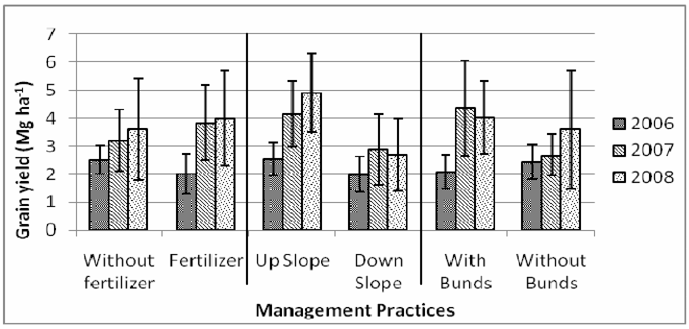

Figure 1 : Rice grain yield under different management practices over three growing season

In contrast, in 2007 and 2008 with average annual rainfall and regular distribution, the plots where fertilizer was applied registered grain yield increase of 16% and 10% compared to the control. However, this increase was not significantly different due to insufficient nitrogen supply during crop development which may affected yield gains (Figure 2b). As shown in Figure 2b, the difference in nitrogen concentration in the rice plants was not significantly different already at 32 DAS. It is obvious, that nitrogen application at planting is not sufficient to maintain nitrogen supply over the whole growing cycle and we recommend a second application in later stages of the development.

(ii) *Effect of slope position on grain yield*

In 2006, a significant effect of plot position on grain yield was observed. The plots situated on the upper slope registered 2.5Mg ha^{-1} grain yield which was 21 % higher than yields from downslope plots.The probable reason behind such an observation could be the significant higher nitrogen concentration on upper slope compared to that on lower slope (Figure 2b). Furthermore, the negative impact of iron toxicity on the crop growth could be an additional reason behind the poor performance of down slope plots (Figure 2a) . The same pattern of results were also observed in 2007 and 2008. In these years upper slope plots registered significantly higher grain yield (34% and 45% respectively) than that obtained from the down slope plots (Figure 1). This was because plots on the lower parts of the slope have iron concentration above the toxicity threshold level (500ppm)in the rice leaves leading to reduced biomass development and yields (Figure 2a). In the leaf, such significant quantities of iron cause increased production of radicals that can irreversibly damage cell structural components (*Thompson* and *Ledge*, 1987) and cause an accumulation of polyphenylene oxides (*Yamauchi* and *Peng*, 1993). The typical symptom linked to this is the “bronzing”or yellowing process of the rice leaves (*Howeler*,1973). Although, bronzing of leaves was not observed in the field, the tissue analysis clearly reveals iron concentration in the toxicity range. It is well known that there are varietal differences in the expression of iron symptoms and NERICAL-26 seems to show no visible symptoms at this level of iron concentration.

(iii) *Effect of bunding of plots on grain yield*

No significant effect of bunding of plots was observed on grain yield in the year 2006. The unbunded plots registered even higher grain yield (2.4Mg ha^{-1}) compared to bunded plots (2.1 Mg ha^{-1}). The probable reason could be the fact that, for rainfed crops, bunding of plots is beneficial especially in wet years, where there is enough rainfall (Table 4) and water and nitrogen can be retained in the plot and is available to the plants. This in turn improves uptake of N applied through mineral fertilizer by rice plants (Figure 2b). Bunds also act as filters that limit the passage if iron, therefore reducing its concentration in soils . This is verified by the findings in 2007 and 2008, where precipitation was adequate (average 1156 mm). In 2007, the plots with bunds registered 4.3 Mg ha^{-1} grain yield, which was significantly higher than those produced in plots without bunds (2.6 Mg ha^{-1}). We observed an increase of 37% in grain yield in bunded plots compared to the production in the plots without bunds. The same was observed in 2008 at 4.0 Mg ha^{-1}, which was higher by 35% compared to yield from unbunded plots (2.6 Mg ha^{-1}) . These findings are in accordance with the findings of *Camara* (2006) which recommends bunding as a means to struggle against iron toxicity. However, in the present study, the retention of nitrogen in the plots, was obviously the overwhelming benefit of the bunds, leading to improved nitrogen supply (Figure 2b). Iron concentrations were only slightly reduced through bunding (Figure 2a).

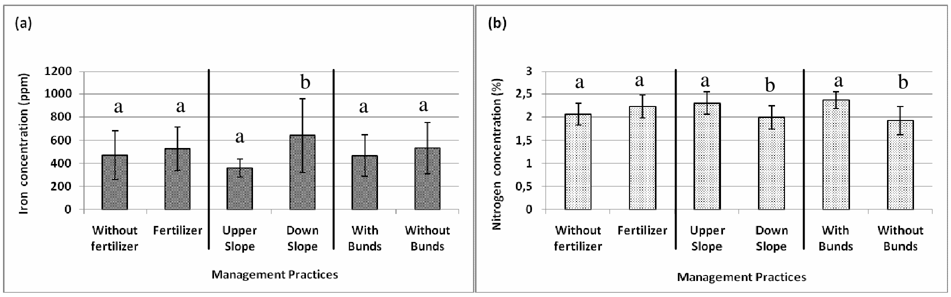

Figure 2(a)(b) : Iron and Nitrogen concentration in leaves of rice plant under different management practices (mean over two years 2007 and 2008).Values with same letter within the group are not significantly different ($p \leq 0.05$)

(iv) *Effect of interactions of management practices on rice yield*

In 2006, no significant effect of factor interaction on grain yield was observed, whereas in 2007 and 2008, significant interactions between bunding and slope position were observed. On the upper slopes, the effect of bunding was variable on grain yield (Table 2). In 2007, bunding with fertilizer application produced the highest yield (4.7 Mg ha^{-1}) whereas in 2008, no bunding with fertilizer application yielded the best results (5.5 Mg ha^{-1}) in contrast, on lower slopes, the effect of bunding was prominent. With approximately 47% and 40% more grain yield in 2007 and 2008 respectively, bunding resulted in more yield even without the addition of fertilizer. On down slope, fertilizer application and bunding produced the highest grain yield compared to other treatments, with 65% (2007) and 52% (2008) more grain yield than that obtained in plots with fertilizer but without bunds (Table 2). This is most likely due to the improvement of water and nutrient retention through bunding and the resulting increase in nitrogen availability. The findings also revealed that the application of fertilizer in bunded plots also decreased iron toxicity effects in the upper slope position (Table 3). The observations suggested that the upper slope of the inland valleys have the highest potential for rice production. On lower slopes, this potential is only reached when plots are fertilized and bunded in order to increase the effectiveness of fertilizer.

Table 2 : Effect of plot bunding and fertilizer application on the grain yield of rice grown at two landscape positions of an inland valley in Benin. Values with same letter within the same column are not significantly different ($p \leq 0.05$)

Landscape position	Bunding	Fertilizer	Grain yield ($Mg\ ha^{-1}$) 2006	Grain yield ($Mg\ ha^{-1}$) 2007	Grain yield ($Mg\ ha^{-1}$) 2008
Valley fringe					
U b 0	yes	none	2.8 a	4.6 ab	4.4 ab
U b F	yes	yes	1.7 d	4.7 ab	4.7 ab
U wb 0	none	none	2.8 ab	3.6 abc	4.8 ab
U wb F	none	yes	2.7 abc	3.7 abc	5.5 a
Valley center					
L b 0	yes	none	2.2 d	3.0 abc	3.2 bc
L b F	yes	yes	1.6 d	5.2 a	3.8 ab
L wb 0	none	none	2.1 d	1.6 c	1.9 c
L wb F	none	yes	2.0 d	1.8 c	1.8 c

Legends: U=Upper slope, L=Lower slope, b=with bunds, wb=without bunds, 0=without fertilizer, F=with fertilizer.

Table 3 : Iron and nitrogen concentration in rice plant under different factor interactions.Values with same letter within the same column are not significantly different ($p \leq 0.05$)

Landscape position	Bunding	Fertilizer	Fe conc. (ppm)	N conc. (%)
Valley fringe			**32 DAS**	**32 DAS**
U b 0	yes	none	423 abc	2.60 ab
U b F	yes	yes	336 abc	2.63 a
U wb 0	none	none	384 abc	1.89 c
U wb F	none	yes	282 d	2.08 c
Valley center				
L b 0	yes	none	430 abc	1.97 c
L b F	yes	yes	670 ab	2.27 ab
L wb 0	none	none	639 abc	1.79 c
L wb F	none	yes	814 a	1.93 c

Legends: U=Upper slope, L=Lower slope, b=with bunds, wb=without bunds, 0=without fertilizer, F=with fertilizer.(mean over two years 2007and 2008

Table 4 : Days of inundation in rice experimental plots over three growing seasons

	Inundation (in days)		
	2006	**2007**	**2008**
U b	31	55	59
U wb	13	52	53
L b	40	103	83
L wb	31	97	80

Legends: U=Upper slope, L=Lower slope, b=with bunds, wb =without bunds

Conclusion

Despite the relatively fertile soil, the inland valley experiment has shown a poor performance in rice production in the bottoms of the valleys. Its major shortcoming was the nutritional disorder caused by an excess of ferrous ion. This disorder greatly affected all plots located on the lower slope positions. An additional problem that undermines the enhancement of the production in the lowlands is nutrient supply. Bunding combined with fertilizer application have proven to improve nitrogen supply in the bottom position and to reduce the negative effects of iron on grain yield. The highest potential for rice production is at the higher landscape position where bunding and fertilizer did not significantly increase the yield, but seem to reduce yield fluctuations.

Acknowledgement

I would like to thank Prof. Heiner Goldbach for his comments on earlier draft of paper and Prof. Mathias Becker for his assistance in the layout of the experiment. Special mention goes to Christiane Stadler and Ezekiel Djakpa for their help in field work. Funding by German Federal Ministry for Education and Research (BMBF) is highly acknowledged.

References

Camara, K. A., 2006. Test de développement des variétés de riz tolérantes à la toxicité ferreuse. In Toxicité ferreuse dans les systèmes à base riz d'Afrique de l'Ouest ; Centre du riz pour l'Afrique (ADRAO) Cotonou, Bénin, pp 68-81.

Castillo, E. G., Buresh, R. J., Ingram, K. T., 1992. Lowland rice yield as affected by timing of water deficit and nitrogen fertilization. Agron. J. 84, 152-159.

De Datta, S. K., 1981. Principles and Practices of Rice Production. Whiley, New York, USA.

Howeler, R. H., 1973. Iron-induced oranging disease of rice in relation to physiochemical changes in a flooded Oxisol. Soil Sci. Soc. Am. Proc. 37, 898-903.

Ponnamperuma, F. N., Tianco, E. M., Loy, T., 1967. Redox equilibria in flooded soils : The iron hydroxide systems. Soil Sci. 103, 374-382.

Thompson, J. E., Ledge, R. L., 1987. The role of free radicals in senescence and wounding. New Phytol. 105, 317-344.

Tuong, T. P., Castillo, E. G., Cabangon, R. C., Boling, A., Singh, A., 2002. The drought response of lowland rice to crop establishment practices and N fertilizer Sources. Field Crops Research 74, 243-257.

WARDA (West Africa Rice Development Association) 2006. Annual Report 2005. WARDA, Cotonou, Benin, pp. 8-25.

Yamauchi, M., Peng, X. X., 1993. Ethylene production in rice bronzing leaves induced by ferrous iron. Plant Soil 149, 227-234.

Yambao, E. B., Ingram, K. T., 1988. Drought stress index for rice, Philipp. J.Crop Sci. 13(2), 105-111.