Agricultural Journal 4 (5): 226-230, 2009
ISSN: 1816-9155

Response of Lowland Rice to Iron Toxicity at Different Slope Positions: A Case Study in Upper Oueme Basin, Benin Republic

[1]Amit Kumar Srivastava, [2]Claude Kanninkpo and [1]Thomas Gaiser
[1]Department of Plant Nutrition, Institute of Crop Science and Resource Conservation, University of Bonn, Karlrobert-Kreiten Strasse 13, 53121 Bonn, Germany
[2]Faculty of Agronomic Sciences, University of Calavi, BP 526 Cotonou, Republic of Benin, Nigeria

Abstract: With growing population pressure and food demands, which are expected to multiply manifold in the coming years, combined with a steady increase of rice consumption per capita and a looming shortage of rice on the world market, the use of inland valleys of the sub-humid savannah zone of West Africa for rice production has become imperative. This study aims to investigate, the potential productivity of rice in the lowlands of the sudano-guinean savannah in Benin Republic (West Africa). A split-split-plot field experiment over three years with three factors (slope position, bunding, fertilizer application) and four replications has permitted to obtain the following results: The plots at the upper slope position produced on average 3.8 Mg ha^{-1} of paddy rice and the yield was significantly different from the yield produced in the down slope position which amounted to 2.5 Mg ha^{-1}. The disliked plots gave on average 3.5 Mg ha^{-1} of paddy rice and were significantly different from plots without dikes, which produced only 2.8 Mg ha^{-1}. The fertilized plots (130 kg of urea and 87 kg of TSP/ha) produced 3.3 Mg ha^{-1} of paddy rice and were not significantly different from the non fertilized ones which produced 3.1 Mg ha^{-1}. The tissue analysis of rice leaves in connection with the field observations showed that yield variability in the different treatments were due to iron toxicity and difference in nitrogen concentration.The results indicate considerable production potential of inland valleys in West Africa and revealed that at down slopes bunding of plots and fertilizer application dampened negative yield effects of iron toxicity and improved nitrogen supply.

Key words: Inland valley, iron toxicity, nitrogen supply, Oryza sativa, fertilizer application, variability

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. The interest for such ecosystems is justified on several fronts. On one hand, they have potentially fertile soil, enriched with nutrients washed in by the runoff and on the other hand, it is the lower portion of the landscape in which the runoff often causes a temporary flood exploitable for rice production. It follows that the bottoms are the most favourable to those crops requiring excess water supply. Their development would be a valuable tool for management and rational exploitation of water for increasing food production. 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. An agricultural growth of 4% per year would be necessary to ensure food security for the rapidly growing population in Africa.Unfortunately, estimations forecast either stagnation or decreases in crop yields resulting from a decline of soil fertility in the region. Additionally, iron toxicity is also, recognised as one of the major constraints to rice production in the lowlands of West Africa (Abifarin, 1988) 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.

Corresponding Author: Amit Kumar Srivastava, Department of Plant Nutrition, Institute of Crop Science and Resource Conservation, University of Bonn, Karlrobert-Kreiten Strasse 13, 53121 Bonn, Germany

MATERIALS AND METHODS

Site description and climate: The experiments were carried out for three years from 2006-2008 at the village of Dogue (Southern Donga) in North west of Benin Republic (West Africa), which is located at 9°06 N and 1°56 E at a distance of about 87 km from the city of Parakou.

The climate on the site is Soudano-Guinean. The rainfall distribution is unimodal with two seasons: a rainy season from mid of April to mid of October and the subsequent dry season. The temperature has little variation within the year. The maximum temperature is 40°C in the dry season, whereas the average temperature is relatively high and is 26.4°C with a magnitude of heat up to 5°C (Sintondji, 2005). On the average, rainfall show a peak in August. First rainfall begins in March and becomes significant from May-September, the period of intensive farming activities. Harmattan (cold and dry wind) and the monsoon (warm and humid wind) are the wind systems in the north of Benin, with harmattan as the dominating system. The average annual rainfall over the period of thirty years (1961-1990) was 1119 mm, which is very close to the values of average rainfall over the years 2007 and 2008 (1156 mm). Thus, in the years 2007 and 2008, good amounts of rainfall were recorded, whereas the year 2006 was particularly dry.

Soil characterisation: Overall, the region is occupied by ferruginous tropical soils in the well drained areas. Hydromorphic soils are located at the bottoms and have a sandy clay texture. According to FAO, soil classification the soils on the experimental plots are characterised as Lixisols (upper slope) and Gleysols (down slope) (Table 1).

Study methodology

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. It belongs to the group of NERICAs (New RICe for Africa) obtained by crossing the Asian variety Oryza sativa var. indica with a variety of African rice Oryza glaberrima followed by a retro-crossing of the hybrid with its African parent variety. It is a variety that integrates the strong hardiness of parent African rice and high productivity of Asian rice (WARDA, 2006).

Table 1: Results of chemical analysis of soil samples (0-20 cm) from the experimental plots before installation of the field experiment

Parameters	Upper slope	Down slope
	Mean±SD	
Total nitrogen (mg g^{-1})	0.39±0.07	0.67±0.1
Organic carbon (% C)	0.6±0.08	0.9±0.2
C/n ration	17±2.2	13±3.7
Available phosphorus (ppm)	5±3	8±5
pH water	5.6±0.3	5.3±0.2
Bases exchangeable (Cmol kg^{-1})		
Potassium (K^+)	0.19±0.1	0.2±0.1
Sodium (Na^+)	0.002±0.004	0.03±0.04
Calcium (Ca^{2+})	1.6±0.5	2.3±1.1
Magnesium (Mg^{2+})	0.5±0.08	0.6±0.1
Total	2.4±0.6	3.3±1.6
CEC (Cmol kg^{-1})	4.1±0.5	5.3±1.4
Base Saturation (%)	57.3±10.0	58.2±19.3

Data are expressed as mean±SD

Experimental design and treatments: The experimental design was a split-split plot. A total of three factors were studied:

Topographical position: Two levels (upper slope and down slope) were tested.

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 (0.5 m wide and 40 cm in height).

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/ha.

Overall, there were 8 treatments with 4 replication. The plot size was 5×5 m.

Field operations: The land was prepared by weeding operation using machetes, followed by a houage of about 20 cm deep and preparing the sowing bed by using hoe and then the rake.

The rice was sown in the line directly in bed with a spacing of 0.20×0.20 m. Each seed hole was then provided with 4 seeds of rice, which were soaked in fresh water for 24 h at a temperature of 30°C. Just before sowing plots were treated with fertilizer with dose 1 (60 kg N + 40 kg P_2O_5). The fertilizer was broadcasted before sowing followed by mixing it into the soil. The plots of dose 0 witnessed no fertilizer application. Density correction (transplanting) was done at 21st (DAS) to provide a density of about 2 plants/hole. In all plots weeding was carried out three times, first about 27 DAS, the second one on 40 DAS) by using hoe, whereas third weeding was at 55 DAS manually. The periodic replacement of missing tufts took place during and after these weeding operations. The harvesting was done on 122 DAS and area of harvest was 2×(1×1 m).

Plant sample 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 h and a subsequent filtering and standard dilution to 100 mL. For nitrogen analysis Kjeldhal method was carried out.

Data analysis: 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 $p \leq 0.05$.

RESULTS AND DISCUSSION

Effect of fertilizer application on grain yield: In the year 2006, a grain yield of 2.0 Mg ha^{-1} was observed with fertilizer application (Fig. 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; Wopereis *et al*., 1996; Yambao and Ingram, 1988). In 2006, drought stress during the reproductive phase hampered floret and spikelet formation (Yambao and Ingram, 1988; Tuong *et al*., 2002).

Additionally, tillering and flowering were affected and maturity was delayed leading to lower yields. Drought stress also, affected biomass accumulation and straw weight was significantly lower than that of well-watered plants even where, fertilizer was applied. 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 (Fig. 2b). As shown in Fig. 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.

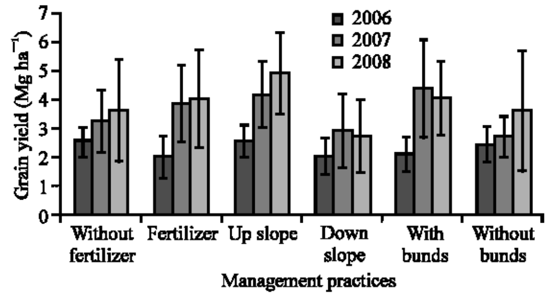

Fig. 1: Rice grain yield under different management practices over three growing seasons

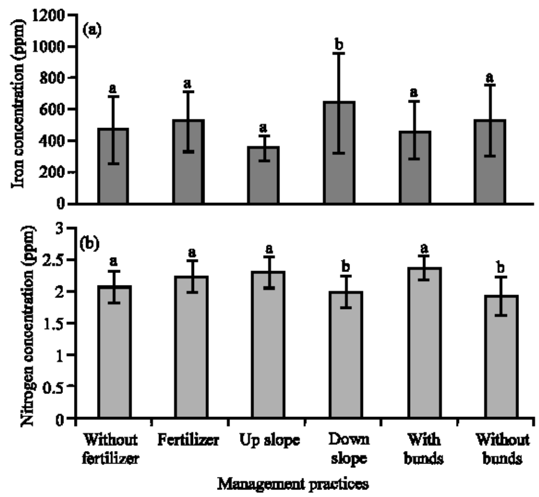

Fig. 2: Iron and Nitrogen concentration in leaves of rice plant under different management practices (mean over two years 2007 and 2008).Values with same letter within the group are not significantly different (p = 0.05)

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 2.5 Mg ha^{-1} of grain yield, which is 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 (Fig. 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 (Fig. 2a) . The same pattern of results were also observed in 2007 and 2008. In these years, plots on upper slopes registered significantly higher grain yield (34 and 45%, respectively) than that obtained from the down slope plots (Fig. 1). This was because plots on the lower parts of the slope have iron concentration above the toxicity threshold level (500 ppm) in the rice leaves leading to reduced biomass development and yields

(Fig. 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. However, a high concentration of iron in the aboveground plant biomass without the expression of the typical damage symptoms (bronzing) does not necessarily indicate symplastic tolerance (Becker and Asch, 2005). Yield losses associated with the occurrence of iron toxicity generally range from 15-50%. In the case of serious toxicity, however, total harvest loss can occur (Abifarin, 1988; Audebert and Sahrawat, 2000).

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 (2.4 Mg 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 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 (Fig. 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 (Fig. 2b). Iron concentrations were only slightly reduced through bunding (Fig. 2a).

Effect of factor interactions on rice yield: In year 2006, no significant effect of factor interaction on grain yield was recorded, whereas in year 2007 and 2008, significant interactions between bunding and slope position were observed.

In 2007 and 2008, 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 position, 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 use

Table 2: Grain yield under different factor interactions on 122 days after sowing.values with same letter within each year are not significantly different ($p \leq 0.05$)

Factor interaction	Grain yield (Mg ha^{-1}) Year 2006	Year 2007	Year 2008
Hp d 0	2.8a	4.6ab	4.4ab
Hp d F	1.7d	4.7ab	4.7ab
Hp sd 0	2.8ab	3.6abc	4.8ab
Hp sd F	2.7abc	3.7abc	5.5a
Bp d 0	2.2d	3.0abc	3.2bc
Bp d F	1.6d	5.2a	3.8ab
Bp sd 0	2.1d	1.6c	1.9c
Bp sd F	2.0d	1.8c	1.8c
Hp d	2.3xy	4.7x	4.6x
Hp sd	2.8x	3.6x	5.2x
Bp d	1.9y	4.1x	3.5x
Bp sd	2.1xy	1.7y	1.9y

Hp = Upper slope, Bp = Lower slope, d = With bunds, sd = 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 ($p \leq 0.05$)

Factor interaction	32 DAS Iron concentration (ppm)	Nitrogen concentration (%)
Hp d 0	423abc	2.60ab
Hp d F	336abc	2.63a
Hp sd 0	384abc	1.89c
Hp sd F	282d	2.08c
Bp d 0	430abc	1.97c
Bp d F	670ab	2.27ab
Bp sd 0	639abc	1.79c
Bp sd F	814a	1.93c
Hp d	380y	2.61x
Hp sd	333y	1.98y
Bp d	550xy	2.12y
Bp sd	727x	1.86y

Hp = Upper slope, Bp = Lower slope, d = With bunds, sd = Without bunds, 0 = Without fertilizer, F = With fertilizer (mean over two years 2007 and 2008)

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

Factor interaction	Inundation (days) 2006	2007	2008
Hp d	31	55	59
Hp sd	13	52	53
Bp d	40	103	83
Bp sd	31	97	80

Hp = Upper slope, Bp = Lower slope, d = With bunds, sd = Without bunds

efficiency. 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 4).

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. 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

Abifarin, A.O., 1988. Grain yield loss due to iron toxicity. WARDA (West Africa Rice Development Association) Technical Newsetterl., 8: 1-4.

Audebert, A. and K.L. Sahrawat, 2000. Mechanisms for iron toxicity tolerance in lowland rice. J. Plant Nutr., 23: 1877-1885.

Becker, M. and F. Asch, 2005. Iron toxicity in rice-conditions and management concepts. J. Plant Nutr. Soil Sci., 168: 558-573.

Camara, K.A., 2006. Test development of rice vaieties tolerant to iron toxicity. In iron toxicity in rice based systems of West Africa; Rice center for Africa (ADRAO) Cotonou, Bénin, pp: 68-81.

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

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

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

Sintondji, L., 2005. Modelling the rainfall-runoff process in the Upper Ouémé Catchment (Terou in Bénin Republic) in a context of global change: Extrapolation from the local to the regional scale. Ph.D. Thesis, University of Bonn, Germany.

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

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

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

Wopereis, M.C.S., M.J. Kropff, A.R. Maligaya and T.P. Tuong, 1996. Drought stress responses of two lowland rice cultivars to soil water status. Field Crops Res., 46: 21-39.

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

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