

Rice cropping with no continuous standing water: A promising technology for high rice productivity in the Office du Niger of Mali

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Abstract

The majority of intensive rice production system in West Africa are based on maintaining permanent standing water in rice plots in order to suppress weeds and ensure good rice growth. However, this system of growing rice leads to an increase in ground water level, which may rise to near the soil surface and cause waterlogging. The processes of capillary rise followed by high evapotranspiration demand in Sahelian conditions lead to soil alkalization and salinization processes, which are well known phenomena in the Office du Niger in Mali.

An exploratory study combining four nitrogen levels and two irrigation regimes (continuous standing water, and plot without standing water) was conducted at the Niono Regional Agronomic Research Center in 2004 in order to determine the productivity of irrigated rice with minimum irrigation water in the Office du Niger. From 2005 to 2007, a second study combining four new varieties and the local check, and three water regimes was conducted at the same research station. A model was constructed to determine water consumption of the plots under different irrigation regimes. The results of these exploratory studies indicated that, in the Office du Niger, optimum rice production can be achieved through irrigating rice plots without permanent standing water. No significant interaction was observed between soil fertility level and soil irrigation regime. There were more tillers in plots without standing water than in those with permanent water. Increasing N rates resulted in higher rice paddy yields in plots without standing water than in plots with continuous standing water. It may be concluded that changing the irrigation regime from continuous flooding to irrigation without standing water can significantly increase rice yields and reduce water need at the plot level in the Office du Niger. However, weed and salinity stress control methods may be new challenges that need further investigation.

Introduction

In 2006, West Africa consumed 9.87 million tonnes of rice (WARDA, 2007). During 2001–2005, rice consumption increased annually at 6.55% — well above the production growth (WARDA, 2007). West African countries can be divided into two groups: a group of countries in which annual *per-capita* rice consumption could be considered low (<45 kg) and another group of countries in which yearly rice consumption is high (>45 kg *per capita*) (WARDA, 2007). Although imports are expected to be a solution to food shortage, massive rice importation may cause negative effects on national production because of differences in prices. Availability of low-quality cheap rice on local markets can jeopardize local rice price and profitability (local production is affected by high input costs). This will lead most farmers to withdraw from paddy rice cultivation, and will affect future rice supply. There is considerable political interest in increasing local rice production as highlighted by the Mali government's rice initiative in 2008 and 2009.

Rice paddy production requires large amounts of water. The majority of intensive rice production systems are based on maintaining permanent standing water in rice plots in order to suppress weeds and ensure good rice growth. However, such systems lead to an increase in ground water level, which may rise to near the soil surface and cause waterlogging. The processes of capillary rise followed by high evapotranspiration demand under Sahelian conditions promote soil alkalization and salinization processes, which are well known phenomena in the Office du Niger.

There is a growing concern about water scarcity in the Office du Niger, which is the main rice-production area of Mali and the largest irrigation scheme in west Africa. In this area, about 90 000 ha is under complete irrigation control. The area is characterized by high evapotranspiration rate, 4 months of rainy season (June–September, with a yearly average of 460 mm rain), followed by an 8-month dry season. The dry season is characterized by 3 months of cool season (mid-November to mid-February, with minimum temperature around 16°C) and 4 months of hot season (with a maximum temperature around 45°C).

Since the 1990s, rice production has increased greatly, because of technology transfer from research centers to extension services. Paddy yield, which was only 2.5 t/ha in the 1980s, now varies between 5.5 and 6 t/ha. This success is attributed to the use of high-yielding varieties and new management practices, such as rice transplanting, fertilizer recommendations and pest control.

High-yield production technology that led to the green revolution is input intensive and can only be adopted by rich farmers. High agricultural input prices do not allow poor farmers to access modern production technologies (Shekhar and Jahesh, 2007). Excessive uses of agro-chemicals such as fertilizers and pesticides degrade soil biota and have negative environmental and social impacts (Shekhar and Jahesh, 2007; Stoop *et al.*, 2002). The System of Rice Intensification (SRI), which was an empirical finding, appears to be an attractive

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technology because of its water economy, reduced chemical fertilizer utilization and increased use of organic nutrient sources (Uphoff, 2004).

Four core practices are involved with SRI: (1) early transplanting of rice seedlings (usually 8–10-day old seedlings); (2) alternate soil flooding and drying; (3) early and frequent weeding (every 10 days); and (4) use of organic nutrient sources such as manure or compost. With the SRI technique, yield ranges of 8 to 15 t/ha have been reported (Uprety, 2004; Uphoff, 2002, 2004; Yuan, 2002). Many authors have attributed the yield-enhancement effects to combinations of many factors such as development of more tillers, greater root elongation, and active soil biota (Berkelaar, 2001; Satyanarayana, 2004). Other researchers have raised questions about the yield benefit of SRI (Dobermann, 2004; Sheehy *et al.*, 2005).

Constraints related to SRI practices include labor intensity, difficulty in obtaining the required amount of organic nutrients (usually 10–15 t manure or compost per ha), and opportunity cost for labor use. In Asia, there is a considerable diversity in how individual farmers adapt and implement the SRI package (Shekhar and Jayesh, 2007). According to Shekhar and Jayesh (2007), SRI is a complex technology package which has little chance for full adoption by poor farmers. In general, farmers tend to focus on only one or two components of the system rather than adopting the full package.

The purpose of the present study was to verify if any yield advantage could be obtained with minimum irrigation in the Office du Niger.

Materials and methods

In 2004 and 2005, an exploratory study combining five nitrogen levels and two irrigation regimes (continuous standing water, and plot without standing water) was conducted at the Niono agronomic research station (5°57' W, 14°16' N, 286 m). The irrigation treatments were a flooded plot (I₁) and a not flooded plot (I₂). The nitrogen rates were 0, 60, 120, 180 and 240 kg N/ha.

The experiment was a split-plot design with main-plot treatments being irrigation levels (flooded, not flooded plots). The irrigation treatments were surrounded by a trench to allow drainage of excess water. The sub-plot treatments were nitrogen levels. The main-plot treatments were completely randomized and replicated four times. The nitrogen levels were randomly attributed to each main-plot. Main-plot size was 10 × 50 m and sub-plot size 10 × 10 m. Overall, the design allowed the estimation irrigation main effects. Rice was randomly transplanted 25 days after sowing. The non-flooded plot was maintained moist throughout the active growing period up to flowering stage, while about 15 cm water level was maintained in the flooded plot. Each plot received a basal application of 100 kg of diammonium phosphate per hectare. Nitrogen fertilizer was split (3/8 at tiller stage and 5/8 at panicle initiation) according to treatment. At harvest, yield and yield components such as numbers of tillers and panicles, and 1000-grain weight were determined.

In 2006 and 2007, a second study combining five varieties and three water regimes was conducted in the same research station. The irrigation regimes corresponded to the following levels: I₁ (plot flooded with 15 000 m³ water/ha), I₂ (plot flooded with 10 000 m³ water/ha) and I₃ (non-flooded plot). The varieties in 2006 were Kogoni 91-1, WAT 310, NERICA-L-2-IER, WAS 161-B-9-2 and TOX 3100. Those used in 2007 were: Nionoka, WAT 310, Wassa, Telimani and WAS 161-B-9-2. The main characteristics of some of the varieties are summarized in Table 1.

Table 1. Agronomic characteristics of some of the varieties used

	Kogoni 91-1	WAT 310	NERICA-L-2-IER	Télimani	TOX 3100
Plant height (cm)	95	95	110	95	105
Days to maturity	135	110	135	115	140
Sensitivity to RYMV	Medium	Sensitive	Medium	Medium	Medium
Yield potential (t/ha)	10	9	10	9	10
Average yield (t/ha)	6	5	6	5	6
1000-grain weight (g)	23	24	29.55	24	29

RYMV, *Rice yellow mottle virus*.

The experiment was a split-plot design with main-plot treatments being irrigation levels (I₁, I₂, I₃) and the varieties were the sub-plots. Each main-plot was surrounded by a trench to allow drainage of excess water. Within the experiment, the main-plot treatments were randomized and replicated four times and varieties were randomized within each main-plot. The sub-plots were 10 × 10 m. At the entry of each main plot, irrigation was monitored using a motor-pump equipped with a volumetric water meter that allowed estimation of the exact amount of water inflow. The device was coupled with a standard gauge type flow Ventury equipped with

ultrasound sensor and a Multilog recorder. Treatments I₁ and I₂ received 15 000 and 10 000 m³ per hectare, respectively. The non-flooded plots (I₃) were maintained moist throughout the active growing period up to flowering stage, thereafter about 15 cm water was maintained up to maturity. The soil moisture in the non-flooded plot was monitored using a moisture probe. Irrigation was applied when the soil was drying up with only 20% moisture content. An automatic station equipped with volumetric moisture control sensor and a TDR100 probe (SDEC, France) was connected to each I₃ plot. This permitted following soil moisture change to the drying point of 80% (or 20% moisture). Overall, the design allowed the estimation of irrigation main effects, while the sub-plots allowed estimation of variety effects.

Each plot received a basal application of 100 kg of diammonium phosphate per hectare. As nitrogen source, all treatments received 200 kg of urea per hectare, which was split 3/8 at tiller stage and 5/8 at panicle initiation. Rice was randomly transplanted 25 days after sowing. At harvest, yield and yield components such as numbers of tillers and panicles, and 1000-grain weight were determined.

Statistical analysis

All data were subject to analysis of variance using the Genstat software package release 3.2 (Lawes Agricultural Trust, 1995). Where appropriate, means separation was done using the Newman and Keul multiple range test.

Results

Effects of flooding and not flooding on yield and yield components

In 2004, no significant interaction occurred between irrigation and nitrogen levels, but the treatment main effects were significant for number of tillers, straw weight and paddy yield (Table 2). There were far more tillers in non-flooded plots than flooded plots ($P > F = 0.041$). Numbers of panicles were not significantly different, but the absolute value was higher for non-flooded plots than for the flooded ones (Table 2). Straw yield and paddy yield were significantly higher in the non-flooded plots than flooded ones ($P > F = 0.012$ and 0.041 , respectively).

In 2005, yield components did not show any interaction effect or significant differences in treatment main effects; therefore, those values are not reported. Significant interaction did occur between irrigation regimes and nitrogen rates (Table 3).

Table 2. Effects of rice cropping with no standing water on paddy, straw and total above-ground biomass yield in 2004 at Niono research station

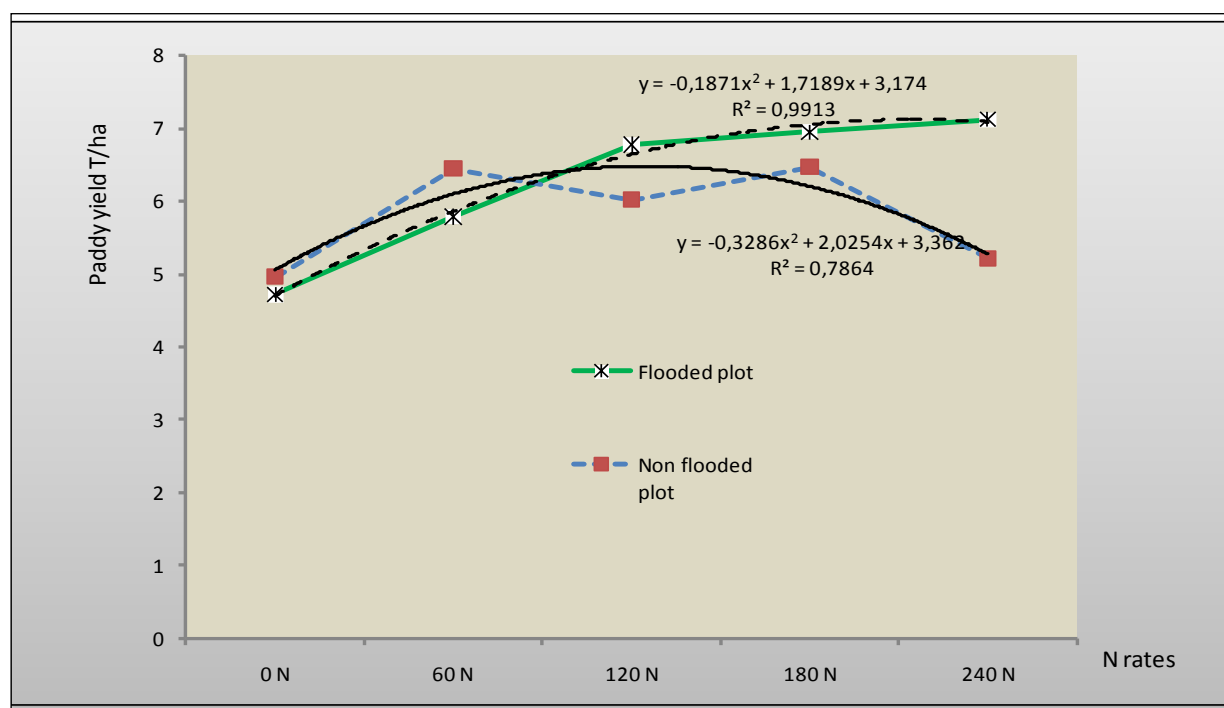
Variable	No. tillers per 10 hills	No. panicles per 10 hills	Straw yield (kg/ha)	Paddy yield (kg/ha)
Irrigation				
Flooded plot	179.0	148.0	8220	6769
Non-flooded plot	245.0	235.0	8600	7513
Nitrogen (kg N/ha)				
0	189.0	158.0	6220	5269
60	245.0	225.0	6600	5513
120	219.0	248.0	7220	6769
180	255.0	235.0	8400	7513
240	279.0	248.0	8220	6769
P>F				
Irrigation (I)	0.041	0.107	0.012	0.050
Nitrogen (N)	0.081	0.107	0.012	0.032
I × N	0.081	0.107	0.038	0.050
CV%				
Irrigation	12	22	28	18
Nitrogen	25	35	36	41

There were quadratic responses of paddy, straw and total biomass yields (Fig. 1 and 2). At low nitrogen levels (0 and 60 kg N/ha), paddy yield was higher in non-flooded plot than in the flooded plot (Fig. 1). However, with increasing rates of nitrogen, the reverse was observed: plots with standing water out-yielded the non-flooded plots.

The highest nitrogen rate (240 kg N/ha) increased rice paddy yield by 36% under continuous flooding conditions over non-flooded conditions.

Table 3. Effects of rice cropping with no standing water on paddy, straw and total above-ground biomass yield in 2005 at Niono research station

Variable	Paddy (t/ha)	Straw (t/ha)	Total biomass (t/ha)
Irrigation			
Flooded plot	5.69	7.22	12.90
Non-flooded plot	6.13	7.10	13.20
Nitrogen (kg N/ha)			
0	4.84	5.77	10.59
60	5.84	6.60	12.43
120	6.40	6.98	13.44
180	6.71	7.75	14.46
240	6.17	8.03	14.22
P>F			
Irrigation (I)	0.042	0.212	0.160
Nitrogen (N)	<.001	<.001	<.001
I × N	0.041	0.037	0.023
CV%			
Irrigation	33	45	28
Nitrogen	15	29	22

**Figure 1.** Interaction effects of irrigation regime and nitrogen rate on paddy yield in 2005.

At low nitrogen level, straw yield was higher for non-flooded plots compared with flooded ones. However, at high nitrogen rates, no significant differences were observed and both treatments responded positively to increasing N application (Fig. 2).

At nitrogen rates between 0 and 120 kg/ha, the total biomass yields were higher in non-flooded plots than flooded ones, but at higher N rates (>120 kg/ha), flooded plots out-yielded the non-flooded plots (Fig. 3).

Response of five rice varieties to water regime

The analysis of variance did not show any interaction effects between genotypes and irrigation in either 2006 or 2007 (Tables 4 and 5). Therefore, only treatment main effects are presented. Significant differences were found between genotypes in all years. In 2006 (Table 4), the best genotypes were NERICA-L-2-IER with 7900 kg paddy/ha, followed by TOX 3100 (7008 kg/ha) and Kogoni 91-1 (6558 kg/ha). In 2007 (Table 5), WAT 310, Nionoka and Wassa gave the highest yields of 7855, 6967 and 6513 kg/ha, respectively.

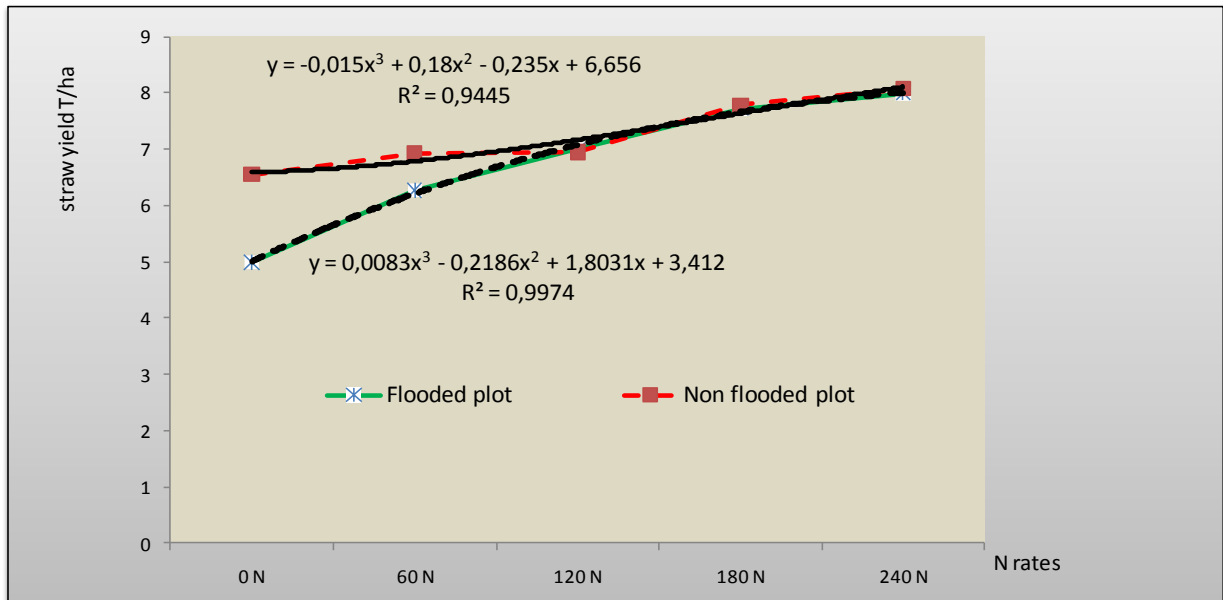


Figure 2. Interaction effects of irrigation regime and nitrogen rate on straw yield in 2005

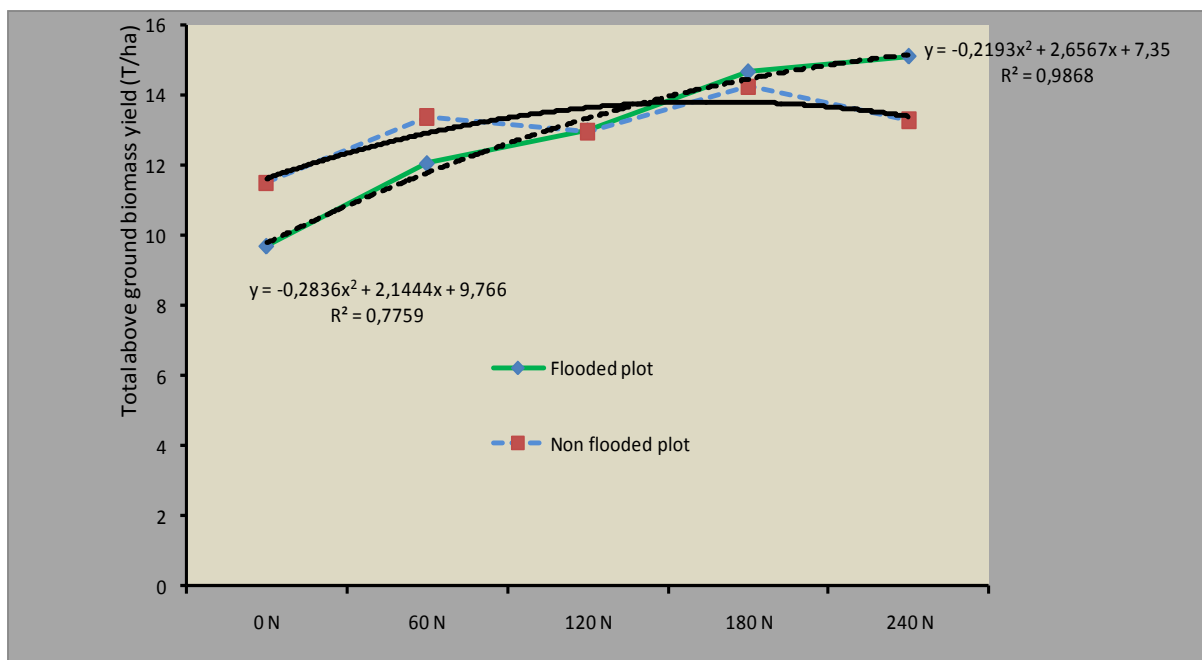


Figure 3. Interaction effects of irrigation regime and nitrogen rate on total above-ground biomass yield in 2005

Table 4. Effects of irrigation regimes on the yield and yield components of five rice varieties in 2006

Treatment	Plant height (cm)	Panicles per m ²	Grains per panicle	Paddy yield (kg/ha)
Irrigation level				
I ₁	111	380	165	6255
I ₂	108	369	167	6345
I ₃	115	370	159	6855
F test†	NS	NS	NS	NS
Variety				
WAT 310	105 b	353 b	168 b	5108 d
Kogoni 91-1	102 a	370 b	168 b	6558 bc
NERICA-L-2-IER	120 a	345 b	199 a	7900 a
WAS 161-B-9-2	109 b	424 a	118 c	5850 cd
TOX 3100	119 a	386 ab	166 b	7008 b
F test†	S	S	S	S
Variety × irrigation				
Mean	NS	NS	NS	NS
CV	8.40	13.00	11.60	14.80

† F test: S = significant when $P > F \leq 0.05$; NS = non significant when $P > F > 0.05$. The Newman and Keul test was used to separate the means. Numbers with the same letters were not significantly different at 5% probability level.

I₁, plot flooded with 15 000 m³ water/ha; I₂, plot flooded with 10 000 m³ water/ha; I₃, plot not flooded.

Table 5. Effects of irrigation regime on the yield and yield components of five rice varieties in 2007

Treatment	Yield (kg/ha)
Irrigation	
I ₁	6210
I ₂	6205
I ₃	6685
F test†	NS
Variety	
WAT 310	7855 a
Nionoka	6967 b
Wassa	6513 bc
WAS 161-B-9-2	5805 cd
Télimani	5063 d
F test†	S
Irrigation × variety	
	NS

† F test: S = significant when $P > F \leq 0.05$; NS = non significant when $P > F > 0.05$. The Newman and Keul test was used to separate the means. Numbers with the same letters were not significantly different at 5% probability level.

I₁, plot flooded with 15 000 m³ water/ha; I₂, plot flooded with 10 000 m³ water/ha; I₃, plot not flooded.

Discussion

The 4-year studies indicated that plant growth can be promoted by the alternation of wetting and drying the soil. In all years, the observed increase in numbers of tillers resulted in higher above-ground straw and total biomass yields when compared to plots with continuous standing water (Fig. 1, 2 and 3). Yield advantage was generally observed in non-flooded plots even though differences were not always statistically significant. The magnitude of the yield advantage depended greatly on soil nutrient conditions. Differences were small when nitrogen rate was high, but greater with low N application. This indicates that under low nutrient conditions, particularly nitrogen, non-flooded conditions may be more advantageous than flooded conditions. Rice yield is determined by the number of grain-bearing tillers per unit area, the number of grains per panicle, and the weight of individual grains (Stoop *et al.*, 2002). According to Stoop *et al.* (2002) rice plants raised under flooded conditions seldom produce 8–13 tillers. With SRI practice, which is usually with no standing water, individual plant may produce as many as 80 tillers (Stoop *et al.*, 2002). Turner and Haygarth (2001) report that SRI practice of alternate flooding and drying of the soil may contribute to large releases of organic phosphorus from soil microbial biomass.

Evidence for improved rooting in moist, aerated soils has been presented by Joelibarison (Stoop *et al.*, 2002), who indicates that twice as much force was required to remove single plants with SRI planting methods as to pull out a cluster of three plants grown under flooded conditions. It was concluded under flooded anaerobic

conditions, the total volume that can be exploited by the root system is restricted. Roots that exploit large soil volume can take up more nutrients than those with limited volume.

SRI results are very challenging and require more investigation by scientists. Scientists have always supported the hypothesis that rice performs best under flooded conditions. Rice plants are known for their ability to transport oxygen from the air through the leaves and stem to the root system. Whether this adjustment mechanism is enough for better plant growth is an area that should be investigated further.

The present study indicated that, in the Office du Niger of Mali, it is possible to reduce water consumption by half without any yield loss. Similar conclusions were reached by Hatta (1967) and Guerra *et al.* (1998) in separate studies. Water supply through the irrigation channel of the Office du Niger is about 15 000 m³ per hectare. The present study indicated that irrigation water supply could be reduced by one-third to a half (potentially 7500 m³/ha).

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