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Exploring Opportunities for Improving Rice Yield and Income in Inland Valleys of West Africa:
The Case of *Sawah* Adoption in Central Nigeria

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Introduction

In West Africa (WA), a substantial gap between rice production and consumption has been identified as a major political issue (Seck *et al.*, 2010). This gap has even been widening, increasing the economic burden of rice import over the past 50 years due to rapid demand growth in the region (Seck *et al.*, 2010). Limited rice productivity (i.e., rice production per unit of land as shown by grain yield), which has remained stagnant at 1.5–2.0 t ha^{-1} during this period, has been a primary drawback. This is in clear contrast to the 4.0–5.0 t ha^{-1} currently achieved in Southeast Asia and Latin America, thanks to the Green Revolution (GR).

Based on lessons learned from the success stories of GR in these two regions, a low adoption rate of GR technologies (i.e., improved germplasms, chemical fertilizers, and irrigation facilities, the key technologies of GR), has been regarded as a bottleneck in WA (Otsuka and Kalirajan, 2006; Seck *et al.*, 2010). However, the adoption of GR technologies alone may not be enough to boost rice productivity in WA, as these technologies often only can realize their potential when applied to a favorable environment for rice growth (Abe and Wakatsuki, 2011; Abe, 2012; Wakatsuki, 2013). From this viewpoint, Wakatsuki and his colleagues have been proposing that *'Sawah'*, an Asian-type paddy field, must be introduced to rice fields prior to the adoption of GR technologies. They argue that *Sawah* can provide such a favorable environment, and create a platform that enables GR technologies to work efficiently.

'Sawah' literally denotes an agricultural production infrastructure that has a bunded, leveled, puddled basin, often connected with irrigation and drainage canals (Abe and Wakatsuki, 2011). In a *Sawah*, the basin can be kept under controlled submergence, which optimizes rice growth. In Southeast Asia, the world granary of rice, rice is predominantly grown under controlled submergence thanks to the existence of *Sawah* all over the region. In contrast, in many parts of WA, rice is produced under uncontrolled conditions or without submergence because of the absence of *Sawah* (Abe and Wakatsuki, 2011; Abe, 2012; Wakatsuki, 2013). The development of *Sawah* in combination with the adoption of GR technologies often results in certain improvement of rice productivity (Asubonteng *et al.*, 2001; Ofori *et al.*, 2005), and may contribute to income generation and poverty reduction in WA (Abe and Wakatsuki, 2011; Abe, 2012; Wakatsuki, 2013). Regardless of its potential to improve rice productivity and income generation, the influence of *Sawah* adoption on these indicators has not been assessed extensively; in particular, there has been no report examining it in relation to the adoption of GR technologies (Wakatsuki, 2013).

The aim of the present study was therefore to compare rice grain yield and associated income as affected by GR technology adoption between plots that have (*Sawah* plots) and have not (non-*Sawah* plots) adopted *Sawah*. To this end, a questionnaire survey was conducted to obtain rice plot-based data in inland valleys of a traditional rice production area in Central Nigeria, where *Sawah* has been introduced by a Japan-funded project.

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Materials and Methods

Study Area

The study area is situated in Bida, Niger State, Nigeria (09°05' N, 06°01' E; 150 m above sea level) (see Fig. 1). The climate in this area belongs to the Guinea savanna agro-ecological zone, with a mean annual daily temperature of 23 °C and a mean annual precipitation of 1100 mm, most of which occurs during May–October in normal years. Sandy soils with siliceous or kaolinitic mineralogy derived from Nupe Sandstone represent the low-fertility status at an advanced weathering stage in the study area (Ishida *et al.*, 1998; Abe *et al.*, 2010). These soils are often classified into Inceptisols or Entisols in US Soil Taxonomy. Inland valleys, the upper reaches of river systems, are an extensive topography and are often suitable for wet rice cultivation (Windmeijer and Andriesse, 1993). The inland valleys in the study area are widely exploited for agricultural use by the Nupe, a dominant ethnic group in this region (Hirose and Wakatsuki, 2002). The Nupe have a long-established tradition in lowland rice farming, and have developed indigenous rice farming systems characterized by distinctive methods of land preparation (Wakatsuki, 1990; Hirose and Wakatsuki, 2002; Ishida *et al.*, 1998) and supported in part by traditional irrigation systems (Fu *et al.*, 2010).

Sawah is of exogenous origin and is relatively new to the study region, although the Nupe's traditional rice fields display some forms of *Sawah*, such as a partially bunded basin (Wakatsuki, 1990; Ishida *et al.*, 1998). *Sawah* was introduced to the Bida region on a trial basis by a Japan-funded project in the early 1990s (Hirose and Wakatsuki, 2002). A reliable *Sawah* development scheme, which relies on farmers' participation and machinery assistance, was established by 2001, and thus real efforts for *Sawah* extension extend from that date (Hirose and Wakatsuki, 2002; Abe *et al.*, 2015). In brief, farmers who participated in the project devoted themselves voluntarily to bund making and preliminary leveling, while small machinery was subsequently applied for puddling and leveling. Voluntary work was also provided for irrigation system development only when necessary for *Sawah* installation. Most often, the project provided a two-wheel walking tractor, a so-called power tiller, for each participating village, which the farmers were expected to operate and maintain for themselves afterwards (Hirose and Wakatsuki, 2002; Wakatsuki, 2013). A farmer who wanted to use the power tiller in his rice fields was obligated to invite a power tiller operator and pay for the fuel and the operator's allowance. All farmers who relied on the power tiller within the village had to share in the cost of repairs if it broke down. In addition, farmers who participated in the project enjoyed seeds of an improved germplasm (i.e., WITA4 [FARO44]), free of charge, and agronomic instructions provided by the project at the beginning of their participation.

Survey Methods

A questionnaire survey was conducted in the study area from June till August 2009. In this survey, we assessed 313 paddy plots managed by 132 households. Heads of these households were invited from eight villages: Ejeti, Emitsun Dadan, Nassarafu, Shabamaliki, Amgbasa, Emitsu, Emiworongi and Tsuwatagi. The

Fig. 1. Location of the study area.

interviews were conducted using a structured questionnaire. Rice plots were categorized into two groups: *Sawah* plot (n=29), and non-*Sawah* plot (n=284). *Sawah* plots were prepared by making bunds manually, followed by mechanical puddling and leveling (Abe *et al.*, 2015); non-*Sawah* plots, lacking complete bunding, puddling and leveling, were prepared thoroughly by farmers using a traditional hand hoe (Ishida *et al.*, 1998). Rice production gains were calculated by multiplying the amount of rice (paddy-basis) by the unit price when it was sold. Production costs included those for procurement of the germplasm, chemical fertilizer, herbicide, rice sacs, labor allowance and mechanical operation. Neither disease nor insect attack that would affect rice yield seriously was observed in the survey year.

Data Analysis

Statistical analysis was performed using Microsoft Excel 2010 and StatView Ver. 5.0.1. (SAS Institute, Inc.). Normal distribution of the datasets was assumed because all rice plots examined in this study were selected randomly. In addition, these data were considered to be independent of each other, even though some of the plots were managed by the same household head.

A Student's t-test was applied to detect statistically significant differences ($P < 0.05$) in the mean values of any entries between the *Sawah* and non-*Sawah* plots, while one-way analysis of variance (ANOVA) was carried out to consider the impact of the improved germplasm adoption, chemical fertilizer application, use of supplemental irrigation, and all possible combinations of these as a fixed effect. Mean values between the categorized groups according to the applied technologies were separated at $P < 0.05$ using Fisher's protected least significant difference (LSD) test.

Results and Discussion

General characteristics of rice plots and agronomic practices applied are listed for the *Sawah* plots and non-*Sawah* plots in Table 1. There was no significant difference in the mean plot area between the two, but agronomic practices differed widely, except for the use of herbicides, which showed a very high adoption rate (>90%) in both types of plots. Transplanting of rice seedlings of the improved germplasm was mostly done in the *Sawah* plots, thanks to the project's seed distribution service and technical advice (Hirose and Wakatsuki, 2002); meanwhile, direct seeding of traditional non-improved germplasms was still predominant in the non-*Sawah* plots, as reported previously (Ishida *et al.*, 1998; Hirose and Wakatsuki, 2002). Also, the higher adoption rates of chemical fertilizers and irrigation observed in the *Sawah* plots could be attributed to the technical supervision provided by the project (Hirose and Wakatsuki, 2002; Wakatsuki, 2013; Abe *et al.*, 2015). The low adoption rate of these GR technologies in the non-*Sawah* plots may have resulted from the farmers' poor accessibility to and limited ability to afford information and technology (Otsuka and Kalirajan, 2006), as well as their farming strategy of coping with local environmental settings and

Table 1. Comparison of general characteristics and agronomic practices between *Sawah* plots and non-*Sawah* plots in the studied inland valleys.

Entry	*Sawah* (n=29)	Non-*Sawah* (n=284)
Total plot area (ha)	15.7	135.7
Plot area (mean±SD ha)	0.54±0.46	0.48±0.40
Max. plot area (ha)	2.14	3.69
Min. plot area (ha)	0.17	0.39
Transplanting (plot number %)	100.0	37.0
Transplanting (plot area %)	100.0	24.3
WITA4 adoption (plot number %)	96.6	42.3
WITA4 adoption (plot area %)	98.5	33.4
Mechanical tillage (plot number %)	100.0	0.0
Mechanical tillage (plot area %)	100.0	0.0
Irrigation use (plot number %)	93.1	42.6
Irrigation use (plot area %)	94.9	29.5
Fertilizer use (plot number %)	86.2	65.8
Fertilizer use (plot area %)	82.9	66.2
Herbicide use (plot number %)	96.6	91.2
Herbicide use (plot area %)	98.3	95.4

occasional disasters such as flood and drought (Abe *et al.*, 2012).

A significantly higher yield of paddy grains was attained in the *Sawah* plots compared to the non-*Sawah* plots (Table 2). The grain yield was still higher when the *Sawah* plots were compared with selected non-*Sawah* plots that received all three GR technologies: improved germplasm, fertilizer and irrigation. This was despite the fact that six of the 29 *Sawah* plots suffered from the lack of one or two of the GR technologies. However, the combined application of all three GR technologies more than doubled the grain yield in the non-*Sawah* plots, resulting in a smaller difference from the *Sawah* plots, contrary to our expectations. These results meant that our hypothesis that *Sawah* is a prerequisite for the effective use of GR technologies for lowland rice farming in WA was not valid in this case study. However, the mean grain yield of 3.2 t ha^{-1} for the *Sawah* plots recorded in this study was certainly lower than the 3.7–6.7 t ha^{-1} recorded in a previously conducted on-farm trial in the Bida region (Hirose and Wakatsuki, 2002). It is likely that this yield gap arose from the insufficient supervision and inadequate technical training given by the project. In fact, based on our observation during the field survey, it would seem that the majority of *Sawah* plots developed by the Nupe farmers had lower quality than the standard ones in terms of size and durability of the bunds and land leveling.

Table 2. Comparison of rice yield (t ha^{-1}) between *Sawah* plots and non-*Sawah* plots in the studied inland valleys, as affected by the adoption of Green Revolution technologies.

Entry	n	Grain yield	SE
Sawah	29	3.15a***	0.36
Control	56	1.23e	0.09
Germplasm (G)	9	1.59de	0.32
Fertilizer (F)	69	1.83d	0.08
Irrigation (I)	11	1.59de	0.18
G X F	29	2.05cd	0.18
G X I	21	2.31c	0.15
F X I	28	1.51de	0.14
G X F X I	61	2.79b	0.10
non-*Sawah* (total)	284	1.93***	0.06

*** indicates a significant difference at $P < 0.001$ by the Student's *t*-test
Different letters denote significant differences at $P < 0.05$ by the Fisher's protected LSD test
SE indicates a standard error

On the other hand, the results of this study indicated that application of a single GR technology prompted little improvement in grain yield. Although the combined application of the improved germplasm with either fertilizer or irrigation increased the grain yield significantly, the combination of fertilizer with irrigation did not. These results suggest that application of a single GR technology is not effective, and combination patterns of the GR technologies affect their efficiency in improving rice productivity.

Income derived from rice production per-unit land area was significantly higher in the *Sawah* plots than in the non-*Sawah* plots. This, however, was simply because the increase in the gain from rice production outweighed the increment in the production costs resulting from the *Sawah* development and the GR technologies adoption (Table 3). In addition, the per-unit land area income associated with rice production was significantly higher in the *Sawah* plots than in the selected non-*Sawah* plots employing all three GR technologies (Table 3). These results suggest that *Sawah* adoption produces a

Table 3. Comparison of economic status (US\$ ha^{-1}) between *Sawah* plots and non-*Sawah* plots in the studied inland valleys, as affected by the adoption of Green Revolution technologies.

Entry	n	Cost	SE	Gain	SE	Income	SE
Sawah	29	423b***	71	1405a***	52	981a***	83
Control	56	138d	16	506d	37	368d	44
Germplasm (G)	9	226bcd	48	662cd	126	437d	133
Fertilizer (F)	69	323bc	29	842c	41	519d	34
Irrigation (I)	11	183cd	90	753c	101	570cd	43
G X F	29	555ab	71	885c	73	329	77
G X I	21	209cd	39	1090b	86	881ab	80
F X I	28	275c	44	689c	72	414d	49
G X F X I	61	553a	48	1270a	53	716bc	53
Non-*Sawah* (total)	284	338***	19	866***	26	528***	22

*** within a column indicates a significant difference at $P < 0.001$ by the Student's *t*-test
Different letters within a column denote significant differences at $P < 0.05$ by the Fisher's protected LSD test
SE indicates a standard error

significant economic advantage, and helps smallholder rice farmers generate income. However, this advantage was not as high as expected based on studies conducted in other regions (Wakatsuki, 2013). Furthermore, the associated income per-unit land area for the *Sawah* plots was not significantly different from the selected non-*Sawah* plots that enjoyed the combined application of the improved germplasms with irrigation, although the *Sawah* plots included six that had the incomplete adoption of GR technologies, as stated earlier. This result is probably due to the inclusion of sample sets from highly productive lands with better soil fertility, which brought about a relatively high yield of rice without any fertilizer application, and thus produced a relatively high income at a lower production cost.

As mentioned above, the *Sawah* plots developed by the Nupe farmers exhibited inadequate quality in the study region. This would have caused lower rice productivity and associated income than those recorded in other study regions or in previous studies (Wakatsuki, 2013). The quality of *Sawah*, however, could be improved with sufficient technical training and adequate supervision of farmers. This would further enhance the advantages of *Sawah* adoption on GR technology adoption.

Conclusion

Rice grain yield and its associated income were significantly higher in the *Sawah* plots than in the non-*Sawah* plots. Furthermore, the *Sawah* plots were still significantly higher in yield and income when compared to selected non-*Sawah* plots that enjoyed combined application of all three GR technologies: improved germplasms, chemical fertilizers, and irrigation facilities. These findings highlight certain advantages of *Sawah* adoption in terms of enhancing rice productivity and income generation. They also shed light on the potential of *Sawah* to narrow the production-consumption gap and combat the epidemic poverty and hunger spreading over WA. As recognized by the Africa Rice Center (2013), dissemination of *Sawah* associated with the adoption of GR technology therefore deserves political promotion and financial assistance as a prime factor of rice production improvement in the wetlands of the region.

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