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Short communication

Factors affecting variation in farm yields of irrigated lowland rice in southern-central Benin

Atsuko Tanaka[a], Kazuki Saito[b], Komla Azoma[b], Kazuhiko Kobayashi[a,*]

[a] Graduate School of Agricultural and Life Sciences, The University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo 113-8657, Japan
[b] Africa Rice Center (AfricaRice), 01 BP 2031 Cotonou, Benin

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ABSTRACT

For increasing rice production in West Africa, both expansion of rice harvested area and raising rice yield are required. Development of small-scale irrigation schemes is given high priority in national rice development plans. For realizing potential of the newly developed schemes, it is essential to understand yield level, farmers' crop management practices and production constraints. A series of field surveys were conducted in six small-scale irrigation schemes in Zou department, Benin during the dry season in 2010–2011 to assess variation in rice yields and identify factors affecting the variation. The schemes were established between 1969 and 2009. Rice yields ranged from 1.3 to 7.8 t ha^{-1} with an average yield of 4.8 t ha^{-1}. The average yield was only 2.9 t ha^{-1} for newer irrigation schemes developed in 2002 and 2009. Multiple regression analysis using farmers' crop management practices as well as abiotic and biotic stresses as independent variables revealed that 75% of the variation in yields could be explained by five agronomic factors (fallow residue management, ploughing method, water stress, rat damage and N application rate) and two edaphic factors (sloped surfaces and sand content in the soil). Removing fallow residue from the fields for land preparation reduced yields. Yields were lower in plots ploughed by hand than by machine. Sloped surface, water stress and rat damage reduced yields. Yield increase due to N application ranged from 0.8 to 1.6 t ha^{-1}. Higher sand content was associated with lowered yields. The low yields in new irrigation schemes caused by sub-optimal crop management practices suggest that farmer-to-farmer learning and extension of good agricultural principles and practices can increase yields. Organizational capacity is also important to ensure the use of common resources such as irrigation water and tractors for land preparation.

1. Introduction

Demand for rice has steadily grown in West Africa due to population growth and consumer preference for rice since the mid 1970s (Balasubramanian et al., 2007; FAOSTAT, 2010). However, local rice production in this region has not met the increasing demand. As of 2007, imported rice accounted for approximately 40% of the total consumption (FAOSTAT, 2010). In the face of declining rice stocks and unstable commodity prices in the global market, increasing rice production is a critical issue for food security and poverty alleviation in this region.

One of the major reasons for the low rice production in West Africa is that most rice is grown under rainfed conditions. The average yields in farmers' fields are 0.5–2 t ha^{-1} for upland rice and 1–2 t ha^{-1} for rainfed lowland rice (Balasubramanian et al., 2007). However, this region has ample opportunity to develop irrigation schemes from large wetland areas with relatively high soil fertility. The total wetland area in sub-Saharan Africa is around 239 M ha (Andriesse, 1986). It is still unknown what fraction of the total wetland area is suitable for rice production, but currently less than 5% is planted to rice (Balasubramanian et al., 2007). Development of small-scale irrigation schemes is preferred over larger ones that include a large initial capital requirement and operational management difficulties (Turner, 1994; Vincent, 2003; Inocencio et al., 2007). New national rice development strategies emphasize the importance of small-scale irrigation to boost rice production in West Africa (Coalition for African Rice Development, 2011). Recently, progress in expansion of rice harvested area has been reported reflecting the domestic and international efforts (Knight and Sylla, 2011).

Subsequently, reducing the deviation of the current crop yield from its potential may emerge as a critical issue. In West Africa, a large yield gap has been reported between potential yields of irrigated lowland rice and actual farm yields (Wopereis et al., 1999; Becker and Johnson, 2001a,b; Becker et al., 2003; Poussin et al., 2003). Becker et al. (2003) showed that large yield gaps of

* Corresponding author. Tel.: +81 3 5841 1292; fax: +81 3 5841 5186.
E-mail address: k.kobayashi.ut@gmail.com (K. Kobayashi).

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Table 1
Characteristics of six irrigation schemes used to survey agronomic aspects of rice production in Zou department of Benin, in 2011.

Description	Parameter	Aize	Bame	Dome	Koussin	Lainta-Cogbe	Lele
Location	Longitude	7°9′N	7°13′N	7°5′N	7°14′N	7°9′N	7°15 - 16′N
	Latitude	2°29′E	2°25′E	2°18′E	2°16 - 17′E	2°20′E	2°16′E
	Surface area (ha)	30	1	45	63	5	40
Development of lowland field	Year	2002	2009	1983	1969	1985	1969
	Founder	National government	Local initiative	Local initiative	Foreign cooperation	Local initiative	Foreign cooperation
Irrigation	Water source	Ground water	Assanto river	Ground water	Koussin river	Wassa and Ologbo river	Lele river
	Irrigation system	Gravity	Pump	Gravity	Gravity	Gravity	Gravity

3.2–5.9 t ha^{-1} across four agro-ecological zones. Wopereis et al. (1999) reported that yield gap between actual and attainable yield ranged from 0.6 to 4.1 t ha^{-1} during the dry season in Guinea savannah zone in Burkina Faso. Previous studies conducted in the 1990s ascribed the yield gaps to a sub-optimal fertilizer application rate, poor weeding practices and inadequate water management (Becker and Johnson, 1999; Becker et al., 2003). These findings provided the basis in considering options for improving productivity, and have been used for development of decision support tools to improve rice yields in some West African countries (Haefele et al., 2003; Segda et al., 2005). In the newly developed irrigation schemes, however, limited information is available on actual production levels and the farmers' practices.

The objectives of this study is to (i) assess the variation in rice yields in small irrigation schemes which have run for a different number of years and (ii) examine factors that affect the variation in yields based on comprehensive information on crop management, and abiotic and biotic stresses. This study was taken during the 2010–2011 dry season in southern-central Benin and used a combination of farmers' surveys, crop measurement and soil analyses.

2. Materials and methods

2.1. Description of the study area

The study site, Zou department, is located approximately 100 km north of the capital of Benin (Fig. 1). This region has high potential to expand the area for lowland rice cultivation in the

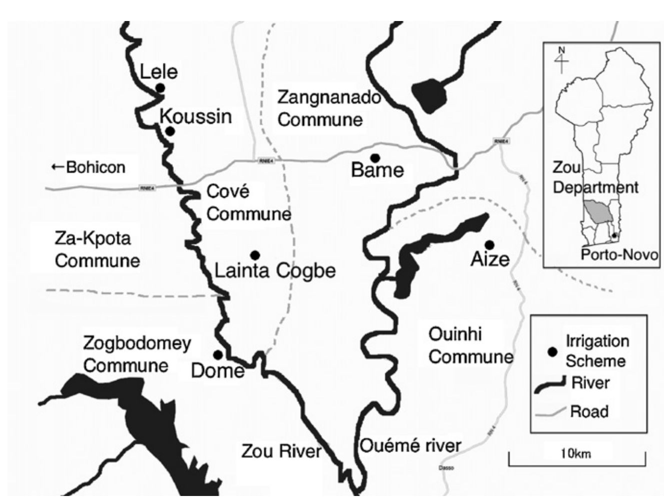

Fig. 1. Map of the study site and location of six irrigation schemes in Zou department of Benin.

country (NEPAD/FAO, 2005). The climate zone is classified as sub-equatorial with two rainy seasons from April to July and September to November. The average annual rainfall is 1100 mm. The soil type is ferralitic (Aregheore, 2009), which is strongly weathered, and in general has a texture of sand loam or finer and clay (Van Wambeke, 1974).

In Zou department, there are seven irrigation schemes for lowland rice cultivation as identified by local government officials. One irrigation scheme, Zomo, was out of production due to a canal blockage, so six schemes were considered in this study (Fig. 1). All six schemes are small-scale which is defined as being "typically 1–100 ha, controlled by farmers' groups, or single individual" (FAO, 1987). Table 1 describes the six irrigation schemes, including Aize (Ouinhi commune), Bame (Zangnanado commune), Dome (Zogbodomey commune), Koussin, Lainta-Cogbe and Lele (Cove commune). The developmental background and history of these schemes differ. Aize was developed by the national government in 2002. In Bame, maize fields were replaced by paddy fields in 2009. Local farmers developed Dome and Lainta-Cogbe in the 1980s. Koussin and Lele in the same area were developed in 1969 with foreign assistance. Double rice cropping is the major production system in all irrigation schemes except for Dome. In most cases, the rainy season rice crop is sown in March, while the dry season crop is sown in October.

2.2. Field survey

In February 2011, we visited the six irrigation schemes and selected 57 farmers who had plots sown with rice. The expected harvesting time ranged from the end of February to the middle of April. The 59 plots surveyed (one plot from 57 farmers, two from two farmers). Plot size ranged from 64 to 400 m^2. A semi-structured interview was conducted to gather information on cropping period and crop management practices including land preparation, crop establishment, fertilizer management, water management, weed control and pest management. The information collected from the field survey is listed in Table 2. Of the respondents 81% were men. Experience in lowland rice cropping ranged from 3 to 50 years. The lowland rice cultivation area ranged from 0.03 to 1.4 ha with an average area of 0.5 ha. Due to serious flooding during the 2010 rainy season, the sowing time was delayed in half of the studied plots and the most common sowing time was November. The fertilizer application rate of nitrogen (N), phosphorous (P) and potassium (K) was calculated using the composition rates of urea (46N–0P–0K) and compound NPK fertilizer (10N–9P–17K), which were the most popular. Field observation was carried out to supplement and verify the collected information. The observation covered paddy conditions: field position (flat area, or bottom, middle or upper part of sloping areas), slope on the surface of the plot, land roughness (visible clods or flat surface), bunds, irrigation inlet, water source, irrigation system and drainage (Table 2). Sloped surface resulted in pronounced water depth differences creating shallow water level in higher parts

Table 2
Independent variables used for multiple regression analysis.

No.	Description	Data collection method	Parameter
Continuous variable			
1	Age	Interview	From 24 to 81 years old
2	Year of experience on rice cultivation	Interview	From 3 to 50 years
3	Area of rice field	Interview	From 256 to 13,500 m^2
4	Seedling age	Interview	From 12 to 40 days
5	pH (H_2O)	Soil analysis	From 4.4 to 6.9
6	Total N (%)	Soil analysis	From 0.03 to 0.83
7	Extractable P (ppm)	Soil analysis	From 0.16 to 16.91
8	ECEC (cmol+ kg^{-1})	Soil analysis	From 1.55 to 25.54
9	Sand (%)	Soil analysis	From 14 to 74
10	Silt (%)	Soil analysis	From 6 to 36
11	Clay (%)	Soil analysis	From 9 to 72
Categorical variable			
12	Sex	Interview	1 = Female, 2 = Male
13	Seed production	Interview	1 = Yes, 2 = No
14	Sowing time	Interview	1= Before October, 2 = November, 3 = December
15	Fertilizer application in nursery	Interview	1 = Yes, 2 = No
16	Rice straw management after harvest	Interview	1 = Incorporate into soil, 2 = Pile on bunds. 3 = Burn
17	Fallow residue management (weeds)	Interview	1 = Incorporate into soil, 2 = Pile on bunds. 3 = Burn
18	Ploughing method	Interview	1 = By hand, 2 = By machine
19	Weeding frequency	Interview	1 = Once (hand weeding), 2 = Once (herbicide), 3 = Twice (hand weeding), 4 = Twice (hand weeding and herbicide), 5 = Three times (hand weeding), 6 = Three times (herbicide once and hand weeding twice), 7 = Three times (herbicide twice and hand weeding once)
20	Water management	Interview	1 = Intermittent irrigation, 2 = Continuous flowing irrigation
21	Water stress	Interview	1 = Yes, 2 = No
22	Frequency of fertilizer application	Interview	1 = None, 2 = Once, 3 = Twice, 4 = Three times
23	N application rate	Interview	1 = Zero kg ha^{-1}, 2 = 1 to 59 kg ha^{-1}, 3 = 60 to 79 kg ha^{-1}, 4 = 80 to 119 kg ha^{-1}, 5 = More than 120 kg ha^{-1}
24	P application rate	Interview	1 = Zero kg ha^{-1}, 2 = 1 to 14.9 kg ha^{-1}, 3 = 15 to 24.9 kg ha^{-1}, 4 = More than 25 kg ha^{-1}
25	K application rate	Interview	1 = Zero kg ha^{-1}, 2 = 1 than 20 kg ha^{-1}, 3 = 21 to 30 kg ha^{-1}, 4 = More than 31 kg ha^{-1}
26	Insects and diseases	Interview	1 = No, 2 = Mild damage, 3 = Moderate damage, 4 = Severe damage
27	Stem borer infestation	Interview	1 = Yes, 2 = No
28	Insecticide application	Interview	1 = Yes, 2 = No
29	Rat damage at harvest[a]	Observation	1 = Yes, 2 = No
30	Hill density at harvest[a]	Observation	1 = Less than 20 hills/m^2, 2 = 21-30 hills/m^2, 3 = 31 to 40 hills/m^2, 4= 41+ hills/m^2
31	Variety	Interview	1 = NERICA L 14, 2 = NERICA L 20, 3 = IR 841, 4 = ITA 304, 5 = Beris, 6 = BL 12
32	Field position	Observation	1 = Flat area, 2= Upper part on sloping area, 3= Middle part on sloping area, 4= Bottom part on sloping area
33	Sloped plot surface	Observation	1 = Yes, 2 = No
34	Rough surface	Observation	1= Visible clods, 1 = Flat surface
35	Bund height	Observation	1 = None, 2 = Low (<10 cm), 3 = Middle (11cm-30 cm), 4 = High (>31 cm)
36	Irrigation inlet	Observation	1 = Connected to waterway, 2 = Connected to other paddy
37	Water source	Observation	1 = River water gravitation, 2 = Groundwater
38	Irrigation system	Observation	1 = Gravity, 2 = Pump
39	Drainage	Observation	1 = Yes, 2 = No

[a] Except for two parameters, data were collected in February 2011, when rice growth stage corresponded to period between the early reproductive stage and ripening stage.

and deep water level in lower parts. Land roughness depended on how well clods were broken by tillage. Proper land levelling can make flat surface and reduce land roughness.

At harvest time, from late February to mid April, grain yield was measured from a 12 m^2 area established in the previous survey. Transplanting two to five rice seedlings per hill was the common crop establishment method. The number of hills in the 12 m^2 area counted at harvest is referred to as hill density in this study. Presence or absence of rat and bird damage was visually observed.

Soil samples (0–15 cm) were collected at harvest. Three cores from the harvested plot of each field were pooled, air-dried and sieved (2 mm) for soil analysis at the International Institute of Tropical Agriculture Laboratory in Ibadan, Nigeria. Soil analysis included pH (H_2O) (1:1 ratio of soil/water), texture (hydrometer method), total N and extractable P. Total N was analyzed by Kjeldahl digestion and colorimetric determination on Technicon AAII Autoanalyser (SEAL Analytical, ltd.). Extractable P was determined by Bray-1 method: 0.25 M HCl + 0.03 M NH_4F (Bray and Kurtz, 1945). The effective cation exchange capacity (ECEC) was calculated by summing exchangeable cations and exchangeable acidity. Exchangeable acidity was determined by extracting the acidity with KCl and titrating the extract with sodium hydroxide. Exchangeable cations in soil were determined by Mehlich 3 extraction (Mehlich, 1984).

2.3. Statistical analyses

Multiple regression analysis using stepwise regression (Hocking, 1976) was employed to identify factors that explained variation in rice yields from the 39 independent variables (SAS, 2008). These identified factors were compared between the two new schemes developed in 2002 and 2009 and old schemes developed between 1969 and 1985. The new irrigation schemes were Aize and Bame while the old schemes were Dome, Koussin, Lainta-Cogbe and Lele (Table 1). Student's *t*-test was performed for comparison between the new and old schemes at the 5% probability level.

3. Results

3.1. Farmers' crop management practices, soil properties and on-farm rice yields

Land preparation started with clearing residue (mainly weeds, which grew during the fallow period) in the plots. In 68% of the plots, residue was burned after slashing (Table 3). Piling up residue on the bunds and incorporating residue into the soil were found in 25% and 7% of the plots, respectively. Machine tillage (59%) was more popular than hand ploughing. There were hand tractors in all the schemes except for Dome and Lainta-Cogbe. However, in Aize and Bame, hand tractors were not used because of breakdowns. Overall, 34% of the plots were rugged, 97% were bunded and 34% had sloped surfaces.

All the farmers grew improved rice varieties: NERICA-L 20, NERICA-L 14, IR 841, ITA 304, Beris or BL 12. In 19% of the plots, rice plants received fertilizer when they were in nursery. Random transplanting was practiced in all plots. Hill density at harvest ranged from 14 to 55 hills m^{-2}.

Fertilizer application, with 93% of the plots receiving urea and/or compound NPK fertilizer. The amount of N, P and K application after transplanting ranged from 31 to 224 kg N ha^{-1}, 7 to 55 kg P ha^{-1} and 12 to 104 kg K ha^{-1}, respectively.

70% of the plots received river water and 30% ground water from intermittent (81%) or continuous flow (19%) irrigation. Intermittent irrigation indicates that rice plots were not irrigated constantly and did not keep deep standing water. The interval of irrigation ranged from 4 to 15 days except for one plot that had a 60 day interval. The continuous flowing irrigation method, in which water flows on surface, was used in Aize only, where rice fields were located on a gentle sloping area. There were two plots where farmers observed severe water stress, when soil became completely dry for several days. One of the reasons for this stress was competition for water among the farmers, while the other was due to the farmer falling sick.

Weed control was carried out in all plots once (12%), twice (68%) or three times (30%) (Table 2). Weed control was by hand and/or herbicide application. Herbicides were applied in 83% of the plots. Among insects and diseases, stem borers (*Maliarpha*, *Diopsis*, *Sesamia* and *Chilo* species) were a major problem with 75% of the plots being infested. Insecticide was used to control stem borers in 70% of the plots. In a few plots, rice blast caused by *Pyricularia grisea* (teleomorph: *Magnaporthe grisea*) was observed. However, farmers did not adopt any measures as they did not generally recognize the symptoms. Bird damage was well controlled mainly through chasing away birds and/or using bird nets. No actual bird damage was observed in any of the study plots. Rat poison was used in all the plots. Additionally, rat traps, cleaning bunds and keeping water in the field were also practiced. At harvest, 12% of the plots had rat damage. After harvest, rice straw was either burned (76%), piled on bunds (20%) or incorporated into soils (4%).

High variation in soil properties, with the exception of pH (mean 5.6), was observed (Table 4). Total N and exchangeable P showed a coefficient of variation (CV) of more than 70%. Total N content on mass basis ranged from 0.03% to 0.83% with a mean value of 0.2%. Extractable P varied from 0.2 ppm to 16.9 ppm mass fraction with a mean value of 4.0 ppm. The mean value of ECEC was 12.3 cmol (+)/kg with a CV of 41%. The mean value of sand content was 33% with 20% silt and 48% clay on mass basis.

Rice yields ranged from 1.3 to 7.8 t ha^{-1} with an average yield of 4.8 t ha^{-1}.

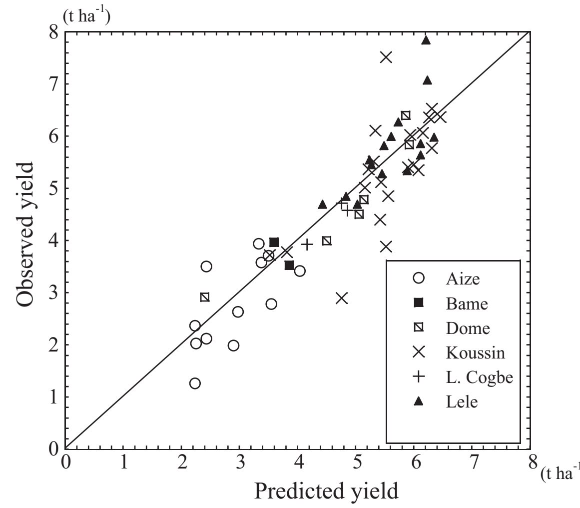

Fig. 2. Observed versus predicted rice yield (t ha^{-1}) from multiple regression analysis in dry season 2010–2011 survey in six irrigation schemes in Zou department of Benin.

3.2. Factors affecting variation in rice yields

Multiple regression analysis identified fallow residue management, ploughing method, sloped surfaces, water stress, rat damage, N application rate and soil sand content as the determinants of the farm yields, and these seven variables accounted for 75% of the total variation in yield (Fig. 2; Table 5). Compared to the plots where fallow residue was incorporated in the plots, the yield was down by 1.4 t ha^{-1} in the plots where residue was burned and by 2.4 t ha^{-1} in the plots where residue was piled on the bunds. The yield was 1.1 t ha^{-1} lower in plots that were ploughed manually when compared with plots that used hand tractors. Plots with a sloped surface yielded 0.7 t ha^{-1} less than flat plots. Where the plots had water stress, rice yield was estimated to be 1.8 t ha^{-1} lower than plots without water stress. Presence of rat damage reduced the yield by 1.1 t ha^{-1}. Yield increase due to N application ranged from 0.8 to 1.6 t ha^{-1} depending on the application rate. N application of 60–80 kg N ha^{-1} showed the highest yield gain of 1.6 t ha^{-1} over plots without N application. Higher sand content was associated with lower yield. In the regression equation in this study, rice yield is calculated by adding the seven terms and the intercept (Table 5). The plots with lowest yields had several negative terms discounting the yield. By comparison, rice yield is estimated at 6.1 t ha^{-1} in a plot where ploughing was done by machine, no water stress or rat damage occurred, residue was incorporated in soil, no N fertilizer was applied, the surface was flat, and sand content was 33%.

3.3. Comparison between newly (2002–2009) and earlier (1969–1985) developed schemes

The mean yield in the newly developed irrigation schemes (Aize and Bame) was lower than those developed earlier (2.9 vs. 5.7 t ha^{-1}) (Table 6). Among the seven yield determinants as shown above, percentage of plots with fallow residues piled on bunds, hand ploughed, with a sloped surface and with rat damage was higher in the new schemes at 93, 100, 57 and 43%, respectively, than the old schemes. There was no significant difference in the percentage of plots with water stress, N application rate or sand content in the soil between the newly developed and the older schemes.

Table 3
Agronomic practices and rice yields from six irrigation schemes in Zou department of Benin. Data were collected through interview.

Description	Parameter	Aize	Bame	Dome	Koussin	Lainta-Cogbe	Lele
Number of plots investigated	N	12	2	6	21	3	15
Fallow residue management							
Slashed and burned	%	0	50	33	90	100	100
Slashed and soil incorporated	%	0	0	67	10	0	0
Slashed and piled on bunds	%	100	50	0	0	0	0
Ploughing method							
Hand	%	100	100	100	0	100	7
Machine	%	0	0	0	100	0	93
Sloped plot surface[a]	%	58	50	0	29	0	40
Crop establishment							
Transplanting time (days after sowing)	Mean ± S.E.	17 ± 1.1	23 ± 7.5	15 ± 1.0	19 ± 1.3	15 ± 0.0	18 ± 1.2
Hill density at harvest (hills m^{-2})	Mean ± S.E.	20 ± 1.3	29 ± 1.3	36 ± 4.7	33 ± 0.9	27 ± 6.3	30 ± 1.4
Fertilizer management							
Fertilizer in nursery bed	%	83	0	0	0	0	7
Total fertilizer application rate after transplanting							
Applied N (kg ha^{-1})	Mean ± S.E.	72 ± 8.9	112 ± 0.0	94 ± 43.8	96 ± 8.8	102 ± 10.1	106 ± 11.8
Applied P (kg ha^{-1})	Mean ± S.E.	14 ± 1.8	17 ± 0.0	21 ± 9.7	15 ± 1.2	20 ± 6.4	17 ± 2.3
Applied K (kg ha^{-1})	Mean ± S.E.	27 ± 3.5	33 ± 0.0	39 ± 18.5	28 ± 2.3	37 ± 12.1	32 ± 4.4
Frequency of fertilizer application after transplanting							
No fertilizer application	%	0	0	50	5	0	0
Single fertilizer application	%	0	0	50	0	0	0
Two-split fertilizer application	%	58	100	0	86	100	100
Three-split fertilizer application	%	42	0	0	9	0	0
Water management							
Intermittent irrigation[b]	%	17	100	83	100	100	100
Continuous flowing irrigation[c]	%	83	0	17	0	0	0
Water stress							
% of plots with water stress[d]	%	8	0	0	5	0	0
Weed management							
Frequency of weeding							
Once	%	17	0	67	0	33	0
Twice	%	83	50	33	71	67	67
Three times	%	0	50	0	29	0	33
Herbicide application	%	92	50	0	100	33	100
Pest damage and management							
Stemborers observed	%	0	100	100	95	100	87
Insecticide application	%	0	0	83	95	100	87
Rat damage	%	50	0	17	0	0	0
Straw management after harvest							
Straw burned	%	0	100	67	100	100	100
Straw soil incorporated	%	0	0	33	0	0	0
Straw piled on bunds	%	100	0	0	0	0	0
Rice yield (t ha^{-1})	Mean ± S.E.	2.8 ± 0.2	3.8 ± 0.2	4.7 ± 0.5	5.3 ± 0.2	4.4 ± 0.2	5.8 ± 0.2

[a] The land surface of the plot was sloped.
[b] Rice fields were not continuously flooded and soils sometimes became dry before subsequent irrigation.
[c] Water flew in paddy fields.
[d] Soil became completely dry for several days.

4. Discussion

This study found a large variation in farm yields of irrigated lowland rice (1.9–7.8 t ha^{-1}). Five out of seven determinants were agronomic including fallow residue management, ploughing method, water management, rat damage control and N application rate. The average yield and the large yield variation were comparable with those reported previously for irrigated rice in the Guinea savanna zone in West Africa (Wopereis et al., 1999; Becker et al., 2003). The finding of various agronomic factors contributing to the yield variation in this study agrees to previous studies in West Africa at some extent (Becker and Johnson, 1999; Wopereis et al., 1999; Becker et al., 2003). In the forest zone of Côte d'Ivore during the rainy season, water control, seedling age, timing

Table 4
Soil properties measured from 59 sites across six irrigation schemes in Zou department of Benin in 2011.

Parameter	All sites	Aize	Bame	Dome	Koussin	Lainta-Cogbe	Lele
pH (H_2O)	5.6 ± 0.1[a]	5.9 ± 0.1	6.4 ± 0	4.7 ± 0.1	5.5 ± 0.1	5.1 ± 0.2	5.9 ± 0.1
Total N (%)	0.18 ± 0.02	0.10 ± 0.008	0.04 ± 0.002	0.25 ± 0.04	0.15 ± 0.01	0.63 ± 0.11	0.16 ± 0.01
Extractable P (ppm)	3.9 ± 0.4	4.1 ± 0.9	7.4 ± 0.08	1.6 ± 0.4	3.5 ± 0.5	10.5 ± 3.3	3.3 ± 0.5
ECEC (cmol(+) kg^{-1})	12.3 ± 0.7	18.4 ± 1.3	1.8 ± 0.3	12.1 ± 1.3	10.4 ± 0.7	17.3 ± 1.0	10.4 ± 0.9
Sand (%)	33.0 ± 2.0	25.3 ± 0.8	72.6 ± 1.8	23.7 ± 3.5	32.3 ± 2.6	50.7 ± 3.4	35.2 ± 4.6
Silt (%)	19.4 ± 0.8	14.2 ± 1.4	16.8 ± 3.2	14.8 ± 1.2	23.3 ± 0.9	17.3 ± 2.4	20.8 ± 1.9
Clay (%)	47.5 ± 2.0	60.4 ± 1.6	10.6 ± 1.4	61.4 ± 4.3	44.4 ± 2.4	32.0 ± 1.2	44.0 ± 3.9

[a] Mean ± S.E.

Table 5
Regression equation for estimating rice yield in 6 irrigation schemes in Zou department, Benin using selected independent variables.

Rice yield* (t ha^{-1})		Residue management**		Ploughing		Sloped plot surface		Water stress		Rat damage		N application rate		Sand content		Intercept
	=	Incorporate in soil = 0, burn = -1.4 ± 0.5***, or pile on bunds = -2.4 ± 0.6	+	By machine = 0 or by hand = -1.1 ± 0.3	+	Flat surface = 0 or slanted surface = -0.7 ± 0.2	+	No stress = 0 or stressed = -1.8 ± 0.6	+	No damage = 0 or damaged = -1.1 ± 0.4	+	No application = 0, < 60 kg N ha^{-1} = 1.4 ± 0.5, 60-80 kg N ha^{-1} = 1.6 ± 0.5, 80-120 kg N ha^{-1} = 1.4 ± 0.5, or >120 kg N ha^{-1} = 0.8 ± 0.5	+	= sand content (%) x (-0.01 ± 0.007)	+	Constant = 6.4 ± 0.5

* e.g., where ploughing was done by machine, without water stress, residue being incorporated in soil, no N fertilizer being applied, without rat damage, with flat surface and 33% sand content, rice yield is estimated at 6.1 t ha^{-1}.
** If fallow residue was incorporated in the given plot, 0 is selected. If burn, −1.4 and pile on bunds −2.4 is selected.
*** The coefficients are given as the estimate ± standard error of the estimate.

of weeding, frequency of N fertilizer application and P application were reported as the major factors in irrigated lowland fields with full and partial water control (Becker and Johnson, 1999). Wopereis et al. (1999) found that timing of N application, seedling age, unreliable irrigation water supply and K and P deficiency were main factors in the Guinea savanna zone in Burkina Faso. The variation in the agronomic factors affecting yields among the three studies is due to differences in sites used, seasons studied [the study by Becker and Johnson (1999) was conducted in the rainy season, while our study was done in the dry season] or approaches used (the previous studies did not consider insect and rat damages). Among the factors affecting rice yield, contribution of single factor to rice yield ranged from 0.6 (difference in sand content between maximum and minimum values) to 1.6 t ha^{-1} (yield response to applied N fertilizer). This indicates that none of the single factor dominantly affected rice yield but did the combination of the multiple factors.

Higher yields were observed in plots where residue was incorporated into soils. The positive effect of weed incorporation into soils on rice yields has been reported previously (Buresh and De Datta, 1991). Through incorporating weeds, nutrients absorbed by weeds can be returned into soil in addition to organic matter accumulation. Burning residue could help recycle K absorbed in weeds although organic matter is lost. On the contrary, piling up weeds on bunds would enhance K depletion from the field. In this study, we did not quantify the amount of residue available before land preparation and did not consider the long-term effect. The effect would be different between plots where fallow residue has been incorporated for many years and plots where they have done so for only a few years. Higher yields in plots ploughed by machine is consistent with previous studies (Curfs, 1976). Machine tillage changes permeability, percolation as well as water retention capacity (Curfs, 1976; Ogunremi et al., 1986; Lal, 1985). Prevention of water and nutrient losses contributes to greater growth of rice plants. Our finding of lower yields in sloped surface is in accordance with the findings by Sharma and De Datta (1985) and Ambumozhi et al. (1998). In plots where land surface is not uniform, unevenly-distributed surface water in the fields could have caused unfavourable rice growing conditions. For example, a shallow water level in higher parts leads to water stress in the rice plants, while reducing nutrient availability, enhancing weed infestation and raising water temperature, and results in yield reduction (Takai, 1970). In lower parts, potential yield may also be reduced as deep-flooding at an early stage limits tiller development (Hoshikawa et al., 1990). Water stress was commonly observed in the previous studies, which was also caused by poor water management (Becker and Johnson, 1999; Wopereis et al., 1999). Rat damage has been reported as a serious constraint to rice production in Côte d'Ivore (Adesina et al., 1994). N fertilizer application increased rice yields, but the yield gains differed little among the four classes of N fertilizer application rates. The reasons behind the small difference in yield gains are not known in this study. It could be due to timing of N application and indigenous nutrient supply, which are not considered in this analysis. Inappropriate timing of N application has been reported as a major factor affecting on-farm yield

Table 6
Comparison of yield affecting variables of new irrigation schemes (2002–2009) and old schemes (1969–1985).

	Variables	New schemes* (2002–2009)	Old Schemes** (1969–1985)
New schemes > Old schemes	Piling fallow residue on bunds	93% a***	0% b***
	Hand ploughing	100% a	22% b
	Sloped plot surface	57% a	27% b
	Rat damage	43% a	2% b
New schemes = Old schemes	Water stress	7% a	2% a
	N application rate	77 kg N a	100 kg N a
	Sand content	32% a	33% a

* New schemes were Aize and Bame irrigation schemes.
** Old schemes were Dome, Koussion, Lele and Lainta-Cogbe irrigation schemes.
*** Different suffix letters indicate significant difference between the two schemes according to Student's *t*-test (α = 0.05).

variation in West Africa (Becker et al., 2003; Becker and Johnson, 1999; Wopereis et al., 1999). As land use history and residue management differed within/among the irrigation schemes, indigenous nutrient supply might vary largely. Cassman et al. (1998) reported that N supply of lowland rice systems in the Philippines varies largely among fields with similar soil types and in the same field with time. Large variation in indigenous N supply might have obscured a correlation between the N application rate and rice yield. For efficient fertilizer application, indigenous nutrient supply would have to be accounted for in addition to the effect of residue management on rice yields. The negative correlation between yield and sand content agrees with the finding of a study in northern Thailand (Homma et al., 2003). It could be attributed to lower water holding capacity (Tsubo et al., 2008) and limited NH_4 buffering capacity (Wang and Alva, 2000) in sandy soils.

The study highlights the importance of adjusting crop management practices both at an individual and organizational level for increasing productivity in the low-yielding fields. The individual management issues are fallow residue management, field levelling, rat damage control and N application. On the other hand, efficient water delivery to avoid water stress and hand tractor maintenance are beyond the control of individual farmers in this region. Organizational capacity development at the irrigation scheme level should be emphasized to address such issues.

In the newly developed schemes, lower yields were attributed to piling fallow residue on bunds, hand ploughing, sloped surfaces and rat damage. It implies limited skills of farmers in the new schemes due to lack of experience. In the older irrigation schemes, the farmers may have had the same problems at the beginning, but their knowledge of rice production and management practices might have evolved over time, probably in part due to external support. The results suggest the possibility of facilitating the farmers' adaptation to lowland irrigation rice farming through farmer-to-farmer learning and development of good agricultural principles and practices in land preparation, fallow residue management and avoiding yield losses in the newly developed schemes. In addition, the lack of ability to repair hand tractors both at Aize and Bame emphasizes the importance of organizational capacity building in new schemes.

5. Conclusions

This study demonstrated large variation in yields of lowland rice within/among irrigation schemes with different development history in southern-central Benin, and identified agronomic factors affecting the variation in yields. Low yields in newly developed irrigation schemes were attributed to sub-optimal agronomic interventions. It implies that knowledge dissemination of good management practices and capacity development are important in realizing potential of newly developed irrigation schemes.

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