Irrigation performance and water productivity in small-holder lift irrigation systems in north-western Nigeria

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Abstract: A study was carried out to determine the productivity of small holder irrigation in northwestern Nigeria. The objectives of this study were to evaluate the performance of small-scale irrigation systems in Nigeria using several performance indicators. On the average crop yields (mean; 3657.4 kg ha^{-1}) for wheat fell within the lower range of expected yields reported for irrigated wheat. However, the farms studied produced fairly high yields (mean; 535.6 kg ha^{-1}). This may be attributed to the resilience of the small-holder farmers and access to subsidized inputs. In terms of output per cropped area, the rice farms gave better results (mean; 2635.9 US$ ha^{-1}) when compared to the wheat farms (mean; 1981.2 US$ ha^{-1}). However, when considering output per unit irrigation supply, the wheat farms averaged better. Similar results for both crops were obtained with respect to output per unit water consumed. With respect to crop water productivity, both wheat (mean; 0.51 kg m^{-3}) and rice (mean 0.50 kg m^{-3}) had similar results. In regards to financial self-sufficiency, the wheat farms (mean; 483%) far out-performed the rice farms (mean; 155.8%). This can be attributed to the greater amount of inputs utilized by the rice farms, particularly the large amount of fuel required to pump the prodigious amounts of water used to irrigate the rice plots. Furthermore, the market price of wheat is about 2.5 times that of rice. However, in all the farms studied income generated far exceeded expenditure. These systems have far greater financial self-sufficiency, than agency managed irrigation systems.

Keywords: crop water productivity, irrigation water management, financial self sufficiency

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1 Introduction

Food production in Sub-Saharan Africa is almost entirely rain-fed while irrigation plays a minor role (Kadigi et al., 2012). The potential to improve livelihoods, food security, and nutrition across Africa by expanding the use of irrigated agriculture is as large as the need to do so (USAID, 2018). Irrigation was often seen as a panacea to the problem of the increased likelihood of food shortages, worldwide. However, formal irrigation schemes under the control and/or regulated by government organizations have in most cases been unsuccessful. This is particularly the case with Nigeria where irrigated agriculture is fraught with a lot of challenges and most government-run schemes are in a constant cycle of degradation and rehabilitation.

The public irrigation sector in Nigeria accounts for 13% of the irrigated area and an estimated 0.25% of total agricultural area. The overall capital cost of these schemes is estimated at ₦170 billion (US$470million). Maintenance and operational costs to sustain the schemes is estimated at ₦2billion (US$5million) annually, while the Federal Government’s budget allocations to these schemes do not cover this amount (Federal Ministry of Water Resources/FAO, 2004).

The hydraulic infrastructures are dilapidated in most of the irrigation schemes with many pumps in need of repair/replacement and conveyance structures damaged or

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deteriorated, weed infested and silted up. The life of some structures especially the larger head-works have only been prolonged as a result of the good/over-design and under utilization (Federal Ministry of Water Resources/FAO, 2004).

Ironically, these dams and associated irrigation schemes were developed on the floodplains of major rivers locally called *Fadama* that have been traditionally irrigated for centuries using traditional water lifting technologies.

Fadama is a Hausa name for irrigable land--usually low-lying plains underlay by shallow aquifers found along Nigeria's major river systems. Such lands are especially suitable for irrigated production and fishing, and traditionally provide feed and water for livestock (The World Bank, 2008). The *fadama* soils are generally classified as Fluvisols and Gleysols (FAO-UNESCO Classification). The low lying *fadama* floodplains are underlain by extensive aquifers, which are in hydrological contact with the river systems and are easily exploitable through the use of shallow (low cost) tube wells and wash-bores (Graham et al., 2003a, 2003b: Graham et al., 2014).

Almost all developmental aid to small-scale irrigated agriculture in Nigeria has been directed towards fadama development. The World Bank financed *Fadama* projects of the 1990’s and 2000’s contributed to the wide dissemination of motorized pumps and manual drilling techniques in the fadama area of Nigeria, increasing agricultural productivity and the incomes of farmers who are fortunate to have access to fadama land (Abric et al., 2011). Furthermore, in 2015, The Central Bank of Nigeria established the Anchor Borrowers’ Program. The programme thrust is provision of farm inputs to small holder farmers. At harvest, the farmer supplies his/her produce to an Agro-processor (The anchor) who pays the cash equivalent to the farmer’s account. At present, the program is mainly for rice and, to a lesser extent, for wheat, which is grown under fadama irrigation.

According to Agide et al. (2016),irrigation systems are complex and consist of several interconnected elements. In general, technical monitoring has rarely been carried out, and reliable data on crop production indices for small-scale *fadama* irrigation system are few and far between. Several performance indicators have been developed for measuring and comparing the performance of irrigated agricultural system (Rao, 1993; Molden et al., 1998; Bos et al., 2005). These performance indicators proposed by various authors have been widely used to evaluate the ability of various schemes across the world to satisfy different objectives such as helping irrigation managers to improve water delivery service or for providing information for policy implementation (Kuscu et al., 2009; Gomo et al., 2014).

The objective of this study was to evaluate the performance of small-scale *fadama* irrigation using these performance indicators. The specific objective of this work was to examine the irrigation performance of rice and wheat small-holder irrigation and to determine the crop water productivity of these crops under irrigation.

2 Materials and methods

2.1 Location of study

The study area (Birnin Kebbi) lies at an approximately altitude of 200m above sea level between Latitudes $12^0$17’ to $12^0$24' N and longitudes $4^0$17’ to $4^0$29' E. The climate consists of a long dry (October to May) and a short wet season (June to September) with a mean annual rainfall of 727.6 mm, averaged over the period 1953 to 2009 (Figure 1).

2.2 Field studies

After a detailed survey, five irrigated farms were selected. The crops assessed were Rice (*Oryza sativa*) and Wheat (*Triticum aestivum*). Primary data was collected by means of observations and semi-structured questionnaires generally relating to management practices, such as irrigation schedule and crop yield. Meteorological data was collected from a weather station located at about 15 km west of the sites.

The amount of water used for irrigation was determined by measuring the discharge rate (L s^{-1}) using a container of known volume. This was then multiplied by the irrigation period for each farm. Socioeconomic data were also collected. A survey will be conducted during the harvest period at each farm. All farmers will be asked the initial cost of seeds, fertilizer, pesticides, as well as quantity of harvest, recorded in number of standard sacks.

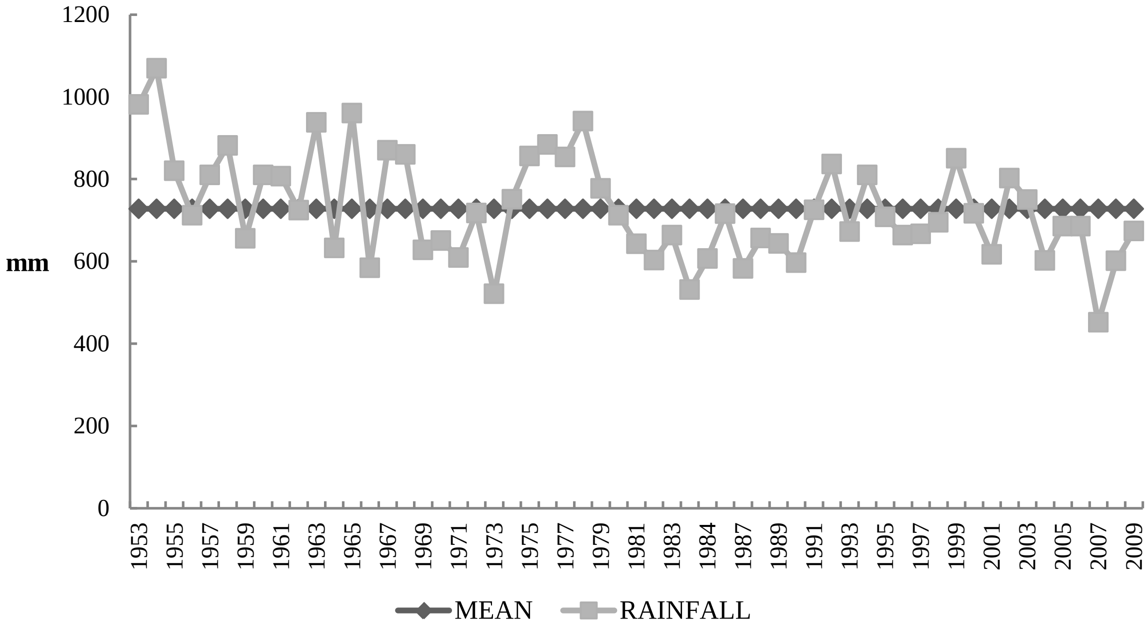

Figure 1 Long-term rainfall trend in the Birnin Kebbi area, northwestern Nigeria (1953-2009).

2.3 Crop water demand

The reference evapotranspiration (ET) according to Penman-Monteith and the effective rainfall were calculated with CROPWAT software (Smith, 1992). Then, the net crop water requirement and the net irrigation requirement were computed for each irrigated crop. The crop coefficients provided with the CROPWAT program are used.

2.4 Irrigation performance assessment

The indicators used to assess irrigation performance are given below (Molden et al., 1998):

Output/cropped area (US$ ha^{-1}) = $\frac{Production}{Irrigated cropped area}$ (1)

Output/irrigation supply (US$ m^{-3})= $\frac{Production}{Diverted irrigation supply}$ (2)

Output/water consumed (US$ m^{-3})= $\frac{\text{Production}}{Volume of water consumed by ET}$ (3)

Relative water supply = $\frac{Total water supply}{Crop demand}$ (4)

Relative irrigation supply = $\frac{Irrigation supply}{Irrigation demand}$ (5)

Crop water productivity (kg m^{-3})= $\frac{Crop yield}{ET}$ (6)

Financial self-sufficiency (%) = $\frac{Revenue from irrigation}{Total O\&M expenditure} \times 100$ (7)

Where;

(1)*Production* is the output of the irrigated area in terms of gross or net value of production,

(2)*Irrigated cropped area* is the sum of the areas under crops during the time period of analysis,

(3)*Volume of water consumed by ET* is the actual evapotranspiration of crops.

(4)*Total water supply* = Surface diversions plus net groundwater draft plus rainfall.

(5)*Crop demand* = Potential crop ET, or the ET under well-watered conditions.

(6)*Irrigation supply* = Only the surface diversions and net groundwater draft for irrigation.

(7)*Irrigation demand* = The crop ET less effective rainfall.

(8)*Revenue from irrigation,* is the revenue generated, either from fees, or other locally generated

(9)income, and

(10)*Total O&M expenditures* are the amount expended locally through Operation and Maintenance plus outside subsidies from the government.

3 Results and discussion

Results pertaining to irrigation performance are presented in Table1. On the average crop yields (ranging from 3000 to 4500 kg ha^{-1}) for wheat fell within the lower range of expected yields (3,500 to 10,000 kg ha^{-1}) (Savva, 2002) and (3,000 to 6,000 kg ha^{-1}). However, yields of over 5,000 kg ha^{-1} have been obtained with improved management and improved cultivars in northern Nigeria. Time of sowing has a strong effect on wheat yield being significantly related to severe incidence of diseases particularly stem rust (Kassam, 1976) and this could be a contributing factor to the relatively low wheat yields obtained.

Average rice yields in Nigeria are consistently low and stand at around 1,500 kg ha^{-1} (Singh et al., 1997). The farms studied produced fairly high yields with a range of 4,260-6,100 kg ha^{-1}. This may be attributed to the resilience of the small-holder farmers and access to subsidized inputs through The Central Bank of Nigeria Anchor Borrowers Programme. The programme provides farm inputs in kind and cash to small holder farmers to boost production.

Table 1 Irrigation performance assessment

Crop	Wheat			Rice		
	Mean	SE±	CV (%)	Mean	SE±	CV (%)
Crop yield (kg ha^{-1})	3,657.4	270.5	14.7	5,356.0	326.5	12.2
Output per cropped area (US$ ha^{-1})	1,981.2	149.8	15.1	2,635.9	346.6	26.3
Output per unit irrigation supply (US$ m^{-3})	0.46	0.04	16.0	0.16	0.02	11.1
Output per unit water consumed (US$ m^{-3})	0.22	0.01	7.5	0.24	0.01	11.1
Relative water supply	1.02	0.02	3.5	3.85	0.06	3.3
Relative irrigation supply	1.02	0.02	3.5	3.14	0.04	2.4
Crop water productivity (kg m^{-3})	0.51	0.03	12.5	0.50	0.009	3.4
Financial self-sufficiency (%)	483.0	8.2	3.4	155.8	1.91	2.4

Note: SE± =Standard error of mean; CV = coefficient of variation

In terms of output per cropped area, the rice farms gave better results (1,350-2,444 US$ ha^{-1}) when compared to the wheat farms (1,590-2,461 US$ ha^{-1}). However, when considering output per unit irrigation supply, the wheat farms averaged better. Similar results for both crops were obtained with respect to output per unit water consumed.

Molden et al. (1998) stated that it was better to have relative water supply (RWS) and relative irrigation supply (RIS) values nearer 1 than a higher value. In this light, the wheat farms had values slightly above this. Rice cultivation is a very water-intensive activity (Gujja and Thiyagarajan, 2009). Though the main function of standing water in rice cultivation is to control weeds, over a period of time this practice has become standard and is widely believed that rice cannot yield well without large quantities of water (Levine, 1999). In the farms studied, the farmers irrigated the rice fields from dawn to dusk on an almost daily basis. It is therefore not surprising that the rice farms had greater RWS and RIS than the wheat farms.

Molden et al. (1998) earlier reported a wide range of mean RIS values from 0.41 to 4.81 in 18 different formal irrigation schemes located in several countries, while Lakmali et al. (2015) reported relative water supply ranging from 1.06 to 1.91 for rice in three major irrigation systems in Sri Lanka. Irrigation systems with an RWS value of 2.5 or greater indicate that water stress might not be an important factor that would affect irrigation performance (Zwart and Bastiaanssen, 2004). The results indicated that the farmers applied superfluous amounts of water to rice. This might lead to the salinization/sodification of the soils in the long term.

With respect to crop water productivity (CWP), both wheat (range: 0.44-0.59 kg. m^{-3}) and rice (range: 0.48-0.53 kg m^{-3}) had similar results. Globally measured average CWP values per unit water depletion are 1.09 kg m^{-3} for wheat and 1.09 kg m^{-3} for rice. The range of CWP is very large (wheat, 0.6–1.7 kg m^{-3}; rice, 0.6–1.6 kg m^{-3}) and this thus offers tremendous opportunities for maintaining or increasing agricultural production with 20%–40% less water resources (Zwart and Bastiaanssen, 2004).

In regards to financial self-sufficiency (FS), the wheat farms far out-performed the rice farms. This can be attributed to the greater amount of inputs utilized by the rice farms, particularly the large amount of fuel required to pump the prodigious amounts of water used to irrigate the rice plots. Furthermore, the market price of wheat is about 2.5 times that of rice. However, in all the farms studied income generated far exceeded expenditure. These systems have far greater FS than agency managed irrigation systems that have FS ranging from 30% to 50% (Molden et al., 1998).

5 Conclusion

On the average crop yields for wheat fell within the lower range of expected yields reported for irrigated wheat. Average rice yields in Nigeria are consistently low; however, the farms studied produced fairly high yields. This may be attributed to the resilience of the small-holder farmers and access to subsidized inputs.

The rice farms had greater relative water supply and relative irrigation supply than the wheat farms. The high RWS and RIS values reported for the rice farms indicate that water stress may not be an important factor that would affect irrigation performance. The results indicate that the farmers apply superfluous amounts of water to rice. This may lead to the salinization/sodification of the soils in the long term. Both wheat and rice farms had similar results with respect to crop water productivity.In regards to financial self-sufficiency, the wheat farms far out-performed the rice farms. This, however, in all the farms studied income generated far exceeded expenditure.

On the whole, from the results obtained in this study, small-holder lift irrigation can cushion against the effects of dwindling water supplies as a result of climate change and alleviate poverty in the semi-arid parts of West Africa.

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