Water Productivity and Economic Analysis of Irrigated Upland Rice in the Fogera, Northwest Ethiopia

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Abstract

Irrigation is critical to Ethiopia's national economy in terms of increasing income and achieving food security. A total of 39.35 Mha of potential rice cultivation area is available in Ethiopia, 3.7 Mha of which are irrigable. Despite this potential, the country is importing a huge amount of rice to meet the increasing food demand. This is because, an irrigated rice production and its water productivity was not practiced. Determining the water productivity and economic feasibility of irrigated rice in the Ethiopian context is supremely important to replace the imported rice. Hence, the goal of this study is to determine the water productivity and economic analysis of NERICA-4 variety upland rice under optimal irrigation scheduling in the Fogera plain. Thirty one year climate data from Bahir Dar and Woreta metrological station were used to compute the reference crop evapotranspiration and the crop factors were used to compute the rice crop evapotranspiration. The effective rainfall was determined using CROPWAT model to determine the irrigation water requirement. Five experimental treatments; recommended manageable allowable soil moisture depletion (MAD) of rice as a control (100%), 60%, 80%, 120%, and 140% MAD. The randomized complete block design in four replications were used. The optimum depletion level based on the highest yield (7164 kg ha^{-1}), highest water productivity (1.85 kg m^{-3}), and higher economic water productivity (0.87 US$ m^{-3}) was obtained at 80% of MAD. Therefore, based on the highest water productivity and economic water productivity 80% MAD water application was recommended for the Fogera plain and, other similar areas in agro-ecology and soil property areas shows better water and economic water productivity.

Keywords: Irrigated Rice, Rice, Water Productivity, Economic Analysis

1. Introduction

Irrigation development is an essential tool to promote economic growth, rural development, food security, and alleviating poverty (Hagos *et al.* 2009). To assist the irrigation development, adequate irrigation water needs to be distributed efficiently for the crops at the right time. Rice is one of the major staple crops globally and, it is the most rapidly growing food commodity in sub-Saharan Africa (SSA). It is introduced in recent years to Ethiopia. It was first introduced in Gambella (1973–1982), Pawe (1985–1988) and Fogera Plain (early 1980s). However, that rice introduced farming systems, Fogera Plain remained to be the major rice producing area; resulting insignificant changes in agricultural relations and social dynamics associated with the introduction of rice and its subsequent commercialization of crop production (Alemu and Thompson 2020).

In Ethiopia rice is classified as the fourth, "National Food Security Crop" next to wheat, maize, and teff (Kassa 2010). The country has 39.35 Mha of rice potential area under this about 3.7 Mha are believed to be suitable for irrigated rice production; these are distributed around the ten river basins in the country and a wide potential production area lies mostly in the western part of the country (Mustofa and Gondar 2017). Regardless of the huge production potential, the country heavily relies in importing rice from abroad (Tadesse 2020). Following the successful farming transformation with rice in the Fogera Plain, the recent expansion of rice production in different regions demonstrates the agro-ecological suitability of the crop and its future prospect of production and consumption in the country. The National Rice Research and Development Strategy (NRRDS) recognizes seven regional rice research and development hubs, these are; Fogera, Pawi, Abobo, Gura Fereda, Chewaka, Gode, and May Tsebri hubs. From these, the Fogera Hub includes the west central highlands of Amhara Region mainly covering Achefer, Dembia, Fogera, Gonder, Metema, and Takusa districts as main places (Alemu and Thompson 2020). It is also observed that the number of farmers involved in rice production has grown year after year (Negussie and Alemu 2011).

Rice production in the Fogera is mainly rain-fed and the irrigation water productivity and its economic using irrigation water is not well studied. Studying the irrigation water productivity of upland rice in the Fogera plain is essential; to rise the rice production under irrigation. This supports the rice producers to improve food security as well as replacing the imported rice. Therefore, this study aimed to determine the yield and water productivity responses of upland rice under irrigation to identify water productivity with economic benefit.

2. Materials and Methods

2.1 Study Area Description

Fogera district is located in the Amhara National Regional State, which stretches from 11° 40′ 30″ and 12° 01′ 30″ north to 37° 30′ 00″ and 38° 00′ 00″ east in the northern Ethiopian highlands. Fogera is one of the ANRS's 106 districts, located in the South Gondar Administrative Zone (Figure 1). Fogera is one of the eight districts bordering Lake Tana and has an estimated water body of 23,354 ha. The total land area of Fogera district is 117,414 ha. Flat land accounts for 76%, mountain and hills 11% and valley bottom 13%. Major crops grown in the district are rice (33.6 %), maize (20.2 %), finger millet (16.07) and teff (13.1 %) and have heavy clay soil (Goshu *et al*. 2003). The seasonal migration of the Intertropical Convergence Zone primarily regulates the temperature of the region. The flood plain experiences yearly rainfall totals between 1100 and 1530 mm. The region's mean monthly temperature is approximately 19 ^{0}C, its mean highest monthly temperature is approximately 27.3 ^{0}C, and its mean monthly minimum temperature is approximately 11.5 ^{0}C. In this region, the wet season lasts from June to September (Enku 2009).

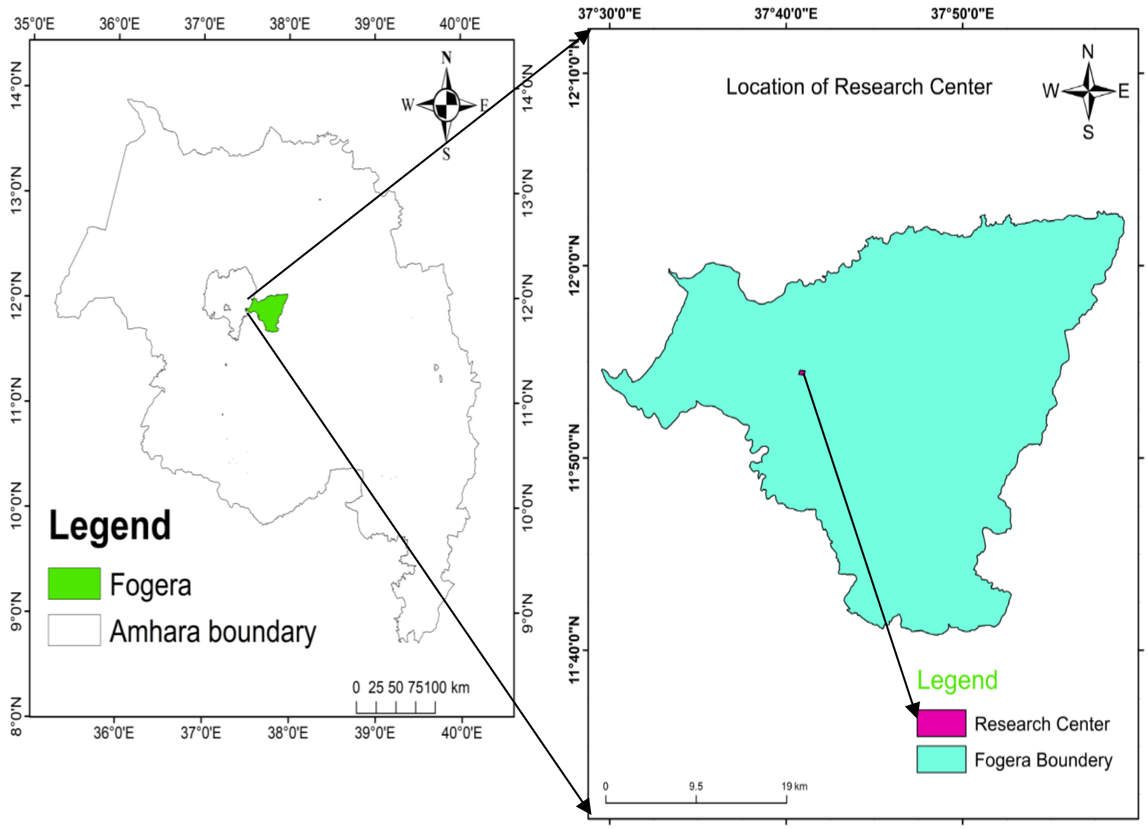

Figure 1. Location of the study area

2.2 Experimental Design

The study was conducted in Fogera National Rice Research and Training Center in 2021. The experimental arrangement was restricted by five treatments of manageable allowable soil moisture depletion (MAD); recommended manageable allowable soil moisture depletion (MAD) of rice as a control (100%), 60%, 80%, 120%, and 140% MAD (Table 1). The experimental design was used randomized complete block design (RCBD) by four replications to increase the degree of freedom at 3*3 m^2 plot size.

Table 1. Treatment distribution

Treatment	Description
Treatment 1	60% of MAD
Treatment 2	80% of MAD
Treatment 3	100%/Control
Treatment 4	120% of MAD
Treatment 5	140% of MAD

Note: MAD is the maximum allowable soil moisture depletion level of rice

2.2.1 Data Collection and Analysis

Soil data was taken within 30 cm interval up to 120 cm depth from three representative point of the experimental site. Then, the physical and chemical characteristics of the soil such as: soil texture, pH, field capacity (FC), permanent wilting point (PWP), and electrical conductivity (EC) were tested in the Amhara Design and Supervision Works Enterprise (ADSWE) soil laboratory. The soil bulk density (BD) was determined by core sampler at 10 cm intervals from the soil surface up to 60 cm (effective root depth of rice). Then bulk density was estimated based on (Mentges *et al*. 2016).

$$\mathbf{BD} = \frac{\boldsymbol{Wt\ of\ dry\ soil}}{\boldsymbol{Vof\ core}} \qquad (1)$$

Total Available Water (TAW) which measures the amount of water that a crop can extract from its root zone was controlled by the soil type and rooting depth (Datta *et al*. 2017). It can be determined from FC and PWP as:

$$\boldsymbol{TAW = (FC - PWP) x \mathbf{BD} x 10} \qquad (2)$$

From Bahir Dar and Woreta metrological station, thirty-one-year (1987-2017) climate data: (Max. and Min. Temperature, Rainfall, Humidity, wind speed, sunshine hour) and crop factors the reference crop evapotranspiration and effective rainfall were determined. The ETo was estimated using the FAO Penman-Monteith method and CROPWAT-8.0 (Allen *et al.* 1998a). The USDA-SCS method was used for calculating effective rainfall, using CROPWAT-8.0.

The readily available water (RAW) and gross irrigation requirement (mm) to meet the water consumed through evapotranspiration (ETc) by a disease-free crop growing in large fields under non-restricting soil conditions. Including soil water and fertility, and achieving full production potential under the given growing environment is known as the crop water requirement (Abolpour *et al.* 2017). The RAW is the proportion of TAW that a crop may take from the root zone without suffering from water stress (Domínguez *et al*. 2011).

Depletion *(p)* is the average fraction of Total Available Soil Water (TAW) that can be depleted from the root zone before moisture stress (reduction in ET) occurs [0-1]. Based on Allen *et al. (1998b)*, RAW was calculated as:

$$\boldsymbol{RAW = TAW x\ p x Dzr} \qquad (3)$$

The water application efficiency (Ea) for surface irrigation methods is up to 60% (Haj-Amor *et al*. 2018). So, for this study 60% irrigation application efficiency was used as the recommended surface irrigation.

$$\mathbf{GIWR} = \frac{\mathbf{RAW}}{\boldsymbol{Ea}} \quad \ldots\ldots\ldots 4$$

Where: GIWR=Gross irrigation water requirement, RAW= readily available water, and Ea= water application efficiency

Water productivity (WP) is defined based on actual evapotranspiration (Hatiye *et al*. 2017), determined by equation 5. Because of actual evapotranspiration measurement material scarcity, crop evapotranspiration was used as it is.

$$\boldsymbol{WP} = \frac{\boldsymbol{dry\ biomass}}{\boldsymbol{ETc}} \quad \ldots\ldots\ldots 5$$

Water use efficiency (WUE) is a measure of how efficient a crop production system is about the amount of irrigation water applied (i.e. the grain yield generated per unit of water consumed by crops) is commonly used to measure (WUE) (De Pascale *et al*. 2011), and it is given as:

$$\boldsymbol{WUE} = \frac{\boldsymbol{Actual\ grain\ yeild}}{\boldsymbol{ETc}} \quad \ldots\ldots\ldots 6$$

The economic analysis of WP (the economic productivity of water) was calculated using the income (I, ETB) from crop yield and volume of water applied (mm ha^{-1} irrigation plus rainfall) (Tewelde 2019), and it is calculated as:

$$\boldsymbol{Economic\ productivity\ of\ water} = \frac{\boldsymbol{I(ETB)}}{\boldsymbol{Water\ applied}\ (\mathbf{mm{-}ha})} \quad \ldots\ldots\ldots 7$$

2.2.2 Analysis

Version 9.4 of the SAS program was used to analyze water productivity, and Analysis of Variance was used (ANOVA). Adapted Duncan's multiple tests were used to compare means at p 0.05 (Duncan 1955).

3. Result and Discussion

3.1 Crop Evapotranspiration

The average reference crop evapotranspiration was 3.46 mm day^{-1}, maximum and minimum were obtained 4.03 mm day^{-1} in April and 3.04 mm day^{-1} in December respectively. The maximum and minimum crop evapotranspiration were 4.93 mm day^{-1} in March and 3.36 mm day^{-1} in January respectively. The crop water requirement of rice was low at the initial stage reaching the value of 3.36 mm day^{-1} and increased during the development stage reaching the maximum value of 4.93 mm day^{-1} at the mid-season stage, and there after declined during the late-season stage reaching the value of 4.2 mm day^{-1}. In this research, at the lesser soil moisture stress the grain yield was high. This study was supported by similar studies such as Kumawat *et al. (2017)*, who reported the highest levels of water productivity and grain quality when irrigation was scheduled at 0 kPa, i.e., in saturated conditions. Akinbile (2010), also reported that the link between ETc and yield is straightforward. This is similar to this study indicating that boosting irrigation water would result in a higher rice yield. When the soil was left to dry at greater tensions than 20 kpa, both direct seeded rice (DSR) and puddled transplanted rice (PTR) yields decreased, with DSR yields declining more rapidly as tension increased to 40 and 70 kpa (Humphreys *et al*. 2011).

3.2 Water Productivity and Water Use Efficiency

Water Productivity (WP) is the most essential factor in quantifying yield factors that affect crop output and it serves as a helpful standard for agricultural production (Edreira *et al*. 2018). WP was defined as the ratio of actual grain yield to actual evapotranspiration. In this finding, the maximum WP was attained at 80% MAD (1.85 kg m^{-3}) and the minimum WP was obtained at 140% MAD (Table 2). The maximum WUE was also observed at the 80% MAD, which was 1.14 kg m^{-3}. The minimum WUE was found at 140% MAD level (0.58 kg m^{-3}) which might be a high yield loss due to moisture stress (Table 2).

In Iran, Kaur and Mahal (2015), did a research work based on three irrigation management of rice (full irrigation, 5-day, and 8-day irrigation intervals). They found that increasing irrigation interval resulted in a decreased water use while increasing water productivity by 40 and 60% respectively, in a 5 and 8-day irrigation intervals compared to full irrigation with no yield loss. Their result is in line with our finding as the irrigation interval increased the water productivity and the water use efficiency was decreased because of soil moisture stress.

Table 2. Water productivity

Treatments	Dry Biomass (kg ha^{-1})	Grain Yield (kg ha^{-1})	Total applied water (m^3 ha^{-1})	Water Productivity (kg m^{-1})	Water Use Efficiency (kg m^{-1})
60%MAD	11560^a	7204.9^a	6505^a	1.78^a	1.1^a
80%MAD	11600^a	7164.3^a	6277^b	1.85^a	1.14^a
100%MAD	9160^b	5341.9^b	5857^c	1.56^b	0.9^b
120%MAD	8720^b	4780^b	5618^d	1.55^b	0.88^b
140%MAD	8640^b	3130.5^c	5415^e	1.6^b	0.58^c
Mean	9936	5524.33	5934.48	1.66	0.93
LSD (5%)	733.77	643.97	0	0.15	0.14

CV (%)	3.42	5.40	2	4.12	7.05

Means with the same letter are not significantly different at the $p < 0.05$ level

3.3 Economic Analysis of Water Productivity

Rice price fluctuation was noticeable during the harvesting season (November–January) since many farmers took their grain to market, resulting in a market glut and, as a result, the price fell every year during that time (Gebey *et al*. 2012). As per the market price of seed, fertilizer, fuel, labor cost per day, and all variable costs of each treatment were determined. Based on the results, 60% MAD has taken high cost (161935 ETB ha^{-1}) than the other treatments, and 140% MAD has taken the minimum cost (83099 ETB ha^{-1}). Return benefit and profit are also analyzed, high profit was observed at 80% MAD (160241 ETB ha^{-1}). Economic productivity of water was also higher at 80% MAD (45.38 ETB m^{-3}) than the other treatments. 60% MAD also showed higher income per drop of water. The benefit-cost (B: C) ratio registered in each treatment and treatment five showed a high B: C ratio (2.4), and has an insignificant difference with treatments two, three, and four. It was due to less availability of water in decreased irrigation events and produced the highest returns (Table 3).

Economic water productivity of irrigated rice results conform with the report of Sathyamoorthy *et al. (2019)*, Rice's many by-products (straw, bran, and husk) have significant economic value and are utilized in animal feed, building, and fuel. Hence, in this research finding, the best economical water productivity was obtained at 80% MAD (0.87 US$ m^{-3}). Irrigation investments were prioritized under Ethiopia's second Growth and Transformation Program, a five-year economic growth plan, and accounted for the largest share (more than one-third) of the Ministry of Agriculture's Agricultural Growth Program's overall budget of US$582 million (Alemu and Thompson 2020; Awulachew 2019).

Table 3. Economic water productivity

Treatments	60% MAD	80% MAD	100% MAD	120% MAD	140% MAD
Total variable cost (ETB ha^{-1})	161935	124592	103845	91397.5	83099
Total Income (ETB ha^{-1})	285008	284833	224250	211399	202833
B:C ratio	1.8	2.3	2.2	2.3	2.4
Total profit (ETB ha^{-1})	123073	160241	120404	120002	119734
IW (m^3 ha^{-1})	6505	6277	5857.4	5618	5415
EWP (ETB m^{-3})	43.81	45.38	38.28	37.63	37.46

4. Conclusions

Among the treatments, the maximum crop water requirement was obtained at 60% MAD (6505 m^3 ha^{-1}) and the minimum was obtained at 140% MAD (5415 m^3 ha^{-1}). Based on the findings, upland rice variety (NERICA-4) in each treatment showed different growth and yield parameters. Based on these results, 80% MAD has shown high water productivity (1.85 kg m^{-3}) and economic water productivity (0.87 US$ m^{-3}) over the other treatments. Consequently, 80% MAD can save about 1090 m^3 ha^{-1} of water as compared with 60% MAD without reducing grain yield, and can increase rice production by cultivating additional land by saved water during the dry season when land is idle but water is an issue. As a general, Irrigation water management of irrigated upland rice was importance to improve irrigated rice in water scarcity area and it improves water productivity as well as economically of the district. Moreover the irrigated rice gives much production to sustain food security of the country. As a conclusion, irrigated rice in different potential area should be widely practiced as a strategic crop to achieve food self-sufficiency of the country.

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