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# AN EVALUATION OF ECONOMIC WATER PRODUCTIVITY AND WATER BALANCE OF DRY SEASON IRRIGATED RICE UNDER DIFFERENT IRRIGATION REGIMES IN NORTHERN GHANA

**Abdul-Ganiyu, S[1]., Kyei-Baffour, N[2]. , Agyare, W[3] and Dogbe, W[4].**

*[1]University for Development Studies, Tamale, Ghana;*
*[2&3]Kwame Nkrumah University of Science and Technology, Kumasi, Ghana;*
*[4]Savannah Agricultural Research Institute, Tamale, Ghana.*

**ABSTRACT**

The major limiting factor for irrigated rice cultivation is water. As the demand for effective management of water increase due to climate change, future rice production will depend heavily on developing and adopting strategies and practices that use efficient water application. The objectives were to evaluate effects of different irrigation regimes on crop and economic water productivities as well as water balance for dry season irrigated rice production. This was to enable rice farmers and irrigation management to make an informed decision on the most economic and efficient water use regime for rice production. Two experiments were conducted using a *randomized complete block design* with 4 replications at On-Station (SARI) and On-Farm (Bontanga Irrigation Scheme) in 2012/2013 and 2013/2014 dry seasons. The treatments were, surface irrigation with applied water equal to: the Field Capacity (FC) moisture content ($W_1$); Saturated soil moisture content (SC) ($W_2$); Continuous flooding (CF) up to 10 cm level, used as control ($W_3$); 10ETc ($W_4$) and 15ETc ($W_5$). A 115 days rice variety, Gbewaa (Jasmine 85) was used for the experiments. Seedlings were transplanted at spacing of 20 cm × 20 cm and one seedling per stand in a 1 $m^2$ micro-plots On-Station and 7 $m^2$ plots on-farm. Data was collected on plant growth parameters and grain yields from four (4) replications. The results showed that grain yield of the On-Station as well as the On-Farm experiments showed significant difference between Field capacity and the rest of the treatments at p=0.05 level of significance. FC gave the highest water productivity (0.311 $kg/m^3$) while SC gave the highest value of Economic Water Productivity (0.084 $\$/m^3$). In terms of water use, it is more economic to produce rice under saturated culture in the Northern Region of Ghana.

**Keywords:** Water Use, Irrigated Rice Production, Economic Water Productivity and Northern Ghana

## 1.0 INTRODUCTION

Rice evolved as a semi-aquatic species with facultative root aerenchyma that facilitate aerobic respiration in flooded soils (Norman *et al.,* 1995). Consequently, rice is significantly sensitive to water deficits more than other grain crops (e.g. Angus *et al*., 1983; Tanguilig *et al.*, 1987; Inthapan and Fukai, 1988). The main reason is its shallow root system; in terms of sensitivity of rice organs to low water potential, it is actually not that different from many other crops (Hsiao *et al.*, 1984). Water deficit during the vegetative stage may have relatively little effect on grain

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yield perhaps owing to the compensatory growth or changed partitioning of dry matter after the stress is relieved (Fukai and Lilley, 1994). A rice plant can transpire its potential rate even when moisture was around field capacity (Jose *et al.*, 2004). In general a rice plant uses less than 5% of the water absorbed through roots from the soil (Jose *et al.*, 2004). The rest is lost through transpiration which helps to maintain leaf energy balance of the crop.

Singh *et al.* (2010) indicates that one of the ways of alleviating water scarcity is by enhancing its use efficiency. According to Singh *et al.* (2010) in many areas, potential productivity of water is not realised partly due to poor irrigation management. Improving performance of irrigated agricultural systems should be a high-priority action. Under irrigation, water losses also include the mismanagement of irrigation water from its source to the crop roots. Generally more than 50% of irrigation water is lost at the farm level (Singh *et al.*, 2010). These losses not only cause wastage but also a potential hazard of soil salinity and water pollution resulting from the transport of nitrates, phosphates, sediments and agro-chemicals to the adjacent water bodies.

The term water productivity is “defined as the physical mass of production or the economic value of production measured against gross inflows, net inflow, depleted water, process depleted water or available water” (Molden and Sakthivadivel, 1999). Water productivity therefore denotes the amount or value of product (in this case, rice grains) over volume or value of water used, in other words, crop per drop (Jianxin *et al.*, 2008). There are large variations in the reported values of water productivity of rice (Tuong, 1999). The variations are caused by large differences in rice yields and the most commonly reported values range from 3–8 $t.ha^{-1}$. The variations are also caused by the denominator used in computing water productivity (Bouman *et al.*, 2007).

Economic water productivity (EWP) is defined as net production value (direct benefits) per unit of water consumed ($\$/m^3$) (Hellegers *et al.*, 2009). In case of a negative EWP, costs of production exceed benefits of production. It can also be used to determine the economically most productive crop. It is, however, important to note that the EWP is rather sensitive to market prices, and that growing solely the most productive crop is usually not desirable for a number of reasons. Market prices may vary and might drop as a result of a substantial increase in production due to market and supply–demand economics. Besides farmers do not prefer monocultures, as they like to spread price risks and disease risk. It is also not desirable from a crop rotational point of view (Hellegers *et al.*, 2009).

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Accurate estimation of different water balance components in a cropped field is essential to achieve an effective use of limited irrigation water. The water balance components can be quantified through field experiments but the process of execution is often expensive and time consuming (Tsubo, *et al.*, 2005). The research therefore attempted to evaluate the water balance, the economic and water productivities of dry season irrigated at both On-Farm and On-station at Bontanga and SARI station respectively.

## 2.0 MATERIALS AND METHODS

### 2.1 Description of the Study Areas

The study area comprised of on-station research at the Savanna Agricultural Research Institute (SARI) in Tolon District and on-farm research at Bontanga Irrigation Scheme at Kumbungu District, both in the Northern Region of Ghana.

SARI is one of the thirteen (13) research institutes of the Council for scientific and Industrial Research (CSIR) of Ghana. It was originally known as the Nyamkpala Agricultural Experimental Station (NAES) and operated as an outpost of the Crops Research Institute (CRI), Kumasi. In 1994, it gained autonomy and was upgraded to a fully-fledged research institute and renamed Savanna Agricultural Research Institute (SARI). SARI is located 16 km west of Tamale at Latitudes $9^{o}$ 25′ N and Longitudes $1^{o}$ 00′ W at 183 m above mean sea level, in the Tolon District of the Northern Region of Ghana.

The Bontanga Irrigation Project on the other hand is a medium scale scheme located in the Northern Region of Ghana, in the Kumbungu District. It lies between latitudes $9^{\circ}$ 30 ″ and $9^{\circ}$35″ N and longitudes $1^{\circ}$ 20″and $1^{\circ}$04 ″ W and in the Guinea Savannah ecological zone. The water source is the Bontanga River, a tributary of the White Volta with a catchment area of 1600 $km^2$. The Bontanga Irrigation Scheme has a potential irrigable area of 800 ha with only 434 ha presently developed and under cultivation. The cropping area is divided into two, upland and lowland; the upland is a free draining soil and plots are designed for furrow irrigation. The upland area is for vegetables production and the lowland is for rice production because of the nature of the soil, that is heavier textured soil and the irrigation of rice is by flooding. The system consists of an earthen dam that delivers water to the field by gravity and incorporated in the embankment are two (2) off-takes and a spillway, which is set to control the top water level in the reservoir. The reservoir capacity is 25.00$Mm^3$ (Abdul-Ganiyu *et al.*, 2012).

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The climate of the region is warm, semi-arid with mono-modal annual rainfall of 800-1100 mm, which occurs mostly between June and September (Kombiok *et al.*, 2005). This short rainy season is followed by a pronounced dry season between October and May annually. The average daily atmospheric temperature ranges from a minimum of 26 $^oC$ to a maximum of 39$^oC$ with a mean of 32 $^oC$.

## 2.2 Treatments

Data from two dry season's On-Station experiments in 2012/2013 and 2013/2014 at SARI and On-Farm experiment in 2013/2014 at Bontanga Irrigation Scheme were collected using five (5) treatments comprising of Surface irrigation with applied water equal to: the Field Capacity (FC) moisture content of the soil, ($W_1$)the Saturation soil moisture content (SC), ($W_2$)Continuous flooding (CF) irrigation (up to 10 cm) used as control ($W_3$) 10 ETc, ($W_4$) 15 ETc, ($W_5$).
All treatments were replicated four (4) times. The experiments were laid out in *randomized complete block design* with four replicates. For the On-Station site, the plots for the experiments were permanently created through masonry work using mortar and sancret blocks. The plots were of equal sizes, one square metre (1 $m^2$) with a lowland soil layer thickness up to 90 cm and 10 cm depth of flooding water above the soil surface. The bottoms of the plots were sealed to serve as a hardpan and to prevent seepage. With regards to the On-Farm experiment, the size of each plot was 1m by 7m (7 $m^2$) surrounded by 15 cm high bunds with bottom widths of 20 cm and top widths of 10 cm. The space between plots in each block was 60 cm, while the space between each block was 1m.

## 2.3 Calculation of Crop Water Requirement

### CROPWAT Model

CROPWAT uses FAO (1992) Penman-Montieth method for calculating the reference crop evapotranspiration. These estimates are used in crop water requirements and irrigation scheduling calculations. CROPWAT requires monthly climatic data (rainfall, minimum and maximum temperatures, percent relative humidity, wind speed and sunshine hours), crop (type of crop, planting date, duration of crop growth stages, crop coefficients, effective rooting depth and plant height) and soil (type of soil, total available soil moisture, maximum soil infiltration rate, maximum rooting depth and initial soil moisture depletion) information as inputs data to

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calculate reference crop evapotranspiration, crop and irrigation water requirement as well as irrigation schedule.

With regards to this research, over thirty years of daily climatic data from the Tamale Synoptic station (1965 to 2011) and that of SARI climate station (1970 to 2011) at Nyamkpala were used as climate input data, while the requisite information on the Jasmine 85 rice crop and soil of the experimental sites were also added as crop and soils data for the modelling of the reference crop evapotranspiration, the rice crop and irrigation water requirements as well as irrigation schedule.

### 2.4 Irrigation Application regimes

After transplanting, all the plots were irrigated to maintain uniform moisture content at saturation for the first week to ensure full establishment of the seedlings. All the plots, after the first week were then irrigated with a management allowable depletion (MAD) of 20 % (Allen *et al.*, 1998) except the control plots. Water application was done at both on-farm and on-station using graduated containers (10, 15 and 20 litre). The water application regimes for Year One (2012-2013) and Year Two (2013/2014) experiments as carried out at the Savanna Agricultural Research Institute (SARI) plots and for Bontanga Irrigation Scheme are presented in Tables 1 and 2.

*Table 1: Irrigation Application based on Saturation, Field capacity and Continous Flooding for SARI and Bontanga Irrigation Scheme*

| Moisture content | Volume (cm/m) | TAW at 30 cm RZD | UW at 20 % MAD (cm) | Application (mm) | Irrigation frequency (days) |
|---|---|---|---|---|---|
| **Saturation ($W_2$)** | 33.6-45.4 | 10.1-13.6 | 2-2.7 | 20-27 | 1 |
| **Field Capacity ($W_1$)** | 20.5-21.5 | 6.2-6.5 | 1.2-1.5 | 12-15 | 1 |
| **Cont. flooding ($W_3$)** | Recommended flooding depth of 2-10 cm with initial application of 2 cm one week after transplanting | | | | 1 |

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*Table 2: Crop water requirements (ETc) (mm) for rice at 1 day interval*

| Month | Decade | Stage | Kc coeff | ETc | 10ETc *(W4)* | 15ETc *(W5)* |
|---|---|---|---|---|---|---|
| | | | | mm/day | Mm | Mm |
| **Dec** | 2 | Init | 0.90 | 3.39 | 33.90 | 50.85 |
| **Dec** | 3 | Init | 0.90 | 3.44 | 34.40 | 51.60 |
| **Jan** | 1 | Init | 0.90 | 3.49 | 34.90 | 52.35 |
| **Jan** | 2 | Deve | 0.93 | 3.67 | 36.70 | 55.05 |
| **Jan** | 3 | Deve | 1.05 | 4.44 | 44.40 | 66.60 |
| **Feb** | 1 | Deve | 1.17 | 5.29 | 52.90 | 79.35 |
| **Feb** | 2 | Mid | 1.24 | 5.99 | 59.90 | 89.85 |
| **Feb** | 3 | Mid | 1.24 | 6.09 | 60.90 | 91.35 |
| **Mar** | 1 | Late | 1.24 | 6.18 | 61.80 | 92.70 |
| **Mar** | 2 | Late | 1.22 | 6.15 | 61.50 | 92.25 |
| **Mar** | 3 | Late | 1.10 | 5.48 | 54.80 | 82.20 |
| **Apr** | 1 | Late | 0.97 | 4.78 | 47.80 | 71.70 |
| **Apr** | 2 | Late | 0.89 | 4.34 | 43.40 | 65.10 |
| **Total** | | | | | 627.30 | 940.95 |

### 2.5 Monitoring of moisture conditions of the experiments

***Time Domain Refectometry (TDR):*** TDR equipment with 30cm long probe was used for measuring volumetric soil moisture content in all the plots before and after irrigation.

***Field Water Tube:*** A simple perforated PVC pipe (field water tube) of 20 cm diameter and 35 cm long installed in the rice fields allowed monitoring of water level beneath the soil surface. The perforations were done up to 20 cm of the pipe length, with holes diameter of 5mm spaced 2cm apart. The tube was then inserted into the soil by leaving 15 cm above the soil surface. Soil inside the tube was then taken out. A ruler was used to measure standing water on top and below the soil surface. The measurements were done and water depth computed using equation 1.

**Water depth = H – D** **1**

Where D = depth of field water table

H = height from soil surface to the top of the tube

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### 2.6 Quantification of Crop Water Productivity and Economic Water Productivity

The crop water productivity was computed using Equation 2.

$$WP_{I-Farm} = \frac{Y_a}{IWU_{Farm}} \qquad 2$$

Where

$Y_a$ is beneficial biomass in kg and

$IWU_{farm}$ is the volume of irrigation water used ($m^3$).

The EWP was calculated by multiplying beneficial biomass and the market price minus variable and fixed production costs divided by water consumed (eqn 3) (Hellegers, *et al.*, 2009).

$$EWP = (P_i \times Y_i - B_i \times Y_i - C_i / ET_{acti}) \qquad 3$$

Where

$Y_i$ is Yield of crop i (kg/ha)

$P_i$ is Market price received for crop i ($/kg)

$B_i$ is Variable production cost of crop i ($/kg)

$C_i$ is Fixed production cost of crop i ($/ha).

### 2.7 Bontanga Field Water Balances for the Various Growth Stages

Ten field tubes were planted in ten plots involving all the treatments and change in water depth ($\Delta S$) measured daily during the various growth stages before every irrigation (I) and with the consideration of daily evapotranspiration (ETc), the computation of the combine effect of seepage and percolation (SP) was done.

Percolation refers to vertical water loss in a system, whereas seepage quantifies lateral movement. In practice, it is extremely difficult to separate these terms and they are usually combined in a single composite parameter (i.e. SP) (Bouman *et al.*, 1994). For flooded rice systems with current irrigation, SP (positive values indicate loss) can be calculated using equation 4, (McDonald, *et al.*, 2006; Lee, *et al.*, 2006).

$$SP = IR - ETc - \Delta S \qquad 4$$

Where

$\Delta S$: change in water depth above the hardpan measured using a perforated PVC tube (cm)

IR: Irrigation water applied (cm)

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ETc: crop evapotranspiration (in general crop evapotranspiration is obtained by multiplying reference ETo with a crop coefficient kc which is dependent on the on among other factors, the stage of crop growth). The ETc was computed using the CROPWAT model.
SP: mean seepage and percolation rate (cm/d)

These components are expressed in depth unit (cm) and the time period considered is one day (McDonald, et al., 2006; Lee, *et al.*, 2006). The inflow to the field consisted of the total water supplied through irrigation, whereas the outflow was made up of water leaving the field through evapotranspiration, seepage and percolation. The assumptions made were that the field storage is considered sufficiently represented by the impounded surface water and that the soil moisture is constant throughout the crop growth period (Lee, *et al.*, 2006).

## 3.0 Results and Discussions

### 3.1 Average Seepage and Percolation rate of the Various Growth Stages for Bontanga Irrigation Scheme

Table 3 shows the combine effect of seepage and percolation (SP) in the rice experimental field at Bontanga irrigation scheme. As can be seen from the table, no amount of SP occurred on plot grown with rice under field capacity and saturation soil culture due to their low irrigation applications; but SP rather occurred in Continuous flooding (W3), 10ETc (W4) and 15ETc (W5) with the intensities varying according to the growth stages of the crop and the irrigation water application regime. The average SP for the field was 3.31 cm $d^{-1}$, with least SP (1.6 cm/d) occurring at initial period while the highest SP (5.23 cm/d) occurred at mid-season period. According to Bouman *et al.* (2007) typical percolation rates vary from 1-5 mm/day in heavy clay soils to 25-30 mm/day in sandy and sandy loam soils. Singh *et al.* (2010) indicates that, maintaining a ponding depth of 10–15 cm causes large percolation loss of water associated with leaching loss of mobile nutrients, especially in light-textured soils. As could be seen from the Table, the highest SP values were associated with 15ETc due to the high depth of water applied to it. Singh *et al.* (2010) indicates that decreasing the floodwater depth in rice fields from 5–10 cm to zero reduces the hydrostatic pressure, thereby reduces water loss through percolation. Rice grown under saturated soil culture or alternate wetting and drying (intermittent flooding) treatments will have little water loss through seepage and percolation.

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*Table 3: Average Seepage and Percolation rate for the Various Growth Stages for Bontanga Irrigation Scheme*

| Treatment | I (cm) | ∆S (cm) | ETc (cm/d) | SP (cm/d) |
|---|---|---|---|---|
| **Initial stage** | | | | |
| **W1 (FC)** | 1.5 | -6.0 | -0.35 | - |
| **W2 (SC)** | 2.5 | -4.8 | -0.35 | - |
| **W3 (CF)** | 4.5 | -2.8 | -0.35 | 1.35±0.10 |
| **W4 (10ETc)** | 4.3 | -3.3 | -0.35 | 0.65±0.08 |
| **W5 (15ETc)** | 5.7 | -2.5 | -0.35 | 2.85 ±0.16 |
| **Crop Development Stage** | | | | |
| **W1 (FC)** | 1.7 | -5.5 | -0.55 | - |
| **W2 (SC)** | 3.5 | -4.2 | -0.55 | - |
| **W3 (CF)** | 6 | -2.1 | -0.55 | 3.35±0.04 |
| **W4 (10ETc)** | 5.7 | -3.0 | -0.55 | 2.15±0.14 |
| **W5 (15ETc)** | 7.1 | -2.0 | -0.55 | 4.55±0.06 |
| **Mid-Season Stage** | | | | |
| **W1 (FC)** | 2.9 | -5.5 | -0.6 | - |
| **W2 (SC)** | 4.2 | -4.0 | -0.6 | - |
| **W3 (CF)** | 7.5 | -1.5 | -0.6 | 5.4±0.16 |
| **W4 (10ETc)** | 7.1 | -2.2 | -0.6 | 4.3±0.15 |
| **W5 (15ETc)** | 8.6 | -2.0 | -0.6 | 6.0±0.86 |
| **Late Season Stage** | | | | |
| **W1 (FC)** | 2.9 | -6 | -0.55 | - |
| **W2 (SC)** | 4.2 | -4.5 | -0.55 | - |
| **W3 (CF)** | 6.3 | -2.3 | -0.55 | 3.45±0.23 |
| **W4 (10ETc)** | 5.7 | -3.5 | -0.55 | 1.65±0.11 |
| **W5 (15ETc)** | 7.1 | -2.5 | -0.55 | 4.05±0.23 |
| **Average** | | | | 3.31±1.10 |

### 3.2 Water Saved Relative to Continuous Flooding (CF) Water Application for On-Station and On-Farm Experiment

Table 4 shows the results of the total quantity of water applied to the various treatments for the On-Station experiments and the amount of water saved by FC, SC, 10 ETc and 15 ETC relative to the CF. From Table 4, it could be realised that FC saved the highest amount of water (65.35 %) followed by SC (48.16 %) and the least was 10 ETc (12.5 %), with 15 ETc recording excess

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water consumed (12.2 %) over CF. Table 5 also shows the results of the On-Farm experiment with similar trend. It could be realised that even though FC saved the highest volume of water as compared to the rest of the treatment, its effects has translated into significant yield reduction due to water stress. However, in the case of SC and 10 ETc, the saving of water brought about no any significant reduction in yield when the yields were compared with that of CF. This suggested that in terms of Water Use Efficiency (WUE), SC and 10 ETc have improved WUE as compared to FC, since the amount of water saved relative to CF did not result in significant yield reduction, unlike FC. According to Singh *et al.* (2010) improving WUE in agriculture will require an increase in crop water productivity (an increase in marketable crop yield per unit of water used by plant) and reduction in water losses from the crop root zone. Bhuiyan and Tuong (1995) concluded that a standing depth of water throughout the season is not needed for high rice yields. They added that about 40–45 % of the water normally used in irrigating the rice crop in the dry season was saved by applying water in small quantities only to keep the soil saturated throughout the growing season, without sacrificing rice yields.

*Table 4: Water Saved Relative to Continuous Flooding (CF) Application for On-Station Experiment*

| Treatment | Grain Yield (t/ha) | Total water Applied ($m^3$/ha) | Water saved relative to W3 ($m^3$/ha) | Percentage of water saved relative W3 |
|---|---|---|---|---|
| **W1 (FC)** | 4.83b | 15525 | 29275 | 65.35 |
| **W2 (SC)** | 7.12a | 23225 | 21575 | 48.16 |
| **W3 (CF)** | 6.85a | 44800 | | |
| **W4 (10ETc)** | 6.24a | 39200 | 5600 | 12.50 |
| **W5(15ETc)** | 6.72a | 50250 | 5450 | (12.16) |
| **Mean** | **6.35** | 34600 | | |
| | **SED=1.04** | | | |

**Values within the yield column followed by a common letter are not significantly different (p = 0.05)**

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[1] sganiyu2000@gmail.com
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*Table 5: Water Saved relative to Continuous Flooding (CF) Application for On-Farm Experiment*

| Treatment | Grain Yield (t/ha) | Total water Applied ($m^3$/ha) | Water saved relative to W3 ($m^3$/ha) | Percentage of water saved from W3 |
|---|---|---|---|---|
| **W1 (FC)** | 4.57 b | 11753.5 | 20656.2 | 63.73 |
| **W2 (SC)** | 6.57 a | 19005.7 | 13404 | 41.36 |
| **W3 (CF)** | 6.20 a | 32409.7 | | |
| **W4 (10ETc)** | 6.12 a | 30580.6 | 1829.1 | 5.6 |
| **W5(15ETc)** | 6.40 a | 38154.3 | 5744.6 | (17.72) |
| **Mean** | **5.97** | 26380.8 | | |
| | **SED=0.68** | | | |

*Values within the yield column followed by a common letter are not significantly different (p = 0.05)*

### 3.3 Crop and Economic Water Productivity for On-Station and On-Farm Experiments

Table 6 shows crop water productivity (kg/$m^3$) and economic water productivity (EWP) for the various treatments for both On-Station and On-Farm experiments. FC has the highest CWP value (0.311 kg/$m^3$), followed by SC (0.307 kg/$m^3$) with CF, 10 ETc and 15 ETc giving 0.153 kg/$m^3$, 0.159 kg/$m^3$ and 0.134 kg/$m^3$ respectively for On-Station. The same trend prevails for the On-Farm experiment. This range of values is within the range reported by Tuong (1999) for rice cultivated at field level (0.05 to 0.6 kg $m^{-3}$). However, Bouman *et al.* (2006), indicated that, modern rice cultivars, when grown under flooded conditions, have water productivity with respect to transpiration for grain yield ($WP_Y/T_r$), of about 2 kg/$m^3$, while water productivity with respect to total water input (irrigation plus rainfall) is around 0.4 kg/$m^3$ (i.e. 0.2 to 1.2 kg/$m^3$). Ximing Cai and Rodegrant (2003) predicted the increment of global average water productivity of rice and other cereals from 0.39 kg/$m^3$ to 0.52 kg/$m^3$ and 0.67 kg/$m^3$ to 1.01 kg/$m^3$ respectively from 1995 to 2025. The results therefore indicated that it is more water productive to produce rice under SC and 10 ETc, since the amount in kg of rice grain produced per unit volume of water ($m^3$) used was higher than CF and 15 ETc. The lower values of CWP for CF and 15 ETc confirmed the report by Barker *et al.* (1990) that, the traditional irrigated rice production system not only leads to wastage of water, as it consumes 3000–5000 litres of water to produce 1 kg of rice but also causes environmental degradation and reduces fertilizer use efficiency. Zulkarnain *et al.* (2009) observed that water use efficiency under saturated condition was higher than flooding and half the amount of water was saved with comparable yield production.

[1] sganiyu2000@gmail.com
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However, for EWP, it was observed that it is highly economical to produce rice under SC (0.084$/m$^3$) than the rest of the treatments. The low values of EWP could be due to the fact that, net income from the sale of rice was used after reducing total cost of labour for weeding and water application when computing EWP. This outcome agrees with the assertion by Barker *et al.* (2002) that, an increase in water productivity may or may not result in higher economic or social benefits. Economists distinguish between net private returns (i.e. the market value of all outputs minus the cost of all inputs, considering the opportunity cost of all inputs not purchased on the market, such as family labour and land) and net social returns (i.e., the value to society of all outputs minus those of all inputs) (Barker *et al.*, 2002). Despite the fact that FC was highest in CWP, it economic water productivity was the least due to significant reduction in yield (29.5 %) and the high cost of labour requirements for weeding (four times of weeding after transplanting to maturity) and also loosing the soil at certain time interval to ensure water infiltration, as the soil surface became harden with time, unlike the other water application regimes (two times of weeding after transplanting to maturity).

*Table 6: Crop and Economic Water Productivity for On-Station and On-Farm Experiments*

| | **On-Station** | | **On-Farm** | |
|---|---|---|---|---|
| **Treatment** | CWP (kg/m$^3$) | EWP ($/m$^3$) | CWP (kg/m$^3$) | EWP ($/m$^3$) |
| **W1 (FC)** | 0.311 | 0.016 | 0.389 | 0.008 |
| **W2 (SC)** | 0.307 | 0.084 | 0.346 | 0.090 |
| **W3 (CF)** | 0.153 | 0.042 | 0.191 | 0.046 |
| **W4 (10ETc)** | 0.159 | 0.039 | 0.200 | 0.047 |
| **W5(15ETc)** | 0.134 | 0.036 | 0.168 | 0.042 |
| **Mean** | 0.213 | 0.043 | 0.259 | 0.047 |

## 4.0 CONCLUSION

The average SP for the field was 3.3 cm d$^{-1}$. The results therefore suggested that flooding rice crop resulted in increasing seepage and percolation rates. FC saved the highest quantity of water followed by SC and finally 10 ETc with 15 ETc rather consuming more than CF. It is therefore more water use efficient to produce rice under FC, SC and 10 ETc, since less water would still

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produce reasonable grain yield of rice as compared to CF and 15 ETc. FC gave the highest water productivity followed by SC and finally 10 ETc with 15ETc rather being less water productive as compared to CF. With economic water productivity, SC gave the highest value and FC the least compared to CF for both On-Station and On-Farm experiments. The results therefore suggest that, it is both crop and economic water productive to cultivate rice under saturation soil culture (W2) and 10 ETc since the yield obtained was not significantly different from that of continuous flooding condition.

In terms of weed control, FC plot was weeded four times as compared to SC, 10 ETc, CF and 15 ETc for which only two times of weeding was done.

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