

Research Article

Evaluating Supplementary Irrigation Depths for the Improvement of Water Productivity and Rice Yield in Semi-arid Climate, Eastern Burkina Faso

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Abstract

In Burkina Faso, supplementary irrigation is promoted as a strategy to overcome the uncertainty of rain and increase sustainably rain-fed rice yield. However, in the actual water scarcity context and the decline of rain water, high productivity cannot be achieved regardless to water use efficiency. Therefore, an experiment was conducted to identify optimal supplemental water depth that increases both water productivity and water savings while minimizing yield losses. Four replications of a randomized block design were implemented and three supplemental water depths of $D_{5\text{cm}}$, $D_{7.5\text{cm}}$ and $D_{10\text{cm}}$ were field-evaluated against farmer's irrigation water depth (FIWD). In $D_{5\text{cm}}$, $D_{7.5\text{cm}}$ and $D_{10\text{cm}}$ treatments, water was applied once a week in case of no rain. In FIWD treatment, irrigation was supplied daily excluding the day of rain. The results revealed that water stress duration and amplitude increased with the decrease of water depth. Severe, moderate and low water stress were recorder in $D_{5\text{cm}}$, $D_{7.5\text{cm}}$ and $D_{10\text{cm}}$ respectively while no stress was registered in FIWD. The severe water stress induced by $D_{5\text{cm}}$ diminished plant height, and the number of tillers by 11% to 3% respectively; while slight ($D_{10\text{cm}}$) and moderate ($D_{7.5\text{cm}}$) stress did not affect the growth. Comparable yield was obtained in $D_{7.5\text{cm}}$ (3.130 t ha^{-1}) and FIWD (3.279 t ha^{-1}). The application of 7.5cm of water yielded the highest gain of water saving ($438 \text{ m}^3 \text{ kg}^{-1}$). We argue that the weekly supply of 7.5cm water depth can be suggested as a sustainable practice in semi-arid regions.

Keywords

Rice Yield, Supplementary Irrigation, Water Productivity

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1. Introduction

Rice is the most consumed food in the world [1]; about 3.5 billion people rely on rice which provides almost 20% of the daily required energy [2]. It is predicted that the increase of 40% in rice production is required to match the demand in 2030 [3] while yield has dropped below 1% over the past decade [1]. In Burkina Faso, rice is becoming an important staple food crop [4]. Consumers' demand has increased faster in the last decades compared to other cereals with a growth rate of 3% every year [5].

In Burkina Faso, rice is mostly produced in the rainy season on almost 87% of total rice areas, but only 47% of the demand is covered by national production; rain-fed rice yields remain low and vary from 1.2-2 tha^{-1} [6] due to the instability of rainfalls. In the rain-fed rice farming system, rainfall is the main source of water but, rainwater is not able to secure rice production. There is an urge gap between rainwater and rice water demand. In rain-fed conditions, not enough water can be assured for the rice field due to the irregularity of rainfall [7]. The rice crop is frequently subjected to insufficient rainwater supply [8] ultimately affecting crop yield and productivity.

Rainfall variability and frequent drought spells have become the key warning to achieving food security and increases vulnerability of farmers. The variation in rainfall patterns coupled with frequent drought spells in rain-fed agriculture induces poor rice yields and low production [9-12]. Farmers failed in achieving high production due to inadequate water supply and inappropriate time of application [13]. As demand is growing rapidly, the increase of rice yield is vital [14].

Numerous drought mitigation techniques and practices in rain-fed agriculture have been developed and validated. Of these, supplementary irrigation has been reported as one of the best alternatives to overcome water stress for increasing and/or maintaining rain-fed rice yield [13, 15, 16]. It is as a countermeasure to the unpredictability of rain during crop growing periods [7, 17] opined that, in rainy season, supplementary irrigation is vital for rice growth.

In supplementary irrigation practice, extra water is provided to cover up the shortage of rainfalls. The suitable scheduling of supplementary irrigation during dry spells should increase or stabilize crop yield [18]. Contrary to full irrigation, the water depth and the application time cannot be estimated in advance. Additional water is just applied to provide minimum water to crop at sensitive stages but, not to create soil moisture-stress-free conditions. This practice has attracted the most attention in semi-arid regions of Sub-Saharan especially in Burkina Faso.

Nowadays, the Government of Burkina Faso is responding to the increasing rice demand by addressing the drought spell through the promotion of supplementary irrigation. The technique is adopted country-wide and irrigation is applied without awareness to a suitable water amount, application timing and the rainfall amount during growth stages. Conse-

quently, productivity remains low with high pumping cost, underscoring the need to increase domestic rice production. Yield gain is low largely attributed to ineffective rainwater use options as well as low supplemental water productivity. Enhancing both rainfalls and supplemental water use efficiency should help in improving rain-fed rice performances while saving more water for dry season cropping.

In order to boost up rice production, it is vital to deal with the water scarcity and resources use efficiency. [19] mentioned the emergency of saving water while increasing the efficiency of water use. Moreover, the analysis of investment return cost in semi-arid Burkina Faso has shown that irrigation is beneficial only if farmers are able to produce vegetable in the dry season after supplementary irrigated cereals [20-22]. Saving water through increase water productivity should increase farm profitability.

Since rainwater decline affects the amount of water stored for the use during rainy and dry seasons, double cropping should be possible solely if water is efficiently used first for supplementary irrigation. The performance of crops and the cropping pattern depend on the efficient utilization of supplemental water [23, 24]. Emphasis should be placed primarily on the effective use of supplemental water. The effectiveness of supplemental irrigation is driven by the amount of water and the time of application. High water productivity cannot be achieved regardless of irrigation depths and application time [8, 25, 26]. The application of water is a key factor guiding the agriculture growth in arid and semi-arid regions [27]. Finding out suitable water depth should help increasing water productivity and optimizing yield. Supplementing the appropriate amount of water is very vital in stabilizing yields, and increasing gross production [8].

Therefore, effective water depth that may optimize the use of water, while enhancing yield should be determined so to help setting up a suitable supplementary irrigation program and improving profitability. Evaluating different water depth regarding rain occurrence in comparison with farmer irrigation practice of farmers, should help identifying a suitable water level that increases farm and water productivity for sustainable rain-fed agriculture. To our knowledge, literature related to such approach is barely accessible. The objective of the current study is the optimization of supplemental water by testing different depths of irrigation to secure rain-fed rice production, improve water productivity and save more water with lesser yield penalty. In term, it may help designing double cropping rice system for achieving high profitability in the dry areas.

2. Methodology

2.1. Nursery Establishment

The nursery was installed on July 23th, 2020 at the exper-

imental field. Land was soaked at soil saturation and manually tilled at 10cm depth. Seed-bed was leveled at 0.15m height. Two nurseries with a total area of 10m² were installed close to the experimental plots. Seeds were then manually broadcast (50kg of seeds per hectare). The seed bed was then covered with a fine layer of soil (1cm) and a rice straw of

1cm height. One extra nursery was also established to eventually replace dead plantlets. The irrigation water was applied at 2 days interval up to the appearance of seedlings. After the emergence of seedlings, water was supplied when needed until transplanting.



Figure 1. Sketch of experimental design (A) and water tube for the monitoring of soil water depth (B).

2.2. Site Location, Experimental Design, Land and Crop Management

The trial was carried out from July to November 2020 at “Bagr é” irrigated area. The site was located at 11.30 °(N) and 0.25 °(W). The soil was sandy loamy (65% of sand, 18% of silt and 17% of clay) with a wilting point of 12% volume; field capacity 21.5% volume; saturation 33.33% volume; bulk density of 1.69gcm⁻³ and infiltration rate at 25mmh⁻¹ [4]. The trial design (Figure 1) was a randomized complete block. Four replications were set up with four water treatments (D_{5cm}, D_{7.5cm}, D_{10cm}, and FIWD) corresponding to the application of 5cm, 7.5cm, 10cm and 12.5cm water depth respectively. The treatment FIWD was farmer irrigation water depth. The total area of each plot was 9 m² with a soil bed height of 0.3m. The distance between plots and between blocks was 2m.

The land was soaked at soil saturation on August 5th 2020 and tilled at 15cm depth two days later. The bunds were well compacted at 30cm height to reduce nonproductive water (seepage and over bund runoff) losses. Plots were leveled and irrigation was applied at 5cm ponded water depth on August 13th. Twenty-one-day old plantlets were manually transplanted one plant hill⁻¹ the same day at the hill spacing of 25cm x 25cm. Rice was a new perfumed lowland variety named «Farak ô-Ba rice 84 (FKR 84).

Fifteen days after transplanting, NPK fertilizer (14: 23: 14), was applied at the rate of 200kg/ha. 50kg/ha and 100kg/ha of urea (46%) were applied, respectively at active tillering and panicle initiation. Pesticides were applied when

needed with the required amount for specific pests. Weeds were frequently hand controlled.

2.3. Irrigation Water Management

After transplanting, water was daily applied at soil saturation in all plots for the adaptation of seedlings. The required water depth was determined using the following Eq. (1):

$$W_{depth} = (SWC_{sat} - SWC_{wp}) \times D_{root} \quad (1)$$

Where W_{depth} is the irrigation water depth (cm) at soil saturation; SWC_{sat} and SWC_{wp} are the soil water content, volume basis (%) at saturation and wilting point, respectively; while D_{root} stands for root depth (cm).

Two weeks after transplanting on August 27th, the interval of irrigation was settled at 7 days [8] and supplementary water was applied once a week in treatments D_{5cm}, D_{7.5cm}, and D_{10cm} when there was no rain. In case of rain during the week, irrigation was postponed to the following week. For Africa countries, the short dry spell lengths are defined to be shorter than 10 days [28, 29]. In farmer practice treatment (FIWD) irrigation depth of 12.5cm was daily applied except when rain occurred as commonly done by farmers. Irrigation ended a week before the harvest.

During land leveling, plastic tubes were placed in the middle of each plot to control the application of water. Tubes were buried so that 5cm, 7.5cm, 10cm and 12.5cm of its length protrudes over the soil surface corresponding to D_{5cm}, D_{7.5cm}, D_{10cm}, and D_{12.5cm}, respectively. The desired water depth was applied accordingly.

2.4. Soil Water Fluctuation Measurement

After land preparation, water tubes, described and suggested by [7], were placed to observe soil water fluctuation during the production cycle. Water tubes were installed near the bund at 1 m away and buried vertically at 30cm into the soil. The variation of the soil water was daily recorded in the morning at the same time using a ruler. The measurement was taken from the water surface in tubes to the tip of the tube. In this study we considered the decrease of water up to 15cm as a threshold under which rice crop is subjected to water stress with yield decline [7]. The soil water (mm) at the threshold and the measurement times was defined according to [8]; then the soil water stress coefficient was determined according the Eq. (2) [30]:

$$K_s = \frac{SW_T}{SW_{ST}} \quad (2)$$

Where ST_T and SW_{ST} stand for soil water content (mm) at the threshold and time T respectively.

2.5. Plant Growth, Chlorophyll and Heading Rate

Two weeks after transplanting, one-meter square quadrat was installed in each plot at the middle for the measurement of agronomic parameters. Measurements were taken from each hill individually in the quadrat. Sixteen hills were considered.

Thirty days after transplanting, plant growth observations were done every week until panicle initiation. Five measurements were taken on plant height, tillers and leaves number. The height was measured from the base of plants to the tip of apical leaf. The number of tillers and leaves in each hill were manually counted.

The chlorophyll of leaves was determined at panicle initiation, at heading and at the onset of ripening stage using a chlorophyll meter (field scout model). The highest and fully expanded leaf was chosen from each of the selected hills. Measurements were done on 16 leaves and three observations were made per leaf on the area located between 40% and 70% along the leaf length from the leaf base [31].

From the emergence of first panicles, headed panicles were daily counted from each quadrat until 50% of the farm headed; the heading rate was then analyzed.

2.6. Yield Components

At harvest, the sixteen hills from each quadrat were individually harvested and tillers were counted. Panicles from each hill were cut at the base and separated from the straw. The panicles were then individually counted and weighted to obtain both the number and weight.

Five hills were randomly picked in each quadrat and yield components such as the length of panicle, the number of

grains, grain weight per panicle and filled grain per panicle were determined following the method described by [30]. Selected panicles from each quadrat were individually measured to determine the maximum length (lengthmax) and the minimum length (lengthmin). The range (lengthmax - lengthmin) was then calculated. The class interval was obtained by dividing the range by the desired number of classes. Three classes of length were considered and panicles were ranged accordingly. Five panicles were randomly picked from each class, and the length was measured. Fifteen panicles were considered per plot.

Each panicle was manually threshed and the grain counting machine was used to determine the number of grains per panicle. The grains were oven dried at 70 °C for 72 h and the grain weight per panicle was determined at a constant weight. A seed blower was used to separate the filled and the unfilled spikelet. The filling percentage per panicle was obtained by dividing the weight of filled grains to the total weight of grains multiplied per 100.

Five samples of 1,000-grains were randomly picked from each selected hill to determine the weight.

2.7. Yield, Straw Weight and Yield Losses

For grain yield and the straw weight, all the hills of quadrats were considered. Grain and the straw weight were determined per hill and yield (tha^{-1}) was estimated using following Eq. (3) and Eq. (4):

$$GY = GW_{hill} \times 16 \cdot 10^{-2} \quad (3)$$

$$SW = SW_{hill} \times 16 \cdot 10^{-2} \quad (4)$$

Where GY and SW represent the yield (tha^{-1}) and the weight of straw (tha^{-1}) respectively, while GW_{hill} and SW_{hill} stand for grain weight (g) and straw weight (g) per hill respectively.

Yield losses (YL) were determined considering the yield in FIWD treatment as a control. YL were obtained using the following Eq. (5):

$$YL = \frac{Y_{FIWD} - Y_X}{Y_{FIWD}} \times 100 \quad (5)$$

Where YL is the yield losses (%); Y_{FIWD} and Y_X expressed yield (t/ha) in FIWD and X treatments respectively.

2.8. Irrigation Water Use Efficiency

The irrigation water productivity (IWP) and the total water productivity (TWP) was determined the following Eq. (6) and Eq. (7) [32]:

$$IWP = \frac{GY}{IWP} \quad (6)$$

$$TWP = \frac{GY}{TW} \quad (7)$$

Where WP and TWP are the irrigation water productivity and the total water productivity (kg/m^3), GY represents the yield (kg/ha), IW and TW stand for irrigation water and total water used (m^3) respectively.

The irrigation water saving was estimated based on the approach described by [26]. The amount of water used in the FIWD treatment was supposed to be a control, and the water saving (%) was the ration of irrigation water in each treatment and the irrigation water in FIWD multiplied by 100.

2.9. Ratio Gain Loss (RGL)

In our study, we defined a ratio gain-losses as the amount of water (m^3) saved per kilogram of yield lost considering the yield and irrigation water in farmer irrigation treatment as the reference. R_{GL} was used to identify the suitable water depth and was obtained using the following Eq. (8):

$$R_{CLX} = \frac{IW_{FIWD} - IW_X}{Y_{FIWD} - Y_X} \quad (8)$$

Where R_{GLX} is the ratio of water saved by losing one kilogram of rice in treatment X expressed in m^3/kg ; IW_{FIWD} and IW_X are irrigation water (m^3/ha) used in the farmer and in X treatment, respectively, Y_{FIWD} and Y_X stand for yield (kg/ha) in the farmer treatment and in the X treatment respectively.

2.10. Statistical Analysis

The data were submitted to statistical analysis, including the analysis of variance, and correlations by employing the SPSS 18 software (IBM, Armonk, New York, United States). The significance of the effect of treatments was captured using F-test. The means of treatments were separated using Duncan's test at 95% level of confidence.

3. Results

3.1. Environment Conditions

Figure 2A illustrates environmental conditions (rainfalls, maximum and minimum temperature) and crop water requirement and effective rain (Figure 2B). Climatic data were recorded from the meteorological station located in the production area. Effective rainfall was estimated using the method defined by the United States Department of Agriculture, Soil and water Conservation (USDA-SC). The crop water requirement was estimated using the standard approach of Penman-Monteith by running the FAO-CROPWAT 8.0 software.

The climate of the study area is characterized by three main seasons (a rainy season, a cold and dry season and a hot and dry season). The rainy season occurs from July to October, followed by the cold and dry season from November to February, and a hot dry season from March to June [4]. The highest values of maximum (40.1° , 39.7° and 37.7°) and minimum (26.9° , 26.2° and 24.6°) temperatures were registered during the hot and dry season meaning that the highest evapotranspiration occurred at that specific period. Along cropping period, rainfalls occurred from August 13th to September 10th with the highest values of 400, 300 and $300\text{m}^3/\text{ha}$ recorded respectively on August 16th, 29th and September 11th corresponding to the vegetative stage. During the vegetative stage, the amount of $2480\text{m}^3/\text{ha}$ of rain was registered whilst only $550\text{m}^3/\text{ha}$ of rainfalls were registered from vegetative to panicle initiation. The crops were grown exclusively under irrigation from the sensitive stage (from panicle initiation to maturation) to harvest. From transplanting to harvest, rainfalls did not fulfill the crop water requirement; only 48% of water demands were covered by effective rain meaning that rice could not grow under rain-fed conditions without supplement water.

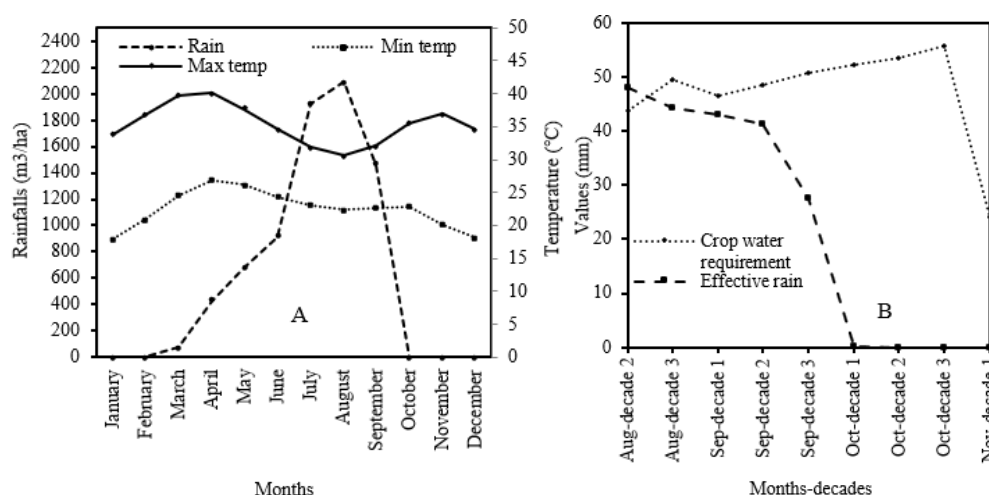


Figure 2. (A) Sketch of monthly rainfall, maximum and minimum temperature and effective rainfalls and crop evapotranspiration (B) in the study area.

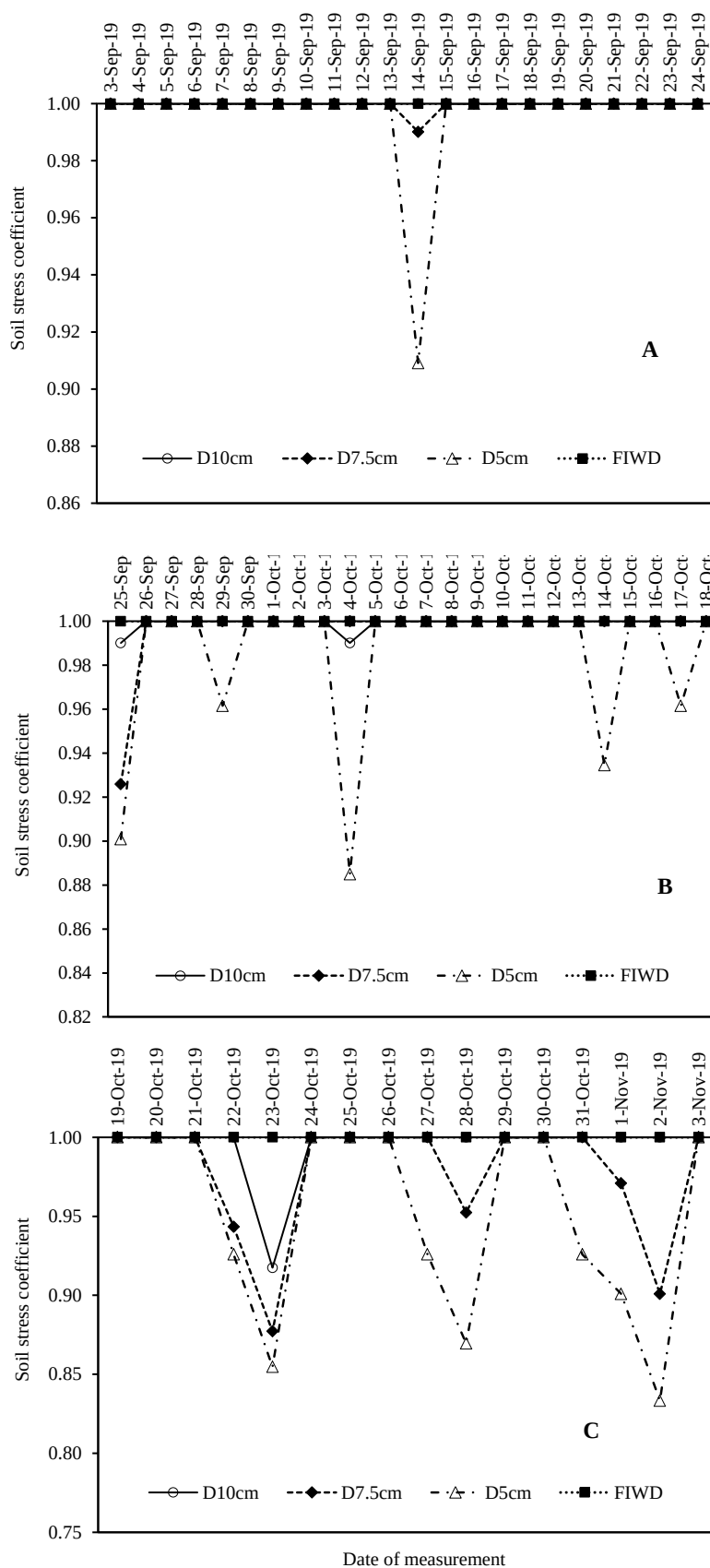


Figure 3. (A) Soil stress coefficient variation at the vegetative stage, (B) from the panicle initiation to the heading stage and (C) from the heading to the harvest.

3.2. Soil Moisture Trends

Figure 3 shows the fluctuation of soil stress coefficient over the three growth stages. During the cropping period, the soil stress ranged from 1 to 0.83 and varied according to the irrigation water depths and growth stages. No water stress ($K_s = 1$) occurred in the FIWD treatment in any of the growth stages; whilst the stress duration and its amplitude differed in other investigated water depths and in different growth phases.

During the vegetative stage (Figure 3A), 1 day of stress was recorded in both $D_{7.5\text{cm}}$ and $D_{5\text{cm}}$ while no stress was observed in $D_{10\text{cm}}$; then the crops were grown stress free in FIWD and $D_{10\text{cm}}$, but they were subjected to slight stress in $D_{7.5\text{cm}}$ and $D_{5\text{cm}}$. From the panicle initiation to the heading stage (Figure 3B), the highest stress duration (5 days) and the highest amplitude (0.926) was given by $D_{5\text{cm}}$ treatment followed by $D_{7.5\text{cm}}$ with the duration of 1 day and the amplitude of 0.93. The lowest stress amplitude of 0.99 on average was

registered in $D_{10\text{cm}}$ for 2 days.

During the reproductive stage (Figure 3C), the crops were submitted to relatively high, moderate and slight stress in $D_{5\text{cm}}$, $D_{7.5\text{cm}}$ and $D_{10\text{cm}}$ respectively. From heading to harvest, the stress duration of 7 days, 5 days and 1 day were respectively recorded in $D_{5\text{cm}}$, $D_{7.5\text{cm}}$ and $D_{10\text{cm}}$ with the amplitude of 0.89, 0.928 and 0.92 in average. The crops faced sharper stress in $D_{5\text{cm}}$ treatment but were subjected to moderate and slight stresses in $D_{7.5\text{cm}}$ and $D_{10\text{cm}}$.

Alongside the crop cycle, the stress was heavier at the ripening stage while moderate and slight stress was observed at the reproductive and the vegetative stages respectively. The crops stand longer under stress in $D_{5\text{cm}}$ (13 days), but they were subjected to medium and shorter time of stress in $D_{7.5\text{cm}}$ (7 days) and $D_{10\text{cm}}$ (3 days) respectively. At that range the water stress was defined to be severe, moderate and low [8]. The decrease of supplementary water depths by 60% ($D_{5\text{cm}}$), 40% ($D_{7.5\text{cm}}$) and 20% ($D_{10\text{cm}}$) induced severe, moderate and low stress in respectively $D_{5\text{cm}}$, $D_{7.5\text{cm}}$ and $D_{10\text{cm}}$.

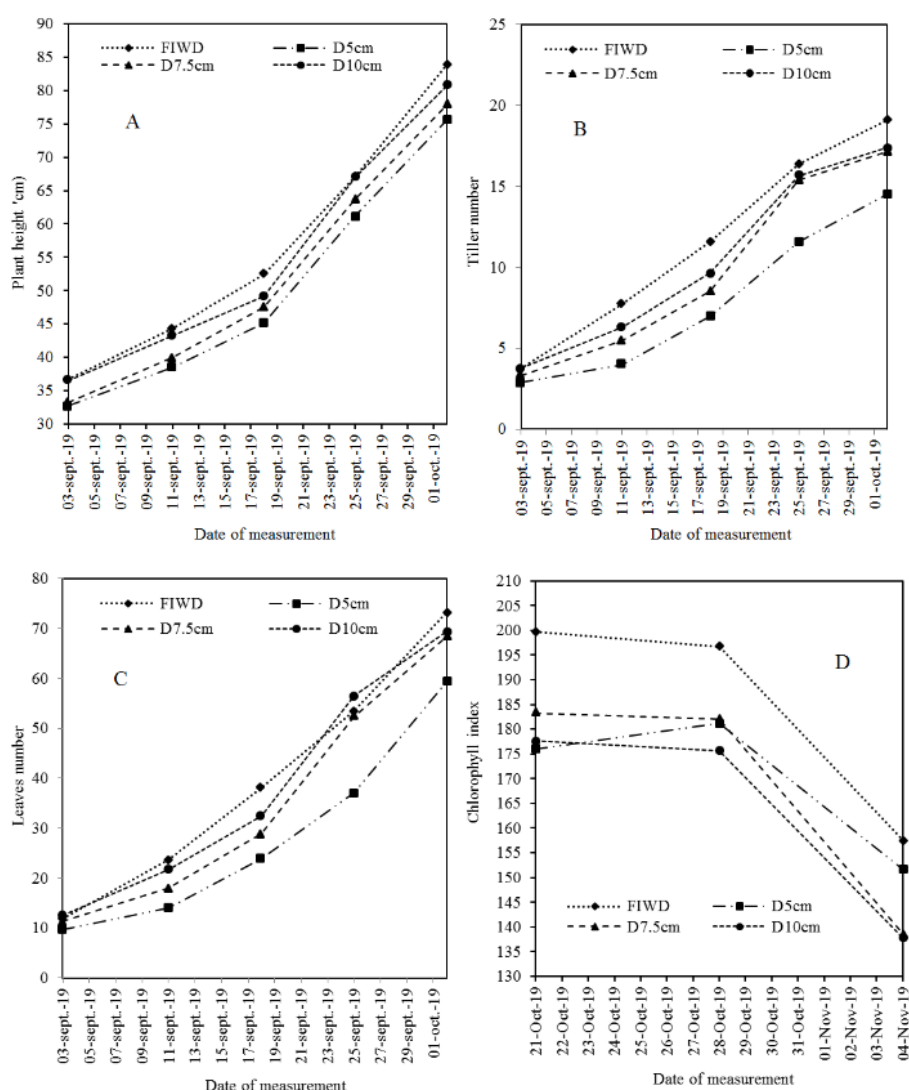


Figure 4. (A) Effects of water treatments on the plant height, (B) the number of tillers, (C) the number of leaves and (D) the chlorophyll index at different growth stages.

3.3. Plant Growth and Chlorophyll Content

The growth parameters illustrated in Figure 4 indicate that the plant height, the number of tillers, the number of leaves and the chlorophyll content were affected by supplementary water variation. From the initial stage to panicle initiation, higher values of the plant height (Figure 4A), the number of tillers (Figure 4B) and the number of leaves (Figure 4C) were notable in higher water treatment while lower values were recorded in lower water depth of 5cm. Intermediate values were registered in D_{7.5cm} and D_{10cm} showing a difference between treatments at panicle initiation.

The irrigation water restriction decreased plant height by 11%, 8% and 4% in respectively D_{5cm}, D_{7.5cm} and D_{10cm} when compared to farmer irrigation water depth. The number of tillers were reduced by 31%, 12% and 5%, respectively in the same treatments. For the number of leaves, the decrease of 23%, 7% and 5% was registered. From the heading to the onset of the ripening stage, leaves chlorophyll content (Figure 4D) decreased in all treatments with lower values registered in D_{7.5cm} and D_{10cm} while higher values were notable in FIWD with no significant difference ($p = 0.48$) with D_{5cm}. At

ripening stage, reduction in chlorophyll by 14% was observed with the restriction of water in D_{7.5cm} and D_{10cm}. However, the severe water decreases in D_{5cm} increased the chlorophyll content by 10% when compared to the average in both D_{7.5cm} and D_{10cm}.

3.4. Effects of Water Treatments on Panicle Emergence

Figure 5 illustrates the incidence of the variation of water depths on heading. Daily headed panicles per square meter were affected by water reduction. The number of cumulative headed panicles increased within the time for all treatments, but the number of panicles in FIWD and D_{10cm} was significantly higher ($p = 0.01$), and the emergence was faster compared to D_{7.5cm} and D_{5cm}. The lower number was recorded in D_{5cm}, while intermediate values were registered in D_{7.5cm}. The supplementary water decreases by 5cm and 7.5cm resulted in the reduction of average headed panicle by 90% and 20% in D_{5cm} and D_{7.5cm}, respectively.

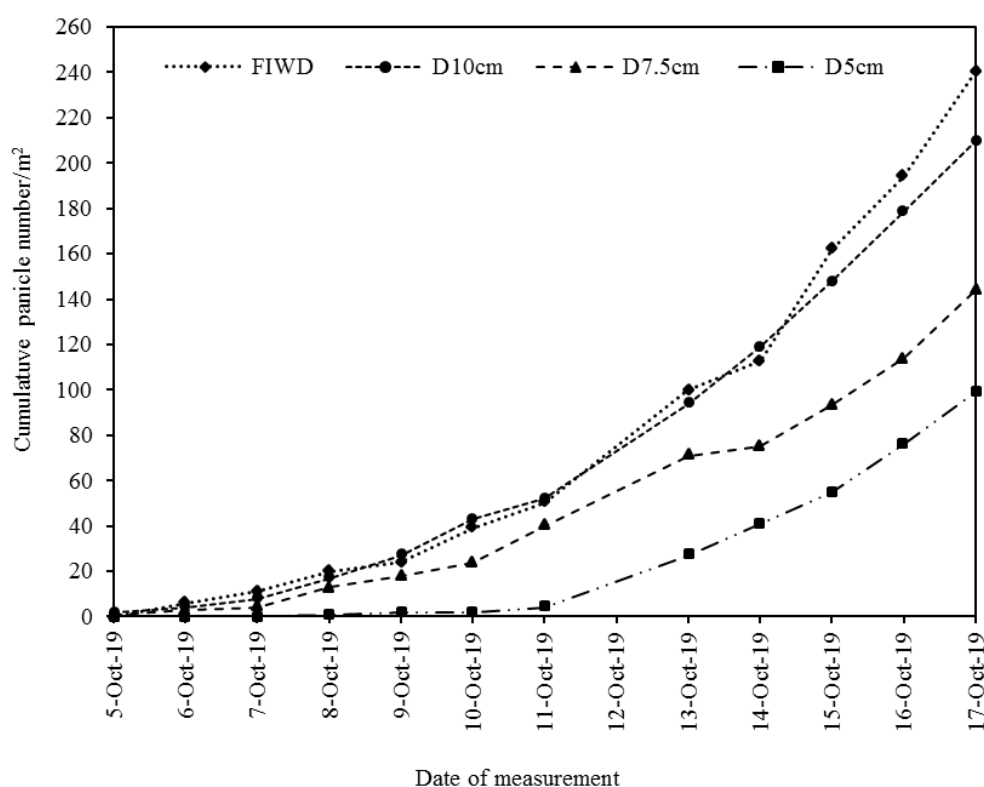


Figure 5. Effect of supplementary irrigation on panicles heading rate.

3.5. Yield Components and Yield Analysis

The number of tillers and panicles, the panicle weight and

the length were notably affected by water treatments (Table 1). The sharper impact of water restriction was observed in D_{5cm}; the decrease of these parameters by 16%, 12%, 17% and 4%, respectively, was notable compared to FIWD. No

significant impact was observed for the tiller number in D_{7.5cm} and D_{10cm} and the panicle number in D_{7.5cm}, while any decrease of water induced the reduction of panicle weight

and length referred to FIWD. The decrease of panicle weight by 19% and 5% and panicle length by 5% and 4% was observed in D_{10cm} and D_{7.5cm} respectively.

Table 1. Effect of treatments on the number of tillers, the number of panicles, panicle weight and length at harvest.

Treatments	Tiller number per hill	Panicle number per hill	Panicle weight (g)	Panicles length (cm)
D _{5cm}	13.11 ± 0.46 ^b	11.11 ± 0.41 ^b	1.65 ± 0.05 ^{cb}	25.60 ± 0.24 ^b
D _{7.5cm}	15.25 ± 0.56 ^a	12.28 ± 0.43 ^{ab}	1.79 ± 0.06 ^b	25.62 ± 0.26 ^b
D _{10cm}	15.41 ± 0.53 ^a	13.17 ± 0.47 ^a	1.61 ± 0.05 ^c	25.33 ± 0.25 ^b
FIWD	15.56 ± 0.57 ^a	12.64 ± 0.46 ^a	1.98 ± 0.07 ^a	26.79 ± 0.26 ^a
Probability	<0.01	<0.05	<0.000	<0.000
Significance	**	*	***	***

*** Means within columns not followed by the same letter are significantly different at p < 0.001 level by Duncan's test

** Means within columns not followed by the same letter are significantly different at p < 0.01 level by Duncan's test

* Means within columns not followed by the same letter are significantly different at p < 0.05 level by Duncan's test

Water treatments significantly affected grain weight, grain number per panicle and 1,000-grain weight, but the grain filling rate was not impacted (Table 2). The highest values of these parameters were observed in FIWD. The results were similar for the number of grains in FIWD and D_{7.5cm}. The

reduction of water depth led to the decrease of grain weight and grain number by respectively 22% and 19% in D_{10cm} when compared to FIWD. For 1000-grain, 4% of the weight was lost in D_{5cm}, D_{7.5cm} and D_{10cm}.

Table 2. Effects of irrigation water on grain weight, grain number, 1000-grain weight and the filling percentage at harvest.

Treatments	Grain weight per panicle (g)	Grain number per panicle	1,000-grain weight (g)	Grain filling rate (%)
D _{5cm}	1.66 ± 0.07 ^{ab}	86.62 ± 3.35 ^{ab}	19.79 ± 0.19 ^b	97 ± 0.69 ^a
D _{7.5cm}	1.59 ± 0.09 ^{ab}	88.45 ± 5.03 ^a	19.73 ± 0.23 ^b	97 ± 0.67 ^a
D _{10cm}	1.42 ± 0.07 ^b	75.43 ± 3.01 ^b	19.86 ± 0.21 ^b	96.18 ± 0.72 ^a
FIWD	1.83 ± 0.1 ^a	93.18 ± 4.83 ^a	20.65 ± 0.23 ^a	96.78 ± 0.57 ^a
Probability	<0.01	<0.05	<0.05	0.803
Significance	**	*	*	ns

* Means within columns not followed by the same letter are significantly different at p < 0.05 level by Duncan's test

** Means within columns not followed by the same letter are significantly different at p < 0.01 level by Duncan's test

ns Not significantly different

Table 3. Effect of water amounts on grain yield, straw weight and yield losses.

Treatments	Grain yield (tha ⁻¹)	Straw weight (tha ⁻¹)	Yield losses (%)
D _{5cm}	2.623 ± 0.11 ^b	2.62 ± 0.96 ^c	20.01 ^a
D _{7.5cm}	3.130 ± 0.16 ^a	3.18 ± 0.11 ^{ab}	4.54 ^b
D _{10cm}	2.879 ± 0.15 ^{ab}	3.05 ± 0.11 ^b	12.20 ^{ab}

Treatments	Grain yield (tha ⁻¹)	Straw weight (tha ⁻¹)	Yield losses (%)
FIWD	3.279 ± 0.14 ^a	3.41 ± 0.13 ^a	-
Probability	<0.01	<0.000	<0.05
Significance	**	***	*

*** Means within columns not followed by the same letter are significantly different at $p < 0.001$ level by Duncan's test

** Means within columns not followed by the same letter are significantly different at $p < 0.01$ level by Duncan's test

The results of yield, illustrated in Table 3, show that grain yield, straw weight and yield losses were significantly impacted by water treatments. Grain yield was reduced by 20% in D_{5cm}; while D_{7.5cm} produced similar results to FIWD. D_{10cm} exhibited intermediate value. The straw weight decreased by 23% and 11% in D_{5cm} and D_{10cm} respectively, whilst D_{7.5cm} produced comparable results to FIWD. The yield losses were 4.4 times and 2.68 times more in D_{5cm} and D_{10cm} respectively compared to D_{7.5cm}.

3.6. Water Productivity

The irrigation water and the total water use efficiency is highlighted in Figure 6. The highest water productivity (Figure 6A) was achieved in D_{5cm} followed gradually by D_{7.5cm} and D_{10cm}; while the lowest water use efficiency was induced by FIWD. The reduction of irrigation water increased the efficiency of water utilization 11 times, 10 times and 7 times more in D_{5cm}, D_{7.5cm} and D_{10cm} (Figure 6B).

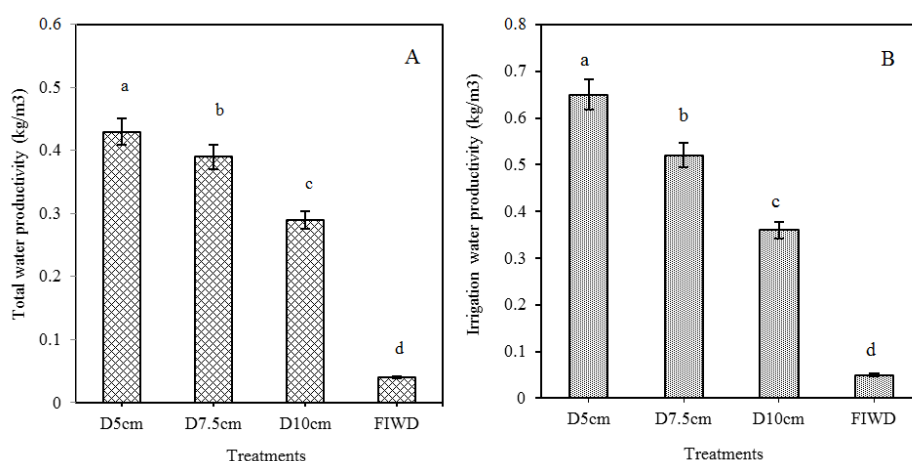


Figure 6. (A) Effects treatments on irrigation water and (B) effective rainwater productivity.

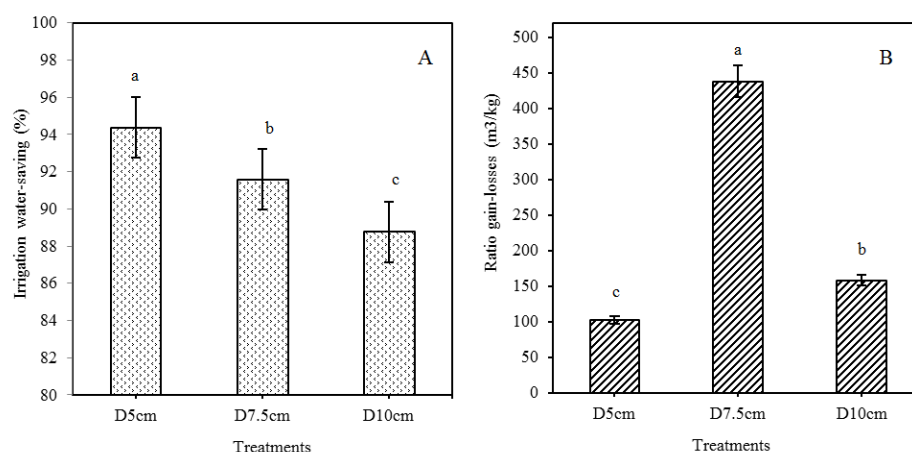


Figure 7. (A) Effects treatments on irrigation water-saving and (B) ratio gain-loss.

The results of the impact of water treatments on water economy are illustrated in Figure 7. It is shown that water savings and the ratio gain-loss were significantly affected by water reduction. The reduction of irrigation water led to the increase of water savings by 94%, 91% and 89% in D_{5cm} , $D_{7.5cm}$ and D_{10cm} respectively (Figure 7A). The highest ratio of gain-losses (Figure 7B) was achieved in $D_{7.5cm}$ indicating that water saving was more beneficial when applying a supplementary water depth of 7.5cm.

4. Discussion

In this research, rice susceptibility to water stress, due to the decrease of the amount of irrigation water, was observed in growth parameters, yield components and yield reduction and water use efficiency. Changes in the soil stress coefficient in the different supplementary irrigation water regimes have affected rice crop growth, yield and yield components resulting in water productivity. The increase of the stress coefficient of the soil due to the irrigation water decrease has induced slight, moderate and severe water stress in D_{10cm} , $D_{7.5cm}$ and D_{5cm} respectively.

The trend of soil stress coefficient indicated that plant in D_{5cm} was mostly affected during the vegetative stage. Severe water reduces growth parameters such as plant height, the number of tillers and leaves through the inhibition of cell elongation. Submitted to severe water stress, the plant gradually closes the stomata and then reduces the evapotranspiration which in turn leads the decline of photosynthesis and the growth suspension or delay. The water stress reduces the water content and the turgor of plants cells; the growth is lowered due to the reduction of the opening of stomata. [33, 34] pointed out that the conductance of stomata was drastically impaired by water stress. The closure of stomata depends on the stress amplitude and duration. Under severe water stress the stomata can completely close relatively to the intensity and the timing of the stress; cell development slows down or ceases and the growth is retarded [8].

Under low (D_{10cm}) and moderate ($D_{7.5cm}$) water stress, the degree of stomata closure, may have slightly affected plant growth with a low decrease in plant height, the number of tillers and leaves. The plant may have recovered from insignificant stress and yielded comparable height to FIWD and D_{10cm} ; tiller to D_{10cm} and $D_{7.5cm}$; the number of leaves was similar in FIWD, D_{10cm} and $D_{7.5cm}$. Under low stress, plants may have developed adaptation mechanisms to overcome water stress through a recovery process. The plants countermeasure to water deficit depends on the time and the amplitude of the water stress. [35] Noticed that the reaction of plants to water decline is based on the stress amplitude and its duration. [26] Confirmed that plants overcame low and moderate water stress induced at the vegetative stage and yielded as well as stress free grown plants, but the stress incidence is observed at the panicle initiation. [36] Demon-

strated that plants grown under stress exhibited the lowest emerged tiller and the lowest growth rate, but those under relatively slight water stress had the fastest rate of tiller production.

It is recognized that photosynthesis reduction due to water stress leads to a reduction in chlorophyll. In this study, severe stress in D_{5cm} has increased the chlorophyll content of leaves from panicle initiation to the onset of ripening stage compared to slight and moderate stress. The severe water stress seems to have slightly simulated leaves chlorophyll. Severe water stress adversely affected growth with less significant effect on the chlorophyll content. The adaptation mechanism involved in severe water treatment may have improved the possibility of the plant to better uptake water since water is the most limiting factor to chlorophyll. Sharper water stress should have developed roots which maximize water capture and allows access to relatively deep water and, in turn improved water absorption by the plant leading to the increase of the chlorophyll content. [26] reported that, when subjected to sharp severe water stress, the plants improved root length and volume; the plant extracted faster water in depth and yielded comparable chlorophyll to stress free grown plants. Similarly, [37] underlined that, under water stress, the possession of the pronounced root system maximized deep water uptake by the plant.

Moderate and severe water stress impacted productive tillers causing a significant decrease in headed panicle per square meter; while slight stress did not affect the emergence of panicle. Despite the fact that growth was not impaired by moderate stress, the heading rate was sensitive to both moderate and severe stress. Maintaining the stress moderate or severe until the reproductive stage increased its duration and have prolonged its effects and, then delayed the heading rate. Keeping the water stress up to the reproductive stage was crucial for the emergence of panicle; the heading rate retarded and the number of headed panicles lowered. The long duration of moderate stress may have retarded the recovery process of the plant in $D_{7.5cm}$ and the reduction of water induced a decline of the number of headed panicles. [8] Mentioned that the plant was not able to faster recover from prolonged moderate stress at panicle initiation, but the recovery effects should be observed at the harvest. By delaying plant growth, the number of tillers and leaves, severe stress in D_{5cm} led to the highest decrease of emerged panicles. [38] Noticed that severe and prolonged water stress lower the number of panicles. [34] Observed that the reproductive stage was more sensitive to drought stress with the maximum reduction of physiological and agronomic parameters. [36] Confirmed that any water stress during the reproductive stage was more destructive and, the rate of panicle emergence significantly decreased for all evaluated rice genotypes.

At the harvest, yield and its components were significantly affected by water reduction, while the grain filling percentage was not impacted. The moderate water stress treatment

(D_{7.5cm}) resulted comparable values to FIWD for the number of tillers and panicles per hill, the number of grain and grain weight and per panicle, the grain yield and the straw weight. Likewise, similar values of the number of tillers and panicles per hill and grain yield were observed in D_{10cm} and FIWD. The slight and moderate water restriction did not markedly affect rice production while severe water stress notably decreased almost all agronomic parameters including yield. The plants may have probably overcome slight and moderate stress, but the long duration and the high amplitude of stress in the lowest water treatment severely diminished yield. However, the highest yield was obtained in moderate water stress treatment when compared to slight water stress. Slight stress did not significantly affect growth parameters, but at term led to the decrease of yield and can be explained by the hydraulic head induced by the application of 10cm water depth. The ponded water depth of 10cm should have induced the infiltration rate which did not match with water uptake by the plant leading to deep percolation and probably leaching and resulted in relatively high yield losses (12.20%). Even though that stress occurred in D_{7.5cm}, it was not so critical and the application of 7.5cm water depth may have coincided in time with water absorption by plants, and hence induced less yield losses (4.54%). [26] when comparing different levels of water on the rice field concluded that such results can be explained by the hydraulic head pressure induced by ponded water depth which affects the infiltration and water uptake, and then optimal deep should be identified accordingly [39].

Globally, the decrease of supplementary irrigation water depth led to the increase of water productivity. The highest irrigation water productivity (0.65kg m⁻³), total water productivity (0.43kg m⁻³) and water saving (94.39%) were obtained in severe water stress treatment. Considering the highest ratio gain-losses (438 m³kg⁻¹) which indicate that the water saving is more beneficial, D_{7.5cm} appeared suitable with less yield penalty. The amount of water saved per kilogram of rice lost is 4.25 times more in D_{7.5cm} compared to D_{5cm}.

5. Conclusion

In our research, we compared three water depths to farmer irrigation practice to find out the suitable supplementary irrigation depth to increase water saving with less yield expenses to face recurrent dry spells in arid climate. The restriction of water led to the increase of the stress coefficient of soil which adversely decreased agronomic parameters depending on the duration and the amplitude of the water stress. The experiment was conducted during one rainy season and may be seen as a limit of the study, but it is clearly shown that good agronomic performances and sustainable water use were recorded in moderate water stress treatment.

The application of 7.5cm water depth at 7 days interval significantly increased the gain of water with the insignificant yield penalty. The evaluation is going to be replicated in other seasons and other climatic zones to better capture the

variability of rainfall and agro-climatic effects. We claim that the weekly application of 7.5cm of supplementary irrigation should be implemented in semi-arid conditions of Burkina Faso as a countermeasure to overcome dry spells in rainy season for increasing both productivity and water saving for other purposes which in turn should improve farm outcome and the revenue of farmers.

Abbreviations

D5 _{cm}	5cm Water Depth
D7.5 _{cm}	7.5cm Water Depth,
D10 _{cm}	Application of 5cm Water Depth
FIWD	Farmers' Irrigation Water Depth
IWD	Irrigation Water Depth
SWC _{sat}	Soil Water Content at Saturation
SWC _{wp}	Soil Water Content at Wilting Point
Droot	Root Depth
Ks	Soil Stress Coefficient
SWT	Soil Water Content at the Threshold
SWt	Soil Water Content at Time t
FKR 84	Farak ô-Ba rice n °84
USDA-SC	United States Department of Agriculture, Soil and Water Conservation
FAO	Food and Agriculture Organization
GY	Grain Yield
SW	Straw Weight
GWhill	Grain Weight per Hill
SWhill	Straw Weight per Hill
YL	Yield Losses
YFIWD	Yield in Farmers' Irrigation Water Depth
YX	Yield in X Treatment
IWP	Irrigation Water Productivity
TWP	Total Water Productivity
IW	Irrigation Water
TW	Total Water
RGL	Ratio Gain-loss
RGLX	Ratio Gain-loss in Treatment X
IWFIWD	Irrigation Water Used in the Farmers' Irrigation Water Depth
IWX	Irrigation Water Used in X Treatment
ns	Not Significant
p	Probability
SAPEP	Smallholder Agricultural Productivity Enhancement Program

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Author Contributions

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Bene-Wende Bernice Sandwidi: Review and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

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