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Article

Evaluation of Water Productivity and Agronomic Performance of Paddy Rice Through Water Saving Irrigation and Nitrogen Fertilization

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Abstract: Tanzania with 945 million hectares of land area and annual rainfall of 300 mm on 67% of its territorial land is considered as a semi-dry region in the world. Rice production in Tanzania needs to be increased to feed a growing population, whereas water for irrigation is getting scarce. One way to decrease water consumption in paddy fields is to change the irrigation regime for rice production and to replace continuous flooding with alternate wetting and drying. In order to investigate the effect of different regimes of irrigation and nitrogen fertilizer on yield and water productivity of hybrid rice, two greenhouse pot experiments comprising soils from upland and lowland production ecologies were conducted at Sokoine University of Agriculture, Tanzania during crop seasons of 2019. The experiment was arranged in split plots based on completely randomized block design with 3 replications. Water regimes were the main factor comparing continuous flooding (CF) and alternate wetting and drying (AWD) wit nitrogen fertilizer levels as the sub-factor including absolute control , 0, 60, 90, 120 and 150 kg/ha. Alternate wetting and drying (AWD) improved water productivity in both upland and lowland production ecologies compared to CF. AWD increased yield under lowland production by 13.3% while in upland there was 18.5% decrease in yield. The average water use varied from 31.5 to 84 L pot-1 under upland trials, while in lowland trials it was 36 to 82.3 L. Higher yield and lower water application led to an increase in WP varying from 1.2 to 1.8 kg cm^{-3} under upland trials, and 0.6 to 1.5 kg cm^{-3} under lowland trials. The variation in water productivity among treatments was mainly due to the differences in the yield, water and nitrogen levels used in the production process. Both sets of trials recorded water saving up to 34.3% and 17.3% under lowland and upland trials, respectively. Under upland trials, the yield varied from 39.9 to 124.1 g pot^{-1} and in lowland trials yield was from 20.6 to 118.2 g pot^{-1} representing paddy rice. The measurements showed that less water can be used to produce more crops under alternative rice growing practices. The results are important for water-scarce areas, providing useful information to policy makers, farmers, agricultural departments, and water management boards in devising future climate-smart adaptation and mitigation strategies.

Key words Water saving; Irrigation; Water productivity; Grain yield; Rice

1.0. Introduction

Rice (*Oryza sativa L.*) is one of the most important grain crops for more than 50% of the world's population, accounting for approximately 20% of total energy intake, and an annual increase of 8–10 million tons is estimated necessary to meet future needs (Li et al., 2017). In Asia more than 2000 million people obtain 70% of their calories from rice and its products (Kangile et al 2018b). Specifically China is the largest rice producer and consumer in the world, and the area under rice cultivation accounts for about 30% of the country's total farmland while consuming approximately 70% of water resources directed to agriculture. According to FAO, 2012 fifty nine million tons of additional milled rice will be needed by 2020 above the 2007 consumption of 422 million tons. Since there is not much scope to increase the area of rice cultivation (due to urbanization and severe water constraints), the additional production has to come from less land, less water and less production costs.

Rice production in Africa is only 3% of the world total production and the biggest producers being Western Africa countries like Nigeria, Cote d'lvoire and Mali. Other major producing countries are Egypt, Madagascar, Tanzania and Mozambique (Kangile et al., 2018b). In Tanzania, about 90% of rice is grown under continuous flooding, a practice that requires large amount of water with less productivity (Katambara et al 2013). Water productivity of rice range from 0.1 to 0.14 kg/m^3 and 0.22–0.32 kg/m^3 for other cereals have been recorded, which are even much lower when compared to the global water productivity situation. The practice of continuous flooding is very inefficient, supplying much more water than the plants' actual requirements and also emitting large volumes of greenhouse gas emissions Arif et al 2019, (Hadi, Inubushi, & Yagi, 2010; Utaminingsih, Soentoro, Winskayati, & Irianto, 2017). Also, this method has water losses from deep percolation, seepage through bunds, and runoff from the soil surface (Bouman, 2001). This entails the loss of nutrients from the field and/or the pollution of groundwater supplies to the extent that inorganic fertilizers and agrochemicals are applied.

The shortage of water across the country has been brought by climate change that leads to low exploitation of suitable land for irrigation. Tanzania is among the most vulnerable countries to climate change. Extreme climatic conditions, such as droughts and floods have already affected production of rice on one hand. On the other hand the estimated rice consumption does not match with the level of production in the country. Kangile et al 2018a reported the milled rice production of 1.4 million tons against the consumption of 1.6 million tons in 2014. Rice demand expected to triple over the next decade as population grows and becomes more urbanized. Another demand driver is the changes in consumers' preference of rice both in urban and rural areas. Rice consumption symbolizes increased status; it is the premium staple consumers aspire to move to as their incomes increase. This demand can be minimized through increasing production of rice in the irrigated schemes by development of water-saving rice production technologies especially in sub Saharan Africa where population is expected to double by 2030. Water plays an essential role in agricultural production, especially for paddy rice which requires more water than other staple crops such as wheat and maize [Yamaguchi et al 2019]. However, with climate change, as well as the increasing water demand from rapid economic development and the urbanization process [Wu et al 2018; Yan et al 2015], increasing food production and increasing agricultural water productivity with limited water resources have become a top priority for the agricultural sector [Yamaguchi et al 2019; Li et al 2015]. Many water-saving techniques have been developed for rice production in response to irrigation water scarcity. The selection of the water-saving methods and the optimum thresholds for obtaining maximum benefits of these regimes are largely site-specific depending mainly on soil type, management and the environment (Cabangon et al 2004. Example of water saving methods are saturated soil culture [Kima et al 2014], aerobic rice (Nie et al 2012], system of rice intensification [Berkhout et al 2015], non-flooded mulching cultivation [Qin et al 2010], alternate wetting and drying irrigation (AWD)[Bouman and Tuong 2001 ; Nalley et al 2015], etc. Among these methods, AWD is the most widely used worldwide, especially in China. In AWD treatment, the field does not need to be kept submerged all the time but is allowed to dry out to some degree when soil water potential reach –10 kPa to –30 kPa before it is re-flooded during the whole rice growing season[Lampayan et al 2015; Yang et al 2007]. The response of rice yield to AWD irrigation is highly variable. Many studies have demonstrated that AWD could indeed save irrigation water and improve water use efficiency compared with traditional flood irrigation [Bouman and Tuong 2001; Yang et al 2007; Yao et al 2012], but the effect of AWD on rice yield was still in debate. Some studies have shown that the adoption of AWD could maintain [Yao et al 2012] or even increase rice yield by 9% to 15% [Escasinas, and Zamora 2011; Nyamai et al 2012; Yao et al 2012; Liu et al 2013; He et al 2014; Carrijo et al 2018;]. However, reduction in rice yield has also been reported by Bouman and Tuong, 2001; Xu, et al 2015. Bouman and Tuong [2001] summarized 31 published researches on AWD and concluded that 92% of the AWD treatments lead to yield decrease compared with continuously flooded treatment. The differences in frequency and threshold of the drying cycles of the AWD, soil types, ground water, table depths, and rice varieties used can all contribute to the contrasting results. Whether AWD could obtain the win-win goal of saving irrigation water and increasing rice grain yield is still a challenge faced by most researchers [Tabbal et al., 2002].Thus the study therefore set to evaluate water productivity and agronomic performance of paddy rice through various nitrogen and water management methods.

2.0. Material and Methods

2.1. Site Description, Experimental pot Establishment, and Soil Characterization

Two screen house pot experiments were carried in (March–July) and (June-September) of 2019 comprising soils sampled from lowland and upland production ecologies respectively.

In this study we distinguish 'lowland' and 'upland' soils used for rice cultivation. Lowland soils, are logically located in lower areas of the landscape and are considered to be flooded at least once per rice-growing season. They have a finer particle size distribution compared to upland soils, set in higher and often sloping areas and hence never flooded. We conducted two pot trials with soils originating from lowland and an upland rice growing fields.

The experiment was conducted in the screen house at the Department of Soil and Geological Sciences of Sokoine University of Agriculture, Morogoro, Eastern Tanzania located at (latitude 6^{0}5′South and 37^{0}37′East at an elevation of 525 m above sea level in the leeward side of Uluguru mountain). The climate of the area is between sub-humid and semi- arid with predominantly alfisols and entisols. The temperature of this area ranges from 24^{0}C-34^{0}C with range of relative humidity of 70-90%. Meteorological data during growing seasons were collected from Tanzania Meteorological Agency station located at Sokoine University of Agriculture, Morogoro Tanzania as shown in (figure 1, 2 &3)

Soils were collected from the plough layer of a paddy field at Mkindo farmer managed irrigation scheme for lowland trial. Mkindo farmer managed irrigation scheme located in Mvomero District in Morogoro region, eastern Tanzania. The district is located between latitude 6°16′ and 6°18′ South, and longitude 37°32′ and 37°36′ East and its altitude ranges between 345 to 365 masl. The experimental farm located at latitude 6°15′13″ south and longitude 37°32′19″. Mkindo farmer managed irrigation scheme is located about 85 km from Morogoro municipality (Kahimba 2011). Mkindo soil is classified as Eutric fluvisol by Msanya et al. (2002).

For upland trial the soil was collected from the on preparation Model farm of Department of Soil and Geological Sciences of Sokoine University of Agriculture, Tanzania located at latitude S 6^{0} 50′ 51″ longitudes E 37^{0} 39′ 26″. All sites are located in the Eastern of Tanzania. Soil samples were collected from the fields before plowing at a 0–20 cm depth. Samples were air dried under shed sieved through 2 mm mesh and analyzed in the laboratory using standard techniques (table 1) where basic physical and chemical properties were estimated (Table 2).

Table 1. used for determination of chemical and physical properties of the studied soils.

Parameter	Method of analysis	References
pH	Soil: water suspension (1:2.5) using glass electrode pH meter,	MacLean (1982)
Soil texture	Bouyoucos Hydrometer method, following by dispersion of soil particle	Day (1965)
Organic carbon	Wet oxidation by Black and Walkley method	Nelson and Sommers (1982)
Total Nitrogen	Micro-Kjeldahl wet digestion-distillation method	Bremner and Mulvaney (1982)
Available P	Olsen method	Olsen *et al.* (1954)
Cation Exchange Capacity (CEC)	Neutral ammonium acetate saturation method (NH4-Ac, pH 7.0) followed by Kjeldahl distillation.	Chapman (1965)
Exchangeable Bases (K^+, Mg^{2+}, Ca^{2+} and Na^+)	1N NH4-Ac (pH 7.0) method	Chapman (1965)
Extractable micronutrients (Fe, Cu, Zn and Mn)	DTPA extraction and determined by atomic absorption spectroscopy (AAS)	Lindsay and Norvel (1978)

Table 2. Soil physical and chemical properties at 0-20 cm depth.

	Soil sampling sites	
Soil properties	**Mkindo Irrigation scheme (LL)**	**Soil science Model farm (UL)**
Soil pH (1:2.5)	5.4	6.6
EC (dS/m)	0.03	0.35
Sand (%)	69.8	46.46
Silt (%)	7.56	11.46
Clay (%)	22.6	42.10
Textural class	Sandy clay loam	Sandy Clay
Cu (mg/kg)	3.47	2.1
Zn (mg/kg)	2.60	5.0
Mn (mg/kg)	7.13	4.2
Fe (mg/kg)	1.65	29.0
Total N (%)	0.11	0.19
Available P (mg/kg)	7.71	3.83
Available SO_4^{2+}-S (mg/kg)	1.04	11.52
Exchangeable bases (Cmolkg^{-1})		
Ca^{2+}	6.37	12.1
Mg^{2+}	1.51	2.42
Na^+	0.06	2.01
K^+	0.07	1.04
CEC (cmolckg−1)	11	18.3

*EC = electrical conductivity;; Avail. P = available phosphorus; Zn = extractable zinc; Cu = extractable copper; Fe = extractable iron; Mn = extractable manganese. LL; Lowland and LU; upland.

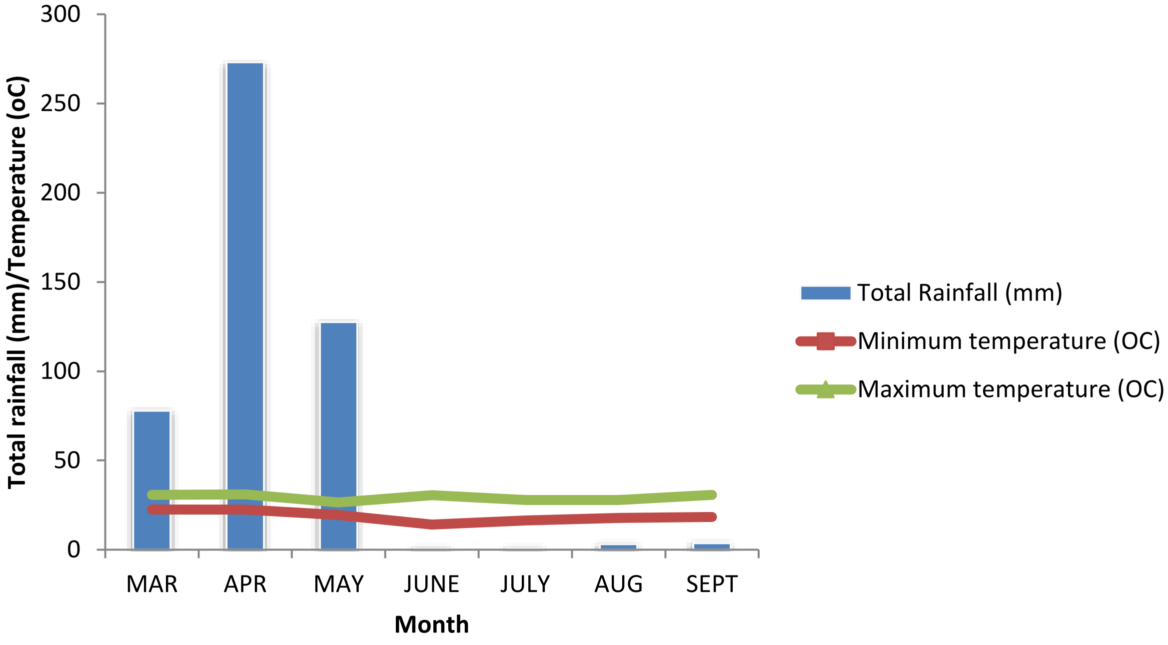

Figure 1. Total rainfall, minimum and maximum temperature during experiments.

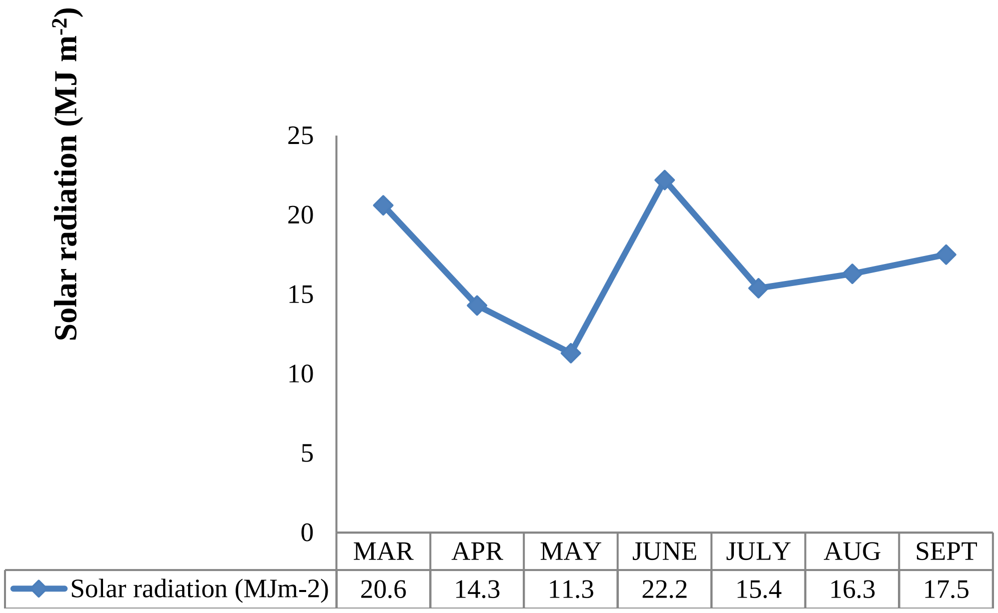

Figure 2. Solar radiation (MJ m^{-2}).

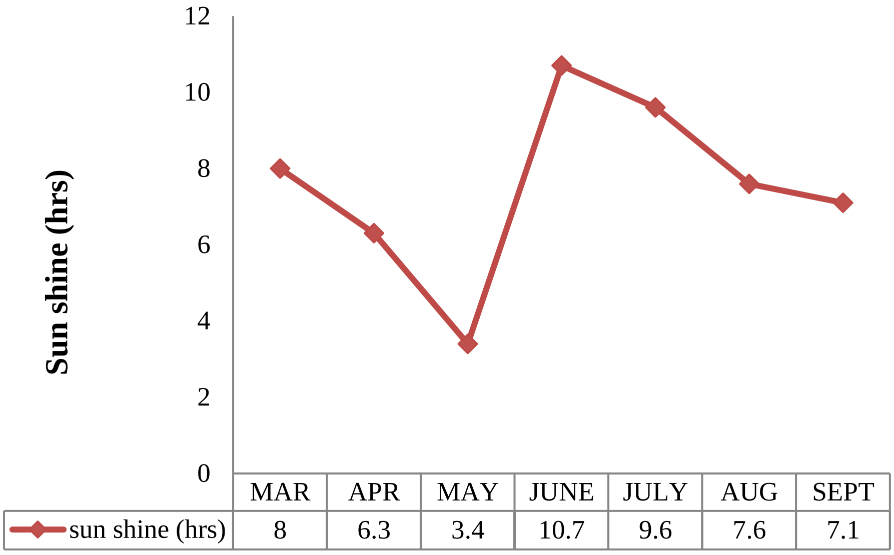

Figure 3. Sun shine hours.

2.2. Experimental design and treatment details

Two greenhouse pot experiments involving lowland and upland soils were used in the experiments. Experiments using the same treatment and design were conducted during 2019. The first experiment covered the period 18th February 2019 to 30th June 2019, while the second experiment began on 10th May 2019 and ended on 21st September 2019 for lowland and upland respectively. The experiments consisted of two irrigation water management and six levels of nitrogen fertilization resulting in a total of twelve different treatments (Table 2). The experiment has a split-plot design with irrigation water management as main factor and the six nitrogen levels treatments as sub factor (Fig. 2). Two separate randomization process was used, one for main factor and another for the sub factor. In each replication, main factor treatments were first randomly assigned followed by a random assignment of the sub factor treatments within each main factor. There were three replications of each treatment making a total of 36 experimental pots.

From each of the six identified sampling spots about 48 kg of soil were collected from a depth of 0-20 cm in both study sites making a total of 288 kg of soil. The soil were taken to the laboratory, air-dried under shed, ground and sieved to pass through 8 mm mesh. Then the soil was mixed thoroughly to form one uniform composite soil sample for pot experiment. Plastic pots with 10 liter capacity, 30 cm height and 10 cm diameter were filled with 8 kg air dried soil mixed with respective fertilizer treatments. Amount of fertilizers applied in each pot was calculated based on the 8 kg air dried soil. The treatment details adopted in are given in Table 3.

Fertilizer treatments comprised six nitrogen levels; these include absolute control treatment (ABC) which did not receive any kind of fertilizer. The absolute control treatment was intended to evaluate rice response under natural soil fertility.The fertilizer treatments also included a control treatment (N0) without any nitrogen fertilizer application but received phosphorus (P) and potassium (K) fertilizers. This treatment is required to assess crop response to nitrogen fertilizer application. Other treatments 60, 90, 120, 150 kg N ha^{-1} these received 50%, 75%, 100%, and 125% of blanket recommended amount of nitrogen fertilization. 120 kg N ha^{-1}, represent the current blanket recommendation for rice grown in the Eastern of Tanzania. The nitrogen fertilizer source was Urea (46%) and was applied two times that is 50% 14 days after transplanting and 50% at panicle initiation. Application of second split of nitrogen was done 55 days after transplanting; at these days the crop was at panicle initiation growth stage. Panicle initiation (PI) is the second best time to apply nitrogen to a rice crop with pre-permanent water being the most efficient. Nitrogen applications at PI are relatively efficient because the full crop canopy reduces fertilizer volatilization and the extensive near surface root system takes up nitrogen soon after application. A source of full dose of P 60 kg ha^{-1} was triple super phosphate and K 60 kg ha^{-1} from Muriate of potash. P and K were evenly broadcasted and mixed with soil during transplanting.

Irrigation water treatments comprised two water regimes, thus alternate wetting and drying (AWD) and continuously flooding (CF). In AWD irrigation was applied to maintain the soil at saturated condition instead of ponding. Irrigation was applied 1- 3 days after disappearance of water in the soil surface from 15 days of transplantation. Thereafter, the alternate wetting and drying method of irrigation was followed, and irrigation water was applied 1-3 days after the disappearance of ponded water. CF pots were kept continuously flooded, being irrigated on alternate days in order to maintain a ponded layer of 1–5cm depth of water during the entire vegetative stage until one week before harvest. The impact of rainfall was avoided using the screen house rain shelter to rigorously control the soil water content in the pots. Each pot was individually irrigated using a graduated measure cylinder. In each pot, the depth of water was measured at 3 selected spots immediately after irrigation by using an ordinary scale meter which had mm and cm marks. Water depths above the soil surface were daily monitored. On the basis of these observations, the mean depth of irrigation water was calculated for each pot as shown in table 3.The quantity of water applied during irrigation was summed to calculate the total amount of water applied to the pot throughout the cropping season.

Table 3. Experimental treatments, which are a combination of water management and nitrogen levels.

Treatment combination	**Water management**	**Nutrient application rates (kg ha^{-1})**			**Nutrient application rates (g pot^{-1})**		
		N	**P_2O_5**	**K_2O**	**N**	**P_2O_5**	**K_2O**
AWD+ABC	Alternate wetting and Drying	0	0	0	0	0	0
AWD+N0		0	60	60	0	9.56	3.84
AWD+N60		60	60	60	4.17	9.56	3.84
AWD+N90		90	60	60	6.26	9.56	3.84
AWD+N120		120	60	60	8.35	9.56	3.84
AWD+N150		150	60	60	10.44	9.56	3.84
CF+ABC	Continuous Flooding	0	0	0	0	0	0
CF+N0		0	60	60	0	9.56	3.84
CF+N60		60	60	60	4.17	9.56	3.84
CF+N90		90	60	60	6.26	9.56	3.84
CF+N120		120	60	60	8.35	9.56	3.84
CF+N150		150	60	60	10.44	9.56	3.84

Table 4. Water management for different growth stages under continuous flooding and alternate wetting and drying irrigation in upland and lowland experiments.

Irrigation regimes	**Seedling recovery stage**	**Initial tillering stage**	**Final tillering stage**	**Jointing - booting stage**	**Heading-flowering stage**	**Milky ripening stage**
CF irrigation						
Highest water depth (cm)^{a}	5	5	5	5	5	Drainage and naturally drying
Lowest water depth (cm)^{b}	1	1	1	1	1	
AWD irrigation						
Highest water depth (cm)	5	3	0	2	3	Drainage and naturally drying
Lowest water depth (cm)	1	0	0	0	1	

[a]Highest water depth, this is when re-flooding after water depth has dropped between lowest and highest depth for a specific growth stage.

[b]Lowest water depth provides feedback to growers/farmers so as not to allow water to drop further so as to reduce moisture stress .

2.3. Crop Establishment.

TXD 360 (SARO 5) a popular rice variety developed by scientists at Agricultural Research Institute-Dakawa Tanzania back in 1999, accepted in 2000 and released by KATRIN Agricultural Institute in 2002 was used in this study. TXD 360 means Tanzania Cross Dakawa selection number 306. The variety is semi- aromatic that is why it is called SARO. This variety is mid late season rice, semi aromatic, can be grown in rain fed or irrigated production ecologies and with yield potential of 7.0-8.5 t/ha and farmers yield 4.5-5.5 t/ha with days to maturity ranging 120-130. Medium plant stature, resistant to lodging and has good tillering ability (more than 20 tillers per hill depending on management).

Before sowing in the nursery, seeds were prepared by separating the unfilled grains from filled grains so as to get vigor plant. Only seeds with good density and formation were used for nursery preparations. To get best seeds, the clean tap water and seed priming techniques were used. Seeds were submerged in a container of tap clean water and stirred well; any light and inferior seeds that floated in the water were discarded. The best seeds were then soaked in clean water for 48 hours (seed priming) and incubated in a warm and shady place for three days. The practice of soaking seed before planting enhances the rate of germination and seedling emergence. Also incubation keeps the seeds warm hence increases growth of the embryo and results in uniform germination. Thereafter the pre-germinated seeds were transferred to the seedbed where they were uniformly sown. 15 and 30 -day-old rice seedlings were transplanted for AWD and CF respectively. One and three seedlings were transplanted in AWD and CF treated pots respectively. Weeding and other intercultural operations were done as needed.

2.4. Agronomic performance and yield data collection

2.4.1. Plant height and number of tillers

Observations on rice growth, yield-forming characters and yield were recorded. Plant height was measured with a graduated straight edge (ruler) from the base of the shoot at the soil surface to the tip of the tallest leaf, and during maturity plant height was measured from the base of the plant to the tip of the tallest flag leaf after every two weeks. All measurement were recorded in centimeter. Number of tillers was counted from each plant per pot on the same day that the plant height data was collected.

2.4.2. Determination of Flag Leaf Area and leaf chlorophyll content

Flag Leaf area was estimated by measuring the length and average width of leaf and multiplying by a factor of 0.75 followed by Yoshida (1981) and was measured at booting stage of the crop in lowland trial. For upland trial flag leaf area was measured two days before harvest.

Chlorophyll content (CC) of leaves was recorded using atLEAF CHL PLUS meter (FT GREEN LLC, Wilmington DE, USA www.atlef.com**)**. The CC value of leaves was determined at (stages) of the rice plant. For lowland trial CC was recorded during maturity and for upland trial was recorded from 28-90 days after transplanting. For each plot, 15 leaves were randomly selected for measurement per treatment.

2.4.3. Yield and yield components

Rice parameters were collected after harvest includes number of productive tillers per plant, number of non-productive tillers per plant, percentage of productive tillers, panicle length, panicle weight, number of grains spikelets per panicle, number of filled grain per panicle, grain weight per panicle, 1 000-grain weight and yield. Number of effective tillers per plant and number of non-effective tillers per plant were determined. The determination of these two parameters was done by counting the tillers with panicles bearing at least one filled grain which in this case was referred to as effective tillers. Tillers with panicles having no single filled grain were termed as non- effective tillers. An average was found for each parameter and recorded. Then the rice panicles (with spikelets) were cut and collected from every pot before being dried in an oven at 60 °C for 2 days. Panicles length was measured by using a ruler and weight per pot were weighed using electronic weigh balance. Then the rice grains were separated from the panicle and grouped into unfilled and filled grains. To determine 1000-grains weight, 1000-filled grains from the sampled panicles were counted by a seed counter and weighed on an electronic balance. Meanwhile, the straw biomass was collected from the remaining plants (without panicles) and dried in an oven at 70 °C for 3 days. After threshing, cleaning and drying, the grain yields were then adjusted to 14% moisture content (IRRI, 2013) using a formula (1). The rice grain yield per pot per treatment was computed and the grain harvest index was calculated based on the ratio of economic yield to total biomass produced.

$$\mathrm{Wf} = \left(\frac{100-mci}{100-mcf}\right) x\ Wi\ , \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

Where Wf is the final weight at 14 % moisture content; *mcf* is the final moisture (14 %); *mci* is the initial moisture content and *Wi* is the initial grain weight. This was done also to all parameters involving weights.

Relative increases were calculated and compared to the control using a relation rmodified by Gachengo et al. 1998; Badu et al, 2019

Yield increase (%) = Grain yield from amended pots/ Grain yield from control pots*100%
.............(1)

$$\text{Grain harvest index} = \frac{\text{Grain yield (g)}}{\text{Grain yield (g) + straw yield (g)}} \quad \text{------ (2)}$$

2.4.4. Water Productivity Assessment

Water productivity was calculated as grain yield divided by total water supplied in the pot, and was expressed in kg m^{-3} according to Bouman and Tuong (2001). Water saving was obtained with reference to the irrigation water and calculated as the difference in irrigation under the two irrigation regimes divided by the irrigation water applied under the CF regime as shown in the formula number 1. Number of irrigation was determined by calculating mean number of all irrigation per each pot.

$$\text{Water saving (\%)} = \frac{\text{Water applied in continuous flooded pot - Water applied in AWD pot}}{\text{Water applied in continuous flooded pot}} \times 100 \text{ ..(2)}$$

$$\text{Water productivity (kg cm}^{-3}\text{)} = \frac{\text{Grain yield kg pot}^{-1}}{\text{Total water consumed (cm}^{3}\text{ pot}^{-1}\text{)}} \quad \ldots\ldots\ldots\ldots\ldots.. \quad (4)$$

2.5. Statistical Analysis

Data of two production ecologies (UL and LL), two water management practices and six nitrogen levels were statistically analysed using the analysis of variance (ANOVA) technique as applicable to combined analysis in split-plot design (Gomez and Gomez 1984). To determine the significance of the difference between the means of the treatments, least significant difference (LSD) was calculated at the 5% probability level. All statistical analyses were performed using by using GenStat (14th Edition)

3. Results and discussion

3.1. Trial with lowland soil

Effect of water management and nitrogen levels on plant height and number of tillers

The dynamic variation characteristic of plant height of lowland trial is shown in table 4. The plant height increased rapidly during the early tillering stage and, then, grew slowly during the middle and late tillering stages when vigorous tillering took place. The plant height increased most rapidly during the jointing-booting stage and reached the highest value during the heading-flowering stage. The plant height was less variable and tended to be stable during the milky stage and ripening stage, which coincided with the time of the reproductive stage.

Rice plants receiving continuous flooding treatments were shorter (34.4 to 106.4 cm) compared to plants receiving alternate wetting and drying water treatments (AWD) (35.5-110.2 cm) though the difference was not significant except during active tillering stage. Nitrogen levels highly significantly affected plant height $p<0.001$ from 28 DAT to harvest stage thus from initial tillering to maturity stage. Highest plant heights of 112.7 followed by 112.5 cm were recorded at harvest stage under 60 and 90 kg N ha^{-1} treatment. While short plant height was recorded in absolute control (98.6 cm) followed by control (0 kg ha $^{-1}$) (98.8) cm treatments at harvest. Interaction of water management and nitrogen levels affected plant height significantly at maximum tillering stage, other stages there was no significant difference in plant height, though highest plant height of 116.7 cm was recorded at AWD ×150 during flowering stage (Figure 4). Similar results were reported by Mazumder et al., 2019; Chen *et al*. (2013) that nitrogen fertilization has a tendency to increase plant height as nitrogen involves cell division and cell elongation of plants. These results are in agreement with Hien and Saitoh, 2020; Yakubu et al., 2019, who reported increase of plant height under AWD water management and 90 kg N ha^{-1} nitrogen level. Zheng et al 2020 reported the contradicting results showing that the final plant height was significantly higher under flooding irrigation than that under water-saving irrigation treatments during both years of experiments.

Table 4. Plant height (cm) as influenced by water management and Nitrogen fertilizer levels.

Treatment	Days after transplanting						
	14	28	42	56	70	90	AT
Water							
AWD	38.5	70.8	84.59	89.6	95.5	110.2	108.1
CF	35.4	65.6	81.17	89.0	96.9	101.3	106.4
L.S.D (P=0.05)	NS	3.39	NS	NS	NS	NS	NS
N fertilizer Levels							
ABC	37.6	60	71.4	77.5	82.8	96.3	98.6
0	39.4	70.6	80.7	80.4	87.1	96.6	98.8
60	35.7	72.6	86.6	92.3	97.0	110.8	112.7
90	35.6	67.5	86.0	95.3	100.8	110.6	112.5
120	36.8	70.2	87.7	95.7	105.1	110.3	110.8
150	36.6	68.3	85.0	94.8	104.6	109.9	110.3
L.S.D (P=0.05)	NS	4.94	4.90	7.13	8.2	7.2	6.048
Interaction							
L.S.D (P=0.05)	NS	NS	7.12	NS	NS	NS	NS

AT; At harvest, NS; not significant

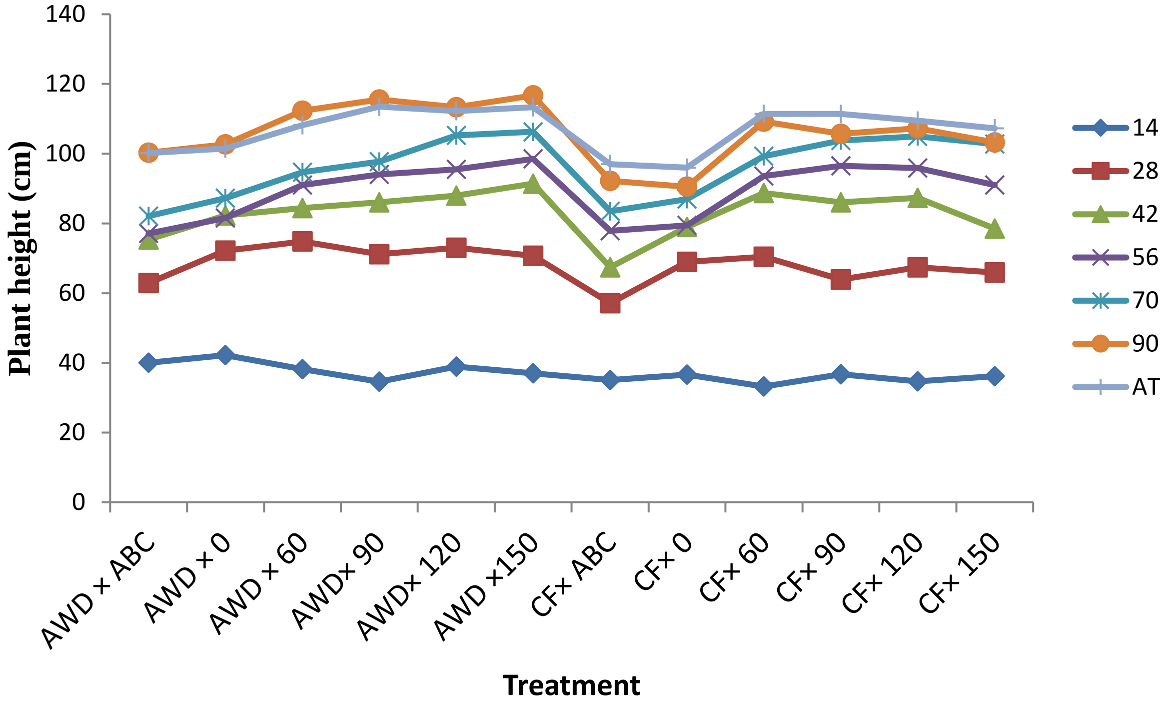

Figure 4. Effect of treatment interactions on plant height at different days after trans planting.

Tillering is an important trait for grain production and is thereby an important aspect in rice yield. However, the productivity of rice plant is highly dependent on the number of effective tillers (tillers with panicles bearing at least one filled grain) rather than the total number of tillers. Average tillers number under different water management treatments and nitrogen levels are given in table **5.** Water management affected number of tillers significantly in all growth stages of rice. The results clearly shown that from 14 to 56 DAT there is increase in tillers among the treatments, starting at 70 DAT there was decrease in number of tillers. however, , the AWD method gives more tillers than CF. The highest number of tillers per hill (34.4) was observed in AWD compared to CF (12.8) at 56 DAT. This shows increase of 261%. Nitrogen levels highly significant affected number of tillers from 42 DAT to harvest. Number of tillers increased from 21 to 56 DAT, there after started to decline. In the present study the highest number of tillers per hill (29.4) was observed in plants treated with 120 and 150 kg N ha^{-1} at 56 and 70 DAT respectively. Interaction of water management and nitrogen levels significant affected number of tillers at 70, 90 and at harvest stages. Highest number of tillers per hill (43.3) was observed in plants received the interaction of alternate wetting and drying and 150 kg N ha^{-1} (AWD ×150) (figure 5). Less number of tillers was recorded in treatments received CF×ABC followed by CF×0. Plants under AWD resulted in profuse tillering which facilitated plants for better utilization of light, soil nutrients and water. Better performance of the AWD treated treatments is may be due to the combined effect of single, young transplanted seedling and alternate wetting and drying processes that creates aeration soil more frequently than other continuous flooding treatments.

Wetting and drying water management improves the environment of root system, so that the root system has enough oxygen and water during tiller development. Horie *et al.*2005; Sujono *et 2011* reported that transplanting young seedling has advantages than aged ones (traditional method). The advantages lie in higher tolerance to transplanting stresses in younger seedling than aged ones. However, not all these tillers develop to maturity (productive tillers), some degenerate to become dormant when young and some die later, depending on environmental and nutritional conditions Sujono *et 2011* as shown in Table 5. The advantage of SRI-AWD method in enhancing numbers of tillers has also been reported earlier by Kahimba et al., 2014, Sato and Uphoff (2007), and Katambara *et al.* (2013).

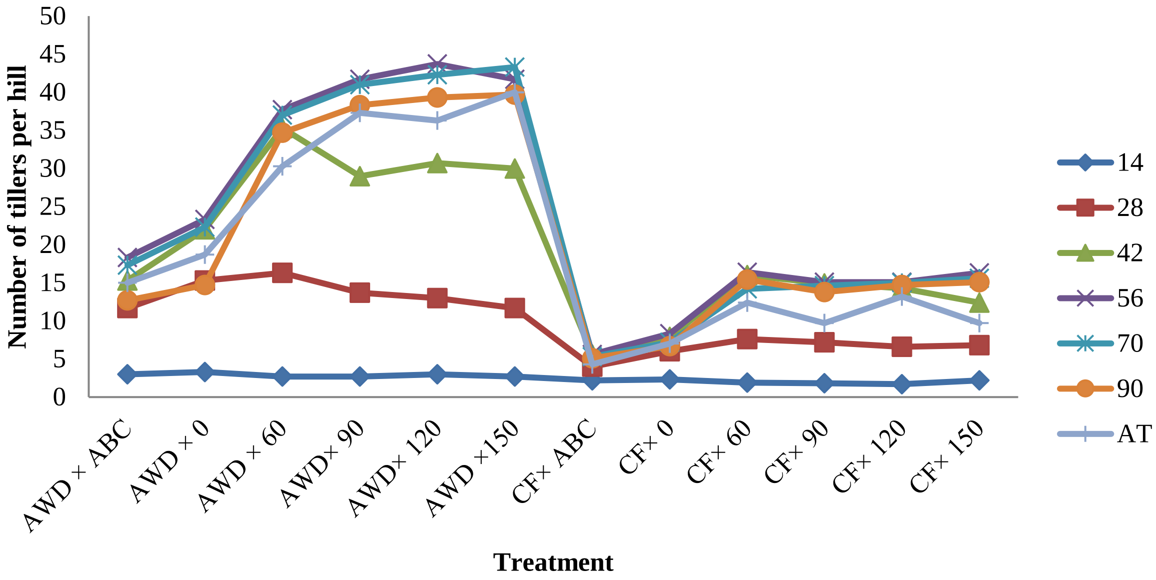

Figure 5. Effect of treatment interactions on tillers at different days of crop growth.

Table 5. Number of tillers as influenced by water management and Nitrogen fertilizer levels.

Treatment	**Days after transplanting**						
	14	**28**	**42**	**56**	**70**	**90**	**AT**
Water							
AWD	2.9	13.6	27.1	34.4	33.9	29.9	29.6
CF	2.0	6.4	11.9	12.8	12.0	11.8	9.9
L.S.D (P=0.05)	0.523	3.752	4.515	8.245	8.181	10.96	7.217
N fertilizer Levels							
ABC	2.6	8	10.4	11.9	11.3	8.9	9.7
0	2.8	10.7	14.9	15.8	14.8	10.7	12.8
60	2.3	11.9	25.7	27.1	25.6	25.1	21.4
90	2.2	10.4	21.9	28.4	27.8	26.1	24.9
120	2.3	9.8	22.5	29.4	28.7	27.0	24.8
150	2.4	9.2	21.1	29.0	29.4	27.4	24.8
L.S.D(P=0.05)	NS	NS	3.815	4.415	4.262	4.15	2.906
Interaction							
L.S.D (P=0.05)	NS	NS	NS	7.209	7.054	8.468	5.651

Effect of water management and nitrogen levels on flag leaf area and chlorophyll content

Measurement of leaf area and leaf chlorophyll concentration (CC) is a basic tool of growth analysis. The two parameters are directly related with both biological and economical yield. In case of any plant, leaves are important organs which have an active role in photosynthesis (Krishnaprabu and Grace, 2017). On the other hand, leaf chlorophyll concentration is often well correlated with plant metabolic activity (e.g., photosynthetic capacity and RuBP carboxylase activity; Fanizza *et al.*, 1991), as well as leaf N concentration. To achieve high yield, maximization of flag leaf area and leaf chlorophyll concentration are important factors (Krishnaprabu and Grace, 2017). In this study the water management did not affect CC (table 6). The AWD recorded high CC (39.2) compared to CF (38.7), however, the two treatments were not statistically different (P=0.697). Nitrogen levels affected CC significantly p<.001, the greatest chlorophyll content (45.2) was recorded in the (120 kg N ha^{-1}, followed by 150 kg N ha^{-1} (44.7). the two treatments were statistically similar (P=0.05). The four nitrogen levels treatments exhibited statistical difference over control (30.4) and absolute control (27.6) which recorded low CC. The observed significant increase in leaf chlorophyll content in application of 120 and 150 kg N ha^{-1} compared to application of (60, 90 kg N ha^{-1}) and other treatments might have been caused by enhanced availability of N. Interaction of water and nitrogen levels had no significant difference on CC (p = 0.575). However the highest CC was recorded under 150× CF > CF×120 = AWD×90; 46.7, 45.6 respectively. Lowest CC contents was recorded in absolute control and control treatments in the following order CF× ABC < AWD ×ABC < CF× 0 < AWD × 0 ; 27.3 < 28 < 31.3 < 29.5 <31.3. In rice, flag leaf provides more than 50% of assimilates for grain filling (Rajand Tripath, 2000). In this study water management did not affect CC. The AWD recorded high flag leaf area (34.8 cm^2) compared to CF (31.4) (table 6), however, the two treatments were not statistically different (P= 0.221). Nitrogen levels influenced the flag leaf area significantly (p<.001). 90 kg N ha^{-1} recorded the highest value (41.5 cm^2) followed by 150 kg Nha-1(41.1 cm2) however the two treatments were statistically similar. Absolute control and control (0 kg N ha^{-1}) 20.7 and 23.7 cm^2 recorded the lowest value respectively. The interaction has no significant effect (P=0.496) on flag leaf area. However AWD ×150 and AWD× 90, (44.6 and 44.3 cm^2) recorded high value of flag leaf respectively compared to other treatments. These results are in agreements with Fageria *et al.* (2010) and Wang *et al.* (2014) who commented that nitrogen is one of the most important nutrients essential for the growth of crops, and are a major component of chlorophyll and protein which are closely associated with leaf color, crop growth status and yield. application of 90, 120, 150 kg N ha-1 and their interactions improved flag leaf are and chlorophyll contents, hence this will have implications on increasing grain yield.

Table 6. content and flag leaf area as influenced by water management and Nitrogen fertilizer levels.

Treatment	Flag leaf area (cm^2)	Chlorophyll content
Water		
AWD	34.8	39.2
CF	31.4	38.7
mean	33.1	39.0
L.S.D (P=0.05)	NS	NS
F Pr	0.221	0.697
N fertilizer Levels		
ABC	20.7a	27.6a
0	23.7a	30.4a
60	35.6b	43.0b
90	41.5c	42.8b
120	36.0b	45.2b
150	41.1c	44.7b
L.S.D (P=0.05)	5.12	5.3
F Pr	<.001	<.001
Interaction		
AWD × ABC	20.1	28.0
AWD × 0	25.8	31.3
AWD × 60	35.6	42.8
AWD× 90	44.3	45.6
AWD ×120	38.6	44.8
AWD ×150	44.6	42.6
CF× ABC	21.3	27.3
CF× 0	21.6	29.5
CF× 60	35.6	43.3
CF× 90	38.6	40.1
CF× 120	33.4	45.6
CF× 150	37.7	46.7
L.S.D (P=0.05)	NS	NS
F Pr	0.496	0.575

Effect of water management, nitrogen levels and their interaction on yield characteristics of rice

In this study the following characteristics were recorded, thus total tillers per pot, number of productive tillers per plant, percentage of productive tillers and number of nonproductive tillers per plant (table 7). The interaction effects of these characteristics are shown in (figure 6).

Total tillers: There was no significant difference in total tillers in both water managements (P=0.903). Nitrogen levels affected total tillers per pot significantly (p<.001). Total tillers increased with increased with increasing nitrogen levels; however there was decrease of tillers at 150 kg N ha^{-1}. Highest number was recorded in 120 followed by 90 kg N ha^{-1} (38 and 37.5) respectively and lowest was recorded in absolute control followed by control (13.8 and 19.2) respectively. Their interaction did not affect total tillers per pot significantly (p=0.036), however AWD ×150 followed by CF× 120 recorded highest total tillers (40 and 39.7) respectively. The lowest value was recorded in this order CF× ABC< AWD × 0 < AWD × 0 < CF× 0; 12.7 < 15< 18.7 < 19.7.

Number of productive tillers, water managements did not affect number of productive tillers significantly (P=0.916). There was significant difference in productive tillers (P<.001) under nitrogen levels. Highest number of productive tillers was recorded at 90 kg N ha^{-1} treatment and the lowest was recorded in absolute control. Their interaction did not affect number of productive tillers (P=0.072), however AWD ×150 and CF× 90 recorded highest productive tillers (34) while AWD × ABC and CF× ABC recorded the lowest number of productive tillers (11) as shown in figure 6.

Percentage of productive tillers

Percentage productive tillers ranged from 69.3% to 91.78% depending upon treatments as indicated in Table 7. Percentage productive tillers was not affected by water management (p=0.3), nitrogen levels (p=0.184) and their interaction (0.285). The highest productive tillers was recorded in interaction of AWD ×120 followed by CF× 90 (91.8 and 90.2%) respectively. The interaction of AWD × 0 treatment recorded lowest percentage of productive tillers 69.3 compared to other treatments.

Number of non-productive tillers. Number of non-productive tillers were not affected by water management (p=0.551), nitrogen levels (p=0.559) and their interaction (0.211). Treatments recorded high number of non-productive tillers includes CF× 120 and AWD ×150 (7.3 and 6). Lowest number was recorded in CF× ABC followed by ABC (1.7 and 2.8) treatments.

Tillers 7. Tillers characteristics at harvest as influenced by water management and nitrogen fertilizer.

Treatment	Total tillers pot^{-1}	Number of productive tillers plant^{-1}	% of productive tillers	Number of non-productive tillers plant^{-1}
Water				
AWD	29.6	25.0	82.4	4.6
CF	29.3	25.7	85.6	4.2
L.S.D (P=0.05)	NS	NS	NS	NS
N fertilizer Levels				
ABC	13.8	11.0	81.0	2.8
0	19.2	14.7	76.0	4.5
60	33.8	29.5	87.4	4.3
90	37.5	33.3	88.9	4.2
120	38.0	32.8	86.9	5.2
150	34.5	29.2	84.0	5.3
L.S.D (P=0.05)	5.23	5.30	NS	NS
Interaction				
L.S.D (P=0.05)	8.12	NS	NS	NS

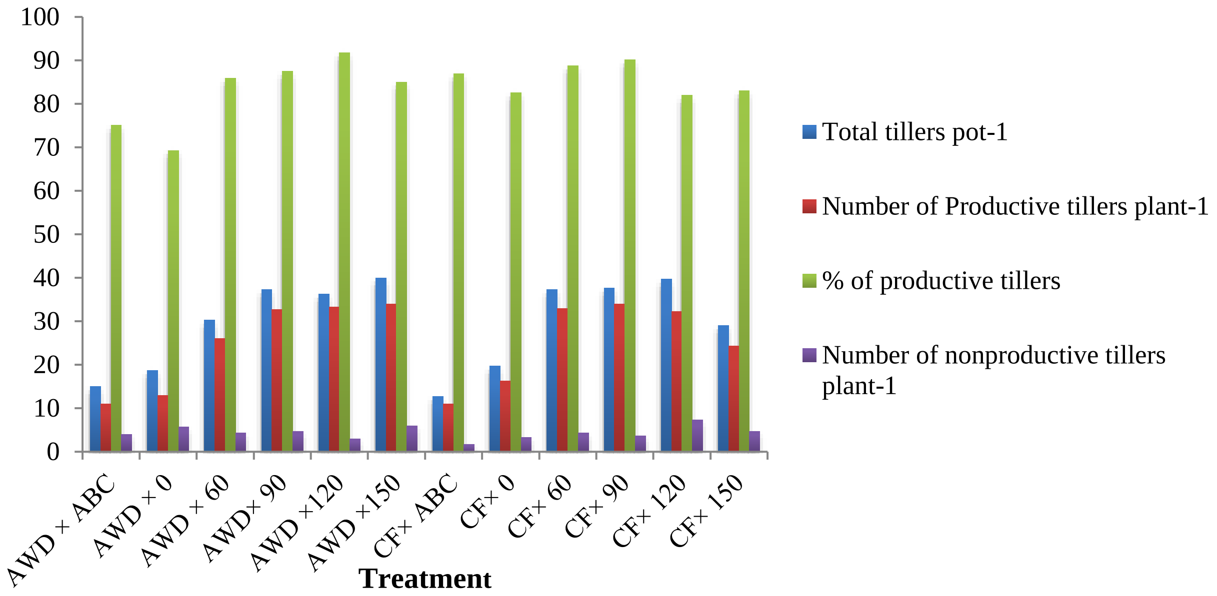

Figure 6. Influence of interaction of water and nitrogen levels on tillers characteristics.

Grains yield

Water management thus continuous flooding and alternate wetting and drying systems had no significant effect on rice grain yields (p=0.192) however AWD recorded higher rice yield. Rice yield increased by 13.3. % under AWD with 79.9g compared with 70.5 g of CF. This is in agreement with Zheng et al., 2020 who reported up to 13% of the yield increase under water-saving irrigation treatments compared to flooding irrigation during both years of experiments. Also Sujono et al 2011 reported up to 42% increasing grain yield under AWD.

Nitrogen levels had a very significant impact on grain yield (p<0.01) at almost every nitrogen level. Yield increased with increase in nitrogen level but any further increase in fertilizer amount to 150 kg N ha^{-1} showed no significant effects on yield, thus the yield followed this order 120>60>90>150>0>ABC .This is in agreement with Sah et al., 2019 who found significant increase yield at 120 kg N ha^{-1}, and there was decrease in yield due to increase in nitrogen at 180 kg N ha^{-1}. Similar results have also been observed in previous studies Sun et al., 2020: Hou et al., 2019; Zhu et al., 2017 revealing that an excessive N application rate has no contribution to the achievement of high grain yield.

Rice grain yield increased from 21.8 g pot^{-1} for the absolute control to 104.1g pot^{-1}for 120 kg N ha^{-1}. The percentage yield increase due to nitrogen application ranged from 411.7 to 435.6, the high percentage being recorded at 120 kg ha^{-1} while lowest at 150 kg N ha^{-1} treatments. The grain yield increase of 8.8 % was recorded at the control treatment over absolute control. This shows that application of phosphorus and potassium in control treatment increased grain yield over absolute control treatment which did not receive any kind of fertilizer. Interaction of water management and nitrogen levels had no significant effect (p=0.068), however the AWD×150 recorded higher grain yield followed by AWD× 120 as shown in (figure 7).

The percentage yield increase due to interaction of water management and nitrogen levels ranged from 315.3 to 516.2, the highest percentage being recorded at AWD ×150 while lowest at CF× 150 treatments. Eliya, 2016; Rajbhandari 2007 reported similar trend in rice grain yield following increasing rates of N application and associated it to increase in chlorophyll content of leaves which led to higher photosynthetic rate and ultimately plenty of photosynthates available during grain filling. This indicates the necessity of application of nitrogenous fertilizer in order to supplement the low amount N available in the soil to get increased rice yield.

These results are in agreement with those found by other researchers like Kahimba et al 2014, Ndiiri et al 2012; Krishna *et al.* (2008), and Vijayakumar *et al.* (2001), that higher grain yields is achieved in the treatment with younger seedlings (10-15 days old) transplanted singly at wider spacing under non-flooded soil moisture conditions.

Straw yield

AWD had high straw yield (70.2 g) compared to CF (65 g) and the difference was highly significant (p=0.005). Cheng et al 2020 reported increase of up to 5.3 % dry matter yield under AWD compared to traditional flooding irrigation. Nitrogen levels had a very significant impact in straw yield ($p<0.01$), highest amount of straw being recorded at 120 kg N ha^{-1} (96.6 g) and lowest at absolute control (22.3 g) showing beneficial effects of nitrogen fertilizer on crop performance. Straw yield decreased with increase in nitrogen application at 150 kg N ha^{-1} (85.9 g). The interaction of water and nitrogen levels had significant effect on straw yield (p= 0.003). The straw yield in the AWD interaction increases with increase in nitrogen levels (22.9 to 102.2 g) while for CF decreased with increasing nitrogen levels (21.7 to 97.7 g) (table 7). Chaturvedi et al., 2005 reported that nitrogen fertilizer enhances more leaf area which lead to higher photo assimilates and there by results in more dry matter accumulation.

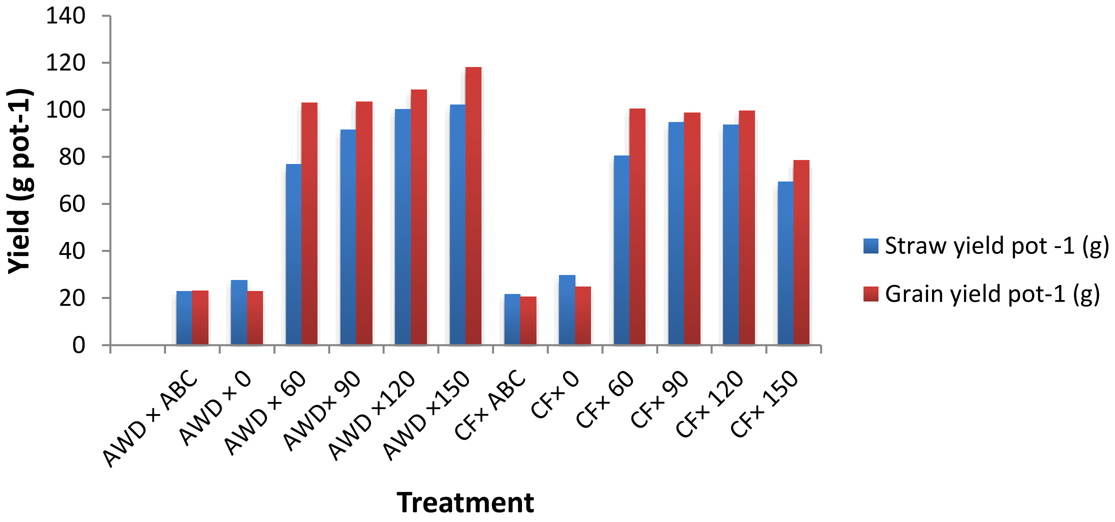

Figure 7. Interaction effect of water and nitrogen levels on straw and grain yield.

Grain harvest index and 1000 grains weight

Neither water management (P = 0.505) nor their interaction (P = 0.993) had significant effect on the grain harvest index, except nitrogen level (P =0.009). Grain harvest index ranged from 0.4 to 0.6, the lowest being recorded from AWD × 0 treatments while highest (0.6) was recorded under the interaction of CF× 60 and nitrogen level of 60 kg N ha^{-1}.

Water management (p = 0.048) and nitrogen levels (p = <.001) had significant effect while their interaction (p = 0.444) had no significant effect on the 1000 grains weight. Yakubu et al., 2019 reported that 1000 grains weight was not significantly ($p > 0.05$) influenced by N fertilizer and water management (Table 4) as well as the interaction of water management and N fertilizer.

Panicle weight and panicle length

Water management had a significant impact on panicle weight (p=0.021). The AWD had higher panicle weight (87.2 g) compared to CF (71 g). Nitrogen levels and its interaction with water had a very significant impact on panicle weight (p <.001). Under nitrogen levels the panicle weight increased followed this order 60>0>ABC and decrease followed this order 150<120 < 90Highest panicle weight was recorded at AWD ×150 (128.3g). Thus high panicle weight108.4 g was recorded under 60 kg N ha-1 and lowest (25.3 g) was in absolute control treatment. The interaction showed difference thus panicle weight increased with increasing in nitrogen levels at AWD while at CF the panicle weight decreased with increasing nitrogen levels.

Panicle length was affected by water and nitrogen levels significantly. AWD had higher panicle length (22.6 cm) compared to CF (21.5 cm) and the difference was significant. Panicle length increased with increasing nitrogen levels, ranged from (19.7 to 23.9 cm), lowest value being recorded from absolute control and highest from 150 kg N ha^{-1}. The interaction was non-significant (p=0.297).

Table 8. Yield characteristics as influenced by water management and nitrogen fertilizer.

Treatment	Panicle weight pot^{-1}(g)	Panicle length (cm)	1000 grains weight (g)	Straw yield pot $^{-1}$ (g)	Grain yield pot^{-1} (g)	% GY increase due to N application pot^{-1}	Grain Harvest Index
Water							
AWD	87.2	22.6	28.4	70.2	79.9	-	0.5
CF	70.1	21.5	27.0	65.0	70.5	-	0.5
L.S.D (P=0.05)	10.85	0.9	1.35	1.57	NS	-	NS
N fertilizer Levels							
ABC	25.3	19.7	27.8	22.3	21.8	-	0.5
0	28.5	20.6	29.5	28.7	23.9	-	0.5
60	108.4	22.4	28.8	78.8	101.8	425.9	0.6
90	107.3	22.9	27.8	93.1	101.1	423	0.5
120	106.5	22.9	26.6	96.9	104.1	435.6	0.5
150	96	23.7	25.9	85.9	98.4	411.7	0.5
L.S.D (P=0.05)	10.41	1.59	1.43	9.09	14.32	-	0.05
Interaction							
AWD × ABC	26.6	19.6	28.3	22.9	23.1	-	0.5
AWD × 0	26.5	20.9	30.8	27.6	22.9	-	0.4
AWD × 60	111.0	23.0	28.8	76.9	103.1	450.2	0.5
AWD× 90	112.5	23.6	28.2	91.5	103.5	452	0.5
AWD ×120	118.2	24.5	27.2	100.2	108.6	474.2	0.5
AWD ×150	128.3	23.8	27.2	102.2	118.2	516.2	0.5
CF× ABC	24.1	19.8	27.3	21.7	20.6	-	0.5
CF× 0	30.4	20.3	28.3	29.8	24.9	-	0.5
CF× 60	105.8	21.8	28.7	80.6	100.5	403.6	0.6
CF× 90	102.0	22.2	27.3	94.7	98.7	396.4	0.5
CF× 120	94.8	21.2	26	93.6	99.6	400	0.5
CF× 150	63.6	23.6	24.6	69.5	78.5	315.3	0.5
L.S.D (P=0.05)	14.37	NS	NS	11.75	NS	-	NS

Effect of water and nitrogen levels and their interactions on water use, saving and productivity

Water management involves the control of water for optimum rice yield and the best use of a limited supply of water resources. Water required to produce optimum yield such as irrigated water must satisfy the evapotranspiration needs of the paddy rice and losses through percolation and seepage. In this study, irrigated water is the amount of water given during paddy rice cultivation started from transplanting up to ripening stage. The irrigated water is purely for rice growing since there is no either seepage or percolation from the pot experiments. The irrigated water requirement varies depending on water irrigation treatments as presented in Table 8.

Water use was significantly ($p < 0.05$) influenced by water management, N fertilizer levels and their interaction (Table 9). Water use ranged from 35.8 to 82.3 L pot^{-1} depending upon water management and N levels used. In the case of water management under AWD 62.4 L pot $^{-1}$ was used compared to 61.2 L pot^{-1} under CF. Continuous flooding water management received higher amount of water use than AWD this is due to the standing water layer maintained continuously on the pot from crop establishment till one week to harvest.

Percentage of water saving ranged from -2 to 34.3%, where AWD ×150 recorded highest water saving (34.3%), followed by AWD × 90, AWD × 60 (11.2 and 10.2 %) respectively. Less water saving (-2 %) was recorded under water management treatments where AWD used more 1.2L pot^{-1} compared to CF. With AWD under SRI practice the water saving accounted for up 65%. Sato and Uphoff (2007) under SRI management in eastern Indonesia reported water saving up to 65%. Similarly, Chapagain and Riseman (2011) reported that water applied in the field can be reduced by about 40–70% without a significant yield loss compared with the traditional practice of continuous shallow submergence if a very thin water layer is maintained at saturated soil condition, or by practicing alternate wetting and drying. Keisuke *et al.* (2007) also reported the reduction of irrigation water requirement for non-flooded rice by 20–50%.

compared to flooded rice, with the difference being strongly dependent on soil type, rainfall, and water management practices. Kahimba et al 2014 reported that SRI demonstrated water saving of up to 63.72% and Keisuke *et al.* (2007) also reported the reduction of irrigation water requirement for non-flooded rice by 20–50% compared to flooded rice, with the difference being strongly dependent on soil type, rainfall, and water management practices. Ndiiri et al., 2012 The reduction in water use under SRI practice ranged between 26%-31%. Sujono et al, 2011 reported The irrigated water reduction from 1.7% to 17.4%.

No significant differences were observed for number of irrigation under water management ($P=0.588$) .However number of irrigation was highly significant affected by both nitrogen levels ($P<.001$) and the interaction ($p=0.026$). Number of irrigation ranged from 17 to 32, where high number of irrigation was recorded under the following treatments AWD ×120 (32) ; CF× 90 (32) and lowest number was recorded under AWD × ABC (17) treatment.

Equivalent amount used to produce 1 kg of rice ranged from 659.6 to 1810.7 lts kg^{-1} depending upon water management, N levels and their interactions. Under water management AWD used less than 10% to produce 1 kg of rice compared to CF. In the case of nitrogen levels, absolute control and control (0 kg N) required high amount of 1683.5 and 1523 L to produce 1kg of rice compared to other nitrogen levels with the range of 705.3 to 729.7 lts kg^{-1}. Under interaction of water management and nitrogen levels CF× ABC treatment recorded high amount of 1810.7 lts kg^{-1} and lowest was recorded under AWD × 60 (659.6 lts kg^{-1}).

Table 9. Water use, percentage water saved, water productivity and number of irrigation.

Treatment	Water use ($Lpot^{-1}$)	Number of irrigation (n)	Water productivity (kg cm^{-3})	Equivalent amount used to produce 1 kg of rice lts kg^{-1}	(%)Water saved relative to CF
Water					
AWD	62.4	25.6	1.2	781	-2
CF	61.2	25.9	1.1	868.1	
L.S.D (P=0.05)	1.18	NS	NS		
N fertilizer Levels					
ABC	36.7	18	0.6	1683.5	
0	36.4	19	0.7	1523	
60	71.8	28	1.4	705.3	
90	76.2	31	1.3	753.7	
120	77.8	31	1.3	747.4	
150	71.8	28	1.4	729.7	
L.S.D (P=0.05)	6.89	2.717	0.28		
Interaction					
AWD × ABC	36	17	0.6	1558.4	3.5
AWD × 0	37	18	0.6	1615.7	-3.4
AWD × 60	68	27	1.5	659.6	10.2
AWD× 90	71.7	29	1.4	692.8	11.2
AWD ×120	79.3	32	1.4	730.2	-3.9
AWD ×150	82.3	31	1.5	696.3	34.3
CF× ABC	37.3	19	0.6	1810.7	-
CF× 0	35.8	19	0.7	1437.8	-
CF× 60	75.7	30	1.3	753.2	-
CF× 90	80.7	32	1.2	817.6	-
CF× 120	76.3	29	1.3	766.1	-
CF× 150	61.3	26	1.3	780.9	-
L.S.D (P=0.05)	20.16	3.603	NS		

Water productivity ranged from 0.6 to 1.5 kg cm^{-3} and was affected by nitrogen levels ($P<.001$) while neither water management ($p=0.304$) nor interaction ($p=0.891$) had effect on water productivity. Water productivity was highest (1.5 kgm^{-3}) in the AWD × 60 and AWD ×150 treatments. Water productivity was lowest (0.6 kgm^{-3}) in three treatments which did not receive nitrogen thus ABC, AWD × ABC, AWD × 0 and CF× ABC. The variation in water productivity among treatments was mainly due to the differences in the yield, water and nitrogen levels used in the production process. There was higher water productivity in the AWD (1.2 kg cm^{-3}) over CF (1.1 kg cm^{-3}), although both recorded no significant difference, but lower water use in CF than AWD. The higher water productivity in AWD can be solely due to lower amounts of water used to produce 1 kg rice in AWD than CF. Chapagain and Yamaji [9] based on experimental research conducted in Japan reported that combinations of practices in the intermittent irrigation plots yield 1.74 g grain/kg water with SRI management and AWD as compared to 1.23 g grain/kg water from nor mal planting methods with ordinary water management. Also higher water productivity and total water use efficiency in SRI was observed by Thakur et al. 2011 and Zhao et al.2009 also reported higher irrigation and total water use efficiency in SRI-AWD over CF. The superiority of AWD in improving water productivity over CF was discussed by Singh ,2013 that high water productivity can be attributed to lower amount of total water used. Fuadi, et al ,2016 reported that SRI-AWD farming increased water productivity from 0.82 to 1.12 g/kg .

Trial with upland soil

Plant height and number of tillers

Plant height increased as days went on, water management affected plant height significantly during 14 DAT the rest of the days there was no significant difference as shown in table 10. The AWD reported higher plant height (105 cm) compared to CF (98.6 cm) though the difference was not significant. The nitrogen levels affected plant height from panicle initiation to maturity stage and highest plant height was reported at 120 and 150 kg N ha^{-1} (108.4 cm) and lowest was in ABC followed by control treatments (90.3 and 92.3 cm) respectively. There was no significant impact of the interaction of water and nitrogen levels in plant height. The highest plant height was reported at AWD× 120 with 112 cm and lowest in CF× ABC (87.7 cm) treatments as shown in figure 8. The increase in plant height in response to application of N can be attributed to enhanced availability of nitrogen which enhanced more leaf area resulting in higher photo assimilates and thereby in more dry matter accumulation (Ikunda, 2016). Chaturvedi (2005) and Halima *et al.* (2017) reported an increase in plant height when N was applied in rice.

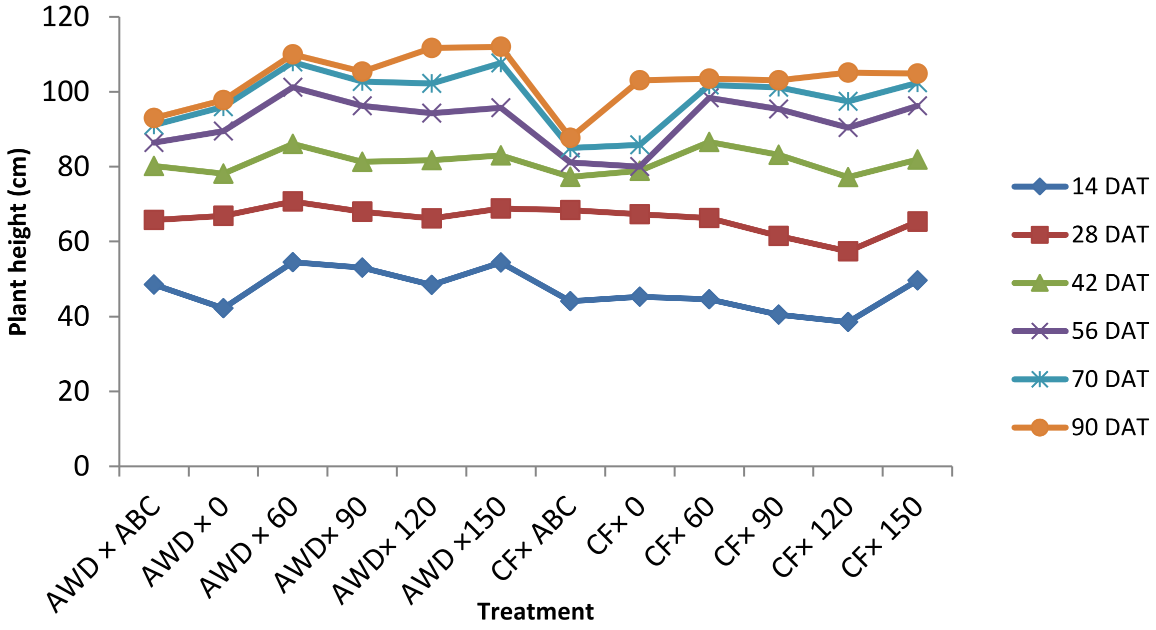

Figure 8. Effect of Treatment interaction on plant height.

Table 10. Plant height (cm) as influenced by water management and Nitrogen fertilizer.

Treatment	Days after transplanting					
	14	28	42	56	70	90
Water						
AWD	50.2	67.8	81.7	93.9	101.3	105
CF	43.8	64.4	80.8	90.3	95.6	98.6
L.S.D (P=0.05)	3.65	NS	NS	NS	NS	NS
N fertilizer Levels						
ABC	46.3	67.1	78.8	83.7	88.1	90.3
0	43.7	67.1	78.5	84.8	90.9	92.8
60	49.5	68.5	86.3	99.8	104.8	106.5
90	46.8	64.8	82.3	95.8	101.9	104.4
120	43.5	61.8	79.4	92.4	99.8	108.4
150	52	67.1	82.5	95.9	105	108.4
L.S.D(P=0.05)	NS	NS	NS	6.41	5.08	5.89
Interaction						
L.S.D (P=0.05)	NS	NS	NS	NS	NS	NS

Number of tillers increased from 14 to 70 DAT then started to decrease until harvest (table 11). Water management affected number of tillers from panicle initiation to harvest. AWD had many tillers (26) compared to CF (13). Under nitrogen levels number of tillers was significant affected from panicle initiation to harvest. The highest number of tillers (28) was recorded at 150 Kg N ha-

[1].Treatment interactions affected plant height from 70 DAT to harvest, AWD × 150 recorded highest numbers of tillers (38) (figure 9). A relative plant height and number of tillers in AWD could be due to early transplanting of the seedlings which is far more important in preserving plant potential for tillering and root growth that is reduced by late transplanting. Ali-Elhefnawy (2012) reported an increase in number of tillers when seedlings were transplanted with young age. Uphoff and Fernandes (2002) suggested that the use of young seedlings is the single most important component practice of SRI, increasing yield in Madagascar by 2.5 ton ha^{-1}. Similar results were obtained by Ram *et al*. (2014). These findings conforms to the results by Katambara et al. 2013; Krishna et al. 2007; Kangile et al 2018 who found that the increase in number of tillers were associated with the increase in spacing that has repercussion in yield increase. Tabar (2012); Ikunda, 2016 similarly reported an increase of number of tillers upon application of N and P together.

Table 11. Number of tillers per hill as influenced by water management and Nitrogen fertilizer.

Treatment	Days after transplanting						
	14	28	42	56	70	84	AT
Water							
AWD	2	6	14	20	26	25	25
CF	2	5	9	12	13	13	11
L.S.D (P=0.05)	NS	NS	NS	6.8	5.2	4.1	4.9
N fertilizer Levels							
ABC	3	6.0	10	11	11	10	9
0	2	4	9	10	10	10	10
60	2	6	13	18	20	18	16
90	2	5	13	21	26	25	23
120	2	4	11	16	24	25	23
150	2	5	13	19	27	28	26
L.S.D (P=0.05)	NS	NS	NS	5.1	4.5	3.9	3.99
Interaction							
L.S.D (P=0.05)	NS	NS	NS	NS	6.3	5.4	5.66

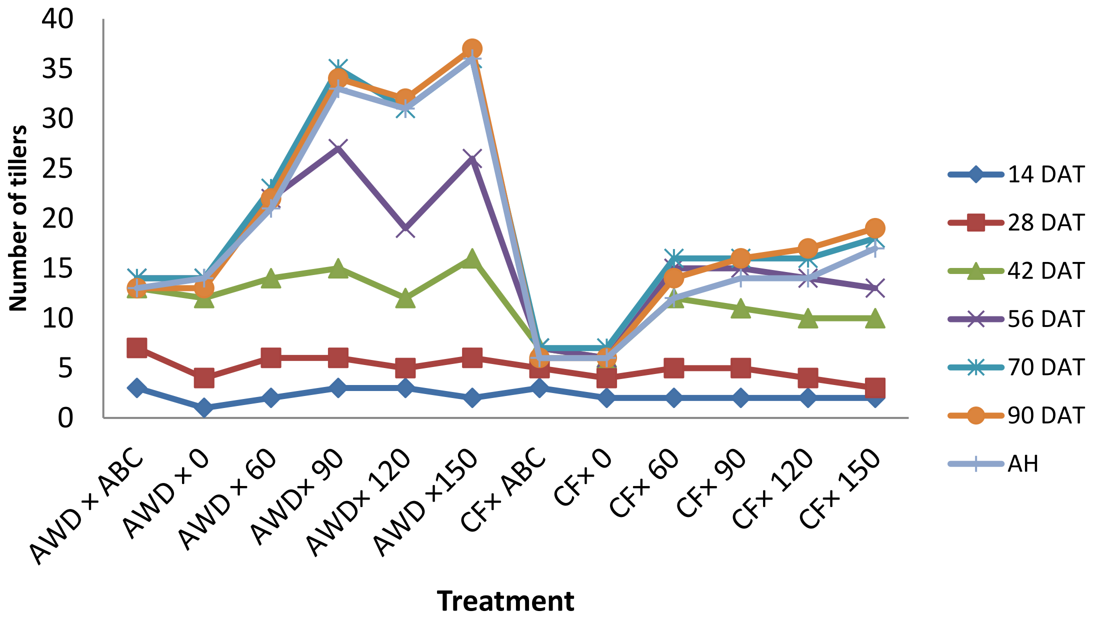

Figure 9. Effect of treatment interaction on number of tillers.

Chlorophyll content and Flag leaf area

Chlorophyll content was measured from 28 to 90 DAT (table 12). Water management affected chlorophyll content at 42 DAT, the rest of the days there was no significant difference. High content was recorded at 70 DAT (51.7 and 49.9) under AWD and CF respectively. Nitrogen levels affected chlorophyll content significantly from 28 to 70 DAT. The interaction of water and nitrogen levels had no significant effect on chlorophyll during all stages of rice growth. However treatments AWD × 60 and AWD× 90 had higher CC (52.5 and 51.5) during 70 DAT (figure 10).

Flag leaf area was only affected by nitrogen levels. Water management and the interaction of water and nitrogen levels have no significant impact. AWD treatment had high flag leaf area (42.4 cm^2) compared to CF (37.9 cm^2) though the difference was not significant (table 13). Nitrogen levels affected leaf area significantly, thus 90 and 120 kg N ha^{-1} (46.8 and 46.3 cm^2) recorded higher area respectively compared to other treatment. The lowest area was recorded under absolute control (28.4 cm^2). Under interaction treatment AWD× 90 recorded highest flag leaf area (50.5 cm^2) and lowest was recorded under CF× ABC (26.8 cm^2)

Table 12. Chlorophyll content as influenced by water management and nitrogen fertilizer at different growth stages of rice.

Treatment	Days after transplanting				
	28	42	56	70	90
Water					
AWD	47.6	48	48.4	51.7	43
CF	46.8	44.7	46.5	49.9	43.7
L.S.D (P=0.05)	NS	2.03	NS	NS	NS
N fertilizer Levels					
ABC	43.9	42.3	42.8	48.1	43.3
0	46.5	44.9	43.1	48.5	42.9
60	50.6	48.5	49.4	52.5	40.9
90	45.7	46.4	48.8	51.5	43.7
120	48.6	46.7	49.1	52.9	44
150	48	49	51.5	51.3	45.4
L.S.D(P=0.05)	3.6	3.74	3.18	3.46	NS
Interaction					
L.S.D (P=0.05)	NS	NS	NS	NS	NS

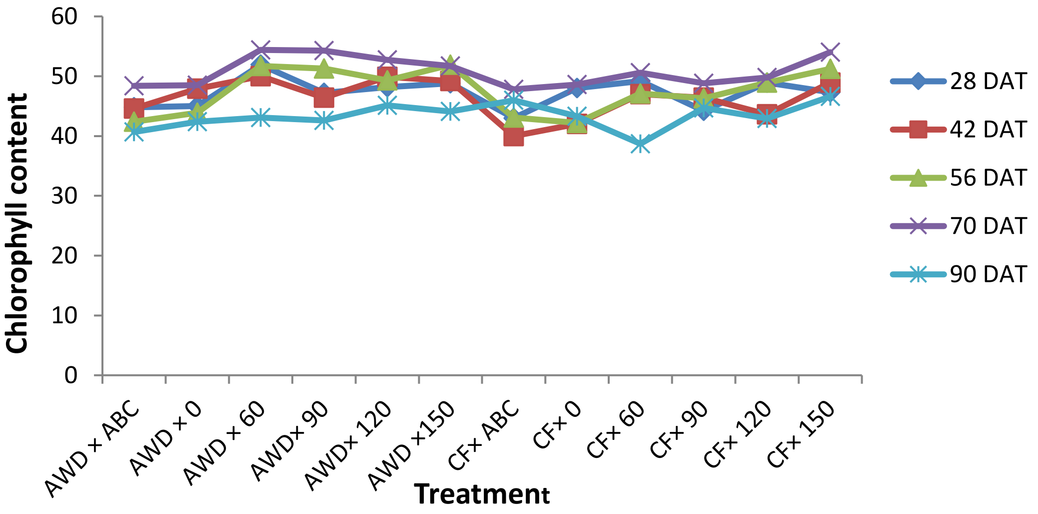

Figure 10. Effect of treatment interaction on chlorophyll content.

Table 13. Flag leaf area as influenced by water management and nitrogen fertilizer.

Treatment	Flag leaf area (cm^2)
Water	
AWD	42.4
CF	37.9

L.S.D (P=0.05)	NS
N fertilizer Levels	
ABC	28.4
0	29.9
60	45.0
90	46.8
120	46.3
150	44.3
L.S.D (P=0.05)	5.14
Interaction	
AWD × ABC	30.1
AWD × 0	30.9
AWD × 60	46.0
AWD× 90	50.5
AWD ×120	49.7
AWD ×150	47.1
CF× ABC	26.8
CF× 0	28.9
CF× 60	44.0
CF× 90	43.1
CF× 120	43.0
CF× 150	41.4
L.S.D (P=0.05)	NS

Tillers characteristics as influenced by water management and Nitrogen fertilizer at harvest

Productive and nonproductive tillers per plant were significantly affected by water management. AWD had high number of productive tillers (21.9) compared to CF (10.4).Nitrogen levels and the treatment interactions also affected number of productive tillers. Numbers of productive tillers increased with nitrogen levels. Whereas the absolute control had low numbers (7.9) and 150 kg Nha^{-1} had highest (23.8) numbers per plant. The interaction followed the same trend, thus numbers of productive tillers increased with nitrogen levels under water management. Interaction under AWD recorded higher number compared to interaction under CF. AWD ×150 had higher numbers (32.3) and CF× 0 had low numbers of productive tillers (5). These findings conforms to the results by Katambara et al. 2013; Krishna et al. 2007; Kangile et al 2018 who found that the increase in number of tillers were associated with the increase in spacing that has repercussion in yield increase. AWD had 2.8 while CF had 0.8 numbers of nonproductive tillers. Under N levels 90 and 150 kg N ha-1 recorded high number (2.6) of nonproductive tillers while 0 kg N ha-1 had low numbers (0.8). Their interaction had no significant difference. % of productive tillers was higher under CF (92.1) while AWD had (88.5) however the difference was not significant. Under N levels 120 kg ha^{-1} had high % (94.3) of productive tillers while lowest (86.9 %) was in absolute control though the difference was not significant. Their interaction affected % of productive tillers significantly as shown in table 14.

Table 14. Tillers characteristics as influenced by water management and Nitrogen fertilizer at harvest.

Treatment	Productive tillers plant^{-1}	Nonproductive tillers plant^{-1}	% of productive tillers
Water			
AWD	21.9	2.8	88.5
CF	10.4	0.8	92.1
L.S.D (P=0.05)	4.3	1.32	NS
N fertilizer Levels			
ABC	7.9	1.3	86.9
0	8.8	0.8	91.1
60	14.4	2	89.4
90	20.4	2.6	89.6
120	21.4	1.4	94.3
150	23.8	2.6	90.3
L.S.D (P=0.05)	4.1	1.23	NS
Interaction			
AWD × ABC	11	2	85.2
AWD × 0	12.7	1	92.7
AWD × 60	18	3.3	84.6
AWD× 90	28.3	4.3	86.7
AWD ×120	29	2.3	92.5
AWD ×150	32.3	3.7	89.1
CF× ABC	4.9	0.7	88.6
CF× 0	5	0.7	89.5
CF× 60	10.9	0.7	94.3
CF× 90	12.6	0.8	92.5
CF× 120	13.9	0.6	96.1
CF× 150	15.3	1.5	91.5
L.S.D (P=0.05)	5.67	NS	NS

Effect of water management and nitrogen levels on yield and yield component

Water management affected rice grain yield significantly (P=0.038), higher rice yield was observed under CF, thus rice yield was increased by 18.5. % under CF with 93.2 g compared with 76 g with AWD. Grain yield increased with increasing nitrogen levels except under 120 kg N ha^{-1}. 150 kg N ha^{-1} reported higher grain yield of 114.3 g pot^{-1} and lowest 41.2 g pot^{-1} was recorded under ABC treatment. Interaction of treatments has no significant effect on grain yield however treatment under AWD increased grain yield as nitrogen level increased, the same trend was observed under CF interaction treatment except 120 kg N ha^{-1} where there was decrease in yield. Higher yield (124.1 g pot^{-1}) was observed under CF× 90 and low yield (39.9 g pot-1) under AWD × ABC. There was grain yield increase due to nitrogen application, thus application on nitrogen increased grain yield from 177.3 to 279.6 %. Straw yield was affected by water management treatments, thus CF had higher straw yield (66.5 g pot^{-1}) compared to AWD (47.3 g pot^{-1}). Under nitrogen levels straw yield increased with increasing nitrogen level (table 15). Treatments interactions followed the same trend. Chaturvedi et al., 2005 reported that nitrogen fertilizer enhances more leaf area which lead to higher photo assimilates and there by results in more dry matter accumulation.

Panicle weight pot^{-1}(g) was higher under CF (100.8 g) while AWD had 83.5g , though the difference was not significant .panicle weight increased with increasing nitrogen level. The same trend was followed in treatment interaction except CF× 120 which led to decrease in weight.

Panicle length was higher under AWD (22.4 cm) compared to CF (21.1 cm) though the difference was not significant. Under nitrogen levels there was difference in panicle weight where 150 kg N ha^{-1} treatment had higher panicle length (22.7 cm) compared to other nitrogen levels. Treatment interaction had no significant effect on panicle weight. Weight^{-1} 1000 grains (g) was not affected by either treatments and the weight ranged from 21.2 to 27.3 g.

Grain Harvest Index (GHI) was affected by water treatment thus AWD had higher GHI (0.6) compared to CF(0.2).Also nitrogen levels and treatment interaction affected GHI significantly.

Table 15. Yield characteristics of rice as influenced by water management and nitrogen fertilizer levels.

Treatment	Panicle weight pot^{-1}(g)	Panicle length (cm)	Weight^{-1} 1000 grains (g)	Straw yield pot $^{-1}$ (g)	Grain yield pot^{-1} (g)	% GY increase due to N application	Grain Harvest Index
Water							
AWD	83.5	22.4	25.3	47.3	76	-	0.6
CF	100.8	21.1	26.3	66.5	93.2	-	0.2
L.S.D (P=0.05)	NS	NS	NS	10.13	14.84	-	0.04
N fertilizer Levels							
ABC	43.9	20.9	24.0	32.9	41.2	-	0.5
0	44.5	20.3	26.5	35.2	44.5	-	0.5
60	100.7	22.6	25.8	58.3	94.2	211.7	0.4
90	116.9	21.8	25.3	64.9	108.8	244.5	0.4
120	119.1	22.3	26.5	70.1	104.6	235	0.4
150	128.0	22.7	26.8	80.1	114.3	256.9	0.4
L.S.D (P=0.05)	15.1	1.64	NS	8.7	12.67	-	0.03
Interaction							
AWD × ABC	42.3	21.7	21.3	31	39.9	-	0.56
AWD × 0	46.7	21.2	26.7	31.1	44.5	-	0.59
AWD × 60	83.7	23.4	25.7	44.8	78.9	177.3	0.64
AWD× 90	100.97	22.2	24.7	54.3	93.6	210.3	0.63
AWD ×120	112.8	22.9	26.3	56.3	94.7	212.8	0.63
AWD ×150	115.1	23.1	27.3	66.3	104.3	234.4	0.61
CF× ABC	45.5	20.2	26.7	34.8	42.4	-	0.37
CF× 0	42.3	19.4	26.3	39.3	44.5	-	0.38
CF× 60	117.6	21.8	26	71.7	109.5	246.1	0.18
CF× 90	133.2	21.4	26	75.5	124.1	278.9	0.16
CF× 120	125.4	21.7	26.7	83.9	114.5	257.3	0.18
CF× 150	140.9	22.2	26.3	93.9	124.4	279.6	0.16
L.S.D (P=0.05)	NS	NS	NS	12.23	NS	-	0.04

GY : Grain yield.

3.4. Water use, saving, productivity, and number of irrigations

Table 16. Water use, percentage water saved, water productivity, and number of irrigations under different water management and nitrogen levels.

Treatment	Water use (Lpot^{-1})	Number of irrigations (n)	Water productivity (kg cm^{-3})	Equivalent amount used to produce 1 kg of rice lts kg^{-1}	(%)Water saved relative to CF
Water					
AWD	48.4	22	1.5	636.8	8.7
CF	65	28	1.4	697.4	
L.S.D (P=0.05)	NS	NS	NS		
N fertilizer Levels					
ABC	35.1	20	1.2	851.9	
0	34.5	20	1.3	775.3	
60	59.9	27	1.6	635.9	
90	70.1	29	1.6	644.3	
120	66.5	27	1.6	635.8	
150	74	29	1.6	647.4	
L.S.D (P=0.05)	7.52	2.71	0.15		
Interaction					
AWD × ABC	31.5	17	1.3	789.5	13.5
AWD × 0	33.3	18	1.3	748.3	6.7
AWD × 60	47.8	23	1.7	605.8	7.7
AWD× 90	59.6	25	1.6	636.8	2.1
AWD ×120	54	23	1.8	570.2	17.3
AWD ×150	64	26	1.6	613.6	9.1
CF× ABC	38.7	22	1.1	912.7	
CF× 0	35.7	22	1.3	802.2	
CF× 60	71.9	31	1.6	656.6	

CF× 90	80.7	32	1.6	650.3
CF× 120	78.9	31	1.4	689.1
CF× 150	84	32	1.5	675.2
L.S.D (P=0.05)	17.05	NS	NS	

Effect of water management and nitrogen levels on water use, water saving, and number of irrigations

Water use under water management treatment was higher under CF (65 L pot^{-1}) compared to AWD (48.4 L pot-1), thus CF used 25.5% more water compared to AWD. Nitrogen levels affected water use significantly. Higher amount of water use was recorded on 120 kg N ha^{-1} (74 L pot^{-1}) and low amount was recorded under 0 kg N ha^{-1} (34.5 L pot^{-1}).

Water saving ranged from 2.1 to17.3 %, where under water management treatments, AWD saved up to 8.7%. The highest water saving was noted under the interaction treatment of AWD ×120 (17.3) followed by AWD × ABC (13.5%). Mao, 2003 reported that AWD saved irrigation water by reasonably adjusting water provision during the key growing phases in rice, and corresponded with the physiological water requirement of rice. Various studies in Asian countries, such as China (Pan et al.,2017), India (Mahajan et al 2012) , and the Philippines (Sibayan eta al .,2018) have reported that AWD has the potential to save more water than CF. Aziz et al., 2018 reported that the decrease in irrigation water requirements is attributed to the reduction in percolation and evapotranspiration. Since there was no percolation in the present study, evapotranspiration was equal to the irrigation water requirement. Pan et al. 2017 reported that AWD decreased irrigation water use by 24.1% and 74.5% in 2014 and 2015, respectively. Carrijo et al. 2017 conducted a meta-analysis on AWD from 56 studies and concluded that mild AWD reduced water use by 23.4% compared with CF. Also Zheng et al. 2019 reported that (improved alternate wetting and drying irrigation (IAWD) reduced total water consumption by 18.4% in 2016 and 7.9% in 2017, relative to the CF treatment. Yakubu et al, 2019; Ceesay et al, 2006 reported water saving up to 60%.

Number of irrigation

Water management treatments had no significant effect on number of irrigation though CF had more number of irrigation (28) compared to AWD (22). Nitrogen level has significant impact on number of irrigation. Treatments of 90 and 150 kg N ha^{-1} recorded high number of irrigation (29) and lowest was recorded under ABC and 0 kg N ha^{-1} (20). Treatment interactions had no significant impact on number of irrigation. CF× 90 and CF× 150 had high number of irrigation (32) and AWD × ABC recorded lowest number of irrigations.

Water productivity

There was no significant difference among water management on water productivity (WP) however AWD had higher WP (1.5 kg cm^{-3}) compared to CF (1.4 kg cm^{-3}). Nitrogen levels had significant impact on WP though the treatment of 60, 90, 120, 150 kg ha-1 had the highest WP (1.6) and lowest was recorded in ABC (1.2 kg cm^{-3}) followed by 0 kg ha-1 (1.3 kg cm^{-3}).

Treatment interactions has no significant impact on WP, and the lowest was recorded under CF× ABC (1.1 kg cm^{-3}) and highest was in AWD ×120 (1.8 kg cm^{-3}).

Amount of water used to produce 1 kg of rice

Under AWD 636.8 liters was needed to produce 1 kg of rice compared to 697.4 liters under CF, thus 8.7% more was needed to produce 1kg under CF. Amount of water used to produce 1 kg of rice was different under nitrogen levels. Thus under ABC treatment high amount (851.9) liters was needed while under 120 kg N ha^{-1} the 635.8 liters was needed to produce 1 kg of rice. Treatment interactions showed that higher amount was needed under CF interactions compared to AWD interaction (Table 16). Treatments interaction which did not receive nitrogen like AWD×ABC, AWD×0, CF×ABC and CF×0 needed higher amount compared to other treatments (Table 16). Kahimba et al, 2011 reported the amount of water used to produce 1 kg of rice in Mkindo Irrigation scheme under field condition which ranged from 2115.95 to 7347.54 lts kg^{-1}. On average, under field condition it takes 1,432 liters of water to produce 1 kg of rice in an irrigated lowland production system. Total seasonal water input to rice fields varies from as little as 400 mm in heavy clay soils with shallow groundwater tables to more than 2000 mm in coarse-textured (sandy or loamy) soils with deep groundwater tables. Around 1300−1500 mm is a typical amount of water needed for irrigated rice in Asia. Irrigated rice receives an estimated 34−43% of the total world's irrigation water, or about 24−30% of the entire world's developed fresh water resources. IRRI, 2009; Mekonnen, and Hoekstra, 2011; reported the amount of water used to produce 1kg (rice water footprint) (lts/kg) is 2,500 -5000.

Conclusion

Based on both trial results, it can be concluded that nitrogen was a limiting factor for the rice productivity. Yield increased with increasing nitrogen except for the lowland trials where there was no significant response beyond 120 kg N ha^{-1}, therefore 120 kg N ha^{-1} could be optimum dose with AWD water saving. This indicates that continuous flooding in lowland irrigation is not an obligation in rice production, and farmers could implement AWD and 120 kg N/ha to reduce water use, and increase water productivity while harvesting greater yields with reduced costs of production.

AWD resulted in differences in water productivity in both trials. The water productivity was higher in the upland trials (1.2 to 1.8 compared to the lowland trials (0.6 to 1.5). Thus in both trials, WP was improved. In the lowland trial, AWD saved more water, up to 34.3%, while in the upland trials the saving was up to 17.3%

Recommendations

Basing on the findings from the study, we recommend that further study on nutrient requirement of irrigated rice in Tanzania is needed to investigate more nitrogen rates on different soil types and agro ecological zones.

Also, future study should include soil moisture monitoring overtime so as to quantify N leaching because of the high irrigation requirement of rice.

The water saved under AWD treatment can be effectively used for increasing the area under rice or for other irrigated dry crops in the cropping sequence, thereby, enhancing the rice productivity. AWD practices can address some key constraints for rice production in Tanzania and in many other countries. It can reduce water use for production while increasing yield, hence increasing water productivity. FAO (2006) indicates that a 1% increase in water productivity in food production makes available an extra 24 liters of water per day per capita. Investing in agriculture and in agricultural water management, therefore, is an attractive strategy for freeing water for other purposes.

Water scarcity is likely to become a more significant problem around the world. Adopting cultivation practices such as ones that use less water is the way forward. A small portion of water saved from rice planting areas can produce huge societal and environmental benefits if the water is used for higher valued uses such as urbanization, industries, or the environment. Thus, it is particularly vital to establish water-saving techniques in rice farming.

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