EFFECTS OF IRRIGATION WATER REGIMES, SOIL TYPES AND THEIR INTERACTION ON WATER USE AND WATER PRODUCTIVITY FROM RICE (*ORYZA SATIVA L*) CULTIVATION IN MWEA, CENTRAL KENYA

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Abstract
Kenyan rice production is an important component for national food security. However, most rice producers in Kenya still use the conventional continuous flooding method that requires a lot of water and produces high amounts of methane (CH_4), a potent greenhouse gas (GHG). The changing weather patterns due to climate change and deforestation has the potential to reduce the water availability for rice production globally. It is therefore necessary to assess locally feasible water-saving irrigation technologies in rice production that can be adapted to not only reduce water use but increase or maintain yield. One such water-saving technology is the alternate wetting and drying (AWD). This study was therefore conducted to assess the water saving and productivity in rice irrigation in Mwea Irrigation Scheme, Kenya during August – December 2017 rice growing season under AWD water application method in comparison to the conventional continuous flooding (CF) for two soil types (Vertisols [VS] and Nitisols [NS]) commonly found in the scheme. Compared with the CF, water saving in the VS and NS soils under AWD was 26 % and 45 % respectively. There were no significant difference ($P < 0.05$) in yield with the introduction of AWD in both soil types and consequently productivity was 28% and 78% higher in the VS and NS respectively under AWD compared to the CF. Rice grain yield is extremely sensitivity water stress and it is therefore important to fine tune the draining and re-flooding cycle of the rice fields under AWD to site specific conditions i.e., soil type and weather conditions.

Key words: Rice, alternate wetting and drying, continuous flooding, vertisols, nitisols, water productivity

1.0 Introduction

Water is an important natural resource that is rapidly becoming scarce mainly as a result of climate change, the growing population and agriculture intensification (Rijsberman, 2006). The ability for the world to meet the increasing food demand is challenged by water scarcity (Hanjra & Qureshi, 2010). Around the world, pressure to reduce water used in irrigation is mounting (Thakur et al., 2016). This is attributed to the fact that; at global level, agriculture accounts for approximately 70 - 80% freshwater abstraction and of this about 85% is used in rice (*Oryza sativa L*) production systems (Jain et al., 2014). For more than half of the world's population, rice is an important staple crop (FAO, 2013). With high rice production to meet global demands; water use is enormous (Bruderle et al., 2009). According to Bouman & Tuong, (2001), water-use per growing season of rice typically ranges from 1000 - 2000 mm, which corresponds to 2 - 3 times more than other cereal crops. However, a large amount of this water is lost through surface runoffs, deep percolation, evapotranspiration and seepage (Guerra et al., 1998).

Rice (*Oryza sativa*) is the third stable food and most consumed cereal crop after maize and wheat in the country (Kimani et al., 2011; Mati et al., 2011; Ndiiri et al., 2013; Nyang'au et al., 2014). However, with the increasing population and changing lifestyles, it is considered to overtake wheat (Aruna, 2014). Rice consumption in the country is increasing steadily at a rate of 12% annually as compared to 1% for maize and 4% for wheat (Mati et al., 2011). According to Kenya's Ministry of Agriculture statistics (2009), rice productivity in irrigated lowland or paddy rice fields is approximately 4 - 6tons (t) ha^{-1}, while that of rain fed production is approximately 1ton ha^{-1} which is far below the optimum of about 10t ha^{-1} and 7t ha^{-1} for irrigated and rain fed rice, respectively (Kimani et al., 2011). The gap is met through imports which are very costly causing a strain for other sectors of the economy (Kimani et al., 2011).

Rice is an aquatic or semi-aquatic plant that requires sufficient water to grow well, hence soils with high water holding capacity like silt clay loam, silt clay and clay are some of the soil textures that are preferred for rice farming compared to light textured soils (Das & Uchimiya, 2002; Akuatik et al., 2016). Soil properties such as soil texture/percolation rate, soil pH, salinity as well as contents of soil organic matter (SOM) play an important role in rice production in terms of water productivity (Dou et al., 2016). Light textured soils are generally less productive to soils with high clay content, this is attributed mainly to the fact that they have a higher percolation rate hence leaching the essential nutrients (including added fertilizers) beyond the root zone (Obasi et al., 2015). According to Dou et al., (2016), soil texture or structure also affects available water content (AWC) with clay soils having greater AWC than sandy soil mainly due to high organic matter. Root production and growth; that aids in water and nutrient uptake, has been found to vary with difference in soil properties i.e. soil texture, which consequently affect the crop yield (Zobel, 1991; Dou et al., 2016).

Production of rice under paddy rice systems is the most predominant method mainly in irrigation schemes established by the Government, which include Mwea, Bura, Hola, Perkera, West Kano, Bunyala and Ahero (Nyang'au et al., 2014). Cultivation of rice in paddy fields requires flooded fields with a continuous supply of water and also soils with high water-holding capacity (Ndiiri et al., 2013; Nyang'au et al, 2014). However, very few areas in the country have a combination of both suitable soils and adequate water supply for rice production (Ndiiri et al., 2013; Nyang'au et al, 2014). This places a limitation on the likelihood of the country meeting the demand for rice from the rice schemes in the country (Mati et al., 2011; Shrestha et al., 2014). Alternate wetting and drying (AWD) is a water-saving technology that is based on draining and re-flooding the rice fields frequently during the entire rice growing season. Alternate wetting and drying (AWD) has been used effectively in parts of east and south-east Asia (van der Hoek et al., 2001; Chidthaisong et al., 2018). Chidthaisong et al., 2018 in their study in Thailand, observed that water use was substantially reduced by AWD and that implementation of this irrigation strategy did not affect yield as compared to the continuous flooding. However, AWD use in Sub Saharan Africa (SSA) is limited (Boateng et al., 2017). In Kenya, various aspects of intensifying rice production; mainly system of rice intensification – SRI, while utilizing available water have been studied (Mati, 2009; Mati et al., 2011; Nyamai et al., 2012; Ndiiri et al, 2012; Ndiiri et al., 2013). However, studies on AWD method, its impact on rice production in different soil types and how much water is saved compared to continuous flooding, has not yet been done. The main purpose of the present study was to evaluate the effects of AWD irrigation system on water use and water productivity from rice (*Oryza sativa L*) cultivation in different soil types and investigate which soil type (vertisols and nitisols commonly found in Mwea Irrigation Scheme) favors this irrigation system.

2.0 Materials and Methods

2.1 Study area, climate and soils

The field experiments were carried out during the main rice growing season (August 2017 to December 2017) in Mwea irrigation scheme (MIS). MIS is located in the lower slopes of Mt. Kenya in Kirinyaga County. The scheme is divided into 5 sections: Tebere (largest section), Mwea, Thiba, Wamumu, and Karaba. The region is classified as a tropical region with semi-arid climate and an annual mean air temperature of 23 – 25^{o}C. The difference between the minimum temperatures in June/July and maximum temperatures in October/March is approximately 10^{o}C. Annual precipitation in this area is approximately 950 mm. The experiment was conducted at the Kirogo rice research farm within the Tebere section in MIS (Table1). The research farm is managed by Kenya Agriculture and Livestock Research Organization (KALRO) in partnership with Japan International Cooperation Agency (JICA).

Table 1: Description of experimental site Kirogo rice research farm, within the Mwea Irrigation Scheme, Kenya

Characteristics	***Kirogo Research Farm***
Latitude	00°38S
Longitude	37°22E
Elevation (masl)	1150
Annual rainfall (mm)	950
Annual maximum temperature (°C)	28.6
Annual minimum temperature (°C)	18.6

The soils found in this section, are pellic vertisols also locally-known as black cotton soils which are dark grey to black, poorly drained and cracking clay and verto-eutric nitisols which are dark reddish brown, well drained and fragile to firm clay (Sombroek et al., 1982). The dominant soil within the research farm is the dark reddish brown nitisol; however, the vertisols (Area 210.6 m^2, ~3.0 m deep) within the research farm were imported from elsewhere within the Tebere section in 2015 to be used for various rice researches. Further details on the soil properties of the two soil types are shown in Table 2.

Table 2: Soils physical and chemical characteristics for the study site: Kirogo rice research farm, within the Mwea Irrigation Scheme, Kenya

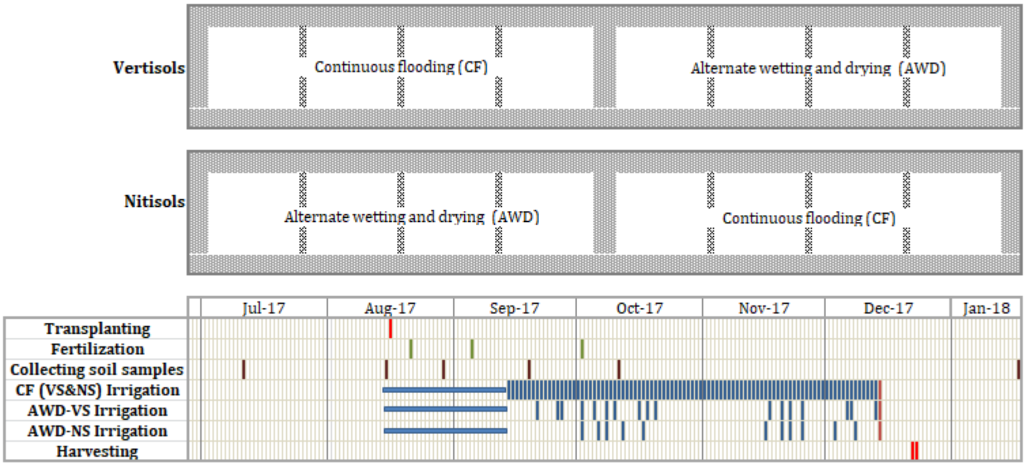
Properties		**Vertisols**	**Nitisols**
pH		7.2	5.7
Bulk density (g cm^{-3})		0.91	1.14
Soil Texture	Sand (%)	13.88	25.08
	Silt (%)	16.68	27.33
	Clay (%)	69.44	47.59

[1]Soil samples for soil texture analysis were taken from 0-50cm depth

2.2 Experimental design

Two treatments; alternate wetting and drying (AWD) and continuous flooding (CF) were implemented in the two soils. The soil types; vertisols and nitisols, were the main plots while the water management systems; AWD and CF, were the subplots. The subplots were further sub-divided into four replications (1350 cm by 135 cm each) as shown in Figure 1. For the vertisols, the two water management systems were separated by concrete banks 30 cm wide and 40 cm above the soil surface and 100 cm deep and lined with a 250-gauge black polyethylene sheeting to avoid cross seepage of water between the two water systems. For the nitisols, the water management systems were separated by PVC corrugated sheets and also lined with a 250-gauge black polyethylene sheeting to avoid cross seepage of water between the two water systems.

Figure 1: Schematic field layout at the Kirogo Rice Research Farm, within the Mwea Irrigation Scheme, Kenya



[1]Increments indicate timeline in days / month when certain events were done for the duration of the experiment;
[2]All sub-plots were subjected to the same water management conditions for up till 30 days after transplant (DAT)
[3]Area of each subplot 105.3m^2

2.3 Field management practices

The study used rice variety Basmati 370 which is a favored variety for local farmers due to its high market value. Basmati 370 rice seedlings were prepared by soaking the rice seeds for three days and thereafter sowing them in a nursery for 21 days. Land preparation in the vertisols and nitisols was standard wet tillage and harrowing. This entailed field submergence for 7 days, followed by manual disintegrating of the soil, wet harrowing and finally puddling. Leveling the field was done using a wooden leveling bar. Pre-germinated Basmati 370 rice seedlings were manually transplanted at two plants per hill into the soils at a spacing of 30 cm x 15 cm. All plots received 25 kg ha^{-1} of N:P:K 17:17:17 (Nitrogen: Phosphorus: Potassium) as basal fertilizer 5 days after transplant (DAT) and 25 kg ha^{-1} of ammonium-sulphate as 1st and 2nd top dressing 21 DAT and 50 DAT respectively. The exact dates when important management practices were done in the AWD and CF water management systems for both soil types are indicated in Table 3.

Table 3 : Calendar of events for the duration of the experiment

Event	CF	AWD
-Soaking of seeds	Soaking of Basmati 370 seeds was done on 23.07.17	Soaking of Basmati 370 seeds was done on 23.07.17
-Seed sowing	The seeds were sown in the nursery on 26.07.17	The seeds were sown in the nursery on 26.07.17
-Land preparation	Fields submerged for 7 days, then conducting manual rotavation, followed by wet harrowing and puddling and leveling from 02.08.17 to 14.08.17	Fields submerged for 7 days, then conducting manual rotavation, followed by wet harrowing and puddling and leveling from 02.08.17 to 14.08.17
-Transplanting	Pre-germinated seedlings were manually transplanted at a spacing of 30 cm x 15 cm on 16.08.17	Pre-germinated seedlings were manually transplanted at a spacing of 30 cm x 15 cm on 16.08.17
-Fertilizer application	Basal application on 21.08.17 1st and 2nd top dressing were applied on 05.09.17 and 02.10.17 respectively	Basal application on 21.08.17 1st and 2nd top dressing were applied on 05.09.17 and 02.10.17 respectively
-Water management	Flooded to about 3cm until 30DAT to allow crop establishment. Continuously flooded with 10cm water from 15.09.17. Irrigation stopped a week before harvest on 14.12.17.	Flooded to about 3cm until 30DAT to allow crop establishment. AWD started on 15.09.17. Irrigation stopped a week before harvest on 14.12.17.
-Harvesting	Harvest was done on 22-23.12.17	Harvest was done on 22-23.12.17

[1]Exact dates when important management practices were done, DAT – days after transplant.

Rainfall and air temperature data were collected from a weather station located in the research farm. The Meteorological data collected during the present study rice growing season at Kirogo farm weather station is as shown in Table 4.

Table 4: Climatic conditions (1st August – 30th December, 2017) at the Kirogo rice research farm, within the Mwea Irrigation Scheme, Kenya

Month	Total rainfall (mm)	Air temperature (°C)	Relative humidity (%)
August	18.1	21.7	59.2
September	23.6	22.3	55.6
October	149.6	23.6	59.0
November	230.8	21.5	74.6
December	0.1	21.6	65.9

2.4 Water application, monitoring and measurement

All subplots were subjected to the same water management conditions for a period of 30 days after transplant (DAT) to allow seedling establishment; after which AWD was introduced in the AWD subplots and water levels raised in the CF plots. During this 30DAT period, AWD and CF plots were flooded to about 3 cm and water allowed to subside before re-flooding. All plots were drained a week before harvest. During the short rains experienced in the months of October to December 2017, CF plots were still flooded to maintain the 10 cm water level. The plots were irrigated using a pipeline system equipped with water flow meters to measure water input. Water was obtained from an existing borehole in the research farm or from pumping water from the unlined open water channels in the research farm. The AWD plots were flooded to a water level of about 5 cm and water was allowed to subside via percolation and evapotranspiration. The plots were then re-flooded when water level had dropped to about 20 cm below the surface of the soil. To monitor water levels in the AWD plots, field water tubes 10 cm diameter plastic pipe cut into 30 cm lengths and perforated with holes up to the 20 cm mark were embedded into the soil for the entire growing season to a depth of 20 cm which left about 10 cm above the soil. The water tubes were placed in accessible and representative parts of the AWD plots.

2.5 Soil Sampling

Soil samples for both the soils to determine soil pH, soil texture analysis and bulk density were collected at the end of the rice growing season. Standard test methods of analyzing these soil properties were used. For the soil texture, soil samples were collected using a soil auger at 0-10cm, 10-20cm, 20-50cm depth intervals. Soil texture was determined by the hydrometer method (Gee & Bauder, 1979). Soil pH was measured in a soil to water ratio slurry of 1:2.5 (Carter & Gregorich, 2008). Soil samples to determine the bulk density were collected by the core method

(Grossman & Reinsch, 2002) and oven dried at 105°C until constant weight was attained (Table 2).

2.6 Plant and yield Observations

This research work was carried out in partnership with Nagoya University-Japan, Kenya Agriculture and Livestock Research Organization (KALRO) and Japan International Cooperation Agency (JICA). Nagoya University student collected dataset on the biomass production over the growing season and final rice grain yields (paper in publish) from the two different rice production systems in the two soil types while we collected dataset on daily water use and greenhouse gas emissions (paper in publish) from the two different rice production systems in the two soil types. Final grain yield data (Table 6) over the growing season was shared to facilitate calculation of water productivity for this paper.

2.7 Statistical Analysis

All data was analyzed using analysis of variance (ANOVA) using R studio (R studio version 3.4.3) to determine the significance of differences in water use between the two water irrigation systems in the two soil types. Tukey Honest Significant Difference (HSD) range test for comparing pair wise differences of means (water regime x soil type interaction effect) was also done.

3.0 Results and discussions

3.1 Soil properties

In this study, soil samples analyzed showed that vertisols had high clay content (69.44%) while the sand and silt content in the vertisols was 13.88% and 16.68% respectively (Table 2). From the nitisols soil samples collected and analyzed for soil texture; clay, sand and silt content was 47.59%, 25.08% and 27.33% respectively (Table 2). Vertisols had a higher clay content compared to the nitisols, while the nitisols had higher sand and silt content compared to the vertisols. Soils with high clay soils have more fine particles thus can retain more water and nutrients needed by the rice plants (Obasi et al., 2015; Dou et al., 2016; IRRI, n.d.). The nitisols had higher sand and silt particles as compared to the vertisols, hence well drained compared to the vertisols. The vertisols are characterized as dark grey to black, poorly drained and cracking clay while the nitisols are characterized as dark reddish brown, well drained and fragile to firm clay.

The bulk density of the vertisols (0.91 g cm^{-3}) was lower than the nitisols (1.14 g cm^{-3}). Generally soils with finer texture have smaller bulk density (Obasi et al., 2015; Dou et al., 2016; IRRI, n.d.). Thus, the low bulk density for the vertisols compared to the nitisols can be attributed mainly to the fact that they have a finer texture. Rice is known to prefer slightly acidic pH, but can grow in soils with a pH range of 5 – 8 (dhanyac, 2011; Matsuo et al., 2015). In this study, the pH of the two soil types was within this range with the nitisols been acidic (pH = 5.7) and the vertisols been neutral pH = 7.2 (Table 2).

3.2 Water use and rainfall contribution in the two soil types

Rice growing season in Mwea Irrigation Scheme (MIS) is usually from July to December each year, which coincides with the short rains experienced in Kenya in the months of October to November.

Table 5: Total water used (irrigation + rainfall) in mm per month in each subplot over the growing season at the Kirogo rice research farm

Subplot	Month	Irrigation water applied (mm)	Total rainfall (mm)	Total water used (mm)
CFVS	August	301.9 ± 4.5	18.10	319.99
	September	1292.9 ± 11.0	23.60	1316.48
	October	2943.1 ± 7.3	149.60	3092.74
	November	3472.9 ± 3.1	230.80	3703.73
	December	3797.3 ± 1.1	0.10	3797.44
AWDVS	August	344.0 ± 4.7	18.10	362.09
	September	1094.9 ± 6.8	23.60	1118.50
	October	1928.2 ± 3.8	149.60	2077.76
	November	2288.9 ± 3.7	230.80	2519.69
	December	2748.7 ± 2.5	0.10	2748.75
CFNS	August	58.7 ± 2.5	18.10	76.77
	September	1013.3 ± 12.4	23.60	1036.86
	October	3276.0 ± 10.7	149.60	3425.62
	November	4340.4 ± 7.8	230.80	4571.22
	December	5868.9 ± 10.4	0.10	5868.98
AWDNS	August	132.7 ± 2.5	18.10	150.84
	September	843.1 ± 6.6	23.60	866.65
	October	1540.0 ± 3.9	149.60	1689.56
	November	1965.5 ± 5.3	230.80	2196.33
	December	2620.6 ± 2.5	0.10	2620.68

[1]CFVS - Vertisols continuous flooding, AWDVS - Vertisols under continuous flooding, CFNS - Nitosols under alternate wetting and drying, AWDNS - Nitisols under alternate wetting and drying

The total rainfall received during this study period (August – December 2017) was 422.2 mm: intermittent rainy period in August and September 2017 (41.7 mm) and short rains (380.4 mm) in the month October and November 2017 (Table 5). Rainfall for a majority of the sampling period resulted in long periods of high soil moisture content. However, to maintain the required water levels (approximately 10cm) in the CF subplots as well as to replenish the water table in the AWD subplots, irrigation was done severally throughout the study.

Table 6 shows the irrigation water applied (m^3) in each individual subplot over the growing season. From the analysis, the water regimes (CF & AWD) had a significant effect on the amount of water applied ($P < 0.001$), while the type of soil (VS & NS) did not have a significant effect ($P = 0.369$) on the amount of water applied (Table 5). However, there was a significant water regime x soil type interaction effect ($P < 0.001$) on the amount of water applied in each subplot (Table 6).

Table 6: Irrigation water applied (m^3) for each treatment over the growing season at the Kirogo rice research farm

Water regime	**Irrigation water applied (m^3)**	
	Soil type	
	VS	**NS**
CF	$269.1^{a} \pm 11.7$	$321.2^{b} \pm 18.5$
AWD	$188.3^{c} \pm 7.2$	$158.0^{c} \pm 7.3$
	ANOVA	
Water regime	P < 0.001	
Soil type	P = 0.369	
Water x Soil	P < 0.001	

[1]Data are averages (mean ± SE) over the growing season in each treatment. Means followed by the same letter are not significantly different P < 0.05

The irrigation water applied (m^3) in the VS under alternate wetting and drying (AWD and under continuous flooding (CF) was 188.3 m^3 per 105.3 m^2 subplot area and 269.1 m^3 per 105.3 m^2 subplot area (equivalent to 17882m^3 ha^{-1} and 25556m^3 ha^{-1} respectively). With the introduction of AWD in the vertisols, total water saving was 26% (equivalent to 7674 m^3 ha^{-1}). The water saving, however, was similar to that obtained by Carrijo et al., (2017). In the nitisols (NS) under AWD and under CF, the irrigation water applied was 158.0 m^3 and 321.2 m^3 per 105.3 m^2 subplot area (equivalent to 15006m^3 ha^{-1} and 30503m^3 ha^{-1} respectively). With the introduction of AWD in the nitisols, total water use (rainfall + irrigation water) was reduced by 45% (equivalent to 15498 m^3 ha^{-1}).

From the study, to maintain the water levels (~10cm above the soil surface); the continuously flooded subplots were irrigated more frequently over the growing season. However, the continuously flooded nitisols were irrigated more frequently (Table 7) compared to the continuously flooded vertisols with the nitisols under CF using 14.2% (equivalent to 4947 m^3 ha^{-1}) more water. This could be mainly attributed to the fact that vertisols; unlike the nitisols, have higher water holding capacity due its high clay content while the nitisols are well-drained compared to the vertisols since they have higher sand and silt content.

However, the nitisols under AWD water regime used 15% (equivalent to 2876 m^3 ha^{-1}) less water compared to the vertisols under AWD. This could be attributed mainly to the fact that the vertisols in the scheme fall under the class of montmorillonitic clays that crack when dry (Sombroek et al., 1982). Upon re-flooding of the vertisols under AWD, a considerable amount of the water applied was lost to deep seepage when cracks were first filled up. This also indicated that there was an interaction effect (water regime x soil type) as the water used in each soil type depended on whether the soil was under AWD or CF.

Following a *meta*-analysis from 56 studies with 528 side-by-side comparison of AWD to CF, Carrijo et al., (2017) reported that, introduction of AWD; mainly during the wet season, reduced water use by 25.7% which translated to great water savings. Other than less irrigation, reduced water use can also be attributed, in part, to reduced seepage and percolation losses in AWD rice fields. These losses are significantly reduced in the absence of flood water and are highly dependent on the hydrological properties of different soils (Carrijo et al., 2017). According to Sharma et al., (2002), 51% of water applied in sandy loam soil in India was being lost via percolation while in clayey soil in California, (Linquist et al., 2015) reported that about 15% of water applied was being lost via both seepage and percolation.

3.3 Productivity in the two soil types

Productivity (kg m^{-3}) was expressed as grain yield of water. Productivity in the vertisols under continuous flooding (CF-VS) and alternate wetting and drying (AWD-VS) was 0.18 kg m^{-3} and 0.23 kg m^{-3}, respectively while in the nitisols under continuous flooding (CF-NS) and alternate wetting and drying (AWD-NS) was 0.13 kg m^{-3} and 0.23 kg m^{-3} respectively.

Table 7: Grain yield (kg), number of irrigation, total water used in m^3, water saving (%) and productivity (kg m^{-3}) for each subplot over the growing season at the Kirogo rice research farm

Subplot	[1] Grain yield	No. of irrigation	Total water used	Water saving	Productivity
	kg ha^{-1}	No.	m^3 ha^{-1}	%	kg m^{-3}
CF-VS	5400.0[a]	53	29778		0.18
AWD-VS	5058.8[a]	32	22104	26	0.23
CF-NS	4613.1[a]	68	34725		0.13
AWD-NS	4418.1[a]	26	19227	45	0.23

[1] Basmati 370 rice grain yield data; provided by Kakehashi showed no significant difference in the yields from all treatments

Productivity was 28% and 78% higher in the VS and NS respectively under AWD compared to the CF. The Basmati 370 grain yield data collected and analyzed in this study showed no significant differences in the grain yield from both water management regimes (CF and AWD) irrespective of the soil type (Table 7). Also as observed in the present study, the interaction effect (water management regime x soil type) showed no significant effect on the grain yield. Although AWD did not significantly increase the yield (kg ha^{-1}), productivity was observed to be higher with the introduction of AWD in both soil types (Table 7).

The introduction of AWD; irrespective of the soil type, did not have a significant effect on the grain yield. This can be attributed mainly to the fact that there was no significant difference in the amount of water applied in the vegetative stage in all subplots (Figure 2); this resulted in ensuring that there were no yield losses with the application of AWD in both soil types. According to Myers et al., (2002), rice plants do not require huge amounts of water for growth but can thrive under flooded conditions during part of its growth cycle. Also, according to Minamikawa & Sakai, (2005), rice plants require water mainly during the rooting stage, but in the other stages during growth, the plant does not always need to be flooded.

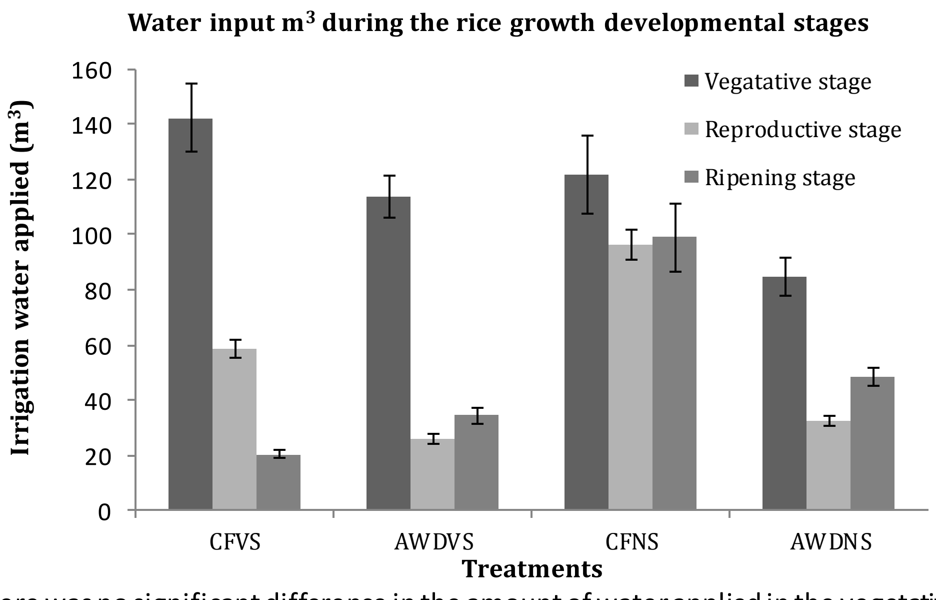
Reported effects of AWD on rice grain yield are highly varied with some studies reporting yield penalties (Y. Xu et al., 2015b; Linquist et al., 2015; Lagomarsino et al., 2016) while others showing no decline or change in yield (Yao et al., 2012; LaHue et al., 2016). This variability is attributed mainly to the wide range of water-saving rice production systems classified as AWD (LaHue et al., 2016). To minimize yield loss, adopting this systems to site specific management such as: flooding duration, drainage frequency, soil type, rice varieties among other factors (Lagomarsino et al., 2016) is crucial. Productivity in the nitisols was much higher than in the vertisols mainly due to the fact that CF in the well-drained nitisols resulted to more frequent irrigation (in the reproductive and ripening stages – Figure 2) to maintain ~10cm water levels lost through not only evapotranspiration but also seepage and percolation losses. With the introduction of AWD in this soil type, the seepage and percolation losses were minimized and less irrigation was done throughout the growing season without affecting the grain yield.

3.4 Water Use in the Rice Growth Developmental Stages

The growing season was subdivided into developmental stages of rice growth (vegetative stage: from transplant to panicle initiation), reproductive stage (from panicle initiation to flowering) and ripening stage (flowering to mature/harvest stage). Water input in the vegetative stage in both soil types was much higher than in the other two stages (reproductive & ripening stage). Total water applied in the vertisols (VS) and nitisols (NS) during the vegetative stage was 65% and 75% respectively. This can be attributed mainly to the fact that during the fallow season before transplanting had been done in the fields, both soils had cracks and were very dry and a lot of water was required to fill the soil pore spaces.

Irrigated rice production is the main consumer of water in the agricultural sector (Ed, 2006). Also, according to Minamikawa & Sakai, (2005), rice plants require water mainly during the rooting stage, but in the other stages during growth, the plant does not always need to be flooded. The Vertisols under continuously flooded water regime received the highest water input during this stage, and this was attributed to the deep cracks in the soil when dry (Sombroek et al., 1982) had been done. The well drained soils, nitisols in continuously flooded conditions received high amounts of water input in the reproductive & ripening stages.

Figure 2: Irrigation water applied in each treatment at different rice growth developmental stages



There was no significant difference in the amount of water applied in the vegetative stage in all treatments (Figure 2). The ripening stage in both soils received the lowest amount of water. According to Myers et al., (2002), rice plants do not require huge amounts of water for growth but can thrive under flooded conditions during part of its growth cycle.

4.0 Conclusion

Although AWD in this study did not have a significant effect on grain yield, there was a significant decrease in water applied in each soil type compared to the continuously flooded plots. If AWD is implemented, relatively adequate and reliable water supply would enable farmers in the Mwea Irrigation Scheme as well as other schemes to cultivate more rice areas with sufficient water while maintaining yield. Thus, when AWD is implemented countrywide, it is expected to result in further increases in rice production in the country. Alternate wetting and drying (AWD) may compromise rice grain yield mainly in dry seasons. It is therefore important to fine tuning this irrigation strategy to site specific conditions and manage the drying and wetting cycle (i.e., rice fields irrigation before water levels go below the rooting zone) as rice plant are extremely sensitivity water stress. Finally, it was observed that with AWD, it is critical to ensure proper rice plants establishment by applying enough water in the vegetative stage due to the sensitivity of rice in this stage hence grain yield was not affected irrespective of soil type.

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