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Irrigation management techniques with anaerobic baffled reactor effluent: effect on rice growth, yield and water productivity

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Abstract

The study evaluated the effect of irrigation management techniques using anaerobic baffled reactor (ABR) effluent on the growth and yield of rice. It was hypothesized that irrigation techniques with ABR effluent have a significant effect on the growth, yield of rice, water productivity (WP) and water balance (WB). The experimental setup was a randomized complete block design for 2017 and 2018 cropping seasons, three treatments each with three replications. The treatments were alternating wetting and drying (AWD), continuous flooding irrigation (CFI) and wetting without flooding (WWF). The effect of irrigation management techniques was significant ($P < 0.05$) for the 2017 season but insignificant ($P > 0.05$) in 2018 on the yield. The effect of irrigation treatments on WP was significant ($P < 0.05$). The effects were not significant ($P > 0.05$) on the plant height, leave area index (LAI) and number of tillers per plant. However, the effect was significant ($P < 0.05$) on the number of panicles per plant. The effects of irrigation treatments were significant ($P < 0.05$) on number of irrigation, amount of irrigation, total water use and daily field WB. In conclusion, the result proved the acceptability of the hypothesis. AWD irrigation with ABR effluent should be encouraged among rice farmers.

Key words: alternate wetting and drying, anaerobic baffled reactor, continuous flood irrigation, effluent, water productivity and wetting without flooding

INTRODUCTION

Water is a valuable resource, yet it is an insufficient resource in many nations. Consequently, there is a need to preserve, protect and conserve fresh water and access lower quality water for irrigation (Al-Rashed & Sherif 2000). Water is a natural asset critical for the survival of human beings. Different human activities, which include disposal of effluent into both surface and ground water resources, coupled with increasing population, have made appropriate management of water resources a very complex requirement throughout the world. Essentially, an increase in the water demands by the urban populations is reducing the fresh water available for agricultural purposes, with a rise in associated costs. To counter the continuous increase in irrigation water needs for growing food and meeting fibre requirements of an increasing populace, it is imperative to enhance irrigation water efficiency to guarantee sustainable agriculture. According to Renner (2012), surface irrigation is the application of

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water to the surface of the field. The entire field might be flooded (basin irrigation), the water might be fed into minor channels (furrows) or strips of land (borders), and it is the most common irrigation method. It is usually applied when conditions such as sufficient or abundant supply of water are favourable, mild slopes, soil type is clayey-loam with medium to low infiltration rate. Basins are surrounded by low bunds. The bunds avert water from moving to the end-to-end fields (Renner 2012).

Recycling of urban wastewater in agriculture has become public practice for a number of reasons, partly due to water scarcity, nutrient worth and environmental safety (Tamoutsidis *et al.* 2009). The need for irrigation, since rainfall is not readily available throughout a season, and the need for water are constantly growing; therefore, water of higher quality is conserved for domestic use while that of lesser quality is suggested for irrigation purposes. Some research has shown that farming households having close contact with wastewater-contaminated surface water have a higher risk of helminth infections compared with those without contact (Pham-Duc *et al.* 2013); although van der Hoek *et al.* (2006) reported no significant association between wastewater exposure and helminth infections. Crop restriction such as crops that will be cooked before consumption, human exposure control and choice of wastewater application method (spray and sprinkler irrigation not recommended) are some of the ways to protect farmworkers and household (Scott *et al.* 2008). The farmworkers must use appropriate protective covers such as clothing, long gloves, shoes and hand washing with soap. Rigorous health education programs and vaccination against typhoid and hepatitis are worthy of consideration (Scott *et al.* 2008). The risks of groundwater contamination due to irrigation with treated excess wastewater have a long-term effect and are challenging to estimate (Shakir *et al.* 2017). Groundwater pollution is considerably more problematic to stop than surface pollution since groundwater can travel a significant distance through invisible aquifers, but impervious aquifers like clays partly decontaminate water by simple filtration through adsorption and absorption, or chemical and biological activity. Musazura *et al.* (2015) found that dense peri-urban settlements in developing countries like South Africa need a cost effective systems such as decentralized waste water treatment systems (DEWATS) to be developed. These involve the use of anaerobic baffled reactors (ABR). Wang *et al.* (2004) defined the ABR as a closed tank with series of hanging and standing baffles which allow wastewater to flow under and over them from the inlet to outlet in the absence of oxygen. DEWATS increases wastewater reuse opportunities. The nutrients in the effluent from DEWATS have an economic value as a fertilizer and it has potential to be used in irrigated agriculture, and since communal ABRs receive input from mainly domestic sources, the probability of heavy metals is very low and the risk is negligible. This makes ABR effluent from a DEWATS a very promising source of irrigation. Major elements like Ca and Mg, required for plant growth, can accrue in soils, thereby improving the pH, especially of acidic soils (Bame *et al.* 2014).

Rice (*Oryza sativa L.)* is the main food for more than half of the world population, plus thousands of families in sub-Saharan Africa (SSA). Rice is grown in almost 115 nations in the world and is only next to wheat in terms of production globally. Approximately 40% of the rice consumed in Africa is imported (Seck *et al.* 2010). Production of rice under irrigation requires high quantities of water at about 2,500 litres for 1 kg of rice. The quantity of water application during the growing season can vary from 500 to 800 mm up to more than 3,000 mm. Rice cultivation needs enormous quantities of water and nutrients; it requires 16 vital elements optimally. The root zone is between 0–20 cm for lowland rice (anaerobic) while that of upland rice (aerobic) is 0–40 cm (Bouman *et al.* 2007). According to the International Rice Research Institute (IRRI), rice is typically grown in bunded fields that are continuously flooded up to 7–10 days before harvest. Currently, rice is cultivated on every continent except for Antarctica (Muthayya *et al.* 2014). According to Balasubramanian *et al.* (2007), SSA faces numerous problems. The key one is to improve the lives of 30% of its populace that is affected by poverty and food insecurity. A report by Africa Rice Center (2007), formerly referred to as West Africa Rice Development Association – WARDA, reported that South Africa and Mozambique have the highest per capita rice consumption at 14 kg/year. Rice production in the Southern Africa region is

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inundated by low yield compared to Western and Central Africa. Rice importations characterize more than 90% of domestic consumption requirements, excluding Zambia and Mozambique. Practically all rice consumed in South Africa is sourced from the international market (Center 2007).

For rice, irrigation water-saving technologies comprise alternate wetting and drying (AWD) and saturated soil culture-wetting without flooding (WWF) (Bouman *et al.* 2007). The well-watered conditions with 100% water holding capacity is another irrigation management technique (Ruíz-Sánchez *et al.* 2011). It is referred to as WWF. However, AWD is the most commonly practiced water-saving irrigation management technology. Yield penalty was a common attribute of AWD irrigation as compared with a conventional way of cultivating lowland rice termed continuous flood irrigation (CFI). In AWD, irrigation water is applied to realize intermittent flooded and non-flooded soil conditions. The rate of irrigation from drying to flooded conditions depend on when the ponded water table drops to a particular level beneath the soil surface or when there are cracks appearing on the soil surface or when plants show feasible symptoms of water shortage. Generally, AWD irrigation increased water productivity (WP) with respect to total water used because the yield reduction compared with CFI was smaller than the amount of water saved (Yao *et al.* 2012).

The abundancy of municipal treated wastewater at the experimental site is a problem that must be addressed in terms of reuse and disposal. There has not been any reported use or adoption of ABR effluent with irrigation management techniques in the Republic of South Africa (RSA) and other parts of the world. The beneficial use of ABR effluents is more a general research activity undertaken by the Pollution Research Group (PRG). This study, therefore, aimed to investigate the effect of ABR effluent irrigation management techniques on the growth, yield parameters of rice, water balance (WB) and WP. The hypothesis stated that irrigation water management techniques with ABR effluent have a significant effect on the growth, yield of rice, WB and WP.

METHODS

Study site

The experimental site and ABR effluents treatment plant are located at the Agricultural Hub, Newlands Mashu research facility, Durban, South Africa. The Newlands Mashu site map is displayed in Figure 1. The site is on latitude 29° 46′ 26″ S and longitude 30° 58′ 25″ E. It is characterized by an average annual precipitation of 1,000 mm and mean daily temperature of 20.5 °C. The soil classification was a clayey-loam. The mean monthly temperature, relative humidity and rainfall obtained from the on-site weather station for the growing period are presented in Table 1.

The ABR effluent was from domestic sources comprising about 83 households within the site. It was a purely domestic unlike industrial effluent, which contains heavy metals. Therefore, the issue of heavy metals being present is negligible for irrigation when using treated effluent (Toze 2006). Table 2 below shows the chemical composition of the effluent. Bedbabis *et al.* (2014) reported that treated effluent does not significantly affect some properties of soil and Musazura *et al.* (2015) observed insignificant changes in the physical and chemical properties of soil after irrigation with ABR effluent.

Experimental design and layout

Experiments were conducted in 2017 and 2018 at two adjacent fields. Experimental design was a randomized complete block design (RCBD) with three replications in both years. The experiments consist of a factor, irrigation water management techniques with three levels of treatments, AWD, CFI and continuous WWF. CFI treatments were used as a control for both seasons. Cut-off drains

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Figure 1 | General overview of the study area

Table 1 | Average monthly temperature, relative humidity and rainfall for the two seasons at the experimental site

Seasons		Month	Average temp. (°C) Max	Min	Ave.	Relative humidity (%) Max	Min	Ave.	Rainfall (mm) Ave.
	Season 1	Oct 17	27.03	15.35	21.19	93.99	47.31	70.65	54.10
		Nov 17	26.64	16.42	21.53	94.15	50.36	72.26	70.44
		Dec 17	28.27	19.39	23.83	94.93	56.96	75.95	86.61
		Jan 18	29.98	20.20	25.09	94.92	54.29	74.60	123.28
		Feb 18	30.10	19.73	24.91	95.33	53.35	74.34	70.79
		Mar 18	29.80	19.27	24.53	96.76	54.65	75.71	88.73
		Apr 18	28.19	15.98	22.09	95.92	47.05	71.49	12.53
		May 18	27.41	12.67	20.04	96.99	41.88	69.44	75.35
Season 2		Jun 18	26.13	9.64	17.88	95.34	33.65	64.49	2.79

were entrenched around the perimeter of the field to prevent surface run-off entering the whole field. The drain collected all the runoff coming from the field, and channeled it to a stilling basin that was dug at the outlet of the cut-off drain. The stilling basin prevented the scouring effect that could cause damage to the adjacent land. The experimental design gave rise to nine plots of equal size measuring 3 m by 1.5 m each (Figure 2). Bunds were established between plots to isolate them from adjacent plots. Bunds (30 cm wide at the base and 20 cm high) were covered with plastic sheeting (250 μm grade) which was dug into the soil with the aid of metal sheeting to a depth of 0.6 m to prevent run-on, run-off, lateral-in and lateral-off in each plot for a proper WB analysis. Zhang *et al.* (2010), Tan *et al.* (2013), Pascual & Wang (2016) suggested 0.5 m, Ye *et al.* (2013) used 0.3 m, while Yao *et al.* (2012) suggested 0.2 m as the depth of inserting plastic sheeting. Inserted in each plot was a 400 mm long and 110 mm diameter PVC observation tube perforated with 5 mm diameter holes at 40 mm intervals. About the half side of the tube was inserted into the field (at least 500 mm away from the bund, 200 mm above and 200 mm below the topsoil) for the monitoring of water table

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Table 2 | ABR effluent characteristics

Parameters	Units	Mean	SD	Range
Ammonium – N (NH_4^+-N)	(mg/L)	58.45	±0.89	43.73–67.57
Nitrite – N (NO_2^--N)	(mg/L)	0.53	±0.01	0.18–1.00
Nitrate – N (NO_3^--N)	(mg/L)	0.30	±0.07	0.10–0.47
Total Kjeldahl N (TKN)	(mg/L)	62.91	±0.87	46.93–76.20
Total nitrogen (TN)	(mg/L)	67.67	±1.37	53.67–76.00
Ortho phosphate (PO_4^{3-}-P)	(mg/L)	18.19	±0.18	14.80–22.23
Chemical oxygen demand (CODt)	(mg/L)	276.60	±5.03	222.67–295.00
Total suspended solids (TSS)	(mg/L)	82.00	±2.03	67.78–123.33
Dissolved oxygen (DO)	(mg/L)	1.37	±0.05	0.22–3.51
Alkalinity	(mg/L)	6.98	±0.19	5.56–7.87
Ecoli	(cfu/ml)	2,600.00	±700.00	2,000.00–3,400.00
pH		7.27	±0.05	7.19–7.38
Electrical conductivity (EC)	S/m	93.22	±0.83	71.57–107.90

Note: cfu is colony forming unit and S/m is Siemens per metre.

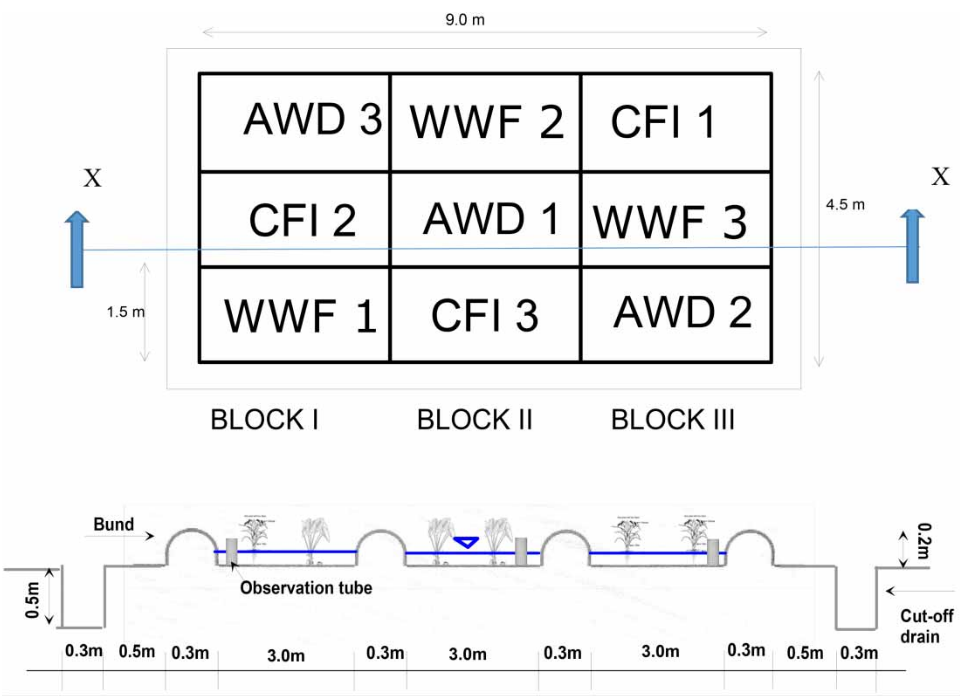

Figure 2 | Field layout and cross-section X – X

and to instruct when to irrigate as per general recommendations (Bouman *et al.* 2007; Ye *et al.* 2013; Lampayan *et al.* 2015). A measuring tape (metal) was used to measure the water level in the tube.

Crop management

The rice variety used for the experiments was FARO 44 lowland adaptation, takes between 110 to 120 days to maturity, has a maximum plant height of 110 cm and average yield of 4.5 to 6.5 t ha^{-1}. Rice was considered for irrigation with the effluent because of its water, nutrients requirement and the need to be cooked before consumption, which reduces health risks for consumers. Prior to sowing,

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rice seeds were washed and soaked for 24 hours in salty water, following which they were incubated at 30 °C for another 24 hours to stimulate strong germination (Mulbah 2010). Seedlings were raised at the seedbed with a sowing date of 21 September in 2017 and 19 January in 2018. Transplanting was done on 8th October in 2017 and 4 February in 2018 at a hill spacing of 25 × 25 cm inter and intra plant spacing. It had three rows of six plants per row (18 plants per plot) for a plant population of 40,000 plants per hectare. Four inner plants were selected for sampling leaving the border plants. Thinning was done at minimum of seven and maximum of 14 days after planting to replace dead seedlings. Neither fertilizer nor insecticide were applied but periodic weeding was done.

Irrigation

The field trials were irrigated by basin/flood method with bunds to control run-off. There were networks of PVC pipes (main, lateral and field) with a ball gate control valve and water tap at each plot. Scouring protection (boulders and granites) was placed at the point of discharge into the plots. The depth of irrigation water (pond) was continuously maintained at a depth of 50 mm and stopped at two weeks before harvesting for all CFI replications. AWD treatments also maintained an irrigation water pond of 50 mm whenever the ponded water level in the tube has dropped to 150 mm below the surface (Lampayan *et al.* 2015). The level of water in the tube for WWF plots was the same with the field (well-watered). Measurement of depth and when to irrigate were dictated by observation of water table level in the water observation tube with the aid of an improvised light weight foams (polystyrene). A Campbell scientific automated weather station (AWS), with a CR 1,000 data logger (Utah, USA) mounted about 12.7 m away from the field trial was used to collect weather data. The AWS measured the total rainfall, reference evapotranspiration (*ET*o in mm/day) according to FAO Penman-Monteith equation and crop evapotranspiration, *ET*c, was calculated as a product of *ET*o and crop coefficient factor, Kc. Figure 3 and 4 presented the graph of duration of planting

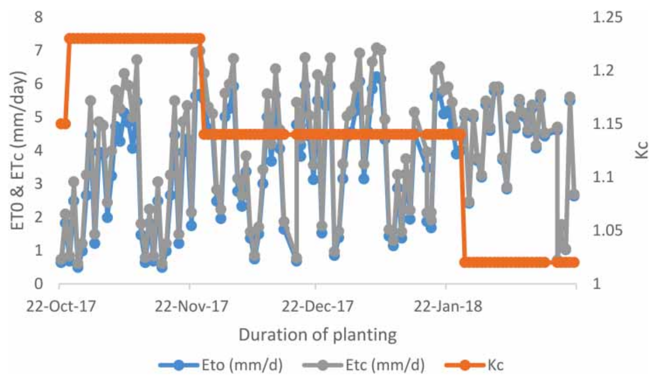

Figure 3 | Duration of planting versus ETo, Kc and ETc for 2017 planting season

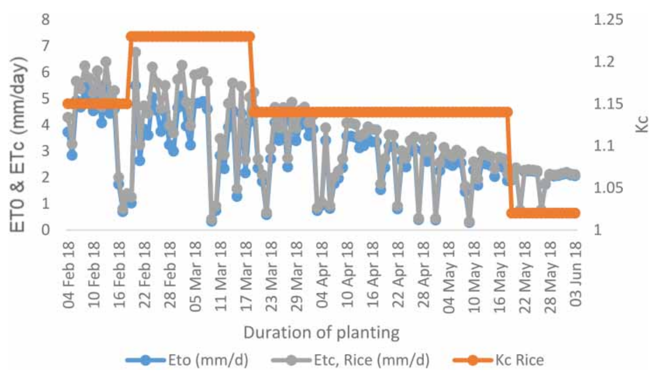

Figure 4 | Duration of planting versus ETo, Kc and ETc for 2018 planting season

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versus ETo, Kc and ETc throughout the trials for season 1 and 2 respectively. Kc for rice is divided as initial (1.15 for 30 days), development (1.23 for 30 days), mid (1.14 for 60 days) and late stage (1.02 for the last 30 days) for a 150-day rice variety (Tyagi *et al.* 2000).

Water saving, water balance and water productivity

Water saving was determined with reference to a particular irrigation water management technique (CFI – control and conventional irrigation for lowland rice) and calculated as

$$Water\ saving\ at\ AWD = \frac{CFI(t) - AWD(t)}{CFI(t)} * 100\%$$

$$Water\ saving\ at\ WWF = \frac{CFI(t) - WWF(t)}{CFI(t)} * 100\%$$

where,

AWD (t), CFI (t) and WWF (t) were the total water used by different treatments (mm).

The WB in the root zone of the irrigated soil in a given time interval (t) was given as Equation (1):

$$\Delta Wt = (I + P + RON + LATON + CR)t - (ET + ROFF + LATOFF + DP)t \quad (1)$$

where

ΔWt = changes in soil water storage (mm) over time, t (day),
I = applied irrigation water (mm),
P = precipitation (mm),
RON = run-on to field (mm),
$LATON$ = lateral or seepage flow into the field (mm),
CR = capillary rise from the water table (mm),
ET = evapotranspiration (mm),
$ROFF$ = run-off leaving field (mm),
$LATOFF$ = lateral or seepage leaving field (mm), and
DP = deep percolation below the root zone (mm).

The effect of plastic sheeting between plots changed the equation to:

$$\Delta Wt = (I + P + CR)t - (ET + DP)t \quad (2)$$

According to Fereres & Connor (2004), deep percolation is negative if capillary rise occurs and Mermoud *et al.* (2005) said rising capillary movement into the root zone results in negative value of deep percolation. It was therefore assumed that the deep percolation negates the capillary rise. Hence, the resultant WB equation became:

$$\Delta Wt = (I + P)t - (ET)t \quad (3)$$

According to Yao *et al.* (2012), WP was defined as the grain yield per unit of total water input including irrigation and precipitation and was calculated as;

$$Water\ productivity = \frac{Grain\ yield}{Water\ use}$$

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Data collection

Data on the growth parameters were measured weekly from four sample plants in each of the three replications for all treatments. The height of the individual plant was measured as the distance (m) from the ground level to the shoot apex. The number of tillers and panicles for each plant were determined by direct counting of functional tillers and panicles, respectively. Leaf area indices (LAI) were measured using the LAI-2200C Plant Canopy Analyzer (LI-COR Environmental) throughout the growing seasons. Yield components such as number of filled grains per panicle, weight of 1,000 filled grains and grain yield were measured at harvest.

Statistical analysis

Data collected were subjected to normality test using Skewness and Kurtosis for numerical and Normal Q-Q plots for graphical outputs. The two methods showed that data were approximately normally distributed. The Data sets for both seasons were then subjected to statistical analysis of variance (ANOVA) with a least significant difference (LSD) test at the 0.05 probability level using GenStat® 18th edition analytical package of 2016. Where differences in treatment means were significant, means were separated using the Duncan LSD test.

RESULTS AND DISCUSSION

Irrigation

The effects of irrigation water management techniques with ABR effluent were highly significant ($P < 0.001$) on number of irrigation events, amount of irrigation, total water use and daily WB for both seasons as shown in Table 3. There was a significant ($P < 0.05$) reduction with respect to number of irrigation events under AWD treatments but an insignificant ($P > 0.05$) reduction in WWF treatments when compared with the control (CFI). The amount of irrigation, total water use and WB on the other hand were significantly ($P < 0.05$) reduced by both AWD and WWF treatments. AWD and CFI treatments had the lowest and highest values respectively in all the variables measured for both seasons (Table 3). The highest quantity of water was recorded under CFI treatments because of the continuous ABR effluent application in order to achieve ponding, unlike the intermittent application characterised by AWD treatments. The WWF was similar to CFI since water application was also continuous, but not to ponding level. The higher the total number of irrigation events, the greater the amount of irrigation and WB. Irrigation amount or total water use is a key parameter of WB.

Table 3 | Effects of irrigation water management techniques with ABR effluents on number, amount of irrigation, total water use and daily water balance for 2017 and 2018 seasons

Season	Treatments	Number of irrigation	Amount of irrigation (mm)	Total water use (mm)	Water balance (mm/day)
2017	AWD	18.00^{a}	888^{a}	1,238^{a}	5.72^{a}
	CFI	63.00^{b}	1,638^{c}	1,988^{c}	11.85^{c}
	WWF	61.00^{b}	1,468^{b}	1,819^{b}	10.48^{b}
	p	***	***	***	***
2018	AWD	21.33^{a}	1,040^{a}	1,281^{a}	7.17^{a}
	CFI	95.00^{b}	2,453^{b}	2,694^{b}	19.36^{c}
	WWF	92.00^{b}	2,363^{b}	2,604^{b}	18.65^{b}
	p	***	***	***	***

Notes: Means with same alphabets within a column in each season do not differ significantly at 5% level of probability.
p = probability.
**** = significant at 0.001 probability level.*

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The total water use for all the treatments were higher in 2018 season than 2017 season. AWD produced water savings of 38 and 52% for 2017 and 2018 season respectively when compared with CFI without any yield penalty. WWF treatments also saved water but with significant yield reduction. The resultant water saving was as a result of intermittent flooding and drying of the rice field. This agreed with the study of Pascual & Wang (2016), which reported water savings of between 50 to 72% for flooded to intermittent drying conditions. Tan *et al.* (2013) reported 16% saving as compared with CFI, Yao *et al.* (2012) noted savings of between 24% and 38% using AWD when compared with CFI, while Bouman *et al.* (2007) reported savings of 200–900 mm. The daily WB showed that the total water used (rainfall and irrigation) was higher than the crop evapotranspiration. The results also showed that the amount of irrigation in the 2018 season was higher than the 2017 season. The difference compensated for the fact that total amount of rainfall was higher in the 2017 season.

Growth parameters

The effects of irrigation water management techniques with ABR effluents on growth parameters of rice are displayed in Figure 5 and Table 4. The effect of irrigation treatments on the number of panicles per plant was significant ($P = 0.003$) in 2017 and also significant ($P = 0.007$) in 2018. Further analysis to separate the means showed that means from CFI and WWF treatments were significantly different from means of AWD treatments as shown in Figure 5. The average number of panicles per plant were higher in 2018 than 2017 season. This may be as a result of early birds' invasion at the trial in 2017 before scarecrows were provided.

Figure 5 | Graphical representation of the effects of treatments on growth parameters of rice. Notes: Means with same alphabets within a season do not differ significantly at 5% level of probability.
*** = significant at 0.01 probability level.*

Table 4 | Effects of irrigation water management techniques with ABR effluents on growth parameters of rice for 2017 and 2018 seasons

Season	Treatments	Height (cm)	Leave area index (LAI)	Tiller numbers per plant
2017	AWD	66.32[a]	3.57[a]	58.51[a]
	CFI	75.53[a]	3.62[a]	52.13[a]
	WWF	70.58[a]	3.32[a]	50.98[a]
	p	*ns*	*ns*	*ns*
2018	AWD	94.58[a]	4.14[a]	59.36[a]
	CFI	100.94[a]	3.92[a]	56.33[a]
	WWF	97.17[a]	4.15[a]	55.79[a]
	p	*ns*	*ns*	*ns*

Notes: Means with same alphabets within a column in a season do not differ significantly at 5% level of probability.
p = probability.
ns (not significant).

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Irrigation water management techniques did not significantly affect the plant height in 2017 ($P = 0.37$) and 2018 ($P = 0.65$). The plant heights at every treatment were higher in 2018 than in 2017. The lowest heights found in AWD agreed with the study of Fonteh *et al.* (2013), who found that reduced depth of ponding and drying enhances the emergence of weeds, which significantly reduces the height of rice plants. LAI was also not significantly affected with the effects of irrigation treatments in both the 2017 ($P = 0.69$) and 2018 ($P = 0.79$) seasons. The LAI was higher in treatment AWD than CFI in 2018 and this agreed with the study of Pascual & Wang (2016), who found that LAI under intermittent irrigation is higher than flooded condition. The maximum number of tillers produced per plant was observed in AWD treatment in both seasons. The effect of irrigation water management techniques however had no significant difference ($P = 0.41$ for 2017 and $P = 0.79$ for 2018) in number of tillers per plant. The physical inspection of rice in the field did not pick up on any sign of growth disorder, even at a high fertilization rate from ABR effluent. This could be attributable to the fact that irrigated lowland rice like FARO 44 is characterised by a relatively low N-fertilizer efficiency because inorganic N applied is rapidly lost from the field of soil-flood water through volatilization and denitrification (Cassman *et al.* 1996).

Yield components

Tables 5 present the effects of irrigation water management techniques on the yield components of rice. The effect of irrigation management techniques was significant ($P = 0.001$ and 0.05) on the number of filled grains per m^2 for both seasons. Further analysis to separate the means of each treatment revealed that the means of number of filled grains per m^2 for treatments AWD and CFI were not significantly different from each other but significantly different from treatment WWF. The effect of irrigation treatments was not significant ($P = 0.08$) in 2017 and ($P = 0.13$) in 2018 on number of panicles per m^2. The treatments did not have significant effect, $P = 0.70$ in 2017 and $P = 0.57$ in 2018 on the weight of 1,000 filled grains. The yield components for both seasons followed the same trend with the exception of number of filled grains per panicles that was significant ($P = 0.05$) in 2017 but not significant ($P = 0.13$) in 2018 trials.

Table 5 | Effects of irrigation water management techniques with ABR effluents on yield components of rice

	Treatments	Number of filled grains per m^2	Number of filled grains per panicle	Number of panicles per m^2	Weight of 1,000 filled grains (g)	Grain yield (t/ha)	Water productivity (kg/m^3)
2017	AWD	$23{,}556^b$	77.33^b	305.30^b	24.13^a	5.68^b	0.46^c
	CFI	$21{,}662^b$	80.67^b	268.70^{ab}	24.90^a	5.39^b	0.27^b
	WWF	$14{,}990^a$	62.67^a	240.70^a	25.69^a	3.86^a	0.21^a
	p	***	*	*ns*	*ns*	**	***
2018	AWD	$24{,}862^b$	81.00^a	307.30^a	25.63^a	6.38^a	0.50^b
	CFI	$23{,}620^b$	84.33^a	280.00^a	26.87^a	6.36^a	0.24^a
	WWF	$15{,}231^a$	61.33^a	248.30^a	26.93^a	4.12^a	0.16^a
	p	*	*ns*	*ns*	*ns*	*ns*	**

Notes: Means with same alphabets within a column do not differ significantly at 5% level of probability, ns (not significant).
* = *significant at 0.05 probability level.*
** = *significant at 0.01 probability level.*
*** = significant at 0.001 probability level.

Grain yield

The effects of irrigation water management techniques on the grain yield of rice for both seasons' trials are presented in Table 5. The effect of irrigation treatments was found to be significant ($P = 0.01$) in 2017 but insignificant ($P = 0.12$) in 2018. There was a significant ($P < 0.05$) reduction in the

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yield of WWF treatments as compared with CFI (control) treatments. However, there was an increase in the yield of rice grain under AWD treatments, though the effect was not significant ($P > 0.05$). The treatment AWD produced the highest grain yields of 5.68 in 2017 and 6.38 t/ha in 2018. Rice grown using AWD irrigation techniques can show a higher yield than continuously flooded irrigation (Yang & Zhang 2010; Zhang *et al.* 2010). The higher grain yield in the 2018 season could be attributed to the higher amount of nutrients-rich effluent applied to the rice field as compared to the 2017 season. Early attack of birds in 2017 before a combination of scarecrows were provided could also have contributed to the low yield. The flood and dry cycles experienced under AWD irrigation enhanced air exchange between the soil and the atmosphere, enough oxygen is supplied to the root system to accelerate soil organic matter, which may have contributed to higher and more LAI, tiller numbers, panicle numbers and eventually grain yield experienced in this study. This was in consonant with the findings of Ye *et al.* (2013). AWD promoted higher LAI compared with CFI because continuous or prolonged flooding resulted in lower LAI and crop growth rate (Pascual & Wang 2016). The result of yield components such as number of filled grains per panicle and 1,000 grain weight agreed with the work of Pascual & Wang (2016) and Zhang *et al.* (2010). FARO 44 (same rice variety with this study) has potential grain yield between 4.0 and 6.0 t/ha (Akintayo *et al.* 2011). The grain yield of rice produced with the ABR effluent irrigation was averagely good when compared with that of the usual cultivation with fertilizer and rain-feeding (FARO 44 varieties) that produced 3.2 t/ha as reported by Akintayo *et al.* (2011). Average yields of 5.86 to 6.86 t/ha and 5.7 to 6.5 t/ha were reported by Oliver *et al.* (2008) and Fonteh *et al.* (2013) respectively. These grain yields were in the range of yields obtained by this study with the application of only ABR effluent without additional organic or inorganic fertilizer. This showed the effect of ABR effluent on the grain yield since they were basically same irrigation methods, similar plant spacing, though different rice varieties and irrigation water. Pascual & Wang (2016) cultivated a fertilized rice field with the same irrigation methods and reported higher average yields of 7.46 to 10.46 t/ha. This could be attributable to the effects of fertilizer concentration of 270 kg/ha of NPK (Pascual & Wang 2016) as against 150 kg/ha applied by Fonteh *et al.* (2013). Nitrogen is the most extensively used input by rice farmers to improve production but over application may reduce potential yield or delay maturity (Ata-Ul-Karim *et al.* 2017). The recommended crop nutrient requirement is N 120 kg/ha (Mohammad *et al.* 2018). The minimum (AWD treatments) N supplied to the rice crop by the effluent amounted to 519 kg/ha, which was higher than the N requirements, hence there was no need for extra fertilizer. All the above N fertilizer input recommendation are lower than that of ABR effluent for this study. The high fertilization of ABR effluent in this study may be responsible for the delay in maturity of the crop and the yield obtained. This was evidenced in this study because FARO 44 was supposed to mature for harvest in four months according to the seed supplier but the crop matured at age five months. The effects of ABR effluent may have been affected by rainfall in the field trials since it was not covered from receiving rainfall. WP is one of the most important criteria to justify AWD irrigation technology. The effect of irrigation water management techniques was highly significant ($P < 0.001$) in 2017 and also significant ($P = 0.002$) in 2018. Each of the treatments were significantly different from one another in 2017. There was no significant different between means of CFI (control) and WWF treatments in 2018, they (CFI and WWF), however, different significantly from the means of AWD as shown in Table 5. The features of total water use and WP came out clearly in the study, showing the highest WP in AWD for both seasons as compared to CFI. This result was supported by the work of Ye *et al.* (2013).

CONCLUSIONS

The results of this study have shown the effects of ABR effluent irrigation water management techniques on growth and yield of rice crop. The growth and yield parameters of lowland rice were

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improved as a result of irrigation management techniques with ABR effluent. The number, amount of irrigation and total water use were lower in AWD as compared to either CFI and WWF treatments. AWD irrigation was able to save 38 and 52% of water use as compared to treatments CFI in 2017 and 2018 respectively. The value of the water saved by this technique would itself be sufficient to address justification for its adoption in cultivating lowland rice because the saved irrigation water may be used for irrigating other crops or fields. In spite of using much less ABR effluent for irrigation, AWD gave the highest yields of 5.68 in 2017 and 6.38 t/ha in 2018. These yields were obtained with the use of ABR effluent that was free of any additional fertilizer. It could be concluded that a submerged paddy field is not necessarily the only solution to optimum rice production. Rice can therefore be grown in an anaerobic and aerobic conditions. The daily WB revealed that the total amount of water (rainfall and irrigation) was in excess of the water lost through evapotranspiration.

AWD was found to be the most suitable because of the highest WP at both seasons. The hypothesis of having a significant difference on the grain yield, panicle number per plant, WB, WP, number of irrigation events and water use should be accepted, but rejected on the effect of irrigation water management techniques on plant height, LAI and number of tillers per plant. Rice has been regarded for a very long time as an aquatic plant, but this conviction has been repeatedly challenged, as rice is known to be capable of growing under both flooded and non-flooded conditions as evidenced in this study and past related studies.

Finally, with the effects of climate change and growing competitions for water in this region, AWD offers an opportunity worth adopting in South Africa. However, further study to investigate the effect of percolation and nitrogen leaching in paddy fields is needed.

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