ISSN 1927-050X E-ISSN 1927-0518
Published by Canadian Center of Science and Education

Water Use Efficiency Differences in Maize Varieties under Every Furrow and Alternate Furrow Irrigation

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Received: December 10, 2019 Accepted: January 13, 2020 Online Published: February 7, 2020

doi:10.5539/sar.v9n2p17 URL: https://doi.org/10.5539/sar.v9n2p17

Abstract

Water-use efficiency (WUE) differences of selected maize varieties under alternate and every furrow irrigation were investigated in a split-plot design trials with three replicates. Alternate furrow (AFI) and Every furrow irrigation (EFI) were main treatments and twenty maize varieties were sub-treatments. Plots were 64 m^2 with one maize seed per station spaced at 0.25m apart. Crop water use results indicated that EFI consumed more water than the AFI. The AFI reduced crop water consumption by 38 - 45% compared to EFI. Differences were also prominent in maize varieties' response to AFI. Late maturing maize varieties proved to have minor yield reduction with AFI compared to early and medium maturing maize varieties. WUE (kg m^{-3}) differed with irrigation water application strategy ($P<0.001$). AFI had high WUE. A combination of AFI with selection of water efficient maize varieties was a good strategy for improving WUE. The AFI is a promising furrow irrigation water management strategy for water saving. According to farmers experience at five irrigation schemes and on station research, it was concluded that AFI is one of the climate smart irrigation technique that farmer can easily adopt and apply as it saves labour, time water whilst reducing conflict for water among irrigators. It was recommended that AFI be applied fully on early and medium maturing maize varieties within an irrigation interval of 7 days. For late maturing maize varieties, AFI technique should be applied from initial stage to mid - stage (up 55 days from planting) then apply EFI at tasselling and silking stages to reduce water stress at this critical stage.

Keywords: maize varieties, alternate furrow irrigation, water use efficiency and every furrow irrigation

1. Introduction

Irrigating crop fields consumes about 70% of the freshwater globally (Kayikcioglu, 2012). In developing countries, about 95% of the total water withdrawal is for agriculture with the demand projected to continue to increase (FAOWATER, 2008). Maize is one of the staple food crops cultivated under irrigation in most developing countries especially in the sub Saharan region. Although maize crop is adapted to a wide range of climatic and edaphic conditions (Sharma and Dass, 2012; Jakhar *et al*., 2017) and has highest yield potential among cereals (Sharma and Dass, 2012; Kumari *et al*., 2017), its cultivation during dry season depends on irrigation and residual moisture. During this season, water as one of the main factors of crop production is scarcely sourced from rivers or groundwater. Most irrigation schemes experience physical and economic water scarcity. This water shortage has resulted into increased cost of crop production or loss of crop yield among smallholder farmers globally (FAO, 2007). On the other hand, high energy requirements for lifting irrigation water complicates and aggravates the issue of water scarcity into economic problems at both large and small-scale farm. This cause compelled studies of efficient water strategies to elucidate issues of water scarcity. Studies on deficit irrigation proved high water savings but with trade-offs of reduced yield and quality (Kang, 1999; Stewart, 1993). A well-balanced optimisation of water is supposed to consider regulation of leaf transpiration and root behaviour (Jones *et al.* 1992; Dass *et al*., 2016; Kumari *et al.*, 2016). Alternating water application to furrows has proved to regulate the plants' stomata to respond to water deficits in the root-zone

(Kang *et al.* 2000; Han and Kang, 2002). Mitchell *et al.* (1992) defined alternate furrow irrigation (AFI) as an irrigation application strategy where the every - other furrow is shifted by one furrow during every irrigation so that all furrow are irrigated over the course of two irrigations. It can be a viable option for water saving as it allows the water to move laterally and across the bed to the non-irrigated furrow (subbing), reduces the surface area of moist soil, the area of soil evaporation and deep percolation (Singh et al., 2016). Thus, AFI is beneficial for plants' survival and carbon uptake maximisation that later increases both yield and water conservation (Jones, 1980; Cowan *et al.,* 1982). Grain yield maximisation and efficient water use are the major agronomic and economic goals for sustainable irrigation management worldwide. Manageable deficit irrigation technologies that promote both yield and water conservation showed AFI is one of such sustainable irrigation management strategies. However, there no studies that generated information of water use efficiency (WUE) for different maize varieties under AFI. It was hypothesised that a combination of efficient maize variety and irrigation strategy would increasingly save water whilst optimising maize grain yield. Water productivity was reported to increase without reducing grain yield with AFI with less water application (Jones *et al.,* 1992). This paper discussed WUE of selected maize varieties under AFI and every furrow irrigation (EFI) strategies. It is based on the study that evaluated the application of AFI for maize production and productivity in Malawi.

2. Materials and Methods

2.1 Location and Establishment

The experiment was carried out at both on-Station and on- farm level from 2014 to 2016 winter cropping seasons. The On-station experiment was carried out at Kasinthula Agricultural Research Station in Chikwawa (16^o 55'S, 34^o 50'E). The on - farm experiment was carried out on seventy On-Farm Demonstrations(OFDs) which were mounted in the five selected irrigation schemes namely - Mpitilira Irrigation Scheme in Salima (1 Mother & 9 Baby trials), Nanzolo A & B Irrigation Scheme in Chikwawa (1 Mother & 9 Baby trials), Chitsukwa Irrigation Scheme in Nsanje (2 Mother & 18 Baby trials), Bwanje Valley Irrigation Scheme in Dedza (2 Mother & 18 Baby trials) and Sanambe Irrigation Scheme in Karonga (1 Mother & 9 Baby trials). The number of farmers participating was equivalent to the number of OFDs implemented from 2015 to 2016.

2.2 Experimental Design and Irrigation Management

2.2.1 On - Station Experiment

The experiments were laid-out in a split-plot design where two irrigation application strategies - 1) Alternate furrow irrigation (AFI) and Every furrow irrigation (EFI) strategy were main-plot treatments and twenty maize varieties were sub-plot treatments. AFI meant that one of the two neighbouring furrows were alternatively irrigated during consecutive watering or every other furrow irrigation (Sepaskhan & Ghaseni, 2008). EFI refers to the conventional way of furrow irrigation in Malawi where every furrow is irrigated at every irrigation, basing on the released technologies (Fandika *et al.,* 2007).

EFI received 30 - 40 mm irrigation at every irrigation. AFI plots received half of the irrigation in EFI. Irrigation was applied through siphons to furrows and crop water use for irrigated treatments was determined by the soil water balance approach (Allen *et.al.* 1998), whilst soil moisture measurements were taken by gravimetric methods. The actual water depth within each plot was monitored (at every irrigation) by using a number of siphons. The irrigation depth for a particular plot was determined as an average of the water depth in the siphon from each plot. The amount of water applied to each plot was totalled and recorded for water productivity assessment.

2.2.2 On - Farm Demonstrations (OFDs)

The OFDs used a Mother - Baby Approach to participatory re-evaluate seven maize varieties selected from the twenty maize varieties participatory evaluation at Kasinthula Agricultural Research Station. In order to understand the seven-maize response to AFI, farmers assessed them at two irrigation water management strategies,: (1) AFI and (2) EFI. In order to understand AFI performance to nitrogen management, AFI was assessed under different nitrogen management in comparison with other irrigation water management strategies.

2.2.3 Plot size and Crop Management

Each plot consisted of 10 rows of 10 m long spaced at 0.75m apart and maize was planted at a spacing of 0.25m apart with one seed per planting station for on – station plots. At On–Farm plots were 5 rows of 10 m long.. Early maturing maize varieties (SC 403, DKC 8033, ZM, 523 PHB 30G79, MRI 514 and DKC 8181), medium maturing maize varieties (SC 537, PAN 53, MH 30, PHB 30G19, DKC 90-53, SC 627, MRI 614 and P2589W) and late maturing crops (SC 719, PAN4M19, MH 31, DKC 90-89, ZM 721 and PAN4M21) were planted for the trials. Fertilizer was applied at 140kgN ha^{-1} with 60kgN ha^{-1} at planting followed by 80 KgN ha^{-1} after 21 days from planting. The basal dressing fertilizer of 23:21:0 +4S was applied at a uniform rate of 45KgP ha^{-1} and 60 KgN ha^{-1}, respectively. All other crop husbandries were carried out accordingly.

2.2.4 Crop Water Use and Water Use Efficiency

A soil water balance method was used to determine the soil moisture deficit (SMD) on a daily basis during the growth of the crops (Premrov *et al.,* 2010). The potential evapotranspiration (ETp) in the soil water balance was determined from evaporation pan (Allen *et al.,* 1998). The crop coefficient factors used in the crop water use computation were for maize as provided by Allen *et al*. (1998). The daily weather data, for running the soil water balance model, were collected daily from Kasinthula Research Station in Chikwawa, Malawi. The actual crop evapotranspiration (ET_c) was determined using equation 1 (Allen *et al.* 1998). Soil moisture change (ΔS) was the difference between soil moisture content at the end and the start of the field experiment as measured using gravimetric method. Drainage and surface runoff (R_o) was ignored as the water was under control in the dry season. ETc was referred to as consumption water use (CWU) according to Hoekstra *et al.* (2009).

$$ETc = P + I - D_p - R_o + \Delta S \quad (1)$$

Water Use Efficiency (WUE) was determined as the total grain yield (kg ha^{-1}), per unit of water used (m^3 ha^{-1}). The economic water productivity index (MK/m^3) was assessed as the overall present value of each crop's marketable produce (in MK) divided by the volume of water (m^3) consumed by the plant (Barker *et al.,* 2003; Molden *et al.,* 2001).

2.3 Data and Statistical Analysis

The data on maize grain yield (kg ha^{-1}), water use efficiency and economic water productivity, were analysed with the ANOVA procedure of Genstat statistical package (18^{th} Edition) in 2014 to 2016 the differences amongst treatment means were compared with the LSD, at the 5% probability level (Meier, 2006).

3. Results & Discussion

3.1 Daily and Cumulative Water Consumption (mm) in Maize

The winter growing season length for maize in dry season ranged from 110 - 126 days with an average potential water requirement of 555 mm, 580 mm and 521 mm, respectively (Tables 1 - 2). The mean daily ET_c for this study period averaged 5.1 mm d^{-1} with a minimum ET_c of 1.2 - 2.6 mm d^{-1} and maximum ET_c of 7.6 mm d^{-1} experienced in the month of July and September, respectively (Fig. 1). The potential water consumption in this study was greater than an average of 423 mm for winter maize in China where daily ET_c averaged 3 - 4 mm d^{-1} between May and June (Kang, 2000). This study indicates that EFI consumed more water (586 - 588 mm) than the alternate and fixed furrow irrigation (317 - 321 mm) (Table 1 - 8, Fig. 2). AFI reduced crop water consumption by 38 - 45% as reported by Kang *et.al*. (2000) compared to EFI which was within average potential water consumption. The high daily water use from our study sites are due to high daily ET_c compared to China, whereas the high actual water use in conversional irrigation is due to its usual goal of meeting the potential water use. The low water use in AFI was also due to their usual goal of optimising water use. The consumption water uses results suggest that where water is scarcer, AFI can be used to save water.

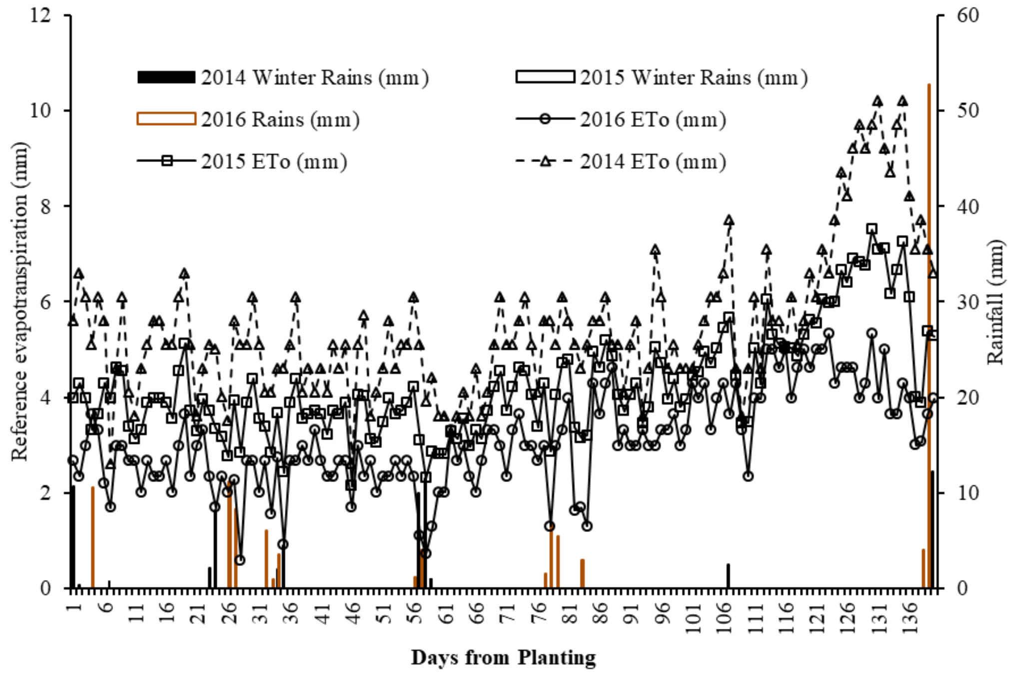

Figure 1. Daily ET_c and rainfall at Kasinthula Agricultural Research Station during the growing winter season

3.2 Crop Water use for Selected Maize Varieties under AFI and EFI

Maize varieties differ both in terms of their daily water needs and the duration of their total growing period. In this study, consumptive water use (m^3 ha^{-1}) was greatest in late maturing maize varieties and lowest in early maturing maize varieties', whilst medium maturing maize varieties were intermediate, despite variation within varieties (Table 1a - c). These results on crop water use indicate that maize variety, is also a main factor influencing irrigation water needs. Maize of different maturity differs in their relationship between their maximum water requirement and actual evapo-transpiration, thus crop coefficient (k_c) and maturity as their growth stages differ too. Every Furrow irrigation strategy achieved 107%, 100% and 94% of the potential water needs for early, medium and late maturing maize varieties, respectively. AFI strategy was approximately 62, 64 and 63% of potential water needs for early, medium and late maturing maize varieties, respectively.

Table 1 (a). Crop water use for early maturing maize varieties under AFI and EFI

Maize Varieties	Irrigation (mm)	Pe (mm)	D_p (mm)	R_o (mm)	ΔS (mm)	Potential water use (mm)	ET_a/ET_p	CWU (mm)
Every Furrow Irrigation strategy								
SC 403	374.6	37.0	0.0	0.0	36.4	448.0	1.00	**448.0**
DKC 8033	372.8	35.2	0.0	0.0	6.9	414.9	1.00	**414.9**
ZM 523	350.8	34.7	0.0	0.0	20.0	287.3	1.41	**405.5**
PHB 30G79	375.0	37.0	0.0	0.0	56.4	468.4	1.00	**468.4**
MRI 514	375.2	38.8	0.0	0.0	62.3	476.3	1.00	**476.3**
DKC 8181	375.0	37.0	0.0	0.0	56.4	468.4	1.00	**468.4**
Mean							**1.07**	**446.9**
Alternate Furrow Irrigation strategy								
SC 403	187.3	37.0	0.0	0.0	36.4	448.0	0.58	**260.7**
DKC 8033	186.4	35.2	0.0	0.0	6.9	414.9	0.55	**228.5**
ZM 523	175.4	34.7	0.0	0.0	20.0	287.3	0.80	**230.1**
PHB 30G79	187.5	37.0	0.0	0.0	56.4	468.4	0.60	**280.9**
MRI 514	187.6	38.8	0.0	0.0	62.3	476.3	0.61	**288.7**
DKC 8181	187.5	37.0	0.0	0.0	56.4	468.4	0.60	**280.9**
Mean							0.62	**261.6**

Late maturing maize varieties may have high daily water needs apart from having long total growing season that made it require more water than early and medium maturing maize varieties which have lowered daily water needs and shorter crop growth seasons. Apart from selecting maize varieties with lower water needs, AFI had proved to reduce the consumptive water in early, medium and late maturity maize varieties by 38, 36 and 37%, respectively (Table 1a - c).

Table 1(b). Crop water use for medium maturing maize varieties under AFI and EFI

Maize Variety	**Irrigation (mm)**	**Pe (mm)**	**Dp**	**Ro**	**∆S**	**Potential water use (mm)**	**ETa/ETp**	**CWU (mm)**
Every Furrow Irrigation Strategy								
SC 537	370.4	38.8	0.0	0.0	96.2	505.4	1.00	**505.4**
PAN 53	370.4	38.8	0.0	0.0	96.0	505.2	1.00	**505.2**
MH 30	359.9	42.6	0.0	0.0	131.4	539.4	0.99	**533.9**
PHB 30G19	419.2	46.4	0.0	0.0	84.9	550.5	1.00	**550.5**
DKC 90-53	359.9	42.6	0.0	0.0	131.4	539.4	0.99	**533.9**
SC 627	370.2	38.8	0.0	0.0	93.5	502.5	1.00	**502.5**
MRI 614	374.1	38.8	0.0	0.0	92.2	505.1	1.00	**505.1**
P2589W	370.2	38.8	0.0	0.0	93.5	502.5	1.00	**502.5**
Mean							1.00	**517.4**
Alternate Furrow Irrigation Strategy								
SC 537	185.2	38.8	0.0	0.0	96.2	505.4	0.63	**320.2**
PAN 53	185.2	38.8	0.0	0.0	96.0	505.2	0.63	**320.0**
MH 30	180.0	42.6	0.0	0.0	131.4	539.4	0.66	**354.0**
PHB 30G19	209.6	46.4	0.0	0.0	84.9	550.5	0.62	**340.9**
DKC 90-53	180.0	42.6	0.0	0.0	131.4	539.4	0.66	**354.0**
SC 627	185.1	38.8	0.0	0.0	93.5	502.5	0.63	**317.4**
MRI 614	187.1	38.8	0.0	0.0	92.2	505.1	0.63	**318.1**
P2589W	185.1	38.8	0.0	0.0	93.5	502.5	0.63	**317.4**
Mean							0.64	**330.2**

Table 1 (c). Crop water use for late maturing maize varieties under AFI and EFI

Maize Variety	**Irrigation (mm)**	**Pe (mm)**	**Dp (mm)**	**Ro (mm)**	**∆S (mm)**	**Potential water used (mm)**	**ETa/ETp**	**CWU (mm)**
Every Furrow Irrigation Strategy								
SC 719	349.1	57.3	0.0	0.0	154.0	629.5	0.89	**560.4**
PAN4M19	354.9	51.9	0.0	0.0	149.2	604.4	0.92	**556.0**
MH 31	354.3	46.4	0.0	0.0	145.2	569.7	0.96	**545.9**
DKC 90-89	359.9	46.4	0.0	0.0	133.5	550.1	0.98	**539.8**
ZM 721	351.0	51.9	0.0	0.0	152.6	610.5	0.91	**555.5**
PAN4M21	352.3	46.4	0.0	0.0	147.9	573.8	0.95	**546.6**
Mean							0.94	**550.7**
Alternate Furrow Irrigation Strategy								
SC 719	174.6	57.3	0.0	0.0	154.0	629.5	0.61	**385.9**
PAN4M19	177.5	51.9	0.0	0.0	149.2	604.4	0.63	**378.6**
MH 31	177.2	46.4	0.0	0.0	145.2	569.7	0.65	**368.8**
DKC 90-89	180.0	46.4	0.0	0.0	133.5	550.1	0.65	**359.9**
ZM 721	175.5	51.9	0.0	0.0	152.6	610.5	0.62	**380.0**
PAN4M21	176.2	46.4	0.0	0.0	147.9	573.8	0.65	**370.5**
Mean							0.63	**373.9**

3.3 Maize Grain Yield and Water Use Efficiency for Selected Maize Varieties at On-Station

In 2014, crop water use averaged 1,733 m^3ha^{-1} and 4,230 m^3ha^{-1} under AFI and EFI, respectively (Table 1 and Table 6). The average maize water uses in 2015 - 2016 was categorised according to maize variety duration - short duration varieties used 4,394 m^3ha^{-1} and 4,469 m^3ha^{-1} under EFI and 2,495 m^3ha^{-1} and 2,616 m^3ha^{-1} under AFI strategy, respectively. The medium maturing maize varieties used 5,439 m^3ha^{-1} and 5,174 m^3ha^{-1} of water under EFI whilst AFI used 3,327 m^3ha^{-1} and 3,302 m^3ha^{-1} in 2015 and 2016 , respectively. The late maturing maize varieties used 6,087 m^3ha^{-1} and 5,507 m^3ha^{-1} of water under EFI whilst AFI used 4,024 m^3ha^{-1} and 3,739 m^3ha^{-1} in 2015 and 2016, respectively. The AFI reduced water use by 59% in 2014, 41 - 43% among short duration maize varieties, 36 - 54% among medium duration maize varieties and 32 - 34% among late duration maize varieties in 2015 and 2016, respectively. This reduction in water use indicates significant water saving by using AFI strategy.

Table 2. Effect of alternate furrow irrigation on different maize varieties grain yield and water use efficiency at Kasinthula Agricultural Research Station, 2014

Irrigation/	**Full Irrigation**				**Alternate Furrow irrigation**			
Varieities	Irrigation (m^3ha^{-1})	Grain yield ($kgha^{-1}$)	WUE (kgm^{-3})	NUE (kg kgN^{-1})	Irrigation ($m^3 ha^{-1}$)	Grain yield (kg ha^{-1})	WUE (kgm^{-3})	NUE (kg kgN^{-1})
Pan 53	1732.7	5190	3.39	51.9	867.13	4306	4.45	43.1
DKC 9089	1732.7	4319	2.50	38.8	867.13	3881	4.47	43.2
DKC8053	1732.7	4827	2.79	48.2	867.13	3652	4.21	38.5
SC627	1732.7	5873	3.40	57.0	867.13	5309	6.12	54.8
ZM523	1732.7	4309	2.50	40.3	867.13	3525	4.07	38.1
SC403	1732.7	3838	2.22	38.1	867.13	3606	4.16	36.4
SC719	1732.7	5536	3.19	55.3	867.13	4678	5.40	46.8
DK8033	1732.7	4503	2.60	45.6	867.13	3680	4.24	36.8
DKC9053	1732.7	5035	2.91	50.3	867.13	4184	4.83	41.8
PHB30G19-6	1732.7	6063	3.50	60.6	867.13	5480	6.32	54.8
Mean (n =)	**1732.7**	**4949**	**2.90**	**48.6**	**867.13**	**4230**	**4.83**	**43.4**
CV (%)						9.7	10.9	
Significance								
Variety						P<0.001	P<0.001	P<0.001
Irrigation						P<0.05	P<0.01	NS
Interactions						Ns	P<0.05	Ns
$LSD_{0.05}$	Variety					518.8	0.4919	
	Irrigation					515.4	0.6390	-
	Interactions					-	0.7310	-

Table 2 indicates that there were significant differences between EFI and AFI irrigated maize varieties on average grain yield (P<0.001) and water use efficiency (P<0.001). However, there was no significant differences on NUE between EFI and AFI irrigated maize varieties. The maize varieties under EFI had increased grain yield by 16.9%. Nevertheless, WUE increased with AFI strategy. Maize varieties strongly influenced grain yield (P<0.001), WUE (P<0.001) and NUE (P<0.001). The highest grain yield, WUE and NUE was found in PHB30G19-6 whilst SC403 had the least grain yield in 2014. The Drought Intensity Index (DII) was 0.15, thus more than 0.07 cut - off point for water stress. The percentage of yield reduction with water stress caused by AFI strategy in 2014 averaged 14%. The yield reduction with water stress was highest in DKC8053 and least in DKC9089 as show in fig. 2.

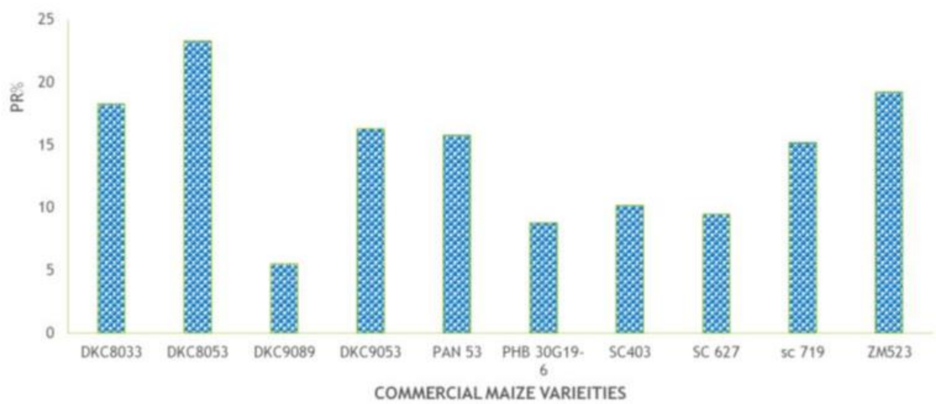

Figure 2. Percentage of yield reduction with water stress in commercial maize varieties

Table 3 - 5 pointed out that there were no significant differences between EFI and AFI irrigated short and medium duration maize varieties on average grain yield (P>0.001), on the other hand, the EFI and AFI strategies significantly differed in grain yields among the late maturing maize varieties in 2015 (P<0.001). The late maturing maize varieties under EFI had higher grain yields (7,774 kg ha^{-1}) than those under AFI (6,264kg ha^{-1}). Early maturing maize varieties did not differ in grain yields (P>0.05), however, medium and late maturing maize varieties differed among themselves in response to irrigation strategies in 2015. PAN 53 had highest grain yields under both EFI (8,155 $kgha^{-1}$) and AFI strategies (7,382 $kgha^{-1}$) among medium maturing maize varieties but not significantly different to DKC 9053 (7,138 kg ha^{-1}) under EFI and DKC 8053 under AFI (6,004kg ha^{-1}).

The 2015 results suggested that AFI strategy is more suitable to early and medium maturing maize varieties but not to late maturing varieties. The possible reason for this is that late maturing varieties required more water than early and medium maturing maize varieties as a result their response to water stress was greater than the other two groups. However, the 2015 findings differed with 2016 results as significant difference between both irrigation strategies and maize varieties among the medium and late maturing categories (P<0.001) were determinedbut not among early maturing varieties (P>0.05). The likely cause for this difference might be weather variability that might contribute to differences in crop water use. The 2016 results also showed that maize grain yields were higher under EFI than under AFI strategies.

Table 3. Grain yield, Water Use Efficiency and Economic Water Productivity for selected early maturing maize varieties under full and alternate furrow irrigation in Malawi

Irrigation/ Maize Variety	**Winter 2015**				**Winter 2016**			
	CWU (m^3ha^{-1})	**Grain yield ($Kgha^{-1}$)**	**WUE (kg mm^{-1})**	**EWP (MK/m^3)**	**CWU (m^3ha^{-1})**	**Grain yield ($Kgha^{-1}$)**	**WUE ($kgmm^{-1}$)**	**EWP (MK/m^3)**
Every Furrow Irrigation								
SC 537	4,644	7,606	16.4	328	4,480	-	-	-
DKC 8033	4,307	7,281	16.9	338	4,149	7,417	17.9^{c}	303.89^{c}
ZM 523	3,928	7,453	19.0	380	4,055	9,083	22.4^{bc}	380.81^{bc}
PHB 30G79	-	-	-	-	4,684	-	-	-
MRI 514	-	-	-	-	4,763	7,271	15.3^{d}	259.51^{d}
DKC 8181	-	-	-	-	4,684	9,031	19.3^{c}	327.78^{c}
MH 18	4,695	7,009	14.9	299	-	-	-	-
Mean	**4,394**	**7,336**	**16.8**	**336**	**4,469**	**$8,201^{A}$**	**18.7**	**318.00**
Alternate Furrow Irrigation								
SC 537	2,759	5,620	20.4	407	2,607	-	-	-
DKC 8033	2,353	6,094	25.9	518	2,285	6,251	27.4^{a}	464.99^{a}
ZM 523	2,182	5,287	24.2	485	2,301	6,344	27.6^{a}	468.68^{a}
PHB 30G79	-	-	-	-	2,809	-	-	-
MRI 514	-	-	-	-	2,887	6,881	23.8^{ab}	405.20^{ab}
DKC 8181	-	-	-	-	2,809	7,490	26.7^{a}	453.27^{a}
MH 18	2,686	5,518	20.5	411	-	-	-	-
Mean	**2,495**	**5,629**	**22.8**	**455**	**2,616**	**$6,741^{B}$**	**26.4**	**448.03**
Cv. (%)		17.2	19.7	19.7		15.6	15.1	15.1
Significance								
Varieties		Ns	Ns	Ns		Ns	p<0.05	p<0.05
Irrigation		Ns	Ns	Ns		p<0.05	p<0.01	p<0.01
$LSD_{0.05}$								
Varieties		-	-	-		-	3.58	60.78
Irrigation		-	-	-		1395.4	3.65	62.09

Note: Columns with similar letters are not significantly different.

Rows with similar capital letters are not significantly different.

Water use efficiency and Economic water productivity (EWP) were significantly different between maize under AFI and EFI in both 2015 and 2016 (P<0.001) except among short duration maize varieties where irrigation and varieties had no significant impact on WUE and EWP in 2015 (P>0.05; Table 3 - 5). Despite increased grain yield by 16.9% with EFI, WUE increased with AFI strategy. Overall , on station results suggested that AFI strategy does save water without significantly affecting maize grain yield among early and medium maturing maize varieties but with significant effect on late maturing maize grain yields.

Table 4. Grain yield, Water Use Efficiency and Economic Water Productivity for selected medium maturing maize varieties under full and alternate furrow irrigation in Malawi

Irrigation/ Maize Variety	**Winter 2015**				**Winter 2016**			
	CWU (m^3ha^{-1})	**Grain Yield ($Kgha^{-1}$)**	**WUE (kg mm^{-1})**	**EWP (MK/m^3)**	**CWU (m^3ha^{-1})**	**Grain Yield (Kg ha^{-1})**	**WUE (kg mm^{-1})**	**EWP (MK/m^3)**
Full Irrigation								
SC 537	5,239	$6,731^{bc}$	12.9^{c}	257^{c}	5,054	$7,906^{bc}$	15.6^{de}	265.94^{de}
PAN 53	5,207	$8,155^{a}$	15.7^{b}	313^{b}	5,052	$9,385^{a}$	18.6^{cd}	315.82^{cd}
MH 30	-	-	-	-	5,339	$7,708^{bc}$	14.4^{de}	245.44^{de}
PHB 30G19	-	-	-	-	5,505	$8,708^{ab}$	15.8^{de}	268.92^{de}
DKC 90-53	5,584	$7,138^{ab}$	12.8^{c}	256^{c}	5,339	$7,208^{c}$	13.5^{e}	229.52^{e}
DKC 8053	5,584	$6,650^{bc}$	11.9^{c}	238^{c}	-	-	-	-
SC 627	-	-	-	-	5,025	$8,521^{ab}$	17.0^{cd}	288.27^{cd}
MRI 614	-	-	-	-	5,051	$7,719^{bc}$	15.3^{de}	259.79^{de}
P2589W	-	-	-	-	5,025	$9,380^{a}$	18.7^{cd}	317.52^{cd}
ZM 623	5,580	$6,412^{bc}$	11.5^{c}	230^{c}	-	-	-	**-**
Mean	**5,439**	**7,018**	**12.9^{B}**	**259^{B}**	**5,174**	**8,318**	**16.1**	**273.90**
Alternate Furrow Irrigation								
SC 537	3,129	$5,191^{c}$	16.6^{b}	332^{b}	3,202	$7,583^{bc}$	23.7^{a}	402.61^{a}
PAN 53	3,107	$7,382^{ab}$	23.8^{a}	475^{a}	3,200	$7,427^{bc}$	23.2^{ab}	394.56^{ab}
MH 30	-	-	-	-	3,540	$6,688^{cd}$	18.9^{cd}	321.15^{cd}
PHB 30G19	-	-	-	-	3,409	$6,833^{c}$	20.0^{b}	340.76^{b}
DKC 90-53	3,474	$5,799^{c}$	16.7^{b}	334^{b}	3,540	$5,510^{e}$	15.6^{de}	264.62^{de}
DKC 8053	3,474	$6,004^{bc}$	17.3^{b}	346^{b}	-	-	-	-
SC 627	-	-	-	-	3,174	$6,583^{cd}$	20.7^{bc}	352.6^{bc}
MRI 614	-	-	-	-	3,181	$6,427^{c}$	20.2^{bc}	343.48^{bc}
P2589W	-	-	-	-	3,174	$7,250^{c}$	22.8^{ab}	388.31^{ab}
ZM 653	3,462	5,877	17.0^{b}	340^{b}	-	-	-	-
Mean	**3,329**	**6,050**	**18.3^{A}**	**365^{A}**	**3,302**	**6,788**	**20.6**	**351.01**
Cv. (%)		16.1	15.8	15.8		16.8	17.3	**17.3**
Significance								
Varieties		P<0.05	P<0.01	P<0.001		P<0.05	P<0.01	P<0.01
Irrigation		Ns	P<0.05	P<0.05		P<0.01	P<0.001	P<0.001
$LSD_{0.05}$								
Varieties		1,086.9	2.55	51.0		1,277.14	3.22	54.69
Irrigation		-	3.81	76.1		480.73	1.16	19.77

Note: Columns with similar letters are not significantly different.

Rows with similar capital letters are not significantly different.

Table 5. Grain yield, water use efficiency and economic water productivity for selected late maturing maize varieties under full and alternate furrow irrigation in Malawi

Irrigation/ Maize Variety	**Winter 2015**				**Winter 2016**			
	CWU (m^3ha^{-1})	**Grain Yield (kg ha^{-1})**	**WUE (kg mm^{-1})**	**EWP (MK/m^3)**	**CWU (m^3ha^{-1})**	**Grain Yield (kg ha^{-1})**	**WUE (kg mm^{-1})**	**EWP (MK/m^3)**
Every Furrow Irrigation								
SC 719	6,515	9,666^{a}	14.8^{bc}	297	5,604	9,771	17.4	296.40
PAN4M19	6,251	7,450^{bc}	11.9	238	5,560	8,500	15.3	259.89
MH 31	-	-	-	-	5,459	8,531	15.6	265.67
MH 26	5,651	7,856^{b}	13.9^{cd}	278				
DKC 90-89	5,706	6,827^{cd}	13.0^{d}	239	5,398	7,708	14.3	242.76
ZM 721	6,312	7,071^{bc}	11.2	224	5,555	9,073	16.3	277.66
PAN4M21	-	-	-	-	5,466	8,187	15.0	254.64
Mean	**6,087**	**7,774^{A}**	**12.8^{B}**	**255**	**5,507**	**8,628**	**15.7**	**266.17**
Alternate Furrow Irrigation								
SC 719	4,426	7,003^{cd}	15.9^{b}	316	3,859	9,615	24.9	423.55
PAN4M19	4,143	5,262^{f}	12.7^{d}	254	3,786	6,771	17.9	304.03
MH 31	-	-	-	-	3,688	7,073	19.2	326.03
MH 26	3,540	7,170^{b}	20.3^{a}	405				
DKC 90-89	3,595	5,754^{ef}	16.0^{b}	320	3,599	6,427	17.9	303.59
ZM 721	4,217	6,132^{de}	14.5^{bcd}	291	3,800	6,521	17.2	292.72
PAN4M21	-	-	-	-	3,705	7,156	19.3	328.36
Mean	**4,024**	**6,264^{B}**	**15.9^{A}**	**317**	**3,739**	**7,260**	**19.4**	**329.54**
Cv. (%)		10.8	10.9	10.9		15.0	14.4	14.4
Significance								
Varieties		P<0.001	P<0.001	P<0.001		P<0.01	P<0.001	P<0.001
Irrigation		P<0.01	P<0.01	P<0.01		P<0.01	P<0.01	P<0.01
Interaction		Ns	P<0.01	P<0.01		-	-	-
$LSD_{0.05}$								
Varieties		784.91	1.618	32.4		1,217.1	2.573	43.762
Irrigation		468.85	1.398	28.0		603.4	1.063	17.977
Interaction		-	2.228	26.3		-	-	-

Note: Columns with similar letters are not significantly different.

Rows with similar capital letters are not significantly different.

3.4 Maize Grain Yield and WUE for Selected Maize Varieties at On-farm

There were significant differences in maize grain yield between the irrigation strategies (P<0.05) and varieties (P<0.001) at Nanzolo irrigation scheme in 2015 (Table 6). Alternate furrow irrigated maize had lower yields compared to every furrow irrigated maize. SC719 had highest yields but there were not significantly different between AFI and EFI strategies. Maize grain yields did not differ between irrigation strategies and varieties at Bwanje, Chitsukwa irrigation scheme in 2015 (P>0.05). At Mpitilira irrigation scheme, differences were only observed between maize varieties but not between AFI and EFI. SC719 had the highest grain yield at EFI but not significantly different to yields at AFI (P>0.05). PHB30G19-6 followed by SC627 had high yield and WUE with the least in SC403 in 2014. SC719 and DKC9053 had high grain yield at On-Farm under AFI. Most varieties with high yield had less per cent reduction. Some late maize maturing varieties were much better under AFI despite long duration (Table 6).

Table 6a. Response of Maize Varieties to AFI & EFI at On - Farm Trials - Nanzolo Irrigation Scheme, 2015

Irrigation Strategy	**Every furrow irrigation**		**Alternate Furrow Irrigation**		Percentage of yield reduction with AFI
Maize Varieties	Amount of irrigation (mm)	Grain yield (kg ha^{-1})	Amount of irrigation (mm)	Grain yield (kg ha^{-1})	
DKC 8033	435.5	4,376[c]	263.2	4,278[b]	- 4.1
DKC 8053	435.5	4,536[c]	263.2	3,785[c]	8.3
DKC 9053	435.5	5,158[b]	263.2	4,852[a]	15.6
DKC 9089	435.5	4,381[c]	263.2	3,925[c]	- 1.0
SC 403	435.5	4,951[b]	263.2	4,300[b]	15.4
SC 537	435.5	4,714[b]	263.2	4,266[b]	11.9
SC719	435.5	6,338[a]	263.2	5,122[a]	27.6
Cv.(%)				8.0	
Sign.	Irrigation			$P<0.05$	
	Varieties			$P<0.001$	
$LSD_{0.05}$	Irrigation			533.5	

Table 6b. Response of Maize varieties to AFI & EFI at Chitsukwa Irrigation Scheme, Winter 2015

Irrigation Strategy	**Every furrow irrigation**		**Alternate Furrow Irrigation**		Percentage of yield reduction with AFI
Maize Varieties	Amount of irrigation (mm)	Grain yield (kg ha^{-1})	Amount of irrigation (mm)	Grain yield (kg ha^{-1})	
DKC 8033	496	6,001	280	6,503	- 7.98
DKC 9053	496	5,890	280	6,088	- 9.89
DKC 9089	496	5,500	280	5,646	- 9.20
SC 403	496	5,518	280	7,076	- 52.85
SC 537	496	4,550	280	6,430	- 58.99
SC719	496	5,250	280	6,719	- 43.02
Cv. (%)				15.9	
Irrigation				Ns	
Maize varieties				Ns	

Table 6c. Response of Maize varieties to EFI and AFI at Bwanje Irrigation Scheme, Winter 2015

Irrigation Strategy	**Every furrow irrigation**		**Alternate Furrow Irrigation**		Percentage of yield reduction with AFI
Maize Varieties	Amount of irrigation (mm)	Grain yield (kg ha^{-1})	Amount of irrigation (mm)	Grain yield (kg ha^{-1})	
DKC8033		5,955		4,714	**20.%**
DKC8053		4,518		6,074	**-34.4%**
DKC9053		6,194		6,608	**-6.7%**
DKC9089		5,360		5,732	**-6.9%**
SC403		6,064		5,615	**7.4%**
SC537		6,008		5,908	**1.7%**
SC719		7,885		5,560	**29.5%**
CV(%)				23.5	
Sign.	Irrigation			Ns	
	Maize varieties			Ns	

Table 6d. Response of maize varieties to EFI and AFI at Mpitilira Irrigation Scheme, Winter 2015

Irrigation Strategy	**Every furrow irrigation**		**Alternate Furrow Irrigation**		Percentage of yield reduction with AFI
Maize Varieties	Amount of irrigation (mm)	Grain yield (kg ha^{-1})	Amount of irrigation (mm)	Grain yield (kg ha^{-1})	
DKC8033		$5,169^{b}$		$5,276^{b}$	-2.07
DKC8053		$5,016^{b}$		$5,291^{b}$	-5.48
DKC9053		$5,123^{b}$		$5,519^{a}$	-7.73
DKC9089		$5,051^{b}$		$5,061^{b}$	-0.20
SC403		$5,309^{b}$		$5,650^{a}$	-6.42
SC537		$5,286^{b}$		$5,775^{a}$	-9.25
SC719		$6,422^{a}$		$5,978^{a}$	6.91
Cv. (%)				12.5	
Sign.	Irrigation			Ns	
	Maize varieties			P<0.01	
$LSD_{0.05}$	Maize varieties			554.7	

4. Conclusion and Recommendation

This study acknowledges that application of alternate furrow irrigation strategy save water without affecting maize grain yield. Only late maturing maize varieties proved to have minor yield reduction with AFI in 2015 and 2016. These results were in line with our null hypothesis ‘AFI strategy improves WUE without greatly reducing maize grain yield.’ This proves that the conventional way of furrow irrigation, EFI used by small scale farmers uses water luxuriously and that does not increase yield but increases water pumping costs and environmental degradation. On the other hand, late maturing results (2015 and 2016) partially challenged our hypothesis by indicating that water needs of maize may not be met by AFI because it imposes greater water stress that decreases maize grain yields. A larger part of the study concluded that AFI is a promising furrow irrigation water management strategy for reducing water use in irrigation schemes in Malawi. The one-year contradiction has been clarified by categorising maize varieties according to their maturing period.

For these reasons AFI technique was recommended to smallholder farmers on the following condition - that AFI is applied fully on early and medium maturing varieties within 7 - days irrigation interval. For late maturing maize varieties, alternate furrow irrigation technique should be applied from initial stage to mid - stage (up 55 days from planting) then apply every furrow irrigation at tasseling and silking stages to reduce water stress at this critical stage.

Acknowledgements

I wish to express my heartfelt indebtedness to the technical team comprising of Mr. Raphael Banda, Mr. Horace Khakiwa, Charles Nthewa, Mr. Helbert Kumwenda and Jonathan Chikankheni who gave enthusiastic and motivating technical support throughout this project. I also thank Department of Agricultural Research Services, Department of Irrigation and Department of Agricultural Engineering at LUANAR for mutual and solitary efforts. I also thank Dr Hendrix Kazembe who gave major contribution and momentum to the project as Soils and Agricultural Engineering National Research Coordinator that time. Many thanks also go to Irrigation & Drainage Research Attendants and staff of Kasinthula Agricultural Research Station with whom we shared knowledge and work in many different ways to accomplish the project objectives.

Finally, I would also like to acknowledge Agricultural Productivity Program for Southern Africa (APPSA) for funding and The Centre for Agricultural Research and Development for Southern Africa (CCARDESA) for administration of APPSA R & D Project entitled “Improving water use efficiency in maize production” that has helped to study Alternate Furrow Irrigation technique at on - farm level at five different irrigation schemes in Malawi.

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