Italian Journal of Agrometeorology
Rivista Italiana di Agrometeorologia

Firenze University Press
www.fupress.com/ijam

Citation: Dessale, S., Fenta, T., Wondatir, S., & Mollaw, G. (2023). Effect of different soil moisture regimes on yield and water use efficiency of groundnut at Kobo irrigation scheme, Kobo Ethiopia. *Italian Journal of Agrometeorology* (2): 41-48. doi: 10.36253/ijam-2201

Received: June 24, 2023

Accepted: November 14, 2023

Published: January 20, 2024

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Competing Interests: The Author(s) declare(s) no conflict of interest.

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Contributions

Sisay Dessale. Performed the experiments, collect, analyzed and interpret the data, and wrote the manuscript. Tigabu Fenta performs data collection and frequent follow-up at the field level. Solomon Wondatir and Gebeyaw Mollaw edited the paper throughout the manuscript work.

Effect of different soil moisture regimes on yield and water use efficiency of groundnut at Kobo irrigation scheme, Kobo Ethiopia

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Abstract. In the arid and semi-arid part of Eastern Amhara, water is the most important yield-limiting factor for agricultural production. Application of the right amount of irrigation water at a right time helps to optimize water loss and increases crop yield. Therefore, a field experiment was conducted at Kobo irrigation scheme to determine the optimal crop water requirement and irrigation frequency for yield and water use efficiency of groundnut. The CROPWAT model could generate the 100% irrigation scheduling as 40 mm irrigation water with 8 days. Field base validation and ground truthing is vital. Therefore, the treatments were formulated by the factorial combinations of the three crop water levels as 75% ETc (30 mm), 100% ETc (40 mm), 125% ETc (50 mm) with three irrigation intervals (6 days, 8 days and 10 days). The treatments arranged in randomized complete block design with three replications. The statistical analysis was carried out using Genstat 15.0 software and the mean comparison was done using least significant difference (LSD) test. The analysis revealed that the crop water use efficiency was significantly ($p<0.05$) affected by the main effects of crop water levels, irrigation interval and by their interaction, whereas the grain yield does not show a significant ($p>0.05$) response. As the water levels declined and the irrigation intervals varied, the grain yield tends a fairly constant trend. However, based on the commerciality of the crop, application 75% ETc (30 mm) with 8 days irrigation interval gave numerically maximum grain yield of 3466.9 kg/ha and it has nearly more than 200 kg relative yield advantage over most treatments. The highest water use efficiency (0.9 kg/m^3) was recorded from the combination 75% ETc (30 mm) with 10 days; while it was statistically at par with 75% ETc with 8 days interval (0.8 kg/m^3) applied treatment. From the result, it could be concluded that the maximum yield and maximum water productivity were simultaneously achieved by combined application of 75% ETc with 8 days interval and saves 4600 m^3 water to irrigate an additional 1.2 ha compared with 125% (50 mm) ETc with 6 days interval applied treatment.

Keywords: crop water level, crop water use efficiency, grain yield, irrigation interval.

1. INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is an important monoecious annual legume to make oils and animal feed all over the world (Upadhyaya et al., 2006). It is the main source of food in various forms and used as a component of crop rotation in many countries (Waktole, 2018). As a legume, it improves soil fertility by fixing nitrogen and thereby increasing the productivity of the semi-arid cereal cropping systems (Sanogo et al., 2017). Groundnut is also a high-value crop; that can be marketed with little processing and it is the second-largest source of vegetable oils next to soybeans (Okello et al., 2010).

Groundnuts are also a significant source of cash income in developing countries that contribute significantly to food security and alleviate poverty (Baiphethi and Jacobs, 2009). The lowlands and rift valley areas of Ethiopia have considerable potential for increased oil crop production including groundnut. The national average area coverage and seed yield of groundnut were 64,649.3 hectares and 1.6 t ha-1 respectively (Kebede et al., 2017). Similarly, in Kobo valley pulse crops like groundnut (*eta*) variety were highly adaptable and gave a better production.

However, food production in many parts of Ethiopia is challenged by the inadequate and unreliable supply of water. The fact that the country's water use in general and agricultural water, in particular, is inefficient due to increases the water demand in all water use sectors (Ayana et al., 2015). "In arid and semi-arid parts of Eastern Amhara, including Kobo Girana valley, water is the most important yield-limiting factor for agricultural production as the rainfall is erratic and non-uniform in time and space". This leads to a common phenomenon of recurrent drought and crop failure (Getahun, 2014; Sisay, 2021). The Raya Kobo valley has good potential in terms of ground and surface water, fertile land and livestock production. Due to the lack of appropriate on-farm water management, many productive lands are posed by soil salinity and alkalinity. The poor practices of irrigation management discourage efforts in the irrigation development sector (Getahun, 2014; Sisay, 2021). For the long-term sustainability of an irrigation system, improvements of the current on-farm water management seem to be more necessary than any other practice (Sarwar et al., 2001).

The two main reasons for studying irrigation scheduling are to save water and protect the environment. However, for farmers and irrigation managers, the usual driving pressure for adopting irrigation scheduling is economic – scheduling is used because it makes or saves money (Henggeler, 2004). The Food and Agriculture Organization (FAO) created the CROPWAT software application to aid irrigation engineers and agronomists in doing common calculations for water irrigation studies, as well as in the management and design of irrigation systems (Allen et al., 1998). To provide better irrigation water management today, anticipated crop water use and irrigation timing should be validated on the field (USDA, 1993). Application of the right amount of irrigation water at a right time helps to optimize water loss and increases crop yield. Hence, the present study was focused to determine optimal crop water depth and frequency on yield and water use efficiency of groundnut at the kobo valley irrigation scheme.

2. MATERIALS AND METHODS

2.1. Description of the study area

The field experiment was conducted at Kobo experimental site from January 25 to June 9 and January 18 to June 2 for 2016 and 2017 respectively. The site is found at about 50 km from Woldia town to the North-East direction and 570 km in the North of Addis Ababa. Geographically, it is located between12.03°-12.08°N latitudes and 39.28°-39.42°E longitudes with an altitude of 1470 m.a.s.l. (Figure 1).

2.2. Climate

The average annual rainfall, mean monthly minimum and maximum temperatures are 644.08 mm, 8.49 °C, and 36.58 °C respectively (Figure 2). "As indicated in Figure 2, ten years (2006-2015) of long-term climatic data (mean rainfall, maximum and minimum temperature) of the study site was collected from Kobo metrological station".

2.3. Irrigation scheduling

ET_0 values were calculated using the FAO Penman-Monteith method with the aid of CROPWAT 8.0 model. The climatic data's (relative humidity, wind speed, sunshine hour, solar radiation, maximum and minimum temperature) were considered by the model for ET_0 simulation. The actual evapotranspiration (ET_c) was calculated as:

$$ET_c = ET_0 * kc \tag{1}$$

where ET_c = actual evapotranspiration;
ET_0 = Reference evapotranspiration;
Kc = Crop factor.

In addition to the climatic parameters, the crop (Kc, length of total growing season, length of each growth

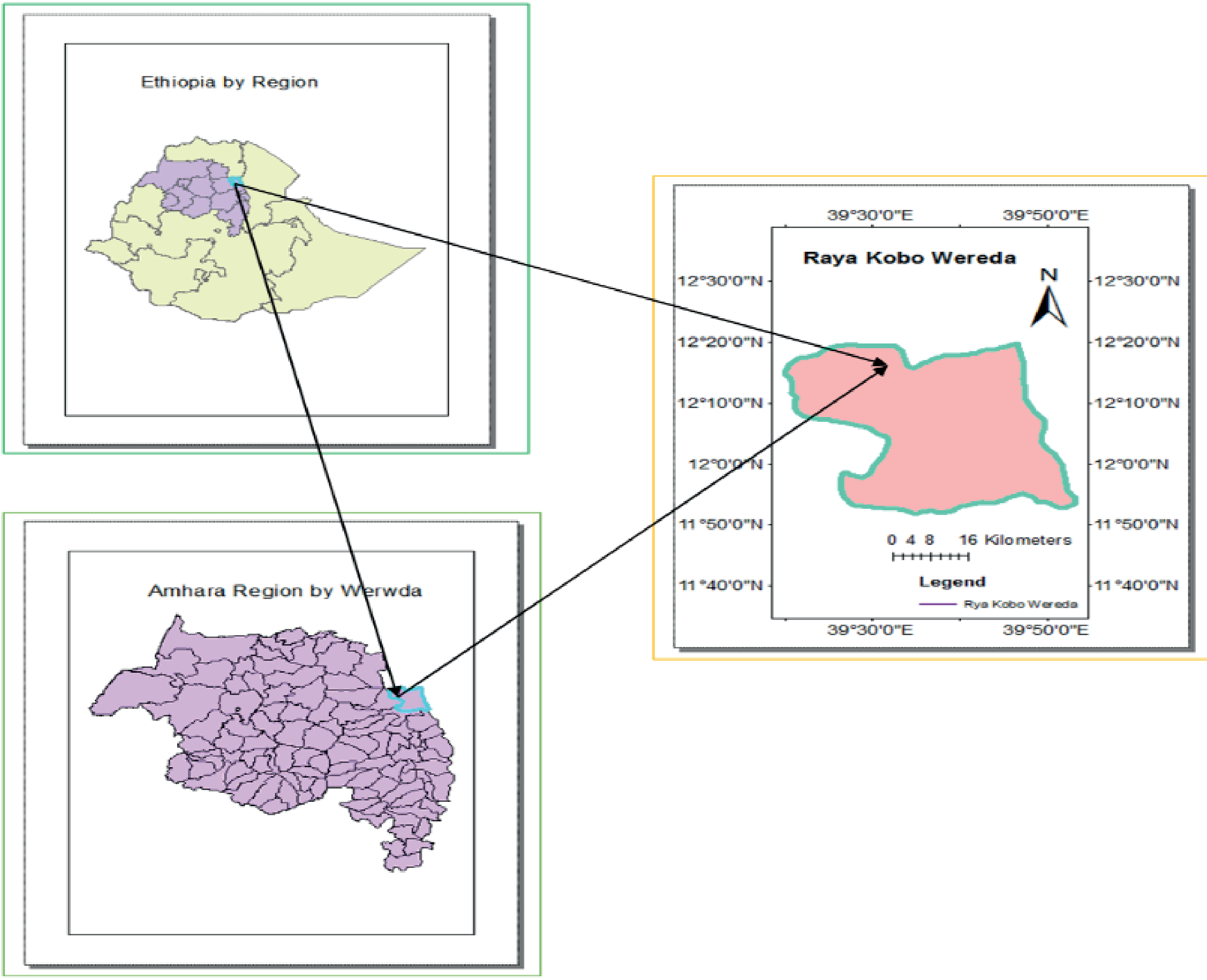

Figure 1. Map of the study area.

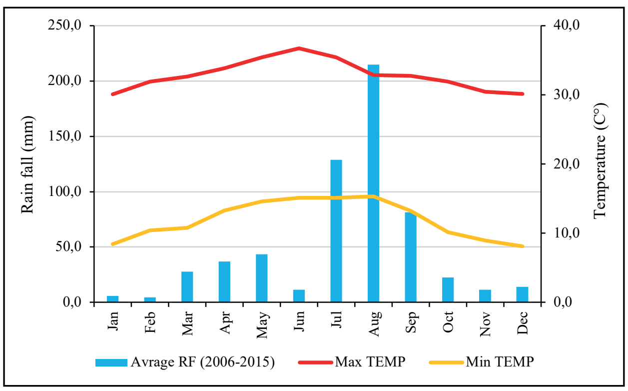

Figure 2. Mean monthly rainfall (mm), maximum and minimum temperature of the study area (2006-2015).

stage, critical depletion level (p) and maximum effective rooting depth) and soil data's (field capacity, permanent wilting point, and soil type) were needed by the model to compute the 100% irrigation scheduling of groundnut. The FAO Penman-Monteith modeling used as a preliminary study for irrigation planning and design purposes. The modeling approach has always certain deviations for under or overestimates of scheduling. During irrigation scheduling, the researcher should always pay attention and consider the simulated ET_c and irrigation interval (100%) as the initial starting point. Field evaluations and ground-truthing should be utilize to fine-tune the estimations used in irrigation system planning (USDA, 1993).

The irrigation requirement at each event was computed by monitoring daily actual rainfall data throughout the experimental season (Kobo meteorological station 2016 and 2017). It estimated as:

Table 1. Crop parameters as an input for CROPWAT model (Allen et al., 1998).

Growth stage	Initial	Development	Mid	Late	Total
Stage lengths (days)	35	35	35	35	140
Crop coefficient (Kc)	0.50	>>	1.05	0.75	
Rooting depth (m)	0.2	>>	0.5	0.3	
Depletion levels (P)	0.50	0.50	0.50	0.50	

$$IR = ET_c - P_{eff} \tag{2}$$

where IR = Net irrigation requirement (mm),
ET_c = Crop water requirement (mm) and
P_{eff} = Effective rainfall (mm).

Effective rainfall is a part of rainfall that entered into the soil and is made available for crop production. The effective rainfall throughout the growing season was calculated as (Allen et al., 1998):

$$P_{eff} = 0.6{*}P - 10/3 \quad \text{If } P < \frac{70}{3} \tag{3}$$

$$P_{eff} = 0.8{*}P - \frac{24}{3} \quad \text{If } P > \frac{70}{3} \tag{4}$$

where, P = precipitation (mm/month)
P_{eff} = monthly decades of effective rainfall (mm).

2.4. Experimental setup

The full irrigation scheduling (100%) which was simulated by the Penman-Monteith equation mostly varied with the approximation of 20% probability level (Rhoades et al., 1992; Allen et al., 1998). To validate the model output the three water levels of 75% (30 mm), 100% (40 mm) and 125% (50 mm) of the ETc with 75% (6 days), 100% (8 days), and 125% (10 days) of the optimal irrigation interval were tested on the field. Totally nine treatments were examined in a factorial randomized complete block design with three replications. The plot size was 3 m * 2.4 m = 7.2 m^2, and the distance between blocks and plots were 2 m and 1 m, respectively. The spacing between rows and plants were 30 and 10 cm respectively. Totally 240 plants were found on each experimental (7.2 m^2). Two days prior to sowing an equal amount of irrigation water was applied up to field capacity (mm) for one irrigation event to initiate seed germination. The irrigation scheduling experimental treatments were started 6 days after sowing. The amount of irrigation water was applied using a partial flume flow measuring device. The treatment combinations were constructed as in Table 2.

Table 2. Treatment combinations.

Factor 1 (Crop water levels in mm)	Factor 2 (Irrigation intervals in days)		
75% ETc (30 mm depth)	6	8	10
100% ETc (40 mm depth)	6	8	10
125% ETc (50 mm depth)	6	8	10

Table 3. Volume of used by the crop.

Treatments	Volume of water used (m^3/ha)	
	2016	2017
30 mm-6	5100	5100
40 mm-6	6800	6800
50 mm-6	8500	8500
30 mm-8	**3900**	**3900**
40 mm-8	5200	5200
50 mm-8	6500	6500
30 mm-10	**3000**	**3000**
40 mm-10	4000	4000
50 mm-10	5000	5000

2.5. Volume of water used

The total amount of water used by the individual treatments were recorded (Table 3).

2.6. Data collection and analysis

Agronomic parameters like plant height at maturity, number of pod per plant, number of seed per pod and grain yield were recorded from each net plot and changed to hectare base to make it ready for statistical analysis. However, water use efficiency is a derived parameter calculated as (Sinclair, 1984):

$$WUE = \frac{\text{Grain yield (kg)}}{\text{Amount of water used by the crop (cubic meter)}} \tag{5}$$

where, WUE= water use efficiency (kgm^{-3})

2.7. Statistical analysis

The Grain yield, plant height, and number of seed per plant and stand count were analysed using Genstat 15.0 software following the statistical procedure described by Gomez and Gomez (1984). The mean separation was carried out using least significant difference (LSD) test.

3. RESULTS AND DISCUSSION

3.1. Soil properties of the experimental site

Based on the soil analytical result the textural classes of the three soil layers (0-30 cm, 30-60 cm and 60-90 cm) categorized as silty clay loam (Table 4). The clay content shows an increasing tendency down the depth from 52% to 62.5% for 0-30 cm and 60-90 cm respectively. Buol et al., (2003) reported that the increasing of clay content down the depth indicates the presence of eluviation and illuviation processes or translocation of clay particles within the layers. The soil water content at FC shows increasing tendency from 31% to 33% for 0-30 to 60-90 cm depths respectively (Table 4). It indicates that, the relative proportion of higher clay content provides for sufficient moisture retention. The study agreed with many findings reported that soils with a relatively higher clay content could enhance a greater water retention capacity and lower permeability than sandy soils (Rengasamy, 2006; Seita et al., 2011). The bulk density varies within the range of 1.28 and 1.14 gm cm^{-3} for 0-30 to 60-90 cm depth respectively (Table 4). It classified as "well aggregated soil" (White, 2006).

3.2. Effect of crop water levels and irrigation frequency on yield-related parameters

A significant difference ($p<0.05$) was exhibited for mean plant height due to the interaction effect of water application depth and irrigation frequency in each year and combined over years (Table 5). The highest mean combined plant height (50.7 cm) was noted by the uniform application of 125% (50 mm) ETc with 8 days interval followed by 100% (40 mm) ETc with 8 days interval applied treatment as 48 cm. As the crop water level varied with the increasing trend the plant height tends to increase. This indicates that the application of moisture depth (50 mm) in the optimal scheduling (8 days) can enhance leaf production, root penetration and stem elongation, which agreed with the findings of Firake and Shinde (2000). "However, application of 50 mm crop water depth with a closer frequency (6 days) could decrease the plant height". In fact, the application of relatively larger crop water depth (50 mm) in a short irrigation interval promote surplus moisture, which influence aeration, plant growth and nutrients through leaching. On the other hand, the crop height was restricted as a maximum crop water level (50 mm) applied in a wider frequency (10 days) due to the relative moisture stress compared with 50 mm with 8 days applied treatment. The study agrees with the findings of MALLIC et al. (2018) state that uniform application of 50 mm depth through the growth period has a greater response in the plant height of groundnut.

Application of crop water levels with variable irrigation interval (Table 5) showed non-significant interaction effects ($p>0.05$) on the number of pods per plant in 2016 and combined over years. Nevertheless, during 2017 there was an interaction effect ($p<0.05$). Based on the combined result the numerically higher number of pods per plant (25) was obtained by the applications of 50 mm and 40 mm crop water depth with 8 days, and 40 mm in 6 days intervals. This implies that the number of pods per plant has not been much affected by variable irrigation scheduling. Similar experiences have been reported as the application of a slightly variable depth of water does not significantly affect the number of pods of groundnut (Aruna, 2017).

3.3. Effect of crop water levels and irrigation interval on grain yield

The interaction effect of crop water levels and irrigation frequency in Table 6 revealed a non-significant difference ($p>0.05$) on grain yield of groundnut in each year and combined of two years (2016 and 2017). Whereas the stand count of the treatments were similar. A comparatively yield reduction of treatments that receive the maximum amount of water (50 mm) with a rela-

Table 4. Effects of irrigation scheduling on yield related parameters of groundnut ($p<0.05$).

Depth (cm)	Particle size distribution (%)			Textural class	ρ (gm cm^{-3})	Soil moisture content		
	Clay	Silt	Sand			FC (%v)	PWP (%v)	TAW (mm)
0-30	52	28.6	19.4	SCL	1.28	31	19	36
30-60	57.5	26.5	16	SCL	1.21	32..2	19.8	47.2
60-30	62.5	22.5	15	SL	1.14	33	20.4	37.8
Average	57.3	25.9	16.8	SCL	1.2	32.1	19.7	∑111

Where, SCL- silty clay loam; SL- silty loam; ρ_b – bulk density; gm- gram.

Table 5. Effects of irrigation scheduling on yield related parameters of groundnut using least significant difference test (p<0.05).

Treatments	Plant height (cm)			Number of pods per plant		
	2016	2017	Combined	2016	2017	Combined
30 mm-6	41.8^{ab}	42.1^{bc}	42.1^{cde}	27.0	18.0^{b}	23.0
40 mm-6	44.9^{ab}	45.6^{b}	45.2^{bcd}	28.0	22.0^{ab}	25.0
50 mm-6	46.9^{ab}	44.7^{bc}	45.8^{bc}	23.0	21.0^{ab}	22.0
30 mm-8	44.3^{ab}	44.3^{bc}	44.8^{bcde}	24.0	23.0^{ab}	23.0
40 mm-8	45.9^{ab}	50.9^{a}	48.0^{ab}	24.0	23.0^{ab}	25.0
50 mm-8	47.9^{a}	53.6^{a}	50.7^{a}	25.0	25.0^{a}	25.0
30 mm-10	41.3^{ab}	42.6^{bc}	42.0^{de}	24.0	20.0^{b}	22.0
40 mm-10	40.7^{b}	41.5^{c}	41.1^{e}	27.0	20.0^{b}	24.0
50 mm-10	43.9^{ab}	44.9^{bc}	44.3^{bcde}	26.0	18.0^{b}	24.0
CV (%)	9.3	4.4	7.31	16.4	10.9	17.1

Where, ns: non-significant difference, CV (%): coefficient of variation in percent, 30, 40 and 50 mm are crop water levels, 6, 8 and 10 days are irrigation intervals.

Table 6. Effects of water application depth and irrigation frequency on grain yield using least significant difference test (p>0.05).

Treatments	Grain yield (kg/ha)		Combined over years
	2016	2017	
30 mm-6	2889.8	3383.6	3110.7
40 mm-6	3265.9	3283.1	3274.5
50 mm-6	2978.6	3080.7	3029.7
30 mm-8	**3435.5**	**3308.1**	**3466.9**
40 mm-8	3361.1	3571.9	3464.4
50 mm-8	3228.0	3468	3348.0
30 mm-10	3094.5	3022.4	3058.4
40 mm-10	3117.4	3427.3	3272.4
50 mm-10	3070.8	3371.1	3209.9
CV (%)	19.0	12.9	15.3
LSD (5 %)	ns	ns	ns

Where, ns: non-significant difference, CV (%): coefficient of variation in percent, 30, 40 and 50 mm are crop water levels, 6, 8 and 10 days are irrigation intervals.

tively closer frequency (6 days) could be due to a result of poor aeration and nutrient leaching. This implies that the application of the right amount of water at the right time optimizes water stress, water loss and nutrient uptake to attain comparatively higher yield. The study in line with the finding of Aruna (2017) states that the availability of the right amount of water enhances the development and final yield of groundnut as reduction imposes stress thus making use of available nutrients for growth and yield.

3.4. Effect of crop water levels and irrigation frequency on water use efficiency

The interaction of crop water levels and irrigation interval (Table 7) showed a significant effect (p<0.05) for water use efficiency in each year and combined over years. Based on the combined result, application of 75% (30 mm) crop water depth with 10 days irrigation interval gave the highest mean water use efficiency (0.9 kg/m^3) followed by 75% (30 mm) crop water depth with 8 days irrigation interval (0.8 kg/m^3). Especially, maximum yield and maximum water productivity were simultaneously achieved by the application of 75% crop water depth with 8 days. This treatment saves 4600 m^3 water and can be irrigated an additional 1.2 ha compared with 50 mm crop water depth with 6 days interval applied treatment. In comparing with the full irrigation (100%) which generated by the CROPWAT model (40 mm with 10 days interval) application of 30 mm crop water depth with 8 days interval has a comparative advantage to save 1400 m^3 water for 0.33 ha groundnut production.

Based on the result as indicated in Table 8, applications of crop water levels in a variable rate were significant impact on water use efficiency. As the water levels increased from 75 to 125% the water use efficiency also linearly decreased from 0.79 to 0.48 kg/m^3. The maximum water use efficiency of 0.79 kg/m^3 was recorded from the 75% ETc applied treatment.

The effect of irrigation interval on crop water use efficiency was exhibited a significant difference (Table 9).

Table 7. Effects of crop water depth and irrigation frequency on water use efficiency using least significant difference test (p<0.05).

Treatments	Crop water use efficiency (kg/m^3)		
	2016	2017	Combined
30 mm-6	0.60^{cd}	0.70^{bc}	0.60^{de}
40 mm-6	0.50^{cd}	0.50^{de}	0.45^{fg}
50 mm-6	0.40^{d}	0.40^{e}	0.30^{g}
30 mm-8	**0.90^{ab}**	**0.70^{ab}**	**0.80^{ab}**
40 mm-8	0.65^{c}	0.70^{bc}	0.60^{bc}
50 mm-8	0.50^{cd}	0.50^{cd}	0.50^{ef}
30 mm-10	**1.03^{a}**	**1.01^{a}**	**0.90^{a}**
40 mm-10	0.80^{bc}	0.90^{a}	0.85^{ab}
50 mm-10	0.60^{c}	0.70^{bc}	0.60^{de}
CV (%)	20.71	12.89	16.4
LSD (0.05)			

CV (%): coefficient of variation in percent, LSD: list significant difference, 30, 40 and 50 mm are crop water levels, 6, 8 and 10 days are irrigation intervals.

Table 8. Effects of crop water levels on crop water use efficiency using least significant difference test (p<0.05).

Water application level	Crop water use efficiency (kg/m^3)		
	2016	2017	Combined
75% (30 mm)	0.8^a	0.85^a	0.79^a
100% (40 mm)	0.60^b	0.65^b	0.65^b
125% (50 mm)	0.47^b	0.49^c	0.48^c
CV	16.3	11.5	15.5
LSD	0.13	0.085	0.09

CV (%): coefficient of variation in percent, LSD: list significant difference.

Table 9. Effects of irrigation interval on crop water use efficiency using least significant difference test (p<0.05).

Irrigation frequency (day)	Crop water use efficiency (kg/m^3)		
	2016	2017	Combined
6	0.49^b	0.52^c	0.5^c
8	0.65^a	0.67^b	0.65^b
10	0.77^a	0.82^a	0.8^a
CV	16.30	11.50	15.50
LSD	0.13	0.09	0.09

CV (%): coefficient of variation in percent, LSD: list significant difference.

As the interval between irrigation events increased from 6 to 10 day the mean crop water use efficiency tends to increase from 0.5 to 0.8 kg/m^3 respectively. The highest mean combined crop water use efficiency of 0.8 kg/m^3 was recorded by the application of 10 day irrigation interval.

4. CONCLUSION AND RECOMMENDATIONS

The effects of treatments were examined using plant height, number of pods per plant, grain yield and crop water use efficiency. The overall result indicates that the crop water levels and irrigation intervals as the main effect do not have a significant response on grain yield. On the other hand, the crop water use efficiency tends to increase due to the decreased and increased of water levels and irrigation intervals respectively. The interaction of 75% ETc with 8 days irrigation interval provides to achieve a simultaneously higher grain yield, water use efficiency and can save a substantial amount of water to irrigate additional land. The present study concludes that for the Kobo irrigation scheme combined application 75 % (30 mm) ETc with 8 days irrigation interval gave the highest crop water use efficiency without affecting the grain yield.

ACKNOWLEDGMENT

I would like to express my priceless thanks to "Almighty God", for his protection and kindness in my entire life. My sincere gratitude extends to Sirinka Agricultural Research Kobo Sub-center for providing me all the necessary research aid and equipments for the successful completion of the study. My genuine gratitude extends to Sirinka Agricultural Research Center soil and water managements directorate researchers for their valuable support to finish this study. I wish to express my thanks to Amhara Agricultural Research Institute for the financial support. Last but not the least, i would like to express my grateful thanks to Dr. Tesfaye Feyisa and Kindu Gashu, for their professional support and providing me with valuable comments.

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