Determination of Optimal Irrigation Scheduling for 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, the 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. To validate the CROPWAT model output the *three crop water levels as 75 % ETc (30 mm), 100 % ETc (40 mm), 125 % ETc (50 mm) and three irrigation intervals (6 days, 8 days and 10 days) were tested in factorial RCBD design with three replications. The statistical analysis was carried out using Genstat 15.0 software and the least significant difference (LSD) test was used to separate the means at p = 0.05. The response of the three crop water levels and three irrigation intervals for groundnut agronomic parameters was evaluated. 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 didn't 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-1 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*

Introduction

Groundnut (*Arachis hypogaea* L.) is an important monoecious annual legume to make oils and animal feed all over the world *(*Shirts et al., 2003; 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 estimated production area and yield of groundnut in Ethiopia in 2010/2011 cropping season were 49,603 hectares and 716,068 quintals, respectively (CSA, 2011). Similarly, in Kobo valley pulse crops like groundnut variety were highly adaptable and gave a better production.

However, food production in many parts of Ethiopia is challenged by the inadequate and

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. 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 (Salam et al., 2019). 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.

Materials and Methods

The field experiment was conducted at Kobo experimental site from January to June in 2016 and 2017. 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. It has an altitude of 1470 m.a.s.l. with the average annual rainfall, mean monthly minimum and maximum temperatures are 644.08 mm, 8.49 °C, and 36.58 °C respectively (Kobo Metrological Station, 2002 - 2015). As indicated in Figure 1 ten years (2006-2015) of long-term climatic data (mean maximum and minimum temperature, relative humidity, wind speed and sunshine hours) of the study site was collected from Kobo metrological station.

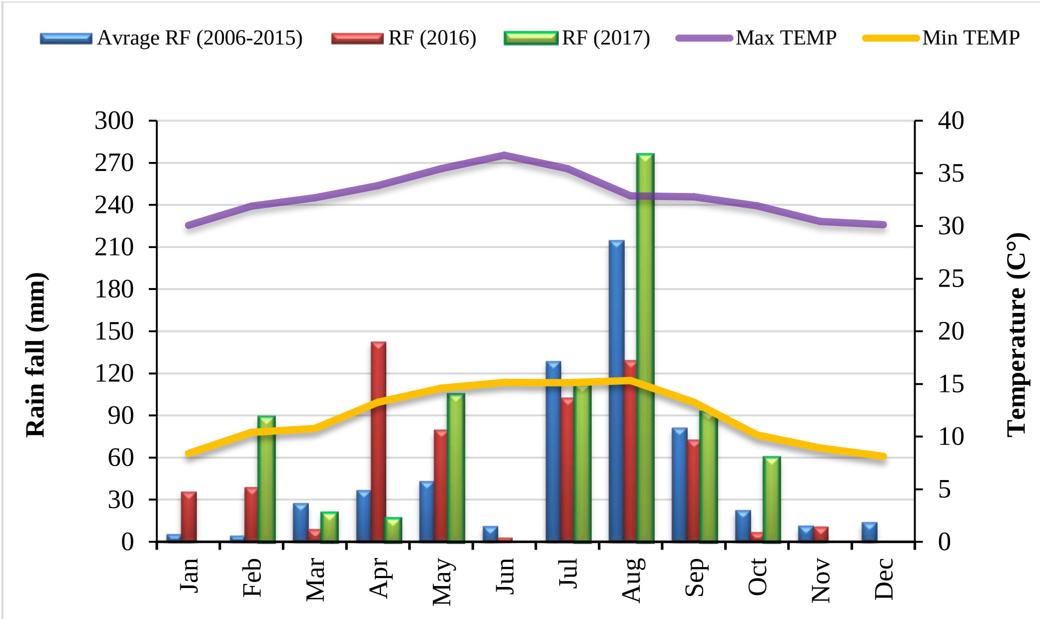

Figure 5: Monthly rainfall (mm), maximum and minimum temperature of the study area.

ETo values were calculated using the FAO Penman-Monteith method with the aid of CROPWAT 8.0 model. Furthermore, actual evapotranspiration (ETc) was calculated using the crop data as an input parameter (Table 1). Those parameters include; Kc, length of total growing season, length of each growth stage, critical depletion level (p) and maximum effective rooting depth were (Allen et al., 1998). The actual evapotranspiration (ETc) was calculated as:-

(1)

Where ETc = actual evapotranspiration

ETo = Reference evapotranspiration

Kc = Crop factor

Based on the climatic and crop parameters 40 mm ETc with 8 days irrigation interval was generated by the model as a full (100 %) schedule of groundnut. The FAO Penman-Monteith equation is always used as a preliminary study for irrigation planning and design purposes. The modeling approach has always certain deviations for under or overestimates of scheduling. Field evaluations and ground-truthing should always be utilized to fine-tune the estimations used in irrigation system planning (USDA, 1993). During irrigation scheduling, the researcher should always pay attention and consider the simulated ETc and irrigation interval (100 %) as the initial starting point. Rainfall varies dramatically over time (Figure 1), therefore irrigation scheduling must be based on real-time information with correlated the long-term expected rainfall used by the model (Rhoades et al., 1992; Allen et al., 1998; Savva and Frenken, 2002).

Table1: Relevant groundnut agronomic data for irrigation scheduling as follows:

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)	0.5	>>	0.75	0.5	
Depletion levels (P)	0.50	0.50	0.50	0.50	

The irrigation requirement at each event was computed by monitoring daily actual rainfall data throughout the experimental season (Kobo meteorological station 2016 and 2017). The effective rainfall which occurred above crop water demand and the mean expected rainfall (2006-2015) was due attention. Is estimated as:

(2)

Where Net irrigation requirement (mm),

= Crop water requirement (mm) and

= Effective rainfall (mm).

Effective rainfall is a part of rainfall that entered into the soil and is made available for crop production. It can be calculated by using the AGLAW or dependable rain formula. Because, t*he dependable rainfall is the rain that can be accounted for a* certain statistical probability (Allen et al., 1998);

If P <— (3)

— If P >— (4)

Where, = precipitation (mm/month)

Monthly decades of effective rainfall (mm).

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. Each experimental plot sizes of (3m * 2.4 m = 5.4 m^2) and the distance between blocks and plots were 2 and 1 m respectively. The spacing between rows and plants was 30 and 10 cm respectively. 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 are constructed indicated in Table 2.

Table 2. Treatment combination

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

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)*:

(5)

Statistical Analysis; The analysis of variance was carried out using Genstat 15.0 software following the statistical procedure described by Gomez and Gomez (1984). The least significant difference (LSD) was used to separate the means with the probabilities of 5%.

Results and Discussion

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

The number of seeds per pod was not significantly affected by the interaction effect of water application depth and irrigation frequency (P >0.05) in each year and combined over years. The number of seeds per pod (2) remains constant across years for all treatments. According to the findings of Jeyaramraja and Fantahun (2014), the number of pods per plant for practically all groundnut types is expected to be two.

Table 3. Effects of crop water levels and irrigation frequency on the grain yield of groundnut

	Plant height (cm)			Number of pods per plant			Number of seeds per pod		
Treatments	2016	2017	Combined	2016	2017	Combined	2016	2017	Combined
40 mm-8	45.9^{ab}	50.9^{a}	48.0^{ab}	24	23^{ab}	25	2	2	2
30 mm-8	44.3^{ab}	44.3^{bc}	44.8^{bcde}	24	23^{ab}	23	2	2	2
50 mm-8	47.9^{a}	53.6^{a}	50.7^{a}	25	25^{a}	25	2	2	2
40 mm-6	44.9^{ab}	45.6^{b}	45.2^{bcd}	28	22^{ab}	25	2	2	2
30 mm-6	41.8^{ab}	42.1^{bc}	42.1^{cde}	27	18^{b}	23	2	2	2
50 mm-6	46.9^{ab}	44.7^{bc}	45.8^{bc}	23	21^{ab}	22	2	2	2
40 mm-10	40.7^{b}	41.5^{c}	41.1^{e}	27	20^{b}	24	2	2	2
30 mm-10	41.3^{ab}	42.6^{bc}	42.0^{de}	24	20^{b}	22	2	2	2
50 mm-10	43.9^{ab}	44.9^{bc}	44.3^{bcde}	26	18^{b}	24	2	2	2
CV (%)*	9.3	4.4	7.31	16.4	10.85	17.06	13.2		9.7
LSD (5 %)				ns	5	ns	ns		ns

** ns: non-significant difference, CV: coefficient of variation in percent, LSD: list significant difference at 5 % probability level, 30, 40 and 50 mm are crop water levels, 6, 8 and 10 days are irrigation intervals.*

Effect of crop water levels and irrigation interval on grain yield

The interaction effect of crop water levels and irrigation frequency in Table 4 revealed a non-significant difference (p>0.05) on grain yield of groundnut in each year and combined of two years (2016 and 2017). However, groundnut is a highly commercial oil crop and the numerically higher mean combined grain yield (3466.9 kg) was recorded by 75 % (30 mm) crop water depth with 8 days interval applied treatment. It was numerically closer compared with 100% ETc (40 mm) with 8 days applied treatment. A yield reduction of treatments that receive the maximum amount of water (50 mm) with a relatively 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 maximum 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.

Table 4. Effects of crop water application depth and irrigation frequency on grain yield

Treatments	Grain yield (kgha-1) 2016	2017	Combined over years
40 mm-8	3361.1[a]	3571.9[a]	3464.4[a]
30 mm-8	3435.5[a]	3308.1[a]	3466.9[a]
50 mm-8	3228[a]	3468[a]	3348[a]
40 mm-6	3265.9[a]	3283.1[a]	3274.5[a]
30 mm-6	2889.8[a]	3383.6[a]	3110.7[a]
50 mm-6	2978.6[a]	3080.7[a]	3029.7[a]
40 mm-10	3117.4[a]	3427.3[a]	3272.4[a]
30 mm-10	3094.5[a]	3022.4[a]	3058.4[a]
50 mm-10	3070.8[a]	3371.1[a]	3209.9[a]
CV (%)*	19.02	12.94	15.32
LSD (5 %)	Ns	Ns	Ns

** ns: non-significant difference, CV: coefficient of variation in percent, LSD: list significant difference at 5 % probability level, 30, 40 and 50 mm are crop water levels, 6, 8 and 10 days are irrigation intervals.*

Crop water levels as the main effect (Figure 2) showed there was a non-significant ($p>0.05$) response on grain yield in each year and combined of the two years. As the water levels decreased the grain yield tends to a fairly constant trend because the groundnut manages the moisture by controlling its vegetative growth. It is obvious that there is high evaporation in semi-arid areas resulting in the application of a high amount of water at one irrigation event not usable by crops. On the other hand, the application of a large amount of water at a time promotes waterlogging and nutrient leaching which poses yield reduction. The numerically maximum combined grain yield of 3337.8 kg ha^{-1} was recorded from the application of 100% *ETc and followed by 3188.95 kgha-1 for 75% ETc applied treatment (Table 5).*

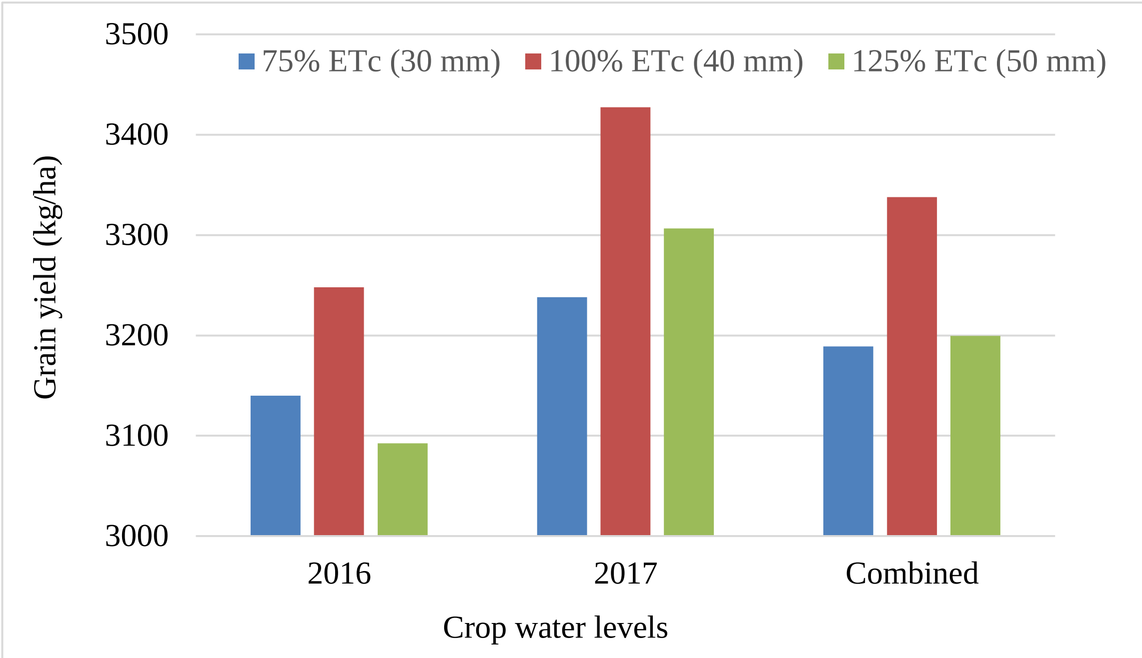

Figure 2: Effects of crop water levels on grain yield

The irrigation intervals as the main effect exhibited a non-significant response ($p>0.05$) on grain yield (Figure 2). As the intervals between two irrigation events increased, the grain yield becomes nearly constant. The numerically highest combined grain yield of 3395.5 *kgha-1* was recorded from 8 days interval applied treatment followed by 3183.9 kgha-1 for 6 days interval applied treatment.

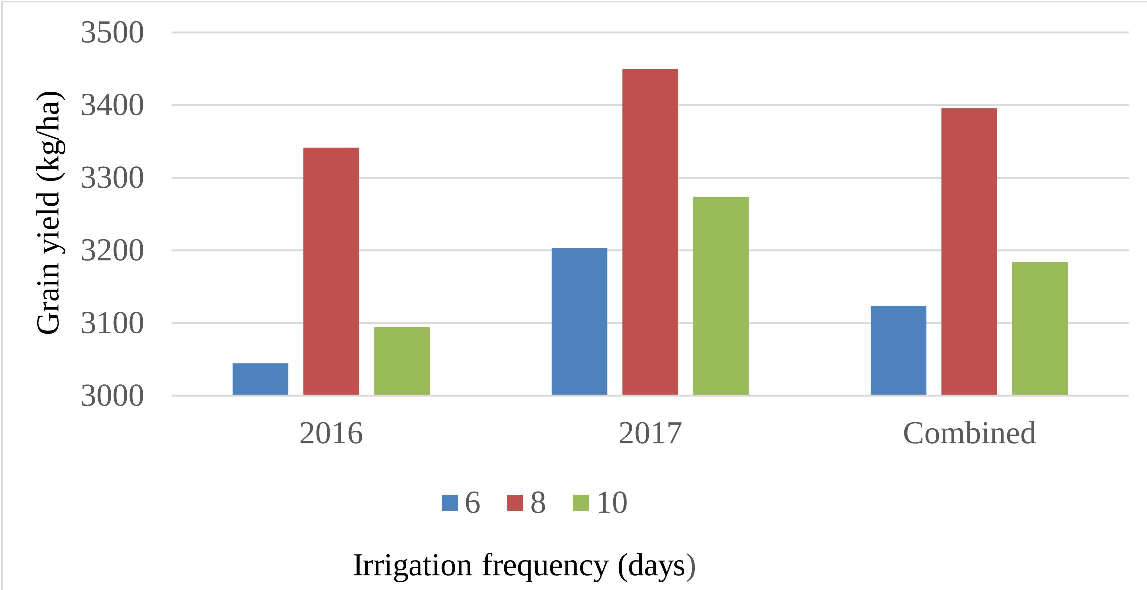

Figure 3: Effects of irrigation interval on grain yield

The interaction of crop water levels and irrigation interval (Table 5) showed a significant effect ($p<0.05$) for water use efficiency in each year and combined over years. 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.

Table 5. Effects of crop water application depth and irrigation frequency on water use efficiency

Treatments	Volume of water used (m^3/ha)		Crop water use efficiency (kg/m^3)		
	2016	2017	2016	2017	Combined
40 mm-8	5200	5200	0.65^{c}	0.7^{bc}	0.6^{bc}
30 mm-8	3900	3900	0.9^{ab}	0.7^{ab}	0.8^{ab}
50 mm-8	6500	6500	0.5^{cd}	0.5^{cd}	0.5^{ef}
40 mm-6	6800	6800	0.5^{cd}	0.5^{de}	0.45^{fg}
30 mm-6	5100	5100	0.6^{cd}	0.7^{bc}	0.6^{de}
50 mm-6	8500	8500	0.4^{d}	0.4^{e}	0.3^{g}
40 mm-10	4000	4000	0.8^{bc}	0.9^{a}	0.85^{ab}
30 mm-10	3000	3000	1.03^{a}	1.01^{a}	0.9^{a}
50 mm-10	5000	5000	0.6^{c}	0.7^{bc}	0.6^{de}
CV (%)*			20.71	12.89	16.4
LSD (0.05)					

**CV: coefficient of variation in percent, LSD: list significant difference at 5 % probability level, 30, 40 and 50 mm are crop water levels, 6, 8 and 10 days are irrigation intervals.*

The combined and each year analysis (Table 6) showed that the water levels as the main effect were a significant effect on crop water use efficiency. As the water levels increased from 75 to 125 % the crop water use efficiency also linearly decreased from 0.79 to 0.48 kg/m^3. The maximum crop water use efficiency of 0.79 kg/m^3 was recorded from the 75 % ETc applied treatment.

Table 6. Effects of crop water levels on crop water use efficiency

Water application level	Crop water use efficiency (kg/m^3)		
	2008	2009	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 (0.05)	0.13	0.085	0.09

CV:: coefficient of variation in percent, LSD: list significant difference at 5 % probability level.*

The effect of irrigation interval on crop water use efficiency was exhibited a significant difference (Table 7). 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.

Table 7. Effects of irrigation interval on crop water use efficiency

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 at 5 % probability level.

Conclusion and Recommendations

In this study, an attempt was made to evaluate three crop water application levels and three irrigation intervals in Kobo irrigation scheme for groundnut production. The three crop water application levels were 75 % (30 mm) ETc, 100 % (40 mm) ETc, 125 % (50 mm) ETc and the three irrigation intervals were expressed as 6 days, 8 days and 10 days. The experiment was designed by a combination of the two-factor levels formed as nine treatments using factorial Randomized Complete Block Design (RCBD) with three replications. The effects of treatments were examined using plant height, number of pods per plant, number of seeds per pod, 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.

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