Determination of Irrigation water Requirements and frequency for Carrot (*Daucus carota* L.) at Chacha Irrigation Scheme, North shoa zone, Amhara Region, Ethiopia.

Tsegaye Getachew*, Demisew Getu, Belihu Nigatu and Biruk Getaneh

Amhara Regional Agricultural Research Institute, Debre Birhan Agricultural Research Center P.O.Box 112, Debre Birhan

Corresponding author: Tsegaye Getachew, email: tsegetemeng2011@gmail.com

Abstract

The development of efficient irrigation management practice is a key to sustain the optimum crop production system in Ethiopia. The field experiment was conducted to determine the best irrigation regimes and validate CROPWAT 8.0 under field trial at Chacha small scale irrigation scheme. To obtain high quality and quantity of carrot root yield, the right amount of water application at the right time is a mandatory. The experiment was designed with four irrigation depths (50%, 75%, 100%, and 125% of the CROPWAT 8.0 generated depth) and three irrigation frequency (irrigation interval as the model, three days before, and three days after) with Randomized complete block design. Carrot root yields and water use efficiency had a high

36503 kg ha^{-1} was found with the application of 100% ETc with every 15 days and the highest water use efficiency of 9.3kg/m^{3} was found in the application of 50% irrigation depth with 9 days interval. However, the statistical result and the partial budget analysis showed that *the best water use efficiency of 8.1kg/m3 and optimum marketable carrot root yield of 32551 kg ha^{-1} was observed in the application 75% of the CROPWAT 8.0 generated depth with every 15 days of 31mm at initial, 35mm at development-1, 39mm at development-2, 46mm at mid, 43mm irrigation depth at late stage with the water saved produce 3829 kg extra yield from an extra land of 0.1 ha over the model treatment. Therefore, the application of 75% of the CROPWAT 8.0 generated depth with an irrigation interval of 15 days interval is recommended on the highland agro-ecology area and clay soil type with surface irrigation methods for satisfactorily carrot production.*

Keywords: Carrot, CROPWAT, Et$_{c.}$, root yield, water use efficiency,.

Introduction

Carrot (Daucus carota L.) is grown all over the world. It is an important short duration root vegetable grown for both fresh market and processed foods (Abdel-Mawly, 2004). However, soil water and nutrient absorption seems to increase with increasing root to soil contact. They can be sown in different seasons and climates. Since carrot crop has high economic value, the irrigation management strategy seeks maximum yield by supplying all requirements of the crop. Carrots grown for roots are managed for rapid root growth during a relatively short growing season (Hutmacher et al., 1990).

Irrigation is a national issue that is supposed to transform the agricultural sector to the industrial sector. It ensures optimal soil moisture during the growing period of crops. An irrigation strategy that assures optimum yields and WUE by synchronizing crop water use with the crop growth stages is a key for the development of the communities. The necessity for water supply depends on the crop development stage. Irrigation in critical periods is one of the main conditions ensuring ahigh-quality yield of carrots. The existence of healthy soil and water leads to healthy crop growth and development and, hence crop production and food security of the society. Water and land management needs an integrated approach to soil-water-plant-nutrient management.

One of the main problems that it has been facing nowadays is the low implementation of advanced technologies for irrigation forecasts in real-time so there are still using traditional methods by which water consumption is higher (Yoima et., 2015). Irrigation is typically applied on a routine basis without scheduling and supply often exceeds crop requirements under local practices. Irrigation methods besides irrigation scheduling play an important role in carrot yield. In Chacha small-scale irrigation, carrots have a very important place of vegetables consumed daily and practiced by the local farmers, investors etc. However, the production of carrots is still not stable from year to year in Chacha small-scale irrigation scheme.

Crop water requirements are defined here as "the depth of water needed to meet the water loss through evapotranspiration (ETcrop) of a disease-free crop, growing in large fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment". To calculate ETc a three-stage procedure is recommended: - (1) the effect of climate. (2) the effect of the crop characteristics (3) The effect of local conditions and agricultural practices(FAO & PAPER, n.d.)

A carrot root yield is affected by different factors. Polak et al. (1999) concluded that very important factors, which influence carrot root quality, are soil structure, its cultivation, nutrient coverage and proportional irrigation regime. The highest carrot yield was obtained by using sprinkler irrigation rather than drip and surface irrigation (Zeipi et., 2014).

In water-scarce areas, WUE is the main criterion for evaluating the performance of production systems, the management of water to the most critical growth stage is important. Reid and Gillespie, (2017) report about water stress and high moisture influence on quality and yield of carrots. The solution is to limit water to specific stages, minimizing loss of yield from water stress and waterlogging.

There are no researches done before in this area regarding irrigation water amount and frequency for better yield of carrots using CROPWAT 8.0 model. Therefore, this study was conducted for two years to determine the optimum irrigation amount and frequency of carrots to improve carrot yield and water productivity.

Materials and methods

Description of the study sites

The field experiment was conducted on Chacha irrigation Scheme to determine the crop water requirements of carrots from 206/17-2017/18. The wereda is located 110km from Addis Ababa, in North Shewa near Debre Birhan town. Its geographic coordinates are located at 10^{0}01’00” northing and 39^{0}45’00” Easting and altitude of 2764 meter above sea level. The land topography is near to flat (2%) and the annual rainfall is about 985mm. The whole area is not cultivated at rain-fed system, rather they cultivate in irrigation season. The soil textural class of the study site is clay type. The water source is either from the dam with gravity flow or the perennial river by pumping system.

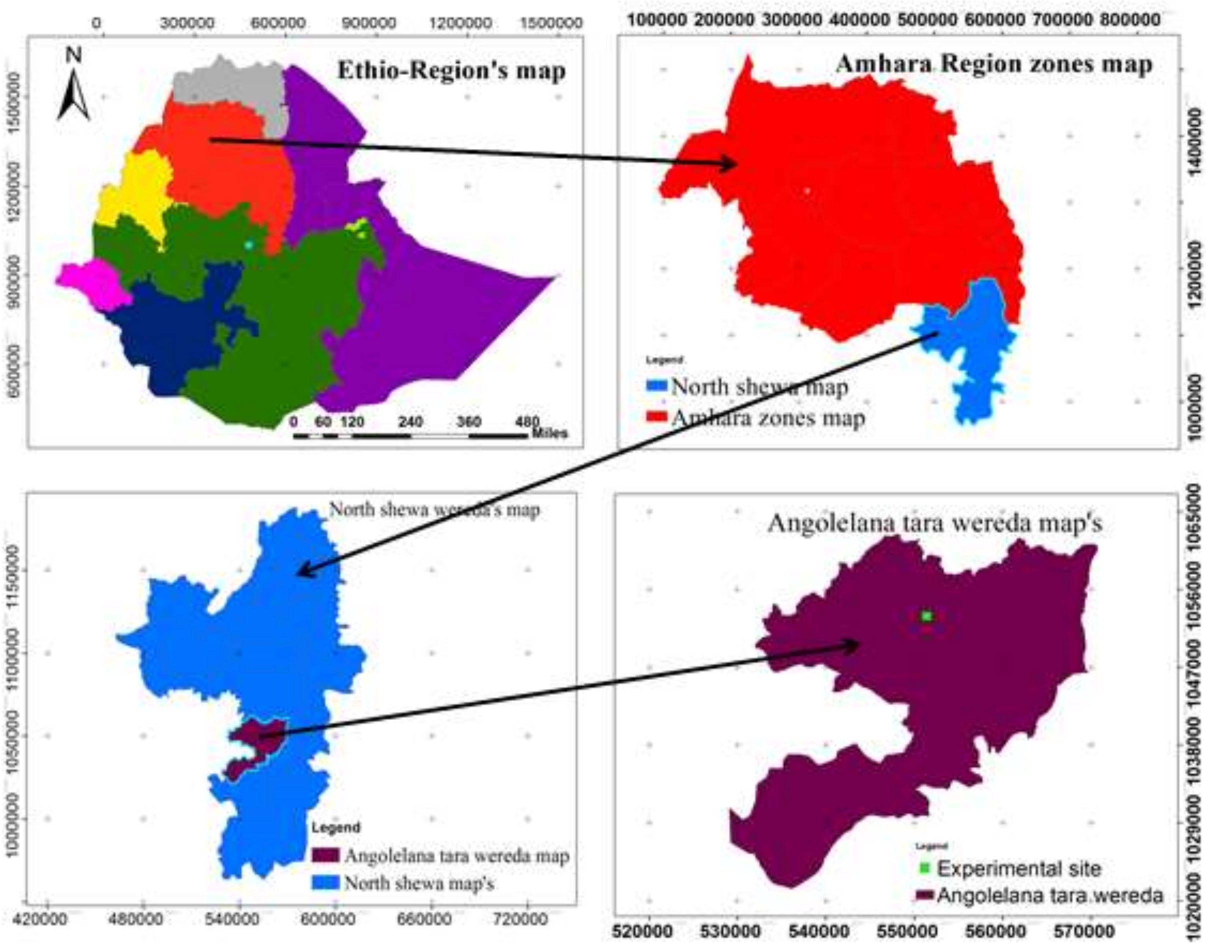

Figure 7. Study location map

Input requirements for CROPWAT 8.0 model

The CROPWAT under windows version 8.0 interfaces was used for determining the irrigation scheduling. The CROPWAT 8.0 version with an input of climatic parameters, soil type, root depth, depletion fraction, crop data (crop type, planting date, crop coefficient /k_c values, stage days) was used to determine the irrigation regimes.

Soil sampling and Analysis

The soil type is one of the inputs for determination of crop water requirement. Composite soil sampling was collected and Analyzed at Debere Birhan Agricultural Research Center during planting to determine the physic-chemical properties. Accordingly, the pH, EC, and OM of the soil was 6.40, 0.089 dSm^{-1}, and 4.27% respectively. The soil water contents at field capacity and permanent wilting point were 31 and 16% respectively.

Crop type and growth stage

Due to the lack of actual Kc of carrot, it was accessed from FAO irrigation and drainage paper No. 56 (Allen et al., 1998). The allowable water depletion of carrot was assumed to be 0.35 of total available water (P = 0.65) during the whole growing cycle as suggested in FAO 56 (Allen et al., 1998). The total period of root carrot from instant of sowing was fixed as 120 days (25 initial stages, 40 development stages, 33 mid stage, 22 late stages).

Climatic parameter

Climatic parameters are a major factor that determines the total water requirements of a crop from sowing to harvesting. The climatic data was taken from nearby metrological station, Debre Birhan Agricultural Research Center.

The maximum evaporative demand of the atmosphere was found on May (4.07mm/day) and the minimum ET_o was found on July and December (3.06mm/day).

Table 11. The monthly average climatic data

Month	Min Temp	Max Temp	Relative humidity	Wind speed	Sun shine hours	Solar radiation	ET_o
	°C	°C	%	km/day	Hours	MJ/m²/day	mm/day
January	5.5	19.7	76	55	8	19.3	3.05
February	7.2	21	68	58	8.4	21.1	3.51
March	8.3	21.8	72	86	7.2	20.3	3.67
April	8.9	21.6	74	78	6.7	19.8	3.62
May	9.1	21.6	74	104	7.6	20.8	3.77
June	8.8	21.8	72	130	6.6	18.9	3.62
July	8.8	19.9	72	104	4.3	15.6	3.04
August	9.1	19.8	74	86	5.5	17.7	3.24
September	8.8	19.7	79	69	6.2	18.8	3.31
October	7.2	19.3	79	69	8	20.7	3.41
November	7.5	19	71	69	9.3	21.3	3.38
December	6.6	18.8	83	86	8.3	19.2	2.98
Average	8	20.3	75	83	7.2	19.5	3.38

Experimental procedures and design

The experiment was designed with four irrigation depths (50%, 75%, 100%, and 125% of the CROPWAT 8.0 generated depth) and three irrigation frequency (irrigation interval as the model, three days before, and three days after) with Randomized complete block design. The carrot seed, Nantus Varity, was sown at beginning of January with seed rate of 1.7 kg/ha (1 seed at every 5 cm and 20 cm row spacing). Prior to sowing the land was well prepared and irrigated to be easily workable. The recommended fertilizer rate of 152.2 kg urea/ha and 157.9 kg/ha NPS was applied, Nitrogen half split application at sowing and vegetation.

The water used in this experiment was sourced from the nearby dam and the river with pumping devices. The mode of applying water used in this experiment was canning system. The ETC of carrots were determined from CROPWAT 8.0 and the treatments were set by using the model as a reference. Common irrigation was applied up to the carrot vegetative and then irrigation was applied as per the treatments code arrangement. Then, the set treatments were applied accordingly to each plot. Unexpected rainfall was recorded with a rain-gauge and it was converted to the effective rainfall by USAD methods in the CROPWAT 8.0 model. Carrot was irrigated 9, 12 and 15 days as per treatment to maintain root zone soil water content above allowable depletion threshold and returning soil water content back to field capacity.

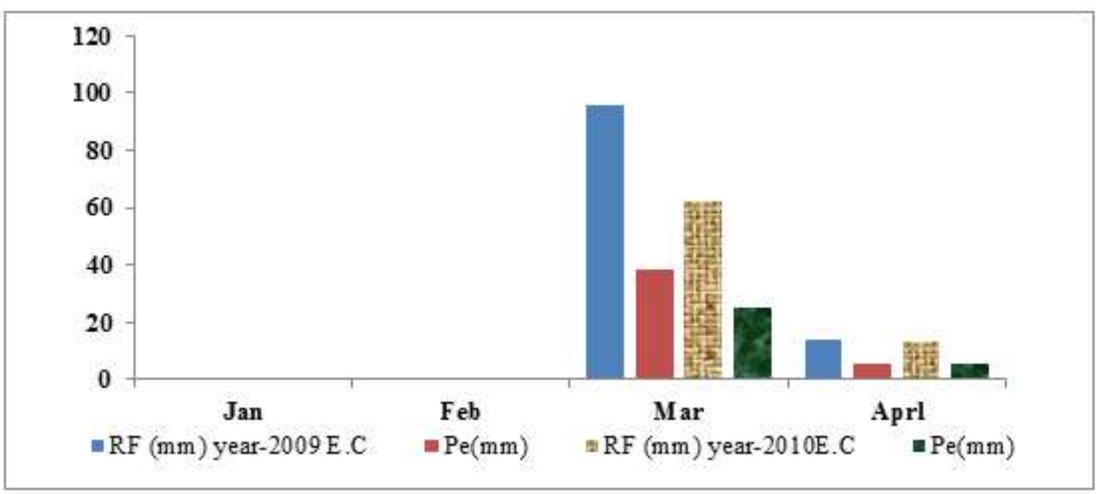

Figure 8. The monthly rainfall pattern in growing season

ET_C=from the CROPWAT model---------------------1

NIR=ETC-P_e--------------------2

GIR=NIR+ losses, or GIR=NIR/E_a. -------------3

Where, ETC is Evapotranspiration of the crop (mm/Season), P_e is Effective Rain fall in mm/Season, NIR is Net Irrigation Requirement in mm/Season, GIR is Gross Irrigation Requirement in mm/Season and E_a is Application Efficiency (taken as 80%)

Table 12. Treatments code and their arrangements in the experimentation

Trt codes	irrigation levels	Initial (mm)	Dev't-1 (mm)	Dev't-2 (mm)	Mid (mm)	Late (mm)
1	50% ETC *12days	16	18	21	25	23
2	75%ETC*12 days	25	28	31	37	34
3	100%ETC*12days	33	37	42	50	46
4	125%ETC*12days	41	46	52	62	57
5	50% ETC *9 days	12	14	16	19	17
6	75%ETC*9 days	18	21	23	28	26
7	100%ETC*9days	25	28	31	37	34
8	125%ETC*9days	31	35	39	46	43
9	50% ETC *15days	20	23	26	31	29
10	75%ETC*15 days	31	35	39	46	43
11	100%ETC*15days	41	46	52	62	57
12	125%ETC*15days	51	58	65	77	71

Data collection

The data collected were number of stand count, plant height, root length, root diameter and core diameter, root yield, number of carrot root and water use efficiency. The weighed samples of carrot roots from each plot were converted into kilogram per hectare and divide by their respective total amount of irrigation water supplied throughout the cropping season to determine the water use efficiency. A sample size of 10 plants per treatment was randomly selected and tagged for easy identification.

Water use efficiency was calculated as ratio of total yield (kg) to total water consumed by the crop (m3). The reciprocal of this gave the amount of irrigation water used to get a kilogram of carrot. As quoted by (Tefera, 2017), the following relationship was employed to calculate water use efficiency (Zhang andOweis , 1999).

$$WUE = \frac{Y}{NIR}$$

Where, WUE is water use efficiency in kg / m ^{3}, Y is carrot root yield in kg ha^{-1} and NIR is total net irrigation requirement m^3 ha^{-1}

Statistical analysis

All yield, yield components and water use efficiency data were subjected to analysis of variance using SAS version 9.0 (SAS Institute, 2004) statistical software. The significance of differences among treatment means was compared using Dunken's multiple range test at $p<0.05$ significant difference and at $p<0.01$ highly significant difference.

Results and discussion

Response of marketable Carrot root yield on the application of water depth and interval

As the combined or two years (2009 & 2010) ANOVA results shows (table 3), that the treatments of 100%ETC*15days, 125%ETC*9days, 125%ETC*12days and 75%ETC*15 days had significantly high on the marketable carrots root yield 36503 kg ha^{-1}, 34674 kg ha^{-1}, kg ha^{-1}, 33750 kg ha^{-1}, and 32551 kg ha^{-1} respectively than other treatments. Rang of the marketable carrot root yield observed in the experiment from 26101 kg ha^{-1} to 36503 kg ha^{-1} in the treatments 50% ETC *12days and 100%ETC*15days respectively. For instance, at optimum moisture, carrot root yield was obtained up to 28,100 - 45,850 kg ha^{-1} (Wassu et al., 2014). Similarly, as reported by Zeipi et al. (2014) the average carrot root yields of Nantus variety was 42,520 kg ha^{-1} when it was released. Quezada et al. (2011) found that the highest yield of carrot crop in a clay soil was obtained with the 100% E_{pan} treatment. The highest root yields were obtained with at 100% evaporation replenishment and 120 kg N/fed. On the other hand, maximum water use value were recorded with 120 kg N/fed and at 75% level of evaporation replenishment (Abdel-Mawly, 2004).

Imtiyaz et al. (2000) reported a higher mean marketable yield of carrot (56.76 and 38.39 t ha^{-1}) and a higher irrigation production efficiency of carrot (9.83 and 6.66 kg m^{-3}). To obtain higher and quality carrot root yields, conditions of good soil fertility and soil structure, optimum soil moisture and efficient technological knowhow are important. As the application of irrigation water depth increases, the yield per unit of water increases and then the trends decrease.

Table 13. Effect of irrigation regimes on carrot yield and yield parameters and water use efficiency

Trt code	Treatment	PH (cm)	RL (cm)	RD (ratio)	TY (kg/ha)	MY (kg/ha)	WUE (kg/m3)
1	50% ETC *12days	24[ab]	12.3[ab]	2.8[ab]	29982[d]	26101[d]	8.7[ab]
2	75%ETC*12 days	24[ab]	12.5[ab]	2.7[ab]	34568[abcd]	29836[bcd]	8.2[abc]
3	100%ETC*12days	26[a]	12.3[ab]	2.8[ab]	34554[abcd]	30211[bdc]	7.1[cde]
4	125%ETC*12days	25[a]	12.4[ab]	3.1[a]	38571[ab]	33750[abc]	6.9[de]
5	50% ETC *9 days	21[b]	12.6[ab]	2.6[ab]	32304[cd]	28452[cd]	9.3[a]
6	75%ETC*9 days	23[ab]	12.7[ab]	2.6[ab]	33247[bcd]	30440[bcd]	7.9[bcde]
7	100%ETC*9days	22[ab]	12.4[ab]	2.7[ab]	36143[abc]	30979[bcd]	7.6[bcde]
8	125%ETC*9days	24[ab]	12.8[ab]	2.6[ab]	37972[ab]	34674[ab]	6.6[e]
9	50% ETC *15days	22[b]	11.9[b]	2.9[ab]	31937[cd]	28795[cd]	8.9[ab]
10	75%ETC*15 days	23[ab]	13.2[a]	2.5[b]	35640[abc]	32551[abc]	8.1[abcd]
11	100%ETC*15days	25[a]	13[ab]	2.4[b]	39542[a]	36503[a]	7.7[bcde]
12	125%ETC*15days	23[b]	12.9[ab]	2.7[ab]	31363[c]	29768[bdc]	5.3[e]
CV (%)		11.8	7.1	12.5	11.5	12.9	12.8
P (0.05)		*	*	*	**	**	**

*Trt is treatment, PH is plant height, RL is root length, RD is ratio of rootdiameter to core diameter, * is significant at 0.05, **is highly significant at 0.001, ns is non - significant, TY is total yield, WUE is water use efficiency, CV is coefficient of variation.*

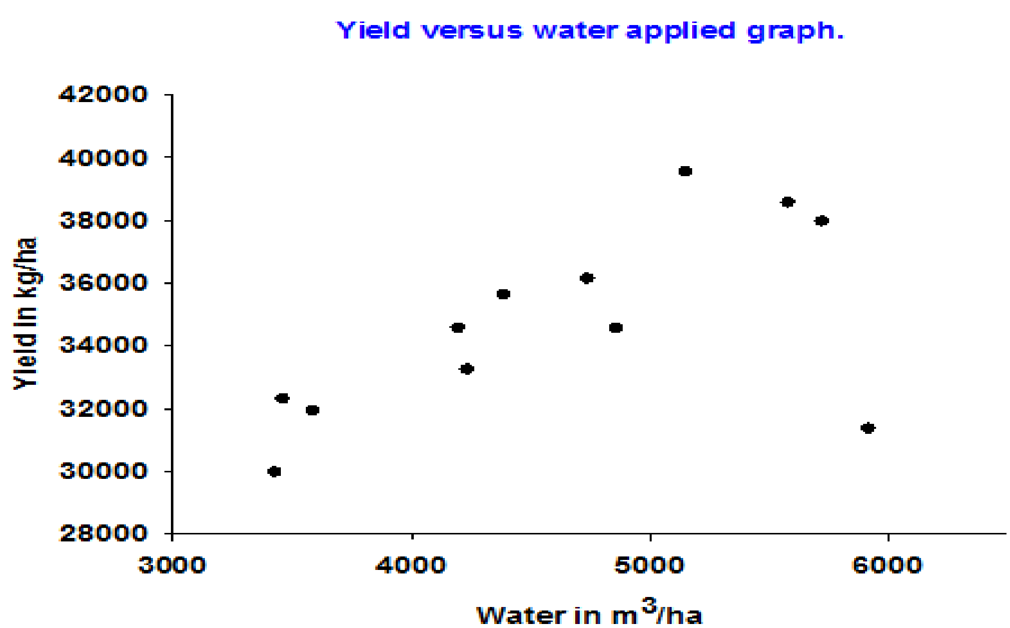

Figure 9. The response of carrot root yield to different water amount

Influence of irrigation regime on water use efficiency of carrot

As the Analysis of variance result indicated, water use efficiencies of carrot root were significantly influenced by irrigation. The combined or two years (2009 & 2010) ANOVA results showed (table 3)that the treatments of 50% ETC *9 days, 50% ETC *15days, 50% ETC *12days, 75% ETC *12days and 75%ETC*15 days had significantly higher water use efficiency of carrots root of yield 9.3 kg m^{-3}, 8.9 kg m^{-3}, 8.7 kgm^{-3}, 8.2 kgm^{-3}, and 8.1 kgm^{-3} respectively than other treatments. The highest and the lowest WUE recorded 9.3 kg m^{-3} and 5.3 kg m^{-3} in 50% of CROPWAT depth with 9 days interval, and 125% of CROPWAT depth with 15 days interval treatments respectively.

As reported by Dysko and Kaniszewski (2007), minimal water supply necessary for carrot development is 350-400 mm, but some authors advise 650 mm for satisfactory development of carrot roots (Fritz et al., 2008). However, the total irrigation water required for its base period in this experiment was between 342mm-591mm. The magnitude and rate of development of soil water deficits markedly influenced carrot responses to developing water deficits (Hutmacher et al., 1990). As a principle, the higher the amount of applied irrigation depth (delta) implies the smaller the duty and hence, the smaller water use efficiency. A total crop water use of approximately 550 to 620 mm was needed to achieve the best yield which is roughly equal to potential evapotranspiration in the San Joaquin Valley, during the time that the crop water use was calculated (Ayars et al. 1991). .

Influence of irrigation regime on marketable carrot root yield and Water use efficiency

The results of this study showed that all irrigation treatments determined based on CROPWAT model gave statistical difference in carrot root yields and water use efficiencies among the treatments. the treatments of 100%ETC*15days, 125%ETC*9days, 125%ETC*12days and 75%ETC*15 days had significantly higher marketable carrots root yield of 36503 kg ha^{-1}, 34674 kg ha^{-1}, kg ha^{-1}, 33750 kg ha^{-1}, and 32551 kg ha^{-1} respectively than other treatments. And the treatments of 50% ETC *9 days, 50% ETC *15days, 50% ETC *12days, 75% ETC *12days and 75%ETC*15 days had significantly higher water use efficiency of carrots root yield 9.3 kg m^{-3}, 8.9 kg m^{-3}, 8.7 kgm^{-3}, 8.2 kgm^{-3}, and 8.1 kgm^{-3} respectively than other treatments. However, the best water use efficiency 8.1kg kgm^{-3} and optimum marketable carrot root yield 32551 kg ha^{-1} was observed in the application 75% of the CROPWAT 8.0 generated depth with every 15 days of 31mm at initial, 35mm at development-1, 39mm at development-2, 46mm at mid, 43mm irrigation depth at late stage. The water saved produce 3829 kg extra yield from an extra land of 0.1 ha over the model treatment.

The investigation recorded a highest WUE in the 75% ET_c treatment equivalent to 3864 m^3 ha^{-1}, which they recommended as the required water application level in irrigation scheduling (Quezada et. al. 2011). The highest yield of carrot crop obtained with the 100 % E_{pan} treatment (94891kg ha^{-1}) and the maximum WUE corresponded to 75 % E_{pan} treatment (24.6 kg m^{3-1}), with an applied water volume of 3864 m^3 ha^{-1}, with drip irrigation scheduling in carrot (Quezada et al., 2011). Statistically, water use efficiency of the treatments had highly significance difference among the treatments. With reference to the Fig below, as the irrigation water depth increases, the water use efficiency of carrot decreases.

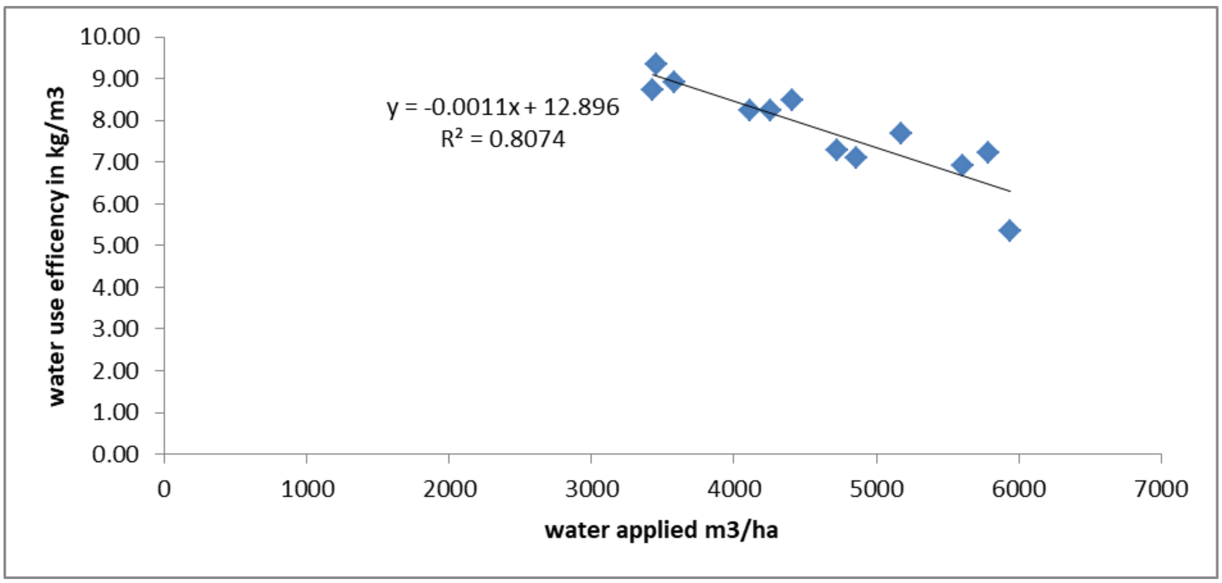

Figure 10. Effect of irrigation regimes on total yield and water use efficiency.

The water saved produce 3829kg from an extra land of 0.1 ha. The 100% CROPWAT model depth; 41mm at initial, 46mmat development-1, 52 mm at development-2, 62 mm at mid, 57mm at late with every 15days registered the highest root yield. However, it is resulted in a yield penalty of 4625kg ha^{-1} due to the 6 percent over application of water above CROPWAT generated. depth.

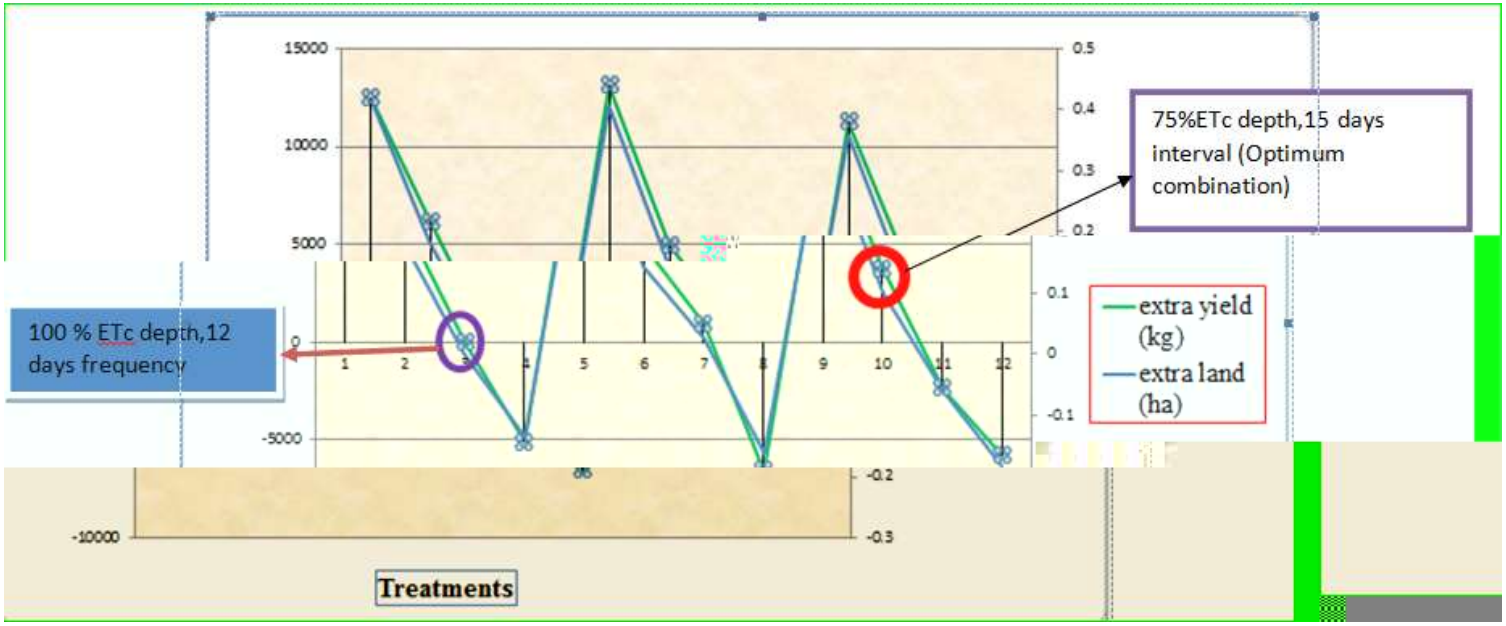

Figure 11. Incremental benefits of different irrigation regimes over the 100% CROPWAT 8.0 generated depth.

statistical result and the partial budget analysis showed that the best water use efficiency of 8.1kg/m^3 with optimum marketable carrot root yield of 32551 kg ha^{-1} was observed in the application 75% of the CROPWAT 8.0 generated depth with every 15 days of 31mm at initial, 35mm at development-1, 39mm at development-2, 46mm at mid, 43mm irrigation depth at late stage. The water saved produce 3829 kg extra yield from an extra land of 0.1 ha over the model treatment. Therefore, the application of 75% of the CROPWAT 8.0 generated depth with an irrigation interval of 15 days interval is recommended on the highland agro-ecology area and clay soil type with surface irrigation methods for satisfactorily carrot production.

Therefore, the local farmers in Chacha irrigation schemes and similar agro-ecologies should applies 31 mm at initial, 35 mm at development-1, 39 mm at development-2, 46mm at mid, 43mm at late stage and with 15 days irrigation interval to obtain satisfactorily yield and water use efficiency. Because, it improves good irrigation water management with optimum carrot root yields. It is easy to demonstrate and adopt the improved agricultural water management practices, which save water and increase crop productivity. This result is particularly important as it allows farmers to increase their income through better root yield and the water saved used to irrigate additional irrigable areas.

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Appendix

Appendix Table 1 Range of Kc values for different crops and at different growth stages

Crop	Crop development stages			
	Initial	Development	Mid-season	Late season
Banana	0.4 – 0.5	0.70 – 0.85	1.0 – 1.10	0.90 – 1.0
Barley/Oats/Wheat	0.3 – 0.4	0.70 – 0.80	1.05 – 1.20	0.65 – 0.75
Beans-Dry	0.3 – 0.4	0.70 – 0.80	1.05 – 1.20	0.65 – 0.75
Cabbage	0.4 – 0.5	0.70 – 0.80	0.95 – 1.10	0.90 – 1.0
Cotton	0.4 – 0.5	0.70 – 0.80	1.05 – 1.25	0.80 – 0.90
Groundnut	0.4 – 0.5	0.70 – 0.80	0.95 – 1.10	0.75 – 0.85
Maize	0.3 – 0.5	0.70 – 0.85	1.05 – 1.20	0.80 – 0.95
Onion	0.4 – 0.6	0.70 – 0.80	0.95 – 1.10	0.85 – 0.90
Pepper	0.3 – 0.4	0.60 – 0.75	0.95 – 1.10	0.85 – 1.0
Potato	0.4 – 0.5	0.70 – 0.80	1.05 – 1.20	0.85 – 0.95
Rice	1.1 – 1.15	1.1 – 1.5	1.1 – 1.3	0.95 – 1.05
Safflower	0.3 – 0.4	0.70 – 0.80	1.05 – 1.20	0.65 – 0.70
Sesame	0.3 – 0.4	0.70 – 0.80	1.10 – 1.20	0.70 – 0.85
Sorghum	0.3 – 0.4	0.7 – 0.75	1.0 – 1.15	0.75 – 0.80
Sugar cane	0.4 – 0.5	0.70 – 1.0	1.0 – 1.30	0.75 – 0.80
Teff	0.3 – 0.4	0.70 – 0.80	0.9 – 1.10	0.65 – 0.75
Tomato	0.4 – 0.5	0.70 – 0.80	1.05 – 1.25	0.8 – 0.95