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Effect of Different Soil Wetting Patterns on Water Availability to Watermelon Crop and its Productivity

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Abstract

Farmers try to adapt to climate change in semi-arid areas by practicing improved agricultural production. However there is a limitation on practices that promote adaptation to climate change in the semi-arid areas. The information on depths and widths of wetted zone of soil under drip application of water have a great significance in the design and management of drip irrigation system for delivering required quantity of water and chemicals to plants. The objective of the study was to determine the effect of different soil wetted patterns from the different frequencies and durations of irrigation application and use of soil super absorbent polymer on the water productivity of watermelon crop. Baringo County soil is mostly clay with frequent droughts and the rains are inconsistent, hence the need for sensitization on improved technologies so as to adopt to climate change. Different plots were laid with different irrigation frequencies and durations, daily for 4.5, 2.25 and 1.5 hours, after two days for 9, 4.5 and 3 hours and after three days for 13.5 ,6.75 and 4.5 hours. Super absorbent polymer was added to the half of the experimental plots. Watermelon crop was planted to maturity on the experimental plots in order to determine the water productivity from the different soil wetting patterns. Water productivity was computed based on the total yield of watermelon crop and quantity of water used for the different wetting patterns. The soil from the study area was classified as clay and the use of the super absorbent polymer did not improve on the water melon crop water productivity. Results from the study revealed that the highest water productivity of 18.2 kg/m^3 was at irrigation frequency of two days and 9 hrs irrigation duration on the soil without the super absorbent polymer and the lowest of 9.78 kg/m^3 at irrigation frequency of 3 days and 13.5 hrs irrigation duration on the soil with the super absorbent polymer. These findings can be adopted by the farmers in proper design of a drip irrigation system for growing of watermelon crop in clay soil with similar climatic conditions in order to improve on its water productivity.

Keywords: Soil wetted patterns; frequency; duration; super absorbent polymer; water productivity.

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1.Introduction

Globally, water demand for irrigation is expected to increase by 13.6% by 2025 however 8-15% of the fresh water supply is diverted from agriculture in order to meet the increased demand for domestic and industrial use. Furthermore the irrigation efficiency is too low and there is therefore need to increase the water use efficiency Reference[1]. In the end, drip irrigation technology is powerful in enhancing crop growth, water use performance, and reducing water shortage at the same time as reducing fertilizer leaching and soil salinity, making it an excellent strategy to the problem of freshwater resource shortage globally [2].

In arid and semi – arid lands, there is insufficient rainfall within the growing season, hence crops must be sustained through irrigation. There is therefore need to develop efficient water application methods because of the rise in water demands in order to optimize the use of irrigation water for optimal crop production. Precise irrigation methods that delivers water to the root zone are therefore necessary [3]. Farm adaptations to climate change is therefore required. Some of the farm practices include, intercropping, diversification, irrigation, growing of drought resilient and less water-intensive crop varieties, higher water efficient practices, mulching, off-farm activities and migration. A number of practices serve as an adaptation means to both climate related problems and other external farm-related issues [4]. The current study worked on the improvement of the irrigation practices.

Rainfall amounts in Kenya have been decreasing since 1960 and studies shows that in 2029 some parts of the country will experience a decrease in rainfall of greater than 100 mm [5]. Farmers try to adapt to climate change in semi-arid areas by practicing improved agricultural production. However there is a limitation on practices that support adaptation to climate change in the semi-arid areas [6]. The problem facing people in Baringo County is drought which is induced majorly by the climate variability specifically decrease in rainfall and rise in temperature. This has led to drought which is a clear indication that there is poor response to climate variability in the county which requires an intervention [7]. The main purpose of drip irrigation design is to efficiently and effectively apply irrigation water to crops. The required water content is kept at the root zone depth in order to increase the yield and quality of the crops [8].

Investment in agriculture is encouraged to increase capacity for agricultural production in order to enhance food and nutritional security through sustainable food production systems and efficient agricultural practices [9]. Irrigation raises food sufficiency, improves rural income and creates employment opportunities. The irrigation and water management challenge to improve food production is realized by extension of irrigation and improved management of the existing ones [10]. The findings of the study can be used to manage evaporation and deep percolation hence increasing crop production and consequently leading to food sufficiency. In Kenya Irrigation is under the mandate of the National Irrigation Authority (NIA). The Government of Kenya has put in place several irrigation projects aimed at stabilizing food security, which fall within the government's development strategy named Vision 2030 that aims at making Kenya a newly industrialized middle-income country by the year 2030 [11].The outcome of the study was a design guideline to provide for an efficient and effective surface drip irrigation system that saves water and thus reducing irrigation cost for the growth of watermelon crop.

Watermelon *(Citrullus lanatus)* is one of the world's important fruit vegetation, and China produces the highest yields and are also the highest consumers of watermelon crop within the global [12]. Watermelon crop is adaptable to most of tropical, and subtropical, Africa, due to its low water requirement and potential commercialization. However, minimal research has been applied to its breeding and production in the continent due to a lack of improved varieties, poor production systems, perishable nature of the fruit, and lack of harvest and post-harvest preservation technologies hinder its large-scale production. Research, particularly in watermelon production practices and breeding, is needed if its true potential in Africa is to be realized [11]. The current study thus works on improving watermelon production through efficient drip irrigation systems.

2. Materials and Methods

2.1 Study Area

The study was carried out in Mogotio Sub County in Baringo County. The area has an average altitude of 1067 metres above sea level and lies on a longitude of $35^{o} 58^{'} 0^{''}$ and a latitude of $0^{o} 1^{'} 0$''South as shown in Figure 1 Reference [13].

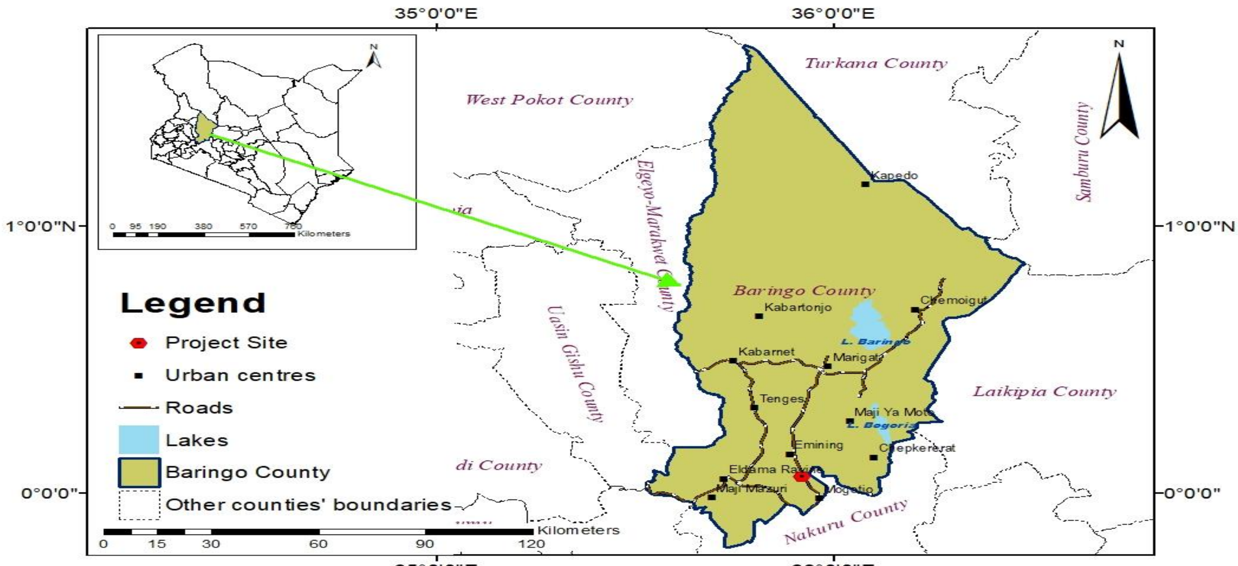


Figure 1: Location of the study area

2.2 Field Experimental Set up

Drip irrigation system was laid out in the experimental site. The layout had a water source, water storage and distribution tanks, mainline, sub mainline, laterals and emitters. The first lateral had button drippers with a discharge rate of 1 l/h, the second 2 l/h and the third one 3 l/h. Over all the three days irrigation cycle, all plots received the same amount of irrigation water but during any instance of irrigation there were different irrigation frequencies and durations. Three irrigation frequencies were applied (once daily, after two days and three days) and three irrigation durations (full, half and a third of the irrigation time). Super absorbent polymer was added to the half of the experimental plots at the rate of 1 g/m^2 as recommended by the manufacturer. Watermelon crop was planted with a spacing of 1.0 m between plants and 1.5m between the laterals in 2 by 3 m plots. The field experimental set up was as shown in Figure 2.

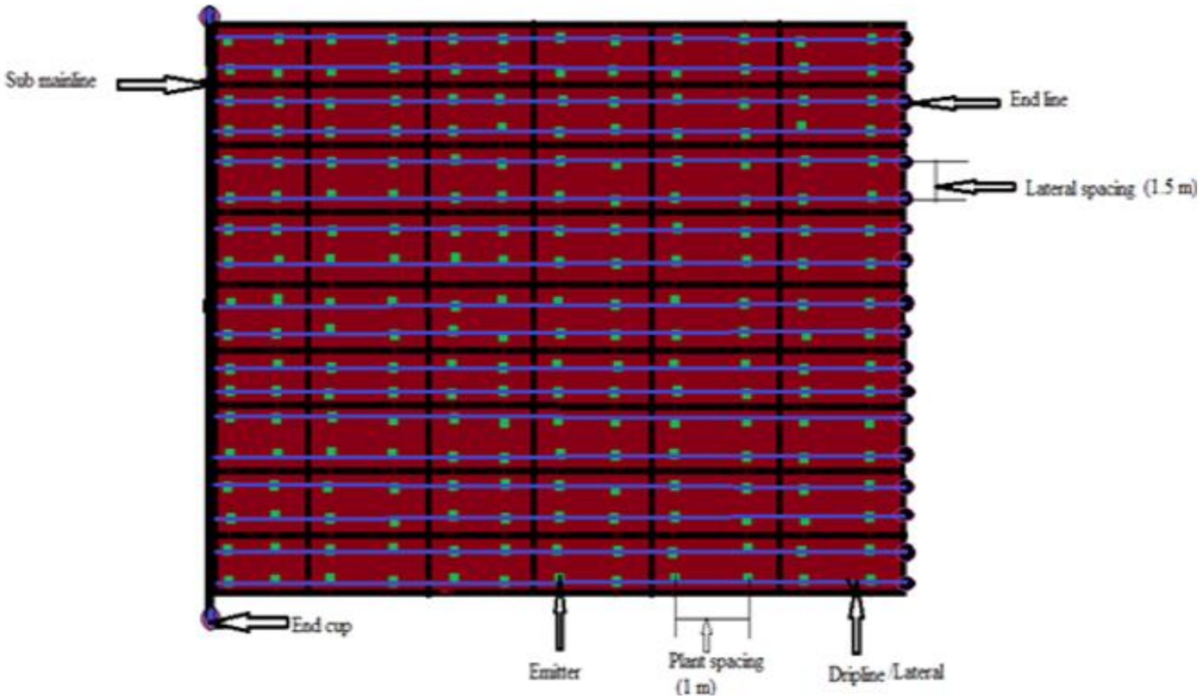


Figure 2: Field experimental layout

The experimental set up involved 18 treatments each with three replications making a total of 54 treatments from the various combinations of the irrigation frequencies as indicated in Table 1.

Table 1: Experimental treatments

Treatment	Irrigation frequency (days)	Irrigation duration (hours)	Supper absorbers (g)
T1	1	4.50	0
T2	1	2.25	0
T3	1	1.50	0
T4	2	9.00	0
T5	2	4.50	0
T6	2	3.00	0
T7	3	13.5	0
T8	3	6.75	0
T9	3	4.50	0
T10A	1	4.50	6
T11A	1	2.20	6
T12A	1	1.50	6
T13A	2	8.00	6
T14A	2	4.50	6
T15A	2	3.00	6
T16A	3	13.5	6
T17A	3	6.75	6
T18A	3	4.50	6

Where,

T1 = Daily irrigation frequency and full irrigation duration

T2= Daily irrigation frequency and half irrigation duration

T3 = Daily irrigation frequency and a third irrigation duration

T4 = Irrigation frequency of two days and full irrigation duration

T5 = Irrigation frequency of two days and half irrigation duration

T6 = Irrigation frequency of two days a third irrigation duration

T7 = Irrigation frequency of three days and full irrigation duration

T8 = Irrigation frequency of three days and half irrigation duration

T9 = Irrigation frequency of three days and a third irrigation duration

A = Super absorbent polymer

2.3 Water Melon Water Productivity

Watermelon crop was grown to maturity with the use of DAP and CAN fertilizers during planting and topdressing respectively. All plots were managed under uniform cultural practices except for the study parameters. The crop matured after between 75 days after which harvesting was done. The biomass and yield of the watermelon crop was determined from the treatments.

3. Results

3.1 Soil Texture

Soil texture analysis was done using the hydrometer method and the proportions of the individual soil particles were as shown in Table 2.

Table 2: Soil Texture Analysis

% Sand	% Clay	% Silt	Texture Grade
24	50	26	Clay

From the USDA soil textural triangle, the soil from the study area was classified as clay. Clay soil is mainly composed of fine grained minerals whereby in presence of water it becomes plastic while it becomes hard when dried or fired. It has a diameter of less than 0.002 mm and is gaining more interest in various fields because of their unique properties [14].

3.2 Estimation of the Water Melon Crop Water Requirement

The crop water requirement was estimated using the relation;

$$ET_c = ET_o \times K_c \quad (1)$$

Where,

ET_c = crop evapotranspiration

ET_o = reference evapotranspiration

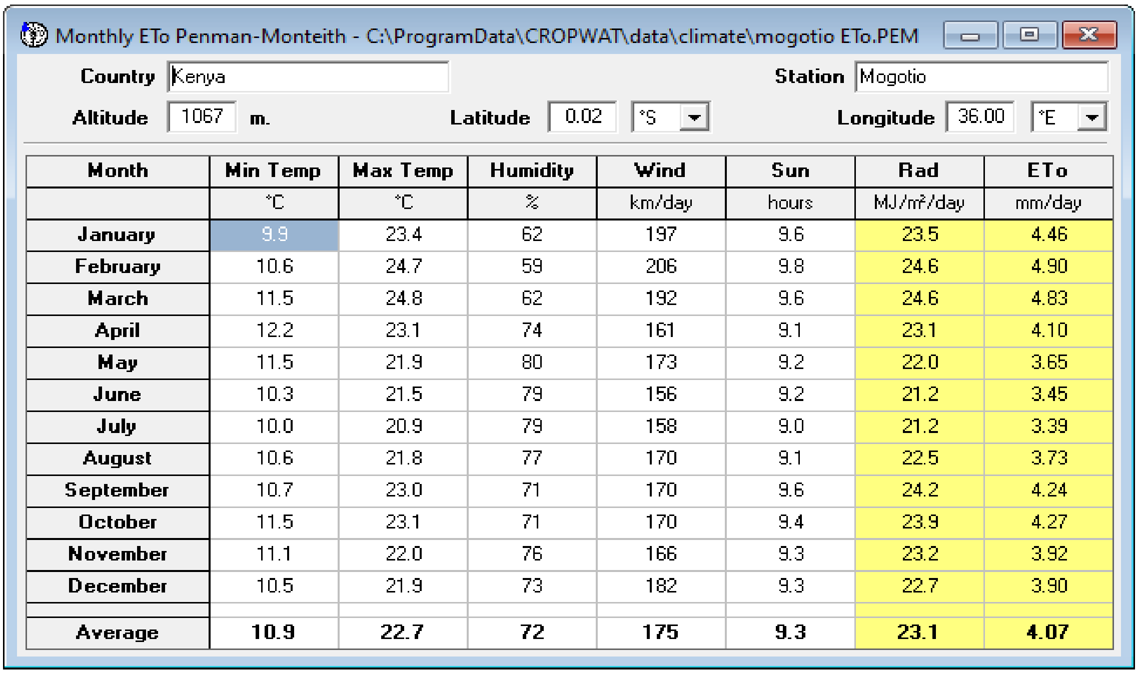
K_c = crop coefficient

The reference evapotranspiration was estimated using the CROPWAT model. The climatic parameters to the model were rainfall, maximum and minimum temperature, humidity, net radiation and the wind speed. The monthly average of the climatic parameters was as shown in Table 3.

Table 3: Monthly average climatic data for Mogotio

Month	Min Temp. (ºc)	Max Temp. (ºc)	Humidity (%)	Wind (km/day)	Sun (hrs)	Rainfall (mm)
Jan	9.9	23.4	62	196.8	9.6	24
Feb	10.6	24.7	59	206.4	9.8	18
Mar	11.5	24.8	62	192.0	9.6	35
Apr	12.2	23.1	74	160.8	9.1	77
May	11.5	21.9	80	172.8	9.2	70
Jun	10.3	21.5	79	156.0	9.2	60
Jul	10.0	20.9	79	158.4	9.0	75
Aug	10.6	21.8	77	170.4	9.1	94
Sep	10.7	23.0	71	170.4	9.6	51
Oct	11.5	23.1	71	170.4	9.4	52
Nov	11.1	22.0	76	165.6	9.3	51
Dec	10.5	21.9	73	182.4	9.3	50

The climatic data were entered into the CROPWAT model and the resulting reference evapotranspiration were as shown in Figure 3.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Country Kenya Station Mogotio

Altitude 1067 m. Latitude 0.02 °S Longitude 36.00 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	9.9	23.4	62	197	9.6	23.5	4.46
February	10.6	24.7	59	206	9.8	24.6	4.90
March	11.5	24.8	62	192	9.6	24.6	4.83
April	12.2	23.1	74	161	9.1	23.1	4.10
May	11.5	21.9	80	173	9.2	22.0	3.65
June	10.3	21.5	79	156	9.2	21.2	3.45
July	10.0	20.9	79	158	9.0	21.2	3.39
August	10.6	21.8	77	170	9.1	22.5	3.73
September	10.7	23.0	71	170	9.6	24.2	4.24
October	11.5	23.1	71	170	9.4	23.9	4.27
November	11.1	22.0	76	166	9.3	23.2	3.92
December	10.5	21.9	73	182	9.3	22.7	3.90
Average	**10.9**	**22.7**	**72**	**175**	**9.3**	**23.1**	**4.07**

Figure 3: Reference evapotranspiration estimated from CROPWAT model

The planting period was from April to June 2023 therefore the average ETo for the three months was;

$$ET_O = \frac{ET_O Apr + ET_O May + ET_O Jun}{3} \quad (2)$$

Where,

$ET_O Apr$ = ET_O for the month of April

$ET_O May$ = ET_O for the month of May

$ET_O Jun$ = ET_O for the month of June

The crop coefficient was obtained from the FAO K_c tables. The crop coefficient values for the initial, middle and the end stages of the watermelon crop was obtained from the table in Appendix. The crop evapotranspiration was then estimated using Equation 3.3. The average value of the K_c values from the FAO K_c tables was as shown

$$K_C = \frac{K_C In + K_C Mid + K_C En}{3} \quad (3)$$

Where,

$K_C In$ = Initial stage K_C

$K_C Mid$ = Middle stage K_C

$K_C En$ = End stage K_C

The crop evapotranspiration (ET_c) was the calculated using Equation 1 and the crop evapotranspiration (ET_c) was found to be equal to 980 L/day. The number of button drippers were 216 and therefore the quantity of water discharged by each button dripper was 4.5 l/day. Since the button dripper discharge was determined to be 1 l/h, the irrigation duration of a button dripper to deliver full ET_c equivalent water was therefore 4.5 hours/day.

3.3 Water Melon Crop Yield

The yield of the water melon crop for the three replications from the two seasons was averaged and related to the respective soil wetted patterns from the various treatments as shown in Table 4.

Table 4: Water Melon Yield from the Different Wetting Patterns

Treatment	**Irrigation Frequency/Duration**	**Diameter (cm)**	**Depth (cm)**	**Wetted volume (cm^3)**	**Yield av (kg)**
T1	F1D1	23	19	7539.36	20.3
T2	F1D1/2	21	17	5517.22	21.8
T3	F1D1/3	15	14	2674.1	18.2
T4	F2D1	27	21	10862.29	22
T5	F2D1/2	23	21	9212.74	20
T6	F2D1/3	18	17	4736.04	20.8
T7	F3D1	28	25	15880.19	17.2
T8	F3D1/2	24	22	10552.93	18
T9	F3D1/3	22	19	7203.56	17
T10A	F1D1A	23	18	6793.79	15.2
T11A	F1D1/2A	21	16	4916.18	16.3
T12A	F1D1/3A	17	15	3469.95	13.3
T13A	F2D1A	21	20	7653.39	15.2
T14A	F2D1/2A	19	18	5606.11	16.3
T15A	F2D1/3A	18	15	3676.14	16.3
T16A	F3D1A	25	21	10004.52	11.8
T17A	F3D1/2A	21	18	6171.67	18.3
T18A	F3D1/3A	20	17	5243.47	16.3

The volume of the wetted soil was assumed to be a spherical cap and was calculated using Equation.

$$V = \frac{\pi h}{6}\left(3a^2 + h^2\right) \tag{4}$$

Where,

h = Height of the spherical cap

a = Radius of the spherical cap

The height of the cap was the depth of the wetted soil while the radius determined from the diameter of the wetted soil.

3.4 Water melon crop rooting depth

The rooting depth of the water melon plants was determined by uprooting and digging and the results were as shown in Table 4.5.

Table 5: Water melon crop measured rooting depth

S/No	**Without absorber**		**With absorber**	
	Horizontal (cm)	**Vertical (cm)**	**Horizontal (cm)**	**Vertical (cm)**
1	240	16	255	15
2	245	17	250	15
3	235	16	252	14

The absorber retained water over a wider area than just the wetted area thereby facilitating further elongation of roots horizontal whereas vertically the roots were limited to the depth of SAP addition. Clay soil possess small pores and poor permeability. The roots of crops grown on the fields with clay soils do not penetrate deeply into the soil and are usually vulnerable to environmental stresses [15].

3.5 Water Melon Water Productivity

The water productivity of the watermelon crop was estimated from the total yield and the total amount of water used by the crop. Each experimental plot had a measurement of 2 m by 3 m giving a total area of 6 m^2. The total amount of water used under full irrigation since it was maintained constant for all the treatments during the entire water melon growth period of 75 days was 0.201 m^3/m^2.

The water productivity was determined from Equation 2;

$$WUE = \frac{Y_T}{I_W} \tag{5}$$

Where,

Y_T = Total yield

I_W = Irrigation water used

The consecutive water productivity for the different treatments was determined and the results presented in Table 6.

Table 6: Water Melon Water Productivity from the Different Soil Wetting Patterns

Treatment	Irrigation Frequency/Duration	Yield (kg/m2)	Total amount of water used (m3/m2)	Water productivity (kg/m3)
T1	F1D1	3.38	0.201	16.83
T2	F1D1/2	3.63	0.201	18.08
T3	F1D1/3	3.03	0.201	15.09
T4	F2D1	3.67	0.201	18.24
T5	F2D1/2	3.33	0.201	16.58
T6	F2D1/3	3.47	0.201	17.25
T7	F3D1	2.87	0.201	14.26
T8	F3D1/2	3	0.201	14.93
T9	F3D1/3	2.83	0.201	14.1
T10A	F1D1A	2.53	0.201	12.6
T11A	F1D1/2A	2.72	0.201	13.52
T12A	F1D1/3A	2.22	0.201	11.03
T13A	F2D1A	2.53	0.201	12.6
T14A	F2D1/2A	2.72	0.201	13.52
T15A	F2D1/3A	2.72	0.201	13.52
T16A	F3D1A	1.97	0.201	9.78
T17A	F3D1/2A	3.05	0.201	15.17
T18A	F3D1/3A	2.72	0.201	13.52

It can be seen from Table 4.30 that the water productivity range matches well with those of [16] who carried out a study on watermelon crop under drip irrigation in North Eastern Iraq and found the watermelon water productivity to be 15+/-7 kg/m^3. They also compared watermelon water productivity from other ten studies under drip irrigation and the range were between 0.94 to 57 kg/m^3.

4. Discussion

4.1 Water Melon Crop Yield from the Different Soil Wetting Patterns

The wetted diameter, depth and yield against the various treatments was as shown in Figure 4.

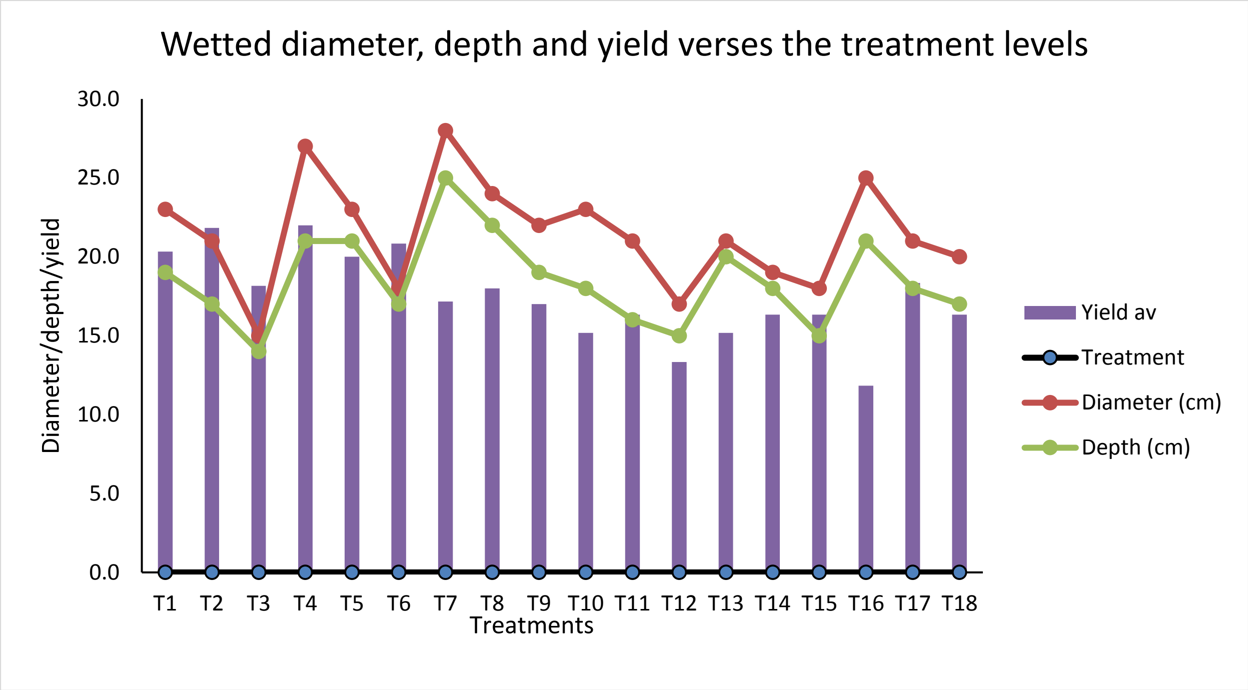

Figure 4: Wetted diameter, depth and yield against the treatment levels

It can be seen from the graph that the highest yield of 22 kg was obtained from the plot without the super absorbent polymer that was irrigated after two days for 9 hours. The lowest yield was seen on the plot with the super absorbent polymer that was irrigated after three days for 13.5 hours. This shows that the irrigation frequency should be shorter for better yield of watermelon crop while the full irrigation duration adopted since the water requirement of the crop is high. The results agreed with those from a study on irrigation scheduling techniques of capsicum that the increase in the irrigation frequency led to an increase in the crop yield [17]. Higher irrigation frequency implies a reduced fluctuation of soil moisture content between irrigations and over the growth duration hence less temporal water stress. High irrigation rate corresponds to a shorter irrigation time and hence the water melon yield was higher in the plot that was irrigated for the full irrigation duration of 9 hours under a low irrigation rate. The results contradict to those of Assefa, Kedir [18] who concluded that high flow rates increased the sugar cane yield. This may be as a result of the variation in the crop type in their studies and in the current study.

4.2 Water Melon Crop Water Productivity

Factorial statistical analysis was carried out using MINITAB Software to determine the statistical differences among the water melon crop water productivity for the different treatments. The response in the MINITAB software was water melon crop water productivity while the factor was irrigation frequency and duration with 18 levels as indicated in Table 6.

Table 6: Factor Information

Factor	Levels	Values
Irrigation Frequency/Duration	18	F1D1, F1D1/2, F1D1/2A, F1D1/3, F1D1/3A, F1D1A, F2D1, F2D1/2, F2D1/2A, F2D1/3, F2D1/3A, F2D1A, F3D1, F3D1/2, F3D1/2A, F3D1/3, F3D1/3A, F3D1A

The ANOVA statistical analysis results from the MINITAB software were as shown in Table 7.

Table 7: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	17	154.8	9.104	*	*
Linear	17	154.8	9.104	*	*
Irrigation Frequency/Duration	17	154.8	9.104	*	*
Error	0	*	*		
Total	17	154.8			

From the ANOVA statistical analysis, the P – value was too low than the significance level of 0.05 which indicated a significant difference among the water melon crop water productivity from the different treatments. It can be concluded that the water melon yield from the different treatments were not the same and thus the yield was significantly affected by the soil wetted patterns from the different irrigation frequencies and durations. The results concurred to the study by NUT, PHOU [19] who carried out a study on the effect of irrigation frequency on water melon water productivity and found out that there was a significant effect of the irrigation frequency on the water use efficiency of water melon crop.

The crop water productivity of water melon from the various treatments was as presented in Figure 5.

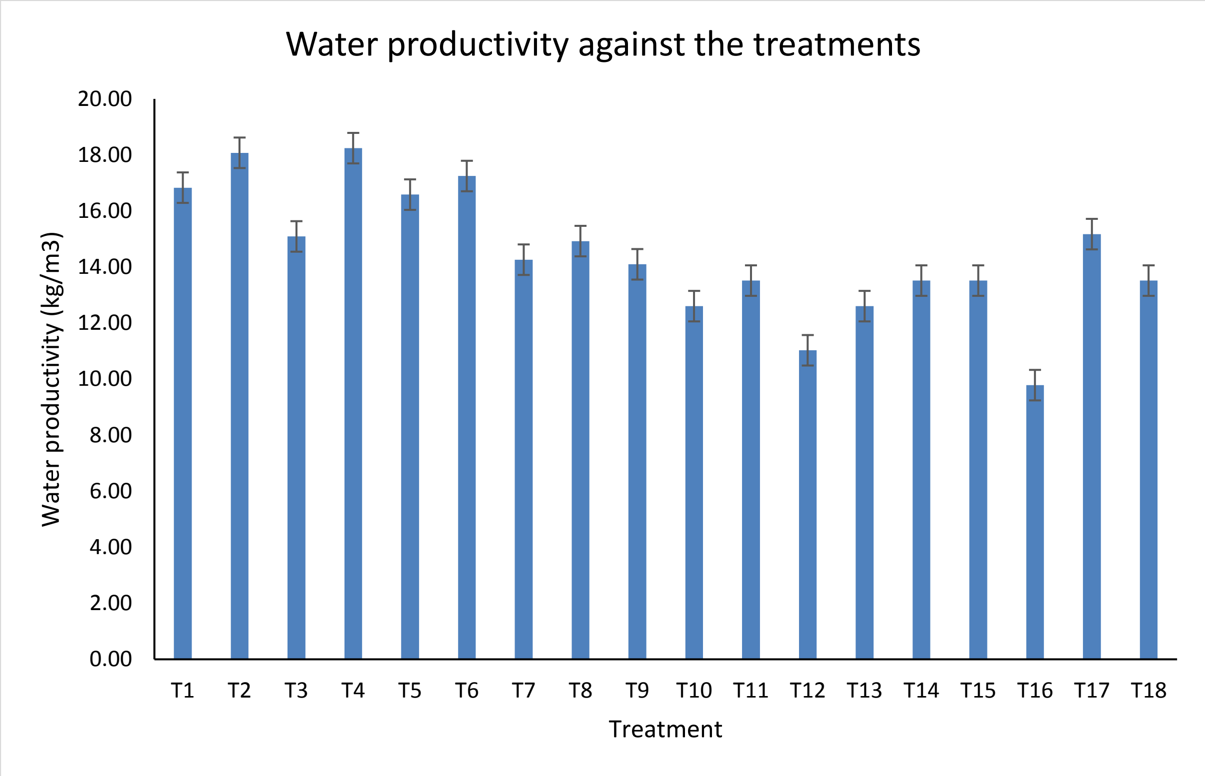

Figure 5: A graph of the water productivity against the treatments

From the graph it can be clearly seen that the highest water productivity of 18.24 kg/m^3 was obtained from the plot without the super absorbent polymer that was irrigated after two days for 9 hours and the lowest of 9.78 kg/m^3 seen on the plot with the super absorbent polymer that was irrigated after three days for 13.5 hours. The wetted diameter and depth that produced the highest yield were 27 cm and 21 cm respectively. The maximum vertical rooting depth of the water melon plant was 16 cm and this shows the suitability of the pattern to the growth of the crop. This is a clear indication that the water below the 16 cm depth went into deep percolation. The results go hand in hand with those of NUT, PHOU [19] who found the highest water use efficiency at the treatment with the highest irrigation frequency of three times per day. The study also recorded a lower water use efficiency at the lowest irrigation frequency of once per day. Water productivity was also found to be high in cauliflower crop production under high irrigation discharge rates which corresponds to shorter irrigation duration from the study by [20] which contradicts to the results in the current study. For the soil without the super absorbent polymer, the lowest water productivity was at treatment T7 with the irrigation frequency of three days and full irrigation duration of thirteen and a half hours. For all the irrigation frequencies, that is daily, after 2 days and after three days the highest water productivity was found at the treatments with a half the irrigation duration except for the irrigation frequency of two days without the super absorbent polymer and frequency of three days with the super absorbent polymer. The water melon crop water productivity was generally lower on the plots with the super absorbent polymer except for the treatment that was irrigated with the frequency of three days and a third irrigation duration. In conclusion, the study shows that high frequency irrigation (multiple, full duration applications) facilitates higher water use efficiency by keeping the applied water closer to the crop roots and thus greater accessibility to plants. The high frequency application also smoothens out the low and high peaks of irrigation application regime reducing the inter-application fluctuations thereby lowering suction stress to the plants with a possible improvement of the plant's biophysical responses

5. Conclusion

The highest water productivity of 18.24 kg/m^3 was obtained from the plot without the super absorbent polymer that was irrigated after two days for 9 hours and the lowest of 9.78 kg/m^3 seen on the plot with the super absorbent polymer that was irrigated after three days for 13.5 hours. High frequency irrigation (multiple, short duration applications) facilitates higher water use efficiency by keeping the applied water closer to the crop roots and thus greater accessibility to plants. The use of the super absorbent polymer did not improve the yield of the water melon crop hence other soil amendments should be tested to determine their effect on the watermelon crop water productivity.

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