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Effect of Irrigation Regimes on Yield and Quality of Grapes (*Vitis vinifera L.*) cv. 'Makutopora red' in Dodoma Tanzania

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Abstract
Application of water to vines at a lower amount than the crop water requirement has shown to improve grape quality in some grapevine cultivars depending on the drought resistance and tolerance of the cultivars. In order to know the amount of water that can be lowered it is necessary to know the exact amount of water that is required by the plant. The daily transpiration (ET_b) of mature *Vitis vinifera* L. cv. 'Makutupora red' grown in Dodoma-Tanzania for wine production during two growing seasons (2014 and 2015) was measured by compensation heat pulse method. Average daily transpiration was found to be 4.46 liters per plant in 2015 and 4.54 liters per plant in 2014. Water lost through evaporation (ET_e) was also determined on daily basis by using soil moisture probes (DFM Software Solution). The average daily evaporation found to be 0.46 liters per plant in 2015 and 0.42 liters per plant in 2014. After the determination of crop water requirement, the vines were subjected to different irrigation regimes in order to study their effects on grape yield and quality. Three different drip irrigation methods conversional drip irrigation (CDI), partial rootzone drying (PRD) and root zone deficit rationing (RDR) together with four levels of water at 100% of crop evapotranspiration (ET_c), 63.5% of ET_c, 56.3% of ET_c and 48.9% of ET_c were interacted in order to determine a combination that would give good grape yield and quality. The results showed that a decrease in the amount of water applied to the vines caused an improvement in grape quality and a decrease in grape yield. Conventional drip irrigation CDI was observed to be the best option for optimum grape yield and high grape quality at 63.5% of crop evapotranspiration. Conventional deficit irrigation at 56.3% of crop evapotranspiration was found to be a good option for very high quality grapes but with a decrease in grape yield.

Key words: Grape yield, grape quality, deficit irrigation.

1. Introduction

Vineyards in Tanzania are located in Dodoma region an area with long dry season. Grapes are harvested twice a year. The first harvest is in the rain season (February- March) and second harvest in the dry season (August-September) (Hussein, 2010). Grape quality is low in the rain season (regularly total soluble solids are below 18 °Brix) due to high night temperatures, high air humidity and frequent occurrence of diseases (Mori *et al.,* 2005). The second harvest is in the dry season (Hussein, 2010; CETAWICO, 2010). The grapes harvested in the dry season have high quality (regularly total soluble solids are over 22°Brix) due to low humidity, cool night temperatures and reduced occurrence of diseases (Luscher *et al.,* 2016). However, the productivity is still low (2.5 Mg/ha) (Hussein, 2010). In the rain season vintage grape growers in Dodoma are advised to manage a health vine canopy and possibly to remove all or leave few grape clusters from the vines for keeping the plants strong and with sufficient reserves for the coming long dry season vintage (Mrosso, 2007). Usually in hot tropical regions, vines are pruned twice but only one crop is harvested (Shikhamany *et al.,* 2009). About 90 % off vines are rain fed and are grown in depressions or low land areas where the water table is high or the soil moisture residual is sufficient to support vines survival in the long dry season (Hussein, 2010).

Soils of Dodoma mostly sand loam to sand clay loam have good drainage characteristics (Msongaleli, 2015) and are suitable for grape production (Borghezan *et al.,* 2014). The major problem is inadequate availability of water for domestic and agricultural uses (Msongaleli, 2015). Recent geological surveys showed there is sufficient reserve of ground water in some parts of Dodoma that if exploited can reduce the water inadequacy for both domestic and agricultural needs (Rwebugisa, 2008). The intention of introduction of drip irrigation for high value crops (grapes) was to economically justify the viability of using the dear groundwater for agricultural purposes **(**MAFC, 2013**)**.

It has been observed that with irrigation, grape yield can be increased to between 8 and 15 Mg per ha (Mrosso, 2007). However, despite the increase in yield, there has been a decrease in grape quality (Cetawico, 2010). Therefore, irrigation may increase grape yield but may also decrease grape quality (Castellarin *et al.,* 2015) The use of deficit irrigation is a solution to maintain grape quality and guarantee plant survival (Green *et al.,* 2003).

Mostly, conventional deficit irrigation (CDI) and partial rootzone drying (PRD) have been used in regulating irrigation regimes that is the amount of water applied and the pattern of water application to the plant (Chaves *et al.,* 2010). Garcia *et al.,* (2011) in Spain found that grape quality and yield were optimal when using irrigation level at 60% of ET_c (crop potential evapotranspiration). Ozden *et al.,* 2009 used irrigation level between 50% and 25% of ET_c and found that irrigation level below 25% lowers the yield and quality of grapes on cv. 'Shiraz'. Stressing plants by controlling water application for manipulating vegetative growth and berry composition has shown to produce inconsistence outcomes among grapevine varieties (Chaves *et al.,* 2010). It is therefore, important to investigate individual grape cultivars in order to understand to what extend grape yields and quality are affected by different levels of water deficits.

Introduction of deficit irrigation to grape growers in Dodoma will enable them to save water, minimize power consumption, minimize operational costs, improve grape quality, optimize grape yield and stabilize the grape industry and market. The wine processors are interested in high quality grapes that will produce high quality wines (CETAWICO, 2010). A grape is now becoming the most profitable cash crop in Dodoma and if the water use is economized profitably more investors will join the grape production industry (Lwelamira *et al.,* 2015). High quality grapes and wine will attract consumers and improve the market locally and in the neighboring countries of Kenya, Uganda, Rwanda, Zaire and Burundi (Cetawico, 2010; Hussein, 2010). Grape growers in Dodoma need information that will enable them to apply deficit irrigation on vines (Lwelamira *et al.,* 2015).

Therefore investigation on the response of grape cv. 'Makutupora red' to irrigation regimes must be carried out for getting a better understanding of effects of water rations and irrigation methods on grape yield and quality

The aim of this study was to investigate the effect of irrigation regimes on yield and quality of *Vitis vinifera* L. cv. 'Makutopora red'

2. **Materials and Methods**

2.1 Description of the study area and the plant material

The study was carried out in Dodoma at Makutupora Agricultural Research Institute (ARI-Makutupora) which is located at latitude **5^{0}58′669″ S** and longitude **35^{0}46′093″** E about 26 km North of Dodoma Municipality. The area lies at an altitude of **1,050** m above sea level (MAFC, 2011). The annual rainfall at ARI Makutupora ranges from 530 mm to 660 mm with rains falling between December and March and April to November like most parts of Dodoma is a dry season (Mahoo *et al.,* 1999**;** Kahimba *et al.,* 2014). The average annual air humidity is 65%, Average minimum daily temperature is 15 °C and average maximum temperature is 32 ^{O}C and wind speed ranges between 1.0 m/s in February to 4 m/s in October (Hussein, 2010).

2.2 Soil

At ARI-Makutupora vine yard, the dominant soil is sand clay to sand clay loam which is well drained and ideal for vine cultivation (MAFC, 2011**)**. The rootzone of cv. 'Makutupora red' was taken to be 100 cm because for irrigated vines about 60 percent of vine roots grow in the top 60 cm of soil. The remaining 40 percent of roots grow mostly within 60 -100 cm of soil depth (Rees and Doyle, 2010).

2.3 Crop management

The plant material was *Vitis vinifera* L. cv. 'Makutupora red' planted in 2002 on 0.4 ha at ARI-Makutupora with spacing of 1.5 m within a row and 2.5 between rows. The rows are in East-West orientation with the sun overhead at noon. During the trial the vines were thoroughly managed with timely weed control, pruning, de-suckering, manure application, vermin control, timely pest and disease control such that the vines did not succumb to any stress. The vines were trained to bilateral cordons trellis (extension of trunk horizontally to Eastern and Western side) at 1 m above the ground and in each season were pruned to three bud spurs.

2.4 Water use determination

Water used (crop evapotranspiration) per plant by mature *Vitis vinifera* L. cv. 'Makutupora red' grown for wine production without stress during two growing dry seasons (2014 and 2015) was measured by compensating heat pulse method to get transpiration as explained by Green (2009) and soil moisture probes were used to estimate soil surface evaporation as explained by Allen *et al.,* (1998), DFM (2011) and Zerizghy *et al*., (2013).

2.5 Irrigation regimes

Irrigation regimes were obtained by a combination of water levels (V) which were the amount of water applied with reference to crop evapontranspiration and irrigation methods (M) which were described according to how the irrigation water was applied or distributed to the vines root zone.

2.5.1 Water levels

The daily crop evapotranspiration per vine was used for getting daily water application for irrigation levels:

- V1 that was equal to 100% of crop evapotranspiration (ET_c) equivalent to 100% of crop transpiration (ET_b) plus evaporation (ET_e)
- V2 that was equal to 63.5% of crop evapotranspiration equivalent to 50% of crop transpiration plus evaporation
- V3 and that was equal to 56.0 % of crop evapotranspiration equivalent to 40% of crop transpiration plus evaporation and
- V4 that was equal to 48.9% of crop evapotranspiration equivalent to 30% of crop transpiration plus evaporation

The daily crop evapotranspiration and daily water applications per vine are shown in Table 1 for season 2014 and Table 2 and for season 2015. Average daily transpiration per plant was 4.46 liters in 2015 and 4.54 liters in 2014. The average daily evaporation per plant was 0.46 liters in 2015 and 0.42 liters in 2014. In the first 45 days (Wool to flowering stage) all vines were irrigated at potential evapotranspiration and thereafter were subjected to deficit irrigation. The vines at early stages of production cycle must receive sufficient water for enhancing health flower and berry development (Ozden *et al.,* 2010, Chaves, 2007, Green *et al.,* 2003; Chalmers, 2007; Rafaat, 2012).

Table 1 Mean daily vine water application in across berry development stages in 2014

Berry development stage	**Time in days**	**ET_e**	**ET_b**	**V1**	**V2**	**V3**	**V4**
Wool	0 - 15	0.48	1.64	2.12	2.12	2.12	2.12
Bud burst	15 - 30	0.29	3.29	3.58	3.58	3.58	3.58
Flowering	30 - 45	0.24	2.24	2.48	2.48	2.48	2.48
Fruit set	45 - 60	0.38	6.51	6.89	3.63	2.98	2.33
Berry enlargement	60 - 75	0.31	5.01	5.32	2.82	2.32	1.81
Beginning of berry touch	75 - 90	0.39	6.96	7.34	3.86	3.17	2.47
Berry touch	90 - 105	0.48	5.37	5.85	3.17	2.63	2.09
Beginning of veraison	105 - 120	0.72	5.69	6.41	3.57	3.00	2.43
Veraison	120 - 135	0.52	4.17	4.70	2.61	2.19	1.78
Grand mean		**0.42**	**4.54**	**4.96**	**3.09**	**2.72**	**2.34**

*ETe, ETb, V1, V2, V3 and V4 are in Liters per vine per day

Table 2 Mean daily vine water application across berry development stages in 2015

Berry development stage	Time in days	ET_e	ET_b	V1	V2	V3	V4
Wool	0 - 15	0.54	2.48	3.02	3.02	3.02	3.02
Bud burst	15 - 30	0.46	3.49	3.95	3.95	3.95	3.95
Flowering	30 - 45	0.46	2.96	3.42	3.42	3.42	3.42
Fruit set	45 - 60	0.45	5.66	6.11	3.28	2.72	2.15
Berry enlargement	60 - 75	0.56	4.89	5.45	3.00	2.51	2.03
Beginning of berry touch	75 - 90	0.47	4.30	4.78	2.63	2.20	1.77
Berry touch	90 - 105	0.35	5.32	5.66	3.01	2.47	1.94
Beginning of veraison	105 - 120	0.44	6.35	6.79	3.61	2.98	2.34
Veraison	120 - 135	0.39	4.71	5.10	2.75	2.27	1.80
Grand mean		**0.46**	**4.46**	**4.92**	**3.18**	**2.84**	**2.49**

*ETe, ETb, V1, V2, V3 and V4 are in Liters per vine per day

2.5.2 Irrigation methods

Irrigation methods used were conventional M1 (CDI), partial rootzone drying M2 (PRD) and rootzone deficit rationing M3 (RDR). The operation and setting of Rootzone deficit rationing is similar to (PRD) but the danger of over stressing one side of the rootzone is eliminated by rationing the amount of water applied to the vines such that one side gets one third of water applied to the vine. The sides are changed alternatively after every fourteen days period.

2.6 Experimental Design

The experiment was a split plot design with four replications. The main factor was irrigation levels obtained by adding evaporation to the fractions of transpiration which were V1, V2, V3 and V4. Potential Transpiration (ET_b) was determined by the compensation heat pulse method as explained by Green (2009) and water lost through evaporation to the atmosphere (ET_e) from the top layer of the soil was determined by method explained by DFM (2011). The water rationing was applied starting at fruit set to veraison (beginning of ripening). The sub factor was irrigation methods M1, M2 and M3. Grapes in the experiment plots were harvested for analysis on 22th of September in 2014 and 28th of August in 2015 about 175 days from the day of pruning (pruning dates were 8th of May in 2014 and 15th of April in 2015).

2.7 Yield and quality components

Yield components measured were grape yield/vine, berry size (diameter), berry weight, bunch weight (g), biomass (g) and leaf area index. Quality components were total soluble solids , titratable acids (TTa), pH, malic acid, tartaric acid, total phenolics and anthocyanins compounds.

2.7.1 Yield components

Samples of grape yield per vine were obtained by harvesting, weighing and dividing by three the weight of harvested grapes from three randomly selected plants in each subplot. Then five bunches were picked from the harvested grapes in each subplot, weighed and then divided by five to get the weight of one bunch. Thereafter, twenty berries were randomly selected from the harvested grapes in each subplot by method explained by Chaves *et al.,* (2007). The berries were weighed and then divided by twenty to get weight of one berry. Then the same twenty berries were fully immersed in water in a measuring jar and the increase of volume was immediately taken and divided by twenty to get the volume of one berry from which the berry diameter was determined because cv. 'Makutupora red' berries are spherical. The biomass per vine was determined by first oven drying the pruned material from one vine in each subplot for 48 hours at 75 ^{O}C and then weighing again the dry matter. Leaf area index was derived from leaf dry mass per unit area (equation 1)

$$LAI = \frac{M_{vd}}{L_{dw}} \text{---------------} (1)$$

.Where; L_{dw} = leaf oven dried mass per unit area
M_{vd} = vine leaves' dry weight
LAI = Leaf area index

2.7.2 Quality components

The grapes harvested from each subplot were crushed (destemed) and fermented for three months. Just after crushing samples of grape juice were taken for determination of total soluble solids (^{O}Brix) by digital refractrometer (Refractrometro, Verona, Italy), titratable acids by titration with a dilute solution of NaOH (Elana, 2006), pH by electronic pH meter (Lopez *et al.,* 2009). After fermentation the must was racked and the wine was bottled. Wine samples in bottles were sent to the laboratory at Sokoine University of Agriculture for determination of malic acid and tartaric acid by titration as explained by SOAC 967 (1995), phenolic compounds according to the method of Iland *et al.,* (2000) and total anthocyanins by the pH differential method described by Giusti *et al., (2005).*

2.8 Data analysis

The collected data were subjected to analysis of variance (ANOVA) using GENSTAT 13 (Stern *et al.,* 2011) based on a split-plot design. The test of significant differences of yield and quality components mean values across treatments were performed based on Duncan multiple range test at a probability value of ≤ 5% (P≤0.5).

3. Results and Discussion

3.1 Grape yield components

The effect of irrigation levels (V1, V2, V3 & V4), Irrigation methods (M1, M2 & M3) and irrigation regimes (interaction) to yield components are shown in Table 3, Table 4 & Table 5 respectively.

Table 3 Effect of irrigation levels on yield components

	Yield		LAI		Pm		Bd		Bw.		Cw		Cn	
V1*	6.39	d	3.86	b	644,64	c	0.992	b	3.915	c	303	c	**26**	c
V2*	4.92	c	3.4	ab	476.39	b	0.933	a	3.479	b	229.6	b	25	bc
V3*	3.77	b	3.04	ab	415.53	a	0.923	a	3.333	ab	183.5	a	24	b
V4*	3.22	a	2.93	ab	392.44	a	0.915	a	3.232		160.7	a	22	a
s.e.d	0.22		0.24		22.953		0.012		0.111		10.18		0.6	
L.s.d	0.49		0.55		51.923		0.028		0.252		23.028		1.3	

*Means of 24 samples of yield components across irrigation levels; In each column, statistically significant differences between means of yield components are indicated by different letters based on Duncan multiple range test at a probability value of 0.05 (P=0.5); S.e.d = Standard error of differences of means; L.s.d = Least significant difference of means; Gm = Grand mean; Cv% = source of variation and Yield = grape yield in kg/vine, LAI = Leaf area index in sq meters, Pm = Dry pruned mass/vine, Bd = berry diameter in cm, Bw = Berry weight in gm, Cw = Cluster weight in kg/vine, Cluster number/vine

Table 4 Effect of irrigation methods on yield components

	Yield		LAI		Pm		Bd		Bw.		Cw		Cn	
M1	5.04	c	3.53	b	517.37	b	0.958	b	3.61	b	241.46	c	25	b
M2	4.17	b	3.07	a	457.54	a	0.92	a	3.3	a	197.23	a	23	a
M3	4.51	a	3.32	ab	471.83	ab	0.945	b	3.56	ab	218.98	b	24	ab
s.e.d	0.18		0.16		25.84		0.009		0.09		9.239		0.8	
L.s.d	0.37		0.34		53.335		0.018		0.186		19.068		1.6	

*Means of 32 samples of yield components across irrigation methods (treatments); In each column, statistically significant differences between means of yield components are indicated by different letters based on Duncan multiple range test at a probability value of 0.05 (P=0.5); S.e.d = Standard error of differences of means; L.s.d = Least significant difference of means; Gm = Grand mean; Cv% = source of variation and Yield = grape yield in kg/vine, LAI = Leaf area index in sq meters, Pm = Dry pruned mass/vine, Bd = berry diameter in cm, Bw = Berry weight in gm, Cw = Cluster weight in kg/vine, Cluster number/vine

Table 5 Effect of irrigation regimes (treatments) on yield components

	Yied		Pm		LAI		Cn		Bw		Bd		Cw	
V1M1	6.84	d	737.38	f	4.33	d	26	d	4.08	d	0.996	fg	324.09	h
V2M1	5.39	c	526.63	cd	3.71	bcd	26	d	3.63	c	0.947	cde	259.61	ef
V3M1	4.49	b	418.18	ab	3.23	abc	26	d	3.44	bc	0.955	de	209.92	cd
V4M1	3.45	a	387.29	ab	2.84	a	21	a	3.31	abc	0.931	bcde	172.21	abc
V1M2	5.79	c	556.95	de	3.32	abc	25	cd	3.59	bc	0.967	ef	274.23	fg
V2M2	4.50	b	458.51	bc	3.28	abc	24	bcd	3.38	bc	0.925	bcd	199.53	bcd
V3M2	3.35	a	457.80	bc	3.00	ab	22	ab	3.23	ab	0.905	ab	164.20	ab
V4M2	3.02	a	356.92	a	2.70	a	21	a	2.99	a	0.881	a	150.96	a
V1M3	6.55	d	639.59	e	3.94	cd	26	d	4.08	d	1.010	g	310.61	gh
V2M3	4.86	bc	444.03	abc	3.22	abc	24	bcd	3.43	bc	0.927	bcd	229.74	de
V3M3	3.45	a	370.61	ab	2.88	a	23	abc	3.33	abc	0.909	abc	176.48	abc
V4M3	3.19	a	433.09	abc	3.25	abc	24	bcd	3.39	bc	0.932	bcde	159.08	a
S.e.d	0.36		48.04		0.36		1.4		0.18		0.019		18.20	
L.s.d	0.74		97.77		0.74		2.8		0.38		0.038		37.04	
CV%	10.9		15.20		14.1		8.9		7.3		2.6		11.90	
Gm	**4.57**		**482.25**		**3.31**		**24**		**3.49**		**0.94**		**219.22**	

*Means of 8 samples of yield components across irrigation regimes (treatments); In each column, statistically significant differences between means of yield components are indicated by different letters based on Duncan multiple range test at a probability value of 0.05 (P=0.5); S.e.d = Standard error of differences of means; L.s.d = Least significant difference of means; Gm = Grand mean; Cv% = source of variation and Yield = grape yield in kg/vine, LAI = Leaf area index in sq meters, Pm = Dry pruned mass/vine, Bd = berry diameter in cm, Bw = Berry weight in gm, Cw = Cluster weight in kg/vine, Cluster number/vine

Almost all yield components were relatively higher in treatments V1M1, V1M2 and V1M3 than in other treatments showing that preveraison irrigation deficits reduce yield. This is the effect of water deficit where the more stressed plants produced relatively lower yield components. These results are similar to the ones found by Chaves *et al.,* 2010, Chalmers (2007), Lopez *et al.*, (2009), Green *et al.,* (2007), Yang *et al.,* (2005). Also yield components when compared at the same irrigation levels were lower in partial root zone drying (M2) treatments than in the other two methods. These results can be explained as the effect of uneven water distribution in the root zone in PRD (M2). In irrigation method M1 roots receive the same amount of water around the vine base. Also in root zone irrigation rationing (M3) roots receive water in different proportions around the vine base and this protects roots from drying permanently from severe water stresses. In partial root zone drying (M2) one side of the plant were not receiving water for 14 days and then receiving water for 14 days alternatively. This caused excessive stress to some roots and consequently a reduction in yield components (Chaves *et al.,* 2009).

3,2 Grape quality components

The effect of irrigation levels (V1, V2, V3 & V4), Irrigation methods (M1, M2 & M3) and irrigation regimes (interaction) on quality components are shown in Table 6, Table 7 & Table 8 respectively.

Table 6 Effect of irrigation levels on quality components

	Tss		TTA		T/T		Alc		pH		M.a		Tar		Phnl		Anth	
V1	20	a	11.6	a	5.465	b	3.62	a	3.606	b	0.1836	b	0.188	a	1.504	a	216.07	a
V2	23	b	13.8	b	5.632	b	4.22	b	3.534	a	0.1669	a	0.194	a	2.114	b	538.94	b
V3	25	c	14.76	c	5.114	a	4.89	c	3.537	a	0.1836	b	0,1925	a	2.42	c	664.57	c
V4	27	d	16.14	d	5.09		5.32	d	3.531	a	0.1614	a	0.187	a	2.701	d	778.02	d
s.e.d	0.3		0.214		0.116		0.1		0.011		0.0028		0.004		0.028		11.116	
L.s.d	0.8		0.483		0.262		0.227		0.026		0.0063		0.008		0.063		25.146	

*Means of 24 samples of yield components across irrigation levels; In each column, statistically significant differences between means of yield components are indicated by different letters based on Duncan multiple range test at a probability value of 0.05 (P=0.5); S.e.d = Standard error of differences of means; L.s.d = Least significant difference of means; Gm = Grand mean; and Tss = Total soluble solids, TTA = Total titratable acidity in g/*l* in T/T = Tss/TTA, Alc = Alcohol in percentage, pH = Grape juice pH, Ma = Malic acid concentration in g/*l,* Tar = Tartaric acid concentration in g/l, Phnl = Phenolic compound concentration in grape juice, Anth = Anthocyanins concentration in the grape juice.

Table 7 Effect of irrigation methods on quality components

	Tss		TTA		T/T		Alc		pH		M.a		Tar		Phnl		Anth	
M1	23	a	13.42	a	5.4	b	4.22	a	3.54	a	0.172	a	0.183	a	2.07	a	503.08	a
M2	25	c	14.79	c	5.02	a	4.99	b	3.56	b	0.171	a	0.185	a	2.31	c	600.76	c
M3	24	b	14.01	b	5.56	c	4.32	a	3.55	ab	0.176	a	0.202	b	2.17	b	544.36	b
s.e.d	0.1		0.079		0.067		0.06		0.008		0.0045		0.004		0.013		5.839	
L.s.d	0.3		0.163		0.137		0.12		0.016		0.0094		0.008		0.027		12.052	

*Means of 32 samples of yield components across irrigation methods (treatments); In each column, statistically significant differences between means of yield components are indicated by different letters based on Duncan multiple range test at a probability value of 0.05 (P=0.5); S.e.d = Standard error of differences of means; L.s.d = Least significant difference of means; Gm = Grand mean; and Tss = Total soluble solids, TTA = Total titratable acidity in g/*l* in T/T = Tss/TTA, Alc = Alcohol in percentage, pH = Grape juice pH, Ma = Malic acid concentration in g/*l,* Tar = Tartaric acid concentration in g/l, Phnl = Phenolic compound concentration in grape juice, Anth = Anthocyanins concentration in the grape juice.

Table 8 Effect of irrigation regimes (treatments) on grape quality components

	Tss		**Alc**		**T/T**		**TTA**		**pH**		**Ma**		**Tar**		**Phnl**		**Anth**	
V1M1	19	a	11.0	a	3.38	a	5.6	f	3.6	de	0.183	cd	0.188	c	1.42	a	185.1	a
V2M1	22	c	13.3	c	4.09	c	5.5	ef	3.5	ab	0.167	abc	0.168	a	2.02	c	500.0	c
V3M1	24	e	14.2	de	4.44	d	5.4	ef	3.5	a	0.177	bcd	0.189	c	2.32	f	625.4	de
V4M1	25	f	15.2	fg	4.99	ef	5.1	bcd	3.5	ab	0.162	ab	0.187	c	2.52	h	701.9	f
V1M2	20	b	11.9	b	3.72	b	5.4	ef	3.6	e	0.185	d	0.189	c	1.55	b	230.6	b
V2M2	24	e	14.5	e	4.84	ef	5	abc	3.6	bc	0.154	a	0.171	ab	2.22	e	582.7	d
V3M2	26	g	15.5	gh	5.51	g	4.7	a	3.5	ab	0.182	cd	0.194	c	2.55	h	720.3	fh
V4M2	29	i	17.3	i	5.89	h	4.9	abc	3.6	bc	0.161	ab	0.187	c	2.92	j	869.5	g
V1M3	20	b	11.8	b	3.75	b	5.4	def	3.6	cd	0.183	cd	0.187	c	1.54	b	232.6	b
V2M3	23	d	13.7	cd	3.73	b	6.4	g	3.5	ab	0.180	cd	0.242	d	2.11	d	534.1	c
V3M3	24	e	14.6	ef	4.72	de	5.2	bcde	3.6	c	0.182	cd	0.194	c	2.38	g	648.1	e
V4M3	27	h	16.0	h	5.10	f	5.3	cdef	3.5	ab	0.161	ab	0.186	bc	2.67	i	762.7	h
S.e.d	0		0.3		0.14		0.2		0.02		0.008		0.074		0.04		14.65	
L.s.d	1		0.5		0.29		0.3		0.04		0.016		0.015		0.07		30.33	
CV%	2		1.6		3.70		3.5		1		7.400		5.9		1.7		3.0	
Gm	**24**		**14.1**		**4.51**		**5.33**		**3.6**		**0.173**		**0.190**		**2.19**		**549.4**	

*Means of 8 samples of yield components across irrigation regimes (treatments); In each column, statistically significant differences between means of yield components are indicated by different letters based on Duncan multiple range test at a probability value of 0.05 (P=0.5); S.e.d = Standard error of differences of means; L.s.d = Least significant difference of means; Gm = Grand mean; Cv% = source of variation Tss = Total soluble solids, TTA = Total titratable acidity in g/*l* in T/T = Tss/TTA, Alc = Alcohol in percentage, pH = Grape juice pH, Ma = Malic acid concentration in g/*l,* Tar = Tartaric acid concentration in g/l, Phnl = Phenolic compound concentration in grape juice, Anth = Anthocyanins concentration in the grape juice.

Total soluble solids (Tss) in ^{O}Brix were significantly lower in irrigation regimes VIMI, VIM2 and V1M3 meaning that the Tss were relatively higher in more stressed vines. McCarthy, (1997), Yang *et al.,* (2009), Hunter et al., (2014) observed that grapes under deficit irrigation had a higher Tss than grapes under full irrigation. Variations of Tss across irrigation method was higher with partial root zone drying than in the other two methods. There was no significant difference in berry juice pH across irrigation levels and irrigation methods. Total titratable acid (TTA) was slightly higher in full irrigated treatments. Chalmers (2007) also found that the value of TTA was lower in grapes under deficit irrigation and was higher in fully irrigated grapes.

The concentration of phenols and anthocyanin concentrations also were increased significantly in treatments under deficit irrigation regimes. This implies that the improvement in berry quality was caused by water deficits between berry set and veraison stages. Similar results were observed by Castellarin *et al., (*2015), Casassa *et al.,* (2015) and Bindon *et al.,* (2011)

3.3 Cost and benefit of using irrigation regimes

The cost and benefits of using irrigation regimes were compared. Convention deficit drip irrigation, partial rootzone drying and root zone deficit rationing were used at four water levels (V1, V2, V3 and V4).Table 9 shows the variation of costs and benefits acrossthe treatments (irrigation regimes).

Table 9 Variation of costs and benefits across irrigation regimes (for cv. 'Makutupora red')

Treatments	**Production cost/tree**	**Yield kg/tree**		**Gross income per tree (Tsh/tree)**		**Net income per tree(Tsh/tree**		**Income per unit cost (Tsh/Tsh)**	
V1M1	1987.28	6.84	e	4368.07	d	2380.79	cd	2.20	bc
V2M1	1694.87	5.39	cd	4485.73	d	2790.86	d	2.65	d
V3M1	1637.36	4.49	b	4011.09	bcd	2373.73	cd	2.45	cd
V4M1	1578.23	3.45	a	3294.27	a	1716.04	abc	2.09	bc
V1M2	2187.28	5.79	d	4106.01	cd	1918.73	abc	1.88	ab
V2M2	1894.87	4.5	b	4028.11	bcd	2133.24	cd	2.13	bc
V3M2	1837.36	3.35	a	3327.01	ab	1489.65	ab	1.81	ab
V4M2	1778.23	3.02	a	3638.91	abc	1860.68	abc	2.05	ab
V1M3	2237.28	6.55	e	4617.33	d	2380.05	cd	2.06	abc
V2M3	1944.87	4.86	bc	4225.78	cd	2280.91	cd	2.17	bc
V3M3	1887.36	3.45	a	3186.61	a	1299.25	a	1.69	a
V4M3	1828.23	3.19	a	3347.95	ab	1519.72	ab	1.83	ab
Gm	**1874.44**	**4.57**		**3886.410**		**2011.97**		**2.08**	
SED		0.362		347.304		347.304		0.19	
Lsd		0.738		707.462		707.462		0.386	
Cv%		10.9		12.500		24.1		13.2	
F.Test		0.541		0.206		0.206		0.203	

*Means of 8readings of samples across irrigation regimes; In each column, statistically significant differences between means of yield components are indicated by different letters based on Duncan multiple range test at a probability value of 0.05 (P=0.5), S.e.d = Standard error of differences of means; L.s.d = Least significant difference of means, Gm = Grand mean.

Treatments V2M1 and V3M1 produced more income per unit cost (Figure 3.2). Treatments V1M1, V1M2 and V1M3 (treatments at 100% of ET_c) produced higher yields(fig. 13) and their gross incomes were not significantly different from treatments V2M1, V3M1, V2M3 and V2M2 but their income per unit cost were lower than in treatments V2M1 and V3M1 (Table 9).This means moderate deficits irrigation generated more profit (Fig.1, Fig.2, Fig.3 and Fig.4).

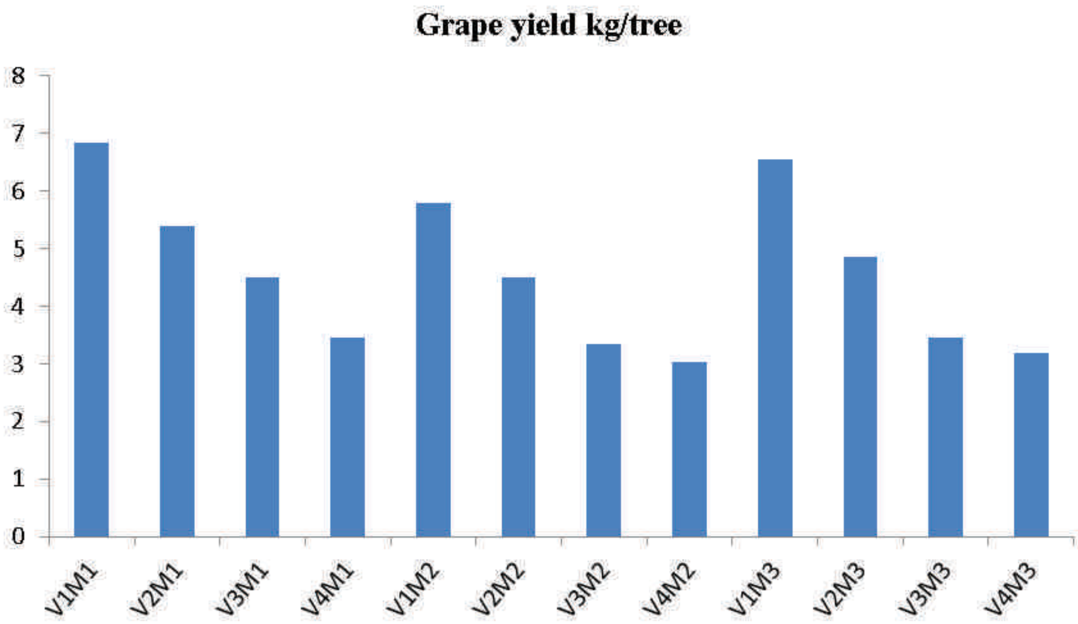

Figure 1 **Variation of grape yield across irrigation regimes**

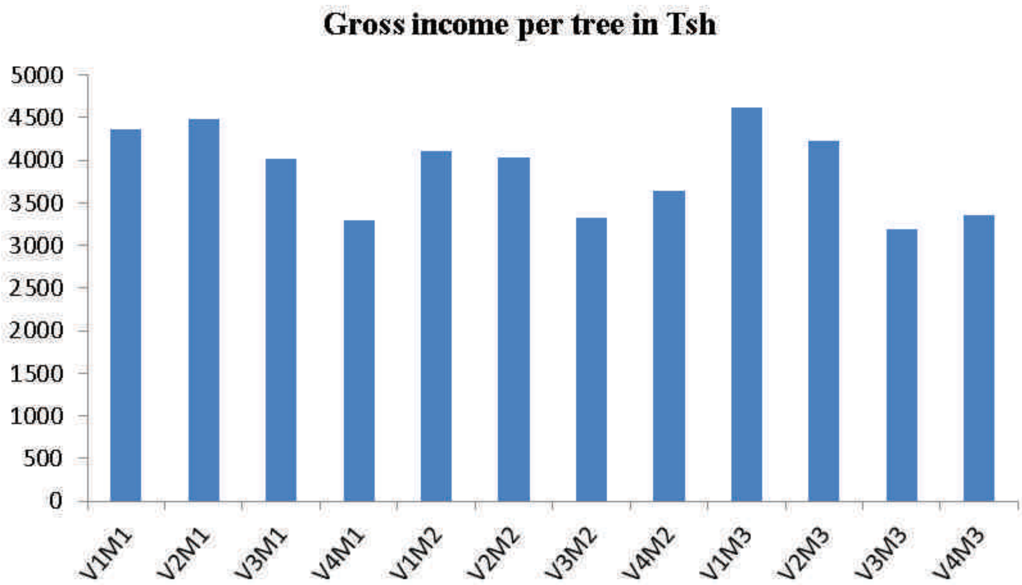

Figure 2 Grape gross income across irrigation regimes

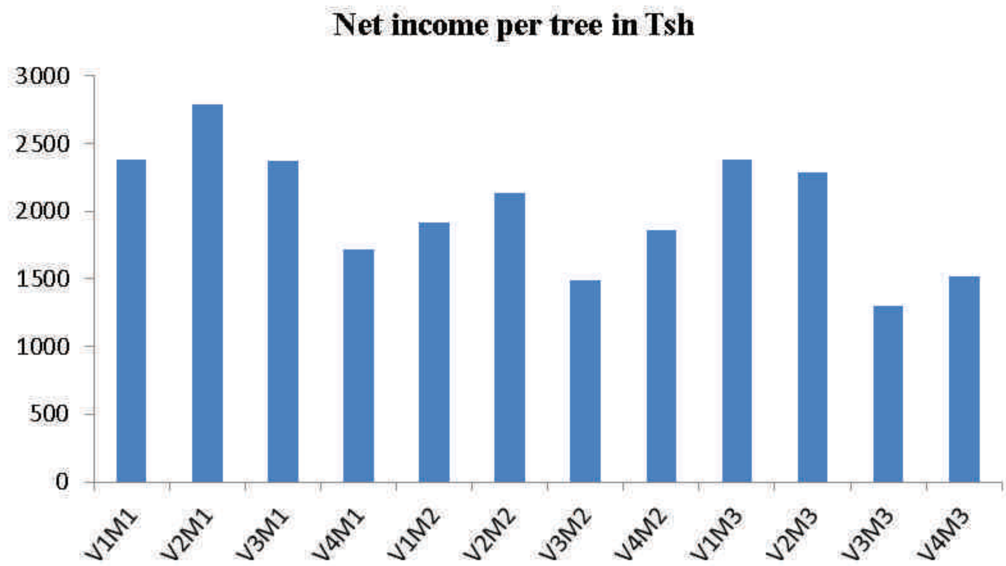

Figure 3 Variation of net income across irrigation Regimes

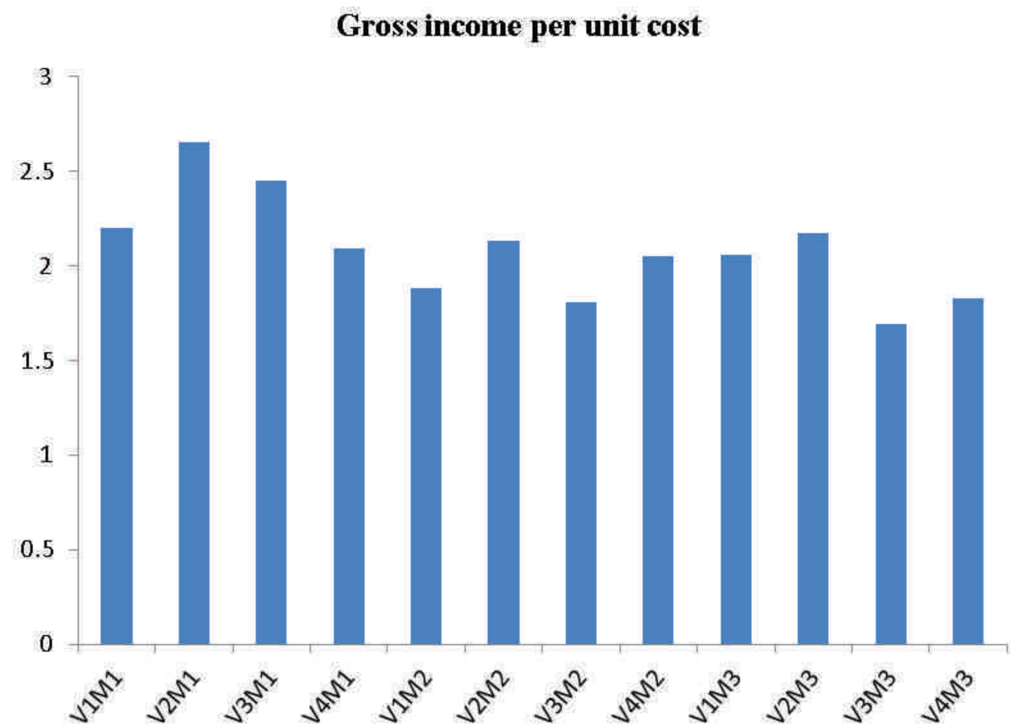

Figure 4 Variation of gross income per unit cost

4. Conclusion and Recommendation

The use of drip deficit irrigation improves grape quality which is a solution to low grape quality that occurs in full irrigated vines. Grape quality was improved significantly in all treatments under deficit irrigation with a decrease in grape yield. Treatments V3M1 and V2M2 had similar results in almost all components. Tss was 24 °Brix and grape yield was 4.50kg/vine in treatment V2M2 whereas Tss was 24 °Brix and grape yield 4.49kg/vine in treatment V3M1.This indicated that what was achieved by PRD at a given water deficit could be achieved by CDI by relatively increasing the water deficit. This indicated that CDI is more water saving than PRD and at the same water level vines under PRD treatments were more water stressed than vines under CDI and RDR treatments.

The application of deficit irrigation in Dodoma vineyards is highly recommended for improving grape quality. The use of deficit irrigation at 63.5% of crop evapotranspiration is recommended to be used by growers as it gave better yield than deficit irrigation at 56.0% and 48.9% of crop evapotranspiration and significantly better grape quality than full irrigated grapes.

In case of inadequate water availability the deficit irrigation at 48.9% to 56.0% of evapotranspiration is recommended for cv. 'Makutupora red' vine yards because the quality of grapes will be good and grape yield will still be higher than in unirrigated vineyards. Further study on the effect of deficit irrigation on other grape cultivars grown in Dodoma is recommended. Further investigation is also needed to find the relationship between grape yield, quality and the amount of water consumed by the grapevines.

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