Estimation of Yield Response (Ky) and Validation of CropWat for Tomato under Different Irrigation Regimes at Melkassa

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Abstract

CROPWAT is FAO computer programme that calculate crop water and irrigation requirements from a given climatic and crop data. Validated CropWat model is useful for irrigation decision support system to help tomato growers. Field experiment was conducted at Melkassa Agricultural Research Center to determine the optimal irrigation levels for maximum tomato production and to assess the effect of limited water supply on field grown tomato yield and to estimate 'yield response of tomato to soil water (Ky)' and to validate CropWat irrigation model using the data for tomato cultivation during hot-dry season conditions. Three irrigation scheduling levels such as 1) 100 % of crop water requirement (ETc) (Full irrigation) 2) 80% ETc (= 0.80 ETc) and finally 3) 60 % ETc (= 0.60 ETc) were used using drip irrigation replicated three times; the tomato was subjected to various levels of water stresses over whole growth period. Yield data such as marketable, unmarketable and total fruit yield were collected at each harvesting and summed at the end of harvesting. The analysis of variance showed that use of various irrigation depth brought significant effect (P< 0.01) on the marketable yield of tomato. However, application of various irrigation depths did not bring significant difference (P< 0.05) on unmarketable fruit yield of tomato. Use of various irrigation depth had a significant effect (P< 0.05) on the total fruit yield of tomato. The mean separation indicated that the highest fresh fruit yield was obtained from full irrigation and the lowest was obtained from 60% irrigation. Thus, the total fresh fruit yield obtained from fully irrigated tomato plot exceeded the fresh fruit yield obtained from tomato plot irrigated with only 60% of full irrigation water by 62.8%. The results showed that with decrease in the amount of irrigation per application, there was a decrease in total fruit yield in tomato due to reduced uptake of water. The calculated yield response (Ky) of tomato was 0.999 indicating that the yield reduction is directly proportional to reduced water use.CROPWAT irrigation model was validated using field data, then modeling efficiency was found to be 94% indicating that the model has a potential to be use full as a decision support system to help tomato growers.

***Keyword**:* CropWat, irrigation, tomato, simulation, crop water requirement

Introduction

The Central Rift Valley (CRV) area of Ethiopia is amongst the pioneers of market-oriented irrigated vegetable crops production in Ethiopia. Using various water sources for irrigation, vegetable production in this area has nowadays expanded where most growers use hybrid seeds and considerable agricultural inputs (Dawit and Hailemariam, 2005).

Agriculture in the CRV is dominated by traditional small scale irrigation at household level with very small farm size (Edossa, 2014; Edossa *et al*., 2014a and Hengsdijk and Jansen, 2006). Thus, improving small scale irrigated vegetable production system is expected to improve livelihoods and sustain the environment. Demeke (2008) and Haile (2008) found that vegetable crops growers that have access to small scale irrigation play an important role in poverty reduction through increased income and improved wellbeing of farming households.

In all parts of Ethiopia, tomato is produced under furrow irrigation in open fields. Based on survey conducted by Edossa *et al*., (2014a) in the central rift valley area, among the vegetable grower using furrow irrigation, 16.5% replied that the knowledge source for their irrigation management packages was obtained from experience, while 12.1% replied the knowledge source was obtained from experience and family and all the remaining replied different sources. In general, the survey result indicated that vegetable growers got knowledge and practices from variety of sources showing that furrow irrigation is mostly practiced based on one's traditional experience (Edossa *et al*., 2014a). Smallholder farmers replied that their irrigation scheduling is not supported by scientific methods and improved irrigation technologies (Edossa *et al*., 2014a).

About 86.81% of vegetable growers in the central rift valley have interest to increase their irrigable farm size and intensify vegetable production (Edossa, 2014; Edossa *et al*., 2014a). However, due to the expansion of irrigated areas and uncontrolled irrigation water in the upstream CRV, middle and all the downstream areas of Awash Basin despite limited availability of irrigation water, there is a need for optimal irrigation management and scheduling in order to use water efficiently and maximize crop yields under water deficit conditions.

It possible to reduce irrigation water loss such as conveyance, surface run off, and deep percolation from furrow irrigation by adopting efficient irrigation methods. Water saved from the use of efficient irrigation methods can be used to supplemental irrigation in larger areas or for longer seasons. The experience from many countries showed that farmers who changed from furrow system to drip systems can cut their water use by 30- 60% and increase crop yields (Sijali, 2001). The use of drip irrigation system permits reduction of water losses by up to 50% (Hochmuth and Hanlon, 2010) and can increase the yield per unit of land by up to 100% compared with surface irrigation systems (Cowater, 2003).

In several places in Ethiopia, there are extensive campaigns of water harvesting, tapping ground water and using appropriate technologies like treadle pump, rope and washer pumps with the realization that in many places existing water resources cannot meet the needs of the expanding population (Moges, 2006). Hence, it is very crucial to assess effects of different irrigation methods on tomato production and to assess the effect of limited water supply on tomato growth and yield. Accordingly, the objectives of this study were; 1) to determine the optimal irrigation levels for tomato production and to assess the effect of limited water supply on tomato growth and yield; 2) to estimate yield response of tomato to soil water (*Ky*) for developing an alternative irrigation schedule that may optimize tomato production under limited water supply conditions and 3) to validate the CropWat irrigation model for tomato using field data collected from field experiments in Melkassa area during hot- dry season.

Materials and Methods

The experiment was conducted at Melkassa Agricultural Research Centre during the hot- and dry season. There was no rainfall since tomato planting to final harvesting during the experimental period. Tomato variety *Melkashola* was used for this experiment. Three levels irrigation scheduling such as 1) 100 % of crop water requirement (ETc) (Full irrigation), 2) 80% ETc (Full) (= 0.80 ETc) and 3) 60 % ETc (= 0.60 ETc) with three replications were used. Equal amount of irrigation water were applied to each treatment before the initiation of irrigation treatments (sum of daily ETc). Once the drip system was installed, the drip irrigation was done on the basis of ETo (FAO, 2009a) value of the previous day. The amount of irrigation water applied, ETm, was determined from the calculated water requirement for tomato as determined from the crop coefficient (Kc) and the daily reference evapotranspiration (ETo). The total amount of irrigation water applied to each treatment was calculated as the sum of water applied during the crop establishment period and the ETc of the remaining period. The daily ETo data were calculated using the software programme EToCalc developed by Raes *et al*. (2006) on basis of the FAO Penman Monteith equation from Melkassa Weather Station (FAO, 2009a). All data on growths, yield and yield components, fruit physiological disorders, physiological parameters were collected. The water productivity behaviour of tomato variety *Melkasholla* and its yield response to water' (*Ky*) was estimated through the following relationship as described by Doorebos *et al*. (1979).

Treatment Arrangement, Experimental Materials and Procedures

Treatment Arrangement

Irrigation scheduling treatments included (1) 100% of crop water requirement (ETc) (Full irrigation), (2) 80% ETc (3) 60% ETc. The plots were replicated three times.

Experimental procedures

Melkashola, a multipurpose tomato variety with semi-determinate growth habit (Edossa *et al*., 2014) that was released by Melkassa Agricultural Research Center was used for the field experiment. Seeds of *Melkasholla* were sown in a nursery in rows with the row spacing of 10 cm and dense within rows spacing. The size of the seedbed was 5 m length and 1 m width. The seeds were drilled into the seedbeds and covered with a soil layer of 0.2 cm. About 100 g Urea and 200 g DAP were applied per bed and thoroughly mixed with the soil as recommended by Lemma (2004). Watering was done in the interval of three days throughout the growth period of the seedlings in the nursery for both experiments.

Field preparation consisted of ploughing by a mould board plough to a depth of 40–50 cm followed by 10 to 15 cm deep disc harrowing before ridging was done. Seedlings were transplanted to the permanent experimental field as per the recommendation suggested by Lemma (2002). Plots with individual size of 7.0 m x 4.5 m, with seven rows, and each row accommodating 15 plants was marked out for data collection. The spacing between rows was 100 cm and 30 cm between plants. A total of 61 plants and 44 boarder plants were transplanted. Since past rainfall was insufficient to replenish the soil profile, irrigation was applied pre-planting (Studento *et al*., 2012). A total of 60 experimental plants were planted within each plot. Before initiating treatments, plants (seedlings after transplant) were irrigated to nearly field capacity for three weeks in order to improve root development (Kirnak *et al*., 2001).

Irrigation System

A low-cost gravitational drip structure used for the experiment comprised water source tanker at the elevated position, filter, water tank connector, straight connector, connector, control valve, main line, lateral pipe, emitter, wood and nail for tanker stand. Four tankers having the capacity of 2000 litres each were placed at the head of strip plot. The tankers were placed in the field at the height of 1.0 m from above the ground to provide the water pressure required in operating the system. Once the seedlings were well established for 20 days, the irrigation treatments were commenced.

Each plot consisted of lateral drip lines with 5.5 m length. The emitters on laterals were spaced at 0.3 m corresponding distance of tomato plant spacing within a row in the field. The lateral line was laid out along each tomato row. Each tomato plants were planted under emitter so that they would benefit from the water supplied by the emitters. The field was furrow-irrigated before planting and after transplanting for ten days for crop establishment before imposing drought stress treatment levels such as 80% ETc and 60% ETc.

Three and half meter distance buffer zone separate each plots or side flows were precluded to avoid lateral run-on and run-off (side flows) from other irrigation treatment plots.

Methods for Estimation of Soil Water

Estimation of daily crop water requirement

The initial soil water content for top soil at the time of transplanting was assumed to be close to field capacity. This assumption is dictated by the fact that small vegetable seedlings are extremely very sensitive to moisture stress. Then the proper amount of daily irrigation for a crop is the amount of daily ET taking place minus any daily effective rainfall (Allen *et al*., 1998).

Application of daily time step irrigation scheduling

Equal amount of irrigation water were applied to each treatment before the initiation of irrigation treatments (sum of daily ETc). After installing the drip system, irrigation was applied on the basis of ETo (FAO, 2009a) value of the preceding day. The amount of irrigation water applied, ETm, was determined from the calculated water requirement for tomato as determined from the crop coefficient (Kc) and the daily reference evapotranspiration (ETo) using the following equation:

$$ETc = ETo * Kc \quad (1)$$

Irrigation scheduling was based on a check book of soil water balance budget (eq.1) where simple accounting approach is used for estimating how much soil-water remains in the effective root zone based on water inputs and outputs. Irrigation was scheduled when the soil-water content in the effective root zone was near the predetermined allowable depletion volume through keeping track of rainfall, evapotranspiration, and irrigation amounts. Irrigation treatments were applied once a day until the required volume of water was completely gone from the tanker. The total amount of irrigation water applied to each treatment was calculated as the sum of water applied during the crop establishment period and the ETc of the remaining period.

Daily Reference ETo

The daily ETo was calculated from Melkassa Weather Station data using the software programme EToCalc developed by Raes, (2006) on basis of the FAO Penman Monteith-equation.

Net irrigation (IRn)

The IRn which is the amount of irrigation water required to bring the soil moisture level in the effective root zone to field capacity (Michael, 2008), was calculated as follows:

$IR_n = ETc - P_{ef} + LR$ (mm) (2)

Where: IR_n = Net irrigation requirement (mm)
ETc = Crop evapotranspiration (mm)
P_{ef} = Effective dependable rainfall (mm)
G_e = Groundwater contribution from water table (mm)
W_b = Water stored in the soil at the beginning of each period (mm)
D = Deep percolation/drainage (mm)
LR = Leaching requirement (mm)

High water tables are rarely expected under drip irrigation conditions and therefore the contribution of groundwater to crop water requirement is usually ignored. Similarly, deep percolation and leaching requirement were assumed to be zero. With those assumptions, the net irrigation requirement could be calculated as:

IRn = ETc - Pe + LR (mm) (3)

Again the estimated LR is found to be less than 10% and it is ignored from the equation.

Gross irrigation:

Gross irrigation requirement is net irrigation requirement plus losses in water application and other losses (Michael, 2008). This is expressed in terms of overall efficiencies when calculating gross irrigation requirements from net irrigation requirements:

$$IR_g = \frac{IR_n}{E} + LR \quad (4)$$

Where,
IRg = Gross irrigation requirements (mm),
IRn = Net irrigation requirements (mm),
E = Field efficiency of the system where drip irrigation system efficiency is determined about 85 % (Muchovej *et al*., 2008)

Daily irrigation, the amount of water was adjusted according to existing reference *ET* and *Kc*. The irrigation treatments were differentiated by their two meters arrangement for strip, irrigation events were controlled manually by using valve. The valve was put on and off after calculating net irrigation and adding losses (gross) depending on amount of water to be applied at desired level for each strip separately. Records of daily applied water were kept from the start of treatment application up to the final harvest date for each treatment. The recorded daily applied water amounts were then summed up for the irrigation period for each treatment.

Adjustments for Kc for development and late stage and for partial wetting

The Kc values of tomato used for this study were 0.6, 1.15 and 0.80 for the initial, mid and late season stages, respectively (Allen *et al*., 1998); during the initial and mid-season stages, Kc was constant and equal to the Kc value of the growth stage under consideration; these growth stage represent 25 days for the initial, 34 days for the development, 20 days for mid and 41 days for the late growing stages totalizing 120 days as recommended by Allen *et al*. (1998). The daily Kc for developmental and late season stages was adjusted using the formula given by Allen *et al*. (1998). During the crop development and late season stages, Kc varied linearly between the Kc at the end of the previous stage (Kc prev) and the Kc at the beginning of the next stage (Kc next), which is Kc end in the case of the late season stage.

Data Collection

Marketable and unmarketable fruit yield were measured at each harvest during the growing season and summed up at end of the experiment and the total fruit yield was obtained by adding all fruit yields.

Estimation and quantifying crop water use

Tomato yield response (Ky): Water productivity behaviour of 'Tomato variety *'Melkasholla'* and its yield response to water' (*Ky*) was estimated as follows as suggested by by Doorebos *et al*. (1979):

$$(1-\frac{Y_a}{Y_m}) = Ky(1-\frac{ET_a}{ET_m})$$

Where,

Y_m= Maximum yield (kg)

Y_a= Actual yield (kg)

ET_m= Maximum evapotranspiration (mm/period)

ET_a= Actual evapotranspiration (mm/period)

The analysis of variance were conducted using SAS software and the treatment means were separated by fisher's protected LSD at 0.05 probability level.

Validation of CropWat

With the help of the CropWat model was used to estimate the yield reduction were estimated and determined and compared with the actual measured yield reduction of field experimentation. The yield reductions were expressed as percentage of the tomato yield obtained under full irrigation.

Results and Discussions

Fruit Yields

Irrigation depth treatments significantly (*P*< 0.01) affected the marketable and total fruit yields of tomato whereas application of various irrigation depths did not significantly affect (*P*>0.05) unmarketable fruit yield of tomato (Table 1).

Table 1. Mean squares of yield and yield components of tomato as influenced by application of various moisture regimes

Sources of variations	df	Mean square value		
		Marketable fruit yield	Unmarketable fruit yield	Total fruit yield
Irrigation	2	55159.9**	861.09 NS	4397.91*
Error	4	917.80	339.72	315.00
Total	44			
CV		22.94	28.00	8.92

Note NS = Indicates non-significant at *P* < 0.05; * significant at *P* < 0.05 and ** significant at *P*< 0.01 probability levels, respectively

The mean separation indicated that the highest fresh fruit yield was obtained from full irrigation and the lowest was obtained from 60% irrigation water with saving of 40% of irrigation water (Table 2). Thus, the total fresh fruit yield obtained from fully irrigated tomato plot exceeded the fresh fruit yield obtained from tomato plot irrigated with only 60% of full irrigation water by 62.8%. The results showed that with decrease in the depth of irrigation, there was a decrease in total fruit yield in tomato due to reduced uptake of water (Table 2).

Table 2. Mean values of various irrigation regimes on fruit yield of tomato grown under drip irrigated condition

Irrigation regimes	Marketable fruit (t ha^{-1})	Unmarketable yield (t ha^{-1})	Total fruit yield (t ha^{-1})
IR -I /Full irrigation/ (100% ETc)	63.63 A	18.267	81.902 A
IR -II (80% ETc)	33.83 B	22.413	56.250 B
IR -III (60 % ETc)	27.82 B	23.062	50.868 C
Mean	41.765	20.813	62.916
LSD (0.05)	9.712	NS	5.689

Key: *= Average of three replications. Means within each column with different letters are significantly different at *P* = 0.05 level of probability

The result of this study corroborate that of Muchovej *et al*. (2008) who reported that high quality and yield of vegetable crops are directly associated with proper water management. Birhanu and Katema (2010) also found that the fresh fruit yields of *Melkasholla* variety was reduced under deficit irrigation level. Similar findings were reported by Kirnak *et al*. (2001) where egg plants grown under high water stress had less fruit yield and quality than those in the control treatment. Halil *et al*. (2001) reported that eggplant fruit yield was reduced by up to 68% when grown in the water stressed container compared with unstressed plants. Studento *et al*. (2012) also reported that restricted water supply for tomato can suppress new leaf development, resulting in a shortened yield formation period. Cetin *et al*, (2008) also reported that water stress significantly reduced final yield of field-grown sweet pepper. .

Water production function of tomato yield under various irrigation scenarios

The relationship between yield and irrigation water applied was presented in Figure 1. Based on the relationship tested, about 92% of the variation in fresh fruit yield was brought about by irrigation treatments (Figure 1). Thus, as irrigation depth increased, total fruit yield increased linearly.

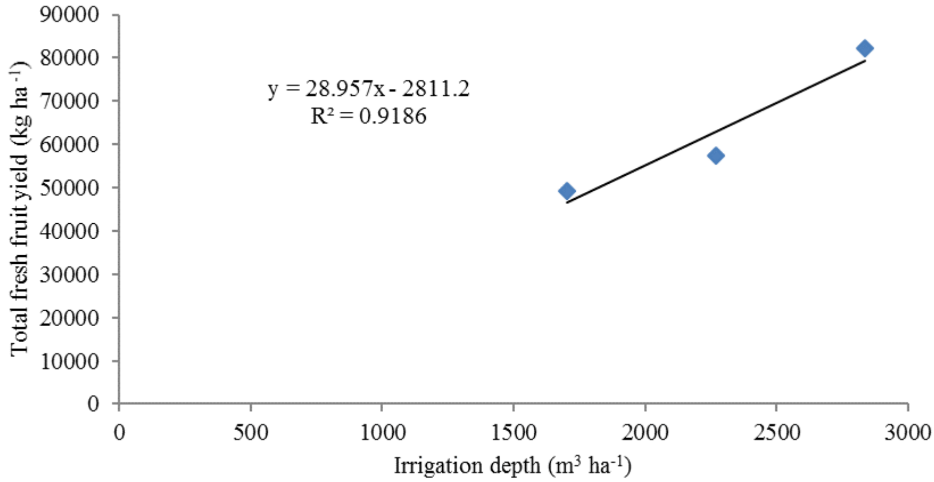

Figure 1. Yield-water relationship of drip irrigated tomato *Melkasholla* variety grown in a dry and hot season at Melkassa.

The relationship between yield and irrigation water supplied could be expressed by a linear relationship very well as: *Fresh tomato fruit yield =28.95x -2811, with* R^2*=0.918*; with a slope of about 28.9:1 in terms of reduced applied water: gross kg yield reduction. Bazza, (1999) conducted an experiment for sugar beet and reported that more than 90% of the yield variation was coming from the variability in depth of irrigation water applications.

Estimation of Yield Response (Ky)

Relationship between relative yield decrease (1-Ya/Ym) and relative evapotranspiration (1-ETa/ETm) of tomato yield response (*Ky*) at Melkassa was determined using the functional relationship described by Doorebos *et al*., (1979). Thus the estimated yield response (*Ky*) of tomato *Melkashola* variety at Melkassa became 0.9998, a little bit lower than 1.05, which was suggested by Allen *et al*., (1998)(Figure 2).

Although tomato is relatively moderately sensitive crop, and the *Ky* is estimated to be 1.05 (Allen *et al*., 1998). Giardini and Giovanardi (2008) also found variable value of *Ky* for tomato. The estimated 0.999 value of Ky in the present study indicated that the yield reduction in tomato is directly proportional to the level/amount of irrigation water applied (Studento *et al*., 2012).

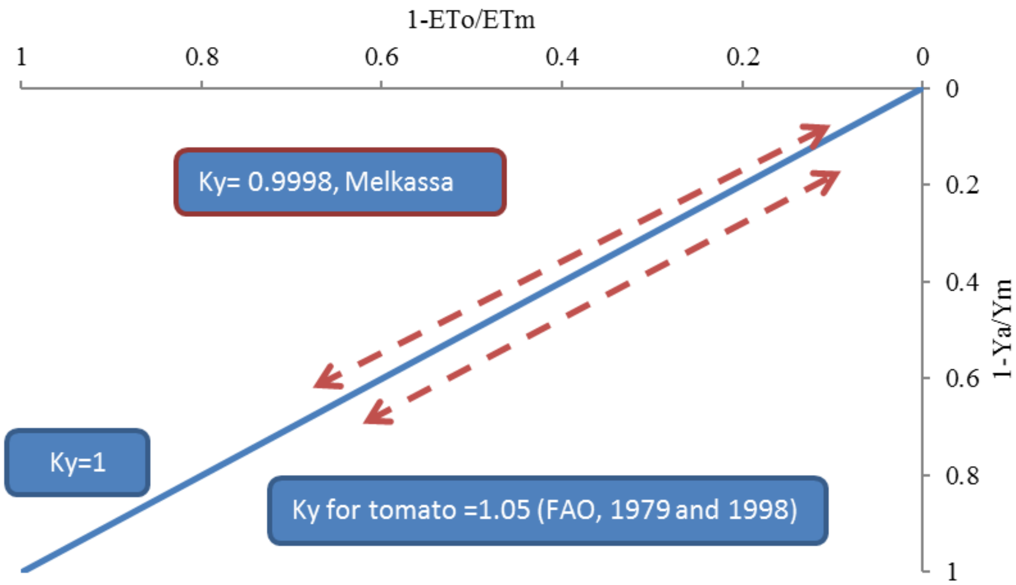

Figure 2. Predicted values and regression line of the functional relationship between relative yield reductions (1-Ya/Ym) and relative evaporation deficits (1-ETa/ETm) of tomato *Melkasholla* variety

In this figure, *Ky* = 1 is shown as a reference line, but *Ky* =1.05 was determined by FAO (1979 and 1998).

Validation of CropWat for Tomato

Different levels of irrigation water were applied to tomato crop during the field experiment, inducing water stress throughout the growing season. The yield reduction was determined using CropWat model and compared with the actual measured yield reduction of field experimentation. Table 3 presents comparison of measured yield reduction with the yield reductions simulated by the CropWat model.

The CropWat model was combined with 35-year local historical weather data and used as a research tool for yield simulation as indicated in Table 3.

Table 3. Comparisons between yield reductions simulated by CropWat and measured for drip irrigated tomato experiment at Melkassa

Irrigation treatment	Measured		CropWat
	Yield (kg ha^{-1})	Yield reduction (%)	Yield reduction (%)
Full ETo	82140	0.00	0.00
80 % ETo	57300	30.24	19.00
60% ETo	49300	39.98	34.10

The observed and simulated values for yield are plotted in Figure 3. The model efficiency was calculated and estimated through comparing predicted values to the one-to-one line rather than the best regression line through the origin points. Accordingly, the model efficiency was found to be 94%. This model efficiency was similar to the correlation (r^2) and the r^2 was found to be 95.1% (Figure 3). The measured and simulated tomato total fruit yield showed a good correlation. Furthermore, the simulated results reflected that the impact of stress in the whole tomato growth cycles was high on fresh fruit yield reduction. The model was confirmed to be a useful decision support system to help farmers to verify the optimal crop management strategy from several points of views.

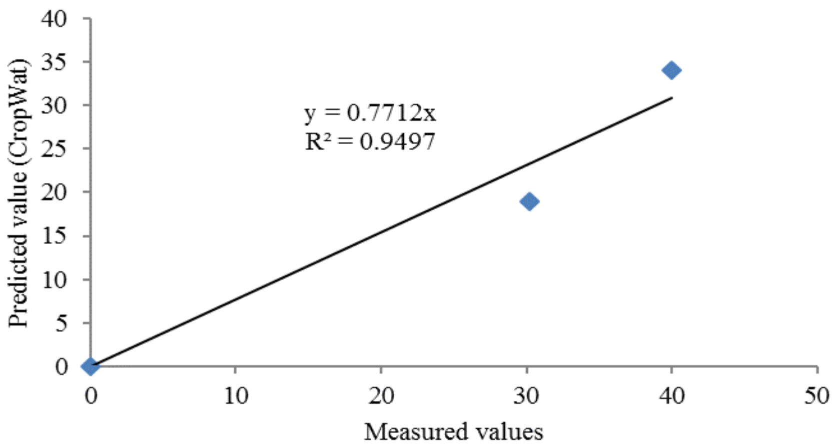

Figure 3. Comparisons of predicted and measured tomato yield reduction under different irrigation regimes at Melkassa

Conclusions

An irrigation experiment with drip method was conducted to evaluate and determine the optimal irrigation levels for maximum tomato production. Three levels of irrigation regimes (100% of crop water requirement (ETc) and also called full irrigation, 80% ETc and 60% ETc) were used and with three replications. Among irrigation levels tested, the highest yield of 82.14 t ha^{-1} was recorded from full irrigation treatment (100% ETc) followed by 57.30 t ha^{-1} from 80% ETc irrigation levels and lowest yield 50.86 t ha^{-1} from 60 % ETc irrigation depth. This indicated that tomato crop should be irrigated at full water requirement to get maximum fruit yield. The relationship between relative yield decrease (1-Ya/Ym) and relative evapotranspiration (1-ETa/ETm) of tomato at Melkassa was determined through the functional relationship and the yield response (*ky*) of tomato *Melkashola* variety throughout the crop cycle was calculated and estimated to be 0.999 indicating the yield reduction in tomato is directly proportional to reduced water use. This figure is a little bit lower than given by Allen *et al*. (1998) which was 1.05. With the help of the CropWat model, the yield reduction simulated by the CropWat was compared with the actual yield reduction of field experimentation. The model efficiency was calculated and estimated. Accordingly, the model efficiency was found to be 94%. This model efficiency was found to be 95.1%. The measured and simulated tomato total fruit yield showed a good correlation. Furthermore, the simulated results reflected that the impact of stress in the whole tomato growth cycles was high on fresh fruit yield reduction. The model was confirmed to be a useful decision support system to help farmers to verify the optimal crop management strategy from several points of views. This further confirm that for rainfed tomato, supplementary irrigation should be switched on during dry spells, and full irrigation should be started on immediately after the rain fall cessation; otherwise much yield loss would occur. This experiment was conducted under drip irrigation conditions. However, almost all tomato growers in the study area practice furrow irrigation. Therefore, we recommend appropriate irrigation method and irrigation depth estimation should be conducted in the future to maximise yield improve crop water use.

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