WATER MANAGEMENT AND IRRIGATION SCHEDULING OF TOMATO BY WATER BALANCE

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ABSTRACT

The objective of this work was to compare three methods of irrigation scheduling of tomatoes in regard to amount of irrigation water with yield. The irrigation scheduling was managed by water balance coupled with Penman-Monteith and evaporation pan to determine the crop evapotranspiration. Tomatoes actual consumptive use of water was estimated by following the soil matric potential for specific range by tensiometers. The field experimental work was conducted during the summer season of 2003 at Saba Basha experimental farm to determine the tomatoes dual crop coefficient, applied irrigation water, yield and water utilization efficiency. Surface irrigation method was used in the experiment. A complete random blocks design with three replicates was used.

Results showed that irrigation scheduling methods have a significant effect on tomato yield and irrigation applied water. Insignificant effect was found on water utilization efficiency. Tomato average yields were 24.19, 26.75 and 27.7 ton/fed. corresponding to water balance with Penman-Monteith, water balance with evaporation pan and tensiometers, respectively. The averages of applied irrigation water were 2130, 2340 and 2445 m^3/fed for the same previous order.

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INTRODUCTION

The basic irrigation is to supply plants with water as needed to obtain optimum yield and quantity of a desired plant constituent (Haise and Hagan, 1967). Efficient irrigation implies complete control of the available soil moisture reservoir. Such control requires knowledge of the soil water content at all times (Berry et al., 2003). Irrigation scheduling attempts to answer two basic questions posed by irrigators: when to irrigate and how much water to apply. Its advantages include the minimizing of water and energy use as well as deep percolation losses while insuring that adequate water is available to plants without placing them under stress that might reduce yield. Irrigation within limits prescribed by scheduling program can also help control salinization.

Irrigation scheduling requires some methods of assessing the water availability to the crop with sufficient lead time to provide for water application. If the method used does not provide sufficient warning, the crop yields will be reduced because of lack of water, while the other extreme could result in too much water applied and a waste of water and energy. Methods currently used are soil moisture measurements, plant measurements, and evapotranspiration models. Two criteria are used for deciding when a crop should be irrigated; the depletion of water in the root zone to some predetermined level or the decrease of water potential at given depth to a predetermined level. Either of these criteria will depend on soil properties, crop rooting characteristics and stage of plant growth.

Differences in evaporation and transpiration between field crops and the reference grass surface can be integrated in a single crop coefficient (Kc) or separated into two coefficients, basal crop coefficient (Kcb) and the soil evaporation coefficient (Ke), i.e., Kc= Kcb +Ke. The approach to follow should be selected as a function of the calculation accuracy required, the available data and the time step which the calculations are executed. Basal crop cpefficient for various crops have been reported by Kincaid and Heermann (1974), Doorenbos and Pruitt (1977), Wright (1982), Stegman (1988) and Allen et. al. (1989). The dual crop coefficient approach is more complicated and more computationally intensive than the single crop coefficient approach. The procedure is conducted on a daily basis and intended for application using computer.

The reference ETo was calculated in this research by both FAO Penmam-Monteith and evaporation pan methods. The objective of the study is to compare various irrigation scheduling procedures in regard to amount of irrigation applied water with tomato yields.

MATERIALS AND METHODS

The present study was conducted in Saba Basha (سابا -باشا) experimental farm during the summer season of 2003. The experiment was laid out on randomized complete blocks with three replicates. Three methods to schedule irrigation of tomato were applied. The first, was by following the soil matric potential, the second and the third were by water balance using evaporation pan and Penman-Monteith methods to estimate the tomato evapotranspiration. Analyses of soil samples for the top 100 cm of the soil were performed. Results revealed that the experimental field is clay soil (49% clay, 15% silt and 36% sand). The soil average bulk density was 1.26 g/cm^3. Actual water consumptive use of tomato along the growing season was determined by using tensiometer. Tomato variety used was Castelrock. Tomato seedlings were transplanted on June 15. Traditional method was followed to plant the tomato. Plants were thinned or added to keep two plants per hill after 15 days from transplanting, Fertilization and all other practices were uniformly applied as recommended. The first picking was on Sept. 15th and the last picking was on Sept. 30 th. Complete canopy cover and initial blooming were noted on Aug. 10 th. Irrigation applied water, yield of tomato, and water utilization efficiency after the growing season were submitted to statistical analysis according to Snedicor and Cochran (1980)

Estimation of tomato dual crop coefficient:

The calculation procedure of estimating the tomatoes daily crop coefficient consists of:

1- Identifying the length of the tomatoes growing stages as 20, 30, 30 and 20 days for initial, development, mid and late season stages respectively, as given by Sharaf et al., 1999.

2- Selecting the corresponding Kcb coefficient of tomato as given by Allen et al., 1998 as 0.15, 1.1 and .7 for initial, mid-season and end stages respectively.

3- Adjusting the selected Kcb of mid-season and end-season of the growth stages for the local climatic conditions, where the values of Kcb cited is based on 45% minimum relative humidity and 2 m/s for wind speed. The prevailing minimum relative humidity and wind speed during the growing season of the experimental site were 36% and 1.3 m/s respectively. The adjusted values of Kcb were 1.11 and 0.71 for mid-season and end-stage respectively. The following formula was applied for this adjustment (Allen et. al., 1998):

$$Kcb_{adj} = Kcb_{cited} + \left[0.04\,(U-2) - 0.004\,(RH_{\min} - 45)\right]\left[\frac{h}{3}\right]^{0.3} \qquad (1)$$

Where:

Kcb_{-adj} = adjusted value of tomato coefficient .

Kcb_{-cited} = original value of tomato coefficient (Allen,1989)

U = mean value of daily wind speed at 2m height (m/s)

RH_{min} = mean value of minimum relative humidity (%)

h = mean plant height taken as 0.6 m for tomato.

4- Estimating the tomatoes daily basal crop coefficient considering that during the initial and mid-season stages *Kcb* are constants and during the development and late-season stages *Kcb* vary linearly between the *Kcb* at the end of the previous stage and the *Kcb* at the beginning of the next stage. The formula applied for this numerical calculation is as follows:

$$Kcb(i) = Kcb_{prev.} + \left[\frac{i - \sum L_{prv.}}{L_{stage}}\right]\left(K_{cb\,next} - K_{cb\,prev}\right) \qquad (2)$$

Where:

- $Kcb\ (i)$ = crop coefficient of the day No. i
- Kcb_{prev} = Kcb value of the previous stage
- L_{stage} = length of the stage under consideration (days)
- $\Sigma(L_{prev})$ = sum of the lengths of the previous stages (days)
- K_{cbnext} = Kcb value of the next stage

5- Calculating the daily values of soil evaporation coefficient *Ke* for surface evaporation. Directly after irrigation, the evaporation occurs at a maximum rate, when the topsoil layer dries out less water is available and a reduction in evaporation begins to occur in the portion of the amount of water remaining in the soil surface layer. This was calculated by the following equation:

$$Ke(i) = Kr(i)(Kc_{max} - Kcb(i)) \qquad \leq \qquad few \quad Kc_{max} \qquad (3)$$

Where:

- $Ke\ (i)$ = soil evaporation coefficient for day No. (i)
- Kc_{max} = maximum value of Kc following irrigation
- $Kr\ (i)$ = dimensionless evaporation reduction coefficient of the day (i)
- few = fraction of soil surface which most evaporation occurs

Following irrigation *Kr* =1, as the soil surface dries, *Kr* becomes less than 1 and evaporation is reduced. *Kr* becomes zero when no water is left from evaporation in the upper soil layer.

Water depleted by evaporation during a complete drying cycle occurs during two stages. The first is the energy limiting stage. The cumulative depth of evaporation at the end of this stage is defined as readily evaporable water (*REW*). For the soil under consideration *REW* was 8 mm. All values of *Kr* during this stage are equal to 1. The second stage where the evaporation rate is reduced, is termed as falling rate stage. It states when the water depleted by evaporation exceeds the *REW*. The amount of water that can be depleted by evaporation during the complete drying cycle in both stages can be estimated as:

$$TEW = 10\ (Fc - 0.5Wp)\ Ze \qquad (4)$$

Where:

TEW = total evaporable water from the topsoil (mm)

Fc = soil water content at field capacity (%)

Wp = soil water content at welting point (%)

Ze = topsoil surface depth subjected to drying by evaporation, taken as 0.1 (m)

The estimation of *Kr* requires daily water balance computation for the top surface soil layer. During both stages, the following equations were used:

$$Kr(i) = 1 \qquad For \quad De(i-1) \le REW \qquad (5)$$

$$Kr(i) = \frac{TEW - De(i-1)}{TEW - REW} \qquad For \quad De(i-1) \rangle REW \qquad (6)$$

Where:

De(i–1) = accumulative depth of evaporation (depletion) at the end of the previous day

For the daily water balance of the topsoil layer to calculate the cumulative evaporation from the wet condition, the following

$$De(i) = De(i-1) - (P - Ro)(i) - \frac{IR(i)}{fw} + \frac{EV(i)}{few} + Tew(i) + Dpe(i) \qquad (7)$$

relationship was applied:

Where:

De(i)	= topsoil evaporation (depletion) following wetting at end of day (i) (mm)
P(i)	= precipitation on day I (mm)
Ro(i)	= precipitation runoff from the soil surface on day i (mm)
IR(i)	= irrigation depth on the day i (mm)
EV(i)	= evaporation on day i (i.e., EV(i)=Ke*ETo)(mm)
Tew(i)	=depth of transpiration from few fraction on day i (mm)
Dpe(i)	= deep percolation loss from the topsoil layer exceeds field capacity (mm)

After irrigation or rain the topsoil layer was assumed to be at field capacity, therefore, the minimum value of depletion *De(i)* is zero. As the soil surface dry *De(i)* increases and in absence of any wetting event will steady reach its maximum value *TEW*. At this moment no water is left for evaporation in the upper layer and *Kr* becomes zero and the value of *De(i)* remains at *TEW* until the topsoil is wetted once again. The limits imposed on *De(i)* are consequently $0 \leq De(i) \geq TEW$. To initiate the water balance calculations *De(i-1)* was assumed equal *TEW*. Following irrigation the soil water content may exceed field capacity, for simplicity, it was assumed to be as field capacity nearly immediately following a complete wetting so that , the depletion *De(i)* in Eq. (7) is zero. Therefore, the deep percolation in the topsoil layer could be estimated by the following equation:

$$Dpe(i) = (P - R0)(i) + \frac{IR(i)}{fw} - De(i-1) \qquad \geq 0 \qquad (8)$$

As long as soil water content in the evaporation layer is below field capacity (i.e., $De(i) > 0$) the soil will not drain and $Dpe(i) = 0$.

The maximum value of the tomato coefficient following irrigation (Kc_{max}) was estimated by the following equation (Allen et al., 1998):
The fraction of soil that is exposed and wetted i.e., the fraction of soil

$$Kc_{max} = \max\left[\left(1.2 + [0.04(U-2) - 0.004(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3}\right), (Kcb + 0.05)\right] \quad (9)$$

from which most evaporation occurs "*few*" was calculated by the following equation:

$$few = \min(1 - fc \quad , \quad fw) \qquad (10)$$

Where:

1-fc = average exposed soil fraction not covered by vegetation.
fc = average fraction of soil surface covered by vegetation.
fw = average fraction of soil surface wetted by irrigation.

For irrigation system, where only a fraction of ground is wetted, *few* must be limited to *fw*. In the study, *fw* was taken as 0.6, where the irrigation was applied through narrow bed furrows 0.5m distance.

The effective fraction of soil surface covered by vegetation *fc* was determined using the following relationship (Allen et. al., 1989) as:

$$fc = \left[\frac{Kcb - Kc_{min}}{Kc_{max} - Kc_{min}}\right]^{(1+0.5h)} \qquad (11)$$

Where:

Kc_{min} = minimum Kc for dry basal soil with no cover, in the study taken as 0.13

Estimation of readily available water for tomato:

The total available water (*TAW*) is the difference between the water content at field capacity and wilting point, that tomato crop can extract water from by its root zone. Although water is theoretically available until wilting point, crop water uptake is reduced before wilting point is reached. The fraction of *TAW* that can be extracted from the root zone without suffering water stress is the readily available water (*RAW*) (in mm), which is estimated by the following:

$$RAW = 10(Fc - Wp)\ Rd\ \ P \qquad (12)$$

Where:

Rd = rooting depth (m).

P = average fraction of *TAW* that can be depleted before water stress.

The fraction "*P*" is a function of evaporation power, soil type, irrigation method and crop type. For tomato *"P"* taken as 0.4 as given by Dooronbos and pruitt (1977). A numerical approximation for adjusting *P* for daily ETcrop is estimated by the following equation:

$$P_{adj.} = P_{orig.} + 0.04\,(5 - ETcrop) \qquad (13)$$

Where:

$P_{adj.}$ = adjusted value of P

$P_{orig.}$ = original P value (0.4)

The amount of water that can be used by the crop depends on the water holding characteristics of the soil and the rooting depth of the crop. This is actually a dynamic variable since the depth of the root zone progresses during the growing season. The root depth prior to when the maximum root depth is reached was described by an empirical function that could be used for several crops (Borg and Grimes, 1986) as:

$$Rd(i) = Rd_{\max}\left[0.5 + 0.5\sin\left(3.03\frac{Dap}{Dtm} - 1.47\right)\right] \qquad (14)$$

Where:

$Rd(i)$ = root depth at the day No. i (m)

Rd_{max} = the maximum root depth (m)

Dap = the days after planting

Dtm = the days from planting to maximum effective depth.

Irrigation scheduling of tomato crop by water balance:

In soil water balance, the root zone can be described as a container in which the water content is fluctuated. It makes the adding and subtracting of losses and gains straightforward as various parameters of the soil water expressed in terms of water depth. Rainfall, irrigation, capillary rise of ground water (if found) towards the root zone add water to the root and decrease the root depletion. Soil evaporation, crop transpiration losses remove water from the root zone and increase the depletion. The daily water balance, expressed in terms of depletion at the end of the day, is expressed by:

$$Dr(i) = Dr(i-1) - (\mathrm{Pr} - Ro)(i) - IR(i) - CR(i) - ETcrop(i) + Dp(i) \qquad (15)$$

Where:

Dr(i)	= root depth depletion at the end of day i (mm)
Dr(i-1)	= root depth depletion at the end of the previous day (mm)
Pr (i)	= precipitation on day (i) (mm)
Ro(i)	= precipitation runoff from the soil surface on the day (i) (mm)
IR(i)	= net irrigation depth on the day (i) (mm)
CR(i)	= capillary rise from the ground water table on the day (i) (mm)
Etcrop (i)	= crop evapotranspiration at the day No. (i) (mm)
Dp(i)	= water loss out of the root zone by deep percolation at the day (i) (mm)

Assumptions:

1- Following irrigation or rain, the top root zone is at field capacity and air is humid, therefore, the depletion at that day *Dr(i)* is minimum and approaches zero.

2- The contribution of ground water due to capillary rise is negligible.
3- Following irrigation or rain, the soil water addition might exceeded field capacity. The amount of water above field capacity is assumed to be lost in the same day by deep percolation or surface runoff, therefore, it could be estimated by:

$$Dp(i) = (\Pr - Ro)(i) + IR(i) - ETcrop(i) - Dr(i-1) \qquad (16)$$

4- In the absence of any wetting events, the water content will steadily decrease until the depletion has reached its minimum value as *TAW*. Therefore, the limit imposed on *Dr(i)* is consequently $0 \leq Dr(i) \leq TAW$, in other word, irrigation should be applied before or at the moment when the readily available water is depleted ($Dr(i) \leq RAW$).
5- By calculating the soil water balance of the root zone on the daily basis by applying Eq.(15), the timing and the depth of irrigation requirements can be planned.
6- To avoid deep percolation, the net irrigation depth is equal to the readily available water (*IR(i) = Raw*)

Reference evapotranspiration:

Evaporation pan:

A standard evaporation pan was used to determine the evaporation in the experimental site. The evaporation from pan was measured daily in mm. The pan was located 10 m apart from the green surface. Applying the historical prevailing weather data, the pan coefficient was determined daily using the following equation (Cuenca, 1989):

$$Kp = 0.475 - 0.24x10^{-3}U + 0.00516RH_{mean} + 0.00118d - 0.16x10^{-4}(RH_{mean})^2 \\ - 0.101x10^{-5}d^2 - 0.8x10^{-8}(RH_{mean})^2U - 10^{-8}(RH_{mean})^2 d \qquad (17)$$

Where:

Kp = pan coefficient

D = distance from green cover (m)

RH_{mean} = mean relative humidity (%)

U Wind speed at 2m height (m/s).

The pan evaporation is related to the reference evapotranspiration by an empirically derived pan coefficient as:

$$ETo_{pan} = Kp \quad E_{pan} \qquad (18)$$

Where:

ETo_{pan} = reference evapotranspiration (mm/day)

E_{pan} = evaporated water from the pan (mm/day).

Awady et al., 1976 found that, the ratio of water rate to evaporation from open pan was 0.7 for the best pea crop.

Penman-Monteith:

Reference evapotranspiration by Penman-Monteith (ETo_p) was calculated by using the prevailing climatic weather data of the local

$$ETo_p = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (19)$$

meteorological weather station by the following equation (Allen et. al., 1998)

Where:

ETo_p = reference evapotranspiration by Penman-Monteith (mm/day)

R_n = net radiation at the crop surface (MJ/m^2 day)

G = soil head flux density (MJ/ m^2 day)

T = mean daily air temperature (^{o}C) measured at 2 m height,

U_2 = wind speed (m/s) at 2m height،

e_s = saturation vapor pressure (kPa)

e_a = actual vapor pressure (kPa)

e_s - e_a = vapor pressure deficit (kPa)

Δ = slope of the vapor pressure curve (kPa /^{o}C), and

Γ = psychometric constant (kPa /^{o}C).

The crop evapotranspiration of tomato then, was calculated by multiplying the reference evapotranspiration,ETo, by the tomato dual coefficient. Most of the effects of the various weather conditions are incorporated into the ETo estimate, therefore, as ETo represents an index of climatic demand, Kc varies predominately with the crop characteristics as:

$$ETcrop = ETo \;\; Kc \qquad (20)$$

Where:

$ETcrop$ = tomato evapotranspiratiom (mm/day)

ETo = reference evapotranspiration (mm/day)

Kc = tomato crop coefficient.

Irrigation scheduling of tomato by tensiometers:

The irrigation scheduling was managed by following the soil matric potential by a couple of tensiometers placed parallel to the row, 10 cm apart from the plant. The first tensiometer (the shallow one) was used to monitor the soil water states at the middle of the root zone (35 cm blow the soil surface) to initiate the irrigation at 50 cbar. The other one (the deeper) was placed as deep as the maximum root reached (70 cm below the soil surface). This tensiometer was used to terminate the irrigation when the reading was 20 cbar. A hose from calibrated water storage tank placed next to the experimental plots delivered the irrigation water quantities.

RESULTS AND DISCUSSION

Tomatoes crop coefficient:

In the dual crop coefficient approach applied, the effects of tomato transpiration and soil evaporation are determined separately. Two coefficients are used, the basal crop coefficient (*Kcb*) to describe plant transpiration, and the soil evaporation coefficient (*Ke*) to describe the evaporation from the soil surface. The *Kcb* represents the baseline potential crop coefficient in the absence of the additional effects of the soil wetting by irrigation. If the soil is wet following irrigation Ke may be large. As the soil surface becomes drier, *Ke* becomes smaller and falls to zero when no water is left for evaporation.

Fig. (1) and Fig.(2) present typical shapes for *Kcb* and *Ke* curves when irrigation scheduling was managed by daily water balance progressed by Penman-Montieth and evaporation pan respectively. The Kcb curves in the figures represent the minimum *Kc* for conditions of adequate soil water and dry soil surface. The *Ke* spikes in the figures represent increased evaporation when the irrigation has wetted the soil surface and temporary increases the total evapotranspiration. These wet soil evaporation spikes decrease as the soil surface layer dries. The spikes generally reach a maximum value depending on climate, the

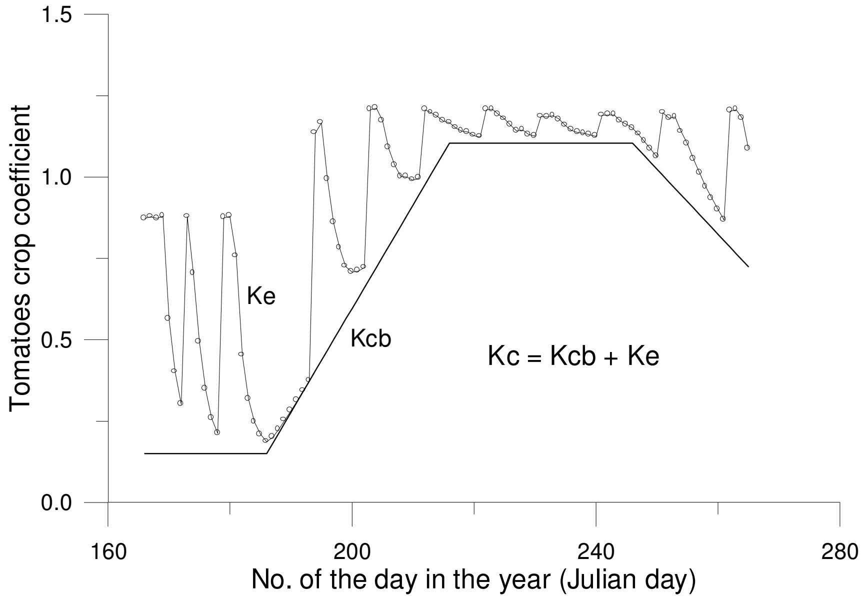

Fig. 1: Dual crop coefficient of tomatoes along the growing season when irrigation was applied by water balance and Penman-Monteith.

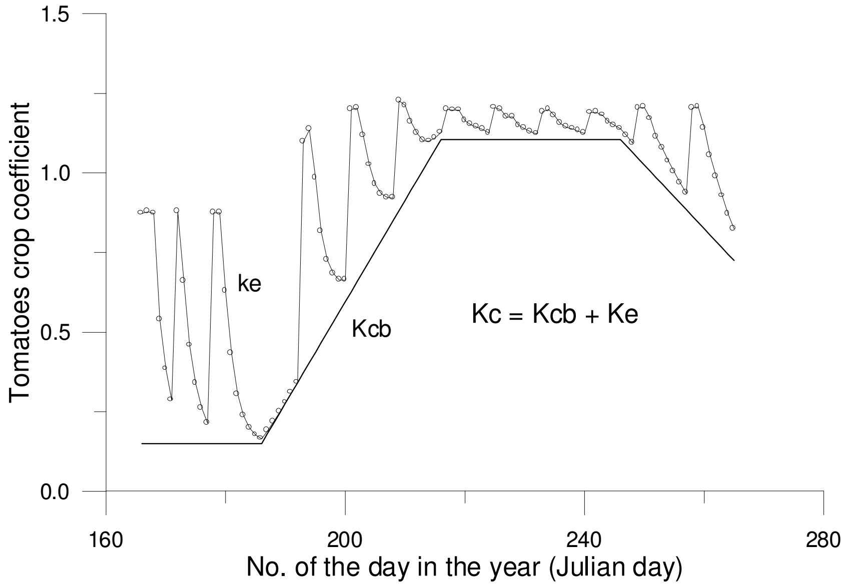

Fig. 2 : Dual crop coefficient of tomatoes along the growing season when irrigation was applied by water balance and evaporation pan.

magnitude of the wetting event and the portion of the soil wetted surface. Summed together, the value of *Kcb* and *Ke* represent the single crop coefficient, Kc that illustrates the effect of averaging *Kcb* +*Ke* over time.

The values of *Kc* at initial and development stages varied considerably on a daily basis, depending on the frequency of wetting by irrigation. The largest difference between *Kc* and *Kcb* is found in the initial stage where the evapotranspiration is predominantly in the form of soil evaporation and crop transpiration is still small. Because crop canopies are near or at full cover during the mid-season stage, soil evaporation beneath the canopy has less effect on the crop evapotranspiration and the value of *Kcb* in the mid-season stage will be nearly the same as *Kc*.

Irrigation scheduling of tomato:

The irrigation applied water to tomato crop and dates of application according to the scheduling methods along the growing season are presented in Tab. (1). The results reveal that seasonal irrigation water requirements were 582, 557 and 507 mm for tensiometer, water balance by evaporation pan and water balance by Penman-Monteith respectively. The irrigation was applied throughout 12, 13 and 12 irrigations for the same previous order.

Pattern of water depletion from the soil along the growing season due to tomato water use and irrigation amount and intervals to replenish the root zone to field capacity is presented in Fig (3) and Fig (4) when water balance was progressed by Penman-Monteith and evaporation pan respectively. A threshold value of both soil field capacity and readily available water in soil in addition to net depth of irrigation all expressed in mm. Superimposed in the graphs that daily water depletion from the soil is resulting from crop water use. The concept of irrigation management by scheduling requires that water to be applied when the moisture depletion level is larger than the allowable soil water.

Table (1):Irrigation dates and applied water by the scheduling methods of tomato.

The scheduling method					
Tensiometer		Water balance			
		Evaporation Pan		Penman-Monteith	
Irrigation date	Applied water mm/irrigation	Irrigation date	Applied water mm/irrigation	Irrigation date	Applied water mm/irrigation
166	40.00	166	40.00	166	40.00
182	39.10	168	9.11	169	9.41
193	42.13	172	10.66	173	11.24
201	42.16	178	14.76	179	15.69
208	44.50	193	31.61	194	32.99
215	43.10	201	41.09	203	44.40
220	43.86	209	50.98	212	53.72
225	45.00	217	57.38	222	59.46
231	53.02	225	60.07	231	60.04
238	58.60	233	60.12	241	60.05
248	63.56	241	60.12	251	60.08
259	67.60	249	60.12	262	60.16
-	-	258	60.12	-	-
Total	582 mm		557 mm		507 mm

Yield and Water Utilization Efficiency:

The mature fruits of tomato were picked from all plants within each plot twice a week during the last two weeks of the growing season. On the last harvest, all the remaining fruits including pink and green fruits were harvested. The yield and water utilization efficiency of tomato as affected by the irrigation scheduling methods are presented in Tab. (2). The mean averages of irrigation water applied to tomato due to the scheduling methods were 2445 m^3/fed, 2340 m^3/fed, and 2130 m^3/fed for tensiometer, evaporation pan, and penman-Monteith respectively.

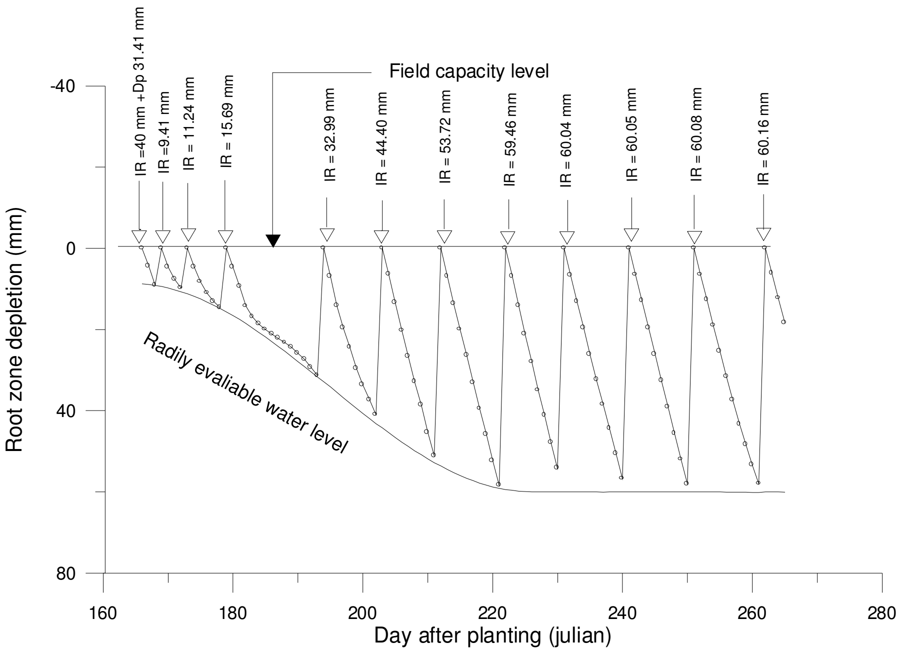

Fig. 3: Water depletion pattern along the growing season of tomatoes by Penman-Monteith.

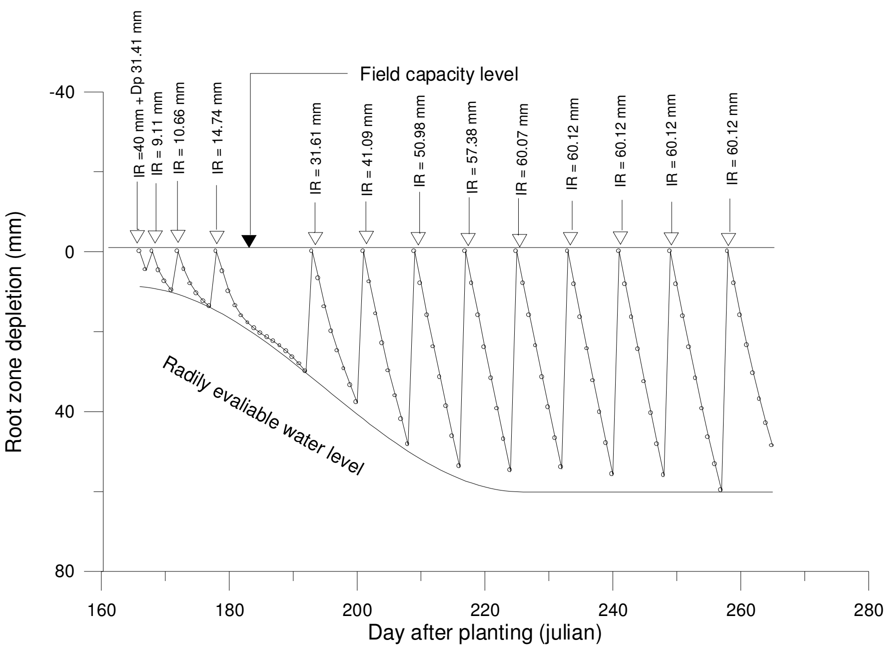

Fig. 4 : Water depletion pattern along the growing season of tomatoes by evaporation pan.

Statistically, significant differences were found due to the scheduling method. Mathematically, the irrigation applied water decreased by 4.3% when the evaporation pan was used relative to the tensiometer method. Meanwhile, 12.88% decrease was found by Penman-Monteith. The yield of fresh tomato due to these irrigation scheduling methods were 24.192, 26.751, and 27.667 ton/fed. for Penman-Montieth, evaporation pan, and tensiometer, respectively. Significant differences in yield were found. Reduction in yield due to use evaporation pan relative to the tensiometer treatment was 3.31%, for Penman-Momteith was 12.56%. The water utilization efficiencies were found as 11.32. 11.44, and 11.36% for tensiometer, evaporation pan, and penman-Monteith respectively. No significant differences were found in water utilization efficiency due to the irrigation scheduling method as indicated in Tab. (2).

Tab. (2) Water utilization efficiency of tomatoes as effected by the scheduling method.

Scheduling method	Total yield ton/fed.	Irrigation water m^3/fed	Water utilization efficiency kg/ m^3
Tensiometer	27.667 a	2245 a	11.32 a
Evapo. Pan	26.751 b	2340 b	11.44 a
Penman-Montieth	24.192 c	2130 c	11.36 a

$L.S.D_{0.05}$ = 0.351 for yield $L.S.D_{0.05}$ = 80.5 for water $L.S.D_{0.05}$ = 0.703 for WUE

CONCLUSION

From the obtained results it could be concluded that:

- Tomatoes actual consumptive use of water under the field experimental circumstances according the following soil matric potential between 0.2 and 0.5 bar along the growing season was 582 mm (2445 m^3/fed). The resulted yield was 27.7 ton/fed. The irrigation scheduling by tensiometers indicated that irrigation water was added throughout 12 irrigations along the season. The water utilization efficiency was 11.32 kg of fresh fruit of tomato per cubic meter of water.

- Irrigation water applied by water balance used Penman-Monteith to schedule the irrigation of tomato along the growing season was about 507 mm (2130 m^3/fed.). The resulted yield was 24.19 ton/fed. and water utilization efficiency was 11.36 kg/m^3. Irrigation water added throughout 12 irrigations.
- Scheduling the irrigation by water balance used the evaporation pan to determine the tomato evapotranspiration indicated that irrigation water should be applied throughout 13 irrigation with total amount of 557 mm/season (2340 m^3/fed). The resulted yield was 26.75 ton/fed.. The water utilization efficiency was 11.44 kg/m^3.
- The irrigation scheduling methods indicated significant effect on both yield and irrigation applied water. Insignificant effect on water utilization efficiency was found.

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الملخص العربى

إدارة المياه وجدولة الرى لمحصول الطماطم عن طريق الاتزان المائي

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نفذت لهذا الغرض تجربة حقلية لجدولة الرى لمحصول الطماطم (صنف كاسيل روك) فى ارض طينية بمزرعة كلية الزراعة سابا باشا، لتقدير كميات مياه الرى المطلوبة ومواعيد إضافتها بناء على التوازن المائي فى التربة لتعويض الفقد المائي عند حدود الماء السهل المتيسر. ولحساب معامل محصول الطماطم اليومي تم فصل الجزء الخاص بالبخر من

التربة والجزء الناتج من نتح النبات لاستنتاج معامل المحصول المزدوج المستخدم فى إجراء الاتزان المائي. واستخدمت طريقة بنمان مونتث وطريقة وعاء البخر القياسي فى تقدير البخر نتح اليومي. كما تم تقدير الاستهلاك المائي الفعلي عن طريق متابعة الشد الرطوبى اليومي للتربة بواسطة أجهزة قياس الشد الرطوبى (التنشومترات). وتم تنفيذ التجربة باستخدام طريقة القطاعات العشوائية الكاملة مع استخدام ثلاثة مكررات.
ويمكن تلخيص أهم النتائج المتحصل عليها فى النقاط التالية:

- الاستهلاك الفعلي لمحصول الطماطم تحت ظروف إجراء التجربة بواسطة استخدام أجهزة الشد الرطوبى طوال موسم النمو تقدر بحوالي ٥٨٢ مم (٢٤٤٥ م^{٣}/فدان)، بناتج إجمالي لمحصول الطماطم حوالي ٢٧,٧ طن/فدان وبكفاءة استخدام للمياه ١١,٣٢ كج/م^{٣}. و أضيفت كميات مياه الري من خلال ١٢ ريه على طول موسم النمو.
- كميات مياه الري المضافة بواسطة الاتزان المائى عند استخدام وعاء البخر القياسى بلغت ٥٥٧ مم/موسم (٢٣٤٠ م^{٣}/فدان) أضيفت خلال ١٣ ريه بناتج إجمالي لمحصول الطماطم بلغ ٢٥,٧٥ طن/فدان وبكفاءة استخدام للمياه مقدارها ١١,٤٤ كج/م^{٣}.
- كميات مياه الري المضافة بواسطة الاتزان المائي عند استخدام طريقة بنمان مونتث بلغت ٥٠٧ مم/موسم (٢١٣٠ م^{٣}/فدان) أضيفت خلال ١٢رية بناتج إجمالي لمحصول الطماطم بلغ ٢٤,١٩ طن/فدان وبكفاءة استخدام للمياه مقدارها ١١,٣٦كج/م^{٣}.
- هناك تأثير معنوي لمعاملات الجدولة المختلفة على كل من إنتاجية محصول الطماطم وكميات مياه الري المضافة بعكس كفاءة استخدام المياه.