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Determination of water requirement, single and dual crop coefficient of garlic (*Allium sativum*) in the cold semi-arid climate

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Abstract

The purpose of this study was to determine the water requirement, single and dual crop coefficient of garlic using a drainage lysimeter. The lysimeter experiments were conducted during 2008–2009. According to the experimental results, garlic water requirements (ET_C) in this period were 546.5 mm and 519.2 mm, respectively, during the growing season. A reference evapotranspiration (ET_0) was simulated with artificial neural network (ANN) method during garlic growth season. Results showed that crop coefficient value (K_C) in initial and final stages were 0.53, 1.4 and 0.3, respectively. The results were compared to the single and dual crop coefficients from the FAO-56 procedure. Results showed that maximum differences between ET_C of single and dual K_C values were observed at initial and final stages. Also, this study showed that dual crop coefficient is more precise (RMSE= 38%) but the advantage of single crop coefficient is simpler for a user.

Keywords*:* Garlic evapotranspiration, Lysimeter, ANN, Single crop coefficient, Dual crop coefficient, Hamedan.

Abbreviations :
ET_C= garlic water requirements, mmd^{-1}
ET_0= reference evapotranspiration, mmd^{-1}
K_C= crop coefficient
ANN= artificial neural network
K_e= soil evaporation coefficient
K_{eb} = crop base coefficient

Introduction

The determination of crop coefficients (species factor) and evapotranspiration are important for estimating irrigation water requirements in order to have better irrigation scheduling and water management (Mostafazadeh-Fard et al., 2009). Garlic (Allium sativum) is a crop which grows well in regions with a cool climate. Total cultivation area of garlic in the world and Iran is 980000 ha and 4900 ha, respectively (Fabeiro et al., 2003 and FAO, 2004). The first reported information for garlic crop coefficient in maximum growth period was by Allen et al. (1998) and Fabeiro et al. (2003) which was a value of 1 in both initial and middle stages. In addition, Villalobos et al. (2004) reported the maximum KC of 1.2-1.3 for garlic crop and total crop water requirements of 470 (mm). In the study of Ayars (2007), Peak crop coefficient (KC) value was estimated in the range of 1.3 to 1.4. Hanson et al. (2003) reported that garlic is a sensitive crop to water deficiencies. Fabeiro et al. (2003) indicated that in the final and middle stages of growth, garlic is sensitive to water deficiency and low irrigation was unsuitable in these stages. KC can be utilized as single KC which is influenced by moderate effect of evaporation and transpiration together (Allen, 2000). Dual KC is expressed by soil evaporation coefficient (Ke) and crop base coefficient (Keb), separately (FAO-56). According to Allen (2000), using single crop coefficient is simpler. Furthermore, Suleiman et al. (2007) reported that using single KC for cotton crop estimation in humid regions is reasonable. KC of some crops has been suggested by Allen et al. (1998). These researchers suggested KC can be used in all weather conditions where no experimental data are available. According to Allen et al. (2005) nonconformity of crop and climate characteristics are engendered to inconclusiveness in KC and ET reluctant in any place in the world. Although, in estimation of crop water requirement, suggested coefficients were used, but there are differences in amount and calculation methods of KC between various crops. With measurement of melon evapotranspiration, Lovelli et al. (2005) showed that the experimental KC was less than the KC suggested by FAO-56. Pruitt and Snyder (1985) and Snyder et al. (1987) reported 1.19 and 1.12-1.16 as the maximum KC for tomato crop, respectively. Allen et al. (1998) reported single and basic KC of tomato as 1.15 and 1.1, respectively. Lopez-Urrea et al. (2009) determined water requirement of onion crop by using single and dual KC and ET0 PM56 methods. Their results showed that dual KC values were lower than the real value that can be improved with adjustment of dual crop coefficient. Bodner et al. (2007) evaluated dual KC of rye, mustard, vetch and phacelia and indicated that dual KC in arid region had rational results. Benli et al. (2006), based on lysimeter method, reported KC of alfalfa in initial, middle and final growth stage to be 0.71, 1.78 and 1.51. Observantly, various values of garlic KC in various sources were reported in spite of ancient acquaintance of garlic sowing in Iran, there is no reported water requirement and crop coefficient for garlic crop. Most regions of Iran are located in arid and semi-arid climate (Sarmadian et al., 2010). No study has been reported about evapotranspiration, single and dual crop coefficients of garlic in Iran. Hamedan is located in cold semi arid climate of Iran and is the biggest producer of garlic in the country. The main objectives of this study were: (1) determining the water requirement of garlic and (2) determining (single & dual) crop coefficient of garlic.

Results and Discussion

Table 1 showed that the maximum, minimum and average meteorological parameters in 2009, which are effective for ET_C during garlic growth seasons, were lower than in 2008. Air temperature and sunshine hours were decreased and relative humidity was increased. Also, implicitly average of precipitation in 2008 and 2009 were 22.4 and 138.2, respectively. Therefore, according to Table 1, ET_C reduction in 2009 compared to 2008 is reasonable. Experimental ET_C by lysimeter and predicted ET_0 by ANN were plotted in Fig 2. The difference between ET_C and ET_0 during initial and final stage of garlic growth season proved that ET_0 increased more than ET_C but in middle stages, ET_C increased more than ET_0. Due to increased LAI in the middle stage, the computed values of ET_C were more than ET_0. This result is similar to the previous study on tomatoes (Hanson and May, 2006). LAI during the growing season of garlic crop decreased rapidly late in the middle stage due to the senescence of large leaves located in the middle positions of the plant, which was caused by an unknown disease of bacterial origin according to a preliminary pathological study (Rizzalli et al., 2002) . Based on Figure 2, ET_C decreased in second year, therefore garlic water requirement in first and second years were 546.45 mm and 519.2 mm, respectively. In study of Santos et al. (2010), garlic water requirement irrigation was 349 mm for Spain with Mediterranean climate. Since water requirement irrigation depends on type of climate. ET_C value in this study has been confirmed. With regard to variation of climatically condition (Table 1), especially the precipitation during crop growth, decrease in ET_C is logical. Similar results about garlic were reported by Villalobos et al. (2004) and Fabeiro et al. (2003). Their obtained values for ET_C were lower than the values in this study, probably due to various climatic conditions, physiological differences of garlic varieties and non performance water stress. Average value of real K_C (Eq. 3) for two consequent years and the 4-stage linear K_C values from data measured by the lysimeter in growth days were calculated and plotted in Figure (3). Linear K_C in each stage was calculated via averaging method. Crop coefficient values of garlic (Fig. 2) at the initial and final development stages were 0.5 and 1.4, respectively. These values were constant at the middle stages and decreased to 0.3 at the final stage. Ayars (2007) reported the maximum and minimum values of K_C for garlic, 1.4 and 1.3, respectively. This value was reported as 1 by Fabeiro et al. (2003). This difference was related to study region (Mediterranean climate) and various irrigation methods. These researchers carried out the experiments under controlled deficit irrigation but in the present study there was no water stress. Single and dual K_C disk manual of FAO-56 are presented in Fig 4. The results indicated that soil evaporation coefficient during garlic growth season decreased because of increase in ground cover (Fig. 4). The dual crop coefficient was higher than single K_C in initial and middle stages, However, at the end of growth season, the dual K_C decreased (Fig. 4). Also at this stage, the dual K_C decreased more than single K_C, due to increase in irrigation period (because of destructive effect on crop) and drying soil surface. It may be because of the complicated physiological conditions at the final stage. Also, Fig. 4 showed that the garlic K_{cb} is 0.93. In study of Bryla et al. (2010) the K_{cb} was obtained 1.0 for central California with Mediterranean-like climate. These results are similar to Bryla et al. (2010) study about different climate. The ET_C was calculated by multiplying the single and dual K_C in ET_0. Percent of root mean square errors and K_C are presented in Fig 5. With regard to the obtained statistical indices (RMSE= 0.38 %, R^2=0.6), the dual crop coefficient has more precision (Fig. 5). But, application of single K_C is simpler. Distribution of estimated ET_C by all methods is depicted in Fig. 6. Maximum differences between ET_C of single and dual K_C values were observed at the initial and final stages. At the initial growth stage, evaporation from soil surface was higher than the transpiration from crop. Therefore the highest value of dual ET_C was obtained in this stage. During the final stage, the difference between single ET_C and dual ET_C was significant. This may be due to garlic physiology and irrigation period.

Table 1. The daily averaged weather data for the study site

Data set	Unit	2008			2009		
		Mean	Max	Min	Mean	Max	Min
Tmax	^{o}c	25.62	36.6	13.8	22.3	37.4	5.7
Tmin	^{o}c	7.97	16.6	-1.4	6.1	17.3	-6
RHmax	%	52.93	97	24	68.8	99	27
RHmin	%	20.96	60	10.2	30.3	88	12
U	ms^{-1}	3.1	11.6	0	1.7	6.7	0
n	hour	9.68	13.5	0	8.6	13.6	0
ET_C	mmd^{-1}	5.3	11.22	0.1	4.3	8.46	0.1

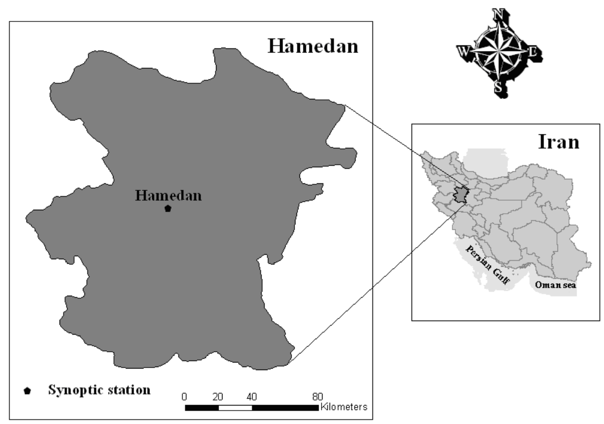

Fig 1. Location of study

Materials and methods

Study area

This study was performed during 2008–2009 in four separate lysimeters in the meteorological station of agricultural faculty

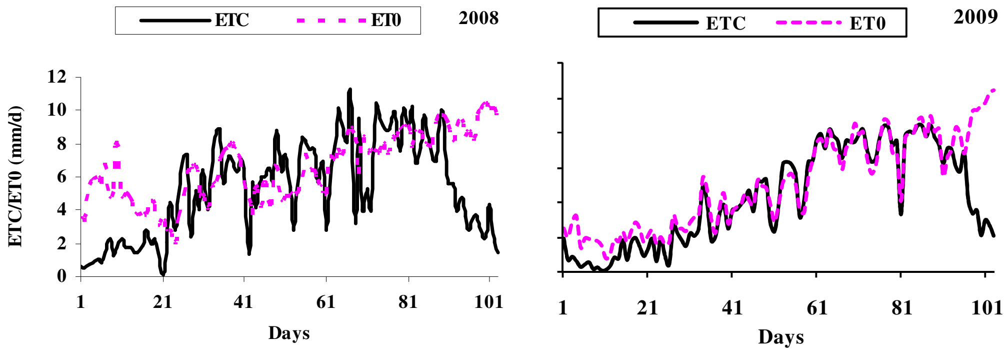

Fig 2. Scatters of reference evapotranspiration (ET_0) and crop evapotranspiration (ET_C) for garlic in 2008, 2009 years

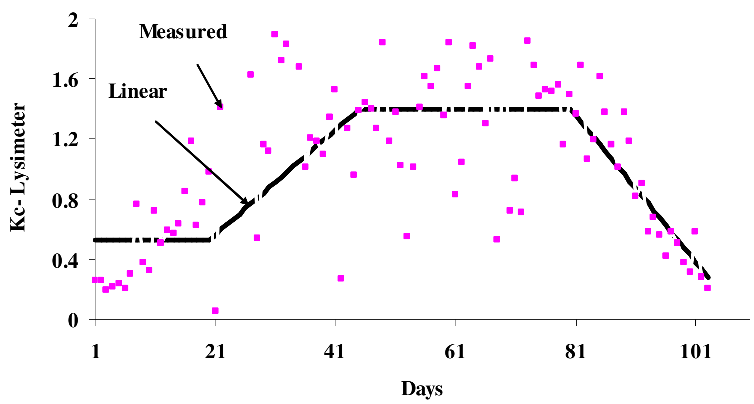

Fig 3. Daily actual crop coefficient (*Kc*) values and the 4-stage linear *Kc* values for Garlic derived from data measured by the lysimeter

of Bu-Ali Sina University, Hamedan, Iran (Fig. 1) (Lat. 34°, 48', long. 48°, 28', M.s.l. 1820 m).

Garlic evapotranspiration estimation method

The lysimeters dimensions were 2 m (depth) × 2 m (width) × 2 m (length) and textures of lysimeter soil were sandy clay, clay loamy, sandy clay loamy. The garlic variety was planted to a depth of 10 cm with a space of 20 cm between rows and 10 cm between plants. Garlic crop planting dates were November 2007 and 2008. In order to increase in plant growth, 37.5 t/h of sheep persistent manure was used. Soil phosphorus concentration in 30 cm depth was constant (20 mg/kg), therefore no additional phosphorus fertilizer was required. Weeding was carried out internally. Irrigation operation was carried out after germination on Mar 20th 2008 and Mar 20th 2009. Garlic harvest date was June 30th 2008 and 2009 (The total growth period of garlic was 103 days). The soil moisture of lysimeters was measured by an ohmmeter device with gypsum block. Management allowed depletion took into account 50%. Drainage water from lysimeter was measured by graduated cylinder and ET_C was measured by water balance equations (Eq. 1). For water use studies, the mass balance for the drainage lysimeter was employed (Shukla et al., 2007).

Reference evapotranspiration estimation method

The Artificial Neural Network (ANN) gives estimations of the mechanization indicators using limited data available from the target region, without the need to calculate them directly, which would require more data (Zangeneh et al., 2010). According to Ghasemi (2008) in Hamedan and most researchers in other regions (Kisi, 2006, Kumar et al., 2008, Moghaddamnia et al., 2009), ANN is the most appropriate method for reference evapotranspiration estimating. Therefore, The ET_0 was simulated with ANN method during garlic growth season. The crop coefficient estimation methods of actual K_C was estimated by Eq. 2:

$$\frac{ET_C}{ET_0} = K_C \tag{2}$$

In FAO-56, two forms of K_C are presented: the single and dual K_C forms (K_{Cb} and K_e, *respectively*). Single crop coefficient by FAO-56 method was determined using Eq. 3:

$$K_C = K_C\,(table) + [0.04(U_2 - 2) - 0.004(RH_{min} - 45)]\,[h/3]^{0.3} \tag{3}$$

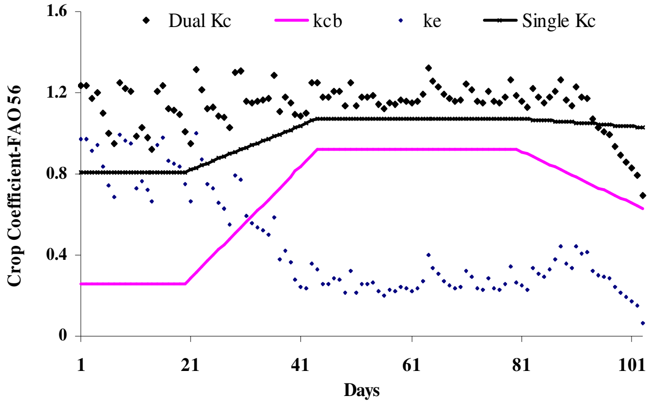

Fig 4. Single and dual K_C on base of FAO-56 method

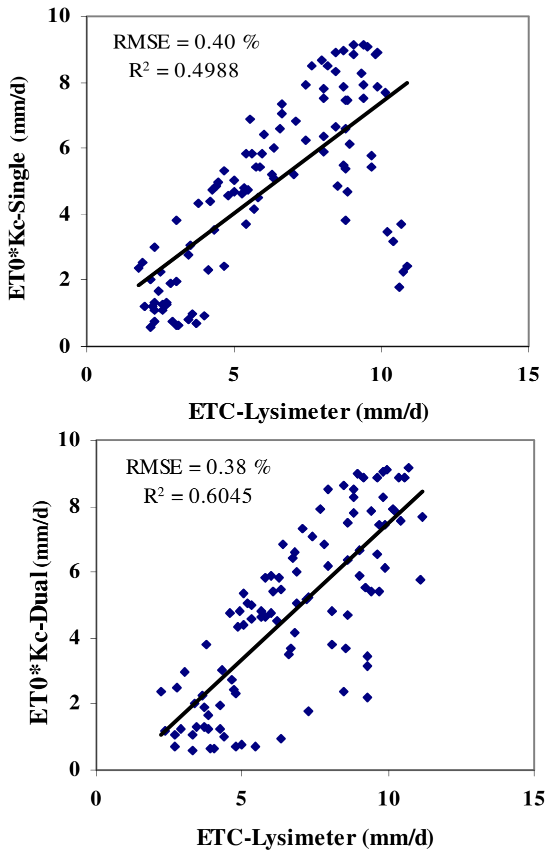

Fig 5. Comparison of the estimated ET_C (single and dual K_C) with the experimental lysimeter ET_C.

K_C *(table)* presented in table of FAO-56 manual, U_2 average wind speed in final period of growth (m/s), RH_{min} average of minimum relative humidity in final stage of growth (%) and h height of plant (m). Dual crop coefficient can present the effects of transpiration from the crop and evaporation from the soil separately (Eq. 4).

$$K_C = K_{Cb} + K_e \quad (4)$$

K_{Cb}: effect of transpiration from the crop (basic K_C) K_e: effect of evaporation from the soil (soil evaporation coefficient).

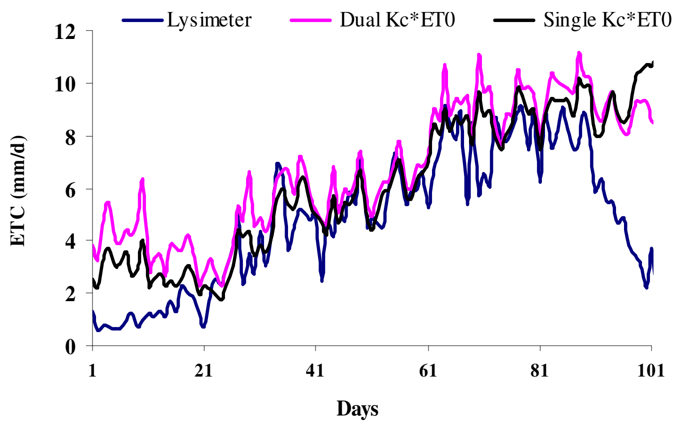

Fig 6. Daily ET_C variations derived from different methods (lysimeter, dual K_C, single K_C)

Basic K_C and single K_C from equation (5) and soil evaporation coefficient from equation (6) can calculate:

$$K_{Cb} = K_{cb}\,(table) + [0.04(U_2 - 2) - 0.004(RH_{min} - 45)]\,[h/3]^{0.3} \quad (5)$$

$$K_e = \min\{k_r\,(k_{Cmax}\,k_{Cb}),\ few.k_{Cmax}\} \quad (6)$$

K_{Cmax}: maximum of crop coefficient after irrigation or precipitation, K_r: oefficient of decreased evaporation from soil surface depends on cumulative water depth exhausts from soil surface; *few*: portions of soil surface which has maximum evaporation. For further details interested readers are referred to Allen (2000).

Conclusions

The following conclusions can be drawn from the experiments: 1- The ET_C of garlic for a semi-arid region were 546.5 mm and 519.2 mm during the growth season in 2008 and 2009, respectively. 2- The two-year averages of ET_C and K_C showed that the maximum daily garlic crop evapotranspiration and the maximum K_C was 9.84 mm/d and 1.4, respectively. 3- Using the FAO-56 single and dual crop coefficient method for estimating evapotranspiration of garlic showed that dual K_C was more accurate than single K_C (RMSE= 38%). These results can be useful for agricultural planning and efficient management of irrigation for cultivation of garlic in semi-arid climates.

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