African Journal of Agricultural Research Vol. 7(19), pp. 2971-2977, 19 May, 2012
Available online at http://www.academicjournals.org/AJAR
DOI: 10.5897/AJAR11.1135
ISSN 1991-637X

Full Length Research Paper

A study on crop coefficients of jujube under drip-irrigation in Loess Plateau of China

Yongxiang Hu[1], Yuannong Li[1]* and Ying Zhang[2]

[1]Northwest Agriculture and Forest University, Yangling, Sha'anxi 712100, China.
[2]Hebei University of science and technology, Shijiazhuang 050000, China

Accepted 11 January, 2012

Jujube, as a kind of drought-tolerant species with great economic value, is widely grown in Loess Plateau of China. The yield of jujube depends on irrigation, and crop coefficient is the basis for calculating the amount of irrigation. The experimental area was located in Mizhi experimental station in Loess Plateau of China. According to the meteorological data observed by automatic weather station of Mizhi experimental station and using FAO Penman-Montieth equation, we calculated the ET_0 in jujube's growth period; additionally, combined with ET_c of jujubes under sufficient irrigation, we studied the crop coefficient of jujubes under drip-irrigation. This study determined the crop coefficient in each growing period of jujube, and it established a function relationship between crop coefficients, days after sprouting and LAI. The crop coefficient of jujubes from this study provided a scientific basis for the water management of jujubes under drip-irrigation in Loess Plateau of China.

Key words: Drip-irrigation, jujube, crop coefficients.

INTRODUCTION

Saving water is the primary method for solving the current problem of water shortage (Zhong and Zhao, 2000), thus, encouraging the development of water-saving irrigation as a requisite for making full use of water resources (Kang et al., 2003). Drip irrigation has been proved as a kind of mature and effective water-saving irrigation method by experiments, which provides a feasible way to solve that problem (Li et al., 2005). Crop evapo-transpiration is affected by soil condition, irrigation method, crop variety and meteorological elements, and it changes with the status of crop development during the crop growth period (Allen et al., 1998; Peng and Suo, 2004; Zhang et al., 2004). Crop coefficient is a significant parameter for indirect estimation of crop evapo-transpiration, because it can provide various effects on water requirement of crop, for instance, biological characteristics of crops, level of crop yield, conditions of soil tillage etc. (Wright, 1982; Liu and Pereira, 1998; Ma and Jiao, 2006). The purpose of this study is to ascertain the crop coefficient of jujube under drip irrigation in Loess Plateau of China (northern Sha'anxi Province) and the distribution principle of crop coefficient in each growth stage to provide scientific grounds for water management in the cropland.

MATERIALS AND METHODS

Site and experimental design

This experiment is conducted in the experimental station of Loess Plateau Study Institute of Mizhi County, Sha'anxi Province. Mizhi county is located in northern Sha'anxi Province, an eastward region of Yulin City center, about the middle reaches of WuDing River. The geographical location is 37° 39'-38° 5 'N and 109° 49 '~ 110° 29'W, the maximum distance from east to west is 59 km, the distance from south to north is 47 km, the total area is 1212 km^2. Mizhi is an area of arid, semi-arid continental monsoon climate, drought , strong evaporation , and with frequent natural disasters. The annual average temperature is 8.5°C, with extreme maximum temperature of 39.2°C and extreme minimum temperature of -25.5°C; the frost-free period is 162 days. Average annual rainfall is 451.6 mm increasing from northwest to southeast and most frequent in July, August, and September, accounting for 50-60% of annual rainfall. Mizhi is a typical Loess Plateau Irrigation District, because its average annual evaporation is 1574 mm and drought index is 3.8. In this experimental area, the dominant soil is loess soil, bulk

*Corresponding author. E-mail: Liyuannong@163.com. Tel: +86 13468810933.

density is 1300 kg/m^3, and the field capacity of 0 ~ 1 m planning moist soil is 23.2% (mass percentage). The contents of effective N, P, K within the experimental area have been determined, which respectively are 34.73, 2.90 and 101.9 mg in each kilogram; content of soil organic matter is 0.21% and PH value is 8.6.

The selected crops were 7 and 8 year-old jujubes (planting dwarfing and close); the distance between rows was 3 and 2 m between plants. These jujubes were drip-irrigated, growing in an area with a gradient of 25/100. This experiment designed a treatment that set minimal water content of 0 to 1 m depth soil as 65% of the field capacity, and irrigation began when water content of the planned moist soil reached the minimum. The irrigation quota was 0.018 m^3 in each square meter controlled by the water meter in the head of the capillary, that is, this experiment was under sufficient water-supply condition. This treatment was settled with three replicates and each replicate involved three jujube trees. All jujube trees were enclosed by 2 × 2 × 1.6 m PVC bottomless boxes; burial depth of these boxes was 1.5 m. The drip line was distributed as one pipeline irrigated one row of jujube (one treatment with three replicates). At both left and right sides, about 0.3 m of the jujube tree trunk set drip irrigation emitters whose flow rate was 4 L/h, and all the emitters were compensatory drip emitters. Each treatment was with same pruning, fertilization and pest control measures being implemented by local farmers on time.

Observation projects

This experiment was required to determine meteorological factors, soil water and physiological indexes, specifically including the following steps: using Diviner 2000 to determine soil water content of 0 to 1 m depth every 10 days and additionally determining it before and after irrigation (checking by oven drying method); using method of water balance to calculate ET_c (crop evapotranspiration) based on the consecutive two times measurement of soil water content of root layers and quantity of irrigation and rainfall data, thus to calculate the ET_c in each growing stage. New tips were measured by ruler, and three equally growing tips of each tree were chosen to be measured; single leaf area was calculated by method of length x width every 10 to 15 days; the yields of these irrigated jujubes are the average yields of three repeated experiments. Meteorological factors like wind speed, temperature, humidity, solar radiation, etc. were recorded by automatic weather station.

Equation of reference crop evapotranspiration and crop coefficient

The crop evapotranspiration is related to weather conditions, soil water, crop type, growth stage, measures of agricultural technology, irrigation and drainage measures. These factors had independent existence other than intricately interactions. Single crop coefficient recommended in FAO-56 (FAO Irrigation and Drainage Paper No. 56) has three relatively independent factors which were ET_0 (reference crop evapotranspiration), ET_c and K_c (crop coefficient) (Ayars et al., 1999; Zhang and Cai, 2001; Sumner and Jacobs, 2005).

According to meteorological data, Penman-Monteith equation (Equation 1) recommended by FAO (Food and Agriculture Organization of the United Nations) was used to calculate the ET_0 within the growth period (Allen et al., 1989, 1994; Choudhury, 1997):

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

Where

ET_o: reference evapotranspiration [mm day^{-1}],
R_n: net radiation at the crop surface [MJ m^{-2} day^{-1}],
G: soil heat flux density [MJ m^{-2} day^{-1}],
T: mean daily air temperature at 2m height [°C],
u_2: wind speed at 2m height [m s^{-1}],
e_s: saturation vapour pressure [kPa],
e_a: actual vapour pressure [kPa],
e_s - e_a: saturation vapour pressure deficit [kPa],
Δ: slope vapour pressure curve [kPa °C^{-1}],
λ: psychrometric constant [kPa °C^{-1}].

To calculate K_c of jujube, we used the method of single crop coefficient recommended by FAO (Shan, 2003), as in Equation 2:

$$ET_c = K_c\, ET_o \qquad 2$$

Where
ET_0: reference crop evapotranspiration [mm].
ET_c: crop evapotranspiration [mm].
K_c: crop coefficient

RESULTS

Change of ET_0 and soil water content in Jujube's growth period

According to the meteorological data collected by automatic weather stations, FAO Penman-Monteith equation has been used to calculate daily ET_0 in the whole growth period of jujube, and the results are shown in Figure 1. According to Figure 1, the value of ET_0 in the whole growth period of jujube is relatively higher in the middle whereas lower in the two ends. In April, the average ET_0 of month is below 4 mm and only a few high values appear at the end of this month. With the increase of sunshine hours and the intensity of radiation, ET_0 gradually increases. ET_0 of May-June reaches the peak value of the whole growth period, which is value of 6.4 mm. After August, rainfall increases, intensity of solar radiation decreases and the temperature drops, thus the average ET_0 reduces to 3.2 mm or so. There are some smaller ET_0 values affected by cloudy weather or continuous rainfall in 5-8 months.

FAO Penman-Monteith equation contains two parts: radiation part and aerodynamic part which respectively represent the impact of solar radiation and convection, turbulence and degree of drying above the evaporating surface (Qi et al., 2002; Zhao, 2010). The ratio of the two parts is influenced by local geography and climate and shows as a dynamic process over time. Analysis shows that the part of solar radiation occupies more than 60% of total evapotranspiration in the experimental period, and it monthly increases from May to August. From April to August, the proportion of solar radiation increases from the lowest of 58% in April to the top of 89.1% in August, during which the percentages of each month are 58, 60.5, 79, 85.1 and 89.1%, respectively.

(a) Sprout-leaf development period (b) Flowering and fruit-setting period

(c) Fruit development period (d) Fruit mature period

Figure 1. Four growth period of jujube.

That is caused by the increase of sunlight hours and sunlight intensity. In contrast, the percentages of aerodynamic part monthly decline, which are relatively large in April and May. That definitely reflects the locally special climate of frequently strong wind in April and May.

Within the whole growth period, the change of layer-soil water content reflects conditions of the water environment and ET_c. In the drip irrigation condition, the evaporation losses of soil water are less than in the surface irrigation condition (flood irrigation etc), and changes of soil water content indirectly reflect characteristics of the crop water consumption. In Figure 2 and 3, in the flowering and fruit-setting period and fruit development period, jujubes are influenced by climate causing the constant increase of evapotranspiration. The flowering and fruit-setting period is prominent. Due to serious drought before and after this period, evapotranspiration changes dramatically after irrigation. To maintain the minimum of water content of topsoil, circulative irrigation is to compensate the consuming water, thus the minimum of water content of topsoil can remain above 65% of field-held water.

The growth of jujube under sufficient drip-irrigation condition

Growth and development of jujube is mainly reflected by two commonly indicators: the length of new shoots and the index of leaf area. These dynamic processes can help to understand the effect of sufficient drip-irrigation on the growth of jujube and better study the effect and mechanism of irrigation. Table 1 shows that during the experiment, the two indicators of new shoot length and

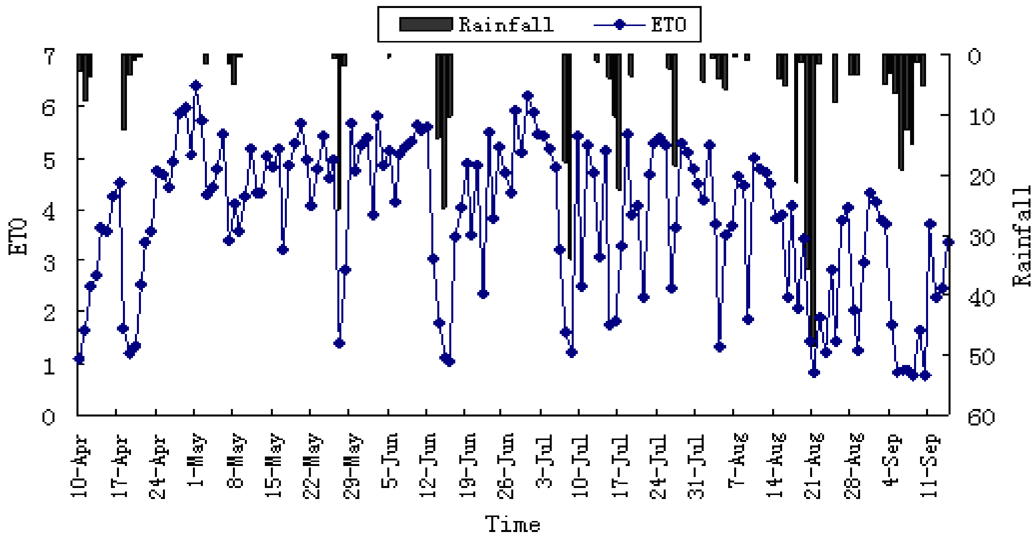

Figure 2. ET_0 and rain during growth period.

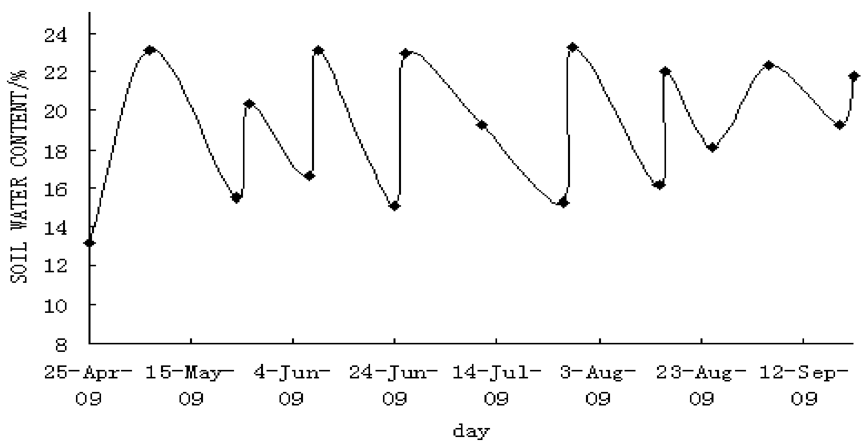

Figure 3. Soil water content in 0-1 m depth.

Table 1. Length of new branch and LAI of Jujube.

Time	April	May	June	July	August	September
LAI	0.0214	0.3266	0.7073	1.0124	1.6452	2.0135
length of new branch(m)	0	0.0987	0.1624	0.2189	0.2567	0.2582

leaf area index are connected. Due to the weather of strong wind and drought in May, the early sprout-leaf development period of jujube has been affected. That is, jujube grows slowly, and values of leaf area index and new shoot length are slightly lower. As the temperature gradually increases, jujubes accelerate their growth stage in the later sprout-leaf development period and flower-fruit period, and these two indicators increase rapidly. Around the pre-expanding period of fruit, new shoot comes into the first stop growth stage and leaf area index also enters the relatively slow growth stage; growth rates of the two indicators are at a lower level. After that, the new shoot enters the secondary growth period; leaf area index also enters the second period of relatively rapid growth rate around the fruit-mature period; new shoot growth rate and leaf area index both come into the stable state and almost reach their peak value. Hereafter, these indicators remain at a high level until the leaf fall period. After October, the

Table 2. Water-consumption regulation and crop coefficient of jujube.

Phonological period	Sprout-leaf development period	Flowering and fruit-setting period	Fruit development period	Fruit mature period	Whole growth period
Date	4.30-5.30	5.31-7.10	7.11-8.28	8.29-9.30	4.30-9.30
Growth days	31	41	49	33	154
ET_0 (mm)	137.41	177.59	177.76	70.13	562.89
ET_c (mm)	68.1	117.4	224.4	66.2	476.1
Water consumption rates (mm/d)	2.197	2.863	4.580	2.006	3.092
Stage modulus of water consumption (%)	14.304	24.659	47.133	13.905	100.000
Crop coefficient (K_c)	0.496	0.681	1.262	0.944	0.846

beginning of picking and leaves falling causes leaf area index to decline.

Water-consumption regulation and crop coefficient of jujube under drip-irrigation

Table 2 shows that using the measured soil water content, irrigation, and data of rainfall, and water-balance equation to calculate ET_c, water consumption rates and stage modulus of water consumption are at different growth stages with drip-irrigation. Additionally, according to that, the crop coefficient (K_c) has been figured out.

As shown in Table 2, the phonological period of jujube in Loess Plateau of Shanbei area lags behind other regions, and the full-growth period lasts for 154 days. Due to the local particular climate conditions, soil, and cultivation, the whole growth period of jujube with drip-irrigation consumes water with 476.1 mm in total, and the water consumption rate is 3.092 mm/d. Within the four phonological periods, the minimum of ET_c appears in the fruit-mature period, the less minimum one appears in sprout-leaf development period; the water consumption rate of crops in flowering and fruit-setting period shows that the water consumption rate of crops in fruit development period is the largest. Therefore, the whole growth period reflects that the water consumption regulation of crop is large in the middle but small in the side and peak value appears relatively later. But atrocious weather of windy and dry is predominated in the sprout-leaf development period, causing the second minimum value of ET_c. The average temperature is relatively low, 17.3°C in sprout-leaf development period. The quantity of rainfall in sprout- leaf development period is only 36.2 mm with a large ineffective proportion leading to large quantity of soil evaporation. Meantime, the gale weather that occurred in the growth period (twice of force 7 wind, once of force 6 wind, sextic of force 5 wind occurred in this period) aggravates this situation. Additionally, within sprout period the sprout is relatively small and tender, LAI is at a low level, the quantity of crop transpiration is small causing the small quantity of ET_c, water consumption rate is 2.187 mm/d; stage modulus of water consumption is 14.304%. When the jujube enters the period of flowering and fruit-setting period, the temperature, LAI, length of new branch and ET_c gradually increase, causing the bloom of jujubes. All these parameters lead to the dramatic increase of ET_c of jujubes; the quantity of rainfall in the growth period, 95.1 mm, mainly occurred in mid-June and early July, which is limited in relieving the soil drought condition, consequently, the irrigation frequency increases and the rate of soil water content changes dramatically. This also causes the increase of jujube's ET_c (water consumption rate is 2.863 mm/ d; stage modulus of water consumption is 24.659%). In fruit-expand period, vegetative and reproductive growth of jujube enters a stage of active growth period, leaf area index reaches the peak value, new shoot also basically reaches the maximum length. The average temperature reaches the maximum, 23.2°C. The quantity of rainfall in the growth period reaches 206.4 mm, which is more moisture than the first two growth periods; however, the physiological action of jujubes is so active that the quantity of crop transpiration becomes the main parameter of ET_c and not the soil evaporation. Therefore, the humid climate does not influence the quantity of ET_c. Correspondingly, ET_c is the highest value of 224.4 mm, water consumption rate is 4.580 mm/d, and stage modulus of water consumption is 47.133%, and crop coefficient also reaches a peak value of 1.262.

Entering the fruit mature period, fruit is ripe, the index of LAI reaches the maximum, and the physiological action of jujube has passed the active stage. However, although the quantity of rainfall in this period is merely 70 mm, the rainfall last for 10 days. Consequently, the average temperature of growth period falls down to 17.9°C. Additionally, the previous growth period is relatively moisture further restraining evaporation. In conclusion, all these parameters cause the decrease of ET_c compared to the previous period. The ET_c in fruit-mature period is relatively small with 66.2 mm, the water consumption rate is 2.006 mm/d, and the stage modulus of water consumption is merely 13.905%, but crop coefficient is 0.944 being affected by the lasting overcast and rainy day during its growth period

Crop evapotranspiration is the fundamental basis for river basin planning, regional water planning and irrigation project planning, design, management and field irrigation and drainage, and it also plays an important role in agriculture. General crop evapotranspiration calculation is as follows: firstly, reference crop evapo-transpiration can be calculated, and then the K_c should be used to work out the value of crop evapotranspiration. In the management of irrigation which requires accurate calculation of crop evapo-transpiration, crop coefficient is significant; the distribution regulation of crop coefficient of each main crop in special areas calculated under geography and weather conditions has become the essential task for relative research on irrigation and crops. According to Table 2, the average K_c for the whole growth period is 0.846 and K_c of the sprout-leaf development period is 0.496 which is the minimum among the four growth periods. That is because in the sprout-leaf development period, the average temperature is merely 17.3°C (the minimum of the four growth periods), the physiological activity of crops is infrequent and ET_c is small. Furthermore, due to the gale and drought weather, ET_0 reaches a big value of 137.41 mm than that in the early mature period; crop evapotranspiration is in large proportion in soil evaporation. Therefore compared to fruit mature period, from the K, the value is clear that crop evapo-transpiration in sprout-leaf development period is larger than that in fruit mature period. That is we candefine the value of the calculated K_c by the minimum among the four growth periods. K_c in flowering and fruit-setting period rose to 0.681, which is the second minimum value among the four growth periods. In the period of flowering and fruit-setting, the physiological activity of jujubes begins to accelerate, especially in the flowering stage. Crops require much water reflected in the large value of ET_c in this period (the second among the four growth periods). Whereas the rainfall is still small, the wind and sand is large, the weather is dry and the temperature is the second highest (22.9°C), all of those causing a relatively high value of ET_0 (177.59 mm) and the value of K_c is only the third one. Crop coefficient of fruit development period is 1.262, which is the maximum. That is, in the fruit development period, the physiological activity of jujubes is violent, average LAI of fruit-expand period is well at high level of roughly 1.6; additionally, the temperature is high, and crop ET_c reaches the highest value of 224.4 among all the growth periods. Meanwhile, the average temperature is the highest (23.2°C) and the sunlight hours continue to lengthen; consequently, ET_0 reaches the largest value of 177.76 mm. Because the value of ET_c is larger than that of ET_0, the calculated value of K_c in this period is the largest among all the growth periods. When entering the fruit mature period, jujube fruit is nearly ripe, and its physiological activity enters the inactive stage. The constant rainy weather and the high moisture cause the low value of ET_c. Also due to the effect of rainy weather, the temperature falls down to 17.9°C and the intensity of solar radiation decreases. Consequently, the ET_0 reaches the minimum value of 70.13 mm among all the growth periods. Simultaneously, K_c falls to 0.944, and K_c takes a downward trend.

As shown in Figure 3, there is a significant quadratic curve relation between crop coefficients of Jujube under drip irrigation and numbers of days after sprout. Correlation coefficient is 0.9024.

The changing of crop coefficient in the growth period is a dynamic process, which proves that there is a relation between crop coefficient and LAI. After jujube sprouting, the increase of transpiration quantity is mainly due to the increase of leaf area. Figure 3 establishes the quadratic curve relation between crop coefficient and leaf area index (LAI), and the data in Figure 3 are of average value. Figure 3 shows that K_c increases simultaneously with LAI, and when LAI reaches its maximum K_c will also do. After that, the trends of these two elements begin to diverge. Potential evapo-transpiration is only affected by the meteorological conditions whereas jujube's evapotranspiration is not only affected by meteorological conditions, but also by crop factor and the interaction between crop and weather factors. The abnormal weather can affect the regulation of crop evapotranspiration. In fruit mature period, the value of K_c was relatively small due to a lasting rainfall (10 days). Therefore, the trend line shows some errors in the later period of time, and correlation coefficient is relatively lower than before (R^2=0.8018).

DISCUSSION

It is a comprehensive and far-flung research process of coefficient of various crops, and most research has focused on the coefficient of common agricultural crops, for instance, research on maize and wheat. However, research on crop coefficients of jujubes (kinds fruit trees) growing in Loess Plateau of China has been rare.

Our results demonstrate jujube's coefficients in each growth period, especially under the irrigation condition, in Loess Plateau of China. Our findings suggest that ET_0, ET_c and K_c of jujube have dramatic divergence with various reasons in different growth periods. The crop coefficient of jujube is affected by specific climatic conditions and is changing through growing time in Loess Plateau, which results in the difference between this coefficient and the crop coefficient set by FAO. Therefore, we purpose that it is necessary to set the crop coefficient of jujube based on locally special weather conditions and experimental data so that the accuracy of irrigation can be improved. Previous studies have demonstrated that the single crop coefficient method can be applied to calculate the ET_0 of apple trees and Alfalfa (Gong et al., 2004; Yang et al., 2008) and to further calculate the crop coefficient K_c; therefore, we employed a similar method to calculate crop coefficient of jujube. The single crop coefficient method employed in this study considers transpiration and evaporation together, which is limited to jujubes with drip-irrigation method. Future studies may use dual crop coefficient method to calculate the crop coefficient. There remains a problem yet to be explored further, that is, to determine the crop coefficient and water stress coefficient of jujube under the condition of deficit irrigation in Loess Plateau of China; the solution of such problem will be a more valuable reference for the production of jujubes.

Conclusion

Within the whole growth period, crop coefficient of jujube under drip-irrigation condition is 0.846. K_c in each growth period is as follows: 0.496 in sprout-leaf development period, 0.681 in flowering and fruit-setting period, 1.262 in fruit development period, and 0.944 in fruit mature period. There is prominently quadratic curve relation between crop coefficients of Jujube, numbers of days after sprout and LAI under sufficient irrigation.

ACKNOWLEDGEMENT

We are grateful for financial support from National Key Technology R and D Program in the 11th five year plan of China (2007BAD88B05).

REFERENCES

Allen RG, Jensen ME, Wright JL, Burman RD (1989). Operational estimates of reference evapotranspiration. Agron. J., 81: 650-662.

Allen RG, Smith M, Perrier A, Pereira LS (1994). An update for the definition of reference evapotranspirafion. ICID Bull., 43(2): 17-23.

Allen RG, Pereira LS, Raes D (1998). Crop evapotranspiration-guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56. Rome: Food and Agriculture Organization of the United Nations.

Ayars JE, Phene CJ, Hutmacher RB, et al (1999). Subsurface drip irrigation of row crops: a review of 15 years of research at the water management research laboratory. Agric. Water Manag. 42(1): 1-27.

Choudhury BJ (1997). Global pattern of potential evaporation calculated from the Penman-Monteith equation using satellite and assimilated data. Remote Sens. Environ., 61(1): 64-81.

Gong DZ, Kang SZ, Zhang JH, YAO LM (2004). Measuring and Estimating Evapotranspiration of an Apple (*Malus pumila* Mill.) Orchard. J. Shenyang Agric. Univ., Z1: 429-431

Kang SZ, Gu BJ, Du TS, Zhang JH (2003). Crop coefficient and ratio of transpiration to evapotranspiration of winter wheat and maize in a semi-humid region. Agric. Water Manag., 59: 239-254.

Liu Y, Pereira LS (1998). Model validation and crop coefficient for irrigation scheduling in the north China plain. Agric. Water Manag. 36(3): 233-242.

Li YN, Liu YJ, Li FH, Fei LJ (2005). Ecological environment effect of irrigation with mulching. Trans. Chin. Soc. Agric. Engine, 21(11): 60-63.

Ma HY, Jiao XY (2006). Research progress of the crop water demand calculation. Water Sci. Eng. Technol. 16(5): 5-7.

Peng SZ, Suo LS (2004). Water requirement model for crop under the condition of water-saving irrigation. J. Hydraulic Engine, 27(1):17-21.

Qi SH, Li ZZ, Gong YS (2002). Evaluating Crop water requirements and Crop coefficients for three vegetables based on Field water budget. J. China Agric. Univ., 7(1): 71-76.

Shan L (2003). Water-Saving Agriculture and of Crop High Efficient Use of Water. J. Henan Univ., (Natural Science). 33(1): 1-5.

Sumner DM, Jacobs JM (2005). Utility of Penman-Monteith, Priestley-Taylor, reference evapotranspiration, and pan evaporation methods to estimate pasture evapotranspiration. J. Hydrol., 308(12): 81-104.

Wright JL (1982). New evapotranspiration Crop coefficients. J. Irrigation Drainage Div. ASCE., 108(2): 57-74.

Yang L, DU TS, Li ZJ, Wang ZC (2008). Growth, Crop Coefficient and Water Use Efficiency on Field-grown Alfalfa under Condition of Regulated Deficit Irrigation. J. Irrigation Drainage, 27(6): 102-105

Zhang ZH, Cai HJ (2001). Effects of regulated deficit irrigation on plastic-mulched cotton. J. Northwest A&F University, (Natural Science Edition). 29(6): 9-12.

Zhang ZH, Cai HJ, Yang RY, Zhao Y (2004). Water requirements and crop coefficients of drip- irrigated crop under mulch in Minqin County Oasis. Trans. CSAE., 20(5): 97-100.

Zhao NN (2010). Calculation of crop coefficient and water consumption of summer maize. J. Hydraulic Engine, 41(8): 953-959.

Zhong ZZ, Zhao JB (2000). Calculation and Analysis on Water Requirements of Major Crops in Northern China. Agric. Meteorol. 21(2): 1-4.