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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Long-term Water Productivity of Maize (*Zea mays* L.) From Limited Irrigation Conditions under Moderate Semi-arid Environment

Abolfazl NASSERİ

Abstract

Crop production has a correlation with the applied water in moderate semi-arid conditions. Due to temperature and rainfall changes enhancing water productivity in crop production are needed for a limited resource conditions. In this study, maize (*Zea mays* L.) yields measured in fields during 11 years from 2005-2006 to 2015-2016 were compared with those simulated by the Agro-ecological Zone method under moderate semi-arid environment located at the north west of Iran with a soil texture of loamy-clay. Different research scenarios involving actual evapotranspirationc (ETa) to potential (ETm) value (ETa/ETm= 100%, 90%, 80%, 70%, 60%, 50% and 40%) under different water application efficiencies (Ea) of 40%, 50%, 60%, 70%, 80%, 90% and 100% were considered in the present study. Research scenarios affected yield and water productivity of maize. To produce potential yield of maize of 10084 kg ha^{-1} under water application efficiency of 100, 90, 80, 70, 60, 50 and 40%, irrigation water requirements were respectively 4683, 5203, 5854, 6690, 7805, 9366, 11708 m^3 ha^{-1} and water productivity were respectively 2.15, 1.94, 1.72, 1.51, 1.29, 1.08, 0.86 kg m^{-3}. Results confirmed that water productivity of maize was from 1.22 to 1.52 kg m^{-3} with an average of 1.38 kg m^{-3} during 11 years under water application efficiency of 68%. Because measured yield ranged from 3800 to 6971 kg ha^{-1} with an average of 5345 kg ha^{-1} and water applied was from 3125 to 4584 and averaged 3836 m^3 ha^{-1}. It is suggested that limited irrigation could be applied to enhance water productivity in maize production under such moderate semi-arid environment.

Keywords: Deficit irrigation, Maize irrigation, Water application efficiency, Water productivity.

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1. Introduction

Maize (*Zea mays* L.) is one of the most important irrigated crop which is cultivated throughout the world and its grain is consumed by human and animal (Güneş and Fatih, 2019). Annual maize production is about 820 million ton over the world (FAO, 2011). Maize yield has positive response to sufficient irrigation water in the field. Its root system is relatively thin, it is therefore sensitive to water insufficiency stress (El-Hendawy et al., 2008). Maize irrigation scheduling depends on rate of root deepening. The rate of root deepening is 25 mm day^{-1} and the effective rooting of this crop reaches to 280 cm at the maturity time (Hsiao et al., 1976). Laboski et al. (1998) reported that about 94% of total maize root length distributed within 60 cm of the soil surface and about 85% of root length was within 30 cm.

Deficit irrigation method is one of the common strategies for producing crops under water deficit and limitation conditions in the arid and semi-arid environments over of the world. Deficit irrigation efficiency in crop production is evaluated by an index known as water productivity (WP) that is crop yield from applying 1 m^3 of irrigation water (Foley et al., 2020; Katerji et al., 2013). This index was considerably applied in crop irrigation researches in irrigated farms (Abadi et al., 2010; Bramley et al., 2013; Du et al., 2010; Fang et al., 2010; Guo et al., 2010; Li et al., 2010; Zhang et al., 2010; Nasseri and Bahramloo, 2009; Nasseri and Fallahi, 2007; Zamani and Nasseri, 2008). This index is defined the as the ratio of crop yield to the crop evapotranspiration or water used in crop production (Nasseri and Fallahi, 2007; Ezenne et al., 2019; Foley et al., 2020). According to the report of Hamdy et al. (2003), increasing WP is an essential priorities in the agricultural production systems under both conditions of irrigated and rainfed production systems. Davis and Hagood (1961) found that the highest water productivity in maize production were attained with an actual evapotranspiration (ETa) lower than the potential rate (ETp) and, the highest water productivity was consequently obtained at 90% of the potential yield (Yp). Foley et al. (2020) reported that enhancing crop yield without application of more water, and/or decreasing irrigation water with sustaining yields are methods to improve water productivity.

Crop yield has a significant correlation with actual evapotranspiration (ETa) and consequently irrigation water. The relation between crop production and irrigation water known as water production function. While, relation between crop production and actual evapotranspiration known as crop water production function (Kipkorir et al., 2002). Previous studies showed that maize yield is a linear function of irrigation water or seasonal evapotranspiration (Gilley et al., 1980; Payero et al., 2006; Klocke et al., 2004; Stone, 2003). According to the Kipkorir et al. (2002) in full and with non-deficit irrigation conditions, water production function in non-linear (a second or third order polynomial) indicating that some of the irrigation water was lost as deep percolation from crop root zone. While for limited irrigation condition, application of crop water production function with linear form is very advantageous and applicable which proposed by Doorenbos and Kassam (1979).

Researches confirmed that in maize production tasseling and silking stages are very sensitive to the water insufficiency stress under semi-arid conditions (Robins and Domingo, 1953; Denmead and Shaw, 1960; Musick and Dusek, 1980; Eck, 1984; Johnson et al., 1987; Rhoades and Bennett, 1990; Lamm et al., 1995). Robins and Domingo (1953) reported that soil moisture depletion to the wilting point at tassel or pollination stages of maize for a week reduced yield as 50% and for one to two days by 22%. Moreover, Denmead and Shaw (1960) explained that moisture deficit stress at silking stage of maize reduced yield 50%, whereas such stress during the vegetative stage and after silking stages decreased yields about 23%. Musick and Dusek (1980) reported that moisture deficit stress during grain filling stage was more injurious than moisture stress during vegetative growth stage in maize production, whereas moisture deficit stress during tasseling and silking to be the most injurious. About two and four weeks of moisture deficit stress during the vegetative stage of maize reduced its yields up to 23 and 46%, respectively (Eck, 1984). Soltanbeigi (2019) reported that the largest damage from water stress was during stages of tasseling and stalking. Also, irrigated maize responded as well to midseason irrigation as it did to more frequent irrigations at 50% soil moisture depletion (Johnson et al., 1987). Limited irrigation strategies generally reduce maize yield according to the findings of Rhoades and Bennett (1990) and Lamm et al., (1995). In this method, crop is irrigated with available water less than potential evapotranspiration (ETp) to obtain optimum yield.

Additionally, Darusman et al. (1997) reported that drip irrigation method resulted in near-potential maize yield and reduced deep percolation losses beneath the root development zone when irrigation and rainfall was totally 75% maize evapotranspiration. Moreover, Norwood (2000) reported that plant population some production inputs management systems such as irrigation and fertilizer significantly increased yields above those of dryland maize. A single irrigation at the tassel stage along with 112 kg N ha^{-1} increased yield with an average of 29%. While, two and three irrigations in combination with increased N rates and plant populations increased yields about 12%. Note that, two irrigation events were applied at the tassel and dough stage of grain fill and three events were at the 9 to 10 leaf stage; and at tassel and dough stage of grain fill of maize production. Limited Irrigation such as every other- furrow irrigation method is one of the effective strategies to save agricultural water, while application efficiency in conventional furrow irrigation is less than every other-furrow irrigation. Research findings show that to produce a similar maize yield, furrow irrigation by every other method with interval of 4 day consumed less water than 7 day interval. In terms of economic analysis the every other method is profitable, as well (Khajeabdollahi and Sepaskhah, 1996).

Water productivity of maize was investigated by researchers over the world under different conditions of irrigation treatments, fertilizers rates and crop populations (Howell et al., 1995; Al-Kaisi and Yin, 2003; Karam et al., 2003; Payero et al., 2008; Katerji et al., 2010; El-Wahed and Ali, 2013; Katerji et al., 2013). But research of WP under unusual conditions for actual evapotranspiration in moderate semi-arid environment was not accomplished. Therefore, the main objectives of this study was to investigate the effect of different ETa/ETm on maize yield and water productivity with different water application efficiencies (Ea) of 40% to 100% under moderate semi-arid environment; and to compare maize yields measured from fields during 11 years from 2005-2006 to 2015-2016 with those simulated by the Agro-ecological Zone method; and to acquire water production function for full and limited irrigation conditions.

2. Materials and methods

2.1. Site description

The present study was conducted on the farms with moderate semi-arid conditions at the north west of Iran with latitude 39º 39’ N, longitude 47º 55’ E and 31.9 m above mean sea level. The region soil was clssified from loamy-clay with wilting point (PWP), field capacity (FC) and acidity (pH) of 16%, 25.4% and 7, respectively to clay-loam with average WP, FC, and pH of 22.36%, 31.51% and 7.2, respectively. Studied region at the north west of Iran is shown by *Figure 1*.

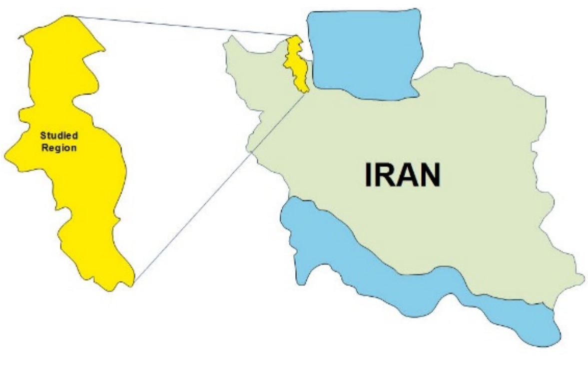

Figure 1. Studied region (Moghan plain) for evaluation of yield and water productivity of maize at the north west of Iran.

Meteorological data such as air temperature and rainfall were obtained from meteorological station located at near of the farms with abovementioned latitude and longitude. The highest and lowest air temperature during the growing seasons of maize ranged from 10 to 30 ºC and 0 to 16 ºC, respectively. Maize evapotranspiration (ETp) was 468 and annual rainfall 277 mm with effective rainfall of 50±7 mm. Based on long-term meteorological data of vapor pressure deficit, wind function and net radiation, reference evapotranspiration (ETo in mm $month^{-1}$) was estimated with Penman’s method under standard conditions for maize production. The potential evapotranspiration (ETp in mm $month^{-1}$) for maize was subsequently acquired by reference evapotranspiration and crop coefficient. Maize yields obtained from farms in the region for 11 years from 2005-2006 to 2015-2016 (Golizadeh et al., 2014). Results were compared with the simulated yields by the methods of Doorenbos and Kassam (1979).

2.2.Study scenarios

Different research scenarios involving actual evapotranspiration to potential value (ETa/ETm= 100%, 90%, 80%, 70%, 60%, 50% and 40 %) under different water application efficiencies (Ea) of 40%, 50%, 60%, 70%, 80%, 90 and 100% were considered in the present study. The potential yield of maize was determined by the Agro-ecological Zone method (Doorenbos and Kassam, 1979). Index of water productivity (WP) from each scenario was subsequently estimated by the following relation. The potential yield of maize was determined by the Agro-ecological Zone method (Doorenbos and Kassam, 1979). Index of water productivity (WP) from each scenario was subsequently estimated by the following relation (Eq.1).

$$WP\ (kg\ m^{-3}) = Maize\ yield\ (kg\ ha^{-1})\ /\ Water\ applied\ (m^3\ ha^{-1}) \qquad (Eq.1)$$

2.3. Maize yield and evapotranspiration relation

Preceding studies showed that maize yield is a linear function of seasonal evapotranspiration (Gilley et al., 1980; Payero et al., 2006; Klocke et al., 2004; Stone, 2003). Also, the linear relationship between relative crop yield (Ya/Ym) and relative maize evapotranspiration (ETa/ETm) as the following relation developed by Doorenbos and Kassam (1979) for the first time. Recently, Süheri et al. (2020) related crop yield to the evapotranspiration (Eq.2):

$$\left(\frac{Ym - Ya}{Ym}\right) = Ky\left(\frac{ETm - ETa}{ETm}\right) \qquad (Eq.2)$$

Where Ya is the actual maize yield (kg ha^{-1}) from ETa (m^3) and Ym is the potential maize yield (kg ha^{-1}) from ETm (m^3); and ETa and ETm are respectively actual and potential maize evapotranspiration during growing season. Moreover, Ky is crop yield response factor that depends on crop growth stage and irrigation management. Ky was 0.40, 0.9, 0.50, 0.2 and 1.25 for vegetative, flowering, yield formation, ripening and total growing stages in maize production (Doorenbos and Kassam, 1979). The Agro-ecological Zone method was applied to simulate maize potential yield for a Moderate semi-arid environment at the north-west of Iran (Doorenbos and Kassam, 1979). Maize variety was Single cross 704 with rooting depth of 20 cm (week 0-4) and 80 cm (week 9-20) which seed planting and end dates were from 1 April to 30 July. Yield was harvest at maturity stage when seed moisture was 11- 13%. Maize farms were irrigated by furrow irrigation system with intervals of 7 days and water application efficiency of 68% (Abbasi et al., 2016).

2.4.Estimation of seasonal potential evapotranspiration (ETm)

The seasonal potential evapotranspiration (ETm in mm) of maize was estimated based on the reference evapotranspiration (ETo in mm) and crop coefficient (Kc) by the following relation (Doorenbos and Kassam, 1979) (Eq.3):

$$ETm = Kc \times ETo \qquad (Eq.3)$$

Crop coefficient (Kc) for maize development stages was 0.35-0.70 (day 0-60), 0.71-1.05 (day 61-90), 1.05-0.60 (day 91-120) at studied region. The reference evapotranspiration (ETo in mm) was estimated by the Penman's method (Penman, 1950; Penman, 1953) (Eq.4):

$$ETo = C \times (W \times Rn + (1-W) \times F(u) \times (ea-ed)) \qquad (Eq.4)$$

where ETo= the reference evapotranspiration in mm day^{-1}; (ea-ed) = vapor pressure deficit i.e. the difference between saturation vapor pressure (ea) at mean air temperature (in mbar) and actual vapor pressure (ed) in mbar where can be estimated by ed= ea× RH/100; F(u) = wind function; Rn=total net radiation in mm day^{-1} and C= adjustment factor .

2.5. Estimation of potential yield of maize

Potential yield (Ymp) of maize was estimated by the following relation known as the Agro-ecological Zone method (Doorenbos and Kassam, 1979) (Eq.5):

Ymp = CL×CN×CH×G×Yo (Eq.5)

where CL= correction for crop development and leaf area, 0.50 for maize; CN= correction for dry matter production, 0.50 for maize; CH= correction for harvested index, 0.40 for maize; G= total growing period (days) which was 150 days at the studied region; Yo = gross dry matter production of standard crop was calculated as (Eq.6):

Yo = F× (0.8 + 0.01×Ym) ×Yo + (1− F) × (0.5 + 0.025 ×Ym) ×Yc (Eq.6)

where Yo = gross dry matter production of standard crop (kg ha^{-1} day^{-1}); F = fraction of the daytime that sky is clouded which was obtained as 0.30 for the studied region and can be obtained from (Eq.7):

F= (Rse-0.5× Rs) / (0.8 ×Rse) (Eq.7)

in which Rse = the maximum active in coming shortwave radiation on clear days in cal cm^{-2} day^{-1}; Rs = the actual measured incoming shortwave radiation in cal cm^{-2} day^{-1}; Yo = gross dry matter production rate of standard crop for a given location on a completely overcast day (kg ha^{-1} day^{-1}); Yc = gross dry matter production rate of standard crop for a given location on a clear (cloudless) in kg ha^{-1} day^{-1}; Ym = maximum leaf gross dry matter production rate of a crop for a given climate (kg ha^{-1} day^{-1}).

3. Results and Discussion

In *Figure 2* crop coefficient and monthly and cumulative potential evapotranspiration of maize during days after seed sowing were depicted. Results showed that crop coefficient for maize varied from 0.35 (0-30 days after seed sowing) to 1.05 (61-90 days after seed sowing). The highest potential evapotranspiration was obtained 193 mm $month^{-1}$ (61-90 days after seed sowing) and cumulative potential evapotranspiration during growing season under mmoderate semi-arid conditions was 468 mm. Also, application of Agro-ecological Zone method produced the potential yield (Ym) of maize as 10084 kg ha^{-1} with net water for irrigation of 4680 m^3 ha^{-1}.

Previous studies demonstrated that maize yield is a linear function of water requirement (Gilley et al., 1980; Payero et al., 2006; Klocke et al., 2004; Stone, 2003). Therefore, in the present study similar to the findings of previous researches, maize yield increased with increasing irrigation water application on the farms and linear water-production function for maize was consequently acquired by plotting irrigation water (mm) on the X-axis and maize yield (kg ha^{-1}) on the Y-axis which is illustrated in *Figure 2* and *3* for furrow irrigation with application efficiency from 100% to 40%. Effective rainfall during maize growing season was not considered in the functions. The best fitting function for water-yield relations were as following *Table 1*.

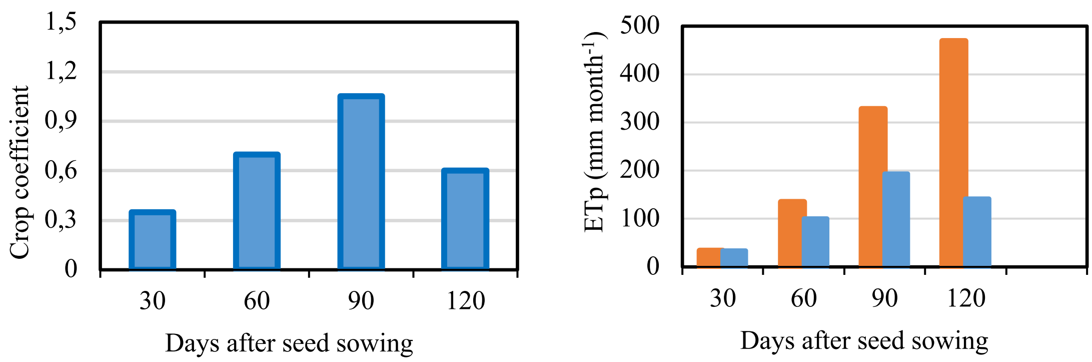

Figure 2. Crop coefficient, monthly and cumulative evapotranspiration of maize during days after seed sowing

Table 1. Water-yield function for maize production under different water application efficiency

Water application efficiency (%)	Yield (kg ha^{-1})=a (Water applied in mm)-b		R^2
	a	b	
Ea=100%	26.917	2521	0.99
Ea=90%	24.225	2521	0.99
Ea=80%	21.533	2521	0.99
Ea=70%	18.842	2521	0.99
Ea=60%	16.150	2521	0.99
Ea=50%	13.458	2521	0.99
Ea=40%	10.767	2521	0.99

To produce potential yield of maize of 10084 kg ha^{-1} under water application efficiency of 100, 90, 80, 70, 60, 50 and 40%, irrigation water requirement was respectively 4683, 5203, 5854, 6690, 7805, 9366, 11708 m^3 ha^{-1}. Therefore, with increasing water application efficiency, irrigation water requirement to produce potential yield was obviously decreased. Consequently, to achieve potential yield, water productivity were respectively 2.15, 1.94, 1.72, 1.51, 1.29, 1.08, 0.86 kg m^{-3} under water application efficiency of 100, 90, 80, 70, 60, 50 and 40% (*Figs. 3* and *4*). Under actual evaporanspiration as 90% potential ones (Eta/ETm=0.90) in order to produce 88% of potential yield of maize (Ya/Ym=0.88 and Ya=8824 kg ha^{-1}), irrigation water requirement (and water productivity) is 10537 (0.84 kg m^{-3}), 8429 (1.05 kg m^{-3}), 7025 (1.26 kg m^{-3}), 6021 (1.47 kg m^{-3}), 5268 (1.67 kg m^{-3}), 4683 (1.88 kg m^{-3}), 4215 (2.09 kg m^{-3}) m^3 ha^{-1} under water application efficiency of 40, 50, 60, 70, 80, 90 and 100%, respectively (*Figs. 3* and *4*). Under actual evaporanspiration as 80% potential ones (Eta/ETm=0.80) in order to produce 75% of potential yield (Ya/Ym=0.75 and Ya=7563 kg ha^{-1}) of maize, irrigation water requirement (and water productivity) is 3746 (2.02 kg m^{-3}), 4163 (1.82 kg m^{-3}), 4683 (1.61 kg m^{-3}), 535.2 (1.41 kg m^{-3}), 6244 (1.21 kg m^{-3}), 7493 (1.01 kg m^{-3}), 9366 (0.81 kg m^{-3}) m^3 ha^{-1} under water application efficiency of 100, 90, 80, 70, 60, 50 and 40%, respectively (*Figs. 3* and *4*).

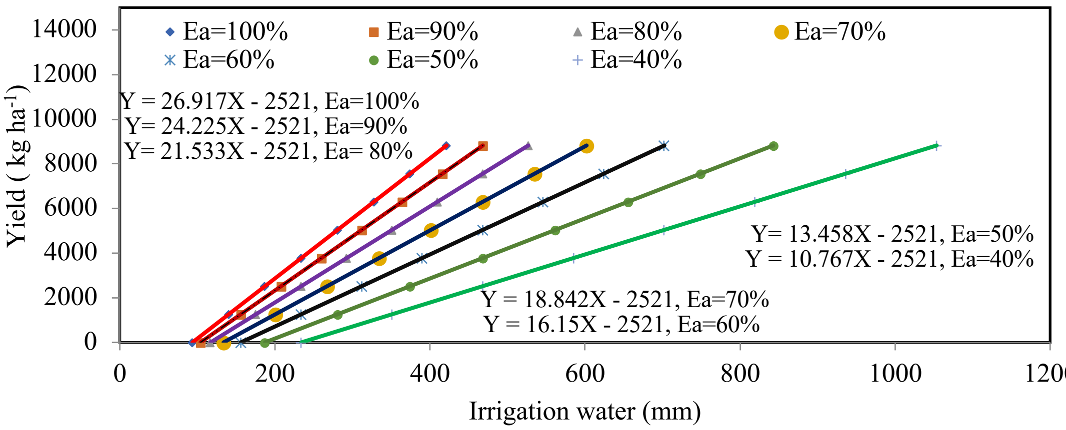

Figure 3. Crop yield versus irrigation water under moderate semi-arid conditions

Under actual evaporanspiration as 70% potential ones (Eta/ETm=0.70) in order to produce 63% of potential yield (Ya/Ym=0.63 and Ya=6302 kg ha^{-1}) of maize, irrigation water requirement (and water productivity) is 3278 (1.92 kg m^{-3}), 3642 (1.73 kg m^{-3}), 4098 (1.54 kg m^{-3}), 4683 (1.35 kg m^{-3}), 5464 (1.15 kg m^{-3}), 6556 (0.96 kg m^{-3}), 8195 (0.77 kg m^{-3}) m^3 ha^{-1} under water application efficiency of 100, 90, 80, 70, 60, 50 and 40%, respectively (*Figs. 3* and *4)*. Under actual evaporanspiration as 60% potential ones (Eta/ETm=0.60) in order to produce 50% of potential yield (Ya/Ym=0.50 and Ya=5042 kg ha^{-1}) of maize, irrigation water requirement (and water productivity) is 7025 (0.72 kg m^{-3}), 5620 (0.90 kg m^{-3}), 4683 (1.08 kg m^{-3}), 4014 (1.26 kg m^{-3}), 3512 (1.44 kg m^{-3}), 3122 (1.61 kg m^{-3}), 2810 (1.79 kg m^{-3}) m^3 ha^{-1} under water application efficiency of 40, 50, 60, 70, 80, 90 and 100%, respectively *(Figs. 3* and *4)*. Under actual evaporanspiration as 50% potential ones (Eta/ETm=0.50) in order to produce 38% of potential yield (Ya/Ym=0.38 and Ya=3782 kg ha^{-1}) of maize, irrigation water requirement (and water productivity) was 2342 m^3 ha^{-1} (1.61 kg m^{-3}) under water application efficiency of 100%. Also, irrigation water requirement (and water productivity) was 2602 (1.45 kg m^{-3}) under water application efficiency of 90%. Moreover, irrigation water requirement (and water productivity) was 2927 (1.29 kg m^{-3}) under water application efficiency of 80%. With water application efficiency of 70%, irrigation water requirement and water productivity were 3345 and 1.13 kg m^{-3}, repectively. Moreover, irrigation water requirement was 3903, 4683 and 5854 m^3 under water application efficiency of 60%, 50% and 40%, respectively. Under these application efficiency, water productivity was 0.97, 0.81 and 0.65 kg m^{-3}, respectively (*Figs. 3* and *4*).

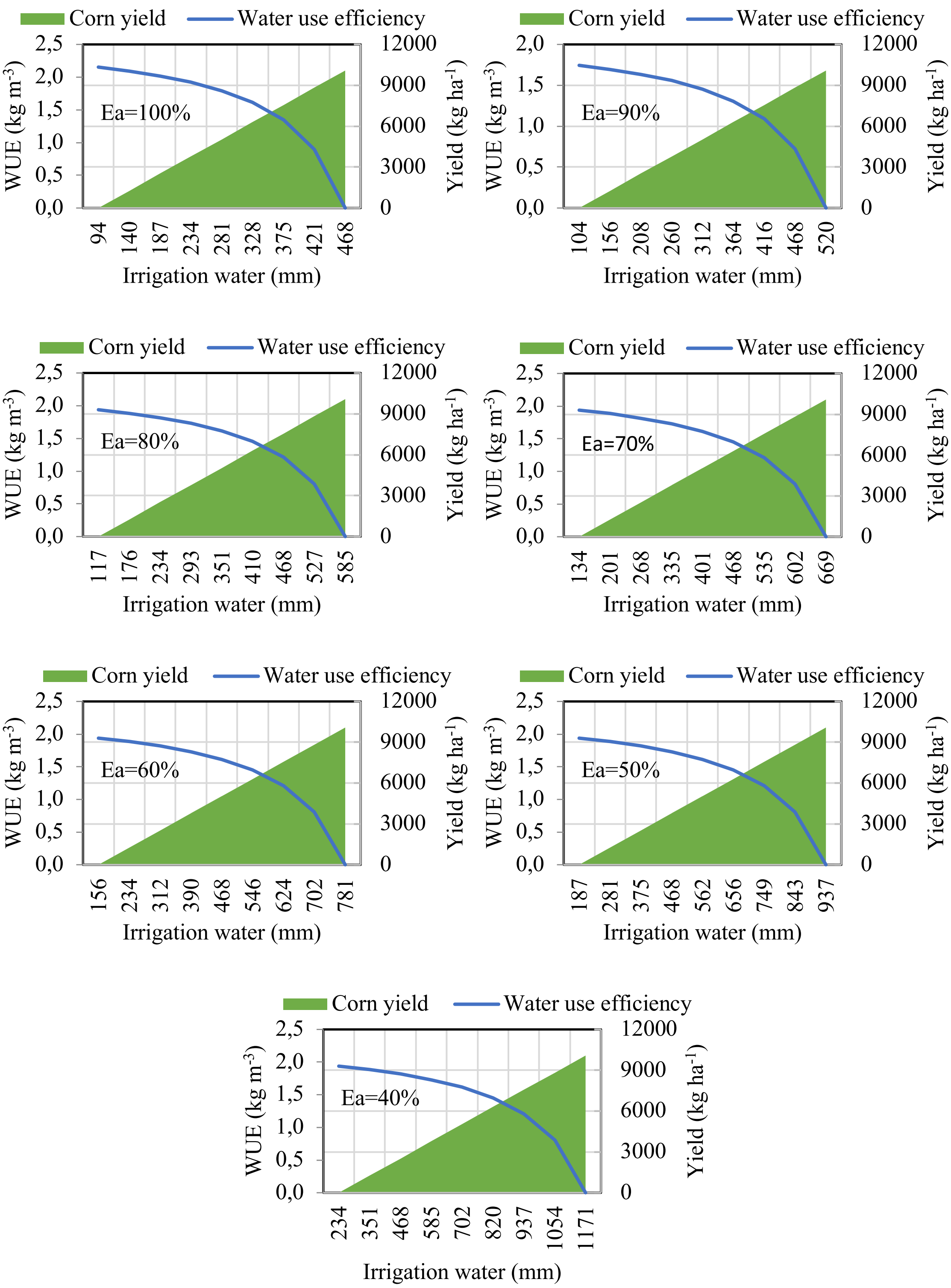

Figure 4. Maize yield and water productivity from irrigation water application under moderate semi-arid conditions

Measured yield, water applied and water productivity of maize during 11 years from 2005-2006 to 2015-2016 under actual and conventional conditions were presented in *Figs 5* and *6*. Results confirmed that measured yield during 11 years ranged from 3800 (in 2007-2008) to 6971 kg ha^{-1} (in 2015-2016) with an averge of 5345 kg ha^{-1}. Note that, water applied to produce maize was from 3125 to 4584 and averaged 3836 m^3 ha^{-1} *(Fiure 5)*. Simliar to the findings of researchers (Abadi et al., 2010; Bramley et al., 2013; Du et al., 2010; Fang et al., 2010; Guo et al., 2010; Li. 2010; Zhang et al., 2010; Nasseri and Bahramloo, 2009; Nasseri and Fallahi, 2007; Zamani and Nasseri, 2008), index of water productivity was applied to evaluate water use of maize in seed production. Water productivity was from 1.22 to 1.52 kg m^{-3} with an average of 1.38 kg m^{-3} *(Figure 6)* during 11 years. Water aplication efficiency was 68% in maize farms (Abbasi et al., 2016). It is recommend that limited irrigation could be applied to enhence water productivity in maize production under studied environment. Further studies are necessary to evaluate interaction effect of limited irrigation and fertilizers viz. NPK applications on maize yield under moderate semi-arid environment.

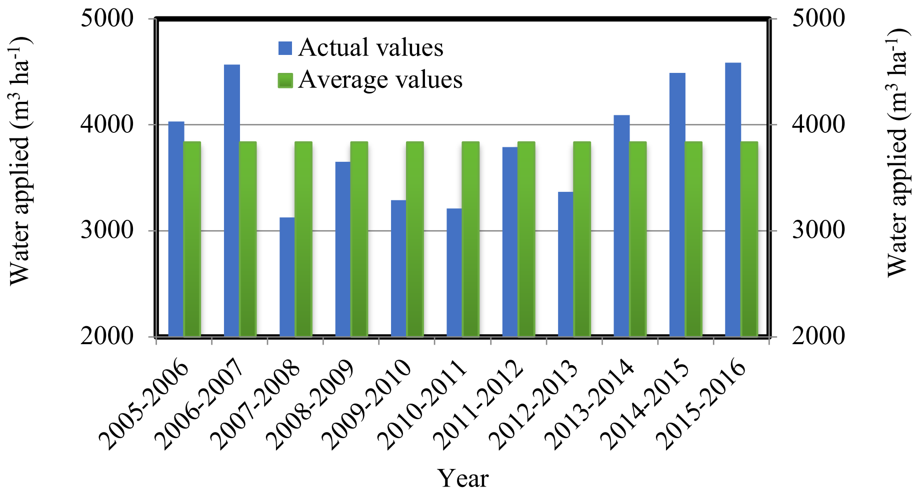

Figure 5. Measured maize yield and irrigation water during 11 years from 2005-2006 to 2015-2016

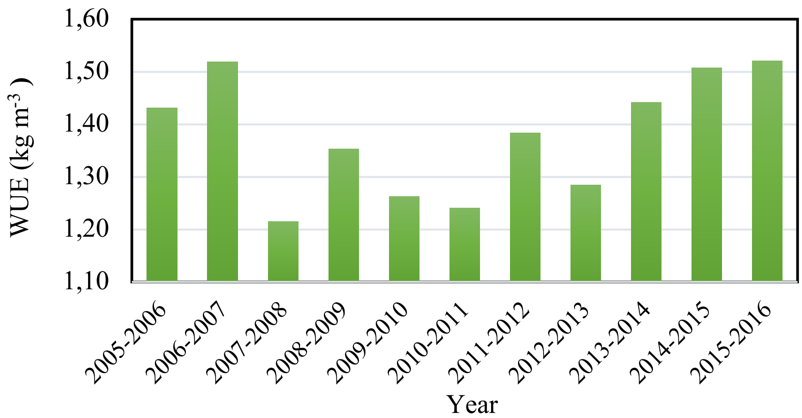

Figure 6. Water productivity of maize during 11 years from 2005-2006 to 2015-2016

4. Conclusion

Maize (*Zea mays* L.) yields measured in fields during 11 years from 2005-2006 to 2015-2016 were compared with those simulated by the Agro-ecological Zone method under moderate semi-arid environment in this study. Research scenarios comprising ETa/ETm under different water application efficiencies affected yield and water productivity of maize. The best water-production function was acquired to estimate or forecast maize yield with available water for irrigation. Index of water productivity of maize was from 1.22 to 1.52 kg m^{-3} with an average of 1.38 kg m^{-3} during 11 years under water aplication efficiency of 68%. Because measured yield ranged from

3800 to 6971 kg ha^{-1} with an averge of 5345 kg ha^{-1} and water applied was from 3125 to 4584 and averaged 3836 m^3 ha^{-1}. It is proposed that limited irrigation could be employed to enhence water productivity in maize production under moderate semi-arid environment. Further studies is essential to evaluate interaction effect of limited irrigation and fertilizers (NPK) applications on maize production under such moderate semi-arid environment.

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