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Evaluating the Effect of Crop Residue on Water Relations of Rainfed Chickpea in Maragheh, Iran, Using Simulation

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ABSTRACT

In no-till management, the crop residue is left on the soil surface. The effect of residue on water relations of soil, and subsequently that of plant are highly dependent on weather conditions. This study was aimed to evaluate the effect of maize residue (3.85 mg ha^{-1}) on water relations of rainfed chickpea, using model CYRUS. Firstly, this model was recoded in Qbasic programming; then a simple sub-routine was added to include the effect of crop residue; finally, it was run for long-term daily weather data (1961-2004) of Maragheh (winter-dominant rainfall), Iran. It was revealed that, as compared to control, the residue treatment results in that the value of fraction transpiration soil water in rooting depth [FTSW: ranges from 0 (wilting point) to 1 (field capacity)] to be 2.72% higher during emergence (E) to flowering (R1), 10.02% higher across R1 to pod initiation (R3), 7.59% higher for R3 to pod filling (R5), 1.82% higher during R5 to pod yellowing (R7) and 1.32% more over R7 to maturity (R8). Across the S-E, E-R1, and R1-R3 periods, the value of evapotranspiration (ET) was higher for non-mulching conditions, as compared to mulching conditions. On the other hand, across the R5-R7 and R7-R8 period, that of ET appeared to be higher for mulching than non-mulching conditions. The difference between named conditions for transpiration appeared to be negligible across R3-R5 period; while it was considerable over other periods. Across the E-R1 period, the transpired water from covered-soil was 56.89 mm, which is about 3.34 mm higher than that from bared-soil. This increasing effect of residue was 6.8% across R3-R5 period, 23.0% across R5-R7, and 35.1% across R7-R8. Considering the ratio of transpiration to evaporation, the mentioned beneficial impact of residue was more considerable across reproductive stages (R1-R8), than across vegetative stage (E-R1). The difference between bared- and covered-soil for named ratio was 0.14 over E-R1 period, 2.00 over R1-R3 period, 3.49 over R3-R5 period, 4.87 over R5-R7 period, and 2.98 over R7-R8 period.

Key words: Crop residue; water relation; chickpea; simulation

INTRODUCTION

There is a general consensus that global average surface air temperature has increased during the 20th century (Acia, 2004). Therefore, it is expected that in most cases the atmospheric demand for transpiration and evaporation to have an upwardly trend. Golubev et al. (2001) reported increasing evapotranspiration (ET) (measured empirically using massive weighing lysimeter data) during past decades in the former USSR where long-term data were available. A trend towards increasing ET is also inferred from continental-scale water balance studies that documented increases in precipitation that were substantially greater than increases in runoff during the period 1950–2000 in the conterminous United States (Milly and Dunne, 2001). Possible trends in evaporation over the oceans and their relation to precipitation and runoff have been addressed indirectly using salinity time-series data. Salinity in the surface 500–1000 m depth increased significantly between the periods 1955–1969 and 1985–1999 along a transect in the western basin of the Atlantic Ocean at latitudes between 40 ^{o}N and 20 ^{o}S (Curry et al., 2003). Curry et al. (2003) also reported systematic freshening poleward of these latitudes. The salinity increase was spatially coherent with measured warming of the sea surface (Curry et al., 2003). For 24 ^{o}N latitude (the salinity maximum), the evaporation minus precipitation (E–P) anomaly averaged 5 cm/year during the 40-year period (Curry et al., 2003).

Additionally, some reports indicate the declining trend in precipitation during past decades. An analysis of rainfall data since 1910 by Haylock and Nicholls (2000) reveals a large decrease in total precipitation and related rain days in southwestern Australia. Over the last 50 years, there has been a slight decrease in annual precipitation over China (Zhai et al., 1999), which is supported by a significant (5% confidence level) decrease in the number of rainy days (3.9% per decade). There have been marked decreases in precipitation in the latter part of the 20th century over sorthern Europe (Scho¨nwiese and Rapp, 1997). Since 1976, decreases in precipitation have occurred in South Pacific Convergence Zone (Salinger et al., 1996). There have also been significant decreases in rain days since 1961 throughout Southeast Asia and the western and central South Pacific (Manton et al., 2001). Hulme (1996) found significant decreases in precipitation being observed since the late 1970s. Using wavelet-based principal component analysis, Mwale et al. (2004) found that East Africa suffered a consistent decrease in the September–October–November rainfall from 1962 to 1997, resulting in 12 droughts between 1965 and 1997. Dore and Lamarche (2005) found evidence of a dramatic decline in precipitation in the Sahel, enough to characterize it as a ‘‘structural break’’.

More over the above mentioned problems, the value of runoff has been increased, which is good index for lower infiltration and storage of rain-water into the soil. Lins and Michaels (1999) found an increased runoff (stream flow) in United States. Georgievskii et al. (1996) also noted increases in stream flow and a rise in the level of the Caspian Sea over the last several decades over western Russia. Multidecadal stream flow data in Canada have revealed that there are apparent increases in runoff (Zhang et al., 2000). Published reports indicating that runoff from the Mississippi river increased by 22% from 1949 to 1997 (Milly and Dunne, 2001). Several analyses (e.g. Lettenmaier et al., 1999) have detected increases in stream flow across much of the contiguous United States. Stream flow data for major rivers in southeastern South America for the period 1901 to 1995 show that stream flow has increased since the mid-1960s (Garcia and Vargas, 1998).

The above mentioned reports reveal the necessity of focusing on the treatment (s), like mulching, which results in decreased soil evaporation and optimized rain-water-infiltration into the soil. The numerous positive impacts have been attributed to the leaving the crop residue on soil surface, like enhancing yield (Power et al., 1998), soil organic carbon (Clapp et al., 2000), soil nitrogen content (Kumar and Goh, 2000), and C/N ratio (Martens, 2000). In this simulation study, it was aimed to investigate the effects of crop residue on water relations at different development stages of rainfed chickpea.

MATERIAL and METHODS

Model Description

In this study, the CYRUS model was recoded in Qbasic programming language, and run to compare the residue-covered-soil with bared-soil for water relations across the different development stages of rainfed chickpea. This model was initially designed in 1999 by Soltani et al. (1999). Then it was developed for seedling emergence (Soltani et al., 2006d), for leaf expansion and senescence (Soltani et al., 2006c), for response of leaf expansion and transpiration to soil water deficit (Soltani et al., 2000), for response to photoperiod (Soltani et al., 2004a), for harvest index (Soltani et al., 2005), for phenological development (Soltani et al., 2006a), for nitrogen accumulation and partitioning (Soltani et al. 2006b), and for the effect of temperature and CO_2 (Soltani et al., 2007). The CYRUS has been used for evaluating yield of chickpea and its stability in dormant seeding (Soltani and Torabi, 2007), determining optimum phenology of chickpea for now and future (Rahimi-Karizaki and Soltani, 2007), potential effects of individual versus simultaneous climate change factors on growth and water use in chickpea (Gholipoor, 2007), evaluating the effect of future climate change on yield of rainfed chickpea in northwest of Iran (Barzegar and Soltani, 2007), comparing relative effects of temperature and photoperiod on development rate of chickpea (Gholipoor and Soltani, 2006), and optimizing the dormant sowing of chickpea (Gholipoor et al., 2006). The soil water balance sub model of this model with some little modifications has been applied for comparative evaluating the climate-related runoff production in slopped farms of Iran (Gholipoor, 2008), and to study the effect of past climate change on runoff in Gorgan, Iran (Gholipoor and Soltani, 2005).

Briefly, in seedling emergence sub model of CYRUS, emergence response to temperature is described by a dent-like function with cardinal temperatures of 4.5 (base), 20.2 (lower optimum), 29.3 (upper optimum) and 40 ^{o}C (ceiling temperature). Six physiological days (*i.e.* number of days under optimum temperature conditions; equivalent to thermal time of 94 ^{o}Cdays) are required from sowing to emergence at a sowing depth of 5 cm. The physiological day's requirement is increased by 0.9 days for each centimeter increase in sowing depth. Snow cover effect is considered on the basis of daily maximum and minimum temperatures, as presented in Ritchie (1991).

In leaf sub model, cardinal temperatures for nod appearance are 6.0 ^{o}C for base, 22.2 ^{o}C for optimum and 31.0 ^{o}C for ceiling temperature. Leaf senescence on the main stem starts when the main stem has about 12 nodes and proceeds at a rate of 1.67% per each day increase in physiological day (a day with non-limiting temperature and photoperiod). Leaf production per plant versus main stem node number occurs in two phases; phase 1 when plant leaf number increases with a slower and density-independent rate (three leaves per node), and phase 2 with a higher and density-dependent rate of leaf production (8–15 leaves per node).

Phenological development is calculated using multiplicative model that includes a dent-like function for response to temperature, and a quadratic function for response to photoperiod. Photoperiod-sensitivity is considered to be different in various cultivars, and cardinal temperatures for phenological development are 21 ^{o}C for lower optimum, 32 ^{o}C for upper optimum and 40 ^{o}C for ceiling temperature. The cultivars require 25-31 physiological days from E (emergence) to R_1 (flowering), 8-12 from R1 to R3 (pod initiation), 3-5 from R3 to R5 (pod filling), 17-18 from R5 to R7 (pod yellowing) and 6 from R7 to R8 (physiological maturity).

The biomass production is calculated based on extinction coefficient (KS) and radiation use efficiency (RUE). It assumes that KS is not radiation- and plant density-dependent. The RUE assumes to be constant (1 g MJ^{-1}) across plant densities, but not across temperatures and CO_2 concentrations. After correction of RUE for temperature and CO_2 concentration, it is not affected by either solar radiation or vapor pressure deficit (VPD). The partitioning of biomass between leaves and stems is achieved in a biphasic pattern before first-seed stage. After this stage, the fixed partitioning coefficients are used for calculating biomass allocation.

Many simulation models assume linearity of harvest index increases as a simple means to analyze and predict crop yield in experimental and simulation studies (see Soltani et al., 2005 and related references for more detail). Despite of these models, the CYRUS model assumes that its increase is biphasic with turning point temperature equal to 17 ^{o}C. The similar approach has been proved to be appropriate for application in wheat (Soltani et al. 2004b).

The relation between total N and total biomass throughout the growth period is based on non-linear segmented model (with two segments/phases). Therefore, the rates of N accumulation during phase 1 and 2 are different, and the turning point between two phases of N accumulation is considered 218.3 g biomass per m^2. The distribution of N to different parts of plant is calculated using appropriate functions and coefficients.

In soil water balance sub model, daily soil water content is estimated as fraction transpirable soil water (FTSW, which ranges from 0 to 1) to calculate the degree of water limitation experienced by the crop. Similar to that described by Amir and Sinclair (1991), it accounted for additions from infiltration, and losses from soil evaporation, transpiration and drainage. Infiltration is calculated from daily rainfall less any runoff. Runoff is estimated using the curve number technique (Knisel, 1980). Soil evaporation

(Ev.) is calculated using the two-stage model as implemented in spring wheat model developed by Amir and Sinclair (1991). Stage I Ev. occurs when water present in the top 200 mm of soil, and FTSW for the total profile is greater than 0.5. Stage II Ev. occurs when the water in the top layer is exhausted or the FTSW for the total soil profile reaches to less than 0.5. In stage II, Ev. is decreased substantially as a function of the square root of time since the start of stage II. The calculation of Ev. is returned to stage I only when rain or irrigation of greater than 10 mm occurs. Like procedure of Tanner and Sinclair (1983) and Sinclair (1994), the daily transpiration rate is calculated directly from the daily rate of biomass production, transpiration efficiency coefficient (=5 Pa) and VPD. The calculation of VPD is based on suggestion of Tanner and Sinclair (1983) that it to be approximately 0.75 of the difference between saturated vapor pressure calculated from daily maximum and minimum temperatures.

Procedure of Calculating the Residue Effects, and Evaluated Attributes

The selected location was Maragheh (37° 22' 54" N and 46° 15' 15" E) from Iran, which has long-term (1961-2004) and reliable daily weather data. A simple sub-routine was added to CYRUS, to include the effect of crop residue. The sub-routine was based on the procedure of Stockle and Nelson (1994). In this method, the actual evaporation is function of residue and canopy cover. The effect of residue is mathematically calculated based on (1) area covered by one average straw per mass of one average straw (a crop parameter), and (2) the total residue mass per unit soil area. The residue mass was set to be 3.85 mg maize residue ha^{-1}.

The main calculated attributes were FTSW for top 20 cm soil, FTSW for top 60 cm soil, FTSW for rooting depth, transpiration, ratio of transpiration to evaporation and evapotranspiration. The value of FTSW lower than 0.34 at which the relative transpiration tends to be decreased (Soltani et al., 1999) was considered as drought.

RESULTS and DISCUSSIONS

The results regarding the value of fraction transpirable soil water in top 20 cm (FTSW-20) of bared- and residue-covered-soil were shown in Fig. 1. For both residue- and non-residue-conditions, the highest and 2nd highest FTSW-20 were found across sowing (S) to emergence (E) period, and E to flowering (R1) period, respectively. This is due to the fact that the studied location, like other locations of Iran, is a winter-dominant rainfall. So that, the considerable portion of precipitation is dropped during autumn and winter. Therefore, as chickpea grow, the soil-stored-water is lost, especially at upper layers of the soil. The difference between periods R1 to pod initiation (R3), R3 to pod filling (R5), R5 to pod yellowing (R7) appeared to be little for averaged value of FTSW-20 over residue- and non-residue-conditions. For period close to maturity, i.e. R7 to maturity (R8), it found no transpirable soil water for both residue and non-residue conditions. Across S-E, that of FTSW-20 was 0.559 for covered-soil, which is about 1.5 times higher than control (bared-soil). For period E-R1, it was 0.202 and 0.230 for bared- and covered-soil, respectively. Over R1-R3, R3-R5, and R5-R7, the value of FTSW-20 ranged from 0.013 to 0.023 for bared-soil, and from 0.018 to 0.030 for covered-soil. Generally, the top 20 cm layer of the soil is called "evaporative layer". The inhibitory effect of left crop residue on evaporation was more considerable at earlier stages of development of chickpea; at the end of growing period of rainfed-chickpea, the residue had not any benefit, which is due to lack of water for evaporation.

In top 60 cm of the soil, the wettest situation was expectedly found during period from sowing to emergence (Fig. 2). Considering the threshold value for experiencing the drought by chickpea, i.e. FTSW equal to 0.34, it could be concluded that in mentioned layer of the soil of Maragheh, Iran, there is enough stored-water for supporting the growth and development of rainfed-chickpea grown in both bared- and covered-soil until flowering. At S-E, leaving the residue on the soil surface caused that the value of FTSW-60 to be 7.3% higher than bared-soil. At E-R1, it was 0.525 and 0.582 for control and mulched-soil, respectively. For bared-soil (and for residue-covered soil) the FTSW-60 was 0.040 (0.069) at R1-R3, 0.013 (0.023) at R3-R5, 0.003 (0.004) at R5-R7, and 0 (0) at R7-R8. These results clearly indicate that there is serious drought in top 60 cm of the soil at reproductive stages of chickpea; mulching the soil can in some extend alleviate the drought.

In view point of growth and development of the rainfed-crops, like chickpea, the averaged value of FTSW across rooting depth of the crop (FTSW-Total) is more reliable than FTSW for top 20 cm and 60 cm of the soil. This is because of the fact that when the upper layers of the soil is dried due to transpiration, and especially evaporation, the lower layers are wetter, which is as result of much decreased evaporation; the roots can absorb the water from these deeper layers of soil, and hence the life-cycle of chickpea could successfully be completed. As seen in Fig. 3, the value of FTSW-Total across R7-R8 has never been declined to zero, which is in spite of FTSW-20 and FTSW-60 cases. Like FTSW-20 and FTSW-60 cases, the value of FTSW-Total tended to be the highest for period S-E. At this period, the beneficial effect of mulching reached to about 13% of the non-mulching situation. Across E-R1, the value of difference between bared- and covered-soil for FTSW-Total was 0.027 over E-R1 period, which is lower than that of difference over R1-R3 period (0.1). This difference was 0.076 over R3-R5, 0.018 over R5-R7, and 0.013 over R7-R8.

The comparative values of transpiration for mulching- and non-mulching-conditions are shown in Fig. 4. The difference between named conditions for transpiration appeared to be little across R3-R5 period; while it was considerable over other periods. Across the E-R1 period, the transpired water from covered-soil was 56.89 mm, which is about 3.34 mm higher than that from bared-soil. This increase in transpiration soil water proves the beneficial effect of residue on saving the water by decreasing the evaporation. This positive effect was 6.8% across R3-R5 period, 23.0% across R5-R7, and 35.1% across

R7-R8. Based on ratio of transpiration to evaporation (Fig. 5), it seems that the mentioned beneficial impact of residue to be more considerable across reproductive stages (R1-R8), as compared to vegetative stage (E-R1). The difference between bared- and covered-soil for named ratio was 0.14 over E-R1 period, 2.00 over R1-R3 period, 3.49 over R3-R5 period, 4.87 over R5-R7 period, and 2.98 over R7-R8 period.

Generally, it is hypothesized that the value of evapotranspiration (ET) may be the same for residue- and non-residue-conditions. Because, leaving the residue cause that evaporation to be decreased, but transpiration to be increased (due to saving the water in to the soil and hence enhancing stored-water for transpiration). The result of present study indicated that this hypothesis is true just for the R3-R5 period (Fig. 6). Across the S-E, E-R1, and R1-R3, the value of ET was higher for non-mulching conditions, as compared to mulching conditions; the difference between mentioned conditions was 8.67 mm across S-E, 3.65 mm across E-R1, and 0.66 mm across R1-R3. On the other hand, across the R5-R7 and R7-R8 period, that of ET appeared to be higher for mulching conditions, when compared with non-mulching conditions; the difference was 3.26 and 1.18 mm for named periods, respectively.

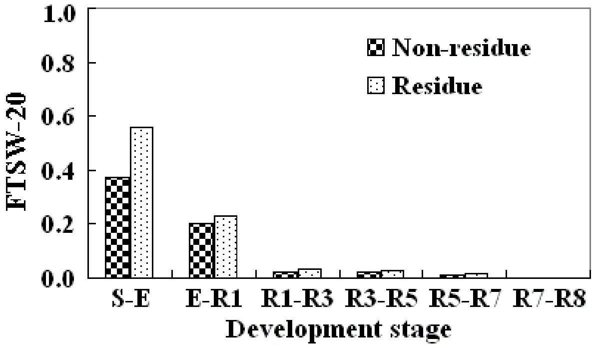

Fig. 1. The value of fraction transpirable soil water in top 20 cm (FTSW-20) of bared- and residue-covered-soil across different development stage of rainfed chickpea.

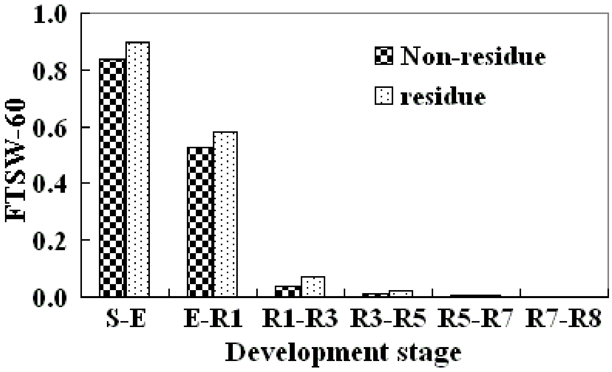

Fig. 2. The value of fraction transpirable soil water in top 60 cm (FTSW60) of bared- and residue-covered-soil over different development stage of rainfed chickpea.

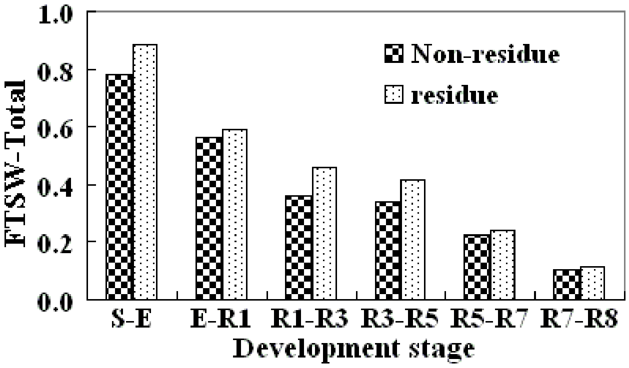

Fig. 3. The value of fraction transpirable soil water in rooting depth (FTSW) of bared- and residue-covered-soil across different development stage of rainfed chickpea.

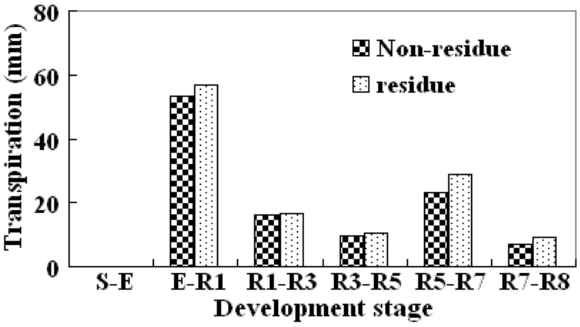

Fig. 4. The value of transpiration across different development stages of rainfed chickpea grown in bared- and residue-covered-soil.

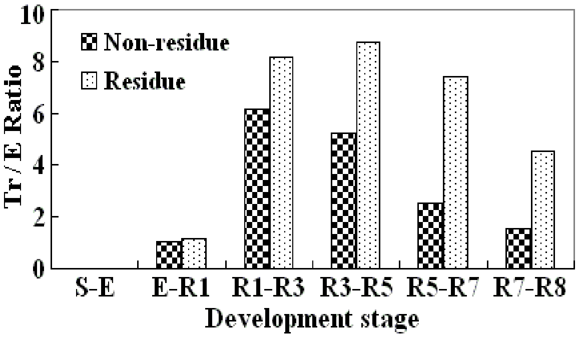

Fig. 5. The ratio of transpiration to evaporation (Tr/E) across different development stages of rainfed chickpea grown in bared- and residue-covered-soil.

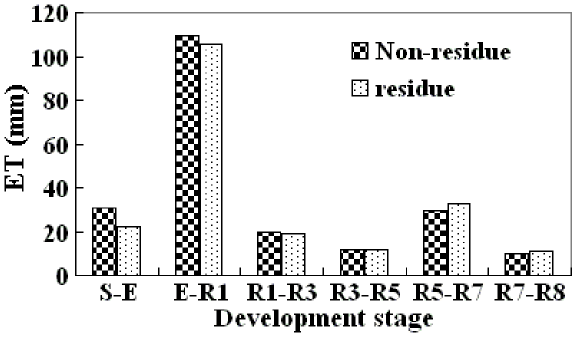

Fig. 6. The value of evapotranspiration (ET) across different development stages of rainfed chickpea grown in bared- and residue-covered-soil.

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