International Journal of

Agricultural Research

ISSN 1816-4897

Academic Journals Inc.

www.academicjournals.com

International Journal of Agricultural Research 3 (3): 202-210, 2008
ISSN 1816-4897

Assessing Potential Drought Avoidance for Five Crops in Iran Using Long-Term Weather Data

[1]M. Gholipoor and [2]A. Soltani
[1]Department of Agronomy and Plant Breeding,
Shahrood University of Technology, P.O. Box 36155-316, Shahrood, Iran
[2]Department of Agronomy and Plant Breeding,
Gorgan University of Agricultural Sciences, P.O. Box 386, Gorgan, Iran

Abstract: Drought may be avoided by matching crop phenology with periods during the cropping season, when water supply is likely to be more abundant. We evaluated long-term (39 to 44 years) weather data for 5 crops (chickpea, spring barley and wheat, lentil and winter wheat) in 5 locations in Iran to assess the potential for drought avoidance. For each day of the year, water deficit was estimated as the difference between the 7 days running sums of rainfall and potential evapotranspiration. For comparative purposes across locations, across crops and across seasons, a 7 days water deficit >50 mm was considered as a drought. Results indicated that among locations, Kermanshah had relatively higher, but Isfahan and Mashhad had lower Drought Risk (DR) for spring crops. Tabriz appeared to have lower DR for spring barley and wheat. The higher DR for winter wheat was also obtained for Kermanshah. Averaged over locations, winter wheat had the highest possibility for Potential Drought Avoidance (PDA). The spring crops with lower base temperature (like spring barley and spring wheat) tended to experience higher PDA than those with higher base temperature (like lentil). It was evident that delayed sowing dates would result in higher DR and decreased water use efficiency. Therefore, other strategies, including dormant sowing and use of cultivars with lower base temperature for earlier sowing should be chosen for increased PDA in Iran.

Key words: Drought avoidance, crop, weather data, chickpea, lentil

INTRODUCTION

Purcell *et al*. (2003) developed an analytical and statistical framework that could be used to evaluate the likelihood of drought from a cropping perspective and from long-term weather data. Their approach has no limitations that have been reported for drought indices which measure how much precipitation for a given period of time has deviated from historically established norms [Willeke *et al.* (1994) and references regarding drought indices in Purcell *et al.* (2003)] and avoids many of the assumptions and crop-specific coefficients inherent in crop simulation models and provides complementary tools for modeling that has broad applicability. More important capability is that it could be simple and easily used for evaluating the possibility of matching crop phenology with periods during the cropping season when water supply is likely to be more abundant. Non-facing and/or less-facing with drought by crop is preferred, compared to facing and tolerating the drought, due to this fact that non and/or less-stressed crops produce relatively higher yield. Additionally, there is little difference among commercial cultivars within a species for drought tolerance (Carter *et al*., 1999; Purcell and Specht, 2003) and few traits are considered likely to increase yield under rainfed conditions

Corresponding Author: M. Gholipoor, Department of Agronomy and Plant Breeding, Shahrood University of Technology, P.O. Box 36155-316, Shahrood, Iran
Tel/Fax: +98-273-3350570

(Ludlow and Muchow, 1990; Serraj and Sinclair, 2002; Sinclair and Muchow, 2001; Turner *et al.*, 2001; Purcell and Specht, 2003). Sowing the crops near the beginning of the wet season and mature before the dry season has been an effective tool for crops grown in monsoonal climates. Similarly, *Glycine max* production in the southern portion of the Mississippi Delta has been shifted to early sowing dates combined with early maturing cultivars to escape drought (say avoid drought) which frequently occur in August (Bowers, 1995; Heatherly, 1999). By applying the latest approach, it has been found that in the midsouth regions of Unites States, shifting the cropping systems to the beginning of the growing season would greatly increase Water Use Efficiency (WUE) and decrease the probability of water deficit occurrence (Purcell *et al.*, 2003). On the other hand, similar opportunities for drought avoidance may occur in the southeast regions by shifting them to the end of growing season.

The reports indicating that in the last century, the global temperature has increased 0.7°C (Rosenzweig and Iglesias, 2006). In Iran, results regarding Kermanshah showed that except for January, February and March, the increase in temperature is considerable for all other months, especially June (Gholipoor *et al.*, 2006a); the upwardly change of temperature has been also significant for other locations, including Gorgan (Ghorbani and Soltani, 2002), Mashhad and Tabriz (Gholipoor *et al.*, data not published). Generally, a large climate-change-resulted decrease in total precipitation and rain days has been reported for few past decades (Haylock and Nicholls, 2000). The report of Ghorbani and Soltani (2002) for Iran, Gorgan indicated that across years 1961-2000, the rate of decrease in yearly precipitation is 4.1 mm per year. These conditions cause that water shortage becomes the most limiting factor in rain-fed agriculture, especially for developing countries in lower latitudes. Based on this issue and on the fact that the population is growing, the evaluating drought risk in each location/country appears to be important. This study was aimed to compare the possibility for drought avoidance for 5 crops across 5 locations and across growing season in Iran, using procedure of Purcell *et al.* (2003). The results of this study may be useful for selecting more appropriate strategy (s) for decreasing the deleterious effects of drought on rain-fed crops.

MATERIALS AND METHODS

Data Sets and Estimation of Weather Variables and WUE

Historical weather data for 5 locations of Iran, including Isfahan, Shiraz, Kermanshah, Tabriz and Mashhad were obtained from the National Climatic Data Center. The locations chosen represent different geographical characteristics (Table 1) and are of major agricultural importance in the Iran. Data sets were for years between 1966-2004 (39 years) for Tabriz and 1961-2004 (44 years) for other locations. Each data set contained daily values for sunshine hours, maximum temperature (T_{max}), minimum temperature (T_{min}) and rainfall. Solar radiation data were calculated from sunshine hours and extraterrestrial radiation as outlined by Doorenbos and Pruitt (1977).

The approach of Purcell *et al.* (2003) with some modifications was used for estimating water deficit which was based on the difference between potential evapotranspiration [E_{to} (mm)] and rainfall (mm). The E_{to} is defined as the theoretical amount of water lost through evapotranspiration from a complete canopy of a cool season grass actively growing with adequate soil moisture and specified crop height, conductance and albedo (Allen *et al.*, 1998). Purcell *et al.* (2003) used a modified form of the Penman-Monteith equation for calculating E_{to} in which wind speed data is required. They estimated this factor by given methods, due to lack of records. In order to minimize estimations, we calculated E_{to} according to the Priestley and Taylor (1972) model in which there is no need for wind speed records. This model has been used by many researchers (Kellner, 2001; Kimball *et al.*, 1997; Loescher *et al.*, 2005; Moges *et al.*, 2003; Soltani *et al.*, 2001). Inputs required for this model are T_{max}, T_{min} and solar radiation. Using these three inputs and soil albedo, this model estimates E_{to}.

Table 1: Mean daily values (over the entire year) for maximum (T_{max}) and minimum (T_{min}) temperatures, solar radiation (Srad.), 7 days running sum of precipitation (Precip.), 7 days running sum of potential evapotranspiration (E_{to}) and 7 days running sum of water deficit (Precip.-E_{to}) for 5 locations with different geographical properties in Iran

Station	Lat.	Long.	Elev.	Obs.	T_{max}	T_{min}	Srad. (Mjm^{-2} day^{-1})	Precip.	E_{to}	Water deficit
					------ (°C) ------			------- (mm $week^{-1}$) --------		
Isfahan	32.62	51.07	1550	16060	23.36	9.43	19.77	2.30	30.79	28.49
Shiraz	29.53	52.60	1484	16060	25.75	9.90	20.39	6.40	33.53	27.13
Kermanshah	34.35	47.15	1318	16060	22.76	6.06	18.58	8.89	28.59	19.70
Tabriz	38.83	46.12	1361	14235	18.16	7.18	17.50	5.42	23.73	18.31
Mashhad	36.27	59.63	990	16060	21.38	7.25	18.38	4.91	26.84	21.93

Lat.: Latitude; Long.: Longitude; Elev.: Elevation; Obs.: Observation

A 7 days water deficit for each day of the year (DOY) was estimated by calculating the 7 days running sum of E_{to} and subtracting the 7 days running sum of rainfall. Summing the rainfall, E_{to} and water deficit variables over 7 days periods was similar to the method used by Virmani *et al.* (1982) in assessing drought risk in India and by Purcell *et al.* (2003). The use of running sums also served to smooth data and to lessen the impact of abnormally large rainfall events on any given DOY.

Like Purcell *et al.* (2003), transpirational water use efficiency (WUE, Pa kPa^{-1}) was estimated for each DOY, using the procedure of Tanner and Sinclair (1983). They derived a simple expression of WUE based on characteristics of leaf gas exchange whereby:

$$WUE = k \times CVPD^{-1} \quad (1)$$

Where, k is a WUE coefficient with a value of approximately 5 kPa for C_3 plants and CVPD (kPa) refers to the weighted, daily vapor pressure deficit experienced by crops during transpiration. Calculation of CVPD was based on estimates of the difference between the maximum saturated water vapor pressure (emax) and actual water vapor pressure (ea) (Tanner and Sinclair, 1983) as:

$$CVPD = (emax - ea) \times 0.75 \quad (2)$$

The values of emax and ea are calculated as:

$$emax = 0.6108 \times \exp (17.27 \times T_{max}) / (T_{max} + 273.3) \quad (3)$$

$$ea = 0.6108 \times \exp (17.27 \times T_{min}) / (T_{min} + 273.3) \quad (4)$$

Statistical Evaluation of Weather Variables

The planting dates for spring (chickpea, lentil, spring barley and spring wheat) and winter (winter wheat) crops were first determined for each location [considering this fact that the planting date (base temperature) is not the same for different cultivars of a given crop, we used the averaged base temperature across popular cultivars]. The 7 days with no rainfall and with mean temperature above the base temperature was considered as planting date for spring crops, using long-term weather data (the averaged planting date over years was used for calculating the value of water deficit and etc). Planting date for winter wheat was calculated based on required Growing Degree Days (GDD) for rosette growth before occurrence of growth cession which is imposed by winter freezing. Growing period for each crop was calculated on the basis of required GDD from planting to maturity.

Based on rooting depth and depletion of soil water, it has been stated that plants typically begin to undergo water deficit stress when 7 days water deficit value reaches to 50 mm (Purcell *et al.*, 2003). Part of this assumption has been based on this fact that farmers in midsouth regions of United States typically schedule irrigations of warm-season crops when the soil water deficit is 37 to 50 mm, which corresponds to a rooting depth of 438 to 592 mm, respectively. Additionally, a 50 mm water deficit over a 7 days period is near the maximum E_{to} expected during the summer (6-8 mm day^{-1}) and, therefore, implicitly includes a decreased probability of rainfall. Therefore, a 7 days water deficit sum and a critical water deficit of a 50 mm reflect the weekly balance between E_{to} and rainfall and disregard long-term water deficit cumulating and soil water storage.

Like Purcell *et al*. (2003), cumulative distribution functions were generated for 7 days water deficit. Then, cumulative p values for 7 days water deficit were made for each DOY. Probabilities of 7 days water deficit exceeding 50 mm were determined for each location for each DOY. Mean values of T_{max}, T_{min}, solar radiation, 7 days cumulative rainfall, 7 days cumulative E_{to} and 7 days water deficit were determined for the entire year and for the growing period of each crop. Additionally, mean values of WUE were determined for the growing period of each crop, for spring season (90 days) and for 90 days of the end-growing-season.

RESULTS AND DISCUSSION

The results of averaged weather variables over all DOYs indicate that Tabriz which is located at relatively higher latitude, had cooler T_{max} (18.16°C) and lower solar radiation (17.50 Mjm^{-2} day^{-1}) and consequently lower 7 days E_{to} (23.73 mm) (Table 1). In contrast to Tabriz, Shiraz (located at lower latitude) with about 7.5°C warmer T_{max}, 3 Mjm^{-2} day^{-1} higher solar radiation, but with relatively similar rainfall, had 10 mm higher E_{to} and 9 mm higher water deficit. The value of rainfall in Isfahan was about 30% of Shiraz. Kermanshah had the highest rainfall, but the 3rd highest E_{to}.

By averaging the mean values for weather variables determined within each of crops respective growing period over locations, it was generally cleared that in spring crops with lower base temperature, like spring wheat, plant faces with lower E_{to}, but higher rainfall and consequently less water deficit, compared to crops with a greater base temperature (Table 2). It was also clear that except for rainfall, the value of all weather variables was lower for winter wheat than for spring crops.

Based on averaged values of weather variables over the growing period, chickpea experiences relatively lower water deficit in Mashhad (26.74 mm $week^{-1}$), but higher one in Kermanshah and Isfahan (31.22 and 30.77 mm $week^{-1}$, respectively) (Table 2). The higher water deficit in Isfahan was due to low rainfall, but in Kermanshah to higher E_{to}, created by high T_{max} and solar radiation. Although the value of E_{to} was the same for Isfahan and Mashhad, the low rainfall in Isfahan resulted in the higher water deficit value in Isfahan than in Mashhad.

Spring barley faced with water deficit 24.74 mm $week^{-1}$ in Isfahan, which is greater than the value of water deficit in Mashhad (18.35 mm $week^{-1}$). These two locations had different amounts of rainfall, but nearly the same value of other weather variables during the growing period of barley. The slightly higher E_{to} in Kermanshah compensated for by the greater amount of rainfall. The value of water deficit in Kermanshah tended to be similar to that of water deficit in Shiraz and Tabriz.

During the growing period of lentil, there was relatively large temperature differential between T_{max} and T_{min} for Kermanshah which is associated with high vapor pressure deficit. In addition, the value of rainfall in this location was like that of rainfall in other locations. These conditions resulted in higher E_{to} and water deficit values in Kermanshah than in other locations. The difference between Isfahan and Shiraz for water deficit was negligible (about 1 mm $week^{-1}$).

We found no considerable differences between spring wheat and spring barley for experiencing weather variables, because the difference for planting and harvesting dates was minimal (Table 3).

Comparing winter wheat with lentil as a warm season crop indicates that difference between locations for T_{max}, rainfall, E_{to} and water deficit is greater for the growing period of winter wheat. The averaged rainfall over growing period of winter wheat ranged from 3.71 (Isfahan) to 13.56 mm $week^{-1}$ (Kermanshah). The averaged water deficit varied between 3.53 (Kermanshah) and 14.88 mm $week^{-1}$

Table 2: Mean values over growing period of each crop for maximum (T_{max}) and minimum (T_{min}) temperatures, solar radiation (Srad.), 7 days running sum of precipitation (Precip.), 7 days running sum of potential evapotranspiration (E_{to}) and 7 days running sum of water deficit (Precip.-E_{to}) for 5 locations in Iran

		T_{max}	T_{min}	Srad.	Precip.	E_{to}	Water deficit
Crop	Station	--------- (°C) ---------		(Mjm^{-2} day^{-1})	------------- (mm week^{-1}) ---------------		
Chickpea	Isfahan	24.81	11.21	23.15	3.08	33.84	30.77
	Shiraz	26.09	10.42	23.02	6.05	34.74	28.69
	Kermanshah	27.94	9.44	24.84	7.36	38.58	31.22
	Tabriz	25.42	13.17	24.54	6.93	35.87	28.94
	Mashhad	25.45	11.31	22.79	6.87	33.62	26.74
Spring barley	Isfahan	21.64	8.54	21.24	3.79	28.53	24.74
	Shiraz	23.14	8.32	21.21	7.83	29.37	21.54
	Kermanshah	24.12	7.10	22.95	10.85	31.55	20.70
	Tabriz	21.79	10.00	22.59	8.88	29.90	21.02
	Mashhad	22.22	8.88	20.47	9.08	27.43	18.35
Lentil	Isfahan	27.38	13.44	24.86	2.59	38.13	35.54
	Shiraz	28.60	12.30	24.82	4.45	39.24	34.78
	Kermanshah	30.64	11.07	26.44	4.79	43.39	38.60
	Tabriz	27.45	14.90	25.78	5.70	39.22	33.51
	Mashhad	27.97	13.23	24.59	5.44	37.95	32.51
Spring wheat	Isfahan	21.51	8.39	21.11	3.70	28.34	24.64
	Shiraz	23.10	8.26	21.16	7.76	29.35	21.59
	Kermanshah	23.64	6.81	22.52	11.06	30.84	19.78
	Tabriz	21.44	9.72	22.29	8.76	29.44	20.67
	Mashhad	22.38	8.99	20.64	8.83	27.89	19.06
Winter wheat	Isfahan	15.65	2.98	14.95	3.71	18.59	14.88
	Shiraz	17.88	3.78	15.34	11.55	19.87	8.32
	Kermanshah	15.66	1.75	13.91	13.56	17.09	3.53
	Tabriz	12.12	2.37	13.31	6.92	14.91	7.99
	Mashhad	15.57	2.65	13.57	6.50	16.58	10.08

(Isfahan). These locations had similar T_{max}, but nearly different T_{min}, solar radiation and E_{to} at growing period of winter wheat. Tabriz had relatively cooler T_{max}, intermediate rainfall (6.92 mm week^{-1}) and water deficit (7.99 mm week^{-1}).

After determining growing period of each crop at each location, based on harvesting and planting dates, it was divided into portions that had $p>0.20$ or $p\leq 0.20$ of 7 days water deficit. According to the procedure of Purcell *et al*. (2003) these two portions are equal to days with water deficit and water deficit-free days, respectively, during the growing period. These variables were presented in Table 3. Tabriz and Kermanshah had the latest and 2nd latest planting date (based on DOY) for spring crops, respectively. Little differences (4 days) were found between Isfahan and Shiraz for planting dates of chickpea and lentil, but no difference for that of spring barley (1 day) and spring wheat (0 day). These two locations had earlier planting dates for spring crops, when compared with other locations. Generally, the difference between locations appeared to be negligible for length of growing period of spring crops, but considerable for that of growing period of winter crop; for example, in contrast to Tabriz, Shiraz had 58 days shorter growing period for winter wheat. The DOY in which 50 mm 7 days water deficit occurred, varied between 132 (Shiraz) and 172 (Tabriz).

Averaged ratio of days with water deficit to growing period over locations was equal to 32.0% for chickpea, 9.3% for spring barley, 42.2% for lentil, 11.2% for spring wheat and 1.7% for winter wheat. Therefore, spring barley and spring wheat had the highest possibility of drought avoidance. The possibility of drought avoidance for chickpea was relatively high in Mashhad (the named ratio is equal to 27.1%) and Isfahan (28.0%), but was low in Kermanshah (39.8%). There was little difference between Isfahan and Mashhad for avoiding drought by spring barley. Kermanshah and Shiraz in turn tended to have the highest and 2nd highest values of this ratio for spring barley. The difference between locations for ratio of days with water deficit to growing period for spring wheat was relatively similar to the ratio for spring barley. Lentils experience the highest value of this ratio in Kermanshah. This was also true for winter wheat.

Table 3: Planting (Plant. date) and harvesting dates (Harvest. date), growing period, occurrence of 50 mm 7 days water deficits (p>0.20) based on day of year and day after planting (50 mm WD Occurr.), days with water deficit during growing period (days with WD), ratio of the days with water deficit to growing period and Water Use Efficiency (WUE) during growing period of 5 crops in 5 locations of Iran

Crop	Station	Plant date (day of year)	Harvest date (day of year)	Growing period (day with DW)	50 mm WD# Occurr. Day of year	Day after planting	Days with WD (day)	WD to growing period ratio (%)	WUE (Pa KPa^{-1})
Chickpea	Isfahan	58	176	118	143	85	33	28.0	5.8
	Shiraz	54	172	118	132	78	40	33.9	5.1
	Kermanshah	83	201	118	154	71	47	39.8	4.4
	Tabriz	95	207	112	172	77	35	31.3	6.0
	Mashhad	71	189	118	157	86	32	27.1	6.5
Spring barley	Isfahan	52	149	97	143	91	6	6.2	6.9
	Shiraz	51	145	94	132	81	13	13.8	6.0
	Kermanshah	76	171	95	154	78	17	17.9	5.6
	Tabriz	84	177	93	172	88	5	5.4	7.5
	Mashhad	65	160	95	157	92	3	3.2	8.0
Lentil	Isfahan	81	181	100	143	62	38	38.0	4.9
	Shiraz	77	177	100	132	55	45	45.0	4.3
	Kermanshah	106	205	99	154	48	51	51.5	3.5
	Tabriz	115	211	96	172	57	39	40.6	5.2
	Mashhad	93	193	100	157	64	36	36.0	5.1
Spring wheat	Isfahan	48	151	103	143	95	8	7.8	7.0
	Shiraz	48	147	99	132	84	15	15.2	6.1
	Kermanshah	69	173	104	154	85	19	18.3	5.9
	Tabriz	78	180	102	172	94	8	7.8	7.8
	Mashhad	63	164	101	157	94	7	6.9	8.0
Winter wheat	Isfahan	304	144	205	143	204	1	0.5	11.1
	Shiraz	308	135	192	132	189	3	1.6	9.3
	Kermanshah	298	164	231	154	221	10	4.3	12.2
	Tabriz	290	175	250	172	247	3	1.2	18.0
	Mashhad	288	159	236	157	234	2	0.8	13.7

#: It is equal to water deficit free days during growing period

Small changes in T_{max} have large effects on WUE, because emax increases exponentially with T_{max} (Eq. 3). Accordingly, the averaged value of WUE over locations tended to be the highest (12.9 Pa kPa^{-1}) for winter wheat. It was equal to 5.6 for chickpea, 6.8 for spring barley, 4.6 for lentil and 7.0 for spring wheat. During the growing period of spring crops, the lowest WUE was obtained for Kermanshah (Table 3). The correlation of WUE with named ratio over spring crops was equal to -0.92**.

In order to compare the value of drought risk across the growing season, we also calculated the duration of water deficit-free days over growing period of very late-sown crops; firstly, the limit of end-growing-season was determined according to occurrence of $T_{min} = 0$ ($p<0.05$) (Purcell *et al*., 2003); then the length of period with water deficit-free days was estimated, based on time at which a 7 days 50 mm water deficit with $p<0.20$ occurs. The limit for end-growing-season was equal to DOY 305 for Isfahan, 306 for Shiraz, 297 for Kermanshah, 300 for Tabriz and 281 for Mashhad. The DOY at which a 50 mm 7 days running sum of water deficit last exceeded the 0.20 level of p towards the end of season, was equal to 250 for Isfahan, 258 for Shiraz, 251 for Kermanshah, 239 for Tabriz and 241 for Mashhad. Therefore, water deficit-free days at the end of growing season were equal to 55 days for Isfahan, 48 days for Shiraz, 46 days for Kermanshah, 61 days for Tabriz and 40 days for Mashhad. These values are lower than the value of water deficit-free days which were obtained during the growing period of chickpea, spring barley and spring wheat, but nearly similar to that of water deficit-free days during the growing period of lentil at the beginning of growing period (Table 3). Also, it should be pointed out that soil-stored moisture would likely to be depleted at the end of the growing season, due to the fact that all locations receive more rainfall in winters than the rest of the season.

Compared to averaged WUE over spring, the value of averaged WUE over 90 days of the end-growing-season was 21% lower in Isfahan and Shiraz, 39% lower in Kermanshah, 30% lower in Tabriz and 40% lower in Mashhad. These findings suggest that cultivating the crops over beginning-part of the growing season may have more advantages, as compared to that over end-part of the growing season. Similar to findings of this study, it has been found that in midsouth regions of Unites States, shifting the cropping systems to the beginning of the growing season would greatly increase WUE and decrease probability of water deficit occurrence (Purcell *et al*., 2003); but, similar opportunities for drought avoidance may occur in the southeast regions by shifting them to the end of growing season.

CONCLUSION

Generally, the results of this assessment indicate that among locations, Kermanshah had relatively higher drought risk (lower possibility of drought avoidance) for all spring crops. In contrast, Isfahan and Mashhad had lower risks. Tabriz had also lower risk for the production of spring barley and spring wheat. Kermanshah tended to have relatively lower possibility of drought avoidance for winter wheat similar to those for spring crops. Other locations with similar values had higher possibility for avoiding the drought. Spring crops with lower base temperature, like spring barley and spring wheat, appeared to have relatively higher possibility of drought avoidance, as compared to those with higher base temperature. It was clear that shifting the growing periods towards the end of growing season by about 100 days, would cause more water deficit and lower WUE.

Based on above mentioned results and on the fact that all locations in Iran receive more rainfall in winter than the rest of the year, it seems that breeding and managing programs should be focused on earlier sowing of the spring crops. So that, breeders should release cultivars with lower base temperatures and shorter growing periods, especially for warm season crops like lentil. Agronomists should choose other strategies like dormant sowing, especially in regions in which wet conditions cause the crop to be late-sown. In this method, the crop is sown during late autumn or early winter after temperatures become too low for seed germination to occur until the following spring. Then, it emerges as soon as temperatures permit and no time is lost in the spring for seedbed preparation and sowing. Soltani *et al*. (2006) found that in dormant sowing of chickpea in Maragheh, Iran, the seedlings emerge 22 days earlier than spring-sown chickpea. In a similar investigation in Kermanshah, it was found that seedlings would emerge 17 days earlier, compared with spring-sown situation (Gholipoor *et al*., 2006b).

In this study we assessed the possibility of drought avoidance for five crops as duration of days with higher rainfall, compared to E_{to} and proposed some strategies for more avoiding the drought risk in Iran. It is obvious that these strategies will have more advantages, if be combined with the other strategies of drought avoidance and/or drought tolerance, including sowing the crops/cultivars with higher rooting depth (Kashiwagi *et al*., 2005), with higher WUE [for example, field pea and faba bean are more efficient users of water than lentils and chickpeas (WUE: about 10 kg ha^{-1} mm^{-1}, versus, 4-6 kg ha^{-1} mm^{-1}, respectively) (www.agric.wa.gov.au)], with higher capability for reflecting the solar radiation (lower rate of transpiration and consequently lower loss of the soil water) and with more considerable capability for osmotic adjustment (Kiani *et al*., 2007).

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