Utilization of soil, crop and meteorological information as tools in irrigation management in arid and semiarid environments

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- **Irrigation practices in arid and semiarid environments generally aim to maximize crop production by over-extending the capabilities of the available and limited source of water. In many of the arid and semiarid regions, ground water is the only available source of water. Over-extension of ground water, i.e. lack of balance maintenance between withdrawal and recharge, leads to the so called "ground water mining" phenomena and eventually results in the depletion of the ground water resources.**

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- **The problem of "ground water mining" has started to show up in many areas of the world. As such, Fars province in southern Iran with mostly an arid and semiarid climate is no exception. Fars province has been a major producer of wheat and barley at the national level. Unfortunately, over the years the production of wheat and barley has maintained its national status in terms of high yield levels, while the ground water depletion problem is becoming more and more an issue of main concern. At the current levels of discharge, it will not take too long before we witness complete ground water depletion levels in many areas of Fars province.**

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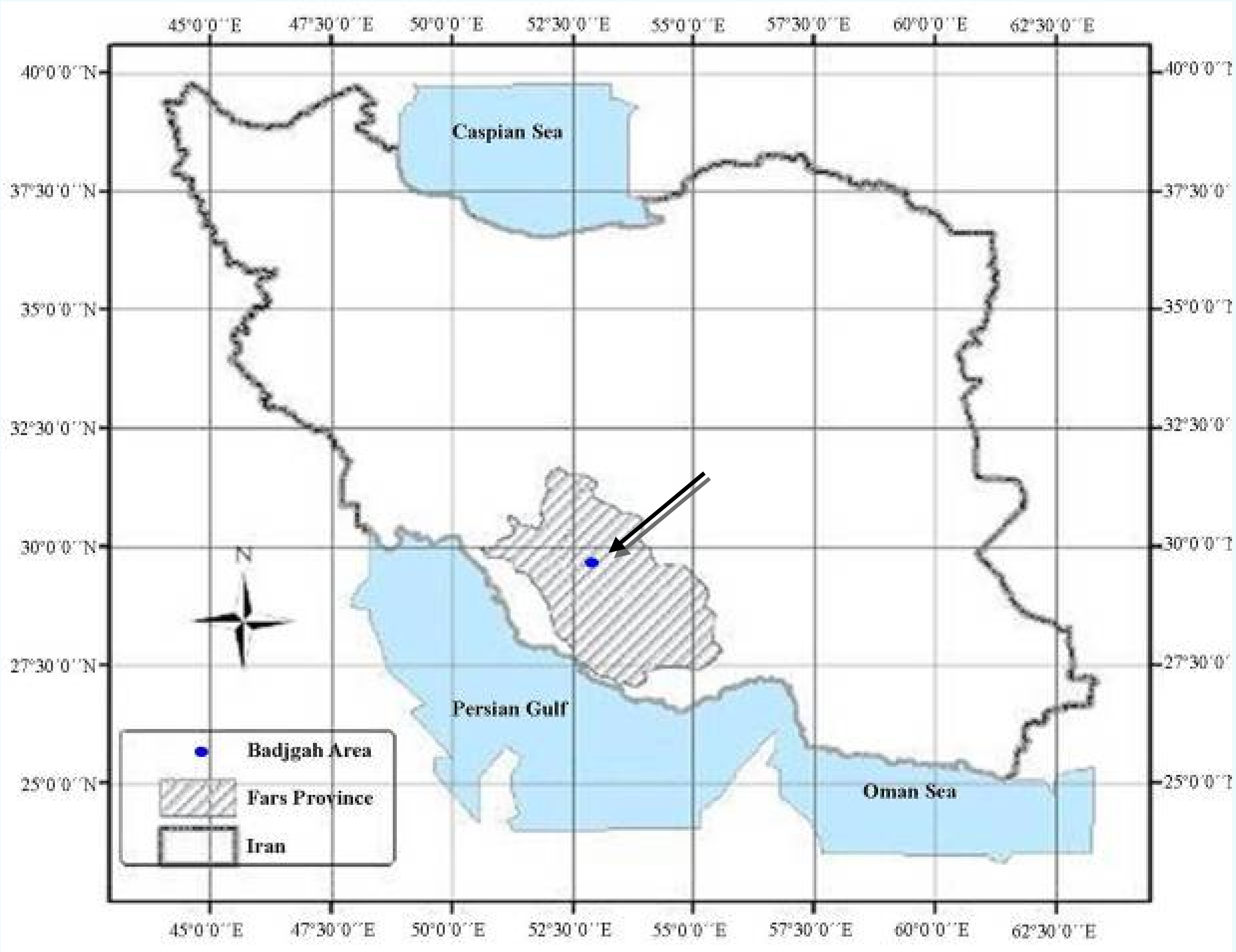

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- Problems associated with ground water levels and the growing need for production of wheat and barley in Fars province call for drastic measures, aimed to utilize all available sources of water.
- In conjunction with irrigated agriculture, studies on agroclimatological land suitability evaluation for dryland farming can help, i.e., dryland farming would be feasible if agroclimatological indicators can justify this type of agricultural practice. For this purpose the ratio of annual rainfall/reference crop evapotranpiration has been used as an agroclimatological index for land suitability classification (Hatfield, 1990). This index provides information on crop biological needs and humidity, rainfall conditions, and heat sources.
- When possible, relationships between crop yield and agroclimatological indices can also help with better land suitability selection.
- The findings of a previous research on utilization of rainfall/reference crop evapotranpiration, as an agroclimatological index for regional land classification in Fars province will be presented.

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- **Regional classification of land suitability for dryland farming can be more effective if details on "site specific" soil moisture storage are also available. Site specific soil moisture temporal variability measurements (on short-term and long-term basis), are useful in irrigation planning or dryland farming. In such a case "effective rainfall" or “agricultural effective rainfall”, i.e., portion of the rainfall stored in the root zone for plant use, can be evaluated.**

- **Soil moisture studies can also be used to justify land fallowing, a common practice in dryland farming, whereby land is fallowed for one season in order to conserve rainwater for the next crop (Hillel, 1994). In such cases “fallow efficiency”, a measure of percentage of moisture stored in the soil in a fallowed land over a specific time period is evaluated.**

- **The findings of previous research on soil moisture storage over time at the Agricultural Experimental Research Station of Shiraz University, Badjgah will be presented.**

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- Development of agroclimatological land classification maps and site specific studies on soil moisture storage can be used to designate areas most suitable for aridland farming. However, for the cases of limited available water irrigation can be applied along with rainfall, for certain crops. In such cases studies on crop water stress levels can be useful in irrigation scheduling.

- Understanding the effect of water stress on physiological activities and yield of agricultural crops requires evaluation of the plant as it responds to its surrounding environment. In such cases information on green cover temperature can be used as a tool to identify the physiological stress level of the plant, and when necessary, to plan for irrigation. This type of information can be developed based on site specific studies.

- For the first time feasibility of saffron production in Badgah will be discussed, based on the findings of previous at the Agricultural Experimental Research Station of Shiraz University, Badjgah.

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Development of agroclimatological indices

- **Fars province is located in southern Iran, at the 50º30′ – 55º38′ longitude and 27º3′-31º42′ latitude, with elevation changing from higher than 3900 m to less than 500 m a.s.l. Winter precipitation in the north-west area is as snow, but for other areas is mostly as rainfall. The mean annual precipitation for the province is in the range of 50-1000 mm (MPB, 1994). Rainfall (P) and reference crop evapotranspiration (ET_o) values were used to calculate (P/ET_o) ratios as an agroclimatological index. ISO-(P/ET_o) lines were plotted on the map of the province for area identification (Sadeghi, 1998; Sadeghi et al. 2002).**

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Site specific temporal soil moisture studies

- The study was carried on a site located at the Agricultural Experimental Research Station of Shiraz University, . The study area is characterized as semi-arid with a mean annual rainfall of 410 mm. Mean annual maximum and minimum temperatures are 26 ºC, and -0.5 ºC, respectively. The study period was for two consecutive years (1996-97 and 1997-98). Annual rainfall depths were 290 mm and 541 mm, respectively, so that the effect of below- and above-average rainfall could be studied. For the study area, one rainy season exists, which starts in early November and ends by late April.

- Two basins (8 by 8 m^2), with almost no slope were prepared. The natural environment for rainfall infiltration was maintained and site boundaries were prepared to contain runoff. Aluminum pipes were installed at two locations in each basin for neutron probe (Troxler-Model 2651), for readings down to a depth of 150 cm. One basin remained fallow during the study period, while the other one was cultivated with wheat. Weed control was done manually (Khalili et al. 2001).

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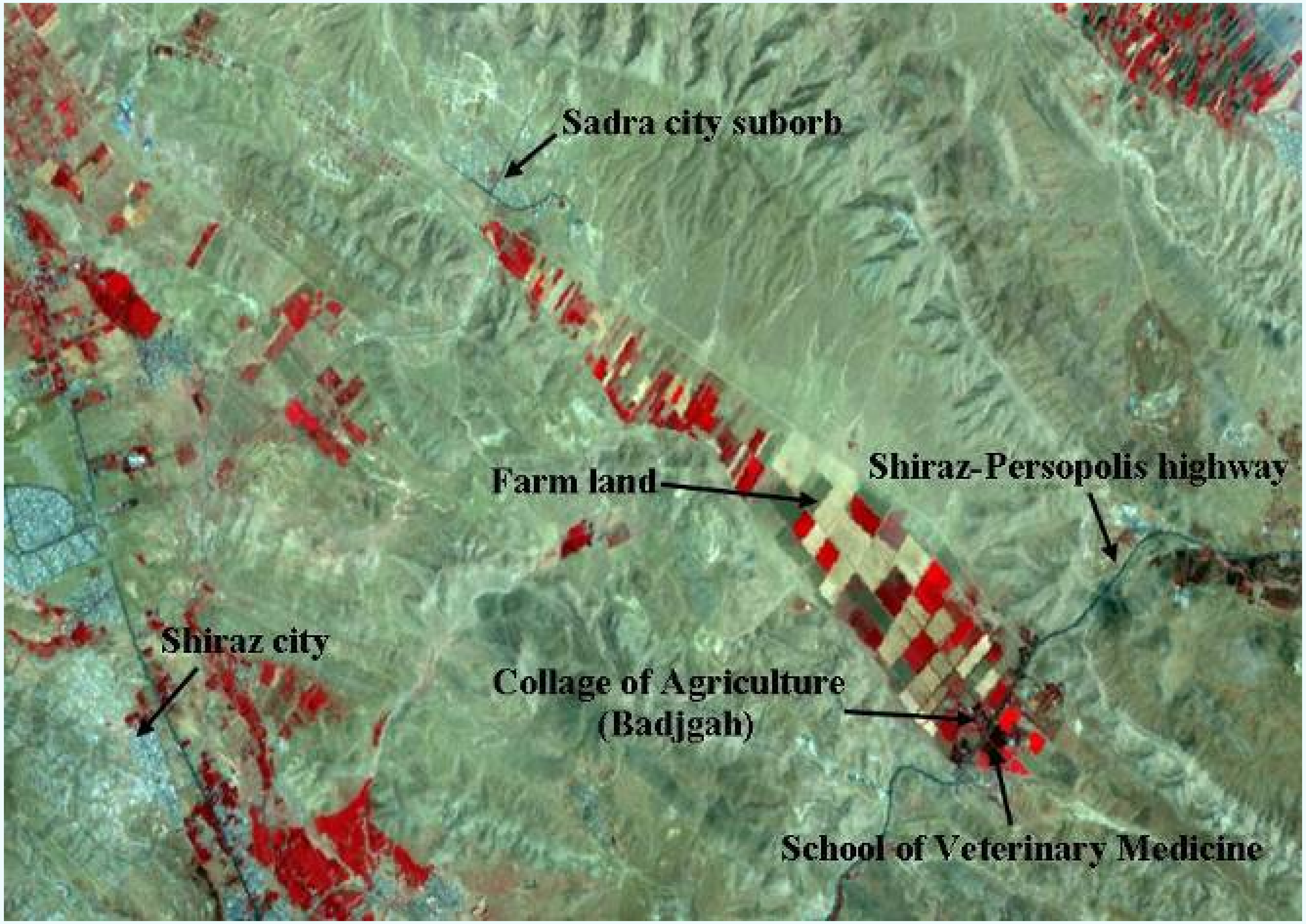

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Saffron crop water stress studies

- The research on saffron water stress was conducted at the Agricultural Experimental Research Station of Shiraz University, . The experimental design set up (864 m^2) was complete randomized block with four replications. Basin and furrow irrigation methods were used and irrigation water was applied at the 100%, 75% and 50% of the potential evapotranspiration of saffron. One sub-plot was used as the "no-irrigation" case. Planting was on late August and early September, 1998 (Azizi Zohan, 2000). Fertilizer as manure was given at the rate of 22.5 tonnes ha^{-1}. Before the first irrigation soil moisture deficit was measured at the 45 cm root zone, and first irrigations were on October 19, 2000 and 2001, respectively. Harvesting was during October of 2000 and 2001. Canopy temperature was measured by infrared thermometry.

- In order to relate plant water stress to canopy temperature, the procedures by Idso, et al. (1982) were used. In this case the “lower limit” linear relationship between differences in green cover and surrounding air temperature (*Te – Ta*) and vapor pressure deficit (*VPD*) was developed. *VPD* (mb) was estimated as a function of relative humidity. The “lower limit” linear relationship was based on data from the "no stress" plot (Shirmohamadi et al. 2006):

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$$T_e - T_a = a - b * VPD$$

Te **and** ***Ta*** **are green cover and surrounding air temperatures (°C),**
a, b **are regression coefficients.**

- **The** ***CWSI*** **was calculated as:**

$$CWSI = \frac{(T_c - T_a)_m - [a - b(VPD)_m]}{(T_c - T_a)_{ul} - [a - b(VPD)_m]}$$

(Tc-Ta)$_m$ **is the difference in surrounding air and green cover temperature, measured at time** ***m*****;**

(Tc-Ta)$_{ul}$ **is the "upper limit" temperature was based on the mid-day difference between green cover and air temperatures of the driest plot.**

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Data Collection and Analysis

- **For study on agroclimatological evaluation, data on daily rainfall and class A pan evaporation were obtained for 52 stations from the archives of the Fars Regional Department of Water Resources, and a study period of 15 years (1978-1992) was selected. This minimum period is suggested in similar studies (Reddy, 1983a). Data quality controls were done through available testing procedures (Bobee & Ashkar, 1991; Mahdavi, 1995).**
- **Monthly reference crop evapotranspiration was calculated using the pan coefficient (K_{pan}) method, proposed by Doorenbos & Pruitt (1977). P and ET_o values were used to calculate (P/ET_o) on the average annual and average fall season basis, and the ISO-(P/ET_o) lines were plotted.**
- **Statistical distributions of monthly rainfall (P) and evapotranspiration (ET_o) values were determined for defining critical probability levels of P and ET_o on the average annual and average fall season basis. Probabilistic ISO-(P/ET_o) lines were plotted.**
- **Data on dry land yield of wheat and barely for nine stations, for the period of 1981-1992, were obtained from Fars province Department of Agriculture (FPDA, 1997). Dry land yields of wheat and barely as a function of annual (P/ET_o) were investigated.**

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Data Collection and Analysis

- For soil moisture study data collection started on October 23, 1996 and ended on October 19, 1998. Soil moisture readings by neutron probe were done for two-week intervals at 15 cm depths and equivalent volumetric soil water content were obtained based on a locally calibrated relationship. At two-week intervals the change in volumetric water content was measured, to evaluate equivalent depth of water for each 15 cm of soil. These values were summed over the 150 cm soil depth, representing agricultural effective rainfall.
- For the study on crop water stress, during 2000 – 2001, and 2001 – 2002, nine days were selected and air temperature, wet bulb temperatures and canopy temperature were recorded for all of the plots (during the 13:00 to 14:00 hours). Canopy temperature was measured by infrared thermometry.

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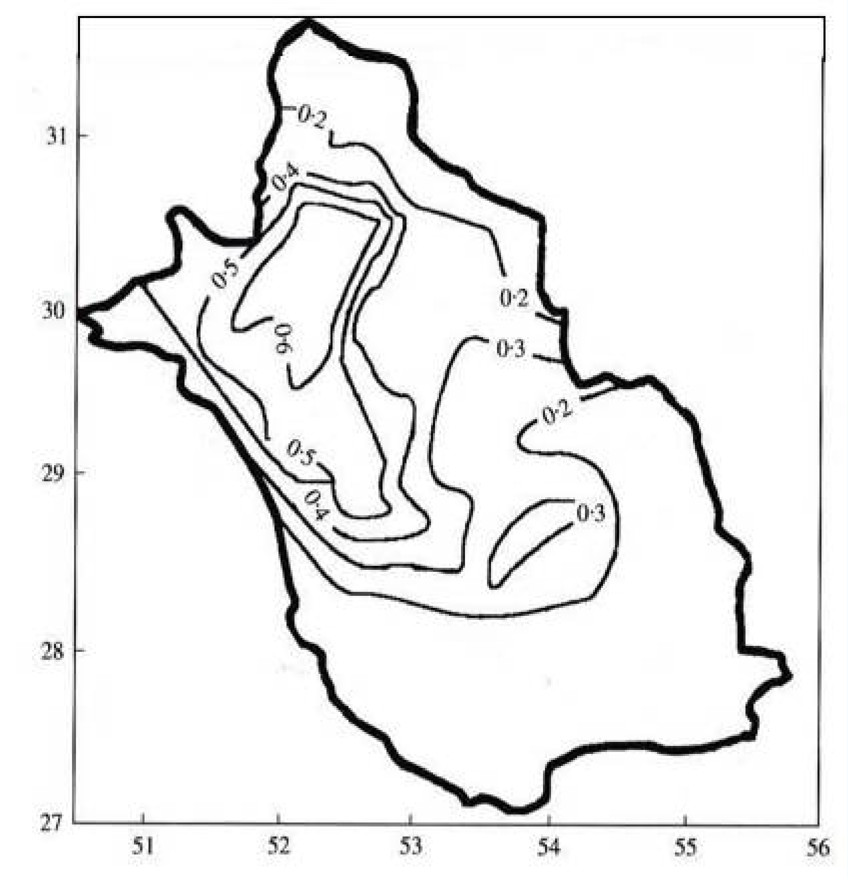
Average annual ISO-(P/ET_o) lines.



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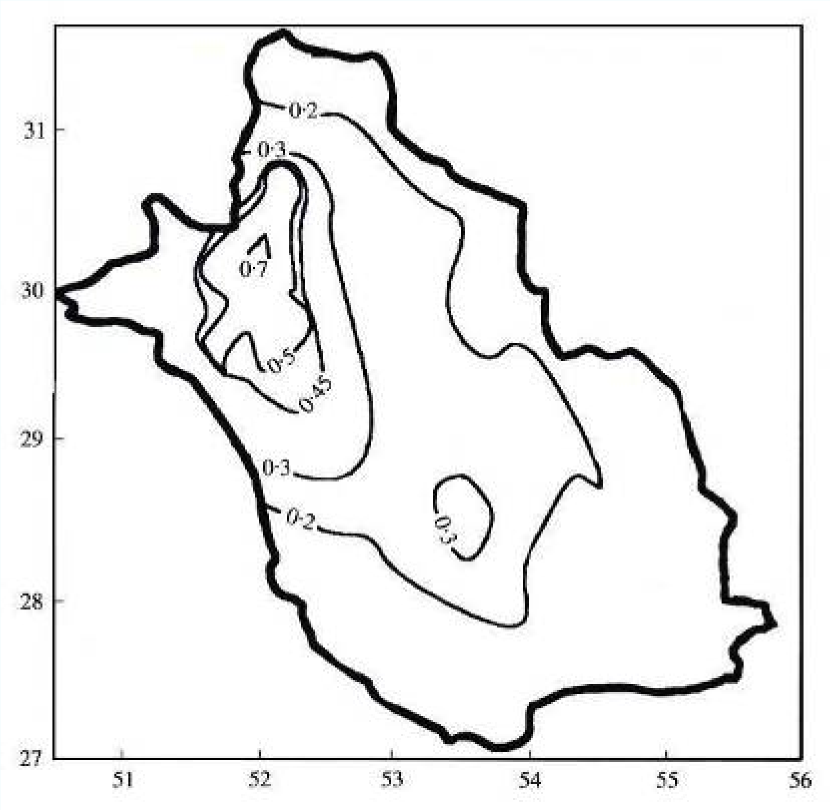
Average fall season ISO-(P/ET$_o$) lines.



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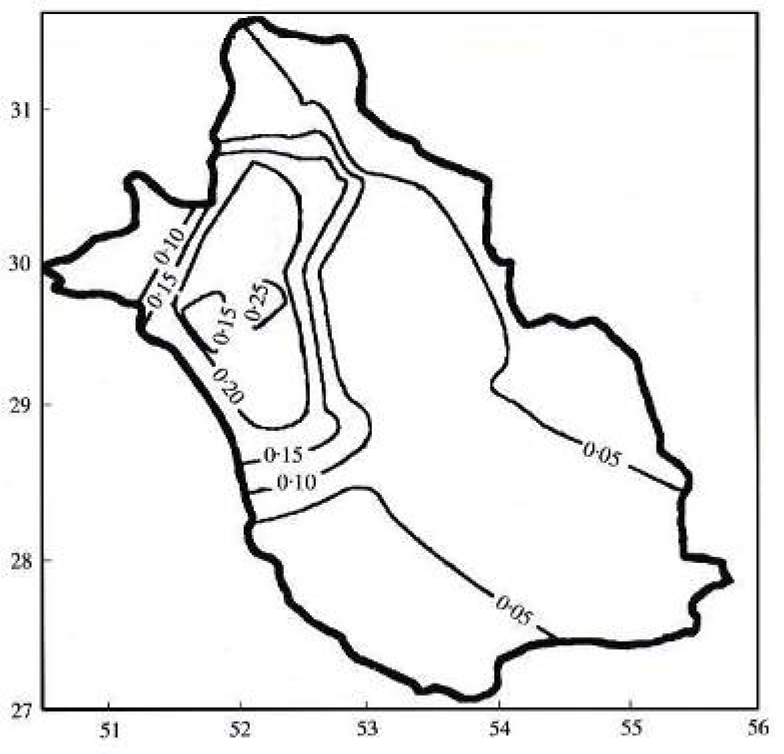
Annual probabilistic ISO-(P/ET_o) lines, at 90% P and 10% ET_o



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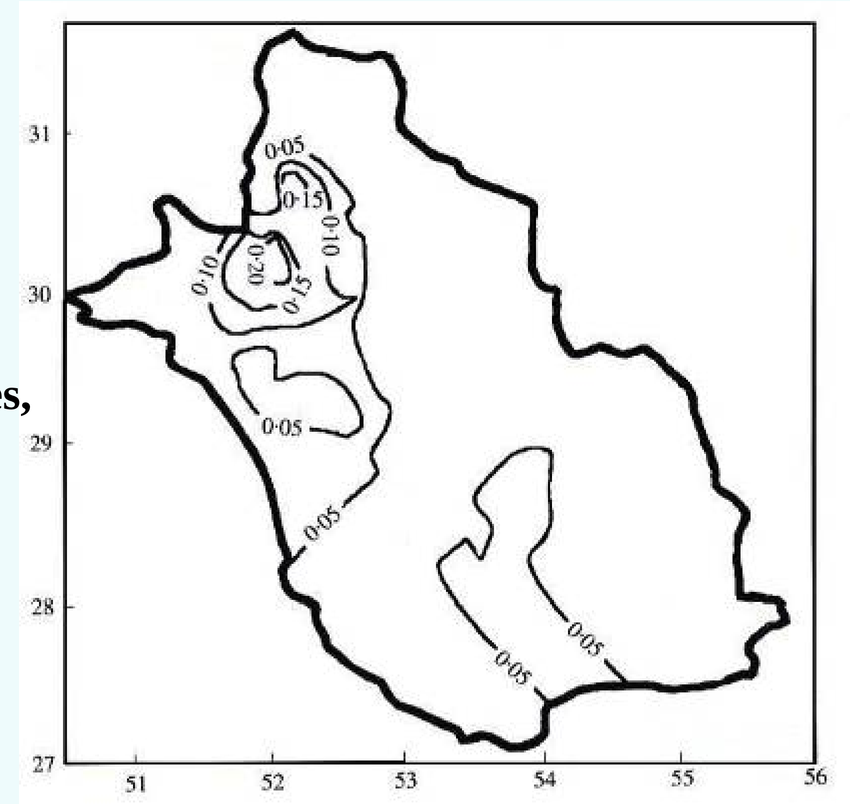
Average fall season probabilistic ISO-(P/ET_o) lines, at 90% P and 10% ET_o



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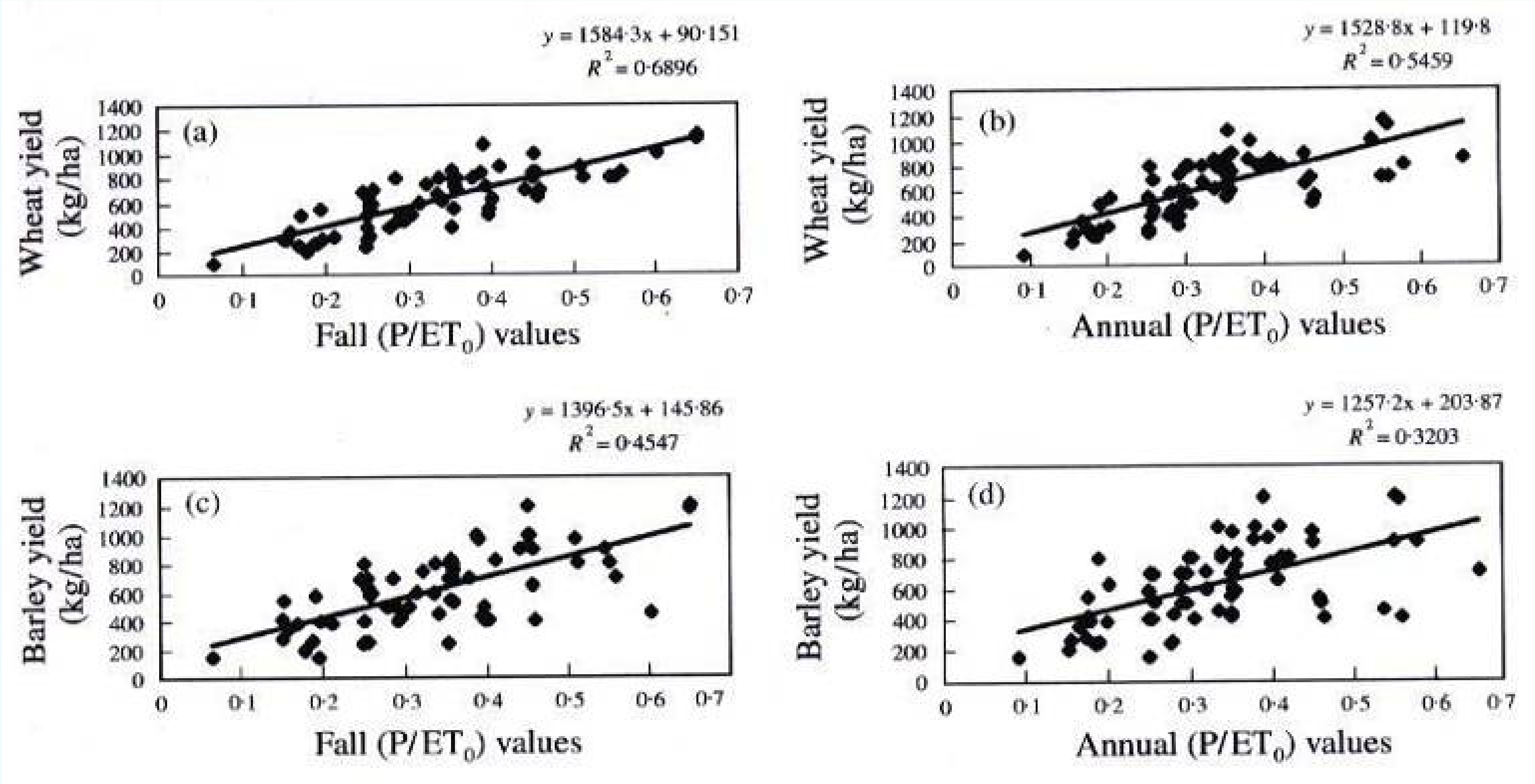
Relationships between crop yield and ISO-(P/ET_o)



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- The average annual atlas, including all of the crop growth stages should be used for land selection. The average seasonal atlas can be used a source of information during the seed germination stage. In conjunction with the average annual atlas, regional yield potential can be useful in land selection.
- North-western areas with annual ISO-(P/ET_o) lines of 0.6 are identified as the most suitable, with an expected yield of 1000 $kgha^{-1}$. The central parts of the province show average (P/ET_o) values in the range 0.2-0.6, suggesting that these areas are suitable, but with yields of lower than 1000 $kgha^{-1}$. Areas with average (P/ET_o) values of less than 0.2 are not suitable for dry land farming.
- An extreme case, i.e., the annual (P/ET_o) ratios based on a rainfall with 90% probability of occurrence and ET_o with 10% probability of occurrence was considered, to evaluate occurrence of a rare situation. Locations with average annual ISO-(P/ET_o) lines of at least 0.2 are the most suitable areas for dryland farming (north-western part).
- Use of water by wheat and barely for most of the winter season is at a minimum level, since the plant is at the dormancy stage. But late in winter during tillering and booting stages, and also early in the spring, plants develop an increasing demand for moisture. With spring rainfall generally having a minor contribution, much needed moisture for crop growth comes from the winter rainfall.

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Site specific soil moisture temporal variability

Soil information at the start of cultivation season (fallow condition).

Soil depth (cm)	FC (%)*	SM_1 (%)	SM_2 (%)	SM_3 (%)	PWP (%)
0-15	31.7	6.4	7.0	7.91	18.0
15-30	33.1	11.0	10.6	12.3	18.6
30-45	32.9	20.5	21.1	24.6	17.6
45-60	32.7	26.2	26.3	28.3	17.5
60-75	33.6	26.0	28.6	28.6	18.5
75-90	33.5	24.3	29.7	30.7	17.3
90-105	29.6	24.2	26.2	31.1	15.8
105-120	31.3	23.1	24.3	30.0	16.0
120-135	33.4	22.5	24.3	30.0	15.6
135-150	35.3	20.5	21.1	32.7	18.8

***FC = Field capacity, PWP = Permanent wilting point, SM_1, SM_2, and SM_3 = soil moisture values at the start of cultivation season, for October 23, 1996, October 21, 1997 and October 19, 1998, respectively, on percent volume basis.**

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Soil information at the start of cultivation season (cultivated condition).

Soil depth (cm)	FC (%)*	SM_1 (%)	SM_2 (%)	SM_3 (%)	PWP (%)
0-15	30.9	5.5	5.6	6.0	17.2
15-30	32.3	9.8	9.6	11.7	19.0
30-45	30.3	14.9	19.7	20.2	17.3
45-60	31.1	22.5	23.8	24.3	17.4
60-75	32.5	25.4	24.2	25.8	18.7
75-90	34.5	26.2	24.8	24.8	18.5
90-105	31.8	25.5	24.2	25.9	16.6
105-120	29.3	24.5	22.2	26.3	15.4
120-135	32.9	22.8	21.9	26.7	15.3
135-150	34.9	21.7	21.1	26.3	16.8

***FC = Field capacity, PWP = Permanent wilting point, SM_1, SM_2 and SM_3 = soil moisture at the start of season (October 23, 1996, October 21, 1997 and October 19, 1998)**

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Efficiency of soil water conservation under fallow and cultivated conditions

	Fallow condition	Cultivated condition
October 23, 1996 DSW* (cm):	30.7	29.8
October 21, 1997 DSW (cm):	32.1	29.6
1996-97 fallow efficiency (%):	4.4	---
1996-97 non-fallow efficiency (%):	---	-0.7
October 21, 1997 DSW (cm)	32.1	29.6
October 19, 1998 DSW (cm)	38.3	32.7
1997-98 fallow efficiency (%):	16.2	---
1997-98 non-fallow efficiency (%):	---	9.5

*** DSW = Depth of soil water at the start of cultivation season.**

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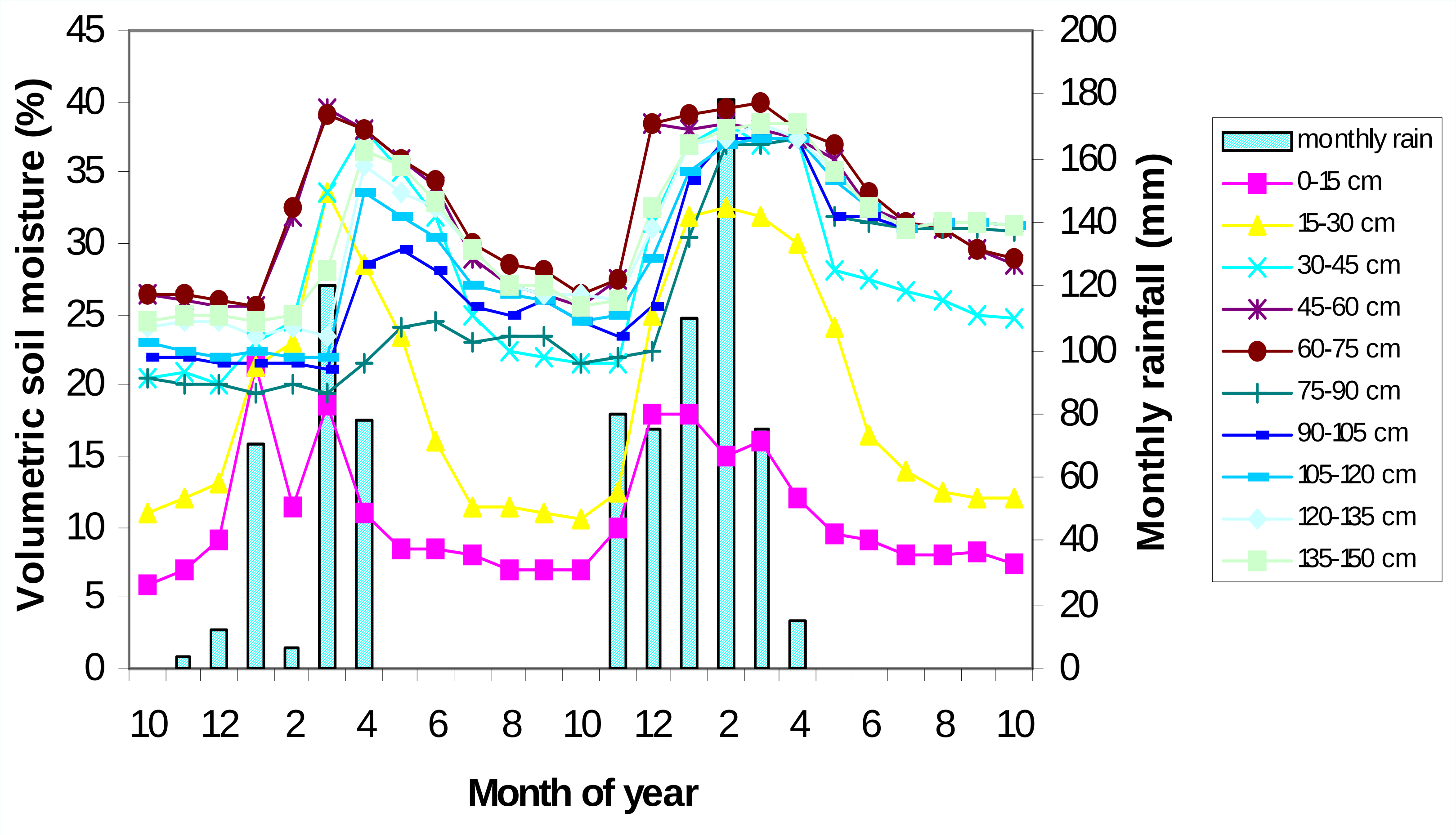

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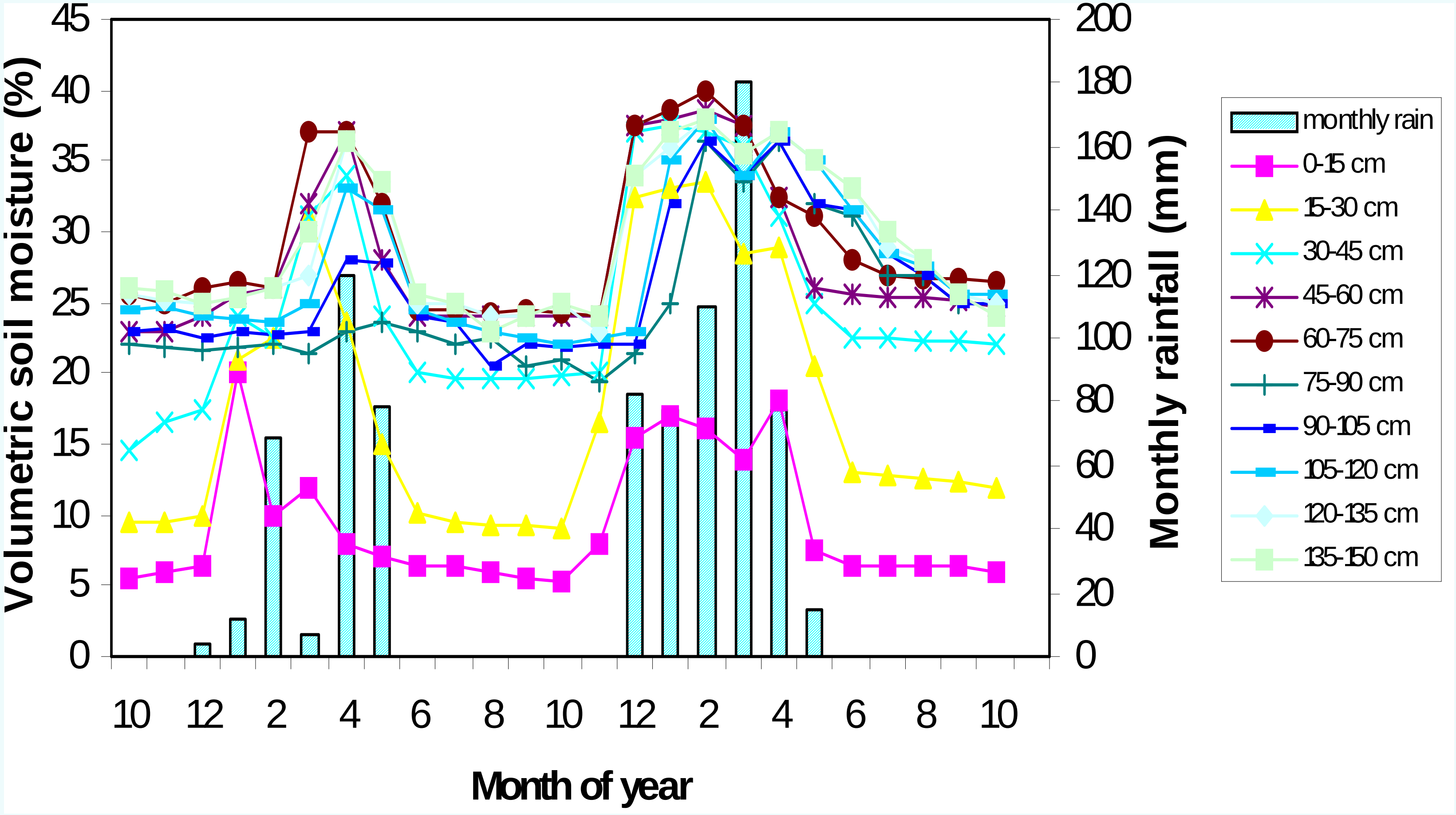

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- **Soil moisture conservation at the end of the first year is minimal, based on the SM_2 and SM_1 values. Soil moisture conservation at the end of the second year shows a slight increase based on SM_3 and SM_2 values.**

- **Fallow efficiencies were 4.4 and 16.2%, while non-fallow (cultivated) efficiencies were 0.7 and 9.5%, respectively, for the two consecutive years (Table 3). Calculated fallow efficiencies do not support land fallowing in the study area. In a similar study in semi-arid southern California, a fallow efficiency of 17% with improved infiltration was reported, and land fallowing was not recommended (Luebs and Laag, 1971).**

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Saffron crop water stress study

$T_e - T_a = 12.2 - 0.25 * VPD,$ ***SE =0.31, p=9.2E-24, R2 = 0.95***

SE **is the standard error of estimate,** ***p*** **is the significance level and** ***R2*** **is coefficient of determination.**

The "upper limit" temperature for saffron was 11 ^{0}C.

Crop coefficients for the "lower limit" equation (Idso, 1982; present research).

Crop	Slope	Intercept
Alfalfa	-1.92	0.51
Barely	-2.25	2.01
Bean	-2.35	2.91
Corn	-1.97	3.11
Cotton	-2.09	1.49
Cucumber	-2.52	4.88
Lettuce	-2.96	4.18
Potato	-1.83	1.17
Soybean	-1.34	1.44
Tomato	-1.96	2.86
Wheat	-2.11	2.88
Saffron in Badjgah area	-0.25	12.2

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Calculated coefficients for saffron are quite different from the listed crops. This is because saffron's leaves are long and narrow with a tendency to lay down on the ground, also transpiration by saffron is much smaller than many of the agricultural crops.

Calculated $CWSI_s$ for different irrigation treatments.

Date	100% Evapotranspiration	75% Evapotranspiration	50% Evapotranspiration	Dryland
Jan. 1, 2001	0	0.08	0.21	1
Feb. 26, 2001	0.05	0.24	0.62	1
Mar. 11, 2001	0.25	0.75	0.78	1
Apr. 1, 2001	0.05	0.12	0.2	0.97
Dec. 31, 2001	0.01	0.17	0.5	0.67
Feb. 2, 2002	0.02	0.26	0.75	1
Mar. 5, 2002	0	0.2	0.73	1
Mar. 22, 2002	0	0.33	0.83	0.83
Mar. 31, 2002	0	0.3	0.8	0.8
Mean value	**0.04**	**0.27**	**0.6**	**0.92**

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$$CWSI = 1.06\left(1 - \frac{Y_a}{Y_m}\right),$$

SE =0.08, p=6.8E-11, R2 = 0.96

Y_a and Y_m are actual and maximum yield (flower production) in a given treatment and the "no-stress" treatment, respectively.

Saffron yield for the 100%, 75% and 50% treatments were 5.4, 4.1 and 3.1 kg ha^{-1}, respectively.

According to the results when *CWSI* = 0.04, it is time to irrigate. If deficit irrigation is intended, for up to 25% reduction in yield, a *CWSI* = 0.27 can be applied.

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- *Thank you for your attention*