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COMPARISON OF ALTERNATIVE METHODS FOR ESTIMATING *ETp* AND EVALUATION OF ADVECTION IN THE BAJGAH AREA, IRAN

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ABSTRACT

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This paper seeks to characterize the impact of advected energy on evaporation behaviour of irrigated lucerne in the arid region of southern Iran. A set of monthly coefficients are presented to account for enhanced rates of evaporation due to divergence in sensible heat flux caused by horizontal transport of dry, hot air over an irrigated field. The coefficients are presented for irrigation scheduling estimates based on Class A pan evaporation.

INTRODUCTION

Net radiation is the only source of energy to determine the maximum amount of evapotranspiration in humid areas, but in regions with sub-humid to arid climates, in addition to net radiation, advection or horizontal transfer of sensible heat from surrounding areas plays a major role in supplying additional energy for evapotranspiration. In an extended region, the surrounding areas may be fallow or covered with native vegetation. When the transfer of sensible heat from surroundings affects only 20–200 m of the irrigated regions (upwind fetch = 20–200 m), it is called "local advection" or "border or clothes-line effect" (Dyer and Crawford, 1965). When this effect covers a vast area, it is called "large-scale or regional advection" or "oasis effect" (McIlroy and Angus, 1964).

Knowledge of the presence or absence of advection in each region is essential for precise and economic planning and designing of water supply and irrigation scheduling. In general, when the estimated or measured potential evapotranspiration (*ETp*) during a week or more is greater than net radiation (*Rn*) during that period, the existence of advection is proved (Brakke et al., 1978).

The existence of advection has been studied by Abdel-Aziz et al. (1964), Rosenberg (1969), Hanks et al. (1971), Verma et al. (1977), Sepaskhah and Reissi (1979), Hashemi and Habibian (1980) and Malek (1982). Empirical and combination methods of estimating *ETp* are not sensitive to advection, so *ETp* is

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underestimated by up to 40% in comparison with *ETp* measured by lysimeters during the same period (Hanks et al., 1971). Sepaskhah and Reissi (1979) showed that the daily water consumption (measured by the water-balance method) of sugar beet was 80% greater than Class A pan evaporation in southern Iran during July and August. Hashemi and Habibian (1980) reported that due to regional advection, estimated *ETp* by Class A pan was three times *Rn* in southern Iran during the warmest months. Malek (1982) showed that *ETp* measured by lysimeter was 85% greater than *Rn* in the Bajgah area during July. Lang (1973) and Verma et al. (1977) modified the Bowen-ratio in the energy balance method of estimating *ETp* and proposed formulae for computing local and regional advection.

In this investigation, alternative methods of estimating *ETp* are compared, the existence of advection is proved by using lysimetric data, and new coefficients are proposed to convert evaporation from Class A pan to *ETp* during advection.

MATERIALS AND METHODS

This investigation was conducted in a 4-ha (400 × 100 m, with the longest length in the direction of the westerly prevailing wind) field of 3-years alfalfa (*Medicago sativa*, L.) in the Bajgah Area (29°32′ N, 52°35′ E, altitude 1810 m), a sunny high level valley in the Fars Province of Iran. Daily meteorological data, such as temperature (*T*), humidity (*RH*), wind speed at 2 m height (*U2*), sunshine duration (*n*), solar radiation (*Rs*), and Class A pan evaporation (*Ep*), were collected during the period 1967–1979.

Evapotranspiration of two water-balance type lysimeters (*ETa*) was measured in the middle of the field during the growing season of 1972–1973. Table I shows some physical characteristics of soil in lysimeters and in the field. The depth of the large lysimeter was 170 cm, and that of the small one was 100 cm. The diameters were 150 and 56 cm, respectively.

Crop populations were the same in lysimeters and in the field, and were irrigated at the same time during the growing season (March–October). Knowing the climatic type of this agricultural experiment station which is arid (Malek, 1982), the amounts of net radiation (*Rn*) were computed using the

TABLE I

Some physical properties of soil in lysimeters and in the field

Depth (cm)	Texture	Bulk density ($g\,cm^{-3}$)	Field capacity *fc* (%)	Wilting point *wp* (%)	*FI*[a] ($cm\,h^{-1}$)
0–15	Clay loam	1.46	24.0	15.6	1.32
15–60	Silty clay loam	1.52	24.7	15.3	
60–120	Silty clay	1.59	25.8	17.0	

[a] Final intake rate.

TABLE II

Some climatic data during the growing season of 1967–1979

Month	T (°C)	RH (%)	$U2$ (m s^{-1})	n (h)	Rs (mm)	Rn (mm)	G (mm)[a]
March	7	60	2.5	6.4	238	124	− 16
April	15	53	2.4	7.1	273	150	− 16
May	19	52	2.3	10.1	360	190	− 10
June	21	45	2.1	11.1	380	211	− 8
July	23	42	1.8	10.2	359	203	− 1
August	22	40	1.7	10.0	347	186	+ 7
September	18	43	1.6	9.9	311	146	+ 11
October	15	46	1.5	9.2	269	109	+ 13

[a] Soil heat flux.

appropriate equation (Jensen, 1973). Table II shows some of the climatic data obtained from the agrometeorological station situated in the middle of the alfalfa field during the period 1967–1979 (Malek, 1979; Malek, 1983).

To compare the alternative methods of estimating ETp, the following methods were used:

(a) Thornthwaite method (Thornthwaite, 1948):

$$ETp \;=\; 16Ld(10T/I)^{a} \tag{1}$$

where ETp and T are potential evapotranspiration in mm month^{-1} and mean monthly temperature in °C, respectively. Ld is the correlation factor for length and number of days in a month expressed in units of 30 days of 12 h, I is seasonal heat-index and a is a function of I. Values of Ld, I and a can be found in the appropriate tables.

(b) FAO-modified Blaney–Criddle (Doorenbos and Pruitt, 1977):

$$ETp \;=\; c(p(0.46T + 8.13)) \tag{2}$$

where ETp, p and T are daily potential evapotranspiration in mm, percentage of annual daytime h day^{-1} and mean monthly temperature in °C, respectively. c is a function of daytime wind (Uday), n/N and RH_{min}. N is maximum possible sunshine duration. Values of c can be found from appropriate equations or graphs (Hillel, 1983).

(c) FAO-modified Penman (Hillel, 1983):

$$ETp \;=\; c\left(\frac{\Delta}{\Delta + \gamma}(Rn + G) + \frac{\gamma}{\Delta + \gamma}(0.27)(1.0 + U2/100)(es - ea)\right) \tag{3}$$

where ETp, Rn and G (soil heat flux) are in mm day^{-1}; Δ and γ are the slope of the saturation vapor pressure versus temperature curve and the psychrometric constant in mb °C^{-1}, respectively, $U2$ is in km day^{-1} and es and ea are saturation vapor pressure and actual vapor pressure in mb, respectively. c is a function of U_{day}/U_{night}, RH_{max}, U_{day} and Rs. Values of c can be found from appropriate formulae (Hillel, 1983).

(d) Class A pan evaporation (Jensen, 1973):

$$ETp = Cet \times Ep \tag{4}$$

where ETp and Ep are in mm day^{-1}, and Cet is a function of RH, $U2$ and upwind fetch. Values of Cet can be found from appropriate tables.

(e) Calibrated Jensen–Haise (Jensen, 1973):

$$ETp = Rs(0.028T + 0.316) \qquad ((5)$$

where ETp and Rs are in mm day^{-1} and T is in °C. The constants were derived using the local conditions.

Calculated amounts of ETp using Eqs. 1–5 during the growing season of 1967–1979 are shown in Table III.

The gravimetric method (0–22.5-cm depth) and a neutron scattering meter (22.5–112.5 cm) were used to measure the amount of actual evapotranspiration (ETa) in lysimeters during the growing season of 1972–1973. ETa was measured by the following equation (Jensen, 1973):

$$ETa = \left(I + P - D + \sum_{i=1}^{n} \frac{\theta 1 - \theta 2}{100} \Delta Si\right) \Big/ \Delta t \tag{6}$$

where I, P and D are irrigation, precipitation and deep-percolation (in mm) from the effective root zone, respectively; and n is the number of layers (in this investigation eight). Variation of soil moisture below 112.5 cm in the large lysimeter and in the field were negligible during the growing season (Bahrani and Malek, 1972). ΔS is the thickness of each layer in mm, $\theta 1$ and $\theta 2$ are volumetric percentages of soil at times 1 and 2 and Δt is the time interval between two consecutive measurements in days. D was measured in the underground room from drain tubes which were connected to lysimeters (Malek, 1974). To convert ETa from lysimeters to ETp for the same growth stage, the following relationship was used (Jensen, 1973; Hillel, 1983):

$$ETa = Ks \times ETp \tag{7}$$

where $Ks = Ln(AW + 1)/Ln(101)$, available water $= AW = 100(d - dwp)/(dfc - dwp)$, and d, dfc and dwp are depths of water at the time when measure-

TABLE III

Calculated ETp, in mm, for eqs. 1–5 during the growing season of 1967–1979

Month	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Oct.	Total
Thornthwaite	23	68	102	116	134	120	83	61	707
FAO Blaney–Criddle	75	130	183	198	214	195	156	124	1275
FAO Penman	94	138	190	220	235	205	155	107	1344
Class A Pan	75	152	204	229	216	198	174	100	1348
Jensen–Haise	122	201	305	344	345	323	255	198	2093

ment was carried out, at field capacity and at wilting point in the effective root zone, respectively.

Irrigation was applied when, on average, 55% of *AW* was depleted (irrigation system was border strip and there were generally 12 irrigations and six cuts during the growing seasons).

RESULTS AND DISCUSSION

Using the data in Table III, the amounts of monthly *ETp* are shown in Fig. 1. This figure shows that computed *ETp* by the Thornthwaite and Jensen-Haise methods are very low and high, respectively, in comparison with other methods. Statistical analyses show a highly significant correlation at the 1% level between computed *ETp* (obtained by Class A pan or FAO-modified Penman) during the growing season of 1972–1973 and those estimated during the growing season of 1967–1979.

Since Class A pan can be constructed locally and estimation of *ETp* can be obtained only by knowing the upwind fetch of green crop and average daily values of *RH*, *U2* and *Ep*, so Class A pan evaporation method and the lysimetric data during the growing season of 1972–1973 were chosen for evaluation of advection in this area. Using the data in Table II and the appropriate table (Jensen, 1973), the average monthly value of Class A pan coefficient, *Cet*, was 0.75 for the whole growing season.

The actual evapotranspirations measured by large and small lysimeters, *ETaL* and *ETal*, respectively, are shown in Fig. 2 during the growing season of 1972–1973. The measurement intervals were 8 days in the early and late growing season and were decreased to 5 days in July and August. Equations 6, 7 and 8 were used to convert the amounts of *ETaL* and *ETal* to *ETpL* and *ETpl* for

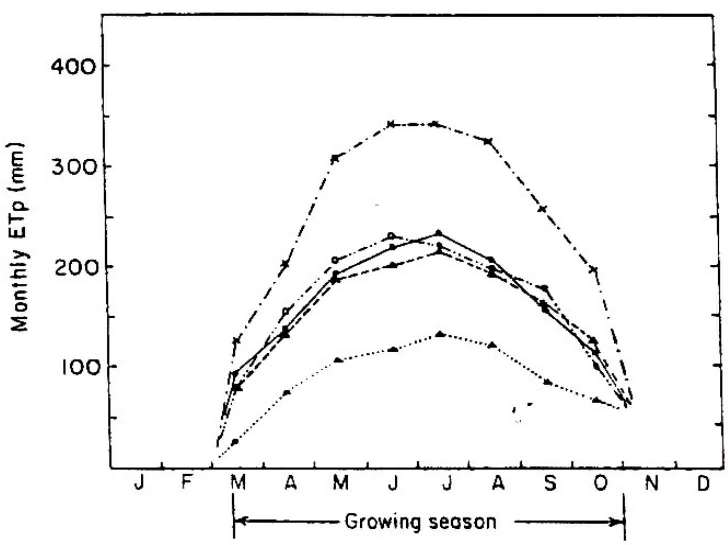

Fig. 1. Computed *ETp* during the growing seasons of 1967–1979. *–·–·–* Jensen–Haise; o–··–··–o Class A pan; ●——● FAO Penman; △– – –△ FAO Blamey–Criddle; ▲ · · · · ▲ Thornthwaite.

TABLE IV

Monthly values of *ETa* and *Ks* and *ETp* for large and small lysimeters during the growing season of 1972–1973

Month	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Oct.	Total (mm)
ETaL	73	149	204	255	275	236	174	100	1456
ETaL	47	129	188	245	265	212	200	75	1361
Ks	0.89	0.89	0.88	0.83	0.82	0.83	0.88	0.93	
ETpL	82	167	232	307	335	272	198	108	1701
ETpl	53	145	214	295	323	256	227	81	1594

the same growth stages. Table IV shows the monthly *ETaL*, *ETal*, *Ks*, *ETpL* and *ETpl* during the growing season. The regression method was used to find the variability between evapotranspiration measured by large and small lysimeters. Statistical results show a significant correlation ($r = 0.895$) at the 1% level between *ETa* measured by these two lysimeters (see Fig. 2). In this investigation, *ETpl* is considered for the following discussion.

If the monthly values of *ETpL* are compared with the values of potential evapotranspiration by Class A pan (*ETpp*), it can be seen that *ETpL* is much greater than *ETpp* during the warm months (Table VI). This can be attributed to the advection of sensible heat flux caused by horizontal transfer of dry, hot air of the prevailing westerly wind. Considering the upwind fetch of 200 m in this investigation, this advection can be considered as a regional one. This result agrees with many reports of the existence of regional advection in

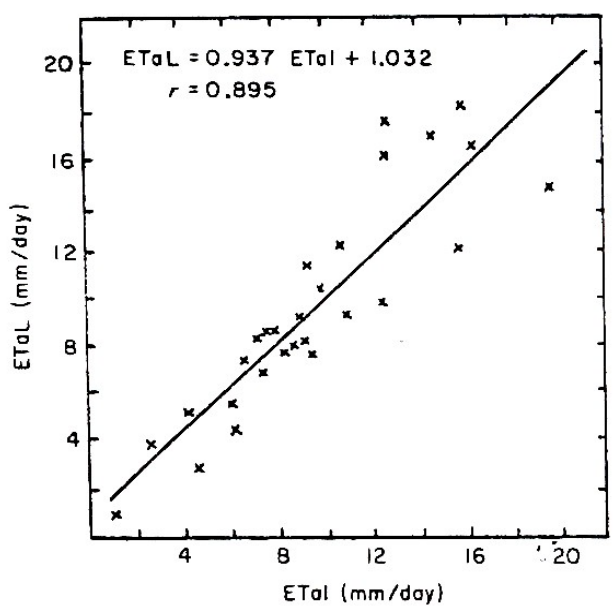

Fig. 2. The relation between *ETa* measured by large and small lysimeters during the growing season of 1972–1973.

TABLE V

Values of *ETpL*, *Rn* and *ETpL/Rn* during the growing season

Month	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Oct.	Total (mm)
ETpL	82	167	232	307	335	272	198	108	1701
Rn	124	150	190	211	203	186	146	109	1319
ETpL/Rn	1.00	1.12	1.22	1.46	1.65	1.46	1.35	0.99	

TABLE VI

ETpL, *ETpp*, percentage of underestimation by Class A pan and amounts of correction factor, α

Month	Apr.	May	June	Jul.	Aug.	Sept.	Average
ETpL (mm)	167	232	307	335	272	198	
ETpp (mm)	152	204	229	216	198	174	
Underestimation (%)[a]	9	12	25	36	27	12	20
$\alpha = ETpL/ETpp$	1.1	1.14	1.34	1.55	1.37	1.14	

[a] Percentage of underestimation of reference crop evapotranspiration by Class A pan method during the existence of advection (April–September).

southern Iran (Sepaskhah and Reissi, 1979; Hashemi and Habibian, 1980; Malek, 1982).

Due to existence of regional advection in the area, the traditional irrigation scheduling based on Class A pan evaporation should be changed. Otherwise, this method will underestimate the consumption of water by crops during the warm months, the crops will be stressed, and finally reduction of yield will occur. As a result, new coefficients should be presented for irrigation scheduling based on Class A pan evaporation to account for the effect of regional advection.

To achieve this, first the ratio of *ETpL/Rn* has been calculated during the growing season. The results in Table V show that this ratio is greater than unity from April to September, which means there is regional advection in this area during this period. Table VI represents the amounts of *ETpL*, *ETpp*, percentage of underestimation of consumptive use of water by Class A pan method ($100(ETpL - ETpp)/ETpL$), and correction factor α ($\alpha = ETpL/ETpp$) to convert *ETpp* to reference crop evapotranspiration during the existence of advection.

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Erratum

E. Malek*, 1987. Comparison of alternative methods for estimating ET_p and evaluation of advection in the Bajgah area, Iran. Agric. For. Meteorol., 39: 185–192.

There were two errors on page 190:

Table IV, second row: *ETaL* should read *ETal*
Line 6 beneath Table IV: *ETal* should read *ETaL*

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