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Effect of irrigation regimes and nutrient management on soil water dynamics, evapo-transpiration and yield of wheat (*Triticum aestivum*) in Vertisol

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ABSTRACT

An experiment was conducted with wheat (*Triticum aestivum* L. emend. Fiori & Paol.) grown on a heavy clay soil (Vertisol) for winter season of 1998–99 and 1999–2000, to find out the effect of varying levels of irrigation regimes and nutrients on soil water dynamics, evapo-transpiration (ET), water-use efficiency and grain yield of wheat. The fertilized plots retained less moisture in the soil profile at harvest than the unfertilized ones. Moisture extraction (%) from the top 30 cm soil increased with the increase in irrigation level (from 33.6% in no irrigation to 50.2% in 3 irrigations), while from deeper layers (60–120 cm) it was higher in the manured and fertilized plots (37%) than the plots where no nutrients were applied (24.5%). Evapo-transpiration throughout the growth stages was higher for irrigated plots (303.0 mm) than unirrigated plots (148.7 mm). However, in the unirrigated plots evapo-transpiration reached its peak earlier (between 75 and 90 days after sowing) compared with the irrigated plots (between 90 and 105 days after sowing). At a particular irrigation level evapo-transpiration was higher in the fertilized and manured plots than the unfertilized plots at all the stages of growth. Grain yield increased significantly with the increase in irrigation levels (89.2 and 103.7%) by 3 irrigations over no irrigation in first and second year respectively) and with integrated application of fertilizer and farmyard manure (138.5 and 123.0% by recommended dose of NPK + farmyard manure @ 10 tonnes/ha over the control in first and second year respectively). The evapo-transpiration showed a linear relationship ($R^2 = 0.71$) with the grain yield. The water-use efficiency was highest at no irrigation, followed by 2 and 3 irrigations treatments, whereas it was higher in the fertilized and manured plots than that in the unfertilized plots.

Key words: Evapo-transpiration, Water-use efficiency, Moisture extraction, Grain yield, Wheat, *Triticum aestivum*

Wheat crop (*Triticum aestivum* L. emend. Fiori & Paol.) is highly responsive to fertilizer nutrients. However, response of wheat to nutrients depends primarily on the availability of soil water. Yield of wheat increases with increased application of nitrogen at several levels of irrigation (Hussain and Al-Jaloud 1995). In the present energy crisis, an alternate to fertilizer nutrient in the form of integrated use of organics and inorganics is a major concern for efficient use of additional irrigations applied as well as for maintaining the productivity of wheat. Thus, judicious and efficient use of irrigation water and of nutrients for wheat has received great attention. Further, management of these limited and costly inputs is closely linked with some climatic and edaphic factors. Yield of wheat under irrigated condition is considered to be a function of evapo-transpiration, which usually reflects in the water-use efficiency and moisture-use pattern of the crop (Van Keulen 1975, Fischer 1979). Therefore, a thorough understanding of these climatic and edaphic variables is the pre-requisite for efficient management of these inputs to boost the productivity of wheat with the limited soil-water availability. Hence the present investigation was undertaken to find out the periodic changes of profile moisture content and evapo-transpiration under different irrigation and nutrient levels, and to correlate the climatic (evapo-transpiration) and edaphic (soil moisture) variables with yield of the crop.

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MATERIALS AND METHODS

The field experiment was conducted at the research farm of the Institute, Bhopal, Madhya Pradesh (23°18′ N, 77°24′ E, 485 m above mean sea-level) during the winter season of 1998–99 and 1999–2000 on deep heavy clay soil (Typic Haplustert). The soil was low in organic carbon (0.40%), available N (245 kg/ha) and available P (5.0 kg/ha) but high in available K (460 kg/ha), having *p*H 7.8 and cation-exchange capacity (CEC) 46 cmol(P^+)/kg soil. Average water-holding capacity and moisture retention of the soil at 0.33 and 15 bar was 62.5%, 40.6% and 25.8% respectively. Rainfall received during the crop period was 63.3 mm and 0.5 mm in 1998–99 and 1999–2000 respectively.

The experiment was laid out in split-plot design with 3 replications. The treatments comprised 3 irrigation schedules [I_0, no irrigation; I_1, 2 irrigations at crown-root initiation (CRI) and flowering stage; and I_2, 3 irrigations at CRI, maximum tillering and flowering stage] as main plots and 3 nutrient management [F_0, no nutrient application (control); F_1, recommended dose of N, P and K @ 100, 21.5 and 24.9 kg/ha; and F_2, recommended dose of N:P:K + farmyard manure @ 10 tonnes/ha] as subplots. One pre-sowing irrigation was uniformly given for proper germination of the crop. For each irrigation 6 cm water was applied and 3 irrigations were scheduled as per critical stage on 2 December, 8 January and 28 January. It may be noted that farmyard manure was applied to the preceding rainy-season *(kharif)* soybean [*Glycine* max (L.) Merr.] crop (data of *kharif* crop are not presented here).

'Sujata' wheat was sown on 11 November at 22.5 cm row spacing, with a seed rate of 100 kg/ha. Plot size of 4 m × 6 m was maintained. Soil moisture was determined by neutron moisture meter (Model 3330), calibrated *in situ* at the experimental site, at every fortnight interval and also before and 48 hr after the irrigation from a depth of 30–150 cm keeping 15-cm interval between 2 depths of sampling. Moisture in the top 30 cm soil was determined thermo-gravimetrically.

The evapo-transpiration (ET) between 2 soil-moisture content measurements was estimated using the following water balance equation:

$$ET = P + I + C_p - D_p - R_r - \Delta S$$

where P, the precipitation; I, the depth of irrigation water applied; C_p, the contribution through capillary rise from ground water-table; R_r, surface water runoff; D_p, deep percolation loss; and ΔS, change in soil water profile. As C_p, D_p and R_f were negligible, evapo-transpiration was calculated as the difference between precipitation and irrigation and changes in total moisture content of the profile. Water-use efficiency was calculated by dividing seed yield with the respective value of seasonal evapo-transpiration of the crop recorded under different treatments. The crop was harvested on 2 and 5 April in first and second year respectively. The data were analysed by analysis of variance using split-plot design as outlined by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Soil water dynamics

Seasonal net changes in total water content of the soil profile (0–1.2 m) are shown in Fig 1. The differences in rainfall amount and distribution between the 2 seasons were reflected in the soil water dynamics of 2 seasons. Occurrence of rainfall and its distribution also influenced water content in the irrigated and unirrigated plots. In the second year, the total stored water of the profile in the unirrrigated plots depleted continuously with the advancement of crop-growth periods due to extraction of water from the profile by the crops and no recharge occurred due to lack of any significant rainfall event during the entire crop-growth period. The decrease in water content from the profile (0–1.2 m) was the maximum under manured and fertilized plots than both the fertilized and unfertilized plots. This could be attributed to better root growth and correspondingly higher uptake of water by the crop.

Soil-moisture extraction pattern

The temporal variation of profile soil moisture in different soil layers due to different irrigation and nutrient levels during the crop-growth period is shown in Fig 2. The moisture-extraction was maximum in 0–30 cm soil depth, irrespective of the irrigation and nutrient treatments and decreased with soil depth. Most of the water (60–80%) was extracted by the crop from the top 60 cm of soil depth (Fig 2). Irrigation levels had considerable effect on the moisture-extraction pattern, as the moisture extraction (%) from the top 30 cm soil increased with the irrigation level. Increased surface evaporation, extensive shallow root density and more water uptake by the crop from surface layers due to availability of surface irrigation water may be the possible reason for such increase in moisture extraction (%). However, in case of no irrigation moisture extraction was more from deeper soil layers (60–120 cm). Here moisture stress allowed wheat roots to go deeper in search of water, which promoted relatively more utilization of water from the deeper soil layers. The result confirms the findings of Gajri *et al.* (1992) and Verma and Acharya (1996). However, reverse was the case for nutrient management (Fig 2b). The moisture extraction from deeper layers (60–120 cm) was higher in manured and fertilized plots than the plots where no nutrient was applied. This might be attributed to better development of roots with increased supply of nutrients that favoured withdrawal of more water from deeper layers. This result substantiates the findings of Hussain and Al-Jaloud (1995) and Sharma and Acharya (1996).

Evapo-transpiration

The seasonal evapo-transpiration for no irrigation and 2 irrigations was more during 1998–99 than that during 1999–2000 (Table 1). This might be due to frequent rain during 1998–1999, which resulted in more water available for the crop. However, with 3 irrigations differences in evapo-transpiration between 2 years was negligible, which might be because higher irrigation water masked the effect of relatively higher rainfall in the first year.

The crop evapo-transpiration increased steadily from germination stage onward in all the treatments, reaching its peak somewhere between 75 and 105 days after sowing. Evapo-transpiration decreased gradually 105 days after sowing and substantial decrease was recorded at maturity (Fig 3). Irrigation had considerable influence on crop evapo-transpiration. Evapo-transpiration throughout the growth

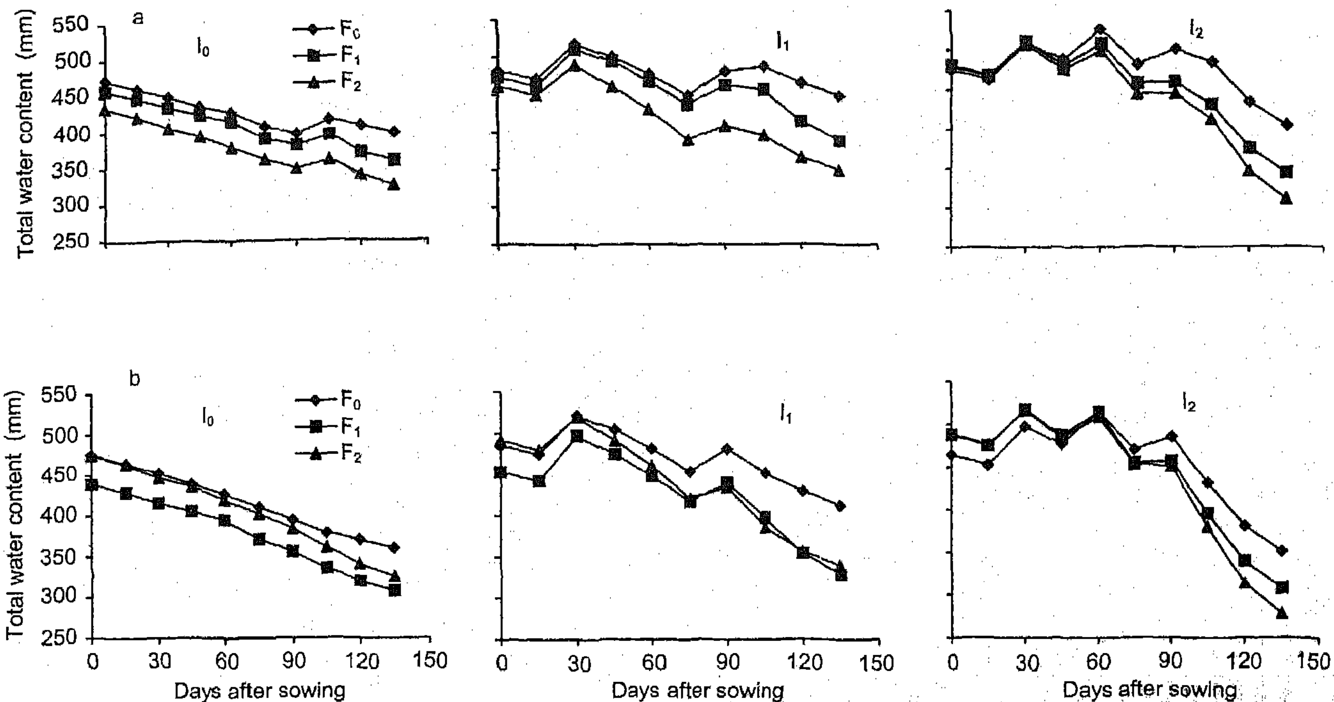

Fig 1 Seasonal changes in amount of total soil water (0–1.2 m depth) of (*a*) 1998–99; (*b*) 1999–2000

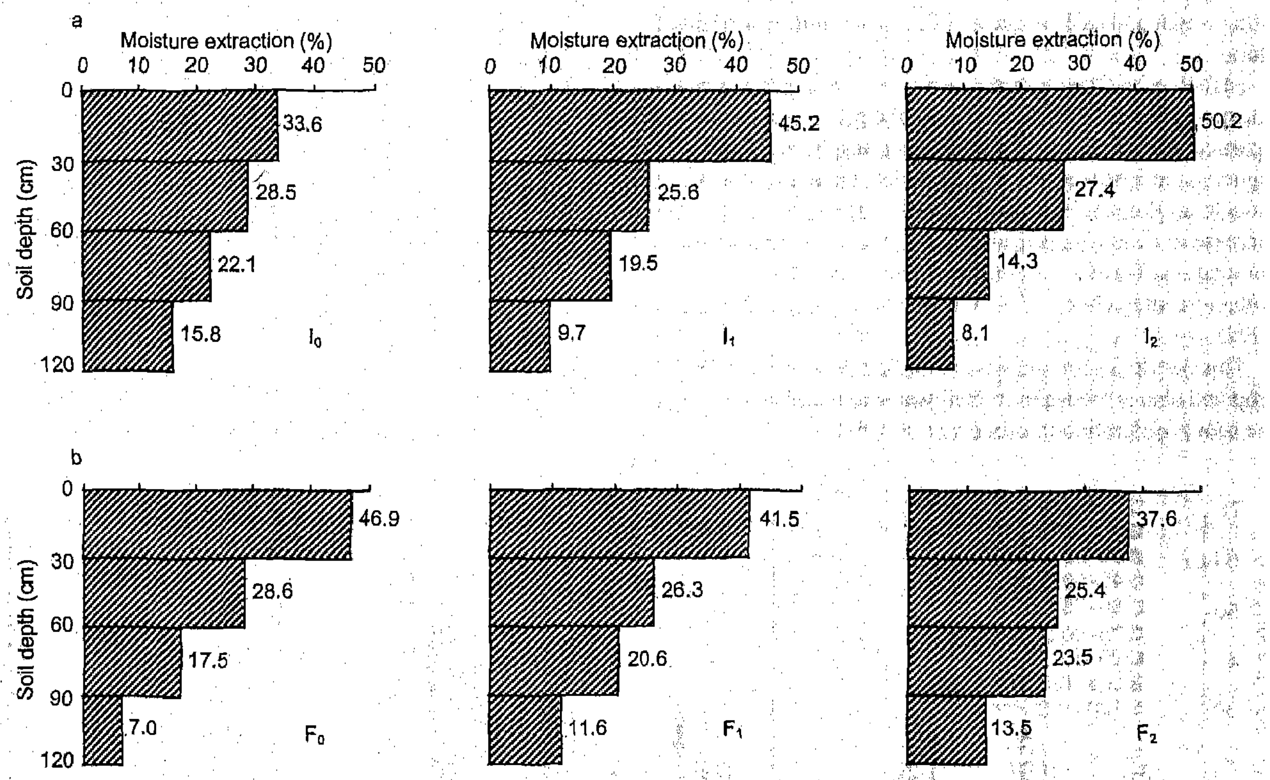

Fig 2 Moisture-extraction pattern (%) of wheat as affected by irrigation levels (*a*) and nutrient management (*b*) (pooled data of 1998–99 and 1999–2000)

stages was higher for irrigated plots (I_2 and I_1) compared with unirrigated plots (I_0). However, evapo-transpiration reached its peak earlier (between 75 and 90 days after sowing) in the unirrigated plots compared with irrigated plots (between 90 and 105 days after sowing). This may be due to depletion of plant-extractable water of the profile during the later part of

Table 1 Evapo-transpiration of wheat (mm) as affected by irrigation levels and nutrient management

Irrigation	Nutrient management			
	F_0	F_1	F_2	Mean
		1998–99		
I_0	149.5	158.6	170.0	159.4
I_1	215.1	278.1	305.1	266.1
I_2	308.3	352.8	386.9	349.3
Mean	224.3	263.2	287.3	
		1999–2000		
I_0	121.4	137.7	155.2	138.1
I_1	199.4	250.3	278.2	242.6
I_2	299.4	365.8	396.5	353.9
Mean	206.7	251.3	276.6	
CD (P=0.05)	*Irrigation*	*Nutrient management*		*Irrigation × nutrient management*
1998–99	15.8	22.4		30.3
1999–2000	11.9	18.8		32.6

Details of treatments are given under Materials and Methods

crop growth and early maturity of the crop in the unirrigated plots.

Effect of nutrient management on the crop evapo-transpiration was observed for both the growing seasons. At a particular irrigation treatment evapo-transpiration value was higher in the fertilized and manured plots than the unfertilized plots at all the stages of crop growth. Effects of nutrient on increase in evapo-transpiration are principally related to the stimulation of growth of both above-ground and root biomass with more interception of incoming solar radiation (Anderson 1992).

This results in a higher transpiration requirement of the crop and also provides more soil water to the plants through the root proliferation (Corbeels *et al.* 1998).

Water-use efficiency

Water-use efficiency of wheat was influenced by irrigation and nutrient management (Table 2). The highest water-use efficiency (10.5 and 11.3 kg grain/mm water during 1998–99 and 1999–2000 respectively) was obtained with no irrigation, followed by 2 and 3 irrigations. The decrease in water-use efficiency associated with irrigation treatments might be due to relatively greater expense of water by evapo-transpiration than the corresponding increase in grain yield. The results confirm the findings of Aggarwal *et al.* (1986) and Singh *et al.* (1987). In contrast, the water-use efficiency was significantly higher in the fertilized and manured plots (F_2 and F_1) compared with unfertilized plots (F_0) in both the years (Table 2). The result substantiates the findings of

Table 2 Water-use efficiency (kg/ha-mm) as influenced by irrigation levels and nutrient management in wheat

Irrigation	Nutrient management			
	F_0	F_1	F_2	Mean
		1998–99		
I_0	7.8	10.0	13.7	10.5
I_1	6.0	10.9	11.8	9.6
I_2	5.9	10.0	11.0	9.0
Mean	6.6	10.4	12.2	
		1999–2000		
I_0	9.0	11.7	13.2	11.3
I_1	7.3	10.6	11.6	9.8
I_2	6.1	9.6	10.9	8.9
Mean	7.5	10.6	11.9	
CD (P=0.05)	*Irrigation*	*Nutrient management*		*Irrigation × nutrient management*
1998–99	0.5	1.5		2.7
1999–2000	0.9	1.1		1.3

Details of treatments are given under Materials and Methods

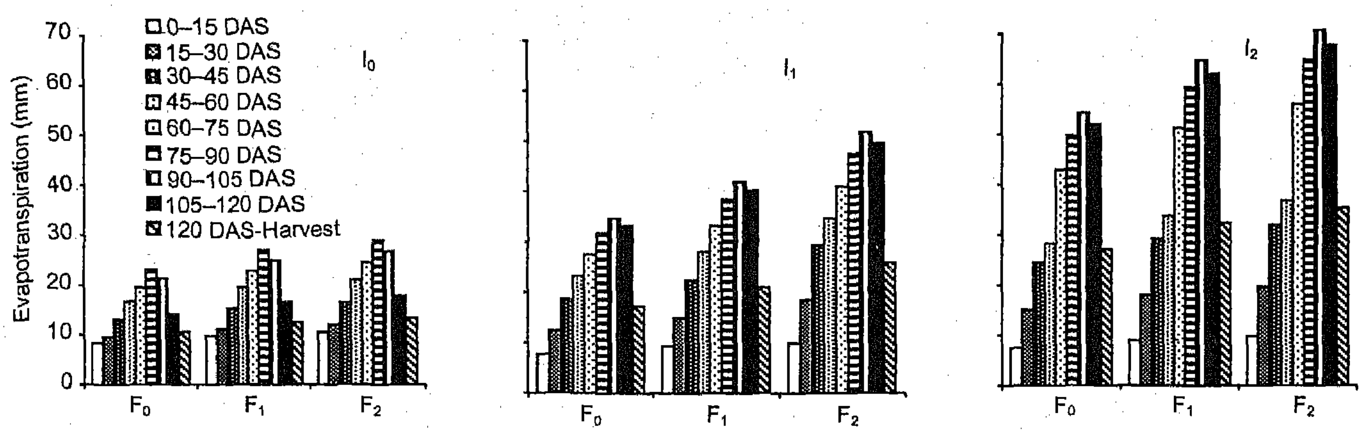

Fig 3 Seasonal variation of evapo-transpiration of wheat as affected by irrigation levels and nutrient management (pooled data of 1998–99 and 1999–2000)

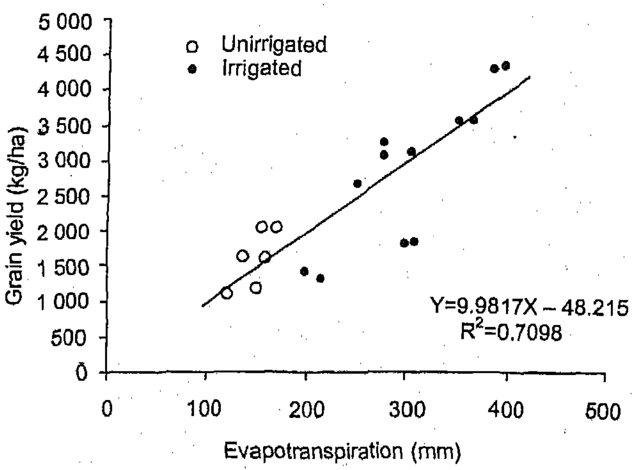

Fig 4 Relationship between grain yield and evapo-transpiration of wheat over 2 seasons (1998–99 and 1999–2000)

Hussain and Al-Jaloud (1995) and Gajri *et al.* (1997). The increase in water-use efficiency with the application of fertilizer and manure might be due to more rapid crop growth during the season with lower vapour deficit which resulted in decrease in evaporation : transpiration (Es : T) ratio and corresponding improvement in transpiration efficiency (Zhang *et al.* 1998). Interaction effect of irrigation and nutrient management was significant in both the years. The water-use efficiency was highest at I_0F_2 and lowest in I_2F_0 in both the years (Table 2).

Yield

Irrigation significantly increased grain yield (Table 3). On an average, an increase in grain yield owing to I_1 and I_2 over the control (I_0) was 55.0 and 96.1%, respectively. Singh *et al.* (1987) also reported significant increase in grain yield with irrigations. Similarly, the highest grain yield was recorded in the manured and fertilized plots (NPK+ farmyard manure), which was significantly higher than both fertilized (NPK only) and unfertilized plots. The combined use of inorganic fertilizers and organic manures enhanced the inherent nutrient-supplying capacity of the soil and improved the physical and biological properties of soil, which, in turn improved the grain yield. However, considerable response of wheat to nutrient management in the present study could only be observed in association with irrigation regimes, as was evident from the significant interaction between these 2 factors. The highest grain yield of 4 264 and 4 320 kg/ha in 1998–99 and 1999–2000 respectively was recorded under I_2F_2 treatment, which was significantly higher than I_2F_1 and I_1F_2 treatments (Table 3).

Table 3 Effect of irrigation levels and nutrient management on grain yield of wheat

Irrigation	Nutrient management (kg/ha)			
	F_0	F_1	F_2	Mean
		1998–99		
I_0	1 168	1 586	2 331	1 695
I_1	1 291	3 047	3 599	2 646
I_2	1 816	3 539	4 264	3 206
Mean	1 425	2724	3 398	
		1999–2000		
I_0	1 087	1 616	2 038	1 580
I_1	1 411	2 647	3 235	2 431
I_2	1 804	3 533	4 320	3 219
Mean	1 434	2 599	3 198	
CD (P=0.05)	*Irrigation*	*Nutrient management*		*Irrigation × nutrient management*
1998–99	400	391		617
1999–2000	356	315		545

Details of treatments are given under Materials and Methods

Evapo-transpiration–yield relationship

The relationship between grain yield and seasonal evapo-transpiration is presented in Fig 4. For the irrigated plots, seasonal evapo-transpiration ranged from 199.4 to 396.5 mm (Table 1) and grain yield from 1 291 to 4 320 kg/ha (Table 3). While seasonal evapo-transpiration under unirrigated condition ranged from 121.4 to 170.0 mm and the corresponding grain yield from 1 087 to 2 331 kg/ha. The combined data from both unirrigated and irrigated treatments provide a wide range of grain yield data for determination of the seasonal evapo-transpiration-grain yield relationship. A positive and significant (R^2=0.71) linear relationship was found between grain yield and evapo-transpiration with a slope of 10 kg grain yield/mm of seasonal evapo-transpiration. Musick *et al.* (1994) and Zhang and Oweis (1998) also reported similar linear relationship of the grain yield with seasonal evapo-transpiration in wheat. The scatter between grain yield and evapo-transpiration data (R^2 = 0.71) was probably due to the variation in rainfall amount and istribution among the growing seasons.

Thus an integrated supply of nutrients (both inorganics nd organics) with 3 irrigation could be an optimum ombination to obtain high grain yield of wheat in Vertisol of central India.

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