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Moisture extraction pattern and ET-yield models in wheat under different management practices in central Punjab

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ABSTRACT

Under water limiting conditions, evaluation of sensitivity of crop growth stages to evapotranspiration is indispensable for efficient and judicious use of irrigation water. The present investigation was carried out at the research farm, School of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana during *rabi* 2006-07 and 2007-08. The experiment was laid out in randomized block design with two planting methods i.e. flat planting (F) and planting on raised beds (B) and five irrigation levels. Flat planting method recorded higher soil moisture depletion / ET as compared to bed planting during both the years of investigation. During 2006-07, soil moisture depletion for rainfed and four post-sowing irrigation treatments was 256 and 376 mm for bed planted, whereas it was 285 and 402 mm for flat sown crop, respectively. Similarly during 2007-08, soil water depletion for the corresponding treatments was 286 and 437 mm for bed planted; whereas it was 337 and 467 mm for flat sown crop. Multiplicative and additive ET and yield models suggested reproductive growth to be the most sensitive crop growth stage to soil moisture.

Key words: Management practices, planting methods, irrigation schedules, evapotranspiration, ET-yield models

In order to sustain the agricultural productivity through judicious use of water resources, it is essential to estimate crop water requirements based on water loss components (Jalota and Arora, 2002). Actual evapotranspiration is the main index of crop-water requirement as major portion of water received through irrigation or rainfall in a crop field is lost through evapotranspiration. Crop water production functions (Cwpf) describe the relationship of crop yield response to varying levels of water input and can be useful for various management applications (Liu *et al*, 2002). Cwpf is very useful in determining irrigation strategies when water supply is limited. Cwpf is often linear and is not unique but varies among varieties of crops and climate zones (Kipkorir, 2002).

With good management and adoption of appropriate practices, improved agricultural water conservation, and subsequent use of that water for more efficient crop production are possible under both dry and irrigated conditions (Wang *et al*, 2004). Furrow irrigated raised bed planting (FIRB) has been found to be the most effective measure to reduce the cost of cultivation, to increase water use efficiency as well as for optimum yield. Hence, this system is fully suitable for irrigated winter wheat production and offers a feasible way for improving the stability of crop production (Zhang *et al*, 2007).

A higher crop water productivity results in either the same production from less water resources, or a higher production from the same water resources (Zwart and Bastiaanssen, 2004). Evapotranspiration is the major parameter for need based and judicious use of irrigation application. But the irrigation practices adopted by the farmers are generally arbitrary and not necessarily based on crop's actual water needs. Keeping this in view, the present investigation was carried out to evaluate the moisture extraction pattern of wheat under different planting methods and irrigation levels.

MATERIALS AND METHODS

The field investigations were carried out at the research farm, School of Climate Change and Agricultural Meteorology, PAU, Ludhiana (30°54'N and 75°48'E, 247m above mean sea level) during *rabi* 2006-07 and 2007-08. Wheat variety PBW-502 was sown during first fortnight of November during both the years after a per-sowing irrigation. The experiment was laid out in randomized block design. The experiment consisted of combination of two methods of sowing i.e. Conventional method of sowing on flat surface

Table 1 : Average daily rate of evapotranspiration (mm day $^{-1}$) computed through soil water depletion methodin wheat during *rabi* 2006-07 and 2007-08

Irrigation level	Planting method			
	Bed		Flat	
	2006-07	2007-08	2006-07	2007-08
I_0	1.65	1.81	1.84	2.13
I_1	1.88	2.05	2.28	2.20
I_2	2.04	2.61	2.29	2.63
I_3	2.06	2.65	2.53	2.67
I_4	2.43	2.76	2.60	2.95

with row to row spacing of 22 cm (F) and sowing of crop on raised beds 37.5 cm wide with two crop rows 20cm apart and 30 cm wide furrow between two beds (B) and five irrigation levels (I_o: no post-sowing irrigation, the treatment was referred to as rainfed; I_1: irrigation at CRI stage only; I_2: irrigation at CRI and flowering stages; I_3: irrigation at CRI, flowering and soft dough stages and I_4: recommended irrigations i.e. first irrigation four weeks after sowing, second 5-6 weeks after first, third 5-6 weeks after second and last 4 weeks after third irrigation). The five corresponding irrigation levels for bed planted crop were abbreviated as BI_0, BI_1, BI_2, BI_3 and BI_4 and for flat planted crop they were abbreviated as FI_0, FI_1, FI_2, FI_3 and FI_4.

Soil moisture extraction

Gravimetric method was used for the measurement of soil moisture in upper 0-15 cm soil layer and neutron probe method for measurement of soil moisture in all the lower layers at frequent intervals as well as before and after each irrigation. Total water use during growth season of the crop was obtained from summation of root zone soil water depletion between successive time intervals (Singh *et al*, 1960). The retention at each soil moisture sampling is given by:

$$\text{Root zone water retention} = \sum_{i=1}^{n} Dj$$

where,

i = Soil depth interval e.g. 0-15 cm, 15-30 cm …… 120-150 cm

D_j = Depth of water retained in the respective soil depth interval

n = Number of soil layers

In order to compute soil water depletion, the difference in water retention between the two successive samplings was taken as soil water use by the crop. The water depletion by the crop computed with soil water depletion method referred as water use by the crop.

Lysimetric method

In order to calculate the actual evapotranspiration, the crop was sown manually on flat surface in weighing type lysimeters on the same day when it was sown in rest of the field i.e. on 1st November, 2006 and 5th November, 2007 during first and second crop season, respectively. The water loss from the lysimeter was computed as:

1 kg of weight loss = 0.6 mm of water loss

Relative evapotranspiration – yield models

In order to account for the effect of growing season on crop response to water supply, the grain yields from moisture stress treatments were expressed as a ratio of stress treatment yield (I_o) to maximum yield obtained from unstressed treatment (I_4). The relative yield (Y_a/Y_m) was then related to relative evapotranspiration (ET_a/ET_m).

Multiplicative ET-Yield Model (Jensen, 1968) and Additive ET-Yield Model (Stewart and Hagen, 1973)

In order to describe the yield-moisture stress relationship holistically, multiplicative and additive models were used. For the development of these models, wheat crop growing period was divided into three stages, namely vegetative growth, reproductive growth and maturity. Multiplicative and additive yield models were developed between retative yield (Y_a/Y_m) and relative ET (ET_a/ET_m) as well as between yield deficit ($1- Y_a/Y_m$) and ET deficit ($1-ET_a/ET_m$). For this, the relative ET and ET deficit for different crop growth stages were recorded, which was then related to relative yield and yield deficit under variable irrigation levels

Jensen (1968) used a multiplicative model to relate relative yield with relative evapotranspiration in different periods. In this multiplicative model, the sensitivity of the crop to water deficit varies with stage.

$$\frac{Ya}{Ym} = \prod_{i=1}^{n} \left(\frac{ETa}{ETm}\right)_i^{\lambda i}$$

Where,

Y_a = Actual grain yield

ET_a = Actual evapotranspiration

Table 2 : Comparison of ET requirement of at different phonological stages of wheat estimated by different methods

Growth stage of wheat crop	Lysimeter ET (mm)	Open pan evaporation (mm)	Modified Penman PET (mm)
Sowing – CRI	31.9	52.1	69.5
CRI – Tillering	19.2	19.1	24.6
Tillering – Jointing	63.5	45.5	58.9
Jointing – Flag leaf emergence	62.5	44.1	55.0
Flag leaf emergence – Flowering	46.2	44.0	58.1
Flowering – Soft dough	69.1	62.9	81.3
Soft dough – Maturity	51.7	132.6	147.4
Sowing – Maturity	344.1	400.3	494.8

Table 3 : Multiplicative and additive ET – Yield models for wheat

Model	Data type	R^2	**Coefficients**		Constant /	
			Veg. growth	Rep. growth	Maturity	Intercept
2006-07						
Linear regression	Relative ET vs. Relative yield	0.54	0.47 (0.93)	0.32 (0.72)	0.31 (0.50)	-0.011 (0.026)
	ET deficit vs. yield deficit	0.54	0.47 (0.93)	0.32 (0.72)	0.31 (0.50)	-0.08 (0.54)
Power function	Relative ET vs. Relative yield	0.58	0.49 (1.001)	0.32 (0.75)	0.34 (0.54)	0.12 (0.627)
	ET deficit vs. yield deficit	0.45	0.43 (1.094)	0.13 (0.302)	0.38 (0.64)	-0.42 (0.487)
2007-08						
Linear regression	Relative ET vs. Relative yield	0.81	-0.08 (0.23)	0.61** (4.11)	0.17 (0.53)	0.25 (0.68)
	ET deficit vs. yield deficit	0.81	-0.08 (0.23)	0.61** (4.11)	0.17 (0.53)	0.06 (0.43)
Power function	Relative ET vs. Relative yield	0.81	-0.096 (0.25)	0.53** (4.181)	0.14 (0.416)	-0.094 (0.572)
	ET deficit vs. yield deficit	0.80	0.043 (0.138)	0.643 ** (3.880)	0.48 (1.307)	0.124 (0.166)

Figures in parenthesis indicate t-values

** Significant at one per cent level of significance

Y_m = Potential yield when ET always remains equal to potential values (ET_m)

λ_i = Crop sensitivity to relate evapotranspiration in ith growth period

n = Number of growth stages

Π = Product

For developing multiplicative and additive ET-yield models, the crop growing period was divided into three phases i.e. vegetative growth period from sowing to jointing, reproductive growth period from jointing to anthesis and maturity period from anthesis to physiological maturity. The value of sensitivity indices (ë) were obtained from the log-transform regression technique by developing multiplicative and additive models of the following form:

$$\frac{Y_a}{Y_m} = \left(\frac{ET_a}{ET_m}\right)_1^{\lambda_1} \left(\frac{ET_a}{ET_m}\right)_2^{\lambda_2} \left(\frac{ET_a}{ET_m}\right)_3^{\lambda_3}$$

$$\frac{Y_a}{Y_m} = \lambda_1 \left(\frac{ET_a}{ET_m}\right)_1 + \lambda_2 \left(\frac{ET_a}{ET_m}\right)_2 + \lambda_3 \left(\frac{ET_a}{ET_m}\right)_3$$

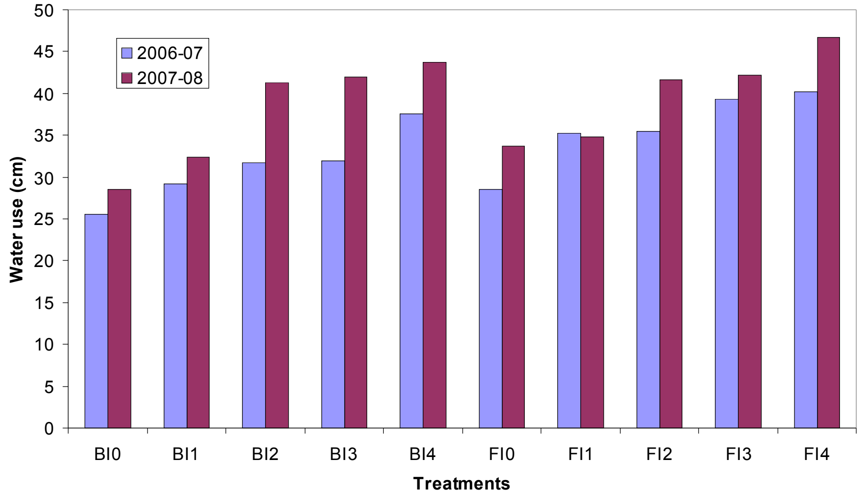

Fig.1 : Water use (cm) by wheat crop under different planting methods and irrigation levels during 2006- 07 and 2007-08

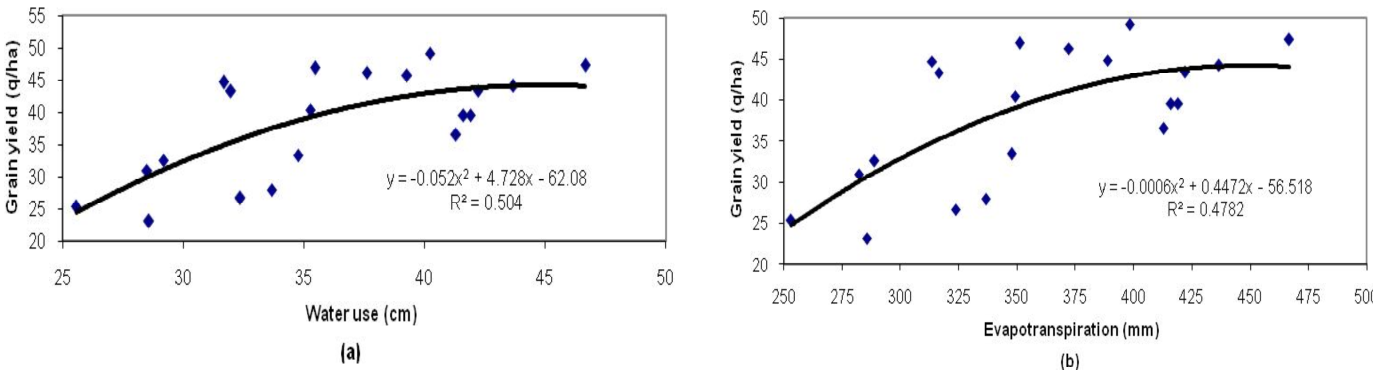

Fig. 2 : Relationship between grain yield of wheat and (a) water use computed from soil water depletion method and (b) evapotranpiration computed from modified Penman method

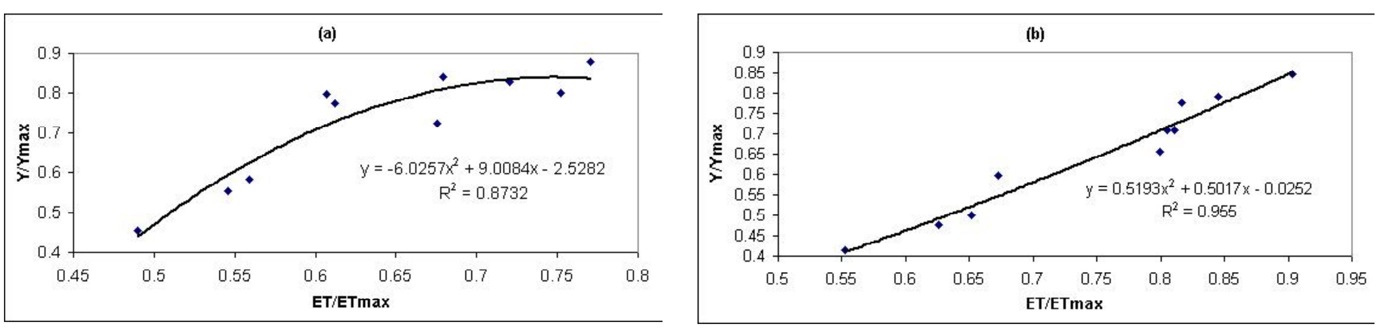

Fig. 3 : Relationship between relative ET and relative yield of wheat during (a) *rabi* 2006-07 (b) 2007-08

Where, the growth stages 1, 2 and 3 indicate the periods from sowing to jointing, jointing to anthesis and anthesis to maturity and $\ddot{e}_1$, $\ddot{e}_2$ and $\ddot{e}_3$ are sensitivity indices for the corresponding crop growing periods. ET_a for different treatments was calculated from soil moisture depletion method and ET_m was calculated from modified Penman method.

RESULTS AND DISCUSSION

Effect of sowing methods and irrigation levels on soil moisture depletion

Crop evapotranspiration obtained from soil moisture depletion method during *rabi* 2006-07 and 2007-08 has been presented in Fig. 1. Rate of evapotranspiration was found to be higher during second crop season than the first year as higher amount of rainfall during first year might have decreased vapour pressure gradient and hence the atmospheric demand. Among the planting methods, rate of evapotranspiration was found to be higher in flat planting as compared to bed planting during both the seasons. Murty *et al* (2004) also observed that ridges and furrows conserved moisture higher by 8.4 per cent than no tillage followed by deep tillage. Among the irrigation levels, the rate of evapotranspiration was lowest in the rainfed treatment and was highest under the highest water application treatment. The crop season evapotranspiration using soil moisture depletion method ranged from 255.6 mm to 376.1 mm for bed planted crop (BI_0, BI_1, BI_2, BI_3 and BI_4) and 285.0 mm to 402.3 mm for flat planted crop (FI_0, FI_1, FI_2, FI_3 and FI_4) during *rabi* 2006-07. During *rabi* 2007-08, seasonal evapotranspiration of wheat ranged from 285.7 mm to 436.7 mm for bed planted and 336.7 mm to 466.7 mm for flat planted crop. During *rabi* 2006-07, daily rate of evapotranspiration ranged from 1.65 to 2.43 mm day^{-1} in bed planted and 1.84 to 2.60 mm day^{-1} in flat planted crop among the different irrigation treatments. Similarly, during *rabi* 2007-08, daily rate of evapotranspiration for different irrigation levels ranged from 1.81 to 2.76 mm day^{-1} for bed planted and 2.13 to 2.95 mm day^{-1} in flat planted crop (Table 1).

ET requirement at different phenological stages of wheat

A study of ET requirement of wheat recorded from lysimeter at different phenological stages indicates that crop water requirement was less during initial growth stages i.e. up to tillering, but as leaf area index of the crop started increasing, the water requirement of the crop increased from jointing to flowering and soft dough stage and again decreases afterwards as the crop approaches senescence and maturity. A comparison of lysimeter ET, open pan evaporation and modified Penman PET also indicates that during initial crop growth stages lysimteter ET is less as compared to open pan evaporation and modified Penman PET, but during rapid increase in leaf area index of the crop, lysimeter ET increases as compared to other methods and as the crop approaches senescence and maturity, again lysimeter ET is lower than open pan evaporation and modified Penman PET (Table 2). This can be explained by the fact that pan evaporation and PET are controlled by the climatic parameters, thus with increase in temperature in the months of March and April, the pan evaporation and PET also increased; whereas lysimter ET depends on crop characteristics and it is highest when the leaf area index is maximum.

ET and yield relationship

Quadratic relationships were observed between water use computed from soil moisture depletion method and grain yield of wheat. 50 per cent variation in grain yield of wheat was explained with water use with the data pooled for two years (Fig. 2(a)). Yield of wheat under irrigated conditions is a function of evapotranspiration, which is usually reflected by the water use pattern of the crop. The relationship between crop yield and seasonal evapotranspiration in the form of evapotranspiration production function (ETPF) has been reported as linear by some workers (Hati *et al*, 2001). Some workers have reported curvilinear ETPF (Bandhyopadhyay *et al,* 2004). Evapotranspiration estimated by modified penman method was also related with yield of wheat crop. The evapotranspiration computed by modified Penman method explained 47 per cent variation in grain yield (Fig. 2(b)).

Relative evapotranspiration – yield models

The relationship between relative yield and relative ET was found to be curvilinear with R^2 value of 0.87 during first year and 0.96 during second year (Fig.3). Curvilinear relationship during first year might be because of higher rainfall (152.0 mm) received during first crop season as compared to second crop season (87.5 mm). Kipkorrir *et al* (2002) also reported that under more availability of water, deep drainage losses increase and curvilinear water production functions are observed. But when the data of two years were pooled, again curvilinear relationship was observed with R^2 value of only 0.48.

Multiplicative and additive ET - yield models

The data indicated that during good rainfall season of 2006-07 both additive (linear regression) and multiplicative (power function) models gave low R^2 values. Linear regression model gave R^2 value of 0.54 for both relative ET vs. relative yield model as well as for ET deficit and yield deficit model (Table 3). Power function model gave R^2 value of 0.58 for relative ET vs. relative yield model and 0.45 for ET deficit vs. yield deficit model. The t-value for the coefficients was not found significant for any of the crop growth stages for all the models during 2006-07. But during 2007-08, when less rainfall was received and all the differential irrigations were applied, a good relationship was observed between relative as well as deficit ET at different stages with relative and deficit yield. Linear regression model gave R^2 value of 0.81 for relative as well as deficit ET and yield. Similarly power function model gave R^2 value of 0.81 for relative ET and relative yield and 0.80 for ET deficit and yield deficit. T-value for the coefficients at reproductive stage was found significant for all the models during 2007-08 which indicated that grain yield was significantly affected by moisture stress during reproductive growth period of wheat crop.

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