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Evapotranspiration and crop coefficients for rice, wheat and pulses under shallow water table conditions of Tarai region of Uttaranchal

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ABSTRACT

Water table contribution, evapotranspiration (ET) and crop coefficients for rice (*Oryza Sativa* L.), wheat (*Triticum aestivum* L) and three winter pulses viz. chickpea (*Cicer arietinum* L.), fieldpea (*Pisum sativum* L.), and lentil (*Lens culinaris medic.*) were determined under shallow water table conditions using lysimeters. The 3-year average percolation (P_c) and ET of rice was 635 and 655 mm from clay loam, 675 and 668 mm from silty clay loam, and 693 and 680 mm from loam, respectively. Similarly average ET of wheat crop was 411 mm, and that of chickpea, fieldpea and lentil was 370, 362 and 352 mm, respectively. A high ET was associated with low yield under shallower than deeper water tables.

Average water table contribution (WT_c) was 78.6, 65.5 and 38.5 percent of ET of wheat crop over the water table at 0.6, 1.0, and 1.6 m depths, respectively. Similarly average WT_c to the ET of the three-pulse crops was 89 ± 0.8, 66.8 ± 2.1, and 47.3 ± 2.4 percent from the water tables at 0.6, 1.0 and 1.6 m depths, respectively. The WT_c was highest in chickpea and lowest in lentil. The crop coefficient (K_c), calculated as ratio of measured ET to potential ET by Jensen-Haise method, was 1.0 to 1.7 for rice during 24-66 days from transplanting, 1.0 to 1.07 for wheat during 65-90 days from sowing and 1.0 to 1.1 for the 3 pulse crops during 70-128 days from sowing. A fifth degree polynomial with highly significant R^2 fitted the data.

Key words: Chickpea, crop coefficient, evapotranspiration, fieldpea, lentil, rice, water table contribution, wheat.

Knowledge of evapotranspiration (ET) of crops together with contribution of groundwater table to the ET requirements, soil water retention characteristics and rainfall are necessary in scheduling of irrigations (Follett *et al.* 1974; Wallender *et al.* 1979; Tripathi, 1992). Whereas rainfall data can be obtained from the observatory and the soil water retention characteristics by one-time measurement, ET and water table contributions must be determined by a precise technique such as using lysimeters. Tripathi *et al.* (1987) designed a low cost lysimeter with water table control and rain shelters for measurements of ET and contribution from the water table. ET can also be estimated as a product of crop coefficient (K_C) at a specific stage of growth to potential evapotanspiration (ET_p) at that time.

$$ET = K_C . ET_p \qquad .....(1)$$

The crop coefficients vary with location, climate, topographic conditions and water table situations (Wright, 1982; Tripathi, 1992; Mohammad and Abo-Ghobar, 1994). Values of well-correlated K_C are often not available due to lack of precise data on daily ET of the crop. This paper presents lysimetric measurement of water table contribution and ET, together with K_C for rice (*Oryza Sativa* L.), wheat (*Triticum aestivum* L.), chickpea (*Cicer arietinum* L.), fieldpea (*Pisum sativum* L.) and lentil (*Lens culinaris* medic.) under shallow water conditions.

MATERIALS AND METHODS

The experiment was conducted at Crop Research Centre of the G. B. Pant University of Agriculture and Technology, Pantnagar (28 ° 26´ N lat., 79 ° 30´ E longitude, altitude 243.8 m above msl). Soils of the area are associated with non-saline natural water tables fluctuating from 0.1 m depth in fine textured soils to deeper than 2 m in coarse textured soils. Eighteen non-weighing lysimeters of surface dimension 1.5 m × 1.5 m and depths of 1.9 m, 2.5 m and 1.7 m with water table control and rain shelters (Tripathi *et al.*, 1987) were used to determine ET and the contribution of water table to the ET requirements of rice, wheat and pulses. The 18 lysimeters were installed in three rows of six each at a spacing of 15 m within rows and 30 m between rows. Each row of lysimeters represented clay loam, silty clay loam and loam soils with water table maintained at 0.6, 1.0, and 1.6m depths, respectively. A stand-pipe opening at the soil surface was installed connected to a well-point in the filter bed inside the lysimeter tank to maintain a constant water table level.

Evapotranspiration (ET, mm) of wheat and pulses was calculated from water input and losses as

$$ET_n = I_n + WT_{Cn} - D_n \pm \Delta S_n \qquad .....(2)$$

where I is surface irrigation (mm), WT_C is water table contribution (mm), D is drainage (mm), and Δ S is change in soil water storage (mm). The subscript n indicates time interval in days. Rain shelters were used to avoid rainfall (Tripathi *et al.* 1987). Daily water table contribution, WT_C, was equal to the amount of water delivered through the stand-pipe. Since soil cannot hold water beyond its potential storage capacity, the drainage, D_n, was determined as (Tripathi and Mishra, 1986).

$$D_n = \{ \frac{0 \text{ for } S_n < S_p}{S_n - S_p \text{ for } S_n > S_p} \qquad ....(3)$$

where S_n is soil moisture storage on 4th day, and S_p is potential storage capacity of soil (equal to soil moisture content at field capacity). The soil moisture depletion from the lysimeters was determined by neutron moisture gauge (Troxler 3222). If J_n be the moisture content on nth day and J_{n-k} be that on (n - k)th the day, with k = 1, 2, 3...............n days,

$$S_n = J_{n-k} - J_n \qquad .....(4)$$

Daily ET of rice under well-watered condition was equal to the amount of irrigation applied to maintain continuous submergence. No water table for rice was maintained because of the submergence and, therefore, WT_C for rice was zero. Daily percolation (P_C) in rice fields was obtained by subtracting ET from the total water used ($ET + P_C$) in four 1.2 m × 1.2 m × 1.2 m bottomless tanks containing the same soil and installed adjacent to the lysimeters (Tripathi *et al.* 1987). The experiment was conducted for 3 consecutive years in lysimeters in a rice-wheat rotation. Rice seedlings (Pant 4) of 25 days were transplanted on July 15 at a spacing of 0.22 m row to row and 0.10 m within rows in the 3 sets of lysimeters in 3 replications. The crop was fertilized as per soil test values. A continuous submergence of 5 ± 2.5 cm was maintained from transplanting to about 15 days before harvesting.

Wheat (RR 21) was planted on December 2 during 1982-83 to 1984-85 at a seed rate of 100 kg ha^{-1} in the 3 sets of lysimeters and fertilized as per soil test values. Irrigation treatments for wheat were I_0 (rainfed), I_1 (irrigation at crown root initiation, CRI, stage), and I_2 (well watered) in 2 replications. In I_1 each Irrigation was equal to soil moisture deficit till that day. In I_2, irrigations were scheduled at 50 % depletion of available water from the top 0.6 m of soil before first irrigation, and from the top 1.0 m of soil in subsequent irrigations until 104 ± 3 days (Milk stage) and at 75 % depletion of available water from the top 1.0 m of soil thereafter (Tripathi, 1992). In clay loam and silty clay loam with water table at 0.6 and 1.0 m depths, respectively, the moisture depletion was considered only down to 0.2 m above the water table. Leaf area of wheat crop was measured by area meter (LICOR-3000).

Chickpea (PG 115), fieldpea (Rachna) and lentil (PL 406) were planted in the third week of November during 1985-86 and 1986-87 at a seed rate of 85, 70 and 45 Kg/h_a, respectively and fertilized as per soil test values. Each crop was planted over the 3 water tables maintained in lysimeters at depths of 0.6 m in clay loam, 1.0 m in silty loam and 1.6 m in loam in duplicate. Irrigations were scheduled at 60 % depletion of available water from the top 0.6 m profile until 40 days crop stage and from the top 1.0 m profile subsequently until 102 ± 4 days and at 75 % depletion from 1.0 m profile thereafter until 20 days prior to maturity (Tripathi, 1986). The moisture depletion was considered down to 0.2 m above the water table at 0.6 and 1.0 m depths as in the wheat experiment. Measurements of WT_C and ΔS were made in all the lysimeters to schedule irrigations and calculate ET.

The crop coefficient (K_C) was determined as a ratio (Eq 1) of measured ET to ET_P (potential ET) calculated as (Jensen and Haise, 1963)

$$ET_P = C_T (T - T_X) R_S \ x \ 0.0171 \quad ....(5)$$

where T is mean daily air temperature (°C), R_S is daily solar radiation (langley). The factor 0.0171 converts R_S in langley into equivalent depth of evaporation in mm. C_T is air temperature coefficient ($degrees^{-1}$) calculated as

$$C_T = 1 / (C_1 + C_2 C_H)$$

in which,

$$C_1 = 38 - (2^0C \ x \ \text{elevation in m} / 305),$$

$$C_2 = 7.6^0C, \text{ and } C_H = 50 \text{ mb} / e_2 - e_1$$

where e_2 and e_1 are the saturation vapour pressure in mb at the mean maximum and mean minimum air temperatures, respectively, during the warmest month in the area based on long-term monthly temperature records. T_X is defined as

$$T_X = -2.5 - 0.14\,(e_2 - e_1)\ ^{\circ}C\ /\ mb - elev.\ in\ m\ /\ 550$$

Both C_T and T_X are constants for the area. Daily maximum and minimum temperatures were taken from the meteorological observatory. Daily R_S (cal $cm^{-2}\ d^{-1}$) required in eq. (5) was measured by solarimeter but can be accurately estimated for Pantnagar situations form the bright sunshine hour (n) as (Tripathi, 1992).

$$R_s = 34.98\ n + 155.83 \quad ....(6)$$

RESULTS AND DISCUSION

Evapotranspiration

Rice

Two days average of 3 years ET and percolation (P_c) in rice under 50 ± 25 mm submergence is shown in Fig. 1. The 3-years' variation in daily ET and in daily P_c was almost equal to the variations in ET and P_c between two consecutive days and, therefore, a mean of the 6 values each of ET and P_c was reported. There was a gradual increase in ET from 2.5 ± 0.1 mm d^{-1} in the initial 5-6 days period to 10.2 ± 0.4 mm/d^{-1} during 50-75 days crop stage followed by a gradual decline to 3 ± 0.2 mm/ d^{-1} by physiological maturity. The P_c declined continuously from its initial 6 times higher value than ET to 2.6 ± 0.2 mm/d by the last irrigation and was equal to ET in the fifth week from transplanting. The fifth degree polynomial that fitted the data accounts for 97 % of the variability in ET and 99 % of the variability in P_c during the crop season (Fig. 1). The 3-year average P_c and ET of rice was 635 and 655 mm from clay loam, 675 and 668 mm from silty clay loam, and 693 and 680 mm from loam respectively. A high ET was always associated with high P_c in the 3 soils considered here. Variations in daily P_c and ET among the 3 soils were within ± 0.3 and ± 0.15 mm respectively. P_c was greatly moderated by puddling. Farmers generally practice more number of passes of a puddler on loam than on clay loam. Since rice is grown normally on clay loam and silty clay loam soils in this region, an average value of ET and P_c (668 mm) for the 3 soils would be reasonable for the purpose of irrigation scheduling. The over estimation of 13 mm ET and 33 mm P_c in clay loam and under estimation of 12 mm ET and 25 mm P_c in loam in a crop season are considered small (< 5%) compared to the errors due to efficiency of irrigation methods for the quantity of each irrigation.

Wheat

Two-day average ET of wheat over the 3 years, under well-watered conditions (Fig. 2), showed almost a constant rate until 40 days (late tillering stage) followed by a rapid increase until 80 days (flowering stage, F). The ET rates were high between 80 and 105 days (F to milk stage) and declined gradually towards maturity. The leaf area index (LAI) also increased until the F stage but decreased thereafter due to senescence (Fig. 3). High ET rates during 80 to 105 days stage could be due to proximity of roots to the water table (Tripathi and Mishra, 1986) and to increased evaporative demand because of relatively dry weather from the third week of February (Tripathi and Ghildyal, 1979). The 3-year average ET under well watered condition was 431 mm, 409 mm and 392

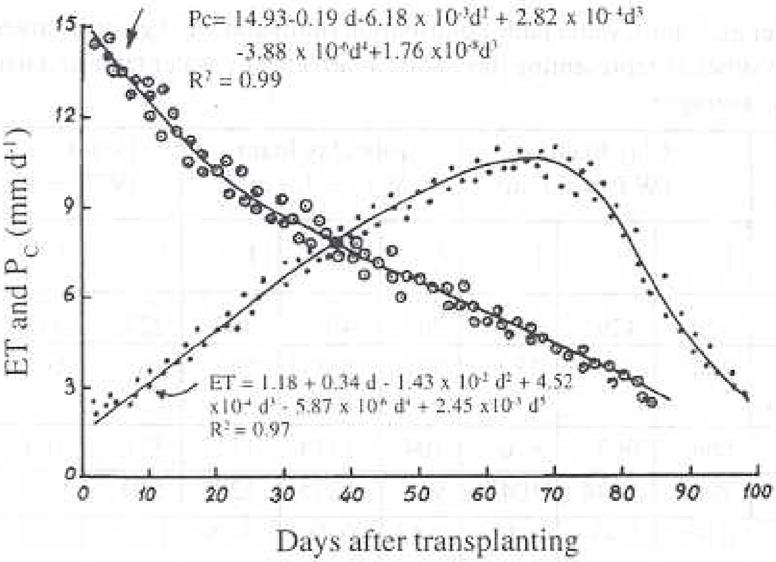

Fig.1 : Two-day average ET and P_C in rice culture (3-year data)

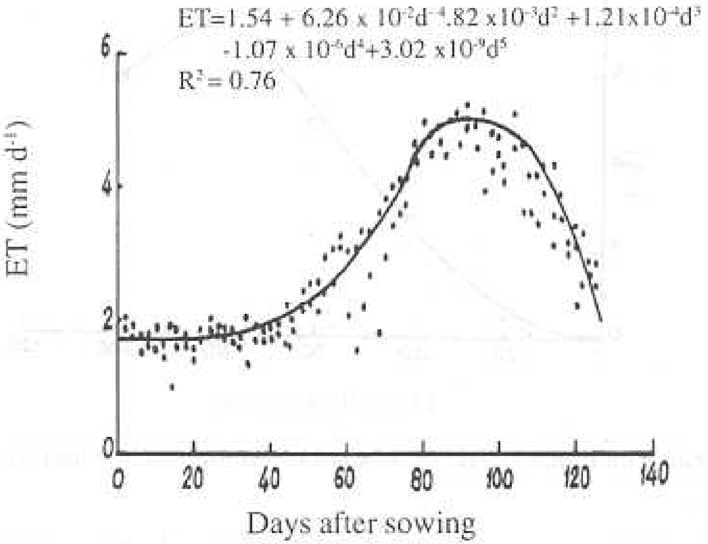

Fig.2 : Two-day average evapotranspiration (ET) in wheat (3-year data)

Table 1: Water use (mm), water table contribution (mm) and yield g per lysimeter of wheat in lysimeters representing three soils as affected by water table and irrigations (3-year average).

Parameters	Clay loam (WT_D = 0.6 m)			Silty clay loam (WT_D = 1.0 m)			Loam (WT_D = 1.6 m)		
	I_0	I_1	I_2	I_0	I_1	I_2	I_0	I_1	I_2
Water use	330	429	431	299	405	409	227	334	392
Water table contribution	284	339	339	221	268	268	86	133	151
Grain yield	664	963	970	704	1114	1127	371	763	1111
Straw yield	796	1044	1047	921	1225	1228	520	915	1226
Harvest index	0.45	0.48	0.48	0.43	0.48	0.48	0.42	0.45	0.47

WT_D = Water table depth; I_0 = No irrigation; I_1 = irrigation at CRI, I_2 = well- watered.

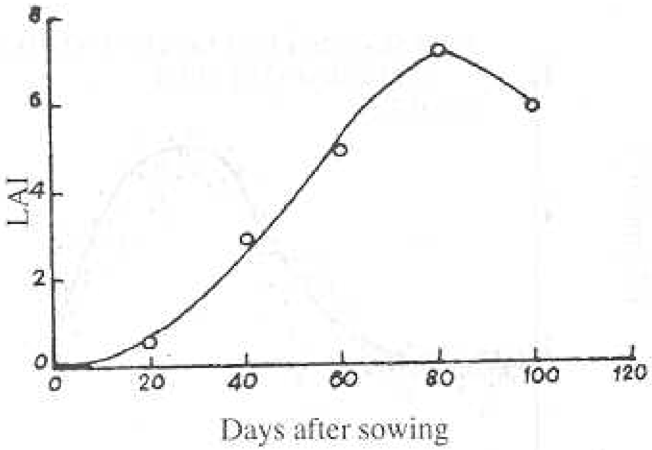

Fig.3 : Leaf area index (LAI) of wheat crop under well-watered condition

mm over 0.6, 1.0 and 1.6 m water tables in clay loam, silty clay loam and loam soils, respectively. Higher ET from clay loam (WT at 0.6 m depth) could be due to high soil evaporation as a result of excessive wetness of the surface soil which also led

Table 2 : Water use (mm), water table contribution (mm) and yield of chickpea, fieldpea and lentil in lysimeters representing three-soil and water table conditions (2-year average)

Parameters	Clay loam (WT_D = 0.6 m)			Silty clay loam (WT_D = 1.0 m)			Loam (WT_D = 1.6 m)		
	CP	FP	LT	CP	FP	LT	CP	FP	LT
Water use	441	428	414	415	399	383	370	362	352
Water table contribution	396	381	365	286	265	248	184	168	158
Grain yield	240	380	360	501	490	470	510	495	478
Straw yield	1050	1020	920	1035	1025	890	980	990	850
Harvest index	0.19	0.27	0.28	0.33	0.32	0.34	0.34	0.33	0.36

WT_D = Water table depth; CP = chickpea; FP = fieldpea and LT = lentil

to poor crop stand and low yields (Table 1).

Pulses

Two-day average ET over the two years shows a slow rise in chickpea as compared to that in fieldpea and lentil until the F stage (Fig. 4). Thereafter, both peak ET rates and duration were greater in chickpea than in fieldpea and lentil. These variations in ET were associated with their rate of canopy growth and wetness of the surface soil. The canopy growth in chickpea was initially slower than in fieldpea and lentil but accelerated much faster in chickpea than in fieldpea and lentil by F stage. The ET of chickpea, fieldpea and lentil ranged from 370 - 441, 362-428 mm and 352 - 414 mm respectively, under the 3 soils and water table conditions (Table 2). A high ET and straw yields but low grain yields were conspicuous over shallower than deeper water tables. Continued luxuriant growth of plant above the podding zone in the 3-pulses under high water contents over the water table at 0.6 m depth was associated with their indeterminate habit, which perhaps led to a competing sink effect. It is probable that competition for assimilate by canopy inhibited pod development and grain formation in the immediate post fertilization period (Baldev *et al.*, 1988). A mild water stress preventing further plant growth at mid-pod filling stage often improved grain yield. Grain yield of chickpea, fieldpea and lentil over the water tables at 0.6 m depth reduced by 52.5, 22.8 and 24 percent respectively from those over the water table at 1.0 and 1.6 m depths (Table 2). Highest ET over the water table at 0.6 m depth was also because of 12-15 days delay in maturity of the crops compared to those over the deeper water tables. Results thus show that clay loam associated with water table around 0.6 m depth was not suitable for chickpea, fieldpea and lentil.

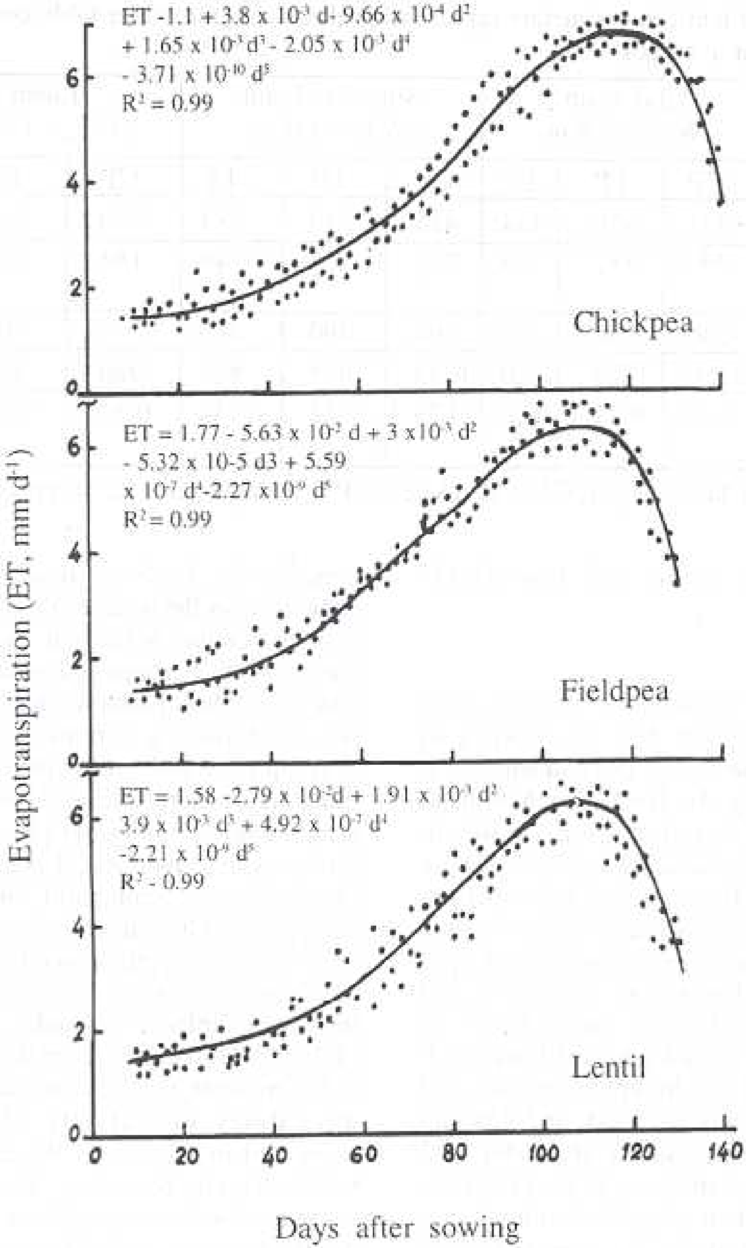

Fig. 4 : Two-day average ET of chickpea, fieldpea and lentil (2-year data)

Water table contribution

Wheat

The 3-year average water table contribution (WT_c) was 78.6, 65.5 and 38.5 percent of the total ET from the well-watered lysimeters associated with water table at 0.6, 1.0 and 1.6 m depths respectively (Table 1). Compared to rainfed (I_0), optimum irrigation (I_2) induced WT_c by 19.4, 21.3 and 75.6 percent from the water tables at depths of 0.6 m in clay loam, 1.0 m in silty clay loam and 1.6 m in loam respectively. The effect was greater under deeper than shallower water table conditions. Irrigation at the CRI stage (I_1) increased WT_c by inducing root growth into deeper layers (Tripathi and Mishra, 1986). The change in water table depth from 0.6 m in clay loam to 1.0 m in silty clay loam and to 1.6 m in loam reduced the WT_c under well-watered condition (I_2) by 20.9 and 55.5 percent, respectively.

Pulses

The contribution of water table (WT_C) to the ET of the three pulse crops (chickpea, fieldpea and lentil) was 89 ± 0.8, 66.8 ± 2.1 and 47.3 ± 2.4 percent from the water tables at depths of 0.6 m in clay loam, 1.0 m in silty clay loam and 1.6 m in loam, respectively (Table 2). The deviation from mean WT_c to the ET of the 3 crops was large under deeper than shallower water tables. The WT_c among the 3 pulses was the highest in chickpea and the lowest in lentil. No irrigation became necessary for the 3 pulses over the water table at 1.0 and 1.6 m depths, respectively. No rainfall was allowed over the lysimeters.

Crop coefficient

Rice

The crop coefficient (K_c) for rice increased steadily from 0.39 at transplanting to 1.0 in 24 days and to 1.7 in 48 days from transplanting (Fig. 5). Thereafter, K_c was almost constant until 66 days followed by a steady decline to the initial value at maturity of the crop. A higher K_c than those reported by Doorenbos and Pruitt (1977) indicates that Jensen and Haise method tends to underestimate ET_p compared with the modified Penman method. A fifth degree polynomial fitted the data with $R^2 = 0.90$.

Wheat

The K_c for wheat increased from 0.47 at sowing to 1.0 by the late jointing stage (about 60 days from sowing). The K_c was more than 1.0 during 65 to 90 days from sowing and declined thereafter (Fig. 6). Highest K_c (1.07) was observed at the flowering stage and lowest (0.45) at maturity. A fifth degree polynomial fitted the data with $R^2 = 0.93$.

Pulses

The K_c for chickpea, fieldpea, and lentil was similar until 40 days from sowing (Fig. 7). Thereafter, K_c for chickpea was lower than for fieldpea and lentil until 90 days from sowing. K_c exceeded 1.0 for fieldpea and lentil in about 67 days and for chickpea in about 73 days and remained so until 120 days for fieldpea and lentil and until 128 days for chickpea. The highest K_c was 1.08 for fieldpea and lentil during 105-112 days crop stage and 1.1 for chickpea during 112-120 days from sowing and lowest (0.29) in the beginning. Lower K_c of chickpea than that of fieldpea and Lentil during 40-90 days crop stage was associated with its slow canopy growth, which

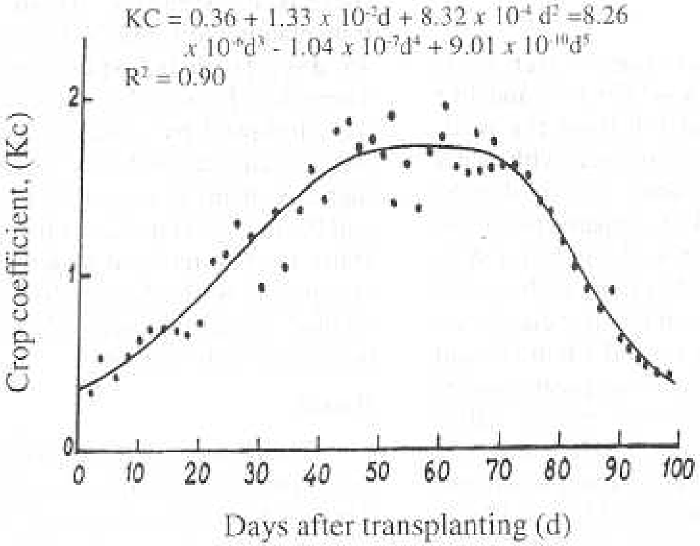

Fig. 5 : Crop coefficients for rice

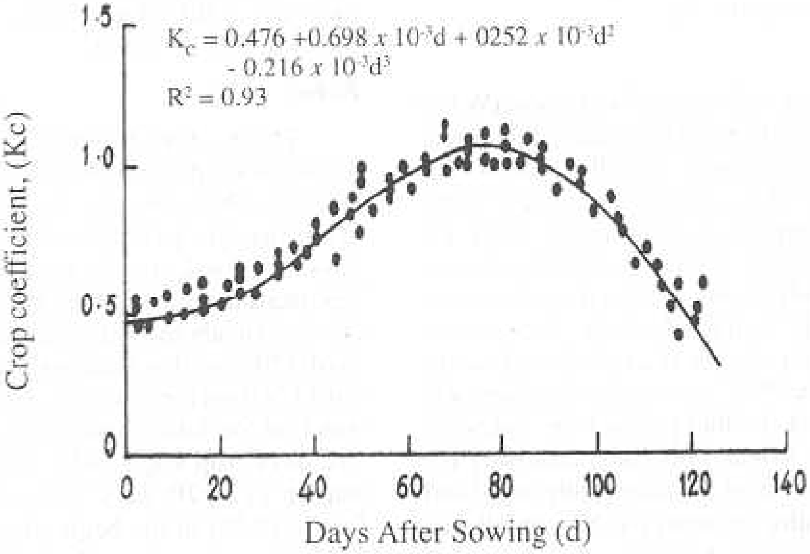

Fig.6 : Crop coefficients for wheat

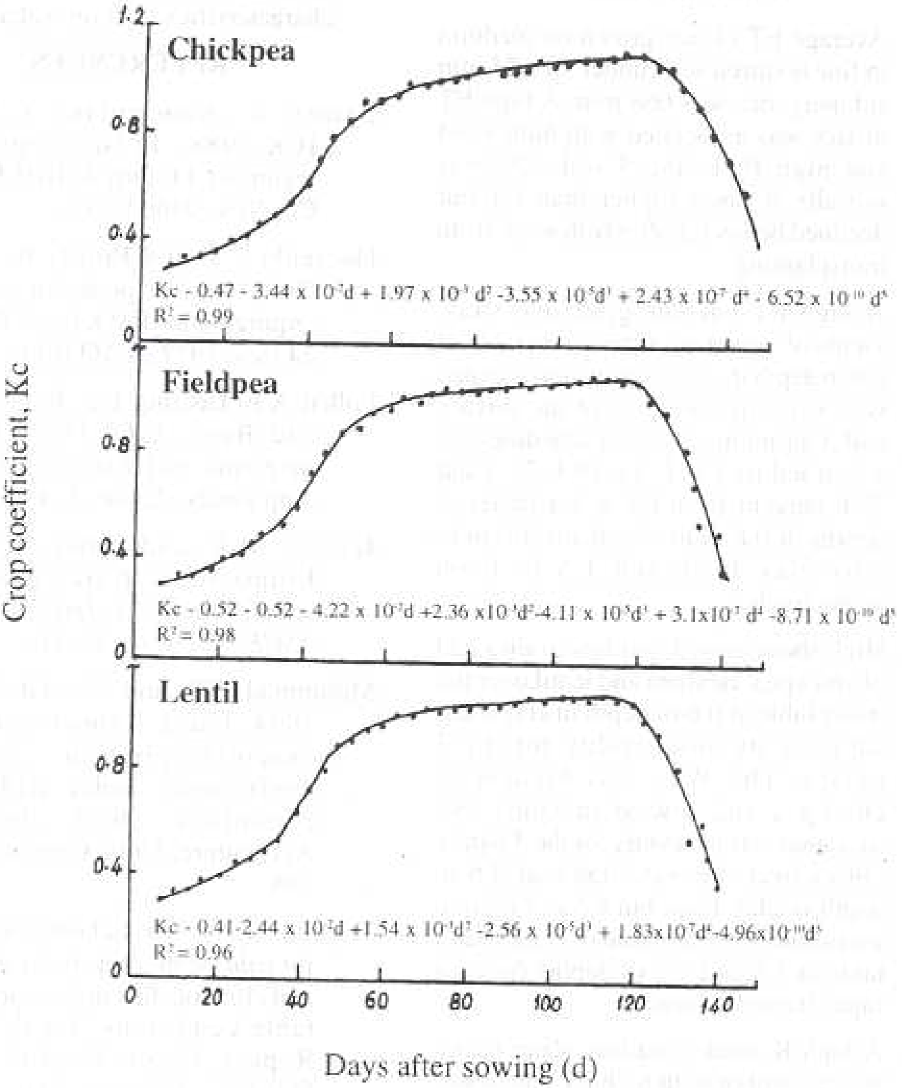

Fig.7 : Crop coefficients for chickpea, fieldpea and lentil

accelerated thereafter and exceeded that of fieldpea and lentil. The increased canopy growth during the podding stage increased ET (Fig. 4) and therefore, the K_c of chickpea exceeded those of fieldpea and lentil. The duration of chickpea was about 10 days more than that of fieldpea and lentil. The fifth degree polynomial that fitted the data accounts for more that 96 % of the variability in K_c of the 3 pulses during the crop season.

CONCLUSION

1. Average ET of rice grown on medium to fine textured soils under 50 ± 25 mm submergence was 668 mm. A high ET of rice was associated with high yield and high P_C in the 3 soils. P_C was initially 6 times higher than ET but declined below ET after fifth week from transplanting.

2. A high ET but low grain and straw yields of wheat over the water table at 0.6 m depth in clay loam was associated with excessive wetness of the surface soil. Optimum irrigation schedules for wheat induced WT_c by 19.4, 21.3 and 75.6 percent from the water tables at depths Of 0.6 m in clay loam, 1.0 m in silty clay loam and 1.6 in loam respectively.

3. High shoot growth but low grain yield of chickpea, fieldpea and lentil over the water table at 0.6 m depth in clay loam suggests its unsuitability for the 3 pulses. The WT_c was highest in chickpea and lowest in lentil. No irrigation was necessary for the 3 winter pulses over the water table at 0.6 m depth in clay loam but 62 and 88 mm irrigations were required over the water table at 1.0 and 1.6 m depths for zero input from the rainfall.

4. A high K_c under shallow water tables was a result of both high ET due to soil surface wetness by capillarity and perhaps underestimation of ET_p by Jenson and Haise (1963) method. Variations in K_c due to the 3 water tables were almost equal to the variations between 2 consecutive day values over the 3 years. K_c of chickpea, fieldpea and lentil depended more on canopy growth characteristics than on water table.

REFERENCES

Baldev, B., Ramanujam, S. and Jain, H.K.1988. Pulse crops (Grains legumes). Oxford & IBH Publishing Co. New Delhi 626 p.

Doorenbos, J. and Pruitt, W. D. 1977. Guidelines for predicting crop water requirements. FAO, Irrig. Drain. Pap. 24 (rev. 1977), FAO Rome, 144 P

Follett, R.F., Doering, E.J., Reichman, G.A. and Benz, L.C. 1974. Effect of irrigation and water table depth on crop yields. *Agron. J.*, 66: 304-308.

Jensen, M.E. and Haise, H.R. 1963. Estimating evapotranspiration from solar radiation. *J. Irrig. Drain. Div., ASCE*, 89 (IR 4): 15-41.

Mohmmad, F.S. and Abo-Ghobar, H.M. 1994. Using lysimeters to deliver evapotranspiration and crop coefficients under arid climatic conditions. Bull Faculty of Agriculture, Univ. Cairo, 45: 4, 785-798.

Tripathi, R.P. 1986. Scheduling irrigation for *rabi* (winter) crops from soil, crop and climatic data under varying water table conditions. Final Technical Report, Deptt. Of Soil Science, G.B.Pant. Univ. of Agric. & Tech., Pantnagar, India, 213 p.

Tripathi, R.P. 1992. Irrigation timing for wheat based on climate, crop and soil data. *J. Irrig. Drain. Div., ASCE*, 118(3): 370-381.

Tripathi, R.P., and Ghildyal, B.P. 1979.

Thermal regime of mollisoils under high water table conditions. *Agric. Meteorol.*, 20: 493-505.

Tripathi, R.P., Kumar, A. and Kushwaha, H.S. 1989. Irrigation requirements of wheat under shallow water table conditions. *Indian J. Agric. Sci.*, 50: 222-226.

Tripathi, R.P., Kushwaha, H.S. and Agrawal, A. 1987. A simple non-weighing lysimeter installation with rain shelter. *Agric. For. Meteorol.*, 41: 275-288.

Tripathi, R.P. and Mishra R.K. 1986. Wheat root growth and seasonal water use as affected by irrigation under shallow water table conditions. *Plant Soil*, 92: 181-188.

Wallender, W.W., Grimes, D.W., Henderson D.W. and Stromberg, L.K. 1979. Estimating the contribution of a perched water table to the seasonal evapotranspiration of cotton. *Agron. J.*, 71: 1056-1060.

Wright, J.L. 1982. New evapotranspiration crop coefficients. *J. Irrig. Drain. Div., ASCE*, 109 (IR 2): 57-74.