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Response of Wheat to Water Use Under Shallow Water Table Conditions of Tarai Region of Uttaranchal

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ABSTRACT

Water use-yield relationships have been developed from the measurements made in clay loam (S_1), silty clay loam (S_2) and loam (S_3), associated with natural water tables (WT) in the range of 0.4 - 0.8 m, 0.66 - 1.4 m, and 1.8 - 2.4 m depths from the surface in the respective soils at Pantnagar. Wheat yields in S_1 were 1.14 - 1.27 times lower than in S_2 and S_3 for a nearly similar evapotranspiration (ET). This led to a non-significant ET-yield relationship for the combined data of S_1, S_2 and S_3. But the relationship became significant when the data of S_1 was taken separately and that of S_2 and S_3 combined together. This indicated that regression of wheat yield on ET was affected by shallow water tables (WT) with associated soil texture. However, the regression of relative yield was uniquely and sigificantly related to relative seasonal ET for the combined data. The yield response factor, Ky, was 1.06, 1.37 and 1.59 for wheat in S_1, S_2 and S_3, respectively, under rainfed conditions and became unity by irrigation at crown root initiation (CRI) stage in S_1 and S_2 and by irrigation at CRI and flowering (F) stages in S_3. This implies that under conditions of limited water supply and water deficits equally spread over the total growing season, the decrease in wheat yield would be highest in S_3 (greatest Ky) and lowest in S_1 (Ky$\simeq$1). The yield versus field water supply or yields versus irrigation funcitons are convex.

Introduction

Water use-yield relationships are important in planning for a desired yield level for a given water supply (*Hanks et al., 1969; Stewart and Hagan, 1973; Stewart et al., 1974; Vaux and Pruitt, 1983*). Inadequate water supplies have direct effect on crop evapotranspiration (ET) and yield. Actual evapotranspiration (ETa) lower than the maximum evapotranspiration (ETm) is always associated with actual yield (Ya) lower than the maximum yield (Ym) of a variety adapted to the prevailing environment and growing under optimum input supply conditions. *Hanks (1974)* suggested a linear relationship between relative yield and relative seasonal transpiration to predict yield as influenced by irrigation management. Later, *Stewart et al.* (1974) reported that for optimal sequencing of ET deficit, the response of yield to water supply could be best quantified through the relationship between relative yield decrease and relative ET deficit as,

$$(1\text{-}Ya / Ym) = Ky\ (1\text{-}ETa / ETm) \quad \dots (1)$$

where ETa is actual ET of the crop corresponding to actual yield Ya, and ETm is the maximum ET of the crop corresponding to the maximum yield, Ym, obtained under non-limiting moisture conditions. Ky is the yield reduction ratio or yield response factor and is a measure of crop sensitivity to water stress. Crops respond differently to water deficit during different growth stages. This paper summaries the ET-yield values obtained from different well planned experiments at Pantnagar to establish yield-water relations under different water supply conditions.

Experimental

The data used in this paper is based on experimental results reported by *Tripathi et al.* (1989) and Tripathi (1997). The experments were conducted at Pantnagar, situated in the Tarai belt of Uttaranchal at 28° 26'N latitude and 79° 30'E longitude at an altitude of 243.8 m above the mean sea level. The soils are associated with shallow water tables in which upward flux from the ground water table to the root zone is significant (Tripathi, 1997). Depth to the natural water table from the surface was between 0.4 and 0.8 m in clay loam (S_1), 0.66 and 1.4 m in silty clay loam (S_2), and

1.8 and 2.4 m in loam (S_3). Irrigation treatments in the 3 soils were rainfed (I_0); irrigation at crown root initiation (CRI) stage only (I_1); irrigation at flowering (F) stage only (I_2); 2 irrigations each at CRI and late jointing (LJ) stages (I_3); CRI and F stage (I_4); CRI and milk (M) stages (I_5); 3 irrigations each at CRI, late tillering (LT) and F stages (I_6); CRI, LT and M stages (I_7), CRI, LJ and F stages (I_8), and CRI, LJ and M stages (I_9); 4 irrigations each at CRI, LT, LJ and F stages (I_{10}); CRI, LT, LJ and M stages (I_{11}), and 5 irrigations each at CRI, LT, LJ, F and M stages (I_{12}).

Crop ET (mm) was determined from water input and losses as

$$ET_n = R_n + I_n + WTc_n - D_n \pm \Delta S_n \qquad ...(2)$$

where R is rainfall (mm), I is irrigation (mm), WTc is water table contribution (mm), D is drainage (mm), and Δs is changes in soil water storage (mm). The subscript 'n' indicates time interval in days. Rainfall data was taken from the observatory near the experiment. Each irrigation was 60 mm measured through Parshal flume. The water table contribution, WTc, was calculated using Eq. (3) by measuring water table through piezometers installed in the plots, soil moisture tension at 0.15 m layer above the water table using mercury tensiometers and hydraulic conductivity functions K (Ψ) of the soil core above the water table where Ψ is soil moisture suction.

$$WTc = K(\Psi)\, \Delta H / \Delta Z \qquad ...(3)$$

where ΔH is hydraulic head difference across ΔZ i.e. between the water table level and mid-point of the tensiometers cup and K (Ψ) is hydraulic conductivity of the soil layer at average of the suctions (Ψ) at water table and tensiometer depth. Since soil cannot hold water beyond its potential storage capacity, the drainage, D_n, was determined as (Tripathi and Mishra, 1986)

$$D_n = \begin{cases} 0 \text{ for } S_n < Sp \\ S_n - Sp \text{ for } S_n > Sp \end{cases} \qquad ...(4)$$

where S_n is soil moisture storage on n^{th} day, and Sp is potential storage capacity of soil (equal to soil moisture content at field capacity). The soil moisture content was measured by neutron moisture gauge (Troxler 3222). If θ_n be the moisture content on n^{th} day and θ_{n-k} be that on $(n-k)^{th}$ day, with k = 1, 2, 3 ..., n days

$$\Delta S_n = \theta_{n-k} - \theta_n \qquad ...(5)$$

Results and Discussion

Evapotranspiration-Yield relationship

Regression of wheat yield on seasonal evapotranspiration (ET), using the data from the 3 soils (Tripathi *et al.*, 1989), taken together showed a poor relationship (Eq. 6)

$$Y = 110.4\ ET + 486.6, \quad R^2 = 0.53 \qquad ...(6)$$

where Y is grain yield, kg/ha, and ET is seasonal evapotanspiration, mm. This was perhaps due to 1.14 - 1.27 times lower yields in clay loam (S_1) than in silty clay loam (S_2) and loam (S_3) for a similar ET. However, the regression of yield on ET with data of S_1 taken separately and that of S_2 and S_3 combined gave a highly significant relationship (Fig. 1). This shows a strong dependence of ET - yield relationship on shallow water tables with associated soil texture. Lower wheat yield in S_1 than in S_2 and S_3 indicates a relatively less suitability of S_1 (clay loam) associated with water table between 0.4 and 0.8 m depths from the surface.

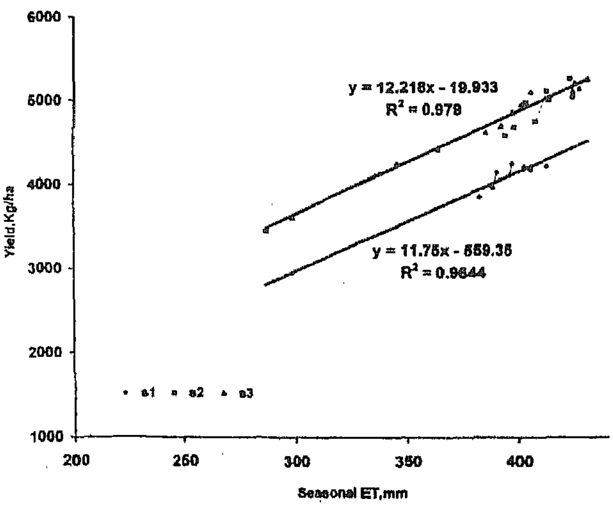

Fig. 1. Regression of wheat yield on seasonal evapotranspiration (ET) resulting from irrigation schedules and water table depths

To avoid the effect of site-specific soil and hydrologic conditions, the relative yield was regressed on relative ET to obtain a linear relationship (Fig. 2) for the entire data as

$$Ya / Ym = 1.02\ ETa / Etm - 0.02, \quad R^2 = 0.94 \qquad ...(7)$$

The relationship is strongly linear (P=0.01).

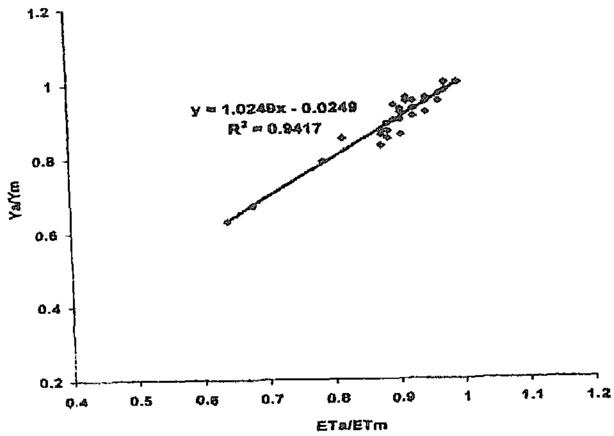

Fig. 2. Regression of relative yield of wheat (Ya/Ym) on relative seasonal ET (ETa/ETm) resulting from irrigation schedules and water table depths

Yield response factor

Yield response factor, which is a measure of crop sensitivity to water stress, was obtained by plotting relative yield decrease with relative ET deficit (Fig. 3). As shown in Fig. 3, the yield response factor, Ky, was 1.06, 1.37 and 1.59 for wheat in S_1, S_2 and S_3, respectively, under rainfed conditions and became unity by irrigation at CRI in S_2 and at CRI and F stages in S_3. This implies that wheat crop in S_3 was 16 and 50% more sensitive to ET deficit than in S_2 and S_1, respectively, and the crop in S_2 was 29% mroe sensitive to ET deficit than in S_1. That is, under conditions of limited water supply and water deficits equally spread over the total growing season, the decrease in wheat yield would be highest in S_3 (greatest Ky) and lowest in S_1 (Ky$\simeq$1). Consequently, for maximum production per unit volume of water, the order of priority of water supply to wheat crop should be in $S_3 > S_2 > S_1$. The relationship also indicates that wheat is most sensitive to water deficit at CRI stage in S_1 and S_2 and CRI and F stages in S_3 (Fig. 3). Thus for optimum yield and efficiency, water supplies should be directed towards meeting full water requirements of wheat crop during these sensitive growth periods. Additional irrigations lead to luxurious growth and lodging during the grain development stage.

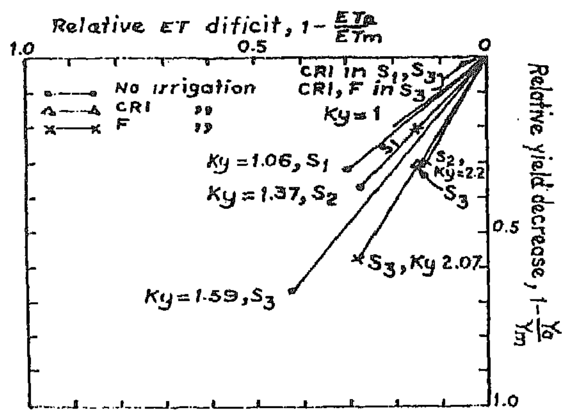

Fig. 3. Relative yield decrease (1 - Ya/Ym) as a function of relative evapotranspiration deficit (1 - ETa/ETm) in Phoolbagh clay loam (S_1), Beni silty clay loam (S_2) and Haldi loam (S_3)

There is no need of 5 irrigations in wheat in these soils under Tarai conditions. Although irrigation at the F stage raised grain yield over the rainfed plot, yet the increase was less than irrigation at the CRI stage. Decrease in grain yield due to ET deficit during the F stage was greater in S_3 than in S_1 and S_2. Water savings can thus be achieved through greater precision in timing and quantity of irrigation applications.

Crop yield as a function of applied water

A plot of yield versus ET, yield versus field water supply (FWS), and yield versus irrigation depth has been shown in Figs. 4 and 5. Each point in the figures represents an average of 4 to 16 values. The field water supply (FWS) refers to the sum of available soil water (ASW) at planting, rainfall (R), water table contribution (WTc) and seasonal irrigation (IRR) depth (Stewart and Hagan, 1973).

In contrast to the linear yield versus ET function, yield versus fields water supply (FWS)

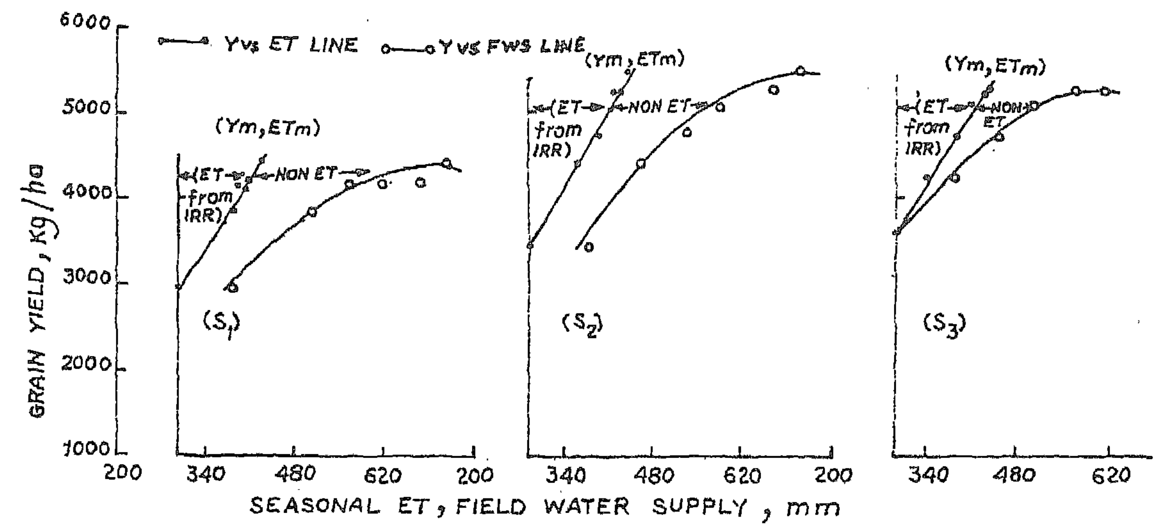

Fig. 4. Grain yield as a function of seasonal evapotranspiration (ET) and field water supply (FWS) in Phoolbagh clay loam (S_1), Beni silty clay loam (S_2) and Haldi loam (S_3). The FWS refers to available soil water (ASW) at planting + rainfall + water table contribution (WTc) + seasonal irrigation (IRR) depth

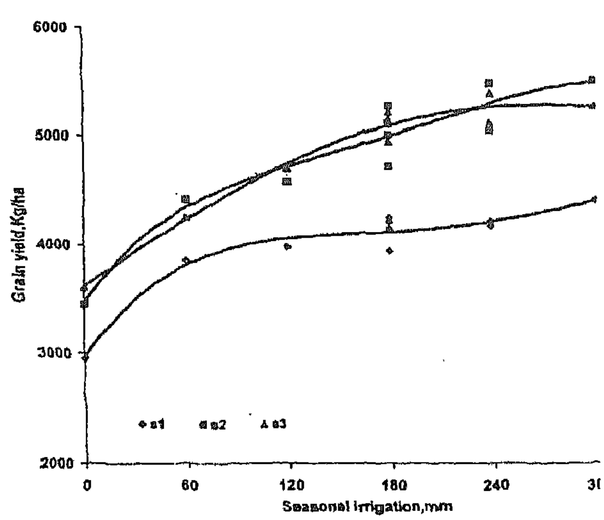

Fig. 5. Grain yield as a function of seasonal irrigation in clay loam (S_1), silty clay loam (S_2) and loam (S_3)

$$y = -6E - 07x^4 + 0.005\ x^3 - 0.166x^2 + 22.353x + 2958,$$

$$R^2 = 0.9541$$

$$y = -9E - 07x^4 + 0.0006x^3 - 0.1605x^2 + 22.205x + 3463.6$$

$$R^2 = 0.9148$$

$$y = 1E - 07x^4 - 9E - 05x^3 - 0.0021x^2 + 10.676x + 3614$$

$$R^2 = 0.971$$

or yield versus irrigation (IRR) functions are convex (Figs. 4 and 5). Owing to the contribution from the water table (WTc), the FWS in S_1 and S_2 exceeded ET even without irrigation despite resposne to irrigations (Fig. 4). But in S_3 in which contribution from the water table to the ET requirements was zero under rainfed condition, the linear and convex functions started together. The convex yield versus FWS function, however, departed from the linear yield versus ET function as the applied water increased. The difference between the two curves is non-ET portion of the applied water.

For 100 per cent irrigation efficiency, all the irrigation (IRR) water or FWS should be used as ET and, therefore, any departure of yield versus FWS or yield versus IRR line from the yield versus ET line should indicate a decrease in irrigation efficiency (IRR EFF). The irrigation efficiency was lowest at maximum evapotranspiration (Fig. 4).

IRR EFF = [ET (from IRR) / IRR] 100 ....(8)

To achieve Ym, field water supply would always exceed ETm because of increased deep percolation with irrigations and heavy rainfall (Tripathi *et al.*, 1989).

The relationship between yield and irrigation depth (Fig. 5) is some time more practical because a farmer can exercise his control. But variability of rainfall, water table contribution and available soil moisture would limit the transferability of such a relationship in the irrigation management.

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