STUDIES ON ENERGY STATUS AND TRANSPIRATION OF WHEAT PLANTS AS INFLUENCED BY AERIAL ENVIRONMENT, SOIL WATER POTENTIAL AND TEXTURE

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SUMMARY

Transpiration rate (E_a/E_p), leaf water potential (ψ_l) and relative water content (RWC) of wheat plants as influenced by soil water potential (ψ_s) were studied at two aerial environments (21° C, 52% R.H. and 31° C, 48% R.H.) grown in three different textured soils and sand. The transpiration rate remained nearly constant at high soil moisture contents, above the thresh-hold soil water potentials, -1.0, -0.5 and -0.1 bars for clay loam, sandy loam soils and sand respectively. Relatively at low ψ_s' the transpiration of wheat was higher in clay loam than in other loam soils, presumably due to the higher hydraulic conductivity of the former. The leaf water potential of wheat leaves declined exponentially with decreasing soil water potential. The effect of environment on the leaf water potential values was conspicuous when the wheat was grown under stress conditions. A statistically significant positive correlation was found between RWC and leaf water potential in wheat plants. The leaf water potential, relative water content and transpiration were affected by aerial environment and soil texture.

INTRODUCTION

Water transport from soil through plant to the atmosphere follows a gradient of potential energy (Gardner, 1960 and Slatyer and Gardner, 1965). Philip (1966) has stressed the need for more realistic studies of various components affecting water relations in soil plant system. However, efforts have been made by many workers to interpret the water relations in the complex soil-plant systems (Denmead

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Formerly Expert, Soil Physics, Unit of Land Reclamation, Institute for Applied Research on Natural Resources, AL-Jadiriyah, P.O. Box 10094, Baghdad, Iraq, and Head Department of Agricultural Chemistry and Soil Science, Marathwada Agricultural University, Parbhani, Marathwada, India respectively.

and shaw, 1959, 1960, 1962: Cowan, 1965; Boyer, 1970, Frank *et al.*, 1973, Beadle *et al.*, 1973, McCree, 1974, Millar and Denmead, 1976, Thomas *et al.*, 1976, Ackerson and Krieg, 1977, Ackerson *et al.*, 1977). As evidenced by the literature related to this subject, and with other physiological systems, usually more than one factor controls the water relations in the complex soil-plant system. Therefore, in order to characterise the soil-plant atmosphere continuum quantitatively, the integrated study of its various components is essential.

Moreover, the quantitative information on water transmission properties of soil in the vicinity of roots and internal energy status of plant in relation to environmental conditions make it possible to evaluate the water flux from soil to plant. Therefore, the objective of our present investigation was to evaluate the energy status and transpiration of wheat (*Triticum aestivum*) as influenced by ambient environment, soil water potential and soil texture.

MATERIALS AND METHODS

Wheat (*Triticum aestivum* L. Var. Kalyan sona) plants were grown in sand and three different soils, namely, latrite sandy clay loam, Balrampur clay loam and Raipur red soil packed into 20 kg capacity pots separately. The bulk density was maintained as 1.40, 1.50 and 1.60 each $+0.05$ g cm^{-3} for Raipur red soil, Balrampur clay loam, latrite sandy clay loam and sand respectively. The pH of latrite sandy clay loam soil was raised from 5.4 to 7.5 by liming. The pertinent properties of soils are presented in Table I (Dhan Pal and Varade, 1972).

Initially the plants were raised in glass house. For the better growth, plants were irrigated frequently. In sand, the plants were irrigated based on the predetermined quantity of water to replenish the water loss. When the plants were 6 weeks old, the pots were transferred to a controlled environmental chamber pre-conditioned for 24 hours before the measurements commenced. The plants were subjected to differential soil moisture stress under two different aerial environments each replicated four times. The pertinent inputs of both the environments are presented in Table II. Artificial illumination was provided for 12 hours a day. During the light period, the light intensity on the top of the leaves was 0.25 cal. cm^{-2} min^{-1} under white flourescent light for both the environments. The temperature and humidity were recorded by thermohygrograph continuously through out the entire period. The variations in air temperature and relative humidity in growth chamber were ± 1 °C and 4 per cent respectively.

The energy status of leaves e.g., transpiration rate, leaf water potential and relative water content were determined. Transpiration rate was measured by

Table I. *Pertinent soil properties*

Material used	Soil fraction	Percentage in soil	Texture	Major soil group	pH	Organic carbon percentage	Total N	Total P_2O_5	Total K_2O	Electrial conducti-vity mmhos/cm at 25 °C
Laterite sandy clay loam soil	Coarse sand	34.4	sandy	Laterite (Oxisols)	5.4	0.38	0.034	0.071	0.78	1.07
	fine sand	22.3								
	silt	19.3								
	clay	23.0								
Raipur red soil	coarse sand	23.7	sandy loam	Red and Yellow (Rholustalfs	7.5	0.30	0.028	0.063	0.37	0.85
	fine sand	37.6								
	silt	17.5								
	clay	20.6								
Balrampur clay loam soil	coarse sand	21.0	clay loam	Vindhya alluvial	7.2	0.42	0.039	0.094	0.92	1.32
	fine sand	23.2								
	silt	24.8								
	clay	30.7								

Table II. Air temperature, relative humidity and saturation deficit in controlled environment chamber as a function of air temperature and relative humidity

Air temperature (°c)	Relative humidity (per cent)	Saturation deficit of air (mm Hg)	Water potential of air (bar)
21.0	52	9.1	- 884
31.0	48	17.1	-1026

weighing the pots periodically. Relative transpiration ratio was obtained by dividing the transpiration of stressed plants (E_a) by potential transpiration (E_p). The

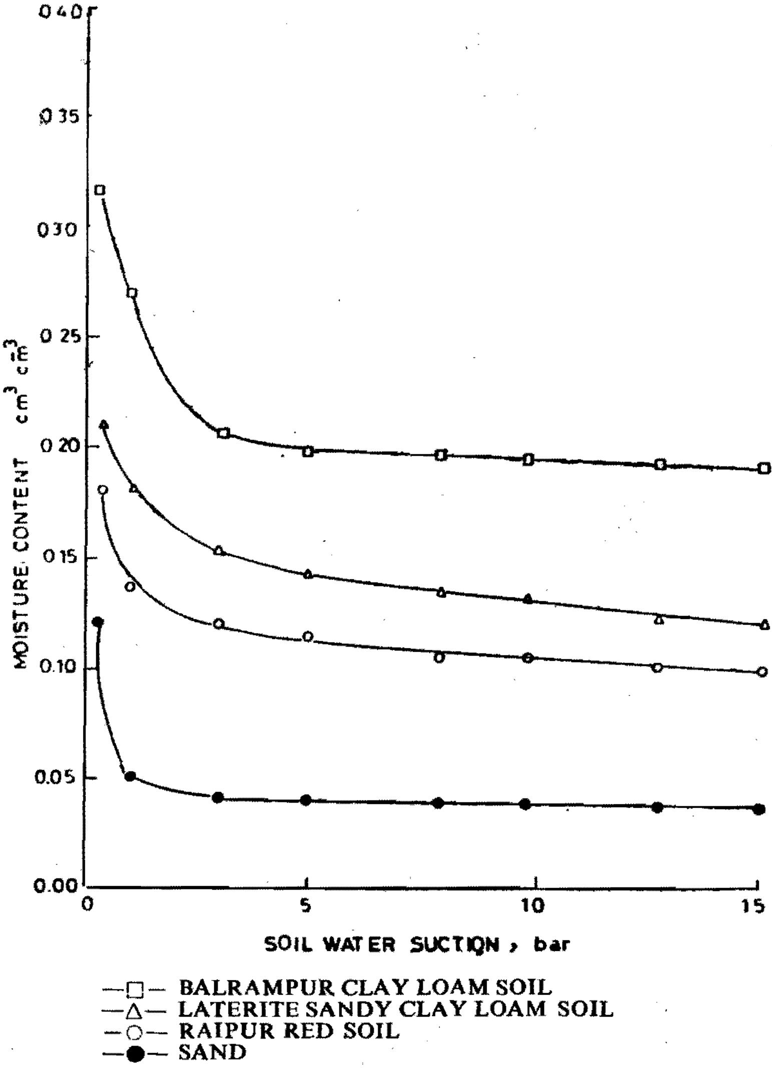

Fig. 1. Moisture characteristics of different soils and sand.

leaf water potential (ψ_l) was measured twice daily for several successive days using pressure bomb apparatus (Dhan Pal and Varade, 1974). Relative water content (RWC) was determined employing the technique as described by Barrs and Weatherly (1962). The soil water potential (ψ_s) upto -0.8 bar was measured directly by tensiometers installed in each pot. Beyond -0.8 bar, the soil water potentials at respective average moisture contents were interpolated from the moisture retention characteristics curves (Fig. 1). The corresponding values of x and y parameters of different curves (Fig. 2 to 6) should be read by drawing the vertical or parallel line of defined values through respective opposite axis for each segment.

RESULTS AND DISCUSSION

The relative transpiration ratio (E_a/E_p) of wheat plotted as the function of soil suction of three soils and sand at two different environments are shown in Fig 3. It is evident from the results that the transpiration remained nearly unity at relatively high soil water contents, above the critical threshhold water

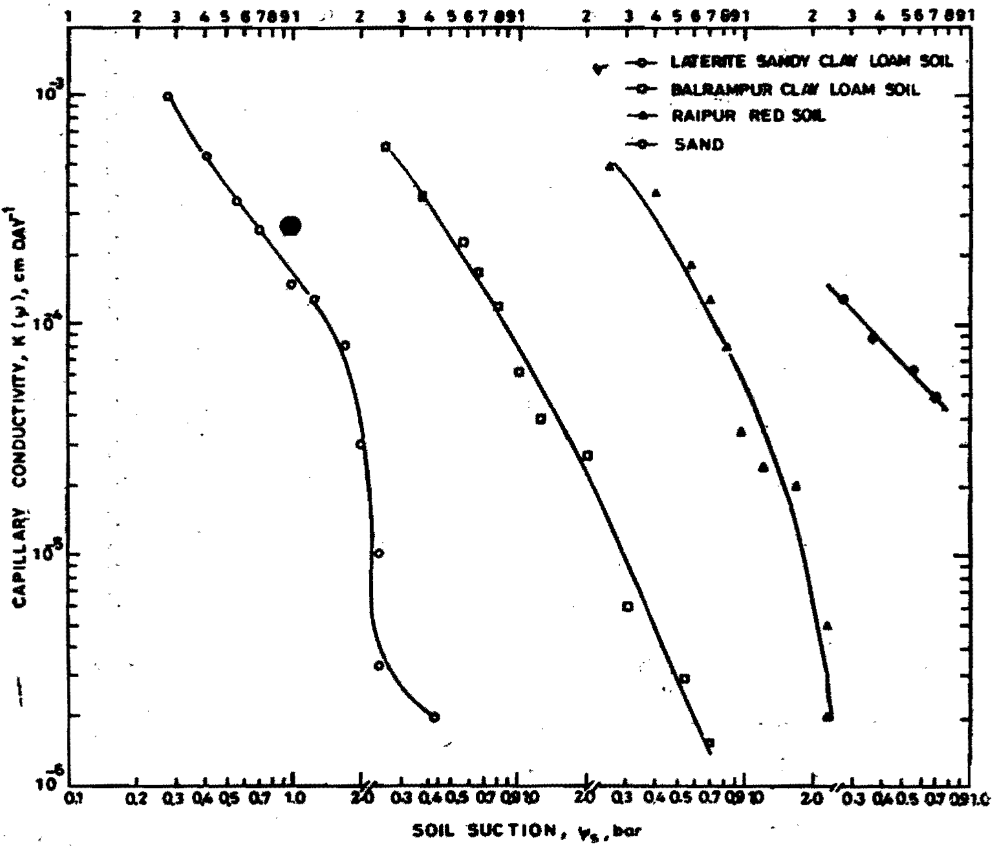

Fig. 2. Capilary conductivity as a functionof soil suction.

potentials -1.0, -0.5 and -0.1 bars for Balrampur clay loam, laterite sandy clay loam and Raipur red soil, and sand respectively. This variation is attributed to differential available water in soils and sand (Fig. 1). It is also obvious that the high evaporative demand induced by high temperature and low relative humidity did not affect the transpiration of wheat grown at fairly high soil water conditions, unless the water extraction by roots is lowered as a result of sufficient decrease in soil moisture content. Thereafter, the transpiration rate declined rapidly with decreasing soil water potential. Similar pattern of decline of transpiration at low water potentials was observed by Denmead and Shaw (1960, 1962), Thomas and Weigand (1970) and Seatan *et al.*, (1977) in corn, cotton and wheat respectively. The E_a/E_p ratio declined more rapidly in loam than that in clay loam soils at decreasing soil water potentials. This is attributed to the differential hydraulic conductivity of soil materials (Fig. 2), identified as the major limiting factor in controlling the water supply to the plant roots. This supports the findings of Gardner (1960), Gardner and Ehlig (1962, 1963), and Lang and Gardner (1970).

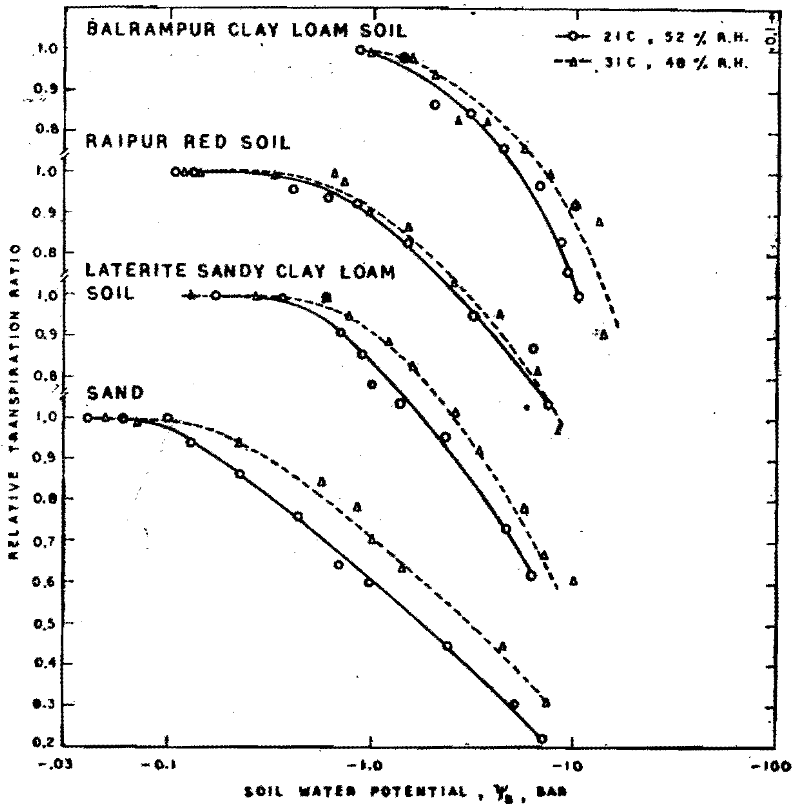

Fig. 3. Relationship between relative transpiration ratio and soil water potential for wheat in two different environments.

Figure 4 depicts the relationship between soil water potential and leaf water potential. It is evident from the measurements that the upper limit of leaf water potential for well watered wheat plants was about -8 bar and decreased to -20 to -22 bars under stressed conditions. There was an exponential decrease of ψ_1 at decreasing ψ_s under both the environments.

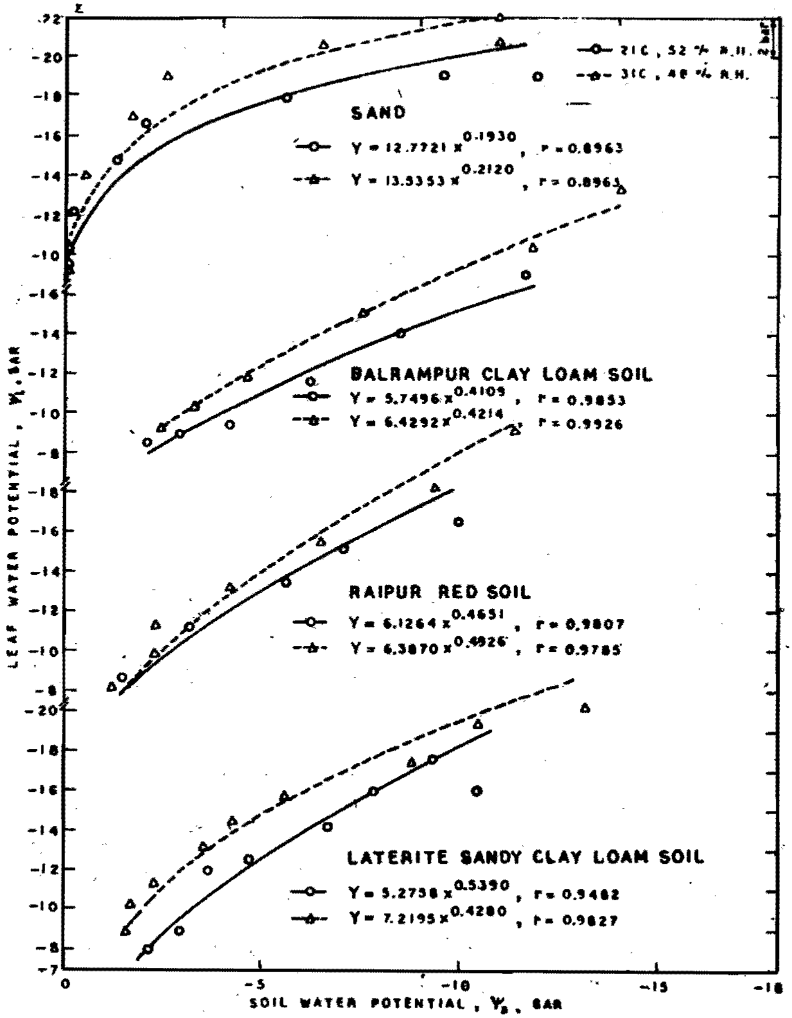

Fig. 4. Relationship between leaf water potential and soil water potential for wheat in two different environments.

The decline in ψ_1 is more conspicuous at low soil water potentials. The effect environment on relationship between ψ_1 and ψ_s is less prominent at higher soil water potentials and it becomes conspicuous at lower ψ_s. In sand, ψ_1 decreasd more rapidly even at higher soil water potential values as compared to the soils. The water supply might become a limiting factor in sand. At same ψ_s under the same environment, leaf water potentials were generally higher for plants grown in Balrampur clay loam than in loam soils. These results were expected since ψ_l and ψ_s are related by the following equation (Gardner, 1966).

$$\psi_l = \psi_s - q\,(I_p + I_s) \qquad \text{............(1)}$$

where q is the transpiration rate, and I_p and I_s are the resistances to water movement in plant and soil respectively. Since I_s is inversely proportional to the hydraulic conductivity, the ψ_l would be greater for soils having higher hydraulic conductivity. When ψ_s remained constant, higher conductivity in Balrampur clay loam soil resulted in higher ψ_l in wheat leaves. Thus, the difference in hydraulic conductivity of these soils (Fig. 2) could account for different relationship between soil and leaf water potentials.

The relationship between leaf water potential and relative water contents of wheat leaves at two different environments is shown in Fig. 5. It is obvious from the data that the variation in RWC closely corresponded with that of leaf water potential. Plants had consistently lower RWC for a given ψ_l under low temperature-high relative humidity than under high temperature-low humidity environment. The slope of curve of RWC *vs* ψ_l changed abruptly between 99 to 95 per cent RWC and thereafter followed a linear trend. Reporting a similar change for barley leaves, Miller *et al.*, (1970) observed that (I) at higher RWC, the turgor pressure dropped more rapidly as compared to the osmotic pressure, (II) at lower RWC, the reverse was true, and (III) the change in slope coincided with a change in elasticity of leaves. Variation in leaf water characteristics with environment (Fig. 5) reduces the usefulness of relative water content as an index of leaf water potential. Gavande and Taylor (1967) found that similar shifts in leaf water characteristics of orchard grass (*Dactylis glomerata*) and tomato (*Lycopersicon* sp.) were largely due to a decrease in osmotic potential of the plant with increased evaporative demand. They attributed the increased concentration of the cell sap to conversion of starch to sugar or a reduced cell water content.

Simultaneous plot of relative water content and leaf water potential to transpiration is shown in Fig. 6. Transpiration rate dropped rapidly as the relative water content of wheat leaves decreased from 98 to 90 per cent, followed by more gradual decrease. Thereafter, the transpiration rate of wheat grown in different soils became almost constant. A similar pattern was observed for barley (*Hordium vulgare*) by Miller *et al.*, (1970); It also agrees with the reported rapid increase in stomatal resistance of snap beans (*Phaseolus vulgaris*) as leaf water potential dropped below -11 atm (Kanemasu and Tanner, 1969). The data demonstrated that transpiration, leaf

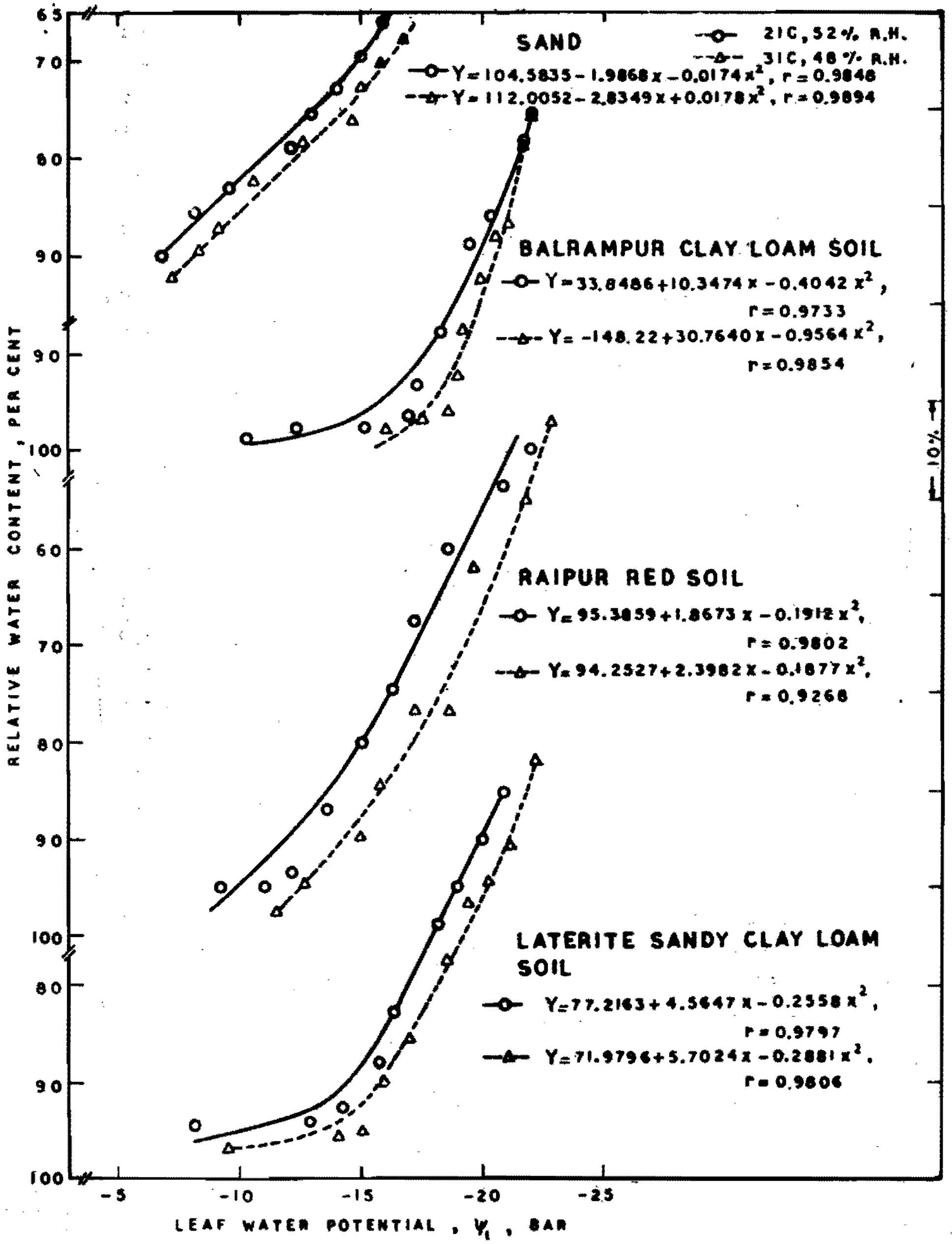

Fig. 5. Leaf water characteristics for wheat grown in different soils in two different environments.

water potential and relative water content of wheat leaves were significantly affected by increased evaporative demand. Also, simultaneous plot of RWC

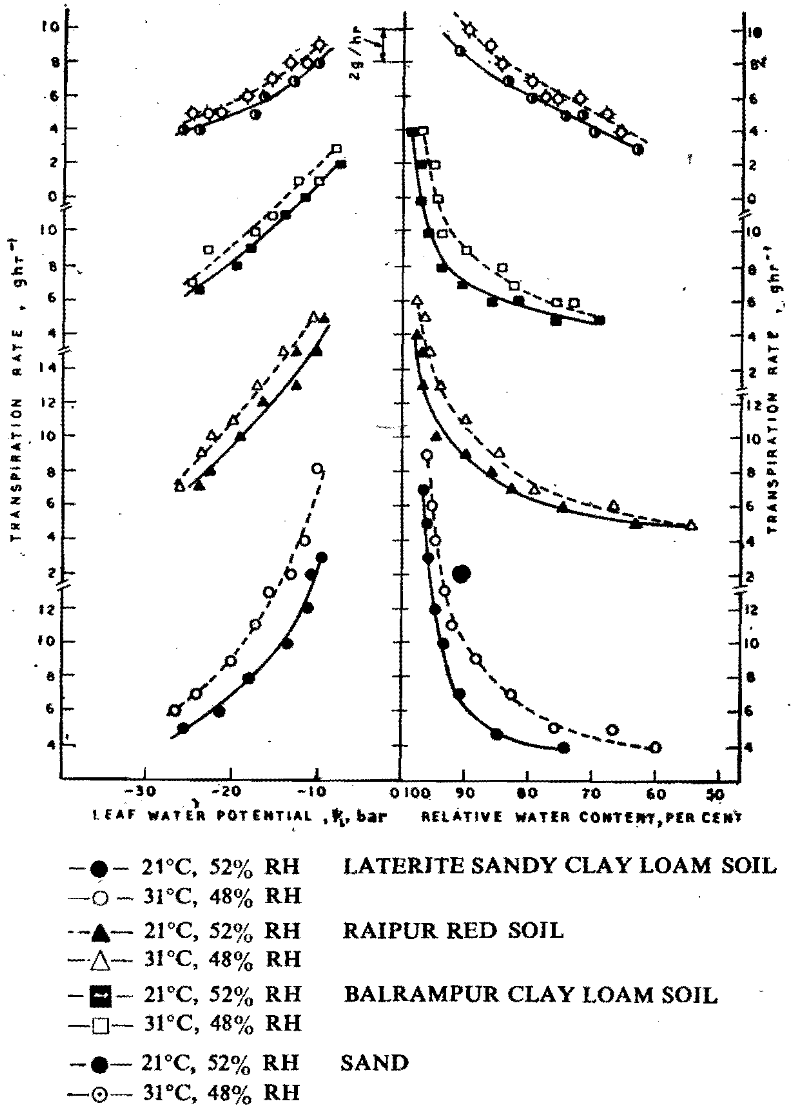

Fig. 6. Relationship between transpiration rate and water status of leaves of wheat in two different environments.

and ψ_1 *vs* transpiration (Fig. 6) showed that around 50 to 60 per cent of potential transpiration occurred when the RWC of leaves decreased from 100 to 90 per cent. It is also evident that the change in relative water contents was proportional to the alteration in water potential of leaves affecting transpiration in all three soils and sand. This strongly supports the view that leaf water content can serve as an index for leaf water potential in wheat plants.

REFERENCES

Ackerson, R.C. and Krieg, D.R. (1977). Stomatal and non-stomatal regulation of water use in cotton, corn and sorghum. *Plant Physiol.*, **60** : 850-63.

———————., ———————, Haring, C.L. and Chang, N. (1977). Effects of plant water status on stomatal activity, photosynthesis and nitrate reductase activity of field grown cotton. *Crop Sci.*, **17** : 81-84.

Barrs, H.D., and Weatherly, P.E. (1962). A re-examination of the relative turgidity techniques for estimating water deficits in leaves. *Aust. J. Biol. Sci.*, **15** : 413-28.

Beadle, C.L., Stevenson, K.R., Neumann, H.N., Thurtell, G.W. and King, K.M. (1973). Diffusive resistance, transpiration and photosynthesis in single leaves of corn and sorghum in relation to leaf water potential. *Can. J. Plant. Sci.*, **53** : 537-44.

Boyer, J.S. (1970). Differing sensitivity of photosynthesis to low leaf water potentials in corn and soybean. *Plant Physiol.*, **46** : 236-39.

Cowan, I.R. (1965). Transport of water in soil-plant-atmosphere system. *J. Applied Ecol.*, **2** : 221-39.

Denmead, O.T. and Shaw, R.H. (1959). Evapotranspiration in relation to the development of corn crop. *Agron. J.*, **51** : 725-26.

——————— (1960). The effects of soil moisture stress at different stages of growth on the development and yield of corn. *Agron. J.*, **52** : 272-74.

——————— (1962). Availability of soil-water to plants as affected by soil moisture content and meteorological conditions. *Agron. J.*, **54** : 385-90.

Dhan Pal and Varade, S.B. (1972). Intrinsic penetrability and diffusivity as influenced by initial moisture content and texture. *Geoderma*, **8** : 103-10.

——————— (1974). Fabrication and performance of pressure bomb apparatus for the measurement of leaf water potential. *Indian J. Agril. Sci.*, **44**(5) : 259-61.

Frank, A.B., Power J.F. and Willis, W.O. (1973). Effect of temperature and plant water stress on photosynthesis, diffusion resistance and leaf water potential in spring wheat. *Agron. J.*, **65** : 777-80.

Gardner, W.R. (1960). Dynamic aspects of water availability to plants. *Soil Sci.*, **89** : 63-73.

——————— (1966). Soil water movement and root absorption. P. 127-148. In W.H. Pierre Don Kirkhan, John. Pesek and Robert Shaw (eds). Plant environment and efficient water use. *Amer. Soc. Agron.*, Madison, Wis.

——————— and Ehlig, C.F. (1962). Some observations on the movement of water to plant roots. *Agron. J.*, **54** : 453-56.

——————— (1963). The influence of soil water on transpiration by plant. *J. Geophysics, Res.*, **68** : 5719-24.

Gavande, S.A. and Taylor, S.A. (1967). Influence of soil water potential and atmospheric evaporation demand of transpiration and energy status of water in plants. *Agron. J.*, **59** : 4-7.

Kanemasu, E.T. and Tanner, C.B. (1969). Stomatal diffusion resistance of snap beans. I. Influence of leaf water potential. *Plant Physiol.*, **44**: 1547-52.

Lang, A.R.G. and Gardner, W.R. (1970). Limitation to water flux from soils to plants. *Agron. J.*, **62** : 693-95.

MaCree, K.J. (1974). Changes in the stomatal response characteristics of grain sorghum produced by water stress during growth. *Crop Sci.*, **14** : 273-78.

Millar, B.D. and Denmead, O.T (1976). Water relations of wheat leaves in the field, *Agron. J.*, **68** : 303-307.

Millar, A.A., Duysen, M.E. and Norum, B.B. (1970). Relationships between the leaf water status of barley and soil, *Can. J. Plant Sci.*, **50** : 363-70.

Philip, J.R. (1966). Plant water relations—some physical aspects. Ann. Rev. *Plant Physiol.*, **17** : 245-68.

Seaton, K.A., Landsberg, J.J. and Sedgley, R.H. (1977). Transpiration and leaf water potentials of wheat in relation to changing soil water potential. *Aust. J. Agric. Res.*, **28** : 356-67.

Slatyer, R.O. and Gardner, W.R. (1965). Overall aspects of water movement in plants and soils. *Soc. Exptl. Biol.*, **29** : 113-29.

Thomas, J.C., Brown, K.W. and Jordan, W.A. (1976). Stomatal response to leaf-water potential as affected by preconditioning water stress in the field. *Agron. J.*, **68** : 707-708.

Thomas, J.R. and Weigand, C.L. (1970). Osmotic suction effects on relative turgidity, temperature and growth of cotton leaves. *Soil Sci.*, **109** : 85-92.