Pak. j. sci. ind. res., vol. 32, no. 1, January 1989

YIELD AND WATER USE OF WHEAT AS AFFECTED BY WATER STRESS

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(Received October 22, 1988; revised January 21, 1989)

The experiment was carried out during December 1986 through March 1987 in the field under natural environmental conditions to study the effects of soil water stress applied at various stages of growth on the yield and water use of wheat (*Triticum aestivum* L. cv. 'Pitic'). Soil water stress treatments consisted of single period without irrigation. Soil water deficit increased progressively in all the stress treatments during the advance of the drying period, with the maximum obtained when the crops were subjected to water stress from booting to flowering stages. The highest cumulative evapotranspiration was found when stress was imposed at shooting due to development of late tillers after the termination of water stress. Crops undergoing water stress during vegetative phase regained a rate of evapotranspiration similar to that of the fully irrigated immediately after the termination of water stress. Water stress at all growth stages studied reduced the grain yield and water use of wheat significantly, but the effect was maximum when stress occurred from booting to flowering stages. Water use efficiency for grain production was highest for the fully stressed crops and lowest for fully irrigated crcps. The increaes in water use decresed the water use efficiency but increased harvest index.

Keywords: Wheat, Yield, Water use, Water stress.

INTRODUCTION

Striking increases in wheat productivity in Bangladesh since early seventies have largely been associated with growing of high yielding varieties under irrigation. Wheat in Bangladesh is usually planted in November and early December and harvested in mid or late March of the following year. Since rainfall during the winter season/wheat growing season is inadequate and uncertain, wheat requires supplemental irrigation for its proper growth and development, otherwise, water stress is likely to develop and reduce crop yield. Irrigation water in Bangladesh is a limited resource and therefore, irrigation practices must be rationalized for high water use efficiency and advisable to schedule irrigations at critical growth stages. Wheat may be more sensitive to water stress at any particular stages of its growth. The effect of water stress on grain yield of wheat depends on the stage of the development of the crop during drought, the duration and the severity of the drought.

A number of growth stages have been identified as the critical stages of water stress. These critical growth stages in wheat include crown root initiation (Patel *et al.*, [1], Alam and Ashadullah, [2]; seeding to maximum tillering (Choudhury and Kumar, [3]; tillering (Sekhon *et al.*, [4], Razzaque, [5]; Jointing (Day and Intalap, [6]; Shooting (Aamodt and Johnston, [7]; booting (Campbell *et al.*, [8]; heading (Salim *et al.*, [9]; tillering to heading (Dragland, [10]; booting to heading (Singh, [11], Campbell *et al.*, [8], Mogensen *et al.*, [12]; flowering (Pope and Hay, [13]; booting to early grain filling (Hochman, [14]; flowering to grain filling (Sionitt *et al.*, [15]; booting to maturity (Robins and Domingo, [16]; heading to grain formation (Talukder *et al.*, [17], and grain filling (Rahman *et al.*, [18], Talukder, [19]). Mogensen *et al.*, [12] and Talukder *et al.*, [17] reported that drought sensitivity of wheat was greatest during tillering to shooting when the grain yield of only normal tillers was considered, but during booting to heading (Mogensen *et al.*, [12] and heading to grain formation (Talukder *et al.*, [17] when the grain yield of both normal and late tillers were included. These results were reported from experiments in which a fixed degree of water stress was imposed for a particular growth stage. However, the sensitivity of various growth stages to water stress may be different, depending upon soil conditions, climatic factors and plant factors.

The relationship between grain yield and water use is much more complex than the total dry matter yield, because the grain yield is more sensitive to water stress at certain stages of its growth and development. However, a linear relationship with a higher correlation coefficient between grain yield and water use was reported for wheat (deWit, [20]; Innes and Blackwell, [21]; Singh *et al.*, [22]; Singh, [11]; Gajri and Prihar, [23]; Talukder, [19]. Water use by the growing crop depended very much on the size of the transpiring surface of the crop (leaf area index) and the evaporative demand of the atmosphere [24]. The experiment described in this paper was designed to evaluate, firstly, the effects of water stress on yield, water use and water use efficiency and secondly, to investigate the relationship between yield and water use (water production function) of wheat as affected by water stress at different growth stages.

MATERIALS AND METHODS

The experiment was conducted during the wheat growing season of 1986-87 at the Field Laboratory of the Department of Genetics and Plant Breeding, Bangladesh Agricultural University, Mymensingh (24°43' N, 90°26' E; 19m above M.S.L.).Only16mm rainfall occurred during the experimental period. The daily pan evaporation varied from 0.6 to 7.3 mm. Soil samples from three different locations were collected at random from the experimental field at depths ranging from 0-20, 20-50 and 50-100 cm and analysed in the laboratory to determine the particle size distribution. Texturally, the soil was silty loam having 23.5% sand, 61.0% silt and 15.5% clay. The pH value and the bulk density of the soil were 7.1 and 1.4 g cm^{-3}, respectively. The soil moisture content held at field capacity (-0.03 Mpa) was 35% and at wilting point (-1.5 Mpa) was 16.8% by weight.

A high yielding cultivar of wheat (*Triticum aestivum* L. cv. 'Pitic') was sown at the rate of 100 kg ha^{-1} on December 2, 1986 and harvested on March 26, 1987. The crops were grown at an usual spacing of 25 cm between rows and 5 cm between plants. The crops emerged on December 7, 1986 and the average plant density before tillering was approximately 74 x 10^4 ha^{-1}. Fifteen plots each of which measuring 20 (5m x 4m)m^2 with 25 cm high ridges, were separated from each other by 1m buffer zone to prevent seepage from plot to plot. Similarly, the replicates were separated from each other by 1m buffer zone in and around the field. Nitrogen, phosphorus and potash fertilizers were applied prior to the sowing at the rate of 200 kg N, 200 kg P_2O_5 and 80 kg K_2O ha^{-1}, respectively. These were mixed with the top 15 cm soil.

Aluminium access tubes, each of 5.0 cm in diameter and 1.5 m long, were installed in each corner at a distance of 1m x 1m in each plot. Changes in soil water content in the 0-110 cm soil profile in all 15 plots were measured twice a week with the neutron moisture meter at 10, 20, 30, 40, 50, 70, 90 and 110 cm depths. These values were periodically checked by use of gravimetric samplings. The quantity of water required for irrigating each plot was calculated on the basis of actual root zone depth from the data recorded with help of neutron moisture meter before each irrigation. A change with time in the soil water content at a particular depth gave the soil water depletion for the depth and time. The soil water depletion of each depth interval was calculated and integrated only for the profile taken for the actual root zone to ascertain the total depletion during a particular time under consideration. Evapotranspiration, ET, between two measurements was then calculated by the following water balance equation.

$$ET = (S_1 - S_2) + I + R - D \quad \text{(i)}$$

where, S_1 and S_2 are the initial and final soil water content for the period under consideration, I is the irrigation, R is the rainfall and D is the drainage or percolated water. In this experiment D was ignored.

The irrigation treatments consisted of single cycle of water stress in which irrigation was with-held. Water stress was terminated by re-irrigating the plots when the particular growth stage at which stress was imposed was over. The fully irrigated (control or reference) treatments were irrigated frequently based upon the soil water deficit ensuring that the deficit in the whole soil profile should not exceed 20-25 percent of the field capacity level. The following treatments were replicated thrice in a randomized block design:

- T_0 - Irrigation was with-held during the entire crop growth period (0-110 days after emergence (DAE) (fully stressed)
- T_1 - Irrigation was with-held from emergence to shooting (0-47 DAE) (stress at shooting)
- T_2 - Irrigation was with-held from booting to flowering (40-90 DAE) (stress at booting, heading and flowering).
- T_3 - Irrigation was with-held during grain formation (61-110 DAE) (stress at grain formation).
- T_c - Fully irrigated during the entire growth period (0-110 DAE). This treatment was considered as control or reference.

An area of 15.75 (4.5m x 3.5m)m^2 from each of the 15 plots were harvested and threshed by hand. Grain and straw yield and thousand grain weight were obtained on an oven dry basis at 80°. The harvest index was calculated as the ratio of grain yield at final harvest to the total dry matter yield. The water use efficiency expressed in kg ha^{-1} mm^{-1} was calculated as the ratio of grain yield at final harvest to the total amount of water used during the entire crop growth period.

RESULTS AND DISCUSSION

Soil water deficit. The changes in soil water deficit for various stress treatments are shown in Fig. 1. Soil water deficit did not exceed 30 mm outside the drought period. However, soil water deficit increased progressively in all the stress treatments during the advance of the drying period. At the end of the drying cycle, the soil water deficits were 162.0, 90.5, 147.8 and 74.6 mm for stress treatments T_0, T_1, T_2, T_3 respectively. The trend of the above results are in agreement with the findings of Talukder *et al.*, [17] who reported soil water deficits of 60.0, 80.0 and 135.0 mm for water stress imposed at shooting; booting and heading; flowering and grain formation stages, respectively. The variations in soil water deficits at various growth stages were mainly due to high or low atmospheric evaporative demand, and increase or decrease in green area index i.e. transpiring surfaces, mainly leaves.

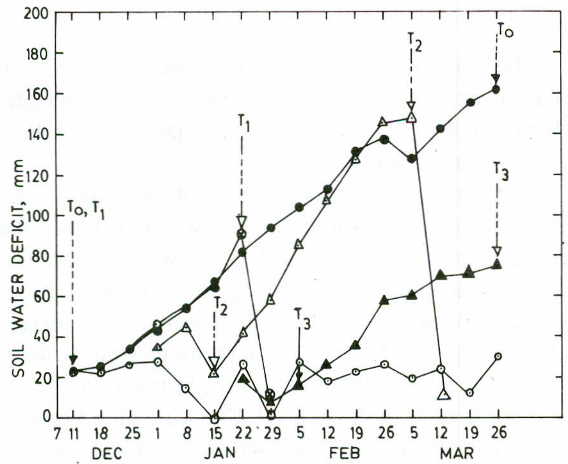

Fig. 1. Soil water deficit of the different irrigation treatments in 0-100 cm soil profile. Solid and broken arrows indicate withholding of irrigation and termination of water stress by re-irrigation.

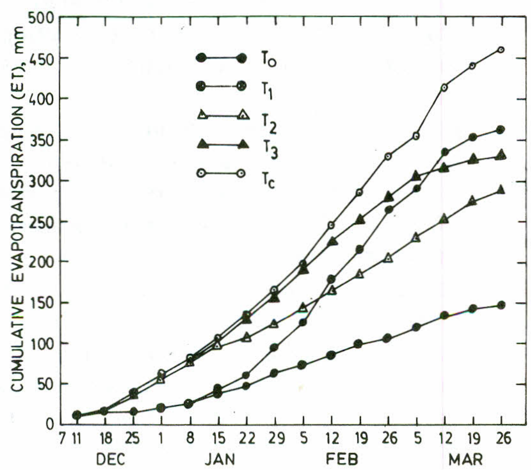

Fig. 2. Cumulative evapotranspiration of wheat grown in the field as affected by water stress.

Cumulative evapotranspiration. The cumulative evapotranspiration for different stress treatments are shown in Fig. 2. The total evapotranspiration varied from 148.3mm in treatment T_0 to 458.3mm in the control or reference treatment. The cumulative evapotranspiration of treatments T_0, T_1, T_2 and T_3 were always lower than that of reference crops, but the lowest value was found in treatment T_0 during the entire growth period due to low green area index and shallow rooting depth as compared to other treatments. Similar results have been reported by Vijay *et al.*, [25]. At the end of the drying cycle the cumulative evapotranspiration were 148.3, 362.3, 288.0 and 330.0 mm in treatments T_0, T_1, T_2 and T_3 respectively. When the crop was subjected to water stress in the vegetative part of the growth period [T_1] the crop almost regained a rate of evapotranspiration similar to that of the reference crop shortly after the termination of water stress. This was due to the development of late tillers and by this re-establishment of a sufficient leaf area index for potential evapotranspiration. The results are in conformity with the findings of Talukder *et al.*, [17]. Their was a lag of about 65 to 70mm of evapotranspiration between treatments T_1 and T_c throughout the growing season.

Yield and yield components. Yield and yield components of various treatments are presented in Table 1. The grain and straw yield of all the stress treatments (T_0, T_1, T_2 and T_3) decrease significantly as compared with reference crops (T_c), but the reduction was maximum when drought was imposed from booting to flowering (T_2) stages. Day and Intalap [6], Innes and Blackwell [21], Hochman [14], and Talukder *et al.*, [17] have also reported similar results. However, the highest reduction in grain and straw yield was attained when the crops were stressed from emergence to maturity (T_0). Significant differences in grain yield were also observed within the stress treatments. It can be seen from the results that water stress at any stages of growth and development reduce the grain yield of wheat but the rate of

Table 1. Yield, water use, water use efficiency and harvest index of wheat grown in the field as influenced by soil moisture stress.

Treatments	Grain yield. kg ha^{-1}	Straw yield. kg ha^{-1}	Harvest index	Water use, mm	Water use efficiency, kg ha^{-1} mm^{-1}	Plant height, cm	1,000 grain weight, am
T_0 - No irrigation	1704.7 (49.8%)	8332.5 (7.7%)	0.17	148.3	67.7	85.6	44.2
T_1 - Stress at shooting	2879.7 (15.2%)	8775.3 (2.7%)	0.25	362.3	32.2	87.0	46.0
T_2 - Stress at booting, heading, and flowering	2469.3 (27.3%)	8563.0 (5.1%)	0.22	288.0	38.2	91.3	46.0
T_3 - Stress at grain formation	2700.7 (20.4%)	8811.0 (2.3%)	0.23	330.0	34.9	89.3	47.1
T_c - Fully irrigated	3394.3	9019.0	0.27	458.3	27.1	103.7	48.7
$LSD_{0.05}$	49.6	137.3	0.008	9.3	2.6	2.4	1.6

reduction depends on the degree and duration of stress and particularly stages of crop growth and development at which stress occurs. Water stress and treatments T_0, T_1 and T_2 reduced 1,000 grain weight significantly as compared with fully irrigated crops. The reduction was maximum (9.2%) when stress occurred either at shooting or at booting to flowering stages because of poor grain development, lighter seeds, and severe reductions in the photosynthetic area including flag leaf and ear (Table 1). The results showed that the grain yield reduction caused by stress in treatment T_2 was mainly due to the reduction in 1,000 grain weight and are in line with the results obtained by Day and Intalap [6], Innes and Blackwell [21], Hochman [14], and Talukder *et al.*, [17]. They reported that stress from booting to grain filling reduced the grain yield of wheat by reducing the grain number and 1,000 grain weight. The plant height was significantly reduced in all the stress treatments as compared with reference crops (Table 1). However, highest plant height was observed in treatment T_c and the lowes in treatment T_0.

Water use and water use efficiency. Water stress at all growth stages studied reduced the amounts of water used by the plants significantly and the effect was maximum when stress was imposed at booting, heading and flowering stages (T_2), mainly due to low green area index (Table 1). Similarly, water stress in treatments T_0, T_1, T_2 and T_3 decreased the water use efficiency for grain production significantly as compared with fully irrigated (T_c) plants, because grain yield did not increase in proportion to water used by the plants (Table 1). The water use efficiency was highest for the fully stress treatment (T_0) and lowest for the treatment with no water stress (T_c) during the entire growth period. The results are in partial agreement with the findings of Talukder *et al.*, [17] who reported highest water use efficiency for the fully stressed treatment and lowest for the treatment undergoing water stress from booting to heading. The increase in water use decreased the water use efficiency and in conformity with the results obtained by Aggarwal *et al.*, [26].

Harvest index. Water stress at all growth stages studied reduced the harvest index significantly as compared with reference crops (Table 1). However, the effect was maximum when stress was imposed at booting to flowering (T_2) and grain formation (T_3) stages because the grain yield reduction was more severe than straw yield reduction. These stages were almost equally sensitive to water stress in terms of harvest index. The increase in water use increased the harvest index and agrees with the findings reported by Aggarwal *et al.*, [26].

Water production function. The relationship between total green yield and seasonal total evapotranspiration of wheat is termed as water production function and is depicted in Fig. 3. A linear relationship between grain yield and seasonal total evapotranspiration was obtained with a high correlation coefficient (r^2 = 0.92). The results are in conformity with the findings of de wit [20], Innes and Blackwell [21], Singh [11], Gajri and Prihar [23], Talukder [19].

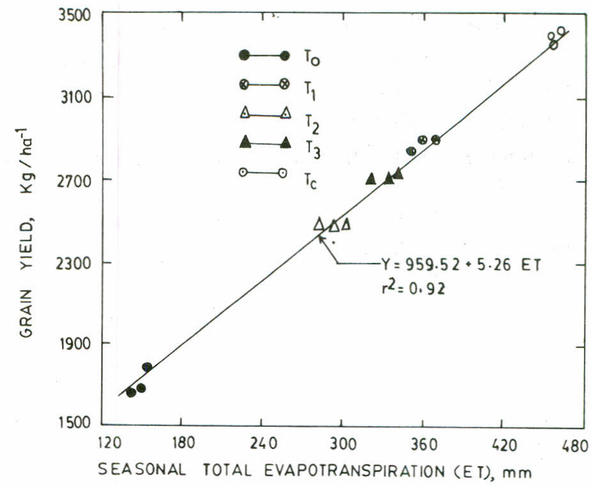

Fig. 3. Total grain yield as related to growing season total evapotranspiration of wheat grown in the field.

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