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AGRO-MORPHOLOGICAL RESPONSE OF MAIZE TO WATER STRESS

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Abstract

Agro-morphological response of two maize (*Zea mays* L.) cultivars viz., Neelum and Akbar to water stress at their different development stages was studied at the agronomic research area, University of Agriculture, Faisalabad. Each cultivar was subjected to water stress either throughout vegetative development, throughout reproductive development or during tasseling and silking only. Water stress enhanced plant maturity and plant sterility substantially compared to control but decreased significantly crop growth rate, number of fertile plants m^{-2}, cobs $plant^{-1}$, grains cob^{-1}, 1000-grain weight, grain yield and harvest index. Water stress during vegetative development delayed tasseling and silking significantly. Both maize cultivars were statistically similar to each other in all parameters except grain yield and harvest index which were significantly greater in Neelum than Akbar. Neelum grown without water stress produced maximum grain yield of 5.74 t ha^{-1}, while Akbar subjected to water stress throughout vegetative development gave the minimum of 2.96 t ha^{-1}

Introduction

In Pakistan, average maize (*Zea mays* L.) grain yield is 1.42 t ha^{-1} (Anon, 1993) compared with the production potential (8.93 t ha^{-1}) of the existing cultivars (Mahmood, 1994). Among various constraints responsible for this low average corn yield ha^{-1}, inadequate supply of water at its critical development stages and high sensitivity of different maize cultivars to water stress are of immense importance. Any degree of water stress may produce deleterious effects on growth potentials (El-Monayeri *et al.*, 1984). Water deficit imposed after planting reduces plant growth and yield significantly (Harold, 1986). However, sensitivity of a plant to water stress varies with its development stage (Grant, 1989). Thus, to bridge up gap between the realised and potential yields of domestic maize cultivars, an efficient use of limited water resources is required. There is therefore need for an adequate understanding of the maize development stages that are highly sensitive to water stress and selection of relatively drought tolerant cultivars. The present report describes the agro-morphological response of maize cultivars Neelum and Akbar to water stress at their different development stages.

Materials and Methods

Effect of water stress at different development stages on growth and yield of two maize cultivars was studied at the agronomic research area, University of Agriculture, Faisalabad, Pakistan. The study comprised of 4 water stress treatments viz., water stress throughout vegetative development from seedling establishment to initiation of tasseling, water stress throughout reproductive development from initiation of tasseling to grain maturity, water stress during tasseling and silking only, and control recommended irrigation schedule, using 2 maize cultivars viz., Neelum and Akbar. The experiment was quadruplicated in a split-plot design with a net plot size of 7x3 m. Maize cultivars and water-stress treatments were placed in main and sub-plots, respectively.

Crop was sown on a sandy clay-loam soil in 75cm spaced single rows with a single-row hand drill. Plants within each row were thinned-out at six-leaf stage to maintain within row inter plant distance of 25 cm. Crop was fertilized @ 175 Kg N as Urea, 90 Kg P_2O_5 as SSP and 70 Kg K_2O as SOP ha^{-1}. All fertilizers were applied at the time of seed bed preparation just before sowing. Water stress was imposed by withholding irrigation water supply during the aforementioned crop development stages. All sub-plots were separated from one another by 30 x 20 x 30 cm drains, along with heavy earthen ridges on both sides of each drain, to prevent lateral flow of surface soil moisture and drain out the rainfall water. All other agronomic practices were uniform in all treatments kept normal according to the recommendations of the Punjab Agriculture Department, Government of the Punjab, Pakistan.

Standard procedures were followed to record observations on number of days to tasseling, silking and maturity, number of fertile plants m^{-2}, number of cobs per plant, number of grains per cob, 1000-grain weight and grain yield. Plant mortality, plant sterility, crop growth rate and harvest index were calculated by using the following formulae:

(i) Plant Mortality (PM)

$$PM\,(\%) = \frac{\text{No. of plants } m^{-2} \text{ at thinning} - \text{No. of plants } m^{-2} \text{ at harvest}}{\text{Number of plants } m^{-2} \text{ at thinning}} \times 100$$

(ii) Plant Sterility at harvest (PS)

$$PS\,(\%) = \frac{\text{Total no. of plants } m^{-2} - \text{No. of cob-bearing plants } m^{-2}}{\text{Total no. of plants } m^{-2}} \times 100$$

(iii) Average Crop growth rate (ACGR)

$$ACGR(g\ m^{-2}\ day^{-1}) = \frac{W_2 - W_1}{T_2 - T_1}$$

where,

W_1 = Plant dry biomass g m^{-2} at thinning
W_2 = Plant dry biomass g m^{-2} at maturity

T_1 = Time corresponding to W_1 (Days)
T_2 = Time corresponding to W_2 (Days)

(iv) Harvest Index (HI)

$$HI (\%) = \frac{\text{Grain yield (kg per plot)}}{\text{Total above-ground plant biomass (kg per plot)}} \times 100$$

In Table 1 and 2 within each column, the value against each of the WS_1, WS_2, WS_3 and WS_4 is the mean of the values of interaction of CV_1 and CV_2 with the respective water stress (WS) stage under treatment combinations, while the value against each of the CV_1 and CV_2 is the mean of the values of interaction of WS_1, WS_2, WS_3 and WS_4 with the respective cultivar (CV) under treatment combinations. Data collected were statistically analysed by using the analysis of variance technique and differences among the treatments' means were tested for significance by the Duncan's New Multiple Range Test (Steel & Torrie, 1984).

Results and Discussion

Results pertaining to the impact of water stress at different development stages on development parameters, grain yield and components of yield of maize are:

A. Development parameters

Data regarding various aspects of crop development are presented in Table 1.

Plant mortality: Water stress increased plant mortality significantly over control. Water stress during reproductive development caused the maximum plant mortality of 31.8 % but did not differ significantly from water stress during the vegetative development. The results suggest that prolonged water stress during vegetative or reproductive development of spring maize poses an equal threat to plant survival. Both maize cultivars Neelum and Akbar on the contrary, exhibited statistically equal plant mortality of about 24.5 %. Thus, both cultivars seem to be equally sensitive to water stress.

Interactive effect of water stress and maize cultivars on plant mortality was significant. Maize cv. Neelum subjected to water stress during reproductive development (WS_2CV_1) exhibited the maximum plant mortality of 32.4 % but did not differ significantly from other treatment combinations except WS_4CV_1 and WS_4CV_2 which were statistically similar to each other. Both cultivars grown without any exposure to water stress (WS_4CV_1, WS_4CV_2) exhibited the minimum plant mortality.

Plant Sterility Water stress at any of the maize development stage under study increased plant sterility significantly . The maximum plant sterility of 34.0% was observed in crop subjected to water stress during its reproductive development against the minimum of 4.2% in control. Greater plant sterility in response to water stress might be due to the enhanced pollen sterility. An increase in pollen sterility due to water stress has been previously reported by Anikiev & Dontsov (1978).

Both cultivars exhibited statistically equal plant sterility that varied from 20.7 to 22.2%. This might be due to similar sensitivity of pollen grains of the two cultivars to

Table 1. Effect of water stress at different growth stages on various development parameters of maize.

Treatment	Plant mortality (%)	Plant sterility (%)	Crop growth rate ($g\ m^{-2}d^{-1}$)	Time (days) taken to complete		
				Tasseling	Silking	Maturity
A. Water stress stages						
WS_1 = Throughout vegetative development	31.0 a	24.2 b	11.2 c	63.1 a	83.6 a	114.7 b
WS_2 = Throughout reproductive development	31.8 a	34.0 a	13.8 b	60.7 b	81.1 b	109.0 c
WS_3 = During tasseling and silking only	27.2	23.8 b	14.2 b	60.8 b	81.7 b	114.1 b
WS_4 = Control (Recommended irrigation schedule)	7.85 c	4.21 c	16.7 a	60.7 b	80.7 b	115.9 a
B. Cultivars						
CV_1 = Neelum	24.7 ns	20.7 ns	14.2 ns	61.2 ns	82.0 ns	113.4 ns
CV_2 = Akbar	24.2	22.2	13.8	61.4	81.[illegible]	113.[illegible]
C. Treatment combinations (WS x CV)						
WS_1CV_1	30.4 a	20.8 c	11.2 c	63.3 ns	83.8 ns	115.0 ns
WS_1CV_2	31.5 a	27.5 ab	11.2 c	62.8	83.[illegible]	114.[illegible]
WS_2CV_1	32.4 a	36.2 a	14.2 b	60.0	81.[illegible]	109.[illegible]
WS_2CV_2	31.1 a	31.8 ab	13.4 b	61.3	80.8	109.[illegible]
WS_3CV_1	29.7 a	20.8 bc	14.5 b	61.0	82.0	113.8
WS_3CV_2	24.6 a	25.8 bc	13.9 b	60.5	81.3	114.[illegible]
WS_4CV_1	6.20 b	4.92 d	16.7 a	60.5	80.8	115.8
WS_4CV_2	9.50 b	3.57 d	16.6 a	60.8	80.[illegible]	116.[illegible]

(1). Any two means not sharing the same letter differ significantly from each other at P = 0.05.

ns = Non-significant

Plant mortality and plant sterility were recorded at crop harvest. Crop growth rate represents the average growth rate for the entire growth period of the crop. Time taken to tasseling and silking was recorded at the completion of tasseling and silking.

water stress. Interactive effect of water stress and cultivars on plant sterility was significant. Maize cv. Neelum subjected to water stress throughout reproductive development (WS_2CV_1) showed maximum plant sterility of 36.2% but did not differ significantly from the treatment combinations WS_1CV_2 and WS_2CV_2. In contrast, cv. Akbar grown without water stress (WS_4CV_2) exhibited minimum plant sterility of 3.57% but was statistically equal to the cv. Neelum grown without water stress (WS_4CV_1).

Average crop growth rate: Average crop growth rate (ACGR) was reduced drastically by water stress at any of the development stage compared to control. Crop subjected to water stress during its vegetative development (WS_1) had the minimum ACGR (11.2 g $m^{-2}d^{-1}$), while control plants (WS_4) exhibited the maximum (16.7 g $m^{-2}d^{-1}$). Suppressive effect of water stress on ACGR was due to significant lower plant height, leaf area per plant and subsequently less dry weight per plant than that of the crop grown without water stress (Data not shown). The slow growth rate might be due to the shortened cells under water stress as reported in root (Fraser *et al.*, 1990). Similar decrease in crop growth rate of maize in response to water stress has been reported by Alam (1985), and McPherson & Boyer (1977). Maize cultivars on the contrary, had statistically equal ACGR varying from 13.8 to 14.2 $gm^{-2}d^{-1}$. Interactive effect of water stress and cultivar on ACGR was significant. Irrespective of the maize cultivars, water stress during vegetative development gave the minimum ACGR of 11.2 g $m^{-2}d^{-1}$, while control plants (WS_4CV_1, WS_4CV_2) exhibited the maximum (16.6 - 16.7 g $m^{-2}d^{-1}$).

Time taken to complete tasseling, silking and **maturity**: Water stress during vegetative development delayed both tasseling and silking, significantly while stress during reproductive development did not delay tasseling and silking compared with the control. In contrast, water stress at any of the development stage of maize enhanced grain maturity significantly. However, crop subjected to water stress throughout its reproductive development ranked first in maturity. Delay in tasseling (Nesmith & Ritchie, 1992) and silking (Villegas *et al.*, 1985 & Frederick *et al.*, 1989), while earliness in maturity (Chiaranda *et al.*, 1977) in response to water stress has also been previously reported. Contrary to the significant effect of water stress, neither effect of maize cultivars nor interactive effect of water stress and cultivars on tasseling, silking and maturity was significant.

B. Grain yield and its components: Data regarding different yield components and grain yield of maize as influenced by water stress and cultivars are presented in Table 2.

Fertile Plants m^{-2}: Water stress either during vegetative (WS_1) or reproductive (WS_2) development of maize decreased number of fertile plants m^{-2} significantly, while stress at tasseling and silking only (WS_3) was statistically at par with control (WS_1). The decrease in fertile plants m^{-2} in response to water stress was ascribed to higher plant sterility (Table 1). A decrease in number of fertile plants per unit area in water stressed maize crop has also been previously reported (Anikiev & Dontsov, 1978). On the contrary, maize cultivars did not significantly differ in number of fertile plants m^{-2} that varied from 4.02 to 4.03.

Interactive effect of water stress and cultivars on fertile plants m^{-2} was significant. Maize cv. Neelum grown without water stress (WS_4CV_1) produced the maximum number of fertile plants m^{-2} but was statistically equal to WS_4CV_2. In contrast, Neelum

Table 2. Effect of water stress at different development stages on yield and yield components of maize.

Treatment	Fertile plants (m^{-2})	Number of Cobs per plant	Grains per cob	1000-grain weight (g)	Grain yield ($t\ ha^{-1}$)	Harvest index (%)
A. Water stress stages						
WS_1 = Throughout vegetative development	3.76 bc	0.819 b	339 c	171 b	3.14 d	24.9 c
WS_2 = Throughout reproductive development	3.71 c	0.733 b	390 b	156 c	3.56 c	22.9 b
WS_3 = During tasseling and silking only	3.96 ab	0.822 b	380 b	162 c	4.09 b	25.6 b
WS_4 = Control (Recommended irrigation schedule)	4.67 a	1.26 a	531 a	203 a	5.61 a	30.2 a
B. Cultivars						
CV_1 = Neelum	4.02 ns	0.911 ns	411 ns	178 ns	4.27 ns	26.7 ns
CV_2 = Akbar	4.03	0.906	409	168	3.93	25.[illegible]
C. Treatment combinations (WS x CV)						
WS_1CV_1	3.50 c	0.868 b	341 b	177 b	3.31 c	26.3 b
WS_1CV_2	4.02 bc	0.770 b	337 b	165 b	2.96 d	23.5 [illegible]
WS_2CV_1	3.67 c	0.695 b	380 b	160 b	3.74 c	23.4 [illegible]
WS_2CV_2	3.75 bc	0.770 b	400 b	152 b	3.37 c	22.[illegible]
WS_3CV_1	4.08 b	0.792 b	3983 b	167 c	4.27 c	26.[illegible]
WS_3CV_2	3.83 bc	0.852 b	377 b	157 b	3.90 b	25.[illegible]
WS_4CV_1	4.83 a	1.29 a	540 a	208 a	5.74 a	31.[illegible]
WS_4CV_2	4.50 ab	1.23 a	522 a	198 a	5.47 a	29.[illegible]

(1). Any two means not sharing the same letter differ significantly from each other at P = 0.05

ns = Non-significant

All of the parameters were recorded at crop harvest.

subjected to water stress during vegetative development (WS_1CV_1) exhibited the minimum number of fertile plants m^{-2} but did not differ significantly from WS_1CV_2, WS_2CV_1, WS_2CV_2 and WS_3CV_2.

Cobs per plant: Water stress at different development stages of maize reduced number of cobs per plant significantly compared with control but the three water stress treatments were statistically at par with one another. A decrease in number of cobs per plant of maize under water stress has also been reported by Puste & Kumar (1988). Maize cultivars in contrast produced statistically equal number of cobs per plant that varied from 0.906 to 0.911.

As regards interactive effect, maize cv. Neelum grown without water stress bore maximum number of cobs per plant (1.29) but was statistically equal to WS_4CV_2. All other treatment combinations exhibited significantly less but equal number of cobs per plant.

Grains per cob: All water stress treatments decreased number of grains per cob significantly. However, water stress during vegetative development caused maximum reduction of 36.16% in grains per cob compared with the control plants which produced cobs with the maximum number of 531 grains per cob. Bajwa *et al*., (1987) and Grant (1989) have also reported significant reduction in number of grains per cob due to exposure of crop to water stress.

Both maize cultivars produced statistically equal number of grains per cob that varied from 409 to 411. Interactive effect of water stress and cultivars on number of grains per cob was significant. Each cultivar subjected to water stress at any of its development stage produced significantly less number of grains per cob compared with the crop grown without water stress. However, differences among various treatment combinations including water stress were non-significant.

1000-grain weight: Water stress at any of the development stage of maize decreased 1000-grain weight significantly compared with the control. However, water stress throughout reproductive development (WS_2) caused maximum reduction in 1000-grain weight but did not differ significantly from water stress during tasseling and silking only (WS_3). A reduction of 12.83, 22.82 and 19.94% in 1000-grain weight was recorded due to water stress throughout vegetative development, reproductive development and tasseling-silking, respectively. Such reduction in grain weight of maize in response to water stress has also been reported by Bajwa *et al*., (1987).

Maize cultivars, however, did not significantly differ from each other in 1000-grain weight that varied from [illegible] to [illegible] g. All treatment combinations containing water stress exhibited significantly less 1000-grain weight than those without water stress (WS_4CV_1, WS_4CV_2) but were statistically at par with one another.

Grain yield: Water stress at any of the development stage under study reduced grain yield ha^{-1} significantly. Water stress during the vegetative development (WS_1) caused maximum reduction of 44.1[illegible]% in grain yield compared with the control and was preceded by water stress throughout reproductive development (WS_2), and water stress during tasseling and silking only (WS_3) which reduced grain yield by 36.6 and 27.1 %, respectively. All water stress treatments differed from one another significantly. Decrease in grain yield ha^{-1} in response to water stress was ascribed to its suppressive effect on various yield components of maize such as number of fertile plants m^{-2}, cobs per plant, grains per cob and 1000-grain weight. Similar suppressive effect of water stress on grain yield of maize has also been reported by Puste & Kumar (1988) and Harold (1986).

Both maize cultivars produced grain yield of 3.93 - 4.27 t ha^{-1} and did not significantly differ from each other. Interactive effect of water stress and cultivars on grain yield ha^{-1} of maize was significant. All treatment combinations including water stress decreased grain yield significantly compared with the crop grown without water stress. The minimum grain yield (2.96 t ha^{-1}) was produced by cv. Akbar stressed throughout vegetative development (WS_1CV_2) against the maximum of 5.74 t ha^{-1} in Neelum grown without water stress (WS_4CV_1) that did not differ significantly from WS_4 CV_2.

Harvest index: Harvest index was reduced significantly by water stress at any of the development stage. However, crop subjected to water stress during reproductive development (WS_1) exhibited the lowest harvest index of 22.9 %. Maize cv. Neelum produced significantly higher harvest index than cv. Akbar. Different treatment combinations also significantly differed from one another in harvest index. All treatment combinations pertaining to water stress exhibited significantly lower harvest index than either of the cultivar grown without water stress (WS_4CV_1, WS_4CV_2).

It would suggest that water stress at any of the maize development stages significantly suppresses various crop development and yield parameters and consequently grain yield ha^{-1} which indicates that maize is a highly sensitive crop to water stress throughout its development. Thus, adequate and regular water supply is essential to harvest the maximum potential of maize. Moreover, Neelum is relatively better grain producer than Akbar both under water stress and with adequate water supply.

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