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EVALUATING DIFFERENT IRRIGATION SCHEDULING CRITERIA FOR AUTUMN-SOWN MAIZE UNDER SEMI-ARID ENVIRONMENT

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Abstract

Drought is a foundation reason of low grain yield in many field crops including maize (*Zea mays* L.). Identifying growth stages of any promising cultivar under local climate and soil fertility permits irrigation scheduling to maximize yield. Potential soil moisture deficit (PSMD) approach (a difference between potential evapotranspiration and rainfall plus irrigation) describes the response of canopy growth to water shortage. To examine the productivity of different autumn-sown maize hybrids under irrigation scheduling at different growth stages and PSMD levels, a field study was conducted with a split plot arrangement at the Agronomic Research Area, University of Agriculture, Faisalabad (Pakistan) during 2009. The treatments consisted of two maize hybrids (Monsanto-919 and Pioneer-30Y87) and seven irrigation levels: I_1 = no irrigation (control), I_2 = 4 irrigations, I_3 = 6 irrigations, I_4 = 8 irrigations, I_5 = 10 irrigations (1st irrigation starting at 6 leaf stage, followed by subsequent irrigations at an interval of 4 leaf stages in all irrigation treatments and addition of two reproductive stages in I_3, I_4 and I_5 successively), I_6 = irrigation at 25mm PSMD and I_7 = irrigation at 50mm PSMD. The results showed that Pioneer-30Y87 produced more plant height but the two hybrids did not differ significantly in other growth and yield parameters. Among all irrigation treatments, 6 and 8 irrigation treatments were statistically at par with treatments of 10 irrigations and irrigation at 25 mm PSMD in radiation use efficiency, water use efficiency, 500-grain weight, grain yield and TDM production. More number of irrigations is not a standard for getting maximum yield in all maize hybrids. PSMD can be used as a useful measure for scheduling irrigation in irrigated conditions of Pakistan.

Introduction

Water is the major yield limiting factor in agricultural system. In the present era of climate change and colossal population pressure, the drought is becoming a critical problem, thus making the water a sparse resource in the world (Hussain *et al.*, 2009). Increased irrigation pumping compels the farmers to lessen the number of irrigations, but when to irrigate and when not to irrigate is a major question. Sensitivity of maize crop to drought at various developmental stages is known to influence the yield long ago. Drought at critical stages decreases yield upto 40%. Both water and light scarcity, at pre-pollination and early post-pollination stages reduces kernel set mainly in apical ear regions (Setter *et al.*, 2001). At about the V_{10} (10 visible leaves) stage the corn plant initiates a rapid increase in dry matter accumulation, which persists until reproductive phase. Water deficit at this stage may limit the size of the leaves. Water deficit between 2 weeks before and 2-3 weeks after silking is known to be the most critical for reduction in yield (Ritchie *et al.*, 1992; Caker, 2004). Recognizing growth stages of any promising cultivar under local circumstances of climate and soil fertility permits irrigation scheduling to maximize yield and most proficient use of inadequate water resources (Pandey *et al.*, 2000).

Potential soil moisture deficit (PSMD), a difference between potential evapotranspiration (PET) and rainfall plus irrigation, approach computes water deficit in a way that can be used constantly to describe the response of canopy growth to water shortage. Several researchers have used PSMD to quantify the response of irrigation to yield of wheat (Hussain *et al.*, 2006), potato (Martin *et al.,* 1990), faba bean (Husain *et al.,* 1990) and maize (Jamieson & Francis, 1991), and that both biomass production and yield (French & Legg, 1979; Jamieson *et al.*, 1995) are associated to this measure of water deficit. The PSMD method is better than one founded on soil water content only because the latter does not essentially relate well to plant performance, because the atmospheric demand for humidity varies widely.

Little research work on these aspects of crop growth and yield has been done under agro-ecological conditions of Pakistan. Similarly the non-availability of suitable hybrids is also a problem (Wajid *et al*., 2011). The present study was, therefore, conducted to examine the productivity of different autumn-sown maize hybrids under irrigation scheduling at different growth stages and to explore potential soil moisture deficit (PSMD) as an alternative approach for determining the effect of water deficit on water use efficiency, radiation use efficiency and yield of different maize hybrids.

Materials and Methods

A field experiment was conducted during 2009 at the Agronomic Research Area of Department of Agronomy, University of Agriculture, Faisalabad (31°24'15"N, 73°3'1"E, and 180 m above sea level). The experimental site has a sandy clay loam soil (Lyallpur series). The soil is low in organic matter (1.09%), nitrogen (0.061%) and phosphorus (6.83 ppm) but appreciable potassium (187 ppm).

As far as weather conditions are concerned, hot and humid weather prevailed in the province including Faisalabad during August 2009. The mean daily air temperature in this month remained about 0.6°C below normal (long-term mean). During the month of September, monsoon rainfall normally remains active up to mid of the month. However in September 2009, monsoon rainfall remained below normal. Rainfall was reported only in the first and second decade, the last decade remained dry. As a whole, less rainfall resulted in water stress conditions. However, the evaporative demand of the atmosphere represented by evapotranspiration (ET_0) remained a bit high due to less cloudiness. The spatial distribution of October precipitation was poor and the total rainfall of the month occurred in the first decade. The evaporative demand of the atmosphere remained far below the normal because of the higher level of relative humidity in October which is the indicator of larger amount of moisture present in the air which provides some moisture to plant through leaves and stem during the dry season (Table 1).

The agronomic performance of two commercial maize hybrids, the most commonly grown in the area, under seven irrigation levels was studied. The experiment was designed as a randomized complete block with a split-plot arrangement and three blocks. Main plots comprised of maize hybrids Monsanto-919 and Pioneer-30Y87 and subplots with irrigation levels: I_1 = no irrigation (control), I_2 = 4 irrigations, I_3 = 6 irrigations, I_4 = 8 irrigations, I_5 = 10 irrigations; 1st irrigation starting at 6 leaf stage, followed by subsequent irrigations at an interval of 4 leaf appearance in all irrigation treatments with addition of two reproductive stages in I_3, I_4 and I_5 successively, I_6 = irrigation at 25mm potential soil moisture deficit (PSMD) and I_7 = irrigation at 50mm PSMD. Land preparation included the tillage implements of disc plough, cultivator and ridger (which formed furrows). Furrows with uniform slope were formed which is an improved method of applying irrigation method. The sowing was done on August 1 on a well prepared seedbed with the help of a dibbler. Seed rate was 25 kg ha^{-1} with row-to-row distance of 75cm and plant-to-plant distance of 25cm. The net plot size was 4.5 m x 5.0 m. NPK fertilizers were applied at the rate of 200-100-50 kg ha^{-1} in the form of urea, DAP and SOP based on soil tests. Half of N and all the P and K were applied as side-dressed at sowing. Remaining half of N was applied as top-dressed in two splits: first at 15 days after sowing and second at flowering. Herbicide atrazine @ 700 ml ha^{-1}was applied twice (at 12 and 17 days after sowing) followed by one hand weeding since the area had been previously infested by intensive weeds. Two insecticides (furadan and bifentharine) were applied @ 25 kg ha^{-1} and 700 ml ha^{-1} respectively.

Irrigation levels I_2, I_3, I_4 and I_5 were based on growth stages in which the measured quantity of water was applied on a particular growth stage (as stated in the treatments) while the other two treatments were based on potential soil moisture deficit (PSMD) which was calculated as a difference between potential evapotranspiration (PET) and rainfall plus irrigation, as suggested by French & Legg (1979). Daily pan evaporation data were collected from the observatory of Department of Crop Physiology, University of Agriculture, Faisalabad and then multiplied by a factor 0.7 to obtain the PET (Cuenca, 1989).

Cut throat flume was used to calculate the discharge of the watercourse and the following formula was used for calculation of time for a specific depth of water as cited by Choudhry (2008).

$$T = A \times d/Q$$

where t = time to irrigate (s)
A = area of the plot to be irrigated (m^2)
d = depth of water to be applied (m)
Q = discharge of the cut throat flume (m^3)

Half of the plot area was used for growth and developmental studies (leaf area index, days to tasseling and days to silking) and the other half for the final harvest data. Five plants were tagged at random in each plot for studying the developmental stages such as days to tasseling, silking and maturity.

The fraction of intercepted radiation (Fi) was calculated by Beer's law as suggested by Monteith & Elston (1983).

$$Fi = 1- \exp(-K \times LAI)$$

where K is an extinction coefficient for total solar radiation equal to 0.7 for maize (Lindquist *et al*., 2005).

The amount of intercepted PAR (Sa) was determined by multiplying values of Fi (based on LAI) with daily incident PAR (Si), during the season.

$$Sa = Fi \times Si$$

The amount of total PAR intercepted by the crop was calculated by multiplying Fi with 0.5 PAR of incident radiation (Szeicz, 1974). Radiation use efficiency grain yield (RUE) was calculated as the ratio of grain yield to cumulative intercepted PAR (∑Sa).

$$RUE = \text{Grain yield} / \sum Sa$$

Table 1. Monthly weather conditions (average and long-term) at Faisalabad during crop period.

Month		Max. temp. (°C)	Min. temp. (°C)	Mean temp. (°C)	Relative humidity (%)	Total rainfall (mm)	ET_0 (mm)
August	Average	36.6	27.6	32.2	65.8	116	152.3
	Long-term	37.7	27.9	32.8	58.1	80.4	-
September	Average	36.3	24.4	30.3	61	20.6	115.2
	Long-term	36.5	23.7	30.2	30.7	55.2	-
October	Average	32.7	17.1	24.9	57.9	17.5	96.9
	Long-term	32.07	18.31	25.19	57.14	5.92	-
November	Average	25.7	10.8	18.2	64.7	0.7	39.0
	Long-term	28.44	10.1	12.97	20.7	56.96	-

Water use efficiency was calculated as ratio of yield and actual evapotranspiration (ET_a). The ET_a of the crop was calculated by multiplying the PET with crop coefficient (K_c) following Doorenbos & Pruitt (1975).

All the data were analyzed statistically using Fisher's analysis of variance technique on computer and least significant difference test (LSD) at 5% probability level was used to compare significance of treatment means (Steel *et al.,* 1997).

Results and Discussion

Plant height: There were significant differences between hybrids regarding plant height (Pioneer-30Y87 being the taller cultivar than Monsanto-919) (Table 2). Similar results were reported by Khaliq *et al*., (2009) who reported that the cultivar effect was significant regarding plant height and the minimum plant height was observed in Monsanto-919 while tallest plants were those of Pioneer-31-R-88.

As far as irrigation levels are concerned, maximum plant height was observed in treatments I_3, I_4, I_5 and I_6.The lowest plant height was found at I_1 which was statistically at par with I_7 (Table 2).

Leaf area index: Figure 1 shows the changes in LAI of maize hybrids with time as affected by irrigation levels. It is evident from the figure that both hybrids attained the maximum LAI at 59 DAS but the hybrids showed non-significant effects in values of maximum LAI. Both hybrids showed different behaviour in terms of LAI at the beginning and at the end of their developmental phase; Pioneer-30Y87 produced greater LAI than Monsanto-919 at these stages.

Different irrigation levels produced maximum LAI differentially. Statistically higher LAI was produced by the irrigation levels I_3 (5.35), I_4 (5.38), I_5 (5.48) and I_6 (5.41) (Table 2). This shows that irrigation levels do affect the behaviour of maize crop in terms of leaf area production.

Table 2. Effect of different irrigation levels on various parameters of maize hybrids.

Treatments	Plant height (cm)	Maximum leaf area index	Days to 50% tasseling	Days to 50% silking	Radiation use efficiency (g MJ^{-1})	Water use efficiency (g m^{-2} mm^{-1})	500-grain weight (g)	Grain yield (t ha^{-1})	Total dry matter (t ha^{-1})
H_1	197.4 b	4.93	52.45	54.25	0.86	2.01	125.6	6.19	16.88
H_2	209.5 a	5.03	52.10	54.34	0.86	1.99	133.6	6.31	17.22
LSD	10.20	NS	NS	NS	NS	NS	NS	NS	NS
I_1	187.6 c	3.97 c	49.61b	51.67b	0.55 c	1.36 c	85.3 c	3.73 c	12.01 c
I_2	196.9 b	4.78 b	52.69a	54.65a	0.75 b	1.77 b	118.5 b	5.34 b	15.76 b
I_3	207.3 a	5.35 a	53.13a	55.26a	0.98 a	2.27 a	138.0 ab	7.12 a	17.28 ab
I_4	211.8 a	5.38 a	53.11a	55.16a	0.95 a	2.16 a	142.0 a	7.00 a	19.47 a
I_5	213.8 a	5.48 a	53.61a	55.72a	1.03 a	2.33 a	153.5 a	7.56 a	19.46 a
I_6	214.5 a	5.41 a	53.20a	55.08a	1.04 a	2.37 a	150.5 a	7.70 a	19.60 a
I_7	192.3 bc	4.49 bc	50.57b	52.52b	0.75 b	1.77 b	119.5 b	5.30 b	15.79 b
LSD	8.01	0.54	1.02	1.30	0.13	0.30	20.6	0.93	2.46

Means sharing different letters in a column differ significantly at p = 0.05
NS = Non-significant, H_1 = Monsanto-919, H_2 = Pioneer-30Y87
I_1 = no irrigation (control), I_2 = 4 irrigations (1st at 6 LS i.e. leaf stage, 2nd at 10 LS, 3rd at 14 LS, 4th at 18 LS), I_3 = 6 irrigations (1st at 6 LS, 2nd at 10 LS, 3rd at 14 LS, 4th at 18 LS, 5th at silking, 6th at blister), I_4 = 8 irrigations (1st at 6 LS, 2nd at 10 LS, 3rd at 14 LS, 4th at 18 LS, 5th at silking, 6th at blister, 7th at milking, 8th at dough), I_5 = 10 irrigations (1st at 6 LS, 2nd at 10 LS, 3rd at 14 LS, 4th at 18 LS, 5th at silking, 6th at blister, 7th at milking, 8th at dough, 9th at denting and 10th at physiological maturity), I_6 = irrigation at 25mm potential soil moisture deficit, I_7 = irrigation at 50mm potential soil moisture deficit

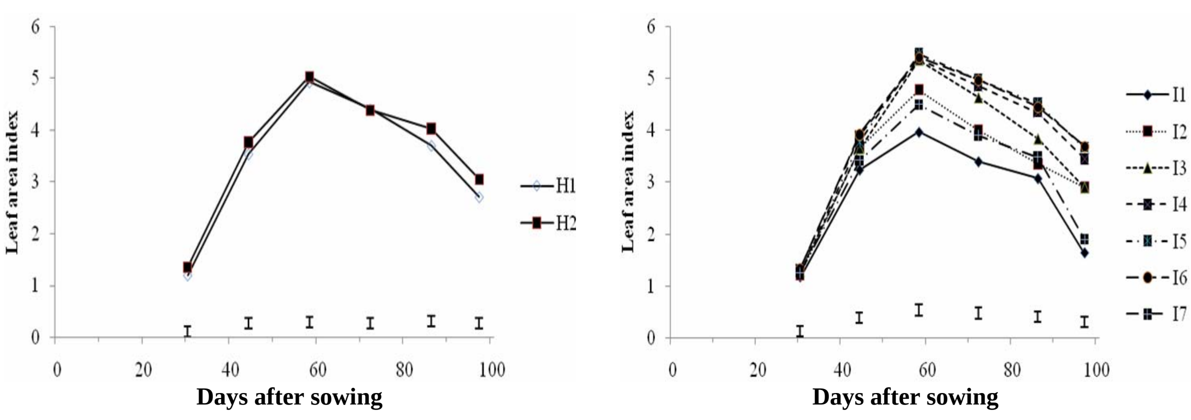

Fig. 1. Changes in leaf area index with time as affected by (a) maize hybrids and (b) irrigation levels.
H_1 = Monsanto-919, H_2 = Pioneer-30Y87
I_1 = nil irrigation (control), I_2 = 4 irrigations (1st at 6 LS i.e. leaf stage, 2nd at 10 LS, 3rd at 14 LS, 4th at 18 LS), I_3 = 6 irrigations (1st at 6 LS, 2nd at 10 LS, 3rd at 14 LS, 4th at 18 LS, 5th at silking, 6th at blister), I_4 = 8 irrigations (1st at 6 LS, 2nd at 10 LS, 3rd at 14 LS, 4th at 18 LS, 5th at silking, 6th at blister, 7th at milking, 8th at dough), I_5 = 10 irrigations (1st at 6 LS, 2nd at 10 LS, 3rd at 14 LS, 4th at 18 LS, 5th at silking, 6th at blister, 7th at milking, 8th at dough, 9th at denting and 10th at physiological maturity), I_6 = irrigation at 25mm potential soil moisture deficit, I_7 = irrigation at 50mm potential soil moisture deficit

Days to 50% tasseling and silking: Table 2 shows the effect of treatments on number of days taken to 50 % tasseling and silking. The cultivars showed non-significant effect. These results are in line with those of Khan *et al.,* (2001) who reported that maize hybrids did not significantly differ in days taken to 50% tasseling and silking. However the results are contrary to those of Younas *et al*., (2002) and Masood *et al*., (2003) who described variability among hybrids to attain tasseling.

Irrigation levels showed a linear response to get tasseling. As the levels of irrigation increased, days taken to tasseling also increased. The control treatment (I_1) and irrigation at 50 PSMD (I_7) showed statistically minimum days taken to tasseling (49.61 and 50.57 days, respectively) whereas other treatments (I_2, I_3, I_4, I_5, I_6) showed statistically higher (ranging from 52.69 to 53.61) days to tasseling than I_1 and I_7. Similarly, treatments I_1 and I_7 showed significantly lower number of days to silking (51.67 and 52.52, respectively). The other treatments (I_2, I_3, I_4, I_5 and I_6) being statistically at par required higher number of days to silking than treatments I_1 and I_7. These results corroborate the findings of Khan *et al*., (2001) who reported that days to accomplish flowering decreased significantly with increasing water stress.

Radiation use efficiency: It is clear from Table 2 that the cultivars showed non-significant differences for RUE. These results are contradictory to the findings of Khaliq *et al*., (2008) getting significant differences in radiation use efficiency between Monsanto-919 and Pioneer-31R88. Irrigation levels affected RUE significantly. More RUE was obtained in treatments with continuing irrigation at later reproductive stages (treatments I_3, I_4, I_5 and I_6).Water stressed treatments (I_1, I_2 and I_7) produced less grain yield as a response of cumulative PAR.

Water use efficiency: The water use efficiency (WUE) was also non-significant between the hybrids. The values of WUE for Monsanto-919 and Pioneer-30Y87 were 2.01 and 1.99 g m^{-2} mm^{-1}, respectively. The non-significant effects of the two cultivars regarding WUE may be due to non-significant transpiration rates of these during vegetative stages. As far as irrigation levels are concerned, treatments I_3, I_4, I_5 and I_6 were good at producing more grain yield per unit water transpired (Table 2). It can be concluded that potential soil moisture deficit (PSMD) can be used as a useful criterion for getting optimum yield if irrigation is applied at some optimum PSMD level for a soil type.

Kumar *et al*., (1996) showed that grain yield and total dry matter production at different irrigation regimes were correlated with corresponding evapotranspiration levels. Zelikovick *et al*., (1997) concluded that WUE was higher in maize when using 290 mm water throughout the growing season than the maize cultivated with no irrigation. Pandey *et al*., (2000) reported that WUE did not enhance when irrigation was withdrawn during vegetative and reproductive stages compared to fully irrigated. However, a reasonable level of deficit irrigation during the vegetative period resulted in similar WUE values as fully irrigated.

Seasonal dry matter production was strongly positive and linearly related with accumulated crop evapotranspiration and the regression accounted for 99.18% giving average value of 7.69 g dry matter produced per mm of water transpired in the process of evapotranspiration (Fig. 2).

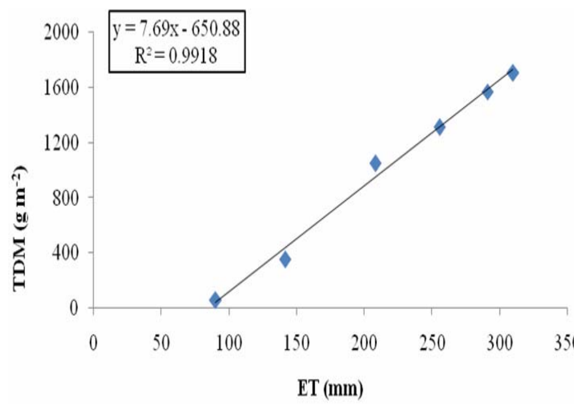

Fig. 2. Relationship between accumulated crop evapotranspiration with seasonal TDM of maize.

500-grain weight: Grain weight is a vital yield contributing factor, which plays a pivotal role in performance of the potential of a cultivar. Data in Table 2 shows that hybrids had non-significant differences in terms of 500-grain weight. These results are in contrary to those of Ahmad *et al*., (2010) who described considerable differences among various hybrids regarding kernel weight but the results are in line with those of Khan *et al*., (2003) who reported that there was non-significant difference among various hybrids in terms of grain weight.

Irrigation levels had a significant effect on 500-grain weight. Table 2 shows that increasing levels had higher grain weight eg., treatments I_3, I_4, I_5 and I_6.The range of 500-grain weight for these treatments was 138.0 to 153.5 g, respectively. These results are in line with those of Khan *et al*., (2001) and Abbas *et al*., (2005) who noticed that grain weight in maize was reduced by increasing water stress.

Grain yield: Table 2 shows that hybrid differences in grain yield were non-significant (6.19 and 6.31 t ha^{-1} in Monsanto-919 and Pioneer-30Y87, respectively).

Increasing number of irrigation levels markedly increased grain yield over control and treatments with more deficit irrigations (treatments I_1, I_2 and I_7). Treatments I_4 (7.00 t ha^{-1}) and I_3 (7.12 t ha^{-1}) were equally good and statistically at par with treatments having higher number of irrigations i.e., treatments I_5 (7.56 t ha^{-1}) and I_6 (7.70 t ha^{-1}). The results are in consonance with those of Khan *et al*. (2003) getting higher grain yield at 6 irrigations over 7 irrigations. Hence it is concluded that applying more and more irrigations is not an anticipated approach for getting maximum yields. Rather, research should be emphasized on scheduling of irrigation water under diverse ecological conditions and also for different cultivars.

Total dry matter: Hybrids had non-significant difference regarding total dry matter (TDM) production. The TDM produced by Monsanto-919 was 16.88 t ha^{-1} whereas TDM yielded by Pioneer-30Y87 was 17.22 t ha^{-1}. However, Khaliq *et al*., (2008) reported significant variation among hybrids regarding TDM production (16.82 to 17.98 t ha^{-1}).

The response of TDM accumulation to varying levels of irrigation was highly significant. More TDM was obtained in treatments I_3, I_4, I_5 and I_6. The range of total dry matter production for these treatments was 17.28 to 19.60 t ha^{-1}. The minimum TDM was accumulated by the control treatment (I_1) followed by the treatments having more deficit irrigations (treatments I_2 and I_7). The higher TDM with higher number of irrigations was due to better plant height and LAI which eventually produced more biomass (Table 2). These results are in line with those of Khan *et al*., (2003) who found that 6 and 7 irrigations in maize produced statistically similar and higher biological yield. Directly proportional relationship of total dry matter production to radiation interception was also reported by Kiniry *et al*., (1989).

Grain yield of different treatments was linearly related to total dry matter production and the regression accounted for 93% (Fig. 3). These results substantiate the findings of Khaliq *et al*., (2009) getting strong relationships between grain yield and TDM.

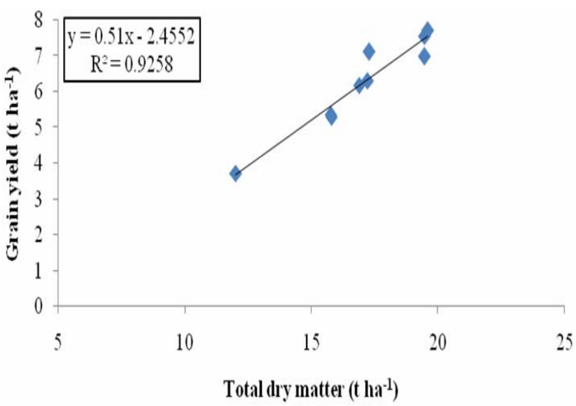

Fig. 3. Relationship between total dry matter production with grain yield of maize.

Conclusion

Study shows that 6 and 8 irrigation treatments were statistically at par with treatments of 10 irrigations and irrigation at 25 mm PSMD in radiation use efficiency, water use efficiency, 500-grain weight, grain yield and TDM production. So more number of irrigations is not a criterion for getting maximum yield in all maize hybrids. PSMD can be used as a useful criterion for scheduling irrigation under irrigated conditions of I.

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