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Full Length Article

Potential Soil Moisture Deficit: An Alternative Approach for Irrigation Scheduling in Wheat

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Abstract

Wheat is a staple food of Pakistan and its productivity is linked with water supply. Potential soil moisture deficit (PSMD) is an approach to save water. PSMD technique was utilized to grow early and late sowing wheat (*Triticum aestivum* L.) for optimum yield. The experiment was conducted at the agronomic research area, University of Agriculture, Faisalabad during 2010–2011 and 2011–2012. The experimental design was randomized complete block design in a split plot arrangement with three replications. The main plot was sowing dates (15th November and 15th December) and the sub-plots were levels of irrigation based on PSMD (full irrigation, 45 mm, 60 mm and 75 mm). The row spacing as set 20 cm and the seed rate was 125 kg ha^{-1} using cv. Sahar-2006. Fertilizer was applied at 120:90 kg ha^{-1} of nitrogen and phosphorus, respectively. Data were recorded for yield and yield components at maturity. Irrigation at 45 mm PSMD for crop sown on November 15 produced maximum grain yield. During both years, maximum plant height, number of grains per spike, thousand grain weight, productive of tillers (m^{-2}), grain yield and WUE were recorded with full irrigation and irrigation at 45 mm PSMD respectively. Results revealed that deficit irrigation at 45 mm PSMD was water saving as compared to farmer conventional practice of full irrigation. © 2016 Friends Science Publishers

Keywords: Deficit irrigation; Sowing date; Yield components; WUE

Introduction

Agriculture is the backbone of Pakistan's economy; it contributes 21% to GDP, employs 43.7% of labor and is responsible for 60% of the livelihood of the rural population (GOP, 2013). Irrigation is an important input for high crop productivity. Wheat is the major and most important crop of the spring season, cultivated throughout the country ranging from arid to sub-humid climate, in both irrigated and rain-fed conditions.

Pakistan has a good irrigation infrastructure. In future, changing climate would result in variability in amount of water withdrawal at canal headwork and variability in intensity and frequency of rainfall. Normal average rainfall during the monsoon season (July–September) is 138 mm. In 2011–2012, Pakistan received 237 mm rainfall (99% more than normal). During winter 2012 (January–March), the amount of rainfall received (34 mm) was 51% less than normal rainfall (71 mm) during the season, resulting in decreased canal head withdrawals (GOP, 2012). Thus, decrease in canal water supplies and variability in rainfall are serious threats for agriculture. The average water requirement for agricultural use during the Rabi season (form October–November to March–April) in Pakistan is 44.9×10^9 m^3. However, severe shortages of water threaten the possibility of achieving those requirements (GOP, 2012). For example, water during the growing season (November to April) of 2011–2012 was estimated to be 36.3×10^9 m^3 which is 19 % less than the requirement. The average annual water available during the last Rabi season was $39.4 \text{ x } 10^9$ m^3, a shortfall of almost $5.6 \text{ x } 10^9$ m^3. This evidences that efficient irrigation systems are required if crop intensity is to be increased for higher agricultural production.

A major constraint limiting sustainable development of agriculture in arid and semi-arid regions is water. Drought has long been a limiting factor in crop production. In Pakistan, farmers are facing a serious challenge to maintain agricultural productivity under drought-stressed environment. Low rainfall and less water available at critical crop growth stages always limit crop growth and yield. Agricultural water management should be integrated with other water management practices to overcome the negative effect of water shortages (Bouwer, 2000). There is a need of innovative research to develop technologies for the efficient use of water for agricultural production in water scarce regions. Supplemental irrigation and deficit irrigation are some of the strategies for improved benefits of water

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management (Pereira *et al*., 2002). Deficit irrigation of crops is a suitable approach under water limited conditions (Flagella *et al*., 2002). Deficit irrigation practices, such as the potential soil moisture deficit (PSMD) reduces water use while minimizing adverse effects on crop productivity (Zhang *et al*., 2004). The goal of deficit irrigation is to increase crop water use efficiency by reducing the amount and number of irrigation (Kirda, 2002; Zhang *et al*., 2006). To adopt those techniques, basic knowledge on the response of crops to water deficit during various growth stages is needed. The benefit of deficit irrigation can be described from three factors: increased WUE, reduced irrigation costs, and opportunity cost of water. Water saved from deficit irrigation can be used to irrigate the additional area to get more production and compensate the lower yield particularly in water limiting conditions. In semi-arid and arid conditions, it has been found that the severity of water deficit and timing on winter wheat should be scheduled considering the stress tolerance capacity of the genotype (Du *et al*., 2010).

The PSMD approach has the ability to consider the variation in supply and demand of water by calculating water deficit at any time during the growing season. The PSMD can be used for determining the effect of water deficit on growth and development of wheat as it indicates the amount and timing of deficit at the same time (Stone *et al*., 2001). If the PSMD level is higher than limiting deficit level, then the crop productivity is compromised. The determination of deficit level will help us to determine when to irrigate and how much to irrigate (Karrou and Oweis, 2012). Excess irrigation or irrigation earlier than the deficit required is the loss of water. Irrigation beyond the allowable PSMD level will decrease up to 55% (Minchin *et al*., 2011). For example, irrigation amount of 100% and 80% of crop evapo-transpired are reported to provide similar grain yield in cereal while water use efficiency is improved with latter (El-Hendawy *et al*., 2008; Dagdelen *et al*., 2009). Reducing post-sowing irrigation water from 300 to 75 mm in silt loam, sandy loam and loamy sand soils has decreased water productivity by 8, 36 and 55% respectively in rice-wheat cropping system in Punjab, India (Jalota *et al*., 2006). Increasing maximum PSMD above the critical deficit decreased the wheat productivity (Minchin *et al*., 2011). Decrease in grain yield was more pronounced in intense water deficit stress (79%) than in mild water deficit stress (51%) in an experiment conducted on sunflower in university of Tehran, Iran. (Alahdadi *et al*., 2011).

The objectives of this experiment were 1) to study the impact of delay in sowing on yield and yield related traits and 2) explore PSMD as an alternative approach for irrigation scheduling in wheat.

Materials and Methods

A wheat study using the local cultivar Sahar-2006 was conducted at the agronomic research area, University of Agriculture, Faisalabad (latitude 31° 26´ N, longitude 73° 04´ E and 184 m above sea level) during the rabi season of 2010–2011 and 2011–2012. The experiment was set in a randomized complete block design using a split plot arrangement; the main plots were sowing dates (15th November and 15th December) and the sub-plots were irrigation regimes (full Irrigation, 45 mm, 60 mm and 75 mm PSMD) and three replications. Full irrigation treatment matched the farmers' irrigation practice and was set as the control treatment. Each plot was 1.2 m × 10 m. A rotavator was used to chop and mix the stubbles of the remaining crop. After rauni irrigation (irrigation before land preparation), when soil was at proper moisture level, three cultivations followed by planking were performed to prepare the final seed bed. Nitrogen (N), phosphorus (P) and potassium (K) fertilizers were applied at recommended rate (120:90:60 kg NPK ha^{-1}). Single row hand drill was used for sowing with inter-row distance of 20 cm at the recommended seed rate of 125 kg ha^{-1} (Tahir *et al*., 2011). Phosphorus and K were applied at the time of land preparation and N was applied in split doses. Source of N, P and K were urea, di-ammonium phosphate (DAP) and sulphate of potash (SOP) respectively. All other cultural practices like weeding, intercultural practices were kept uniform for all the experimental treatments.

For the full irrigation treatment (I_1), four irrigations, each of 75 mm, were applied at tillering, stem elongation, booting and grain formation which is a normal practice by farmers. Other irrigation treatments were based on PSMD which was calculated with a water balance using the mass conservation approach considering reference evapotranspiration (ET_o), rainfall (R) and irrigation (I).

$D = ET_o - (I+R)$

Where D is deficit (mm)

The ET_o was calculated using CROPWAT 8.0 (FAO) which is based on the modified Penman-Monteith equation (FAO, 1998). Daily weather data of maximum and minimum air temperature, relative humidity, wind speed and bright sunshine hours required as input for CROPWAT 8.0 were collected from the Meteorological Observatory of the Department of Crop Physiology, University of Agriculture, Faisalabad, located within 1 km of research area (Fig. 1).

Irrigation Water Inputs

A cut throat flume was used to calculate the discharge of the watercourse (Table 1) as follows:

$t = A \times d/Q$

where

T is the time of irrigation

A corresponds to the area of the plot to be irrigated (m^2),

d is the depth of water to be applied (m), and

Q is the discharge of the cut throat flume (m^3).

Water Use Efficiency

The water use efficiency (WUE) was calculated as the ratio of yield (total dry matter and grain) to water used to produce yield. The ET_c of the crop was calculated by multiplying the ET_o with crop coefficient (K_c) following Doorenbos and Pruitt (1975).

$$WUE = Y / ET_c$$

The results were analyzed employing Fisher's Analysis of Variance. Differences among means were compared by using the Least Significant Difference (LSD) test at 0.05 probability level (Steel *et al*., 1997).

Results

Effect of PSMD and Sowing Date on Plant Height

Plant height was significant ($P < 0.05$) during both growing season (Table 2). The delay in sowing by one month from 15th November (SD_1) to 15th December (SD_2) significantly decreased plant height. Irrigation scheduling impact based on PSMD on plant height was significant ($P < 0.01$). Maximum plant height was recorded for full irrigation and irrigation applied at 45 mm and 60 mm of PSMD gave statistically same plant height. Plant height reduced to the least at PSMD of 75 mm.

Effect of PSMD and Sowing Date on Grains per Spike

No significant differences in number of grains produced per spike in both the growing seasons (Table 2). More grains per spike were recorded when crop was sown earlier (SD_1) and 5% less grains with delay in sowing (SD_2). As regards irrigation scheduling, number of grains per spike were significant ($p < 0.01$), with increased soil moisture deficit. Full irrigation treatment produced maximum number of grains per spike. Deficit irrigation at 45 mm PSMD significantly lowered the number of grains per spike and it continued to decrease as potential soil moisture deficit increased.

Effect of PSMD and Sowing Date on Number of Productive Tillers

More productive tillers were produced in 2011–2012 as compared to 2010–2011 because of differences in weather conditions which remained mild during the phase of tillering in second year (Table 2). Sowing date has significant ($p < 0.05$) impact on number of productive tillers per m^{-2} in both growing seasons. It was noted that productive tillers were enhanced by 16% and 15% in 2010–2011 and 2011–2012, respectively when crop was sown early in the season (15th November) but correspondingly decreased with delay in sowing in both the years. Irrigation levels have shown a significant ($p < 0.05$) decrease in productive tillers with increase in water stress in 2010–2011 and the effects were more pronounced ($p < 0.01$) in the year 2011–2012. In 2010–2011, 344 tillers (m^{-2}) were recorded in plots received full irrigation (I_1). Number of productive tillers with full irrigation were statistically at par with the plots under mild water stress and irrigated at 45 mm PSMD). Increasing water stress from 45 mm PSMD to 75 mm PSMD has reduced the productive tillers but this reduction was statistically non-significant. In year 2011–2012, fully irrigated plot (I_1) produced similar number of grains per spike as recorded in plots receiving irrigation at 45 mm PSMD (I_2). During both years, subsequent increase in potential soil moisture deficit level reduced the productive tillers up to 11%.

Table 1: Irrigation applied to different treatments and rain fall received

Date	I_1	I_2	I_3	I_4		I_1	I_2	I_3	I_4
	mm	mm	mm	mm		mm	mm	mm	mm
	SD_1= 15th November					SD_2= 15th December			
2010-2011									
15/12/2010	75	60	60	60					
14/01/2011	75								
20/01/2011		40			20/01/2011	75	60	60	60
27/01/2011			45		14/02/2011	75	45		
05/02/2011	75			60	27/02/2011			45	
14/02/2011		45			05/03/2011	75	45		50
27/02/2011			40		12/03/2011				
05/03/2011	75	45			19/03/2011		45	45	
12/03/2011				50	26/03/2011	75			60
19/03/2011		40	50		02/04/2011		45	55	
Rain	28	28	28	28	Rain	29	29	29	29
Total	328	258	223	198	Total	329	269	234	199
2011-2012									
09/12/2011	75	60	60	60					
08/01/2012		40							
15/01/2012	75				17/01/2011	75	60	60	60
24/01/2012			45		12/02/2011	75	45		
31/01/2012				60	27/02/2011			45	
07/02/2012	75	45			07/03/2011	75	40		50
18/02/2012			40		12/03/2011				
28/02/2012		45		50	21/03/2011		45	40	
06/03/2012	75		55		28/03/2011	75			60
14/03/2012		45			05/04/2011		45	60	
Rain	14	14	14	14	Rain	21	21	21	21
Total	314	249	214	184	Total	321	256	226	191

Effect of PSMD and Sowing Date on 1000-grain Weight

In late sown crop (SD_2= 15th December), plants were exposed to higher temperature during reproductive phase which shortened its grain growth period that ultimately reduced assimilates translocation. The average mean temperature during grain formation was 21ºC in 15th November sowing and remained 25ºC in 15th December sowing during same growth period in 2011–2012. Thus, the grain growth rate was slower in early sown crop than late sown which increased duration and filled grain with proper assimilation.

Table 2: Effect of sowing date and potential soil moisture deficit on plant height (cm), number of grains per spike and productive tillers (m^{-2}) of spring wheat

Treatment	Plant Height (cm)			Grains per spike			Productive Tillers (m^{-2})		
	2010-2011	2011-2012	Mean	2010-2011	2011-2012	Mean	2010-2011	2011-2012	Mean
A) Main plot (Sowing Date)									
SD_1= 15th November	83.78	87.73	85.76 a	32.93	36.43	34.68 a	340 a	355 a	348
SD_2= 15th December	72.04	77.24	74.64 b	31.53	34.45	32.99 b	292 b	308 b	300
LSD 5%			6.43			2.21	44	43	
Significance			*			*	*	*	
B) Sub-plot (Irrigation)									
I_1= Full Irrigation (Control)	83.00	86.37	84.69 a	37.23	39.23	38.23 a	344 a	365 a	355
I_2= 45 mm PSMD	81.30	83.90	82.60 ab	35.53	37.53	36.53 a	327 ab	341 ab	334
I_3= 60 mm PSMD	77.23	81.47	79.35 b	29.40	33.40	31.40 b	304 b	319 bc	312
I_4= 75 mm PSMD	70.10	78.21	74.16 c	26.77	31.60	29.18 b	288 b	302 c	295
LSD 5%			4.52			3.31	39	28	
Significance			**			**	*	**	
Sowing Date x Irrigation			NS			NS	NS	NS	
Year Mean	77.91	82.49		32.23	35.44		316 b	332 a	
LSD 5%							8		
Significance	NS			NS			*		

Figures having different letters among the treatments differ significantly at $P \leq 0.05$
*, ** = Significant at 5% and 1%, respectively, NS = Non-significant
PSMD = Potential Soil Moisture Deficit

Table 3: Effect of sowing date and potential soil moisture deficit on 1000-grain weight (g), grain yield (kg ha^{-1}) and WUE (kg m^{-3}) of spring wheat

Treatment	Thousand Grain Weight (g)			Grain Yield (kg ha^{-1})			WUE (kg m^{-3})		
	2010-2011	2011-2012	Mean	2010-2011	2011-2012	Mean	2010-2011	2011-12	Mean
A) Main plot (Sowing Date)									
SD_1= 15th November	35.30	39.23	37.27 a	3364 a	3856 a	3610	2.13	2.21	2.17 a
SD_2= 15th December	30.11	31.60	30.86 b	2566 b	2897 b	2731	1.66	1.71	1.68 b
LSD 5%			3.76	461	608				0.09
Significance			*	*	*				**
B) Sub-plot (Irrigation)									
I_1= Full Irrigation (Control)	36.09	38.82	37.46 a	3833 a	4249 a	4040	2.22	2.22	2.22 a
I_2= 45 mm PSMD	34.27	36.50	35.39 ab	3355 a	3882 a	3618	2.07	2.17	2.12 a
I_3= 60 mm PSMD	31.54	34.37	32.96 bc	2645 b	3008 b	2826	1.78	1.83	1.80 b
I_4= 75 mm PSMD	28.90	31.97	30.44 c	2027 c	2367 c	2196	1.51	1.61	1.55 c
LSD 5%			2.69	478	472				0.14
Significance			**	**	**				**
Sowing Date x Irrigation			NS	NS	NS				NS
Year Mean	32.70	35.42		2965 b	3376 a		1.89	1.96	
LSD 5%				407					
Significance	NS			*			NS		

Figures having different letters among the treatments differ significantly at $P \leq 0.05$
*, ** = Significant at 5% and 1%, respectively, NS = Non-significant; PSMD = Potential Soil Moisture Deficit

The difference in thousand grain weight in both growing season was not significant (Table 3). Higher thousand grain weight was recorded in wheat sown on 15th December (SD_1). Signification ($p < 0.05$) reduction in 1000-grain weight (-17.20%) was recorded with delayed sowing (15th December). Effect of PSMD on thousand grain weight was highly significant and maximum of it was recorded with full irrigation (I_1) and was at par with 45 mm PSMD (I_2). Grain weight continued to decrease (up to 14%) as potential soil moisture deficit level was increased and minimum 1000-grain weight was measured in maximum deficit level (I_4= 75 mm PSMD).

Effect of PSMD and Sowing Date on Grain Yield

The grain yield was significantly ($p < 0.05$) affected by year in 2011–2012 due to significantly higher number of productive tillers (Table 3). Each treatment performed comparatively better in 2011–2012 as compared to 2010–2011 due to more favorable climatic conditions (Fig. 1) and longer growing season with interception of more solar radiation and its transformation into economical part. Shorter growing season length, less interception of PAR (475 and 435 MJ m^{-2} in 15th November and 15th December sowing date respectively) and exposure to high temperature (average mean temperature during grain formation was 21°C and 25°C in 15th November and 15th December sowing date during 2011–2012) particularly during grain formation finally leads to lower grain yield in late sown crop.

Effect of sowing date on grain yield was significant ($p < 0.05$) in both growing season. Higher yield was recorded in 15th November sowing (SD_1). Grain yield was decreased by 23.72% and 24.87% due to delay in sowing on

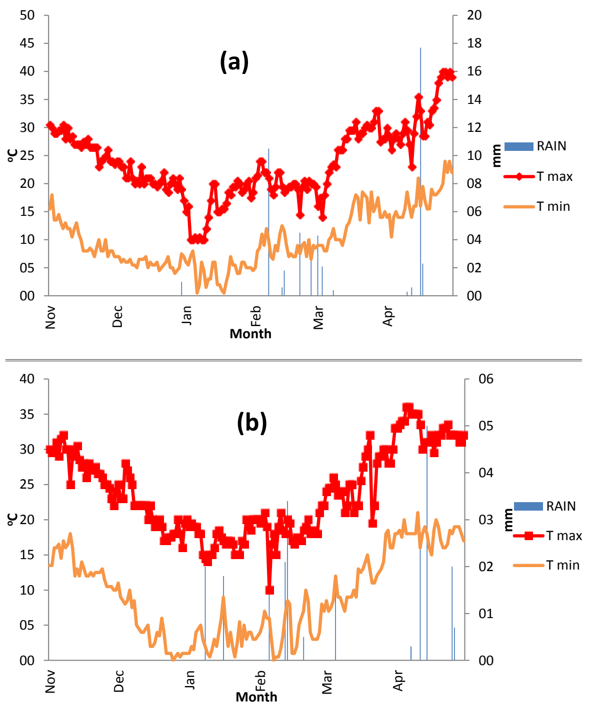

Fig. 1: Summary of daily weather conditions at the experimental site during the (a) 2010-2011and (b) 2011-2012 growing season

2010–2011 and 2011–2012 respectively. The effect of PSMD on grain yield was highly significant ($p < 0.01$) during both growing seasons. Highest grain yield was recorded in full irrigation treatment which was statistically at par with 45 mm potential soil moisture deficit. Less grain yield was found in higher potential soil moisture deficit level (I_4= 75 mm PSMD). A similar trend of decrease in grain yield with the increasing potential soil moisture deficit level was noticed in 2011–2012.

Effect of PSMD and Sowing Date on Water use Efficiency

Our results showed that wheat produced the same amount of grain yield by millimeter of water used (Table 3). Sowing date significantly ($p < 0.01$) affected water use efficiency (WUE). SD_1 produced 2.17 kg of grain biomass in unit area by losing unit of water applied to crop. But this efficiency of grain yield production for same amount of water was reduced to 1.68 kg m^{-3} for crop sown on 15th December (SD_2). The impact of irrigation scheduling on WUE was highly significant ($p < 0.01$). Maximum water use efficiency of (2.22 kg m^{-3}) was recorded with fully irrigated treatment. The performance of full irrigation was statistically similar to the treatment having a deficit level of 45 mm PSMD (I_2). Amount of water applied in I_2 was less as compared to I_1, but the efficiency of grain biomass production was statistically same in both plots. Higher PSMD levels of 60 and 75 mm PSMD reduced the water use efficiency to 1.80 and 1.55 kg m^{-3}, respectively. This means that 60 mm PSMD is minimum allowable deficit level in wheat.

Discussion

Evidences have shown that the reduction in plant height is due to reduced carbon dioxide absorption by plant under circumstances of drought stress (Imam and Segha-Al-Islami, 2005). Reduction in turgor pressure of cell is the cause for reduction in plant height (Baroutzadeh *et al*., 2009). Increase in plant height was observed with the increase in soil moisture with more frequent irrigation. This increase is attributed to the increase in height and/or number of internodes per stem. Shehzad *et al*. (2012) observed maximum plant height when irrigated at 50 mm PSMD. Decrease in plant height was recorded by increasing deficit level to 75 mm PSMD. Qasim *et al*. (2008) reported decreased plant height in wheat sown on 15th December in Peshawar and justified the higher plant height with longer vegetative growth period. Studies have shown that a wheat plant may stop its vegetative growth and shift towards its reproductive phase after reaching its photoperiodic requirement and that may result in shorter plant height in late sowing in Peshawar (Ahmad *et al*., 2005).

Alignan *et al*. (2009) reported an increase and a decrease in the number of grains per spike in wheat sown on 15th November and delayed sowing respectively. Qasim *et al*. (2008) documented highest grain number in crop sown on 15th November followed by 30th November and then 15th December in Peshawar. Inamullah *et al*. (2007) documented 25% reduction in grain number with delay in sowing date in Khyber Pakhtunkhwa, Pakistan. Shehzad *et al*. (2012) reported maximum number of grains per spike in 50 mm PSMD and grain number decreased with the increase in deficit level to 75 mm PSMD. Khan *et al*. (2007) reported that more grains per spike were obtained when irrigation applied at 5 week interval. Decreasing irrigation frequency would decrease number of grains per spike due to increased moisture stress.

Khokhar *et al*. (2010) also found that tillering in wheat was improved by additional irrigation as compared to a single irrigation for crop establishment. Shehzad *et al*. (2012) also reported that productive tillers per unit area in 50 mm PSMD and spike bearing tillers were decreased as deficit increased to 75 mm PSMD. Khan *et al*. (2007) documented highest number of fertile tillers with more frequent irrigation. Decreasing irrigation frequency will set up high water deficit and reduce number of productive tillers per unit area. Qasim *et al*. (2008) noticed 350 tillers m^{-2} in wheat sown on 15th December with delay in sowing.

Shehzad *et al*. (2012) reported higher grain weight at 50 mm PSMD and it decreased with the increase of deficit level to 75 mm PSMD. Similarly, pattern of 1000-grain weight for deficit irrigation was observed in present study. Qasim *et al*. (2008) recorded higher 1000-grain weight in crop sown on 15th November and it decreased when sowing was delayed to 15th December in Peshawar. In delayed sowing, shortening of each growing stage, particularly grain formation is the main reason for lower grain weight. Inamullah *et al*. (2007) in Khyber Pakhtunkhwa noted 19.72% decrease in grain weight due to delay in sowing of wheat because plant does not have sufficient time to increase grain weight due to shorter photoperiod and higher temperature.

Alignan *et al*. (2009) reported that agronomic traits of wheat responded differently planted at different sowing dates. Yield components decreased due to late sowing in Australia (Asseng and Milory, 2006; Spiertz *et al*., 2006) and decrease in grain yield can be related to the differences in weather conditions prevailing throughout the growing season particularly during grain formation (Coventry *et al*., 2011). Higher temperature and terminal drought were pronounced in delayed sowing date. Early sowing benefited the crop due to early flowering and long maturation time. Tripathi *et al*. (2005) reported reduction in wheat yield at the rate of 32 kg ha^{-1} day^{-1} with delay in sowing time from first fortnight of November to first fortnight of December. But this decrease of yield is not uniform with the change in sowing date. Malik *et al.* (2007) reported yield reduction at the rate of 8.85 kg ha^{-1} day^{-1} and 30.11 kg ha^{-1} day^{-1} with second fortnight of November and December. Hussain *et al.* (2004) suggested increase in grain yield by promoting early leaf expansion which is more likely to occur in early sown crop as compared to late sown crop. Qasim *et al*. (2008) reported decrease in grain yield by 45.19% as sowing was delayed from 15th November to 15th December. Inamullah *et al*. (2007) reported maximum grain yield in early sown wheat crop and there was significant reduction in yield as sowing was delayed. Decrease in grain yield in late sown crop is due to reduced growing degree days, longer photoperiod and higher temperature during reproductive stage (Slafer and Whitechurch, 2001). Similarly Ali *et al.* (2004) reported higher grain yield in wheat crop sown on 10th November and yield decreased by 33.86% as planting date was shifted towards 30th December. Khan *et al*. (2007) also supported the idea that too early and too late irrigation decrease the grain yield due to moisture stress.

Conclusion

It is concluded from the above mentioned study that deficit irrigation has significant impact on crop productivity. Deficit level of 45 mm PSMD can be used as an alternative to conventional farmer practice without any significant reduction in grain yield and other agronomic traits like productive tillers, grains per spike and thousand grain weight in both early and late sowing dates. Water use efficiency in farmer practice of irrigation and irrigation at 45 mm PSMD are statistically at par with each other and it decreased with the increase in PSMD due to increase in water stress.

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