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Management Interventions to Enhance Productivity of Wheat and Water Use in Changing Climate of Indian Punjab

Bharat Bhushan Vashisht

Department of Soil Science, Punjab Agricultural University, Ludhiana 141004, Punjab, India

bharatpau@pau.edu

Abstract

Indian Punjab is known as grain bowl of India. Water resources here are scarce in conjunction with problems of water table decline. In rice–wheat system though irrigation water requirement of wheat crop is less than rice yet the water deficit (evapotranspiration-(rainfall + surface supply)), responsible for water table decline is more in wheat crop than rice. In rice, transplanted at recommended time, evapotranspiration (ET) is almost equal to the rainfall, while in wheat ET is 3.9 times that of rainfall. It warrants the ET reduction in wheat for amelioration of water table decline in rice-wheat system. For ensuring regional food security, it is important to evaluate temperature variability, its effects on wheat yield and development of management strategies to sustain yield. A gradual or abrupt change in weather parameters especially maximum and minimum temperature compared to the apposite not only during entire growth season but at different stages also may adversely impact growth and yield of wheat. Field and simulation studies undertaken at Ludhiana location of central Punjab have facilitated to understand impact of temperature variability on wheat yield in changing climate; and to identify best management intervention such as planting date, variety and irrigation schedule in relation climate variation to sustain yield as well as to amelioration of ground water decline. It concludes that growing of longer duration varieties in last week of October, medium to longer duration in 1st week of November with adequate irrigation emerged as the best adaptive measure to minimize impact of temperature variability on wheat yield and water use by reducing soil water evaporation (E) component of ET. Reduction in ET is realized by implementing real water saving technologies like scheduling irrigation based on IW/Pan E ratio, diversification of wheat to low ET crops under possible area and reduction in E during the bare period, which would help in amelioration of water table decline in rice–wheat cropping system.

Keywords: Wheat; Water Use; Climate Change; Groundwater Decline; Cropping-system Models

1. Introduction

Punjab state is known as grain bowl of India. In the central districts of Punjab, rice (*Oryza sativa* L.)–wheat (*Triticum aestivum*L.) is a dominant cropping system. The productivity of rice is 5.5-6.5 t ha^{-1} and that of wheat is 4.0-5.5 t ha^{-1}. Water resources in the state are scarce in conjunction with problems of water table decline and increased energy demand for pumping. Approximately 61 % of the total water demand is through by the two major crops i.e. 33 % by rice and 28 % by wheat. In wheat-based cropping system, rice was introduced during the end of seventies. From that time onward, the area under both the crops has increased. In 1980, the areas under rice and wheat were 1.18 and 2.81 M ha, which increased to 2.60 and 3.50 M ha in 2013, respectively. This shift in cropped area has led to overexploitation of sub-soil water in 80% blocks of the state coupled with increased energy demand from 1850 M kWh to 10780 M kWh (Anonyms, 2014) for pumping water due to fast declining of water table. The average water table depth in central Punjab was 6.0 m in 1980 that increased to 9.0 m in 1995, and 21.0 m in 2013. So, there is a need to enhance crop water productivity. To achieve that, quantification of water balance components is of prime importance. Knowing the soil water balance is important for good irrigation management to reduce the risk of applying excess/deficit irrigation water and scheduling irrigation water efficiently at a field and a regional scale (Jalota and Arora, 2002). Assessment of water balance components in different management interventions would be helpful in identification of most profitable and water- use efficient best management practice (BMP) in wheat using a combined approach of field experimentation and simulation (Jalota et al., 2011).
Changes in global climate are likely to affect spatial and temporal pattern of temperature and rainfall (RF) at the regional level (Gosain et al., 2006), which will affect crop phenology and yield (Jalota et al., 2014; Parry, 1990). Any gradual or abrupt change in weather parameters especially maximum temperature (Tmax) and/or minimum temperature (Tmin) from apposite at any growth stage of the crop may adversely affect the growth and ultimately the yield of crop. As climate conditions are inherently variable from year to year, it may cause inter– and intra– seasonal variation in temperature and subsequently wheat yield. It is expected that due to climate change in future these variations would be accentuated coupled with a greater number of hot days (Pittock, 2003). To modify climate change/variability effects, adaptation measures like change in management

interventions such as planting date, variety and irrigation regime have been advocated in the literature. Improved understanding of how climatic and management factors contribute to changes in crop production is essential for the development of future management strategies (Liu et al., 2010).

There is a general notion that more withdrawal of groundwater for rice is the main cause of water table decline. However, field water budgeting by Jalota (2004) showed that it is not rice crop per se, but it is its transplanting date that decides the decline or rise in water table depending upon the water deficit or gain (evapotranspiration – (rainfall + surface water)) during the crop season. Water table declined when ET exceeds rainfall plus surface water and vice versa. Based on that concept and using mean values of ET and rainfall for 20 years (1981–2000), it has been estimated that in June 1st (Julian day 162) transplanted rice, water table declined by 0.28 m while in that of June 21st (Julian day 182) water table raised by 0.075 m, regardless of groundwater withdrawal. It suggested that for ameliorating water table decline ET has to be managed. In wheat crop, water management strategies from the last five decades have been focussed mainly on increasing yield and rationalization of irrigation water. Different management strategies including irrigation technology per se (irrigation scheduling and methods) and allied management (i.e. crop/varietal diversification, tillage and use of fertilizers, use of crop residue for mulching and cultural practices like planting time and plant population) for reducing irrigation water in wheat have been accomplished, but not even a single study explaining water table change corresponding to water deficit in wheat crop is available. The present paper concerns to understand dynamics of water balance components in wheat, water table change in relation to seasonal water deficit; and ways to reduce ET in wheat crop, overlooked so far under rice-wheat cropping system.

2. Materials and methods

The study pertains to rice-wheat cropping system in central zone of the Punjab State, India. This zone covers 2.36 M ha, 44 % area of the state. The climate of the zone is characterized by hot dry semi-arid with summers (April to June with maximum temperature of 35–39 °C) and cool winters (December to February with minimum temperature of 6–9 °C). The temperature reaches as high as 46 °C in summer months of May and June comprising the hottest months of the year. January is the coldest month of the year, occasionally drops to 2–3 °C. The major portion of the rain is through summer monsoons, which generally set in July and continue till September covering K*harif* season. During *Rabi* season the rains are by western disturbances. The annual average rainfall over last 40 years is 573±109 mm. The area is highly productive underlain with good quality water. Two- third of the state's tube wells are located in this zone and provide irrigation to 85 % area. In several parts of this zone water table has gone beyond 30 m depth and has increased the energy requirement for pumping water.

2.1. Field study

Field experiments for six seasons' (2008–09 to 2013–2014) were conducted at the Research Farm of Punjab Agricultural University, Ludhiana (30°56'N, 75°52'E and 247 m amsl). The management intervention treatments were three dates of planting *viz.* Oct. 20 (D1, Nov. 05 (D2) and Nov. 20 (D3); two inbred varieties PBW 343/PBW 621 (V1) and PBW 550 (V2), and two irrigation schedules *viz.* based on crop stage – crown root initiation, tillering, jointing, flowering and grain formation (I1), and based on IW/PAN–E ratio of 0.9 (I2). In I2 irrigation was scheduled when ratio of depth of irrigation water (IW) to cumulative (pan evaporation minus rainfall) reached a pre-set value (0.9). Ratio was started from the day 30th after sowing. Daily weather data on maximum and minimum temperature, maximum and minimum relative humidity, wind speed, sunshine hours and rainfall were recorded at the meteorological station of Punjab Agricultural University, Ludhiana situated at 50 m from the experimental site.

2.2. Simulation studies

Crop yield of wheat (variety – PBW 343/621 and PBW 550) was predicted using the already calibrated and validated CERES–wheat crop growth model (Vashisht et al., 2013; Jalota and Vashisht, 2016), which is one of the crop modules in the cropping system model (CSM) framework of the DSSAT (Jones et al., 2003), and also with CropSyst model (Jalota et al., 2011; 2014). The management options in the model included variety selection, planting, irrigation, fertilization, tillage operations, harvest and chemical application similar to experimentation. The weather data on Tmax, Tmin and rainfall (RF) used was the observed at meteorological station at Punjab Agricultural University for the present time slice (1989-2008) and projected under A1B scenario were derived from regional climate model PRECIS for mid–century, MC, (2021–2050).

3. Results and discussion

Field data of six wheat seasons (from 2008–09 to 2013–14) reveals that inter– and intra–seasonal variation of 3.4 °C and 10.3 °C in Tmax; 4.6 °C and 27.5 °C in Tmin caused 8.7 % variation in wheat yield in central Indian

Punjab. Wheat yield decreases with increased number of days having Tmax ≥27 °C, Tmin ≥11 °C and ≤3 °C during whole crop period; and ≥34 °C during grain formation and development stage (Table 1). A strong interaction of year and management interventions implies that the impact of inter– and intra– seasonal variation on wheat yield can be minimized by staggering date of sowing with appropriate variety and irrigation schedule. Growing of longer duration varieties in last week of October with adequate irrigation, longer and medium duration in 1st week of November with adequate or deficit irrigation is the practical adaptive measure to minimize impact of temperature variability on wheat yield (Table 2). Apart from temperature, wheat yield is also related to amount and distribution of rainfall. In the present study higher rainfall than the normal and well distributed rain during the season of 2013–14 has significantly increased the yield compared to seasons of 2008–09, 2009–10, and 2011–12. In a simulation study, higher wheat yield with increased rainfall in North China Plain was also noticed by Chen et al. (2010). In mid-century it is projected that yield would be sustained by delaying planting date by 15 days. These results warrants developing management practices which stay the plant green and healthy and temperature–tolerant varieties to overcome decreases in yield to future climates.

Table 1. Mean (standard error) wheat yield as influenced by number of days associated with maximum and minimum daily temperatures (Tmax, Tmin).

Year	Grain Yield, kg ha^{-1}	Tmax> 27°C	Tmin> 11°C	Tmin<3°C	Tmax>34°C (in 120–150 d period)
2008/2009	4176 (270)	41	54	0	1
2009/2010	4377 (278)	35	50	3	11
2010/2011	5020 (180)	34	45	4	0
2011/2012	4249 (177)	32	46	15	4
2012/2013	4064 (238)	32	52	3	1
2013/2014	4914 (257)	18	32	3	1

Duncan’s multiple range test (DMRT) was performed for grain yield and its coefficient of variation (CV) for grain yield is 0.09

(Vashisht and Jalota, 2018)

Table 2. Effect of year, planting date, irrigation and variety on wheat yield.

Year	Wheat yield (kg ha^{-1})							
	Year	Date of planting			Irrigation		Cultivar	
		Oct-20	Nov-05	Nov-20	I1	I2	V1	V2
2008-09	4176	3970	4617	3940	4392	3960	4370	3982
2009-10	4376	4597	4317	4215	4542	4211	4435	4318
2010-11	5020	4956	4830	5274	5033	5007	5189	4851
2011-12	4249	4283	4359	4105	4330	4167	4417	4081
2012-13	4064	4388	3796	4009	4112	4016	4082	4046
2013-14	4914	5420	4719	4603	4998	4830	5021	4807
Mean	4467	4602	4440	4358	4568	4365	4586	4348
CD(0.05)	304	NS			94		83	

I1-irrigation at growth stages, I2- irrigation based on IW/ PAN ratio of 0.9 (I2); V1- variety PB 343/PBW 621, V2-variety PBW 550

(Vashisht et al., 2019)

3.1 Dynamics of water balance components

The dynamics of water balance components in wheat crop, based on an averaged data of past 10 years (1999-2009) simulations with CropSyst model, showed that accumulated ET remained higher than rainfall throughout the growing period (Figure 1). Irrigation water remained higher than ET during initial 90 days of planting and became equal thereafter. At 155 days, cumulative ET, irrigation water and rainfall were 380, 355 and 91 mm, respectively, indicating that water lost as ET was more than individual rainfall or groundwater withdrawn for irrigation (Jalota et al., 2018). The drainage (85 mm) was almost equal to rainfall. However, water balance components varied with soil texture, e.g., the ET was more by 36 per cent and drainage less by 44 per cent in medium–textured soil than coarse–textured (Jalota and Arora, 2002).

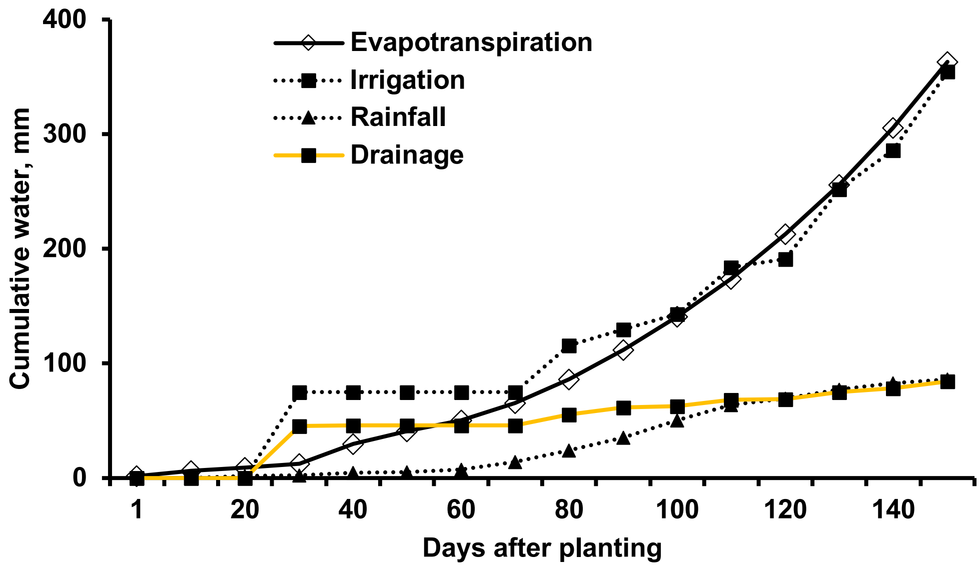

Figure 1. Water balance components dynamics in wheat.

3.2 Water table change

The analysis of observed groundwater data during 1999-2009 showed that the water table declined almost in all the years except 1999, 2007 and 2009. But the seasonal trends showed that water table raised after *Kharif* season (mid-June to mid-October) and fell during the *Rabi* season (mid-October to mid-June). Jain and Sondhi (1998) also reported falling of water table @ 0.94 m yr^{-1} during *Rabi* seasons from 1980 to 1992 in *Bist Doab* tract of Indian Punjab. These observations do not corroborate the general notion that rice in the rice–wheat system is the major culprit for the water table decline but supports that there are seasonal changes in water table, which are related to water deficit in the crop. Seasonal water deficit (averaged across years, 1999–2009) showed that water table rose during rice as rainfall (649 mm) exceeded ET (553 mm) by 96 mm, and fell during wheat as rainfall (91 mm) was less than ET (380 mm) by 289 mm. It indicates that rice though requiring higher irrigation water input (1600 mm against 355 mm) cannot be considered as the reason for overall water decline since the most of it helps in the recharge of the water table as rainfall is mostly more than ET (Jalota et al., 2018). The wheat though expends less groundwater as irrigation than rice yet causes decline in water table because almost the whole groundwater withdrawn for irrigation due to low rainfall is expended as ET. In an experiment of rice–wheat cropping system during 2008–09, water table depth measured with automatic water table depth recorder also confirmed that there was a rise of water table during rice crop and decline during wheat (Jalota et al., 2018).

3.3 Ways to reduce ET in wheat

Irrigation scheduling to a crop mainly aims at developing amount and time of irrigation water that eliminates over– or under– irrigation and ensures optimum yields with high water productivity. An irrigation schedule based on the plant phenology was developed, by which 5 to 6 post–sowing irrigations to wheat crop are applied at fixed growth stages (i.e. crown root initiation, tillering, jointing, booting and grain formation). This schedule along with optimum dose of fertilizers gave maximum yield (5.5 t ha^{-1}). Another simple concept (Prihar et al., 1974) to schedule irrigations to wheat based on the ratio of fixed depth of irrigation water (IW) to cumulative pan evaporation minus rainfall since previous irrigation. Being a deficit irrigation technique, it promoted use of profile-stored water by inducing deeper rooting in wheat and saved 75–125 mm irrigation water without any loss in yield (Jalota et al., 1985).

Diversification of wheat to crops with lower ET like raya (*Brassica juncea* L.) and gram (*Ciceraeritinum* L.) reduced 100 mm and 90 mm ET, respectively (Jalota, 2004). Planting time and cultivars selection are also important ways to reduce ET. The wheat sown from end of October to first week of December months experiences a wide range of weather conditions, which may influence the crop yield and water balance components under irrigated (Jalota et al., 2011) as well as rain-fed (Vashisht et al., 2013) environments. For instance, averaged across six cropping seasons (2008-09 to 2014-15) yields in October 20, November 05 and November 20 sown irrigated wheat were statistically at par (Vashisht and Jalota, 2018), but there was a saving of 80 mm irrigation water and reduction of 81 mm ET in November 20 sown wheat compared to October 20 (Table 3).

Table 3. Effect of planting date on yield and water balance of wheat.

	Planting date		
	October 20	November 05	November 20
Yield, kg ha^{-1}	4602	4440	4358
Irrigation, mm	400	320	320
Evapotranspiration, mm	449	365	368

(Jalota et al., 2018; Vashisht et al., 2019)

4 Conclusions

The critical analysis of water deficit and water table decline in rice–wheat cropping system concludes that during rice season (if transplanted at 166-177 Julian day), rainfall is sufficient to meet ET demand and water deficit is almost nil; whatsoever groundwater is withdrawn, significant part of that contributes to recharge. Water table is declined only if transplanting time is 135–166 Julian day (high evaporative demand) when ET>rainfall. In wheat ET is 3 to 4 folds of rainfall, which results in appreciable water deficit; whatsoever groundwater is withdrawn to irrigate the crop is totally expended as ET, which causes water table decline. Moreover, the area covered under wheat is large. The plausible means to ameliorate water table decline in rice–wheat cropping system are reduction in ET not only in rice, but also in wheat by implementing real water saving technologies and reduction in evaporation during the bare period. All these measures of water saving and reducing ET will be meaningful only if adopted in both the crops at regional scale. Apart from reducing ET, another option strategy to reduce water deficit is meeting the ET demand of rice-wheat system by enhancing cost effective surface water supply rather than pumping groundwater.

Further, a strong interaction of the year with management practices observed in the present study forms a sound basis for deciding the adaptation measure to reduce the impact of climate change on wheat yield and water use efficiency in future. In the mid-century (2021-2050) an increase of temperature (1.4 °C maximum and 1.5 °C minimum) could shorten the crop duration (5 days) and decrease yield (22 %) compared to present time slice (2008-2010). Though there would be decrease in ET due to shortening of crop cycle, yet soil water evaporation would increase (26 %), which would cause water stress (5 %) and decrease water use efficiency (15 %). The results of the field and simulation studies revealed that planting of longer duration wheat varieties up to mid-November with efficient irrigation schedule based on climate are the suitable adaptation technology in future climate to sustain yield and enhance water use efficiency in the Punjab, the grain bowl of India.

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