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Minimize water deficit in wheat crop to ameliorate groundwater decline in rice-wheat cropping system

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ABSTRACT

There is a notion that more withdrawal of groundwater for irrigating the rice crop in rice-wheat cropping system is responsible for water table decline in central Punjab of India. Any reduction in irrigation water by the improved irrigation schedules in rice like alternate wetting and drying, and based on soil moisture potential; shifting planting date, crop diversification of higher irrigation requirement to lower, direct seeded rice, laser levelling etc.; and appropriate tillage system to reduce percolation losses save water and increase water productivity. However, the present study showed that water deficit [evapotranspiration – (rainfall + surface water)] can approximate the water table decline/rise rather than groundwater withdrawal alone. In rice-wheat system though irrigation water requirement of wheat crop is less (300–400 mm) than rice (1500–2000 mm) yet the water deficit, 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, overlooked so far, for supplementary amelioration of water table decline in rice-wheat cropping system. Reduction in ET and saving of energy by different technologies in wheat crop has also been discussed.

1. Introduction

Rice (*Oryza sativa* L.)-Wheat (*Triticum aestivum* L.) cropping system being highly productive and profitable dominates the irrigated alluvial tract of Indo-Gangetic Plains of South Asia. In Indo-Gangetic Basin of India, area under rice-wheat double cropping is 10 million hectare (M ha), out of that 2.6 M ha falls in Indian Punjab, the grain bowl of India. The productivity of rice is 5.5–6.5 t ha^{-1} and that of wheat is 4.0–5.5 t ha^{-1}. Rice is grown during the months of June to October (locally named as *Kharif* season) and wheat from October to April (locally named as *Rabi* season) under irrigated conditions. Water resources in the state are scarce in conjunction with problems of water table decline and increased energy demand for pumping of groundwater. The annual utilizable water resources are 3.48 million hectare meter (M ha-m), constituted by 1.80 M ha-m by surface water entering Punjab from Indus River System plus 1.68 M ha-m by groundwater. The total water demand as evapotranspiration (ET) for agricultural plus non-agricultural uses is 4.76 M ha-m resulting in annual deficit of 1.28 M ha-m (Jain, 2013). Approximately 61 per cent of the total water demand is through by the two major crops i.e. 33 per cent by rice and 28 per cent by wheat. For meeting the ET demand, the total water input made is normally 2200 mm (600 mm by rain + 1600 mm by irrigation) in rice and 510 mm (110 mm by rain + 400 mm by irrigation) in wheat. However, the water input and ET varies spatially depending upon soil type, crop variety and seasonal weather conditions (Jalota and Arora, 2002; Jalota et al., 2011, 2014). 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 area under rice and wheat was 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 over-exploitation of sub-soil water in 80 per cent blocks of the state coupled with increased energy demand from 1850 M kWh to 10,780 M kWh (Anonymous, 2014) for pumping water due to fast declining of water table. During that period, water table decline rate increased from 0.20 m yr^{-1} (1980–1990) to 0.45 m yr^{-1} (2008–13) with intervening decline rates of 0.90 m yr^{-1} (2000–2005) and 0.75 m yr^{-1} (2005–2008). 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.

There is a general notion that more withdrawal of groundwater for rice is the main cause of water table decline in rice-wheat cropping system. However, field water budgeting by Jalota (2004) showed that it is not rice crop per se, but is its transplanting date that decides the

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decline or rise in water table depending upon the water deficit or gain [evapotranspiration – (rainfall + surface water)] during the crop season. Water table declines 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 moved up by 0.08 m. It suggests that for ameliorating water table decline, ET has to be managed. Following that approach, an integrated management in rice i.e. shifting transplanting date to lower evaporative demand (on June 25) concomitant with shorter duration cultivars (90 days from transplanting to harvest) was advocated by Jalota et al (2009), by which ET was reduced by 140 mm (almost double than managing the single i.e. 69 mm by shifting transplanting from May 25 or 71 mm by growing shorter duration variety than longer of 110 days). In wheat crop, water management strategies from the last five decades have been focussed mainly on increasing yield and rationalization of irrigation water. In a simulation study, options for increasing yield and water productivity of wheat in Punjab, India has been evaluated by Timsina et al (2008) using the DSSAT-CSM-CERES-Wheat model. Different adaptations including irrigation technology (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. Therefore, the present study was undertaken to understand dynamics of water balance components in wheat and water table change in relation to seasonal water deficit, 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 (Fig.1). 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 months with maximum temperature of 35–39 °C) and cool winters (December to February months 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 *Kharif* 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 percent area. In several parts of this zone water table has gone beyond 30 m depth and has increased the energy requirement for pumping water.

In the present study water balance components in wheat were simulated using the weather data collected from agro-meteorological laboratory at Punjab Agricultural University, Ludhiana and already customized CropSyst model (Jalota et al., 2011, 2013). In an independent field experiment on rice-wheat cropping system, at Punjab Agricultural University Farm, water table depth was measured with automatic water table depth recorder. Annual, *Rabi* and *Kharif* water table change was worked for Ludhiana from water table depth (data reported by Directorate of Water Resources and Environment, Govt of Punjab) and approximated from water deficit divided by specific yield (= 0.20). The energy required to lift water was worked out using Eq. (1).

$$E = \frac{mgh}{Time_{cf} \times Pumping_{efficiency}} \quad (1)$$

Where E is energy required in kWh, m is mass of water in kg, g is acceleration due to gravity in Newton (9.8 m s^{-2}), h is height of water lifting in m, $Time_{cf}$ is time conversion factor (3.6×10^2). Pumping efficiency was taken as 50 percent.

3. Results and discussion

In the last two decades, a number of technologies focussing on reduction in irrigation for saving water in rice crop have been established by the researchers in the region (Table 1). Based on that Punjab Agricultural University, Ludhiana made laudable recommendations in rice crop like shifting of trans-/planting date to June 20 (which became an act in 2009), growing shorter duration varieties and scheduling irrigation based on soil water potential of –16 k Pa. Like rice, in wheat crop also irrigation water saving technologies like planting date in relation to crop duration and irrigation scheduling based on irrigation water/cumulative pan evaporation (IW/Pan-E) ratio and appropriate tillage have been recommend to reduce irrigation water by Punjab Agricultural University (http://web.pau.edu/content/pf/pp). All these irrigation water saving technologies in rice and wheat crops resulted in reduction of withdrawal of groundwater by 0.91 M ha-m during the period 2008–2014 compared to that of 2002–2008. However, no relation of these management interventions and decline of groundwater table was developed in rice and wheat crops individually and in the cropping system. This warrants the understanding of water balance dynamics, water table change in the crop season and ways to reduce ET in wheat crop.

3.1. Dynamics of water balance components in wheat

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. Irrigation water remained higher than ET during initial 90 days of planting and became equal thereafter (Fig. 2). At 155 days, cumulative ET, irrigation water and rainfall were 363 mm, 355 mm and 86 mm, respectively, indicating that water lost as ET was more than groundwater withdrawn for irrigation. The drainage (84 mm) was almost equal to rainfall (86 mm). 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 than coarse textured soils (Jalota and Arora, 2002).

3.2. Water table change

The analysis of observed groundwater data during 2001–2016 showed decline in water table annually in all the years except 2002, 2004 and 2009 (Fig. 3A). Season wise water table mostly moved up during mid June to mid October (*Kharif*), and fell during mid October to mid June (*Rabi*) (Fig. 3B). Water table also declined in some *Kharif* seasons, but that was less than that in *Rabi season*. 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 and that of Minhas et al (2010) 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 moved up during rice as rainfall (649 mm) exceeded ET (553 mm) by 96 mm, and fell during wheat as rainfall (86 mm) was less than ET (363 mm) by 277 mm. It indicates that rice though requiring higher irrigation water input than wheat (1600 mm against 355 mm) cannot be considered as the reason for overall water decline since most of it helps in the recharge of the water table depending upon rainfall and water table depth. The wheat crop though expends less groundwater as irrigation than rice yet causes decline in water table because almost the