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Climate smart agricultural technologies in rice-wheat water stressed regions of Punjab, India- A review

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Abstract
Intensively cultivated rice-wheat cropping sequence of Punjab, India responsible for many sustainability issues viz. declining underground water, declining soil health, arising micro-nutrient deficiencies etc. Around 1.3 M ha-m additional withdrawal of water from the ground is being taken place annually in Punjab and mainly it is used for the rice crop which is not a traditional crop of the region. Puddling, seepage and percolation losses are the main sources of water loss from the rice based cropping systems in the Indo-Gangetic plains (IGPs) and many Resource Conservation Technologies (RCTs) have been recommended for water saving. The real water saving techniques are those which hinder the water from going into those sinks from where it cannot be reused (Evaporation, E) and diverted greater fraction of water of ET toward transpiration (T) which is desired as greater transpiration, greater the inflow of water and nutrients andwhich ultimately increase the grain yield with the lesser consumption of irrigation water as interval in between two irrigation increases, which further increase the water productivity. Among different RCTs, short duration crop varieties and delaying transplanting time are the real water saving techniques for the regions where water table is already declining down, however other RCTs may be suitable for the regions facing water logging problems as these cut down the drainage losses and these energy saving rather than water saving techniques.

Keywords: ET, IGPs, Puddling, Rice, RCTs, Water saving

INTRODUCTION

In Punjab, rice-wheat cropping sequence intensively cultivated which is responsible for many sustainability issues as declining water table, declining soil health, arising micro-nutrient deficiencies etc. (Arora *et al.,* 2008; Arora *et al.,* 2011; Bhatt *et al.,* 2018 a,b,c ; Hossain and Bhatt, 2019; Bhatt and Kukal, 2018; Bhatt and Singh, 2018; Sur *et al.,* 1981; Jalota and Arora, 2002). Rice-an important staple foods for >50% world's population (IRRI, 2006) and influences the livelihoods of farmers. Approximately 154 million ha of rice was harvested worldwide during 2010, of which 88% of the global rice harvested was in Asia– of which 31% harvested were harvested in Southeast Asia. Irrigated rice has higher land productivity than rainfed rice (Wallace and Gregory, 2002). More than 80% of freshwater resources are used for irrigation purposes, 50% of it further used only in rice (Dawe, 2005). In agriculture, global demand for water will increase over time with increasing population, rising incomes, and change in dietary preferences (Bhatt *et al.,* 2018 a,b,c,; Bhatt *et al.,* 2016; Bhatt and Kukal, 2017). By time, industrial and urban water needs increased, which further intensify the water competition and water scarcity. Being largest groundwater user, India consumed >25% of the global water use (Tyagi *et al.,* 2012), which further needs attention. "GRACE"- NASA's gravity mapping satellite tracks that in North India about in an area of 440,000 km^2 under-ground water declined with rate of 30 cm $year^{-1}$ which outcome in the loss of 4 cm of raw ground water (Soni, 2012).
Must use input for agriculture is irrigation water and it's timely and assured availability significantly affects both land and water productivity in any region. For supplementing irrigation needs > 80-90% of the underground water is used, which further effected by the soil type and agro-climatic conditions. Further, water usage is almost nil in the humid regions as compared to that of the arid and semi-arid region. During 2010, groundwater demand soared from 10-20 km^3 before 1950 to 240- 260 km^3 by the turn of the century in Indian

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sub-continent (Prihar *et al.,* 2010). Punjab and Haryana often referred to as the 'Food Bowl' of the country, as provides > 50% of the national rice production (Dhillon *et al.,* 2010). To improve the declining water productivity in the region, several resource conservation technologies (RCTs) being recommended for efficient water management (Humphreys *et al.,* 2010). Hira *et al.,* 1998 delineates the rising water stressed conditions as current annual water deficit of ~1.27 M ha-m (Jain and Kumar, 2007, Bhatt *et al.,* 2016). During the last forty years, water demand jumped from 2.76 to 4.76 M ha-m (Minhas *et al.,* 2010). Throughout the India, area irrigated with underground water has amplified to 6-times from 1950-51 to 2005-06 (Tyagi *et al.,* 2012) as ground water use soared from 10-20 km^3 to 240-260 km^3 during the same period. The water table is declining in the region year per year, as a result of which a number of different RCTs have been recommended, but we will have to pick the exact ones which are suitable to our conditions i.e not cutting down the drainage in the water scarce regions because that water could be reused for meeting our irrigation requirements (short duration crop varieties and delaying transplanting time), while in the water logged conditions, cutting the drainage losses are desirable as that regions are already suffering from the problem of waterlogging and salinity (Bhatt *et al.,* 2018a,b,c). The objective of the present review was to look into detail performance of each RCTs regarding their role for improving both land and water productivity with best and efficient use of water under texturally divergent soils and under different agro-climatic conditions.

Role of laser leveler in water saving: Flood irrigation is most adopted practice in rice-wheat cropping system in the IGP because of which a significant amount of water lost (10-25%) because of uneven fields (Kahlown *et al.,*2002) which further results in poor resource use efficiency (Jat *et al.,* 2009). Frequent dikes and ditches in the fields always results in lower water productivity as uneven fields results in uneven distribution of the irrigation water, thus more water used for producing fixed amounts of grains. According to Jat *et al.,* (2009) laser leveling results in improved crop stand because of uniform distribution of water along with improved crop productivity and lower labour requirement. LL improved the farm income by improving system productivity to 7% and by saving irrigation water upto 14% in rice and upto 13% in wheat (Jat *et al.,* 2009). According to Jat *et al* (2011) LL helps in saving of 31.26% water in flat planting and 22.56% in raised beds, however in western UP, LL results in reduction of 33% in water which further improved application efficiency from 60% to 88% and distribution efficiency from 80% to 92%. As a result, irrigation water productivity (kg grain m^{-3}) improved upto 24.4% and 19.6% respectively in rice and wheat. Laser leveling also improved the nutrient use efficiency by 110%, 100% and 228% for nitrogen, phosphorus and potassium. Along-with improving water and nutrient use efficiency, laser leveling also enhanced weed control efficiency and improved crop land productivity. Thus, LL cut down the water requirements, increases water productivity but another question associated with LL is that it cuts down the water recharge rate which is not desirable particularly in the water stressed areas. The performance of laser leveler in differently textured soils given by different authors is being given in given in Table 1.

Role of Direct Seeded Rice (DSR) in water saving: As reported by many scientists that puddling deteriorates the soil structure (Kukal *et al.,* 2003a,b). Secondly it also causes problems in the establishment of the succeeding crop viz. wheat. Water input in rice must be reduced by one or other way. In Asia, rice is transplanted into flooded puddled soils where soil textured already deteriorated because of puddling, forming plough pan which further restricted the root growth of next upland aerobic crop viz. wheat. For puddling, land prepared by soaking/flooding with good quality irrigation water, breaking the aggregates and forming the plough pan following the stroke's law. Even then, large water losses are there by seepage, percolation, and evaporation, generally resulting in lower irrigation water productivity (Bouman and Tuong, 2001). Direct seeded rice come out with a hope as no puddling operations are required here which further means lower use of irrigation water and good soil health, which is free from the plough pan and offers no restrictions to the wheat roots (Yadav *et al.,* 2015). Mainly DSR comprised of three types viz. DSR-CT (DSR-Conventionally tilled), DSR-ZT (DSR-zero tilled) and DSR-P (Wet DSR) (Bhatt and Kukal, 2017), last one required puddling and the pre-germinated rice seeds dropped using the drum seeder in lines. Detailed reviewed work highlighted that DSR is not universally applicable, weather it is a site specific technology and its performance varied as the soil texture varied (Bhatt and Kukal, 2015, Jat *et al.,* 2009). DSR proves to be a great failure in light textured soils because of significantly higher weed seeds and severe iron deficiency (Bhatt and Kukal, 2017). Because of no puddling, water drained away frequently and as a result more no. of irrigation water applied which further results in lower irrigation water poroductivity (Bhatt and Kukal, 2018). Gupta and Seth, 2007 also reported varied performance and claimed a possible reason for this differential performance in north-western versus eastern IGP is lower annual rainfall in the former (400–750 mm) than in the later (1000–1500 mm).

Bhuiyan *et al.,* (1995) and Hukkeri and Sharma

(1980) reported higher irrigation water use which could be due to (1) a longer crop growth period in the main field in DSR than in PTR (Rashid *et al.,* 2009) and (2) higher percolation losses in DSR (Sudhir-Yadav *et al.,* 2011a). Further, under clay loam soil in Punjab, Sudhir-Yadav *et al.,* (2011b) observed substantial saving in irrigation water with statistically land productivity with both methods of establishment's viz. DSR and PTR under intermittent irrigation. DSR plants being sown directly into the soil established earlier than the other method but required more water because of higher seepage losses as there is no plough or puddle layer (Tuong *et al*.,2000). Though at some places initially some irrigation water saving observed because of no puddling but on the long run total irrigation water use claimed to be higher in the DSR than PTR. Rainfall pattern and time of occurrence are other major deciding factors in irrigation Bouman productivity of rice has been reported to be higher in DSR than PTR (Sudhir-Yadav *et al.,* 2011b, Humphreys *et al.,* 2010). Bouman and Tuong (2001) observed that DSR, results in some yield losses because of severe competition with weeds and severe iron deficiency. Hence, number of drops used to produce per kg of water assumed to be the best parameters for ranking a particular technology under a particular soil texture in terms of their effective use of irrigation water and grain production (Tuong 1999).

Land productivity in DSR generally reported to be on the inferior side than the puddle sites principally owing to poor crop stand and high weed infestation (Singh *et al.,* 2005). Micronutrient deficiencies such as Zn and Fe, due to imbalanced N fertilization and high infiltration rates in DSR, are of major concern (Gao *et al*., 2006). Production costs reported to be higher in DSR because higher required power for irrigations (Rao *et al*., 2007). Because of new technology and absence of nursery raising, seedling uprooting, and transplanting, farmers are adopting this technology. But our recommendation here is to first consider your soil type as only medium to heavy textured soils respond to DSR while in light textured soils it is not economical to go with DSR.

Role of permanent beds in water saving: Bed Planting is also known to be a very important RCT for saving water upto 20-30%, has been first tried for wheat on the pattern of Mexico and later for rice (Singh *et al*.,2005). Beds solved of the problem of aeration stress in wheat particularly in the heavy less permeable soils. It also reduces the lodging due to lesser water in wheat and increase in thickness of basal internodes. Beds seems to improve water productivity as water use efficiency is always higher in furrows for both rice and which further reflected in the reported higher water. In the IGP, wheat grows successfully on raised beds, with similar or higher yields and about 18% to 30-50% less irrigation water than conventional tillage on the flat (Singh *et al.,* 2005) but usually these beds are destroyed after wheat for successful puddling operations for paddy establishment. Permanent beds reported to improve the soil structure and water infiltration down the profile as compared to the PTR. Humphreys *et al*. (2010) in their review showed that irrigation water savings for direct-seeded and transplanted rice on beds in the IGP varies from 12–60%, but with variable effects on yield and water productivity. Higher cracking of loam in permanent beds when a full-furrow depth of irrigation was applied (Kukal *et al.,* 2010). But at some sites, on the contrary, higher water use efficiency (WUE) was observed in bed planted crops (Brar *et al.,* 2011). Lower irrigation water productivity with time on permanent beds reported to be because of higher bulk density in the side slopes as they were compacted due to tractor-tyre (Kukal *et al.,* 2008). Secondly, higher beds reported to offer higher surface area for higher evaporation which further requires frequent irrigations, which further resulted in lower irrigation water productivity. Further Kukal *et al* (2008) reported that compaction of the side slopes of the beds during repeated reshaping increases the bulk density of the side slopes and due to natural aging of the beds, which further hinders the proliferation of the rhizo-

Table 1. Performance of laser leveler in differently textured soils.

Scientist and year	**Soil texture**	**State, Country**	**Total Water saving (cm)**	**Average percent yield increase (t ha^{-1})**
Jat *et al.,*2009	sandy loam	Uttar Pardesh, India,	12-14%	NS
Jat *et al.,*2011	sandy loam	Modipuram, India	25%	15% to 35%
Jat *et al.,*2003	--	-----	49% in wheat and 31.7% in Paddy	6.9% in wheat
Jat *et al.,*2006	Sandy laom			7.31% in rice and 6.14% in wheat
Rickman, 2002				24% increase in rice yield
Sattar *et al.,*2003				20.1% increase in seed cotton
Pal *et al.,*2003		Modipuram, India		
Abdullaev *et al.,*2007	Loamy soils	Tajikistan	811 M^3/ha	31% increase in cotton yield

sphere in the 0-15 cm, but this problem could be handled by using narrow tyres. Rice land productivity decreased by 19%, 45% and 59% in 2004 to 2006 against the 2003.

Role of tensiomters in water saving: Changing global climatic patterns coupled with declining surface and ground water resources (Yadav *et al.,* 2018; Bhatt *et al.,* 2018 a,b,c) have put agriculture on the back foot. Annually, we are extracting >13 Lakh ha-m of additional water from the ground which further decline the water table. In these conditions application of irrigation water as and when required is very important in improving the water productivity. Thus, tensiometers which work on the principles of soil matric potential (a force with which water is held in the soil matrix) helps us to apply water as and when required (Bhatt *et al.,* 2014). Work done by Bhatt and Sharma (2010) showed that during the years from 2006-2010, the water saving varies from 11.1 to 30.7% with almost similar yields as it avoids unnecessary supply of water and helps us to apply water as and when required in right quantity. Kukal *et al* (2005) reported that water saving with Tensiometer based irrigation varies from 25 to 46.1% as compared to the 2day interval irrigation (Ea-rlier practice of irrigation) and thus reported highest water productivity (0.5 g kg^{-1}) as compared to 2 day interval (0.34 g kg^{-1}) and continuous irrigation (0.28 g kg^{-1}). Thus, tensiometer helped to increase both land as well irrigation water productivity by timely and judiciously irrigating the crops (Bhatt *et al.,* 2016).

Conclusion

For improving both land as well as water productivity in the region, number of technologies *viz.* laser leveler, bed planting, direct seeded rice and tensiometer, are being recommended. But before adopting them, this needs to keep in mind that these technologies are both site and situation sensitive as one technology working in one site might be a failure at other site under other soil textural class. Therefore, utmost care is to be taken while selecting one or other RCT depending upon one's conditions for improving declined both land and water productivity on one side while practicing sustainable agriculture on the other after mitigating the adverse effects of the global warming.

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