International Journal of Agriculture Sciences
ISSN: 0975-3710 & E-ISSN: 0975-9107, Volume 13, Issue 8, 2021, pp.-10855-10862.
Available online at https://bioinfopublication.org/pages/jouarchive.php?id=BPJ0000217

Research Article

ON FARM STUDY ON MICRO IRRIGATION EFFECT OF ENHANCING WATER PRODUCTIVITY OF RICE (*ORYZA SATIVA* L.) UNDER DIFFERENT CROP ESTABLISHMENT METHODS IN HARYANA, INDIA

SHARMA N.[1], BHARDWAJ A.K.[2], SOMAN P.[3], PANDIARAJ T.[4] AND LABH B.K.[5]
[1]Executive Engineer, Irrigation and Water Resources Division, Haryana, India
[2]Agronomist, Jain Irrigation Systems Ltd., Jalgaon, 425001, Maharashtra, India
[3]Principal Agronomist (Global), Jain Irrigation Systems Ltd., Jalgaon, 425001, Maharashtra, India
[4]College of Agriculture, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, 224229, Uttar Pradesh, India
[5]Jain Irrigation Systems Ltd., Jalgaon, 425001, Maharashtra, India
*Corresponding Author: Email - dr.soman@jains.com

Received: August 01, 2021; Revised: August 26, 2021; Accepted: August 27, 2021; Published: August 30, 2021

Abstract: The growing scarcity of water for irrigation warrants improved water productivity to maintain the present agricultural production. The main objective of the study was to evaluate the water productivity of rice under different crop establishment methods and irrigation systems. Three rice establishment methods consisting of direct-seeded rice (DSR), mechanical transplanted rice (Mech. TPR) and manual transplanted rice (manual TPR) were evaluated along with three irrigation systems, conventional flood irrigation, drip irrigation and sprinkler irrigation systems against farmers' practice. On-farm evaluation is conducted at Gumthala Garhu village, Pehowa, Kurukshetra district, Haryana, India from 2018 to 2020 during Kharif (June-September) seasons. The study showed that the manual TPR produced highest grain yield of rice (6781 kg ha^{-1}) compared to the other establishment methods. Drip irrigation resulted in highest yield (6851 kg ha^{-1})) and flood irrigation had lowest grain yield in all three years. Statistically, the manual TPR had high PWPIWU and TCWU than other rice establishment methods and farmers practice. Similarly, drip irrigation resulted in higher PWPIWU and TCWU over other irrigation practices. Drip irrigation provided 2.44 & 3.24 times higher PWPIWU than flood irrigation & farmers practice, respectively. The EWP and EWPIWU&TCWU over three years were highest for the manual TPR (Rs. 14.70 m^{-3} & Rs. 7.96 m^{-3}, respectively) while it was lowest for DSR. Drip irrigation produced highest EWPIWU&TCWU with Rs. 16.84 & 8.86 m^{-3}, respectively. Rice in Haryana alone consumed about 132.5 cm ha^{-1} (8.12 BCM) of irrigation water out of the total 221 km^{-3} water consumed by rice in whole of India. It has a PWP of 0.40 kg grain m^{-3} of TCWU and 0.22 kg grain of irrigation water alone. It is equivalent to an EWP of Rs. 6.82 m^{-3} in that state. Water saving in terms of water used to produce one kg grain yield (l kg^{-1}) of rice by converting from conventional farmers' practice to drip irrigation can support a 52% expansion in the current rice irrigated area in this region. Hence, micro irrigation, particularly drip irrigation is a viable option for irrigated rice that will enable growth of food production. This is also a sustainable method to meet the future demand of the growing population under declining resources.

Keywords: *Drip irrigation, DSR, Rice, Sprinkler, Water productivity, Economic water productivity, Physical water productivity, Crop establishment*

Citation: Sharma N., *et al*., (2021) On Farm Study on Micro Irrigation Effect of Enhancing Water Productivity of Rice (*Oryza sativa* L.) under Different Crop Establishment Methods in Haryana, India. International Journal of Agriculture Sciences, ISSN: 0975-3710 & E-ISSN: 0975-9107, Volume 13, Issue 8, pp.- 10855-10862.

Introduction

Rice is the most vital crop in the world and is the basic diet of more than half of the global population *i.e.* 3.5 billion people [1]. Globally, rice covers an area of 162.06 m ha with about 755.47 million t annual production in 2019. Asian countries account for 85.53% (138.61 m ha) of the world's acreage and 89.65% (677.28 mt) of the world's production. Rice is grown in India in 44.00 m ha, which is the largest area after China among all rice-growing countries, with rice production of 117.94 t. According to Kumar and Ladha [2] estimated that additional milled rice about 114 t would be required by 2035 to meet the world food demand.

Irrigation is the largest consumer of water in India which accounts for more than 90 per cent of groundwater draft in India. The net irrigated area of India is about 67.3 m ha (2015-16). Irrigated area of rice accounts for only 57% which is 25.12 m ha. Among the various sources of irrigation in India, canal irrigated area has remained steady at 16.18 m ha (23.66%); however, tank irrigation has declined from 2.59 in 2009-10 to 1.72 m ha (2.52%); whereas tube-well irrigation is progressively increasing and has attained about 42.96 m ha (62.82%); area under other wells has remained unchanged with an average of 7.52 m ha (11.00%) [3]. An indiscriminate exploit of groundwater irrigation has caused alarming depletion in the Northern parts of the country such as Rajasthan, Punjab and Haryana; a satellite-based report showed that ground water has depleted at the rate of 54 ± 9 km^3/year between April 2002 and June 2008; this depletion was equivalent to a net loss of water about 109 km^3 from August 2002 to October 2008 [4].

In India, water used for paddy cultivation ranged from 1566 mm in clay loam soil to 2262 mm in sandy loam soil. In the Indo-Gangetic Plains (IGP), it varied from 1144 mm in Bihar to 1560 mm in Haryana [5]. On average, about 2500 l of water would be required to produce one kg of rough rice which is 2-3 folds higher than other cereal crops [6]. Water input to paddy fields is largely used for saturating fields, performing puddling operation, maintenance of water film, and meeting for seepage, percolation, evaporation and transpiration losses. On average, an ET loss from rice fields is about 4-5 mm d^{-1} during wet months and about 6-7 mm d^{-1} during dry months; this can be as high as 10-11 mm d^{-1}in subtropical provinces. It was projected that evaporation alone accounts for about~30-40% of ET [7]. Seepage and percolation losses of water account for 1-5 mm d^{-1}in heavy clay soils and 25-30 mm d^{-1} in sandy and sandy loam soils [8]. It is estimated that the combined losses through seepage and percolation maybe 25-50% of total water loss in heavy soils with shallow groundwater table (20-50 cm depth); and 50-85% of total water loss in coarse textured soils with deep groundwater table (1.5 m depth or more) [9].

Such an alarming rate of declining ground water is urging scientists and grower to choose new approaches for increasing the water productivity of rice.

It entails that water input needs to be applied precisely through water-saving techniques in the future. Many approaches are being practiced to reduce water use of rice, such as alternate wetting and drying (10], aerobic rice [11, 12], saturated soil culture, system of rice intensification (SRI) and micro irrigation [13,14, and 15]. Micro-irrigation (sprinkler and drip irrigation) is a promising and emerging water-saving technique. This is widely practiced in various horticultural crops such as vegetable and fruit cultivation and many row crops like sugarcane, cereals and pulses. Studies have been initiated since 2007 to find out the feasibility and viability of adopting micro-irrigation for growing rice [13].

In India, micro irrigation has been popularized with a subsidy module by both the central and state governments. The area under micro-irrigation as of 2020 is about 12.3 m ha. This is still only about 13% of the potential area. A survey-based study reported that micro-irrigation has more advantages in commercial crops other than rice; for instance, 28.5% savings in fertilizer consumption, 50-90% increase in WUE, 31.9% savings in irrigation cost, 30.5% savings in energy consumption, 52.7 and 42.4% increase in vegetables and fruits productivity, respectively, and 42% increase in farmers' returns. It is clearly pointed out that the overall micro-irrigation efficiency (50-90%) is greatly higher than conventional surface irrigation (30-35%). However, rice farmers are slow in adopting micro irrigation as they think rice can only grow in water stagnated fields. Therefore, there is need to address the issues in adopting micro irrigation for rice crop and to promote its reach among the farmers.

Some of the pioneering studies have been carried out the use of drip and sprinkler irrigation for rice in India [13, 15] where both enhancement of rice yields and water productivity were established. Drought resistant rice varieties in drip irrigation in Shanghai, China resulted in better yield potential than conventional puddled condition and proved increased 95% of the grain yield as compared to puddled one [16]. A wide-scale adoption of micro irrigation including drip and sprinkler has not been done with regards to rice crop in IGP in India. Therefore, there is a need to accomplish a detailed evaluation of the impact of micro-irrigation on the rice grain yield while working towards scaling it up. These results would encourage rice farmers and stakeholders on the benefits that may be derived from such approaches. In this study, water productivity was used as a major parameter to determine the efficiency of drip and sprinkler irrigation systems in comparison to conventional practices.

Originally, crop physiologists defined water use efficiency as the amount of biomass or marketable yield per unit of transpiration or evapotranspiration. Irrigation scientists and engineers used the term water (or irrigation) use efficiency as "the ratio of irrigation water transpired by the crops to the water delivered from a river or other natural source. Conversely, this concept of water use efficiency provides only a partial view because it does not indicate the total benefits produced, nor does it specify that water lost by irrigation is often used by other users downstream [17]. In this condition, productive use of water is of special interest in water scarce regions and where the farmers need to realize the full benefits of fertilizers, high quality seeds, tillage, and the labour, energy and machinery. With no gains in water productivity, average annual agricultural evapo-transpiration could double in the next 50 years [18]. Thus, the concept of water productivity started gaining importance since the realization of increasing threshold being faced by countries and regions on account of its available water resource, particularly with respect to the huge allocation towards agriculture sector. Water productivity serves as a plausible option for quantifying the extent of sustainable water use in agriculture and thereby proposing suitable economic policies to ensure intelligent and informed allocation of the scarce resource among crops to meet the present demand without foregoing the needs of the future generation.

So, physical water productivity has been taken into consideration to evaluate the efficiency of a system. Physical water productivity is defined as the ratio of agricultural output to the amount of water consumed (from all available source of water like rainfall, irrigation, etc). The concept of total consumptive water use (TCWU) used in PWP, is based on the evapo-transpiration rate in the region. Rice being an irrigation intensive crop, this scientific estimation of water productivity based on PWP alone does not reflect the actual field situation, as the volume of irrigation water applied in field is often more than the actual water requirement of the crop owing to the low overall efficiency of the surface irrigation system. Therefore, the concept of irrigation water productivity, which estimates the crop productivity with respect to unit volume of irrigation water applied by the farmer. Further, the economic water productivity by taking into account the value of crop output created per unit of TCWU and irrigation water applied is also estimated. This will serve as an important tool for economic policy makers to relate it to the concept of sustainability and efficiency of water use in agriculture. Hence, in the present study, we attempt to analyze the agricultural productivity from the water use perspective and improved water productivity in the Indo-Gangetic region of Haryana, India.

Materials and Methods

Description of the study area

Three years on-farm field experiments were carried out on a farmer's field in 2018, 2019 and 2020 at Gumthala Garhu village, Pehowa of Kurukshetra district, Haryana, India. The research site is located at 30 ̊75'N Latitude and 76 ̊78'E Longitude and at an altitude of 260 m above sea level. The climate is sub-tropical with a hot-dry summer, wet monsoon season (late June to mid-September) and a cool-dry winter. The area receives an average annual rainfall of 720 mm but with much deviation in quantity and distribution, more than 80% of which falls between the months of July and September. However, late onset and early cessation of rains, and intermittent periodic dry-spells are general causes of fluctuation in crop production with sporadic drastic reductions in yield. The dominant soil type of the area is alluvial with sandy clay loam texture having low in organic matter, nitrogen and phosphorus and medium range in potassium.

Experimental design and treatments

The experiment was conducted in two different segment fields. A field consisting of nine acres was equally divided into three portions and each portion with three acres used for laying drip, sprinkler and flood irrigation methods. On the other hand, three acres field was divided into three portions and each portion with one acre arranged for establishment methods *i.e.* direct-seeded rice, mechanical transplanted rice and manual transplanted rice. Besides, a farmer's practice with conventional rice cultivation was included in the experiment to compare with different treatments. The data were arrayed in the factorial randomized block design experiment with three replications.

The treatments of irrigation were based on the average water requirement of rice crop. The drip irrigation was supplied to the field through drip in-line laterals with 16 mm thickness laid out at a spacing of 0.6 m with a 2.4 lph discharge rate and emitter position at a distance of 40 cm. In case of sprinkler irrigation system, a line source of the sprinkler irrigation system was installed in the field. The sprinkler heads were placed at 10 m intervals on the lateral pipe and the total number of sprinklers was 120 with a part cycle for a one-hectare land area. The treatment of flood irrigation reflects the existing package of practices of irrigating two days after the floodwater has dissipated. The plots with farmers' practice were maintained irrigation by keeping water up to 5 cm depth. The transplanted rice plots remained continuously flooded until shortly prior to harvest. The irrigated direct-seeded rice maintained like transplanted rice. Net plot 10 m^2 was harvested for recording yield.

Crop management

The field was ploughed and well leveled before the establishment of the experiment. Before rice crop in each year, there were two harrowing subsequently planking for DSR or puddling for both manual as well as mechanical transplanted rice. In DSR plots, pre-sowing irrigation was given each year and the seed was sown when the topsoil attained field capacity. In the case of transplanted rice, plots were flooded for two hours followed by puddling was carried out using a tractor power tiller. Afterward, the rice seedling was transplanted on the next day.

The DSR was sown on the first fortnight of June in all three years with the medium duration variety 'PR 126, PR 121 and PR 114 by drilling the seed (25 kg ha^{-1}) at a row spacing of 20 cm. On the same day, the seedbed for the transplanted treatments was prepared. Rice was transplanted on 1st week of July in each year, in the spacing of 20 cm between rows 20 cm and 15 cm for plant-to-plant within the row.

The fertilizer NPK recommendation is 150-60-40 kg ha^{-1}. All flood irrigation treatment plots were applied with a basal fertilizer (50% as urea, 100% P as SSP and 100% K as MOP) before sowing (DSR) or after puddling (TPR). Another 50% N as urea was broadcasted in two equal splits *i.e*. on 22 and 45 days after sowing/transplanting (DAS/DAT). Whereas, drip and sprinkler irrigation treatment plots received recommended N and K nutrients through fertigation and P applied in the soil at sowing time. 50 kg NPK (12-32-16) was applied as basal and rest as fertigation [Table-1].

Table-1 *Fertigation schedule given in study field*

DAS/DAT	Fertigation details
20-59	36.75 kg urea/week for six weeks 2.5 kg MOP/week for five weeks 6.25 kg Mg SO_4/week for four weeks
60-89	12.75 kg urea/week for four weeks 2.5 kg MOP/week for four weeks 2.5 kg chelated zinc EDTA/week for three weeks
90-115	3.0 kg MOP/week for three weeks

Weeds in DSR were controlled by applying a pre-emergence herbicide (pendimethalin @ 2.50 l ha^{-1}) next day after sowing, and a post-emergence herbicide (Bispyribac sodium @ 250 ml ha^{-1}) on 21 DAS. Weeds that escaped these treatments were removed manually at 45 DAS. In transplanted rice, weeds were controlled using post-emergence herbicide (Butachlor @ 150 g ha-1) on 15 DAT. Other management practices were followed as per the recommendation of the state agricultural department.

Observation

Grain Yield

Grain yield was determined from an area of 10 m^2 in the center of each plot, which was harvested and threshed manually and yield was expressed as kg ha^{-1} at 14% grain moisture.

Water productivity

In this study, physical water productivity was estimated by the following equation as per the methodology given by Sharma *et al*., [19].

Physical water productivity (PWP) was calculated as the ratio of agricultural output to the amount of water consumed from all available sources including irrigation, rainfall etc and expressed in (kg m-3) (Eq.1&2).

$$PWP_{TCWU}=\frac{\sum_{ie\ crop}\text{Average Yield}_i}{TCWU}\times \text{Area} \quad \text{.................. [Eq.1]}$$

$$TCWU=\sum_{iecrop}^{n}\left(TCWU_{ki}^{IR}+TCWU_{ki}^{RF}\right) \quad \text{.................. [Eq.2]}$$

Irrigation water productivity or use (IWU)was estimated as ratio of the crop output to the irrigation water applied by the farmer/ irrigation system either through surface canals, tank, pond or the well and tube well during the crop growth (Eq.3).

PWP_{IWU}={Irrigated Yield of i^{th} crop ×Area under i^{th} crop} / (Irrigation water applied per unit area of i^{th} crop ×Irrigated area under i^{th} crop) .... [Eq.3]

Like PWP, The Economic Water Productivity (EWP) was also calculated in two approaches. EWP was estimated as the ratio of value of crop output to the amount of water consumed (Eq. 4) or to the amount of irrigation water applied by the farmer (Eq. 5) and expressed as (Rs m3).

EWP_{TCWU}={(Average Yield of i^{th} crop ×Area under i^{th} crop × Farm Harvest Price of i^{th} crop per unit quantity of crop output)}/(TCWU of the i^{th} crop)...... [Eq.4]

EWP_{IWU}={(Irrigated Yield of i^{th} crop ×Area under i^{th} crop ×Farm Harvest Price of i^{th} crop per unit quantity of crop output)}/(Irrigation water applied per unit area of i^{th} crop ×Irrigated area under i^{th} crop output) .... [Eq.5]

In the above equations, $\sum_{iecrop}$ Average Yield is the average yield of i^{th} crop *i.e.* rice. TCWU is the total consumptive water use. IR and RF means irrigated and rainfall, respectively. $TCWU_{ki}^{IR}$ and $TCWU_{ki}^{RF}$, respectively represent irrigated and rainfall water used of i^{th} crop in k^{th} season. The farm harvest price of crop used in this study based on minimum supporting price as per the recommendation of government of India in the respective year. The price of rice for the period of 2018, 2019 and 2020 were INR. 17.50, 18.15 and 18.68 per kg grain of rice, respectively.

Statistical analysis

All data were analyzed by analysis of variance (ANOVA) using OPSTAT programme. The comparison of treatment means was done by the least significant difference (LSD) at 5% probability ($P \le 0.05$).

Result and Discussion

Grain Yield

Yield is an essential part of crop function in a crop environmental condition. In this experiment, rice yield is defined as the quantity of grain yield harvested from the experimental plots at the stage of harvest maturity *i.e*. moisture content at 14% expressed in kg ha^{-1}.

Results showed that both Irrigation methods and crop establishment methods significantly influenced grain yield in all the years [Table-2]. The interaction between the two treatments was also significant.

Averaged across the planting methods, manual TPR increased the yield in 2018 in the order of 15.4% and 10.2% over the mechanical TPR and DSR, respectively. However, in 2019 and 2020, the highest yield was harvested in mechanical TPR treatment as 7433 and 6477 kg ha^{-1}, respectively. This variation of mechanical TPR with respect to grain yield was not considerable as just only increased by 1.07% and 1.65% over manual TPR in 2019 and 2020, respectively. Even, grain yields in farmers' practice were higher as compared to different establishment methods. The higher yield could result from the adoption of better agronomical practices with full potential of long duration varieties like Pusa 44. The DSR treatment yielded a significant reduction in grain yield of rice except in 2018. Higher grain yield of rice under TPR might be ascribed to the plant population control in TPR compared to other rice establishment methods. The modification consists of transplanting optimum time of seedlings, controlled irrigation and favourable microclimate. The transplanted seedlings which have a better expression of tillers and rooting could be the reason for higher yielding with manual TPR method. It is in corroboration with the results of earlier research (20]. Several studies from many countries [21, 22] have reported yield reduction in DSR. The main attributes of the yield gap in DSR could be the weed infestations, the intra and inter-plant competition, lack of good quality direct seeding seed drills, proper training of tractor operation for direct seeding and depth of sowing of seed and unsuitable soil preparation. Moreover, increased plant population in DSR may make rice crops more susceptible to pests and diseases and result in lower yield. The results are quite in line with Pandey and Velasco [23] and Castilla *et al.* [24] who obtained a higher yield of rice in TPR. Hence, more research on DSR is required. Some studies reported higher grain yield in DSR planting methods. Bhardwaj *et al*., [25] obtained a higher grain yield in DSR than TPR and that was attributed to an increased panicle number, higher 1000 kernel weight and lower sterility percentage.

Among the irrigation methods, maximum (6406, 7684 and 6463 kg ha^{-1} in 2018, 2019 & 2020, respectively) and minimum (5698, 6912 & 6029 kg ha^{-1} in 2018, 2019 & 2020, respectively) yields were recorded from the drip and flood irrigation methods, respectively. Irrigation through sprinkler system increased yield which is next to drip irrigation method. Averaged across the irrigation methods, drip and sprinkler irrigation techniques increased 12.43 & 9.74% in 2018, 11.17 & 2.50% in 2019 and 7.20 & 4.58% in 2020, respectively compared to flood irrigation. Crop under drip irrigation received congenial situation for better growth and development.

A positive effect of yield in drip irrigated field could also be influenced by nutrient availability in the soil since optimum soil moisture availability plays a crucial role in the processes of mineralization. Soman [13] and Rao *et al.*, [26] and Rajeev *et al.* [27] also found higher grain yields of rice under drip irrigation. It is assumed that drip- fertigation promotes higher absorption of nutrients from aerobic soil resulting in higher yield.

Soman *et al.* [15] studied the yield components and found that under drip irrigation rice crop puts forth more productive tillers (panicles), higher number of filled grains per panicle and a marginal increase in grain weight. All these yield components lead to higher yield under drip as compared to that under flood irrigation. Rajeev *et al.* [27] reported a yield increase of 11.65% and Soman *et al.* [14] 22 % under drip irrigation over those of flood irrigation method.

Table-2 *Grain yield of rice (kg ha-1) as influenced by irrigation and crop establishment methods in farmers' field*

	2018				2019				2020			
	Flood	Drip	Sprinkler	Mean	Flood	Drip	Sprinkler	Mean	Flood	Drip	Sprinkler	Mean
DSR	5745	6344	5933	6007	6373	7371	6934	6893	5367	6242	6232	5947
Mech. TPR	4892	5998	6311	5734	7257	7697	7344	7433	6328	6650	6454	6477
Manual TPR	6457	6877	6516	6617	7104	7984	6976	7355	6390	6497	6230	6372
Mean	5698	6406	6253		6912	7684	7085		6029	6463	6305	
Farmers' Practice				6870				7085				7033
Statistical Analysis												
			SE(m)	LSD (P≤0.05)			SE(m)	LSD (P≤0.05)			SE(m)	LSD (P≤0.05)
Planting			49.90	150.89			50.09	151.46			55.39	167.48
Irrigation			49.90	150.89			50.09	151.46			55.39	167.48
Interaction (E×I)			86.43	261.34			86.76	262.34			95.93	290.08

Table-3 *PWP_{IWU} (kg m^{-3}) as influenced by irrigation and crop establishment methods in farmers field*

	2018				2019				2020			
	Flood	Drip	Sprinkler	Mean	Flood	Drip	Sprinkler	Mean	Flood	Drip	Sprinkler	Mean
DSR	0.274	0.862	0.642	0.593	0.449	0.778	0.707	0.645	0.245	0.560	0.516	0.440
Mech. TPR	0.281	0.805	0.733	0.606	0.526	1.273	1.028	0.942	0.375	0.827	0.716	0.639
Manual TPR	0.356	1.093	0.956	0.802	0.565	1.354	1.085	1.001	0.369	0.838	0.700	0.636
Mean	0.304	0.920	0.777		0.514	1.135	0.940		0.330	0.742	0.644	
Farmers' Practice				0.271				0.317				0.278
Statistical Analysis												
			SE(m)	LSD (P≤0.05)			SE(m)	LSD (P≤0.05)			SE(m)	LSD (P≤0.05)
Planting			0.008	0.023			0.008	0.024			0.005	0.015
Irrigation			0.008	0.023			0.008	0.024			0.005	0.015
Interaction (E×I)			0.013	0.040			0.013	0.041			0.009	0.027

Table-4 *PWP_{TCWU} (kg m^{-3}) as influenced by irrigation and crop establishment methods in farmers field*

	2018				2019				2020			
	Flood	Drip	Sprinkler	Mean	Flood	Drip	Sprinkler	Mean	Flood	Drip	Sprinkler	Mean
DSR	0.195	0.401	0.336	0.311	0.283	0.414	0.382	0.360	0.215	0.439	0.411	0.355
Mech. TPR	0.189	0.377	0.370	0.312	0.328	0.536	0.475	0.446	0.320	0.609	0.542	0.491
Manual TPR	0.243	0.467	0.427	0.379	0.340	0.561	0.473	0.458	0.316	0.611	0.529	0.485
Mean	0.209	0.415	0.378		0.317	0.504	0.443		0.284	0.553	0.494	
Farmers' Practice				0.203				0.231				0.250
Statistical Analysis												
			SE(m)	LSD (P≤0.05)			SE(m)	LSD (P≤0.05)			SE(m)	LSD (P≤0.05)
Planting			0.003	0.008			0.004	0.013			0.004	0.011
Irrigation			0.003	0.008			0.004	0.013			0.004	0.011
Interaction (E×I)			0.005	0.014			0.008	0.023			0.006	0.019

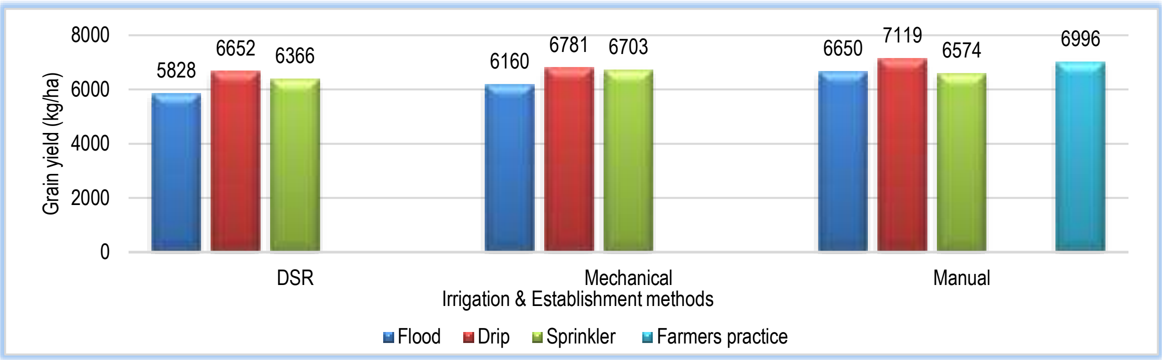

Fig-1 Grain yield of rice (mean of three year data) as influenced by irrigation and crop establishment methods in farmers' field

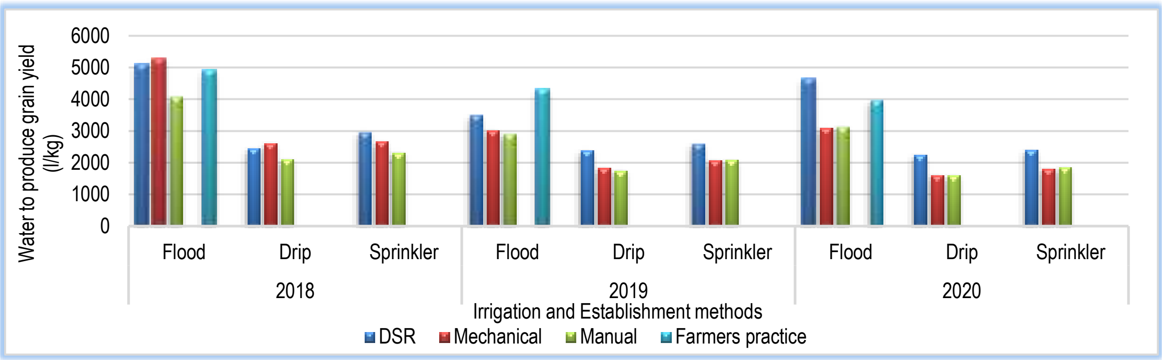

Fig-2 Water used to produce one kg rice (l kg^{-1}) as influenced by irrigation and crop establishment methods in farmers' field

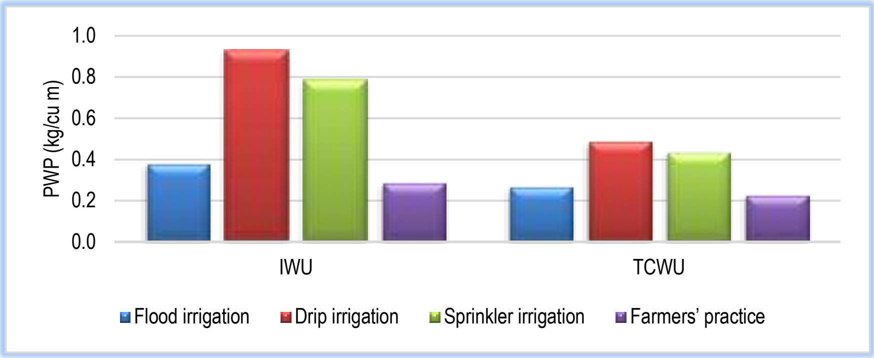

Fig-3 PWP of rice (kg/cu m) (three years mean) as influenced by various irrigation methods in farmers' field

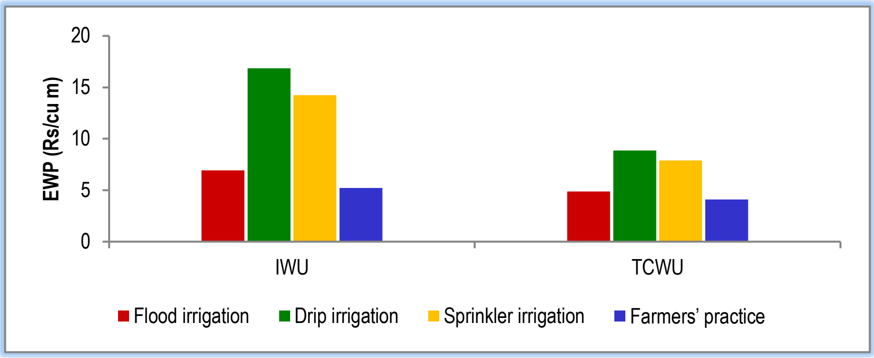

Table-5 *Economic water productivity (irrigation water supplied) (Rs. m^{-3}) as influenced by irrigation and crop establishment methods in farmers field*

	2018				2019				2020			
	Flood	Drip	Sprinkler	Mean	Flood	Drip	Sprinkler	Mean	Flood	Drip	Sprinkler	Mean
DSR	4.80	15.09	11.24	10.38	8.16	14.12	12.83	11.70	4.58	10.46	9.63	8.22
Mech. TPR	4.91	14.08	12.83	10.61	9.54	23.11	18.66	17.10	7.00	15.45	13.37	11.94
Manual TPR	6.23	19.13	16.73	14.03	10.26	24.58	19.69	18.17	6.89	15.66	13.07	11.87
Mean	5.32	16.10	13.60		9.32	20.60	17.06		6.16	13.86	12.02	
Farmers' Practice				4.74				5.75				5.19
Statistical Analysis												
			SE(m)	LSD (P≤0.05)			SE(m)	LSD (P≤0.05)			SE(m)	LSD (P≤0.05)
Planting			0.08	0.25			0.15	0.45			0.08	0.24
Irrigation			0.08	0.25			0.15	0.45			0.08	0.24
Interaction (E×I)			0.14	0.44			0.26	0.78			0.14	0.42

Table-6 *Economic water productivity (total water supplied) (Rs m^3) as influenced by irrigation and crop establishment methods in farmers field*

	2018				2019				2020			
	Flood	Drip	Sprinkler	Mean	Flood	Drip	Sprinkler	Mean	Flood	Drip	Sprinkler	Mean
DSR	3.34	6.87	5.74	5.31	5.14	7.51	6.94	6.53	4.01	8.20	7.68	6.63
Mech. TPR	3.24	6.45	6.33	5.34	5.95	9.72	8.62	8.10	5.98	11.38	10.14	9.17
Manual TPR	4.16	7.98	7.30	6.48	6.17	10.19	8.58	8.32	5.91	11.42	9.88	9.07
Mean	3.58	7.10	6.46		5.76	9.14	8.05		5.30	10.33	9.23	
Farmers' Practice				3.48				4.19				4.66
Statistical Analysis												
			SE(m)	LSD (P≤0.05)			SE(m)	LSD (P≤0.05)			SE(m)	LSD (P≤0.05)
Planting			0.07	0.20			0.08	0.23			0.11	0.32
Irrigation			0.07	0.20			0.08	0.23			0.11	0.32
Interaction (E×I)			0.11	0.34			0.13	0.39			0.18	0.55

With manual TPR, higher grain yield of 6877, 7984 & 6650 kg ha^{-1} in 2018, 2019 & 2020, respectively were obtained under drip irrigation. On the other hand, with mechanical TPR, grain yield of only 4892 ha^{-1} in 2018 and with DSR, and 6373 & 5367 kg ha^{-1} in 2019 & 2020, respectively were obtained under flood irrigation method.

Mean value of three years is presented in [Fig-1]. Highest yield (7119 kg ha^{-1}) is obtained in drip and manual TPR combination. A treatment mean grain yield of 6781 kg ha^{-1} was obtained in manual TPR followed by 6548 kg ha^{-1} in mechanical TPR. Among irrigation methods, drip irrigation could produce a higher grain yield of 6851 kg ha^{-1} followed by sprinkler irrigation of 6548 kg ha^{-1}. This study showed that drip irrigation with any crop establishment method produced higher yield. Flood irrigation in all the establishment methods produced lower grain yield of rice.

There was a heavy infestation of weeds and a favourable microclimate around the crop for more pest and disease incidence in DSR with flood irrigation. Similar results are found in Choudhury *et al.* [5]. In contrast, Bhardwaj *et al.*, [28] reported higher grain yield of rice possible in long-term practices of DSR method. However, the DSR vs. TPR issue still need to be resolved by more research.

Water use

The amount of water used to produce one kg rice was determined [Fig-2]. This study revealed that water use varied from 2867 to 3546, 2270 to 2854 and 2202 to 3120 l kg^{-1} in 2018, 2019 and 2020, respectively among crop establishment methods. Manual TPR involved a lower amount of water in 2018 (2867 l kg^{-1}) and 2019 (2279 l kg^{-1}). DSR seemed to have consumed more water to produce rice.

Table-7 *Water used, physical water productivity (PWP) and economic water productivity (EWP) as influenced by irrigation and crop establishment methods in farmers field (Three years pooled data, 2018 to 2020)*

Treatments	Water used (l/kg rice grain)	PWP (kg m-3)		EWP (Rs. m-3)	
		IWU	TCWU	IWU	IyTCWU
Establishment methods					
DSR	3168	0.559	0.342	10.11	6.16
Mech. TPR	2696	0.729	0.416	13.21	7.53
Manual TPR	2458	0.813	0.441	14.70	7.96
SE(m)	16.03	0.004	0.002	0.07	0.05
LSD (P≤0.05)	48.48	0.012	0.006	0.21	0.14
Irrigation system					
Flood irrigation	3886	0.382	0.270	6.933	4.88
Drip irrigation	2100	0.932	0.491	16.84	8.86
Sprinkler irrigation	2336	0.787	0.438	14.24	7.91
SE(m)	16.03	0.004	0.002	0.07	0.05
LSD (P≤0.05)	48.48	0.012	0.006	0.21	0.14
Farmers' practice	4420	0.288	0.228	5.23	4.11
Interaction between E×I					
SE(m)	27.77	0.007	0.003	0.12	0.08
LSD (P≤0.05)	83.97	0.021	0.010	0.36	0.25

With respect to irrigation methods, drip method consumed the least water; 2427, 2021 and 1851 l kg^{-1} in 2018, 2019, and 2020, respectively which is closely followed by sprinkler irrigation treatment. Flood irrigated plots had recorded highest use of water. Drip irrigation with manual TPR recorded lowest water use; (2142, 1781 & 1636 l kg^{-1} respectively for each year). The data showed that manual TPR (2458 l kg^{-1}) was found to be lowest water user compared to others. The DSR planting method consumed 3168 l water per kg yield. Among irrigation methods, drip irrigation showed lowest water use (2100 l kg^{-1}) whereas flood irrigation the highest water use (3886 l kg^{-1}). Water used in farmers' practice was found to be still higher, 4420 l kg^{-1}. This study revealed that water-saving by drip irrigation was 52.49% and sprinkler 47.15% over farmers' practice. Rao *et al*., [26] reported that drip irrigation of rice could reduce water use by 45.25% than conventional flood irrigation of 3-5 cm water depth. Thus, adopting micro-irrigation particularly drip is a viable option to save water.

Water Productivity

Physical Water Productivity (PWP)

Water productivity is defined as the amount of filled grain produced per unit of water used. PWP was taken into consideration for both irrigation water and total consumptive water uses. As total irrigated water used and the yield varies among the irrigation treatments, their water productivity will be variable [Table-3].

There was a large effect of the treatments on PWPIWU which ranged from 0.593 - 0.802 kg m^{-3}, 0.645 - 1.001 kg m^{-3} and 0.440 - 0.636 kg m^{-3} in 2018, 2019 and 2020, respectively. The highest PWPIWU was achieved with manual TPR. The PWPIWU was significantly higher with manual TPR in 2018 and 2019, but in 2020 DSR had higher PWPIWU. Throughout the experimental period, drip method showed significantly higher PWPIWU (0.920, 1.135 and 0.742 kg m^{-3} in 2018, 2019 and 2020, respectively) than in all other irrigation treatments. Sprinkler method recorded next lowest PWP_{IWU} (0.777, 0.940 and 0.644 kg m^{-3} in 2018, 2019 and 2020, respectively). The PWP_{IWU} was found to be lowest with the flood irrigation method and farmers' practice since a large amount of water used to irrigate these plots. The average PWP_{TCWU} was reported to be 0.40 kg m^{-3} rice for Haryana state [19] and 0.50 kg m^{-3} for Punjab under farmer's conditions

Further, the statistical analysis showed a strong interaction between planting and irrigation methods for PWPIWU in all three years. Manual TPR with drip irrigation outperformed all other methods.

Besides the PWP_{IWU}, this study investigated the effect of planting and irrigation methods on PWP_{TCWU}. It is noted that the relationship between planting and irrigation methods on PWP_{TCWU} follows the same general trend as PWP_{IWU}. The ranges noticed from 0.311 to 0.379, 0.360 to 0.458 and 0.3554 to 0.485 kg m^{-3} in the years of 2018, 2019 and 2020, respectively. The PWP_{TCWU} of manual TPR was generally greater than other methods in 2018 and 2019. In 2020, however, mechanical TPR had a significantly higher PWP_{TCWU} followed by manual TPR [Table-4]. DSR recorded significantly lower PWP_{TCWU}. Among the irrigation methods, PWP_{TCWU} of drip was significantly higher (0.415, 0.504 and 0.553 kg m^{-3} in 2018, 2019 and 2020, respectively) than in all other treatments. The lower values of PWP_{TCWU} were recorded in flood treatment. Sharma *et al*. [19] in a report to NABARD reported that IWP kg m^{-3} of irrigation water supplied was 0.22 kg for both Haryana and Punjab for rice.

The results showed that there was strong significant interaction between planting and irrigation methods. Manual TPR with drip irrigation resulted in highest PWP_{TCWU} as 0.467, 0.561 and 0.611 kg m^{-3} in 2018, 2019 and 2020, respectively.

Results from three years study on the effects of treatments on the PWPIWU & PWP_{TCWU} are presented in [Table-7]. In both cases, maximum and minimum values were recorded from the manual TPR and DSR planting methods, respectively. On the other hand, drip-irrigated rice performed better in both cases which were closely followed by sprinkler irrigation methods. Irrigation through flood method perceptibly decreased PWP (0.382 & 0.270 kg $m^{-3}$with respect to IWU & TCWU, respectively) in both cases (DSR and TPR).

The treatment, manual TPR recorded higher PWPIWU &PWP_{TCWU} followed by mechanical TPR. Rice in DSR showed lower water productivity. The PWPIWU &PWP_{TCWU} increased by 1.4 & 1.2 fold in manual TPR, respectively over DSR. Rice in drip method showed higher PWPIWU &PWP_{TCWU} followed by sprinkler method. Rice with least water productivity was observed in conventional flood irrigation [Fig-2]. This study proved that the PWP_{IWU} &PWP_{TCWU} increased by 2.5 & 1.9 fold in drip irrigated fields, respectively as compared to flood irrigated field; whereas PWPIWU &PWP_{TCWU} of sprinkler irrigation increased by 2.1 &1.7.

The primary reason for higher PWP in manual TPR can be attributed to the lower percolation losses and prolonged standing of water in the field under puddled condition. During the experiment, it was noticed that the disappearance of water in DSR field was more frequent than that in the puddled field; so, it was forced to apply a huge volume of water every time in DSR field leading to higher water use. Further, higher inter and intra-plant competition occurred due to the crowding of plants and weed growth in DSR leading to lower water productivity. Drip irrigation could improve PWP of rice. The result was similar to that of Kato *et al*. [29] that water productivity of rice improved under drip irrigation. The higher water productivity in drip method is the combined result of less consumption of water and comparatively higher grain yield. These results are in line with the results of Soman [13] and Soman *et al* [14]. Our findings are also in close line with Bouman *et al*., [10] and Parthasarathy *et al*., [30], Tanmoy *et al*., [31]; Bhardwaj *et al*., [28].

Economic Water Productivity (EWP)

In this study, EWP is also estimated to describe the principle of 'cost of water to society' by accounting the amount of irrigation water and the price of crop output in EWP computation. The EWP for IWS and TCWS was calculated and given in [Table-5] and [Table-6], respectively.

The EWP under different planting methods ranges from Rs. 10.38 to 14.03 m^{-3}, Rs. 11.70 to 18.17 m^{-3} and Rs. 8.22 to 11.87 m^{-3} in the year 2018, 2019 and 2020, respectively. Manual TPR was consistently increased EWPIWS in 2018 and 2019.

However, it was true with mechanical TPR in the year 2020. It is a fact that there was lower EWPIWS in all the plots of DSR planting methods. Among irrigation methods, the ranges of EWPIWS were Rs. 5.32 to 16.10 m^{-3}, Rs. 9.32 to 20.60 m^{-3} and Rs. 6.16 to 13.86 m^{-3} in 2018, 2019 & 2020, respectively. The lower EWPIWS was observed with flood irrigation methods. The farmers' practice had recorded lowest EWPIWS. Each year, there was a significant interaction between planting and irrigation methods on EWPIWS.

In the present investigation, drip irrigation with manual TPR (Rs. 19.13, 24.58 & 15.66 m^{-3} in 2018, 2019 & 2020, respectively) performed superior to other treatments. Besides, drip irrigation with mechanical TPR was the next higher value of EWPIWS in 2019 and 2020. Flood irrigation with DSR planted plots recorded comparably lower EWPIWS in all three years. The consistent result was also seen for EWPTCWS in all three years [Table-6].

Based on the analysis of three years, the average EWP with respect to IWU and TCWU was greater by Rs. 14.70 m^{-3} and Rs. 7.96 m^{-3}, respectively under manual TPR. Among irrigation methods, drip irrigation method had significantly higher EWPIWS&TCWS with Rs. 16.84 m^{-3}& Rs. 8.86 Rs [Table-7].

EWPIWS was highest for drip irrigation indicating that the initial cost made in installing drip irrigation in a region is likely to generate large benefits. The mean EWPIWS ¬here indicate that drip irrigation increased it by 3.22 & 2.43-fold than farmers practice flood irrigation methods, respectively. The EWP_{TCWU} was also found to be highest in drip ((Rs. 8.86 m^{-3}) followed by sprinkler method (Rs. 7.91 m^{-3}) which was about 2.16 & 1.82-fold higher than farmers practice and flood irrigation methods, respectively [Fig-3]. This indicated that relating to the cost of irrigation water applied, general farmer's practices do not exhibit a sustainable EWP scenario. The non-judicious application of irrigation water in flood irrigation method as commonly done by farmers for rice crop is not sustainable. Sharma *et al*., [19] have reported that in Haryana, the EWP of irrigated water for rice is Rs. 6.182 m^{-3}. Excess irrigation to produce maximum grain yield would not be the most efficient use of irrigation water.

Therefore, efforts should be made to shift rice cultivation from conventional flooding methods to micro-irrigation methods such as drip method thus achieving more sustainability and food security for the country. Further, farmers of Haryana are accessing virtually free electricity and canal water. Thus, there is a common propensity among the farmers to excess irrigate the crop irrespective to the actual crop water demand resulting in low values of EWP. Hence, this powerful nexus of water- energy resulting in inefficient use of both water and energy requirements must be addressed on priority. Therefore, drip and sprinkler methods have a big opportunity to improve rice productivity with low water use on a sustainable basis. There is a need to accomplish a comprehensive evaluation of EWP on the impact of micro-irrigation. These results can be used in persuading farmers to adopt micro irrigation.

Conclusion

The rampant scarcity and increasing significance of water in the Indo-Gangetic plains of the region provoke farmers and irrigation institutes and/or companies to look for different ways to enhance crop output. This study on use of micro irrigation in farmer's field in Haryana indicated that drip irrigation enhances grain yield and water productivities *i.e*. PWP_{TCWU}, and EWP. Therefore, efforts should be made to shift rice cultivation from conventional flooding to micro-irrigation.

Application of research: The technology of Drip irrigation is of immense value and should be implemented in all rice farms. It is highly applied.

Research Category: Water productivity, Drip irrigation

Abbreviations: PWP =Physical water Productivity, EWP = Economic Water Productivity, IWU = Irrigation water use, TCWU = Total cumulative water use (irrigation

Acknowledgement / Funding: Authors are thankful to CADA, Government of Haryana and Jain Irrigation Systems Ltd., Jalgaon, 425001, Maharashtra, India

****Principal Investigator or Chairperson of research: Dr P. Soman**
University: Jain Irrigation Systems Ltd., Jalgaon, 425001, Maharashtra, India
Research project name or number: On farm study on Micro Irrigation for Rice crop.

Author Contributions: All authors equally contributed

Author statement: All authors read, reviewed, agreed and approved the final manuscript. Note-All authors agreed that- Written informed consent was obtained from all participants prior to publish / enrolment

Study area / Sample Collection: Pehova Taluka of Haryana State

Cultivar / Variety / Breed name: Rice (*Oryza sativa* L.)

Conflict of Interest: None declared

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.
Ethical Committee Approval Number: Nil

References

[1] GRiSP (Global Rice Science Partnership) (2013) In Rice Almanac, International Rice Research Institute, Los Baños, Philippines, 4th ed, 283.
[2] Kumar V., Ladha J.K. (2011) *Adv Agron*., 111, 297-413.
[3] Directorate of Economics and Statistics, Government of India (2018) - https://eands.dacnet.nic.in/PDF/Stateof_Indian_Agriculture,2017.pdf.
[4] Matthew Rodell, Isabella Velicogna and James S.F. (2009) *Nature*, 460 (7258), 999-1002.
[5] Choudhury B.U., Bouman B.A.M. and Singh A.K. (2007) *Field Crops Res*., 100, 229-239.
[6] Bouman B.A.M. (2009) *Rice Today*, 8, 28-29.
[7] Tuong T.P. and Bouman B.A.M. (2003) In Water Productivity in Agriculture: Limits and Opportunities for Improvement (eds Kijne J.W., Barker R.and Molden D.), CABI Publishing, UK., pp. 53-67
[8] Bouman B.A.M., Peng S., Castaneda A.R. and Visperas R.M. (2005) *Agric. Water Manage*., 74, 87-105.
[9] Dong B., Molden D., Loeve R., Li Y.H., Chen C. D. and Wang J. Z. (2004) *Paddy Water Environ*., 2, 217-226.
[10] Li Y.H. (2001) In Water-Saving Irrigation for Rice (eds Barker R., Li Y. and Tuong T.P.) *International Water Management Institute, Sri Lanka*, 135-144.
[11] Bouman B.A.M., Yang X., Wang H.Q., Wang Z., Zhao J. and Chen B. (2006) *Field Crops Res*., 97, 53-65.
[12] Mandal K.G., Kundu D.K., Thakur A.K., Kannan K., Brahmanand P.S. and Kumar A. (2013) *J. Food, Agric. Environ*., 11(3&4), 1148-1153.
[13] Soman P. (2012) Asian Irrigation Forum, Asian development Bank, Manila, April 11-13, 2012. ADB. Manila, Philippines.
[14] Soman P., Sundar Singh, Balasubrahmanyam V.R. and ChaudharyAmol (2018) *International J. Agri .Sci*., 10(10), 6040-6043.
[15] Soman P., Prasad M.S., Balasubramaniam V.R., Singh Sarwan, Dhavarajan C., Patil V.B. and Jha Sanjeev (2018*) International J. Agri. Sci*., 10 (14), 6672-6675.
[16] Adekoya M.A. *et al*., (2014) *J. Agric. Sci., Can*., 6(5), 110-119.
[17] Seckler D., Molden D. and Sakthivadivel R. (2003) In: J.W. Kijne, R. Barker and D. Molden (eds). Water Productivity in Agriculture: Limits and Opportunities for Improvement. CAB International, Wallingford, UK, 37-51.
[18] De Fraiture C., Wichelns D., Rockstrom J. and Kemp-Benedict E. (2007). In: Molden D.(Ed.), Water for Food, Water for Life: A Comprehensive Assessment of Water management in Agriculture. Earth scan and International Water Management Institute, London and Colombo.

[19] Sharma Bharat R, Ashok Gulati, Gayathri Mohan, Stutiman Chanda, Indro Ray, and Upaliamara Singhe (2018) NABARD and ICRIER Report.
[20] Jayadeva H.M. and Prabhakara Setty T.K. (2008 *Oryza*, 45, 166-168.
[21] Berkhout E., Glover D. and Kuyvenhoven A. (2015) *Agric. Syst*., 132, 157-166.
[22] Sumberg J., Andersson J., Giller K.E.N. and Thompson J. (2013) *Geogr. J.,* 179, 183-185.
[23] Pandey S., Velasco L.E. and Suphanchalmat N. (2002) In Direct Seeding: Research Strategies and Opportunities; Pandey S., Mortimer M., Wade L., Tuong T.P., Lopez K. and Hardy, B., Eds.; International Rice Research Institute: Los Baños, Philippines, pp. 139-150.
[24] Castilla, N.P., Leaño R.M., Elazegui F.A., Teng P.S. and Savary S. (1996) *J. Phytopathol*.,144, 187-192.
[25] Bhardwaj A.K., Pandiaraj T., Sumit Chaturvedi, Churachand Singh T., Soman P., Bhardwaj R.K. and Bijay Labh. (2018) *Current Journal of Applied Science and Technology*, 26(6), 1-9.
[26] Rao K.V.R., Gangwar S., Keshri R., Chourasia L., Bajpai A. and Soni K. (2017) *Appl. Ecol. Environ. Res*., 15(4), 487-495.
[27] Rajeev Bansal, Neeraj Sharma, Soman P., Sarvan Singh, Bhardwaj A.K., Pandiaraj T. and Bhardwaj R.K. (2018) *Int. J. Curr. Microbiol. App. Sci*., 7(2), 506-512.
[28] Bhardwaj A.K., Pandiaraj T., Soman P., Bhardwaj R.K. and Singh T. C. (2018) *Int. J. Environ. Climate Change*, 8(4), 332-340.
[29] Kato Y., Okami M. and Katsura K. (2009) *Field Crops Res*., 113, 328-334.
[30] Parthasarathi Theivasigamani, Koothan, Vanitha, Sendass, Mohandass and Eli Vered (2018) *Agronomy J.,* 110 (6),2378-2389
[31] Tanmoy Bhowmik, Bhardwaj A.K., Pandiaraj T. and Arnab Roy (2018) *Int. J. Curr. Microbiol. App. Sci.,* 7(02) 3185-3191.