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Effect of micro-irrigation on water productivity in system of rice (*Oryza sativa*) and wheat (*Triticum aestivum*) intensification

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ABSTRACT

A field experiment was conducted during 2011-2013 to study the performance of different irrigation methods on water productivity in system of rice and wheat intensification (SRI and SWI) at research farm of ICAR-Research Complex for Eastern Region, Patna. Three methods of irrigation, Low Energy Water Application (LEWA), micro-sprinkler and check basin irrigation methods were combined with three establishment methods SRI/SWI, line transplanting/sowing and farmers' practices of transplanting/sowing respectively, in rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) crops laid out in 3^2 factorial randomized block design. SRI under micro irrigation system (LEWA and micro-sprinkler) resulted in significantly higher (128 and 123 %) grain yield of rice as compared to farmers' practice of rice transplanting under check basin irrigation (3.80 tonnes/ha). However, the grain yield variation between LEWA and micro-sprinkler irrigation under different establishment methods was insignificant. Whereas, a combination of SRI and micro-irrigation (LEWA and micro-sprinkler) significantly increased water productivity by 153 and 156 % respectively in comparison to check basin under framers' practices of rice establishment (0.34 kg/m^3). There was a mean saving of 27 and 39% water observed in LEWA and micro sprinkler irrigation, respectively as compared to check basin irrigation (340 mm) in rice crop. In case of wheat, SWI in combination with micro-irrigation system (LEWA and micro-sprinkler) recorded significantly higher (132 and 131%) grain yield in comparison to farmers' practice of wheat establishment under check basin irrigation (3.10 tonne/ha). Whereas, a combination of SWI and micro-irrigation (LEWA and micro-sprinkler) significantly increased water productivity by 190 and 233 % respectively in comparison to check basin under framers' practices of wheat establishments (1.07 kg/m^3). There was a mean saving of 23 and 36 % water observed in LEWA and micro-sprinkler irrigation respectively as compared to check basin irrigation (249 mm) in wheat crop. It has been clearly established that SRI and SWI in combination with micro-irrigation played crucial role in enhancing the grain yield and water productivity of rice and wheat.

Key words: Check basin irrigation, Irrigation method, Micro-irrigation, System of Rice Intensification (SRI), System of Wheat Intensification (SWI), Water productivity

To cater the food needs of ever increasing population in India and particularly in Indo-Gangatic Plains, there has been tremendous pressure on farming community as well as on researchers to increase the production and productivity per unit area of the rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) crops. The area, production and productivity potential of rice-wheat system in Bihar is estimated to be 1.6 million ha, 4.50 tonnes/ha and 7.5 to 12.0 tonnes/ha respectively (Khan 2010). Bihar experienced aberrant rainfall situation in 5 out of 10 years (2004, 2005, 2009, 2010 and 2013) impacting adversely rice-wheat productivity. India Meteorological Department, Pune for monsoon 2015 clearly forecasts a deficit of 12% less rainfall than normal across the country which will have adverse effect on rice production.

A method of cultivation of rice called System of Rice Intensification (SRI) that evolved in the 1980s in Madagascar is also gaining popularity in India in general and in eastern states in particular. Bihar has become pioneer in this endeavour where government policy has become effective in farmers' fields for increasing rice and wheat production. New world record of rice grain yield (22.4 tonnes/ha) was established in Nalanda District of Bihar. On the similar concept of rice cultivation, System of Wheat Intensification (SWI) was also developed. In SRI, a seed rate of 5 to 7 kg/ha is required as compared to 35 to 45 kg/ha normal seed rate which is 5 to 6 times lesser than the normal. In SWI also around 5 times less seed is sown as compared to normal seed rate (100 kg/ha). Apart from low seed rate input, the most important aspects noticed were conservation of available natural resources such as soil

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and water. It also reduces competition between plants; active soil aeration and the careful application of water are proved to raise the productivity and profitability of crops. Ghritlahre *et al*. (2011) reported that SRI saves not only the seed (a seed rate of 5 to 7 kg/ha as against 25 to 30 kg/ha for normal) but also saves water (35 to 40 %) as the fields are not inundated continuously. It leads to higher ripening ratio and increases yield by 10 to 25%.

As per Thiagarajan and Gujja (2013), SRI has been found to have a number of advantages beyond the most obvious one of increasing rice productivity. The main one is bringing down the irrigation water requirement by nearly 30 to 40 %. This alone should be attractive to water managers and to decision makers who are responsible for ensuring adequate water supplies for agricultural, industrial and domestic uses.

However, there are not yet any fixed recommendations for water management under SRI and SWI systems. Irrigation through micro-irrigation is very much suited to the concept of SRI because in this system inundation of water is not required, rather saturation of soil is needed during most of the crop growth period. Moreover, water productivity (WP) is significantly enhanced over surface method of irrigation under new establishment methods of Rice-Wheat Intensification system. To identify the best irrigation technology for Rice-Wheat Intensification system, line transplanting/sowing and farmers' practices of transplanting/ sowing respectively in rice and wheat crops, this experiment was planned and carried out under three methods on irrigation system such as Low Energy Water Application (LEWA), Micro-Sprinkler and Check Basin Irrigation for achieving the optimum potential of rice-wheat productivity per unit area in the eastern region and water scarce region of India.

MATERIALS AND METHODS

A field experiment was conducted during 2011-12 to 2012-13 at research farm of ICAR-Research Complex for Eastern Region, Patna. The experimental soil was silty-clay loam analyzed as medium in organic carbon (0.67 %), medium in available N (301 kg/ha) and P_2O_5 (29 kg/ha) but high in K_2O (325 kg/ha) with pH 6.2. The top 15 cm soil layer had bulk density of 1.50 g/cm^3, field capacity 35.0 % and permanent wilting point of 16.5 % on oven-dry basis. The rice and wheat crops were grown in net plot size of 5 × 5 m, with dose of 100, 60 and 40 kg of N, P_2O_5 and K_2O/ha, respectively. The recommended dose of N @ 100 kg/ha during rainy and winter season was applied through 50 % organics (Vermicompost) + 50 % chemical fertilizer (urea) in System of Rice and Wheat Intensification as well as in line transplanting/sowing treatments, while whole of the recommended dose of P was applied through single super phosphate and K was applied through muriate of potash as basal along with one third dose of N through urea and remaining 2 more splits of N through urea in case of farmers' practices of transplanting/sowing of rice and wheat, respectively. However, apart from the one third dose of N and K, the remaining part of chemical N and K was applied in 2 splits, i.e. at tillering and panicle initiation stages in rice and at crown root initiation (CRI) and ear initiation (EI) stages in wheat in System of (R-W) intensification as well as in line transplanting/sowing treatments. The experiment was laid out in 3^2 factorial randomized block design with three replications. Three methods of irrigation (I_1 - LEWA, I_2 - Micro-sprinkler and I_3-Check basin irrigation) were combined with three establishment methods (E_1-SRI/SWI, E_2- Line transplanting/sowing and E_3- Farmers' practices of transplanting/sowing). Buffer zone was formed between plots to avoid the overlapping of treatments influence in other plots.

LEWA is a new sprinkling device developed at ICAR-Research Complex for Eastern Region which operates at very low pressure of 0.6 kg/ cm^2 has been found very much suitable for cereals like rice and wheat due to its higher discharge rate.

Twelve days old seedlings in SRI at a spacing of 25 × 25 cm (5 kg/ha) by keeping one seedling/hill and 2 to 3 seedlings of 30 days old seedlings of rice variety Swarna were used in line transplanting (20 × 15 cm spacing), while 3 to 5 seedlings were used in the farmers' practices (35 kg/ha). Water management in the LEWA and micro-sprinkler irrigation treatments was done for SRI, i.e. depending on the moisture content water was applied once in 3-4 days, just to keep the soil moist, while it was irrigated regularly in the check basin irrigation to maintain submergence of 5 ± 2 cm. Three weeding was done with Cono weeder in 10 days interval starting from 15th day after transplanting, while Butachlor @ 1.5 kg a.i./ha (pre-emergence) was applied for weed control in plots where rice was transplanted in line as well as in the farmers' practices. This was supplemented by hand-weeding once at 40 days after transplanting.

System of Wheat Intensification (SWI) which is based on the principles of SRI is a new wheat cultivation technique which demands seed priming for which first bold seeds (20 kg/ha were dip in 50 litre of lukewarm water (60°C) in an earthen pot and then 7.5 kg vermicompost, 7.5 litre cow urine and 5 kg jiggery were added into it by mixing thoroughly to keep it for 6 to 8 hours. Whole material was filtered so that solid materials along with seeds and liquids got separated. After that 50 g of carbendazim was mixed properly and kept in moist gunny bags under shade for 10-12 hours. Such primed seeds were used for sowing in the tilled field at spacing of 20 × 20 cm by placing 2 seeds at 2.5 to 3 cm depth using seed dibbler with marker manufactured in Rukka village, Ranchi, Jharkhand. Wheat was drilled in row and placed 2.5 to 3 cm deep below the soil using seed drill at a spacing of 20 cm for line sowing while under farmers' practices of sowing wheat variety HD 2733 was broadcast (100 kg/ha) after seed treatment with Carbendazim @ 2.5 g/kg of seed. Four irrigations each of 5± 2 cm depth was applied at CRI, tiller completion, boot and milk stages in check basin method of irrigation. Whereas in LEWA and micro-sprinkler irrigation methods water was applied at 80 % of field capacity. In SWI crop was weeded

3 times by single hoe double wheel weeder. Weed control in other plots was ensured by the tank mix application of isoproturon 1.0 kg/ha + 2, 4-D @ 0.5 kg/ha applied 35 days after sowing. Furthermore, one hand weeding was also done to keep the crop free from weeds.

For planting of rice 100 mm water was irrigated in addition to 200 mm rainfall for puddling. One pre-sowing irrigation of 50 mm was given to all the treatments in wheat crop. Evaporation was recorded daily with open pan evaporimeter for the period 2011-12 and 2012-13, respectively. Flexible PVC pipe was used to deliver the required volume of water in each plot. The rainfall was measured with the help of rain gauge. Necessary corrections in scheduling of irrigation were made whenever effective rainfall was received. A total rainfall of 740 mm and 793 mm were received in *kharif* season of 2011-12 and 2012-13, respectively, whereas a rainfall of 25.0 and 55.4 mm were received in *rabi* season of 2011-12 and 2012-13, respectively. Treatment wise crop was harvested (excluding the border rows), sun-dried, threshed and weighed. The field data on growth, yield attributes and yield were statistically analyzed by using 3^2 factorial randomized block design for rice and wheat, respectively. Grain yield was divided by sum of rainfall and irrigation water to calculate water productivity (WP). Standard error and least significant difference of yield attributes, grain yield and water productivity were compared to their means with the help of a statistical package ICARSTAT.

RESULTS AND DISCUSSION

The SRI method of rice cultivation (5 kg/ha) saved seven times less seed than farmers' practice of rice cultivation (35 kg/ha). Being less availability of quality input like seed, it is a huge boost to the farmers.

Rice crop growth, yield attributes and yield

Observation on root area per hill, leaf area index (LAI), panicles/m^2, panicle weight, grain and straw yield were taken during the period of crop cultivation of rice. Data are presented in Table 1 and 2 except of LAI. Methods of irrigation and establishment did not show interaction on LAI. However, there was significant variation in all other yield attributes and grain yield of rice due to interaction effect of irrigation and establishment methods. Among all the irrigation methods, LEWA and micro-sprinkler under SRI recorded significantly highest root area at booting (12 and 11.5 cm^2/hill), number of panicles/m^2 (326 and 319), panicle weight (3 and 3 g) and grain yield (8.68 and 8.49 kg/m^3) than that of check basin under farmers' practice, i.e. root area (7.5 cm^2/hill), number of panicles/m^2 (279), panicle weight (2.3 g) and grain yield (5.98 kg/m^3). Under micro-irrigation system, micro-sprinkler irrigation in combination with SRI did not show significant variation on the entire yield attribute parameters and grain yield of rice as compared to LEWA with SRI. This shows that frequent and light irrigation with micro-irrigation like LEWA and micro-sprinkler is well suited with the concept of SRI. Moreover, square planting of rice seedling in SRI gives all the individual rice plant to have access of inputs like nutrients, moisture, sunshine and air. This gives healthy plant development resulting into higher grain and straw yield.

Table 1 Effect of different irrigation and establishment methods on growth and yield attributes of rice crop (pooled data of two years)

Irrigation methods	Root area (cm^2/hill)			No. of panicles/m^2		
	Establishment methods			Establishment methods		
	SRI	Line transplanting	Farmers' practice	SRI	Line transplanting	Farmers' practice
LEWA	12.0	8.7	7.5	326	311	279
Micro-sprinkler	11.5	8.4	7.0	319	290	276
Check basin	7.0	7.8	5.0	280	276	240
SEm ±	0.19			3.83		
LSD (P=0.05)	0.7			19.7		

Table 2 Effect of different irrigation and establishment methods on growth, yield attributes and yield of rice crop (pooled data of 2 years)

Irrigation methods	Panicle weight (g)			Grain yield (tonnes/ha)			Straw yield (tonnes/ha)		
	Establishment methods			Establishment methods			Establishment methods		
	SRI	Line transplanting	Farmers' practice	SRI	Line transplanting	Farmers' practice	SRI	Line transplanting	Farmers' practice
LEWA	3.0	2.5	2.3	8.68	6.92	5.60	11.39	9.42	8.62
Micro-sprinkler	3.0	2.2	2.1	8.49	7.03	4.60	11.93	10.11	7.26
Check basin	1.9	2.0	1.8	6.13	7.01	3.80	9.53	10.94	5.98
SEm ±	0.09			0.16			0.78		
LSD (P =0.05)	0.15			0.84			0.19		

However, 1 000-grain weight was not affected significantly by different treatments due to genetic characteristic of the variety. A well developed and healthy root system in SRI plays an important role in uptake and translocation of nutrients from the soil than conventional system (Uphoff 2005) and this ultimately results in healthy plant growth, better tillering, higher biomass and higher yields. Similar findings were observed by Sharma and Masand (2008) and Barla and Kumar (2011).

In case of establishment methods, the SRI with LEWA or micro-sprinkler recorded significantly higher grain and straw yield over line transplanting and farmers' practices of transplanting. Increased yields in SRI compared to conventional method were reported by several authors (Thiyagarajan *et al*. 2005, Uphoff 2005 and Satyanarayana *et al*. 2006).

Water use in rice crop

An average rainfall of 766.4 mm was received over two years and the highest volume of irrigation water of 340.2 mm was given under check basin followed by 247.2 and 207.1 mm in LEWA and check basin irrigation, respectively (Table 2). Significantly higher (56 and 58%) water productivity was recorded in micro-irrigation, i.e. LEWA (0.86 kg/m^3) micro-sprinkler (0.87 kg/m^3) under SRI as compared to check basin irrigation (0.55 kg/m^2) under SRI (Table 3).Whereas, a combination of SRI and micro-irrigation (LEWA and micro-sprinkler) significantly increased water productivity by 153 and 156 % respectively, in comparison to check basin under framers' practices of rice establishment (0.34 kg/m^3). Water saving of 27 to 39 % were recorded in LEWA and micro-sprinkler irrigation in comparison to check basin irrigation. It reveals that 37 and 64 % more area of rice crop can be brought into the irrigation through LEWA and micro-irrigation, respectively, in comparison to check basin irrigation.

Significantly higher (56 and 58 %) water productivity was recorded in micro-irrigation, i.e. LEWA (0.86 kg/m^3) micro-sprinkler (0.87 kg/m^3) under SRI as compared to check basin irrigation (0.55 kg/m^2) under SRI (Table 3).

This result shows that a combination of SRI with micro irrigation is a good option for increasing water productivity of rice crop.

Wheat crop growth, yield attributes and yield

The SWI method of wheat cultivation (20 kg/ha) saved five times less seed than farmers' practice of wheat cultivation (100 kg/ha). Similar to SRI, in SWI also, fewer requirements of quality seed of wheat is very important. With the same amount of seed required for 1 hectare of land under farmers' practice, 5 hectares of land through SWI can be sown. Apart from above, SWI in combination

Table 3 Rainfall occurred and irrigation given in different treatments of rice crop (pooled over 2 years)

Irrigation methods	Rainfall (mm)			Irrigation (mm)		
	Establishment methods			Establishment methods		
	SRI	Line transplanting	Farmers' practice	SRI	Line transplanting	Farmers' practice
LEWA	766.4	766.4	766.4	274.2	247.2	247.2
Micro-sprinkler	766.4	766.4	766.4	207.1	207.1	207.1
Check basin	766.4	766.4	766.4	340.2	340.2	340.2
SEm ±						
LSD (P=0.05)						

		Irrigation (mm) *Establishment methods*		
	Rainfall (mm)	*SRI*	*Line transplanting*	*Farmers' practice*
LEWA	766.4	247.2	247.2	247.2
Micro-sprinkler	766.4	207.1	207.1	207.1
Check basin	766.4	340.2	340.2	340.2

Table 4 Water productivity in different irrigation and establishment methods and water saving for rice crop (pooled over 2 years)

Irrigation methods	Grain yield (tonnes/ha)			Water productivity(kg/m^3)			% less irrigation than check basin
	Establishment methods			Establishment methods			
	SRI	Line transplanting	Farmers' practice	SRI	Line transplanting	Farmers' practice	
LEWA	8.68	7.92	5.60	0.86	0.68	0.55	27.3
Micro-sprinkler	8.49	7.99	4.60	0.87	0.72	0.47	39.1
Check basin	6.13	7.01	3.80	0.55	0.63	0.34	
SEm ±				0.03			
LSD (P =0.05)				0.08			

with micro-irrigation (LEWA and micro-sprinkler) almost all the growth and yield attributing parameters including root area at tillering, root area at flowering, LAI at flowering, number of ear head/m^2 and ear head weight were significantly higher than SWI under check basin irrigation (Table 4, 5 and 6).

Significantly higher wheat grain (7.20 and 7.15 tonnes/ha) and straw (9.25 and 9.24 tonnes/ha) yields were

Table 5 Effect of different irrigation and establishment methods on growth and yield attributes (pooled data of 2 years)

Irrigation method	Root area at tillering(cm^2/hill)			Root area at flowering(cm^2/hill)		
	Establishment methods			Establishment methods		
	SWI	Line transplanting	Farmers' practice	SWI	Line transplanting	Farmers' practice
LEWA	5.3	4.3	3.0	10.2	8.0	5.8
Micro-sprinkler	5.3	4	2.9	10.1	7.7	5.4
Check basin	3.40	3.8	2.30	6.5	7.2	4.4
SEm ±	0.162			0.346		
LSD (P=0.05)	0.45			0.64		

Table 6 Effect of different irrigation and establishment methods on growth and yield attributes (pooled data of 2 years)

Irrigation method	LAI at flowering			No. of ear head/m^2		
	Establishment methods			Establishment methods		
	SWI	Line transplanting	Farmers' practice	SWI	Line transplanting	Farmers' practice
LEWA	8.0	6.5	4.6	198	165	140
Micro-sprinkler	7.9	6.2	4.3	192	163	130
Check basin	5.1	5.6	3.4	138	140	128
SEm ±	0.195			6.867		
LSD (P =0.05)	0.29			26.45		

Table 7 Effect of different irrigation and establishment methods on growth and yield attributes and yield of wheat crop (pooled data of 2 years)

Irrigation method	Earhead weight (g)			Grain yield (tonnes/ha)			Straw yield (tonnes/ha)		
	Establishment methods			Establishment methods			Establishment methods		
	SWI	Line transplanting	Farmers' practice	SWI	Line transplanting	Farmers' practice	SWI	Line transplanting	Farmers' practice
LEWA	4.6	3.8	3.6	7.20	5.80	4.10	9.25	7.53	5.68
Micro-sprinkler	4.5	3.9	3.5	7.15	5.60	3.90	9.24	7.68	5.55
Check basin	3.6	3.5	2.9	4.60	5.10	3.10	6.30	6.60	4.65
SEm ±	0.104			0.162			0.205		
LSD (P=0.05)	0.19			0.84			1.07		

Table 8 Rainfall occurred and irrigation given in different treatments of wheat crop (pooled over 2 years)

Irrigation method	Rainfall (mm)			Irrigation (mm)		
	Establishment methods			Establishment methods		
	SWI	Line transplanting	Farmers' practice	SWI	Line transplanting	Farmers' practice
LEWA	40.2	40.2	40.2	191.8	191.8	191.8
Micro-sprinkler	40.2	40.2	40.2	160.4	160.4	160.4
Check basin	40.2	40.2	40.2	249.0	249.0	249.0

		Irrigation (mm)		
		Establishment methods		
Irrigation methods	*Rainfall (mm)*	*SWI*	*Line transplanting*	*Farmers' practice*
LEWA	40.2	191.8	191.8	191.8
Micro-sprinkler	40.2	160.4	160.4	160.4
Check basin	40.2	249.0	249.0	249.0

Table 9 Water productivity in different irrigation and establishment methods and water saving for wheat crop (pooled over 2 years)

Irrigation method	Grain yield (tonnes/ha)			Water productivity (kg/m^3)			% less
	Establishment methods			Establishment methods			
	SWI	Line transplanting	Farmers' practice	SWI	Line transplanting	Farmers' practice	
LEWA	7.20	5.80	4.10	3.10	2.50	1.77	23.0
Micro-sprinkler	7.15	5.60	3.90	3.56	2.79	1.94	35.6
Check basin	4.60	5.10	3.10	1.59	1.76	1.07	
SEm ±	0.280			0.123			
LSD (P =0.05)	0.84			0.371			

recorded in micro-irrigation (LEWA and micro-sprinkler) under SWI as compared to check basin under SWI (grain yield 4.60 tonnes/ha and straw yield 6.30 tonnes/ha) (Table 6). Grain and straw yield of wheat significantly decreased as one moves from SWI under micro-irrigation to line transplanting under micro-irrigation followed by farmers' practice of establishment methods. Significantly lowest wheat yield (grain yield 3.10 tonnes/ha and straw yield 4.6 tonnes/ha) was recorded for farmers' practice of establishment under check basin as compared to almost all other treatments. However, micro-sprinkler irrigation in combination with SWI did not show significant variation on the entire yield attributing parameters and grain yield of wheat as compared to LEWA under SRI. These results show that SWI under micro-irrigation may be a good option for improving wheat crop productivity.

Water use in wheat crop

An average meager rainfall of 40.2 mm was received over two years and the highest irrigation water of 249 mm was given under check basin followed by 190.8 and 160.4 mm in LEWA and check basin irrigation, respectively (Table 7). Significantly higher (95 to 124%) water productivity was recorded in micro-irrigation, i.e. LEWA (3.10 kg/ m^3) micro-sprinkler (3.56 kg/m^3) under SRI as compared to check basin irrigation (1.59 kg/m^2) under SRI (Table 8).Whereas, a combination of SRI and micro-irrigation (LEWA and micro-sprinkler) significantly increased water productivity by 190 to 233 % in comparison to check basin under framers' practices of wheat establishment (1.07 kg/m^3) (Table 9). Water saving of 23 and 36% were recorded in LEWA and micro-sprinkler irrigation respectively in comparison to check basin irrigation (249 mm). It reveals that 30 and 55 % more area of wheat crop can be brought into the irrigation through LEWA and micro-irrigation respectively in comparison to check basin irrigation.

These results show, as similar to SRI, that a combination of SWI with micro-irrigation is a good option for increasing water productivity of wheat crop and more area can be brought under irrigation through micr- irrigation.

It is concluded that SRI under micro-irrigation system (LEWA and micro-sprinkler) resulted in significantly higher (128 and 123 %) grain yield of rice as compared to farmers' practice of rice transplanting under check basin irrigation (3.80 tonnes/ha). A combination of SRI and micro-irrigation (LEWA and micro-sprinkler) significantly increased water productivity by 153 and 156 % respectively in comparison to check basin under framers' practices of rice establishment (0.34 kg/m^3). In case of wheat, SWI in combination with micro-irrigation system (LEWA and micro-sprinkler) recorded significantly higher (132 and 131 %) grain yield in comparison to farmers' practice of wheat establishment under check basin irrigation (3.10 tonnes/ha). A combination of SRI and micro-irrigation (LEWA and micro-sprinkler) significantly increased water productivity by 190 and 233 % respectively in comparison to check basin under framers' practices of wheat establishments (1.07 kg/m^3). It has been clearly established that SRI and SWI in combination with micro-irrigation played crucial role in enhancing the grain yield and water productivity of rice and wheat.

REFERENCES

Barla S and Kumar S S. 2011. Evaluation of rice establishment techniques in Jharkhand plataue. *Oryza* **48** (1): 79–88.

Ghritlahre S K, Serial A K, Ram M, Aneja D R and Singh R. 2011. Genetic yield potential of rice (*Oryza sativa*) through water saving and high-yielding SRI technology. *Indian Journal of Agricultural Sciences* **82** (3): 260–3.

Khan A R. 2010. Resource conservation technologies for food security and rural livelihood in eastern Indo-gangetic plains. *Resource Conservation Technologies for Food Security and Rural Livelihood* pp 1-60. Khan A R, Singh S S, Bharti R C, Srivastava T K and Khan M A (Eds).Agrotech Publishing Academy, New Delhi.

Satyanarayana A, Thiagarajan, T M and Uphoff N. 2006. Opportunities for water saving with higher yield from the system of rice intensification. *Irrigation Science* 1 432–1 519.

Singh S S, Prasad L K and Upadhyay A. 2006. Root growth, yield and economics of wheat (*Triticum aestivum*) as affected by irrigation and tillage practices in South Bihar. *Indian Journal of Agronomy* **51** (2): 131–4.

Sharma P K and Masand S S. 2008. Evaluation of system of rice intensification in a high rainfall area of North-Western Himalayas. Oryza **45** (3): 206–11.

Thiagarajan T M and Gujja B. 2013. SRI: transforming rice production with SRI (System of rice intensification) knowledge and practice. National Consortium on SRI Publication.

Thiyagarajan T M, Senthilkumar K, Priyadarshini R, Sundarsingh J, Muthusankaranarayan A, Hengsdijk H and Bindraban P S. 2005. Evaluation of water saving irrigation and weeder use on the growth and yield of rice. *(In) Proceedings of an International Symposium on Transitions in Agriculture for enhancing water productivity*, 23-25 September 2003,

Killikulum, Tamilnadu.

Uphoff N. 2005. Possible explanations for the productivity gains achieved with the system of rice intensification (SRI). *(In) Proceedings of an International Symposium on Transitions in Agriculture for enhancing water productivity*, 23-25 September 2003, Killikulum, Tamilnadu.