



Feasibility of mini-sprinkler irrigation system in direct seeded rice (*Oryza sativa*) in Indo-Gangetic plains of India

RANBIR SINGH^{1*}, AJAY SINGH², SATYENDRA KUMAR^{3*}, A K RAI⁴, SONIA RANI⁵, D K SHARMA⁶, P K JOSHI⁷, S K CHAUDHARI⁸, PARDIP DEY⁹, THIMMAPPA K¹⁰ and R S TRIPATHI¹¹

ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, India

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ABSTRACT

Surface irrigation methods in puddle transplanted rice (PTR) requires a huge amount of irrigation water and leads to decline in water table in rice (*Oryza sativa* L.) growing areas of Indo-Gangetic Plains (IGP) of India. Mini sprinkler irrigation system with high water application efficiency in direct seeded rice (DSR) can save substantial amount of irrigation water. With this hypothesis, a four-year field experiment was conducted at ICAR-Central Soil Salinity Research Institute, Karnal to assess the feasibility of mini-sprinkler irrigation system for growing rice crop under conservation agriculture. Total 4 treatments, viz. mini-sprinkler irrigation system in direct seeded rice (SPRL-DSR), mini-sprinkler irrigation system in direct seeded rice with 1/3rd wheat residue (SPRL-DSR+R), surface irrigation in direct seeded rice (SUR-DSR), and surface irrigation in puddle transplanted rice (SUR-TPR), were laid out. Significantly higher grain yield, grains/panicle, and 1000-grain weight were recorded under SUR-TPR, while higher number of effective tillers/m.r.l. was recorded in SUR-DSR. The yield penalty in SPRL-DSR (6.84 t/ha) was 8.3% as compared to SUR-TPR. The saving in irrigation water and nitrogen was found to be 52.8 and 26.7%, respectively in SPRL-DSR as compared to SUR-TPR. SPRL-DSR also recorded 1.6-2.6 times higher grain water productivity (GWP) in comparison of SUR-TPR. Higher water and nitrogen use efficiency suggest that mini-sprinkler irrigation system is a viable option for DSR cultivation in groundwater depleting Indo-Gangetic plains of India.

Key words: Direct seeded rice, Mini sprinkler, Water productivity

The water table in North Indo-Gangetic plain is declining at an alarming rate of ~0.33 m/yr (Tomar *et al.* 2012; Narjary *et al.* 2014). The rice and wheat are main crops in this part of the country, posing a great challenge for agricultural sustainability in the region. In surface irrigation method, about 2000 mm of water is applied in puddle transplanted rice with a very low irrigation efficiency of 30-35% (Mandal *et al.* 2019). Besides current annual water deficit of 1.27 M ha-m (Jain and Kumar 2007) owing to escalated water demand from 2.76 to 4.76 M

ha-m during the last four decades (Minhas *et al.* 2010), there is a need to address the issues relating to sustainable crop production, rational water use and develop alternative efficient approaches for water use in irrigated rice based cropping system.

Rice (*Oryza sativa* L.) grown on 43.8 million ha (Mha) with productivity of 3848 kg/ha, is essential for food security of India (FAO 2017). But at the current rate of depleting water resources, its sustainability is under tremendous pressure. So, to feed ever increasing population with limited resources is a challenge. As predicted by English *et al.* (2002), irrigated agriculture will need to produce 2/3rd more food grains to feed ever growing population.

Transplanting of seedling in puddle soil is common practice of cultivating rice (TPR). However, in TPR, water losses in terms of percolation and surface evapotranspiration are very high (Khepar *et al.* 1997, Farooq *et al.* 2011). Crop establishment by broadcasting/line drilling seed directly in the non-puddle soil having optimum moisture is called as direct seeded rice (DSR). DSR saves substantial amount of irrigation water and achieves higher water use efficiency as compared to PTR (Kumar *et al.* 2019). The use of efficient water application method can be a pragmatic solution of the aforesaid concerns as sprinkler and drip irrigation systems in rice consumes 40% less water with

^{1,4}Principal Scientists (Ranbir.singh@icar.gov.in, raiarvindkumar@gmail.com), ^{2,5}Senior Research Fellow (ajayyadavhau@gmail.com), (Sonia.sagwal18@gmail.com), Division of Soil and Crop Management, ICAR-CSSRI, Karnal, ^{3*}Principal Scientist & corresponding author (s.kumar2@icar.gov.in), ⁶Ex-Director ICAR-CSSRI, Karnal (dk.sharma@icar.gov.in), ⁷Principal Scientist (pk.joshi@icar.gov.in), ⁸ADG-Soil and Water Management, ICAR, New Delhi, (surchaudhari@hotmail.com), ⁹Ex-Project Coordinator, IISC, Bhopal (pradipdey@yahoo.com), ¹⁰Senior Scientist(thimpu@rediffmail.com), ¹¹Ex-Head, Division of Social Science Research, ICAR-CSSRI, Karnal.

18% higher grain yield compared to traditional flooded basin irrigation (Kahlowan *et al.* 2007; Sharda *et al.* 2017). Karim *et al.* (2014) also observed 34% saving in irrigation water with 7.6, and 31% higher grain yield and net profit, respectively under sprinkler irrigation system than flood irrigation in boro rice. Crop residue as soil cover can be another important management practice to reduce water loss from soil surface which results in increase in water use efficiency in semi-arid regions. Ali *et al.* (2018) observed increased soil water availability, higher yield and WUE with wheat residue at 5 t/ha as compared to no residue. Keeping above facts in mind, the present study was undertaken to study the feasibility of using mini sprinkler system of irrigation in DSR under conservation agricultural practices to reduce groundwater pumping and achieve higher water productivity in rice.

MATERIALS AND METHODS

A field experiment was conducted during *kharif* seasons of 2012-2015 at Research Farm (28°43' N, 73°58' E, 244 m above mean sea-level) of ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, India, with rice crop. The experimental site was typical reclaimed sodic soil (pH 7.82 and EC 0.25 dS/m) and subtropical monsoonal climate with mean max. and min. temp of 33.5 °C and 23.8 °C respectively, and 700 mm average rainfall, of which 70% precipitation received within a short span of July to September months. The soil physico-chemical properties at the initiation of field experiment are given in Table 1.

Based on irrigation method and crop establishment technique, total of 4 treatments, viz. mini-sprinkler irrigation system in direct seeded rice (SPRL-DSR), mini-sprinkler irrigation system in direct seeded rice with 1/3rd wheat residue (SPRL-DSR+R), surface irrigation in direct seeded rice (SUR-DSR), and surface irrigation in puddle transplanted rice (SUR-TPR), were laid out in randomized complete block design with four replications. The DSR was done under reduced tillage, i.e. ploughing the field twice, once using disc harrow, once using power tiller and then planking while transplanting was done after ploughing the fields four times (two with disc harrow and 2 with cultivator),

followed by planking. Under puddle transplanted rice, transplanting of 25 days old seedlings was done in well puddled soil. The rice cv. Arize 6129 was direct seeded in first week of June with seed rate of 25 kg/ha using zero seed drill machine. Transplanting was done in first week of July with spacing of 15 × 15 cm. 1/3rd wheat residue was incorporated with disc harrow 3 weeks before sowing of rice (SPRL-DSR+R), while it was totally removed from other plots.

Fertilizer dose of 150 kg N, 60 kg P, 40 kg K, and 30 kg Zn through urea, diammonium phosphate muriate of potash and zinc sulphate, respectively, was applied to rice each year. In puddle transplanted rice, one-third of N and full dose of P and K was applied as basal dose. Rest two-third N was applied in 2-equal splits, in 3rd and 6th weeks after transplanting. In DSR, full dose of P and K was applied basally and N was applied in three equal splits at 20, 40, and 60 days after sowing. In addition, ferrous sulphate (FeSO₄·7H₂O) @ 7 kg ha⁻¹ was also top dressed in DSR to check iron deficiency. In mini-sprinkler irrigation, full dose of P and K was applied basally and nitrogen was applied based on leaf color chart (LCC) reading throughout crop season. The N was applied through fertigation @6 kg ha⁻¹ at the time of irrigation.

Weeds in puddle transplanted rice were managed using butachlor 1.25 kg/ha at 25 days after sowing (DAS). In DSR, weeds were managed with sequential application of pendimethalin 1.0 kg/ha as pre-emergence followed by bispyribac-Na 25 g/ha at 25 DAS. In puddle transplanted rice, submergence conditions were maintained for first 20 days and after that 7.5 cm irrigation water was applied at 1 day after disappearance of ponded water (DADPW). In SUR-DSR, irrigation was scheduled at 5 DADPW when soil surface looks dry with small cracks. In mini-sprinkler irrigation system in DSR, irrigation water was computed (m³) as depth of water equals to cumulative pan evaporation (CPE) of two days and applied on alternate day.

The irrigation water was measured in surface irrigation method using Parshall flume, while in mini sprinkler it was measured by using water meter. The water applied during the season was used for computation of water productivity in respective treatments.

The crop water productivity (CWP), grain water productivity (GWP), and nitrogen use efficiency (NUE) of different treatments computed using the following equations.

$$\text{CWP (kg/m}^3\text{)} = \frac{\text{Biological yield (kg/ha)}}{\text{Total irrigation water applied (m}^3\text{/ha)}} \quad (1)$$

$$\text{GWP (kg/m}^3\text{)} = \frac{\text{Grain yield (kg/ha)}}{\text{Total irrigation water applied (m}^3\text{/ha)}} \quad (2)$$

$$\text{NUE (kg grain/kg N)} = \frac{\text{Grain yield (kg/ha)}}{\text{Total nitrogen (kg/ha)}} \quad (3)$$

Mini-sprinkler with wetted radius of 10.0 m and flow rate of 434 l/h was operated at 2.0 kg/cm² operating pressure. Nozzles were mounted on risers at 1.30 m height. The lateral

Table 1 Chemical and physical characteristics of soil of the experimental site in 2012

Soil property	Depth (cm)	
	0-15	15-30
pH (1:2)	7.82	7.65
EC (dS/m) (1:2)	0.25	0.26
Organic carbon (%)	0.75	0.62
Texture	Sandy clay loam	Sandy clay loam
Available N (kg/ha)	94.9	82.9
Available P (kg/ha)	34.8	12.2
Available K (kg/ha)	257.3	234.1
Bulk density (g/cm ³)	1.50	1.53
Infiltration rate (mm/hr.)	3.5	

and nozzles were placed at 10 m interval. The uniformity of water distribution in mini sprinkler system was > 85%.

Production cost, gross return, and net return of produce for different irrigation systems were estimated with the assumption that the salvage value of the different components of irrigation systems will be zero after their useful life. The useful life of the mini-sprinkler irrigation system was assumed to be 10 years. The annual fixed costs were calculated using the approach of James and Lee (1971) as given below:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

where, CRF = capital recovery factor, i = interest rate (fraction) at 9%, n = useful life of the component (yr). Annual fixed cost/ha was estimated by multiplying CRF by fixed cost/ha. The operating cost included labour charges (system installation and agronomic practices such as tillage operations, irrigation, application of fertilizers and chemicals, harvesting and threshing, etc.), diesel fuel, fertilizers and chemicals, electricity charges, repair and maintenance. The gross return was calculated considering the economic yield and minimum support price of rice in that particular year.

All the data were analyzed using analysis of variance (ANOVA) as applicable to randomized complete block design using SAS 9.4 (SAS Institute 2004). Treatment means were compared at 5% level of significance.

RESULTS AND DISCUSSION

Irrigation water applied

The irrigation water (IW) applied in different treatments varied largely across the years mainly due to variation

Table 2 Effect of different crop establishment technique and irrigation methods on irrigation water applied in rice crop

Treatment	Irrigation water applied (mm)					% saving of IW
	2012	2013	2014	2015	Mean	
SPRL-DSR	670	320	620	330	485	52.8
SPRL-DSR+R	670	320	620	330	485	52.8
SUR-DSR	750	500	800	560	653	36.5
SUR-TPR	1320	880	1130	780	1028	0.0

in rainfall occurred. However, irrigation method and establishment techniques also had significant effect on irrigation water requirement of rice. The IW in SUR-TPR varied from 780 mm in 2015 to 1320 mm in 2012 (Table 2 and Fig 1), while in SUR-DSR, IW varied from 500 mm in 2013 to 800 mm in 2014. The IW in SPRL-DSR showed maximum variation, from 320 mm in 2013 to 670 mm in 2012. The same volume of irrigation water was applied in SPRL-DSR and SPRL-DSR+R because a criterion for scheduling irrigation was similar, i.e. based on climatic demand in both the treatments.

The applied IW in mini-sprinkler was 49.2 and 10.7% lower than SUR-TPR (1320 mm) and SUR-DSR (750 mm), respectively in 2012. Following similar trend, water saving in SPRL-DSR was 63.6, 45.1, and 57.7% compared to SUR-TPR and 36.0, 22.5, and 41.1% compared to SUR-DSR during 2013, 2014, and 2015, respectively. Averaged across four years, overall water saving in SPRL-DSR was 52.8% as compared to SUR-TPR. However, SUR-DSR also consumed 36.5% less water as compared to SUR-TPR. The higher water application efficiency in mini sprinkler reduced water losses from the field and resulted into less IW requirement. The less IW requirement in DSR as compared to TPR was attributed to reduced deep drainage, seepage

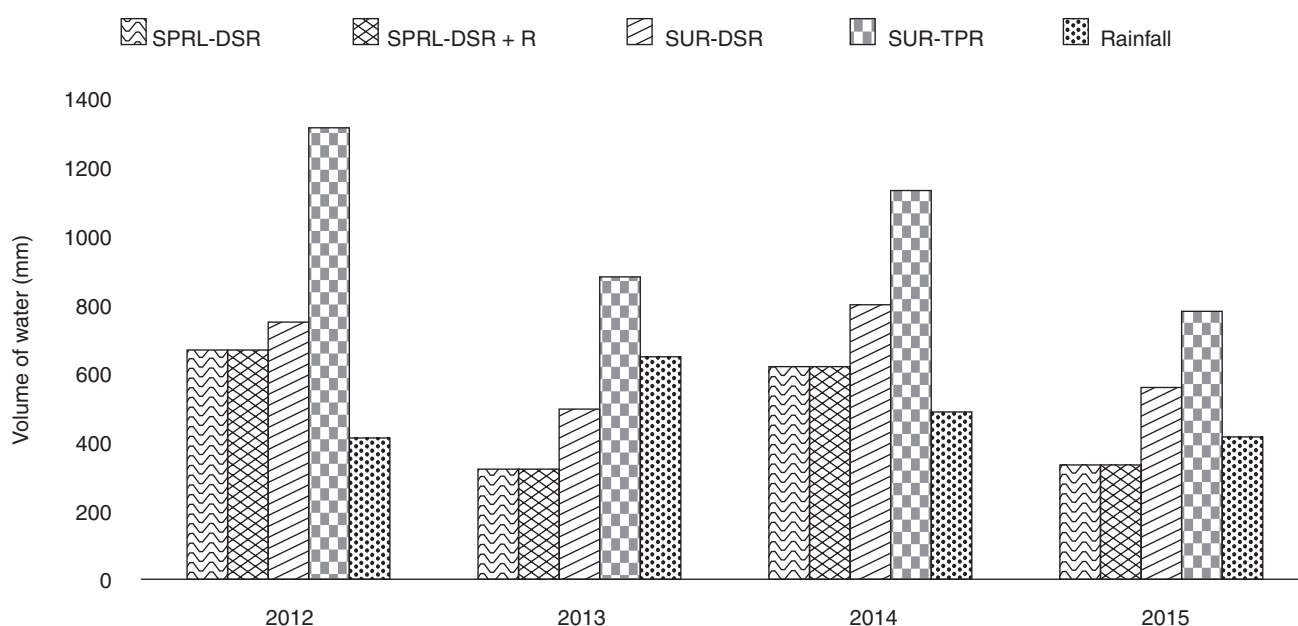


Fig 1 Irrigation water applied in different treatments and rainfall received during crop growing season.

Table 3 Effect of different crop establishment technique and irrigation methods on yield attributes and grain yield of rice (pooled data of four years)

Treatment	Effective tillers/m.r.l.	Grains/panicle	1000 grain wt. (g)	Grain yield (t/ha)
SPRL-DSR	57.4b	121.5b	24.44d	6.84c
SPRL-DSR+R	55.7b	118.5b	24.90c	6.75c
SUR-DSR	60.9a	124.7b	25.30b	7.13b
SUR-TPR	49.6c	138.5a	26.69a	7.46a

* Means followed by different lowercase letters within a column are significantly different according to LSD (P=0.05) test.

and runoff losses than surface irrigation method (Kumar *et al.* 2019).

Rice yield attributes and grain yield

The effect of different irrigation methods and crop establishment techniques was significant on grain yield, effective tillers/m.r.l., grains/panicle, and 1000-grain weight (Table 3).

The maximum number of effective tillers/m.r.l. was recorded under SUR-DSR(60.9) followed by SPRL-DSR, and SPRL-DSR+R while minimum was in SUR-TPR. This was due to higher plant population in DSR as compared to TPR (Nawaz *et al.* 2017). However, the lower number of grains/panicle and 1000-grain weight was recorded in DSR irrespective of irrigation methods as compared to SUR-TPR. This was due to the fact that more competition for light and nutrients and a lower photosynthetic rate might have resulted into lesser number of grains/panicle, higher spikelet sterility, and lower test weight in DSR as compared to TPR. The finding is in accordance of Akhgari and Kaviani (2011) who reported higher number of grains/panicle with more 1000-grain weight under TPR as compared to DSR. Based on pooled data of four years, the grain yield of rice was significantly highest under SUR-TPR followed by SUR-DSR and SPRL-DSR, respectively. The grain yield in SUR-TPR was ~9.5, 8.3, and 4.4% higher than SPRL-DSR+R, SPRL-DSR, and SUR-DSR, respectively. The lowest grain yield was recorded in SPRL-DSR+R (6.75 t/ha) at par with SPRL-DSR. The highest grain yield in SUR-TPR can be attributed to proportionally higher number of

grains/panicle and 1000-grain weight which compensated the lower number of effective tillers in this treatment. Similar observation was reported by Kumar *et al.* (2019) for rice crop.

Water productivity

The crop water productivity (CWP) and grain water productivity (GWP) were estimated to assess the performance of irrigation systems in terms of production per unit volume of IW. In all four years of experimentation, the crop water productivity (CWP) was found to be the highest in SPRL-DSR which was at par with SPRL-DSR+R, but significantly higher than SUR-TPR and SUR-DSR (Table 4). The CWP in SPRL-DSR ranged from 2.38 to 4.68 kg/m³ while under SPRL-DSR+R and SUR-DSR, it varied from 2.33-4.69 and 1.92-3.10 kg/m³, respectively during 2012-2015. The significantly lowest CWP was computed in SUR-TPR (1.42-2.04 kg/m³). The significantly higher CWP in SPRL-DSR than SUR-TPR was due to marked difference in irrigation water applied. In SPRL-DSR, about 52.8% less water was applied as compared to SUR-TPR.

The grain water productivity (GWP) also followed the similar trend that of CWP. The highest GWP was recorded in SPRL-DSR (1.04-2.16 kg/m³), which was closely followed by SPRL-DSR+R (1.01-2.10 kg/m³), but that was significantly higher than SUR-TPR (0.62-0.92 kg/m³). The highest GWP in SPRL-DSR was due to the fact that reduction in IW was higher (52.8%) as compared to grain yield (8.4%) in SPRL-DSR as compared to SUR-TPR. Kahlown *et al.* (2007) also reported higher GWP under sprinkler irrigation system in rice crop. However, higher GWP was recorded in all treatments in year 2013 and 2015. This was due to the fact that higher effective rainfall (143 in 2013 and 141 mm in 2015) resulted into lower demand of irrigation water for crop raising.

Nitrogen use efficiency

Averaged over four years, total nitrogen applied in rice crop under mini-sprinkler and surface irrigation treatment was 110 and 150 kg/ha, respectively (Table 5). Fertigation through mini-sprinkler saved 26.7% nitrogen compared to top dress application in SUR-TPR and SUR-DSR. Kumar *et al.* (2006) also observed higher nutrient use efficiency in drip fertigation of potato. The nitrogen

Table 4 Crop water productivity (CWP), and grain water productivity (GWP) under different crop establishment technique and irrigation methods in rice (Pooled data of four years)

Treatment	2012		2013		2014		2015	
	CWP (kg/m ³)	GWP (kg/m ³)	CWP (kg/m ³)	GWP (kg/m ³)	CWP (kg/m ³)	GWP (kg/m ³)	CWP (kg/m ³)	GWP (kg/m ³)
SPRL-DSR	2.38a	1.04a	4.74a	2.16a	4.68a	1.08a	4.55a	2.06a
SPRL-DSR+R	2.33ab	1.01a	4.67a	2.10a	4.69a	1.10a	4.51a	2.04a
SUR-DSR	2.20b	1.00a	3.10b	1.45b	1.92b	0.89b	2.67b	1.19b
SUR-TPR	1.43c	0.62b	1.81c	0.82c	1.42c	0.65c	2.04c	0.92c

* Means followed by different lowercase letters within a column are significantly different according to LSD (P=0.05) test.

Table 5 Effect of different crop establishment technique and irrigation methods on irrigation water applied, nitrogen applied, and nitrogen use efficiency in rice crop (pooled data of four years)

Treatment	Nitrogen applied (kg/ha)	% saving of nitrogen	NUE (kg grain/kg N)
SPRL-DSR	110	26.7	62.2
SPRL-DSR+R	110	26.7	61.4
SUR-DSR	150	0.0	47.5
SUR-TPR	150	0.0	49.7

use efficiency (NUE) was almost similar in mini-sprinkler treatments (61.4 and 62.2 kg grain/kg N in SPRL-DSR and SPRL-DSR+R, respectively), while much higher compared to surface irrigation treatments (47.5 and 49.7 kg grain/kg N in SUR-DSR and SUR-TPR+R, respectively). This saving in nitrogen with higher NUE under mini-sprinkler system may be due to less volatilization and leaching losses with split application of urea dissolved in water (Kumar, 2015).

Economic analysis

The four-year pooled data on economic analysis revealed that the highest gross return was obtained in SUR-TPR (102.0×10^3 ₹/ha), followed by SUR-DSR (97.4×10^3 ₹/ha), SPRL-DSR (93.5×10^3 ₹/ha), and lowest in SPRL-DSR+R (92.4×10^3 ₹/ha) (Table 6). The highest gross return in SUR-TPR treatment is ascribed to highest grain yield of rice than all other treatments. However, cost of cultivation was maximum in SPRL-DSR+R (46.3×10^3 ₹/ha) closely followed by SPRL-DSR (41.7×10^3 ₹/ha) and SUR-TPR (41.3×10^3 ₹/ha). The minimum cost of cultivation was recorded in SUR-DSR (36.5×10^3 ₹/ha). The higher cost of cultivation in SPRL-DSR+R was due to cost incurred in installation of mini-sprinkler irrigation system and cost of wheat residue and its incorporation. Price of wheat residue left in the field and its incorporation in SPRL-DSR+R accounted for additional cultivation cost by 4.65×10^3 ₹/ha compared to SPRL-DSR. The higher cost of cultivation under SUR-TPR was attributed to more tillage operations which consumed more fuel and labour in manual transplanting of rice seedlings.

The net return was maximum in SUR-DSR (62.7×10^3 ₹/ha) followed by SUR-TPR (60.6×10^3 ₹/ha), and SPRL-DSR (51.9×10^3 ₹/ha). The highest B:C ratio was observed in SUR-DSR (1.81) followed by SUR-TPR (1.47), and SPRL-DSR (1.25). However, the lowest B:C ratio (0.99) was found in SPRL-DSR+R which shows net return of Rs 0.99 against the cost of cultivation of Rs 1. Hence, economic indicators show that all treatments were economically viable.

Conclusion

The mini-sprinkler irrigation system in DSR saved 52.8 and 26.7% irrigation water and nitrogen, respectively as compared to surface irrigated puddle transplanted rice.

Table 6 Economic analysis of different crop establishment technique and irrigation methods in rice crop (data pooled over four years)

Treatment	Gross return ($\times 10^3$ ₹/ha)	Cost of cultivation ($\times 10^3$ ₹/ha)	Net return ($\times 10^3$ ₹/ha)	B:C ratio
SPRL-DSR	93.5	41.7	51.9	1.25
SPRL-DSR+R	92.4	46.3	46.1	0.99
SUR-DSR	97.4	34.7	62.7	1.81
SUR-TPR	102.0	41.3	60.6	1.47

However, grain yield and net return were higher by 0.62 t/ha, and 8.7×10^3 ₹/ha, respectively in surface irrigated puddle transplanted rice (SUR-TPR) than mini-sprinkler irrigated DSR (SPRL-DSR). The benefit- cost (B:C) ratio in SPRL-DSR was 1.25. But, significantly higher crop as well as grain water productivity in mini-sprinkler irrigated DSR suggest that mini-sprinkler system can be an effective intervention for irrigation management in limited water availability regions. Further, study reveals that wheat residue incorporation in mini-sprinkler irrigated rice does not have significant effect on rice grain yield and it is better to remove wheat residue from the field and use elsewhere as fodder etc.

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