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Water saving and productivity benefits of SRI: a study of tank, canal and groundwater irrigated settings in South India

A. Narayanamoorthy* and P. Jothi

Department of Economics and Rural Development, Alagappa University, Karaikudi, Tamil Nadu, India
**Corresponding author. E-mail: narayana64@gmail.com*

Abstract

Paddy, which is predominantly cultivated under the conventional inundation method, is the largest water consuming crop in India. Given looming water scarcity, the inundation method of paddy cultivation is no longer sustainable. A newly introduced method of paddy cultivation, popularly known as the System of Rice Intensification (SRI), is reportedly helping to reduce water consumption and increase land productivity. SRI has now been in practice for some years in India but the various impacts of SRI on water saving, land and water productivity as well as on profitability which are expected to vary in different ecological settings – namely in tank, canal and groundwater irrigated areas – remain largely unexplored. In this study, using data collected from a total sample of 300 farmers from three different settings in Tamil Nadu state, an attempt has been made to fill this gap. The study shows that by adopting the SRI method farmers can save about 40% of irrigation water and increase land productivity by about 46% while reducing the cost of cultivation by 23% over the conventional inundation method. While increasing irrigation water productivity and economic water productivity substantially, SRI also generates an additional profit of Rs 17,169/acre (1 USD = INR 70.12; 1 acre = 4047 m^2) compared to that realised by non-SRI farmers.

Keywords: Indian agriculture; Irrigated settings; Paddy cultivation; SRI; Water productivity; Water saving

Introduction

The major objective of this study was to investigate the impact of the System of Rice Intensification (SRI) on water use and productivity for paddy in three different agro-ecological settings. Although over 80% of the available water in India is currently used for agriculture, looming water scarcity has affected the performance of agriculture in recent years (Saleth & Amarasinghe, 2010; Narayanamoorthy, 2011, 2015; Gulati & Mohan, 2018). Despite investing huge sums of money into surface irrigation development, the country's irrigation coverage has not grown appreciably over the last two decades or so, due to the misappropriation of water by other sectors (Kumar, *et al.*, 2009; Narayanamoorthy, 2013a). At the same time, the groundwater which has supported the agricultural sector in a considerable way since the

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early 1970s has also started showing a decrease in its irrigated area (Narayanamoorthy, 2010; CGWB, 2017). In the meantime, due to fast urban agglomeration and industrial growth, the water originally envisaged for irrigation purposes has been increasingly transferred to non-agricultural use. This competing demand for irrigation water has increased water scarcity more than ever before in India. But, with an increased population and income growth, the demand for food is going to increase considerably in the future (Chand, 2007). Gulati & Mohan (2018, p. 1) rightly surmised that 'with per capita incomes likely to rise by about 6% per annum for the coming decade or so, it is obvious that demand pressures for food, feed and fibre are going to increase in India. Thus, to combat the pressure coming from rising population, increasing purchasing power, urbanisation and industrialisation, there is a need to increase land as well as water productivity in agriculture.'

In view of the increased scarcity of water, many new methods/technologies have been introduced in the agricultural sector to increase the efficiency of water use and to ease water scarcity. Paddy is an important food grain crop which not only consumes a large quantity of water but also uses the water inefficiently. Paddy's contribution to India's agricultural sector is very significant: with a cultivated area of over 44 million hectares, paddy accounted for over 35% of the country's total food grain area and over 23% of the cropped area in 2016–17; production of paddy is now over 105 million tonnes, which is a little less than 50% of India's total food grain production (GOI, 2018). Besides providing livelihood opportunities to millions of farmers, cultivation of paddy directly provides employment opportunities for rural labourers who rely on agriculture for their livelihood. Paddy reportedly consumes 3,000–5,000 litres of water to produce one kg of rice as against the requirement of only 900 litres for wheat; for a recent account of crop wise consumption of water for selected states in India, see Gulati & Mohan (2018). Some estimates suggest that over 60% of water in India is used by paddy and sugarcane, which accounts for only 24% of gross cropped area (Gulati & Mohan, 2018).

To increase water use efficiency in paddy cultivation, a new method – popularly called the System of Rice Intensification (SRI) – was introduced relatively recently. SRI is not a new variety or hybrid but a new method of cultivation, in which a set of innovative principles are followed for cultivating paddy. A note from the World Bank (2008) summarises that six key elements distinguish SRI farming practices from traditional rice growing methods. They are: (a) seedlings are transplanted much earlier than in conventional methods; (b) only one seedling per hill is planted, rather than a handful; (c) plants are spaced wider apart than in conventional methods and arranged in a square pattern; (d) water is applied intermittently instead of by continuous flood irrigation; (e) rotary weeding is used to control weeds and promote soil aeration; and (f) organic fertilisers are applied to enhance soil fertility and yield.

SRI was first developed in the 1980s by Henri de Laulanie, a French priest and farming practitioner living in Madagascar, and developed further in the 1990s by curious farmers, scientists and researchers (Uphoff, 2004; World Bank, 2008). SRI has been proved to increase the yield of paddy significantly with less water, less seed and with less chemical inputs than the conventional method of paddy cultivation (Reddy, *et al*., 2005; WWF, 2007; World Bank, 2008). Using the SRI method of paddy cultivation, countries like India, Indonesia, Cambodia, Vietnam and the Philippines have recorded increases of rice yield from 60% to over 170% (Uphoff, 2003, 2004; World Bank, 2008). Yield increases and other SRI experiences in different countries can also be seen on the SRI website; see: http://ciifad.cornell.edu/sri/.

Considering the benefits of SRI, both central and state governments have introduced various promotional measures including subsidy schemes to widely popularise this method. Some estimates suggest that the area under SRI may now have reached about one million hectares in India (Gujja & Thiyagarajan, 2013). While the area of paddy cultivation using SRI has increased in India, comprehensive studies using farm level data covering different agro-ecological settings are still lacking. The impact of SRI on water use and productivity, etc., is expected to be different when different sources of irrigation water (tank, canal and groundwater) are used for cultivation. This aspect has not been adequately covered by existing studies. How much water is actually saved due to the adoption of SRI? Is the water saving the same across all three settings (i.e. tank, canal and groundwater irrigated areas)? Can SRI increase paddy productivity to be significantly better than its counterpart non-SRI method? What is the level of Irrigation Water Productivity (IWP) in SRI vis-à-vis the non-SRI method? Can the SRI method achieve better results, in terms of economic water productivity (EWP)? Only a few comprehensive studies are available covering all these issues and the present study aims to fill this gap using field data collected from three different settings located in Pudukkottai district of Tamil Nadu State.

Data and method

This study was carried out using field survey data collected from Pudukkottai district in Tamil Nadu State, which is located in the southern part of India. Paddy has traditionally been a major crop in the State and, as of 2015–16, it was grown over an area of 2.04 million hectares in the State, which is almost 5% of India's total paddy area. Different sources of irrigation water (tank, canal and groundwater) are used for cultivating paddy. The impact of the SRI method of paddy cultivation on water use and productivity is expected to be varied under the different settings and therefore the study was carried out in three different locations (with different settings).

It is important to underline that the source of water used for cultivating paddy in the three selected settings is different. Tank irrigated settings get water from small water bodies, which are a traditional source of surface water. Tanks are small in size and their storage levels rely heavily on rainfall. Therefore, scarcity and uncertainty of water supply for the paddy crop are very high in tank irrigated settings. Canal irrigation, another source of surface water, is provided to paddy from water stored by dams/in reservoirs. Though canal irrigation also heavily depends on rainfall levels, the supply of water to crop is relatively assured as the storage capacity of dams is relatively larger. Groundwater irrigation is totally different from the other two sources of water. Groundwater structures are predominantly owned by individual farmers, and water is lifted from tube wells using pumpsets to irrigate paddy and other crops. Since they are owned by farmers, certainty and controllability of water supply to paddy is better in groundwater settings (Dhawan, 1988; Narayanamoorthy, *et al*., 2015). However, in all three sources of irrigation – under both SRI and non-SRI methods – water is supplied to the paddy fields through open channels, where conveyance and distribution losses of water are high. The major difference in water use between SRI and non-SRI methods is that the former follows a dry-wetting irrigation system, while the latter follows the conventional inundation method of irrigation. The key differences between conventional and SRI methods of paddy cultivation are presented in Table 1.

Although paddy has been cultivated as a major crop in most districts in Tamil Nadu State (see www.tn.gov.in/dear/), Pudukkottai district was selected deliberately as it satisfied all three criteria fixed for the selection of the study area: (1) cultivation of paddy in large area; (2) prevalence of severe water scarcity; and (3) SRI method must be practised in all three settings, namely tank, canal and groundwater irrigated areas. A total of 100 farmers were selected for the study in each of the three settings (50 using the SRI method and 50 the conventional non-SRI method) – thus 300 sample farmers in all – from whom field data were collected pertaining to the samba crop in the kharif season 2011–12.

Table 1. Key differences in management practices between conventional and SRI methods.

Operation	Conventional method	SRI method
1. Seed	50–60 kg/hectare	5 kg/hectare
2. Transplanting	Seedlings of about 30 days old	Seedlings of about 8–12 days old
3. Number of seedlings/hill	Generally, three or more seedlings are planted	Only one seedling is planted
4. Application of fertilisers	Application of chemical fertilisers, pesticides, herbicides and insecticides are followed	Preference given to organic fertilisers and non-chemical means of weed control; pesticides, insecticides usually not necessary
5. Weed management	Weeds are removed from field two–three times using human labour	Weeds are turned down into the field by a weeder or cono-weeder.
6. Water management	Continuous flooding, over-irrigation, low level of water use efficiency	An alternate dry-wetting irrigation system is followed, with a high level of water use efficiency

Source: reconstructed from WWF (2007).

SRI is a newly introduced method of paddy cultivation and its spread has not been uniform across the district. Therefore, detailed discussions were made with officials of the Agricultural Department of Pudukkottai district to identify suitable locations for carrying out the field survey. Accordingly, Thirumayam *taluka* was selected as the tank irrigated setting while Alangudi *taluka* was chosen as the groundwater irrigated setting. As the spread of the SRI method in a canal irrigated area has been very thin, both Aranthangi and Avudaiyarkoil *talukas* were selected for the canal irrigated setting. A purposive sampling method was used to select sample farmers because the spread of adoption of the SRI method is very limited in each village. SRI farmers were identified in each selected location with the help of the Agricultural Officer of the respective *taluka*. Soil and other locational factors play a considerable role in determining the water use and productivity of crops. In view of this, farmers who cultivate paddy using the conventional method very close to the field using the SRI method were selected as non-adopters of SRI.

Measuring water consumption in farmers' fields is very difficult when different sources of water are used under the flood method of irrigation. Farmers have an enormous amount of practical knowledge on using water for crop cultivation. Given this, to measure water consumption in a standardised way, the sample farmers were asked to provide data equivalent to Horse Power Hours of Water (HPHW) for each turn of irrigation. After obtaining water consumption details, the total HPHW per acre (4,047 m^2) was computed by multiplying the number of irrigations by the hours of water used for each turn of irrigation.

One of the major advantages of the SRI method is that it can increase paddy productivity significantly when compared to the same cultivated area under the conventional method. In order to study the impact of the SRI method on paddy productivity more precisely, multiple regression analysis was carried out. The variables used in the regression model were: age of the farmers (AGE), education (EDU), farming experience of farmer (FEF), fertiliser cost (FER), farmyard manure cost (FYM), pesticide cost (PST), weeding and interculture cost (WAI), irrigation application cost (IRR), machinery cost for field preparation (MCF) and a dummy variable representing the method of paddy cultivation (MCD). As the study was carried out at three different locations with three different sources of irrigation, multiple regressions were estimated separately for each source of irrigation and also combining all the three sources of irrigation. The reduced form of the regression model used in the analysis is as follows:

$$\begin{aligned} \text{PoP} &= \text{a} + \text{b}_1 \text{ AGE} + \text{b}_2 \text{ EDU} + \text{b}_3 \text{ FEF} + \text{b}_4 \text{ FER} + \text{b}_5 \text{ FYM} + \\ &\quad \text{b}_6\text{PST} + \text{b}_7 \text{ WAI} + \text{b}_8 \text{ IRR} + \text{b}_9 \text{ MCF} + \text{b}_{10} \text{ MCD} + \text{u} \end{aligned} \tag{1}$$

where:

PoP = Productivity of paddy (kg/acre)
AGE = Age of farmers (Years)
EDU = Education of farmers (Years)
FEF = Farming experience of farmers (Years)
FER = Fertiliser cost (Rs/acre)
FYM = Farmyard manure cost (Rs/acre)
PST = Pesticides cost (Rs/acre)
WAI = Weeding and interculture cost (Rs/acre)
IRR = Irrigation cost (Rs/acre)
MCF = Machinery cost for field preparation (Rs/acre)
MCD = Dummy variable to represent method of cultivation (SRI = 1; non-SRI = 0)
a = constant
b = Regression coefficients to be estimated
u = error term

As the major objective of the study was to capture the impact of the SRI method on water use and paddy productivity, a comparison was made between SRI and non-SRI farmers in all parameters.

Results and discussion

Water consumption

Widespread water scarcity has created a great many constraints on the farming sector in recent years and this is expected to be aggravated further due to climate change and other reasons (MoF, 2018). To tackle the issue of water scarcity, many new practices/methods have been introduced. As reported above, some earlier studies have shown that the SRI method can save a considerable amount of irrigation water, while increasing paddy productivity. However, existing studies seem not to have analysed the pattern of water use (number of irrigations) and the amount of water used in paddy crops cultivated using different sources of water (namely tank, canal and groundwater). The pattern of water use is expected to be varied from source to source – because of the uncertainty of water availability, tank irrigation is expected to be totally different from canal and groundwater (Dhawan, 1988; Narayanamoorthy, *et al.*, 2015). Given this, an analysis of the pattern of water use in paddy crops under different sources of water is needed to find out the real impact of the SRI method on water saving.

Table 2 clearly shows that the pattern of water use under the SRI method is totally different from that of the non-SRI method of paddy cultivation for all the three settings. The average number of irrigations

Table 2. Pattern of water use under SRI and non-SRI methods of paddy cultivation.

	TIA		CIA		GIA		ASA	
Details	CM	SRI	CM	SRI	CM	SRI	CM	SRI
1 Number of irrigations/acre	16.70 (4.85)	14.70 (3.57)	13.22 (1.94)	9.76 (1.17)	18.54 (2.95)	22.62 (4.79)	16.15 (3.25)	15.69 (3.18)
2 Hours of irrigation for each turn/acre	8.14 (2.28)	5.32 (1.30)	9.20 (1.48)	8.20 (1.01)	6.92 (1.56)	3.06 (0.47)	8.09 (1.77)	5.53 (0.93)
3 Total hours of water used/acre (standardised to HP hours)	635.70 (68.88)	372.00 (40.37)	594.40 (17.92)	396.20 (37.41)	624.90 (105.33)	338.40 (49.77)	618.33 (74.98)	368.87 (48.75)
4 Percentage of water saved over CM	−41.48		−33.34		−45.84		−40.34	

Source: computed using field survey data.

Notes: TIA, Tank irrigated area; CIA, Canal irrigated area; GIA, Groundwater irrigated area; ASA, All settings average; CM, Conventional method; SRI, System of rice intensification. Figures in parentheses indicate Standard Deviation.

used per acre by SRI farmers (15.69 times) is less than that of their counterpart non-SRI farmers (16.15 times). However, SRI farmers in a groundwater area used relatively higher number of irrigation than non-SRI farmers did because of the increased availability of water there, compared to the other two settings where water scarcity is common. Although we do not see any consistent differences in the number of irrigations used across all three settings, there are differences in the hours of irrigation (standardised in terms of 5 HP pumpsets) used for each irrigation turn between the SRI and non-SRI methods. SRI farmers (in all three settings) used 5.53 hours of irrigation water for each turn of irrigation, whereas non-SRI farmers used 8.09 hours for each turn, per acre. This means that, on average, SRI farmers used about 32% fewer irrigation hours than non-SRI farmers per acre of paddy. While this is true across all three settings, SRI farmers belonging to a groundwater area used much fewer hours of irrigation for each turn, compared to non-SRI farmers. Since water availability is assured for well water irrigated farmers, they just have to provide dry-wetting irrigation for paddy crops, as advocated by agricultural department officials. But this is not strictly followed in tank and canal irrigated areas, where farmers allow more than dry-wetting irrigation because of the uncertainty of getting a next turn of irrigation water. This means that the water used for each turn of irrigation, even under the SRI method of paddy cultivation, varies considerably across different sources of water.

As a result of using less water for each turn, the total number of hours of water used per acre (standardised HP hours of water) under the SRI method was found to be substantially lower than for non-SRI paddy in all the three settings. The estimated total water used by SRI farmers was about 369 HP hours/acre, whereas it was about 618 HP hours/acre for non-SRI farmers, showing a saving of about 40% of water for SRI farmers over non-SRI farmers. This same trend was found across all the three settings (see Figure 1). However, water saving due to the SRI method was found to be relatively higher in groundwater areas (about 45%) and lower in the canal irrigated area (about 33%). There are reasons for this variation: water availability is assured in the groundwater irrigated area and, therefore, farmers were able to control the water supply by strictly following a dry-wetting irrigation system, allowing the farmers cultivating SRI paddy to save a substantial amount of water. This was not possible in the canal irrigated area where water control is not in the hands of farmers and, therefore, they tend to over-irrigate the crop as and when water is available to them.

In addition to descriptive analysis, to exactly measure the impact SRI method on the use of water, a simple regression (OLS method) analysis was also carried out treating HPHW per acre as dependent

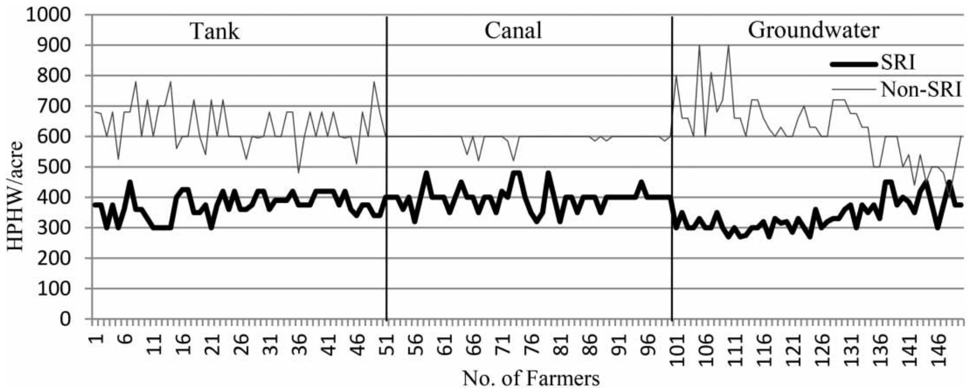

Fig. 1. Water use in SRI and non-SRI paddy.

variable and MCD (SRI = 1 and non-SRI = 0) as an explanatory variable (HPHW = a + b_1MCD + *u*). The regression results presented in Table 3 suggest that when farmers shift from the conventional method of paddy cultivation to the SRI method, they could save about 250 HP hours of water when all the three settings are considered for the analysis. Further, the estimated regression coefficients also show that, of the three settings, farmers from a groundwater irrigated area are able to save higher amounts of water (about 287 HPHW) than those in the other two settings. The regression results clearly reinforce the findings from the descriptive analysis.

What are the key reasons for the substantial water savings under the SRI method? An in-depth inquiry undertaken with the sample farmers revealed the following results. First, unlike the conventional method of paddy cultivation, inundation with water is not advocated under the SRI method; rather, an alternate wetting and dry method is enough for better crop growth, saving a substantial amount of water as compared to conventional paddy cultivation (WWF, 2007). Second, in-depth and repeated ploughing is not needed for the SRI method, which also saves a substantial amount of water. Third, unlike under the conventional method, watering is undertaken very sparingly during the time of transplanting. Fourth, in order to run a hand-drawn cono-weeder effectively in a paddy field, plain wetting of land is adequate (Uphoff, 2004; Reddy, *et al*., 2005; Palanisami, *et al*., 2013). A cono-weeder is a tool which effectively removes weeds when paddy is cultivated by the SRI method; by moving the tool backwards and forwards at 7–10-day intervals from 15 days after planting the seedlings, weeds are buried and the soil aerated. Operating a cono-weeder repeatedly during the initial period of transplantation of paddy helps increase culm (stem) growth, ultimately also increasing panicle-paddy. Without cono-weeding, paddy productivity under the SRI method is expected to be drastically lower and its use is therefore always recommended. Fifth, the stem growth from transplanted seedlings reduces if too much water is given under the SRI method. Sixth, irrigation under the SRI method is undertaken only to moisten the soil in the early period after transplanting, allowing enormous water savings to be made (Uphoff, 2008; World Bank, 2008). Overall, it is clear that the SRI method of paddy cultivation can save over 40% of water per acre, compared to the conventional paddy cultivation method.

Impact of SRI on productivity

Apart from making an impact on water consumption, SRI also helps substantially increase the crop's productivity – and that too using relatively smaller amounts of inputs (Uphoff, 2004; WWF, 2007). Higher crop productivity is essential for increasing farm income (NITI Aayog, 2015). But, the

Table 3. Impact of SRI on water consumption: regression results.

	HPHW = a + b_1MCD + *u*			
Settings	Constant	Coefficient	R^2	Adjusted R^2
TIA	635.70 (79.62)	−263.70[a] (− 23.35)	0.85	0.85
CIA	594.40 (143.30)	−198.20[a] (− 33.79)	0.92	0.92
GIA	624.90 (53.64)	−286.50[a] (− 17.39)	0.75	0.75
ASA	618.33 (119.75)	−249.47[a] (− 34.16)	0.80	0.80

Source: computed using field survey data.
Notes: [a]Significant at 1% level. HPHW, Horse power hours of water; TIA, Tank irrigated area; CIA, Canal irrigated area; GIA, Groundwater irrigated area; ASA, All settings average. Figures in parentheses are 't' values.

growth in productivity of many crops, including paddy, has not been very appreciable in recent years, despite the increases in cost of cultivation (Narayanamoorthy, 2007, 2013b; Narayanamoorthy & Alli, 2013; Narayanamoorthy & Suresh, 2013; GOI, 2014). The SRI method of paddy cultivation follows new management practices under which an artificial environment is created for the growth of the paddy plant for exploitation of its full genetic potential, as well as of land and water resources, ultimately helping to increase its productivity.

Can the SRI method increase paddy productivity across all sources of irrigation? The survey results presented in Table 4 show that the productivity of paddy cultivated under the SRI method is substantially higher than the conventional method of paddy in all three settings. The overall productivity difference between SRI and non-SRI paddy (computed when including all the three settings) is 46% per acre. The productivity difference was found to be large in groundwater irrigated areas (50.85%) followed by canal (47.62%) and tank irrigated areas (40.90%). This was expected because the productivity of groundwater irrigated paddy is generally higher when compared to the same crop cultivated with canal and tank irrigation, mainly due to the improved certainty and controllability of irrigation; a detailed analysis of the productivity differences by source of irrigation can be found in Dhawan (1988). What is interesting here is that despite using higher inputs and costs of cultivation for non-SRI paddy, the SRI productivity is significantly higher than that of non-SRI paddy. This suggests that the new practices followed for the SRI method might have helped to harvest a higher yield over conventional paddy cultivation.

There are many reasons for the increased productivity of paddy cultivated by the SRI method (Uphoff, 2004, 2008; Reddy, *et al*., 2005; Prasad, 2006; Palanisami, *et al*., 2013). First, the square planting with wider spacing at 25 cm × 25 cm rather than in clumps of seedlings helps to increase the number of branches from each paddy seedlings. Second, young 12–15-day old paddy seedlings at the two–three leaf stage have a great potential for profuse tiller and root development which ultimately results in increased yield. Third, the alternate wetting and dry method of irrigation allows the paddy plant roots to grow healthily and deeply in all directions. Extended root growth also takes place due to the wide spacing followed during transplanting. Fourth, since fields are intermittently irrigated and dried, microorganisms grow well which makes nutrients available to the paddy plants, helping to increase the growth and crop yield. Fifth, the cono-weeders used to remove weeds from the field also add organic matter by incorporating the weed plants into the soil. Sixth, as a result of the better growth of the paddy

Table 4. Productivity of paddy under the SRI and non-SRI methods (quintal/acre).

Sl. no.	Setting	CM	SRI	Increase over CM	
				Quintals[a]	%
1	TIA	16.60 (2.86)	23.39 (3.25)	6.79	40.90
2	CIA	16.99 (1.52)	25.08 (1.52)	8.09	47.62
3	GIA	16.42 (2.19)	24.77 (3.18)	8.35	50.85
4	ASA	16.67 (2.25)	24.41 (2.85)	7.74	46.43

Source: computed using field survey data.
Notes: [a]1 quintal = 100 kg. TIA, Tank irrigated area; CIA, Canal irrigated area; GIA, Groundwater irrigated area; ASA, All settings average; CM, Conventional method; SRI, System of rice intensification. Figures in parentheses indicate Standard Deviation.

plants, the number of panicles per plant, the number of grains/panicle, the length of panicles and the number of filled grains per panicle are much higher than can normally be obtained from the conventional method of paddy cultivation.

SRI and the productivity nexus: regression analysis

To what extent can SRI influence paddy productivity? To study this, a multiple regression (OLS method) analysis was carried out using the variables specified in Equation (1). It was expected that all the ten independent variables included in the regression model would, in one way or the other, influence paddy productivity. The influence of the SRI method was expected to be varied under different settings. Therefore, regression analysis was undertaken separately for each setting and also together, including samples for all three settings. The regression results presented in Table 5 show that the value of adjusted R^2 estimated using the data from the three different settings varies from 0.60 to 0.88, suggesting that the variables included in the model seem to be appropriate in explaining the variation in paddy productivity.

The regression analysis shows that, except for the MCD variable, none of the other variables included in the model consistently and significantly influenced paddy productivity in all three settings. This means that the influence of human resource variables, yield enhancing input costs and other input costs used for paddy cultivation did not make a significant difference in productivity between the SRI and non-SRI methods of cultivation. However, the dummy variable coefficient included reflecting the method of paddy cultivation (MCD) turned out to be consistently significant in all three settings, which was expected. Within the three settings, the influence of the SRI method on productivity appears to be relatively higher in the canal irrigated area, followed by in the groundwater and tank irrigated areas. For instance, the regression coefficient of MCD pertaining to the canal irrigated area demonstrates that paddy productivity can be increased by about 883 kg/acre when a farmer shifts their method of paddy cultivation to SRI from non-SRI. But, the same influence of shifting to the SRI method comes to about 790 kg for a tank irrigated farmer and about 753 kg for a groundwater irrigated farmer. Many farmers following the SRI method of paddy cultivation in a canal irrigated area harvested much higher yields than non-SRI farmers. Notwithstanding the variation across the three settings, the regression analysis on the whole clearly confirms the significant influence of the SRI method on paddy productivity.

Water and economic productivity

Increasing land productivity of paddy is no longer sustainable and profitable given the fast decline of irrigation water availability. Therefore, an increased thrust has been given to augmenting the water productivity and economic productivity of crops that are water guzzling (such as paddy, sugarcane and banana) in recent years (Kumar, 2005; Saleth, 2009). Paddy grown under the SRI method has been proved to increase land productivity substantially while also reducing water consumption, which is also reinforced by the present study. But, can the SRI method be used to increase water productivity and economic productivity? In order to study this question, both water and economic productivity for the SRI and non-SRI methods of paddy were calculated. Irrigation Water Productivity (IWP) was estimated by dividing the yield of paddy per acre by the HP hours of water consumption, and Economic

Table 5. Factors contributing to productivity of paddy: regression results.

			Dependent variable: productivity (kg/acre)			
Variables	Description of the variables	Unit	TIA	CIA	GIA	ASA
AGE	Age of farmers	Years	1.98^{ns} (0.52)	0.99^{ns} (0.32)	-0.01^{ns} (−0.00)	2.43^{ns} (1.02)
EDU	Education of farmers	Years	14.57^{b} (2.00)	-0.04^{ns} (−0.01)	-2.84^{ns} (−0.25)	9.44^{b} (2.22)
FEE	Farming experience of farmers	Years	0.67^{ns} (0.21)	-2.28^{ns} (−0.93)	-1.54^{ns} (−0.26)	-0.61^{ns} (−0.29)
FER	Fertiliser cost	Rs/acre	-0.09^{d} (−1.39)	-0.01^{ns} (−0.21)	0.05^{ns} (0.56)	0.02^{ns} (0.53)
FYM	Farmyard manure cost	Rs/acre	0.12^{c} (1.97)	0.02^{ns} (0.66)	0.00^{ns} (0.09)	0.02^{ns} (0.94)
PST	Pesticide cost	Rs/acre	0.33^{b} (2.07)	0.14^{b} (2.42)	-0.37^{a} (−2.83)	-0.01^{ns} (−0.28)
WAI	Weeding and interculture costs	Rs/acre	0.12^{b} (2.24)	0.05^{c} (1.75)	0.03^{ns} (0.38)	0.03^{d} (1.44)
IRR	Irrigation cost	Rs/acre	-0.03^{ns} (−0.50)	-0.03^{ns} (−0.46)	-0.07^{ns} (−0.74)	-0.07^{b} (−1.98)
MCF	Machinery cost for field preparation	Rs/acre	0.07^{ns} (0.96)	-0.07^{d} (−1.56)	0.03^{ns} (0.44)	-0.00^{ns} (−0.09)
MCD	Dummy variable: SRI = 1 and Non-SRI = 0	–	790.20^{a} (6.94)	883.00^{a} (9.26)	753.61^{a} (5.89)	731.53^{a} (13.02)
	Constant	–	565.71^{a} (1.22)	$1,683.94^{a}$ (4.91)	$1,906.89^{a}$ (3.53)	$1,478.90^{a}$ (6.66)
	R^2	–	0.64	0.90	0.74	0.71
	Adjusted R^2	–	0.60	0.88	0.71	0.70
	F-Value	–	16.08	77.38	24.75	70.94
	D-W	–	1.54	2.16	1.72	1.54
	N	–	100	100	100	300

Source: computed using field survey data.

Notes: ^{a}, ^{b}, ^{c} and ^{d} are significant at 1%, 5%, 10% and 20% levels, respectively; ns: not significant; figures in parentheses are 't' values.

TIA, Tank irrigated area; CIA, Canal irrigated area; GIA, Groundwater irrigated area; ASA, All settings average; CM, Conventional method; SRI, System of rice intensification.

Water Productivity (EWP) was worked out by dividing the value of output (VOP; in Rupees) per acre by the HP hours of water consumption.

As expected, it is clearly evident from Table 6 that both the IWP and EWP for paddy cultivated under the SRI method are substantially higher than for the non-SRI method. The IWP computed taking all three settings into account comes to 6.62 kg for the SRI method, whereas the same comes to only 2.70 kg for the non-SRI method, which is a difference of about 145%. Similarly, the overall EWP comes to about Rs 108 for the SRI method, but is only about Rs 45 for the non-SRI method. That is, the SRI method allows farmers to realise about 140% higher EWP over the non-SRI method. Farmers cultivating paddy under the SRI method in a groundwater irrigated area seem to be more efficient in terms of IWP and EWP than farmers belonging to tank and canal irrigated areas. This was expected because both water saving and paddy productivity are relatively higher for those farmers who have adopted the SRI method in a groundwater irrigated setting. While the variation in IWP and EWP was expected across the three selected settings for agro-ecological reasons, the results of the present study clearly suggest that the SRI method can be a viable option to increase water and economic productivity.

Profitability of SRI and non-SRI paddy

Farmers would not adopt a new method/technology of crop cultivation if it was not economically viable for them. If a new technology/method helps to save only water without increasing yield or the value of output in crop cultivation, then that technology would not be adopted extensively. Similarly, if a crop technology promotes only resource conservation without augmenting productivity, then it would not get an adequate response from farmers. Therefore, after studying water and productivity, an attempt has been made to study whether the SRI method of paddy cultivation is more profitable for farmers than non-SRI paddy.

The Government of India's Commission for Agricultural Costs and Prices (CACP) uses nine different cost concepts to compute cost and income for different crops (CACP, 2013). These are: Cost A1 = All actual expenses in cash and kind incurred in production by owner; Cost A2 = Cost A1 + rent paid for leased-in land; Cost A2 + Family Labour = Cost A2 + imputed value of family labour; Cost B1 = Cost A1 + interest on value of owned capital assets (excluding land); Cost B2 = Cost B1 + rental value of owned land (net of land revenue) and rent paid for leased-in land; Cost C1 = Cost B1+ imputed

Table 6. Water and economic productivity of SRI and non-SRI paddy.

	Irrigation water productivity (Kg/HP hours of water consumption)			Economic water productivity (Rs/HP hours of water consumption)		
Settings	CM	SRI	% over CM	CM	SRI	% over CM
TIA	2.61	6.29	140.82	41.73	97.54	133.76
CIA	2.86	6.33	121.44	51.80	110.76	113.81
GIA	2.63	7.32	178.61	43.08	117.12	171.84
ASA	2.70	6.62	145.51	45.41	108.26	138.39

Source: computed using field survey data.
Notes: TIA, Tank irrigated area; CIA, Canal irrigated area; GIA, Groundwater irrigated area; ASA, All settings average; CM, Conventional method; SRI, System of rice intensification.

value of family labour; Cost C2 = Cost B2 + imputed value of family labour; Cost C2* = Cost C2 estimated by taking into account statutory minimum or actual wage, whichever is higher; Cost C3 = Cost C2* +10% of cost C2* on account of managerial functions performed by the farmer. In this study, the profit was calculated by deducting the value of output from the cost of cultivation (cost A2 + FL) and it should therefore perhaps ideally be referred to as farm business income instead of profit. The value of output (VOP) was computed by multiplying paddy productivity by its price (per quintal = 100 kg) received by the sample farmers.

Results presented in Table 7 show that the value of output and the profit obtained by SRI farmers is substantially higher than that achieved by non-SRI farmers in all the three settings. The average profit of all three settings comes to about Rs 21,738/acre for SRI paddy, but it is only about Rs 4,569/acre for non-SRI paddy, indicating a difference of about 376% between the two methods. This means that by adopting the SRI method, farmers are able to generate an additional profit of Rs17,169/acre over the conventional method of paddy cultivation. Among the three settings, the difference in profitability in absolute terms is relatively higher in the canal irrigated area (about Rs18,712) and lowest in the tank irrigated area (about Rs 15,158). But, the difference in profitability in terms of percentage is higher in the tank irrigated area (about 781%) and the lowest is observed in the canal irrigated area (about 197%). These variations occurred mainly because of differences in cost of cultivation and paddy productivity among the three settings selected for analysis. The relatively reduced cost of cultivation and increased productivity have helped SRI farmers to realise significantly higher profits over that realised by non-SRI method farmers.

Conclusion

Paddy, a water-intensive crop, is predominantly cultivated under the inundation method throughout India. But, due to reduced water availability, farmers are no longer able to cultivate paddy with profitability as in the past. In view of looming water scarcity, the SRI method of paddy cultivation was introduced relatively recently in India to reduce the consumption of water and to increase the productivity and profitability of paddy. In this study, an attempt was made to study the impact of the adoption of the SRI method on the water consumption and productivity of crops covering three different agro-ecological settings, namely tank, canal and groundwater irrigated areas. This study shows that by adopting the SRI method, farmers can save about 40% of water and increase land productivity by 46% over the conventional method of paddy cultivation, and that too with reduced costs of cultivation. Further, irrigation water productivity and economic water productivity are also found to be significantly higher among farmers adopting the SRI method over those cultivating paddy under the conventional method, across all three settings considered in this study. SRI farmers are able to realise a profit of Rs 21,738/acre, whereas non-SRI farmers realise only Rs 4,569/acre. While the SRI method has significantly benefitted farmers belonging to all the three settings considered for the analysis, farmers from groundwater irrigated areas are able to realise more benefits in terms of water saving, augmented land productivity and water productivity, as well as profitability, than those in the other two settings (namely in tank and canal irrigated areas).

Although the SRI method of paddy cultivation has been proved to generate bundles of economic and resource-related benefits, the spread of the adoption of this new method has not been very appreciable in India, as of today. This study has revealed that even those sample farmers adopting the SRI method have not completely followed all the recommended practices. In fact, most sample farmers have not followed

Table 7. Profitability of paddy cultivated under SRI and non-SRI method, in Rs/acre (1 USD = INR 70.12; 1 acre = 4,047 m^2).

	Cost of cultivation				Value of output				Farm business income			
			Gains over non-SRI				Gains over non-SRI				Gains over non-SRI	
Setting	CM	SRI	Rs	(%)	CM	SRI	Rs	(%)	CM	SRI	Rs	(%)
TIA	24,585 (2,034)	19,187 (1,401)	−5,398	−21.96	26,525 (3,869)	36,284 (5,640)	9,759	36.79	1,940 (3,890)	17,097 (5,668)	15,158	781.48
CIA	21,319 (1,125)	15,699 (1,297)	−5,620	−26.36	30,792 (2,760)	43,884 (2,377)	13,092	42.52	9,473 (2,730)	28,185 (2,637)	18,712	197.54
GIA	24,629 (1,674)	19,699 (1,588)	−4,929	−20.01	26,923 (3,735)	39,632 (6,392)	12,709	47.21	2,294 (3,978)	19,933 (6,655)	17,639	768.81
ASA	23,511 (2,262)	18,195 (2,282)	−5,316	−22.61	28,080 (3,968)	39,933 (5,957)	11,853	42.21	4,569 (4,976)	21,738 (7,049)	17,170	375.79

Source: computed using field survey data.

Notes: TIA, Tank irrigated area; CIA, Canal irrigated area; GIA, Groundwater irrigated area; ASA, All settings average; CM, Conventional method; SRI, System of rice intensification. Figures in parentheses indicate standard deviation.

the key practice of the alternate wetting-dry method of irrigation, due to poor literacy and lack of knowledge of the recommended irrigation practices. As a result, farmers have not harnessed the full potential benefits of the SRI method. As of 2013–14, an area of about one million hectares is covered by the SRI method (Gujja & Thiyagarajan, 2013), which is less than 3% of India's total paddy area. The adoption of SRI in most states is taking place either due to state specific incentive programmes or through national level incentive programmes such as the National Food Security Mission (NFSM) introduced by the Government of India during 2007 (https://www.nfsm.gov.in/). For example, the SRI method has been extensively adopted by farmers in Tamil Nadu mainly because of the incentives provided through the World Bank funded Tamil Nadu Irrigated Agriculture Modernisation and Water Bodies Restoration and Management (TN-IAMWARM) project. With the prime motive of maximising the productivity of water, this unique project was implemented in 61 sub-basins in Tamil Nadu with an outlay of Rs. 25,470 million for a period of 6 years from 1 April 2007 to 31 March 2013. While the adoption rate of SRI was reportedly very high during the time of implementation of the TN-IAMWARM project, the present state of adoption in the state is not clear (for full details of the IAMWARM project, see: http://www.iamwarm.gov.in).

Due to poor knowledge of the benefits of SRI, farmers still continue to cultivate paddy under the conventional inundation method which is no longer sustainable due to looming water scarcity. Today, paddy is cultivated in 43–44 million hectares of land in India. With fast depleting water availability, cultivating paddy under the inundation method is going to be very difficult for farmers in the future. Therefore, special programmes with attractive incentives need to be formulated to popularise the SRI method of paddy cultivation in all those regions/states that are experiencing severe water scarcity.

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