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Impact of system of rice intensification (SRI) on the water holding capacity (WHC) of soil and water use efficiency (WUE) in a tropical rainfed agro-ecosystem of Odisha

Ayesha Mohanty, Kshitendra Narayan Mishra, Lalit Mohan Garnayak and Alok Kumar Patra

Abstract
The effect of crop establishment methods involving system of rice intensification and conventional method (SRI and CT) with rice based cropping systems on soil water holding capacity and water use efficiency of the system were studied in a tropical rainfed agro-ecosystem. Changes in soil water holding capacity was measured after 5 years of establishing different soil management strategies, which were deemed to be environmentally sound. The soil water holding capacity was readily altered and improved under SRI practice with application of organic matter as compared to the conventional system. Practice of SRI increased the WHC of soil from initial value of 37.6 percent to 41.2 percent with concomitant decrease in the WHC of the soil under conventional system (38.5 percent). Water use efficiency (WUE) was higher under SRI method of stand establishment (70.8 kg REY ha-cm^{-1}) than the than CT (67.0 kg REY ha-cm^{-1}). The use of single young seedlings, reduced plant densities, use of mechanical weeder and alternate wetting and drying in SRI method of rice establishment helps in soil aeration, enhanced organic matter, improved soil physico-chemical and biological properties of the soil leading to higher productivity of succeeding crops in a sequence.

Keywords: System of rice intensification (SRI), Water holding capacity (WHC), Water use efficiency (WUE), Alternate wetting and drying (AWD)

Introduction
Rice is the most important staple food for 60 per cent of Indians and source of livelihood for 120-150 million rural households. India is the largest producer of rice next to China and rice is cultivated in 44.0 M ha area with a production of 106.7 Mt and productivity of 2.45 t ha^{-1} (Agricultural Statistics at a Glance, 2016) [1]. In Odisha, the productivity of rice is 2.47 t ha^{-1} (Economic Survey Odisha, 2017-18) [7]. The spread and extent of rice-based cropping systems across the country and more precisely in eastern India is predominant and diversified as well (Mahapatra *et al.*, 2012) [11]. Rice is the principal crop grown in this tract and rice based cropping systems is the normal cropping practice. It accounts for nearly 42.2 percent of the total food grain production and occupies around one quarter of the total cropped area in the country. Of India's total irrigated areas, nearly 23 percent is used for rice cultivation. Rice is the „thirstiest" crop in the world, requiring several thousand litres of water to produce 1 kg of rice when using conventional rice-growing methods with continuous flooding. Over half of our rice area is irrigated that contributes 75 percent of the total production. This area consumes 50-60 percent of the nation's freshwater resources. Production of rice has increased considerably in India after the Green Revolution. In 2006, it reached almost 140 million tons, which was 4.5 times the level of 1950. This productivity gains achieved during the Green Revolution was because of the development and use of high yielding crop varieties which were highly responsive to fertilizers, agrochemicals and irrigation water. After the wide spread of the ''Green Revolution" throughout irrigated paddy fields in Asia, however the rice yield has reduced that is reflected by the decline in the annual rate of rice yield increase from 2.7 percent in the 1980s to 1.1 percent in the 1990s. The downside of Green Revolution is that it has made the Indian agriculture system, including rice cultivation, highly dependent on availability of large quantities of surface and ground water. It is estimated that under modern system of rice cultivation, the typical water requirement to produce one kilogram of rice is 3000-5000 litres (WWF/ICRISAT 2009) [8].
Rice production causes significant discharges of greenhouse gas methane. When paddies are flooded with water, the conditions become nearby perfect in the soil for generating methane. Different methods of establishment of rice like SRI have been reported to reduce emission of

Green House Gases (GHGs) from rice field (Swarup *et al.*, 2008) [19] and saves about 20-30 per cent water as compared to conventional planting. Also irrigated rice production is the largest consumer of water in the agricultural sector, and its sustainability is threatened by increasing water shortages. Such water scarcity necessitates not only development of alternative irrigated rice systems that require less water than traditional flooded rice (Bouman *et al.*, 2005) [3] but also improving the water holding capacity of the soil. To improve resource use efficiency and for sustainable agriculture, it will be necessary to solve the growing concerns regarding water scarcity, higher fertilizer costs, and negative environmental impacts due to the increasing use of agrochemicals for rice production.

Some possible solutions include breeding superior genotypes under water-saving rice-cultivation methods (aerobic rice; Atlin *et al.*, 2006) [2], improving water management (Shi *et al.*, 2002; Yang *et al.*, 2004) [17, 25] and fertilizer use efficiency via more frequent split applications (Dobermann *et al.*, 2000). In such a situation, the System of Rice intensification (SRI), which is a low-cost and high yielding system, might be a sustainable alternative to conventional paddy production (Tsujimoto *et al.*, 2009) [22]. The System of Rice Intensification (SRI) developed in Madagascar by French Priest Father Henri de Laulani over 30 years ago (Laulanie, 1993) [10] is reported to offer an opportunity for reducing water demand accompanied by yield enhancement of rice (Chapagain and Yamaji, 2010; Satyanarayana *et al.*, 2007; Thakur *et al.*, 2010, 2011; Uphoff, 2007; Zhao *et al.*, 2010) [5, 14, 20, 21, 23, 27]. SRI proposes the use of single young seedlings, drastically reduced plant densities, keeping fields unflooded, use of a mechanical weeder which also aerates the soil, and enhanced soil organic matter. In the broadcasting, one has to use a minimum of 100kg of rice seeds for one hectare, in planting one required about 30-60kg of seeds or so. But in SRI, only 4-10kg of seeds are required for one hectare (Randriamiharisoh R, *et al.* 2006). The secret behind the gains obtained through SRI practices is that they stimulate biological processes that are beneficial for the development of plants and the production of grains. SRI, as opposed to traditional rice production, involves alternate wetting and drying (AWD) of rice fields (Kepha, Bancy and Patrick, 2014) [9] which are considered as an effective water-saving technology in rice production. SRI method of rice cultivation is done in nearly saturated soil conditions with less water, which is conducive to abate the discharge of methane.

Study by Zhang *et al.* (2009) [26] showed that moderate AWD not only saves water, but also increases grain yield by 11%. The incorporation of organic manure into the soil can bring beneficial effect to root growth by improving the physical, chemical and biological environments in which root grow (Yang *et al.*, 2004) [25]. Under continuous water logging condition, there is significant decrease in root growth (Satranarayana, *et al.*, 2006), whereas under intermittent irrigation, the incorporation of organic matter improves root morphological characteristics and root activity of rice plant. Further, soil microorganisms beneficial for plant development will be more abundant and diverse when soil is kept aerated. The transplantation of very young seedlings also contributes to an improved development of root systems, which ultimately leads to a better nutrient supply to the plant. The wider spacing allows for sunlight to get through to the plant's lower leaves and results in a higher level of photosynthetic activity. In addition, more balanced and more complete nutrition of soil and plants is achieved in SRI through the reliance mostly on organic materials like compost and mulch. This also renders plants more resistant to pests and diseases.

Principle of SRI

The principles of SRI which are fundamental to achieving the expected benefits are translated into certain practices, adapted to local conditions. The six principles form the 'SRI Hexagon,' and when adopted together they have a profound effect on the growth of rice plants (Fig. 1). The main components of SRI are (1) single seedling per hill, (2) young seedlings, (3) wider spacing, (4) un-flooded irrigation, (5) inter-cultivation, and (6) organic fertilization.

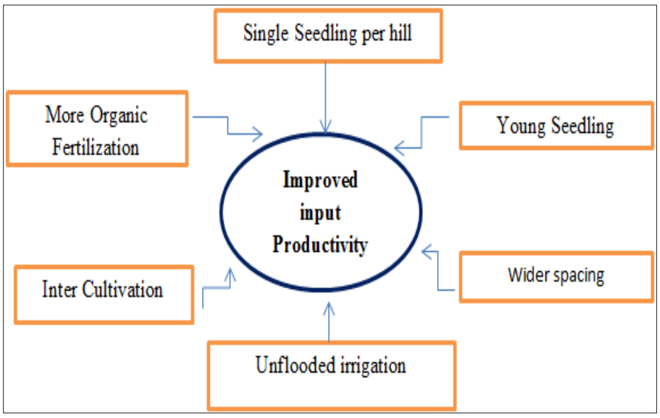

Fig 1: Six Principles of SRI

Materials and Methods

The experimental site is located at the Central Research Station of the Orissa University of Agriculture and Technology, Bhubaneswar ($20^0 15'$ N and $85^0 52'$E, 25.9 m above MSL and at about 64 km away from the Bay of Bengal) and the climate is hot, moist-sub humid with mean annual rainfall of 1527 mm. The treatments are two crop establishment methods (SRI and CT) and two cropping systems (CS1 and CS2) which were allotted to the main plots and combination of two mulching to *rabi* and summer crops and two nutrient management practices to all the crops in the sub-plots (Table 1) resulting in a total of 16 treatment combinations. Seedlings of 12 and 25 day-old which were raised in wet nursery bed were planted under SRI and CT methods, respectively. During Kharif season, for rice in SRI establishment technique, spacing of 25 cm x 25 cm was adopted for which a seed rate of 5 kg ha^{-1} was required for sowing in the nursery bed and for rice in CMS, spacing of 20 cm x 10 cm was adopted for which a seed rate of 50-60 kg ha-1 was required for sowing. For SRI method, weeding was done thrice at 10 days interval starting from 10 days after transplanting (DAT) using a cono weeder. Two hand weedings were done at 20 and 35 DAT of CT rice. Experimental plots of SRI were kept moist up to panicle initiation stage by suitably maintaining the water level in the side channels of each bed. Thereafter a thin film of water was allowed to stand over the bed from panicle initiation stage to 10 days before the harvest of the rice crop. Excess rain water was drained out as and when required. All the crops grown in different seasons were irrigated optimally as and when required. In all crops irrigation was withheld a week to 10 days before harvest. Number of irrigations for each crop is presented in Table 2.

The maximum water holding capacity (MWHC) of the soil was determined by Keen Raczkowski box method as described by Piper (1950) [12]. The soil samples of the field experiment were drawn from a depth of 0-15 cm at the end of the 5th cropping cycle (2015-16) using soil sampling auger and brought to the laboratory immediately for analysis of water holding capacity of soil. The samples were air-dried, aggregates were broken in a mortar and pestle, then the samples were passed through a 2.0 mm sieve and were mixed properly. The weight of the Keen box along with the filter paper placed inside on the perforated bottom was taken (A). The box was completely filled with the processed soil in close packing. The box containing soil was put in a water tray for saturation overnight and the next day the weight of the box containing saturated soil was measured (B). The box with the saturated soil was then placed in an oven at 105°C and was dried to a constant weight(C). A correction was applied for the amount of water absorbed by the filter paper (D). The maximum water holding capacity of the soil was calculated as follows:

Table 1: Treatment Details

Main plot (4): Crop establishment (2) x Rice based cropping systems (2)	
Crop establishment (2)	
T_1	System of Rice Intensification (SRI)
T_2	Conventional method of transplanting (CT)
Cropping systems (2)	
CS_1	Rice-groundnut-fallow
CS_2	Rice-toria-greengram
Sub-plots (4): Mulching (2) x Nutrient management (2)	
Mulching to rabi & summer crops (2)	
M_1	No mulch
M_2	Crop residues mulch to ***rabi*** **& summer** crops only
Nutrient management (2)	
F_1	RDF to all crops
F_2	75% RDF + 25% N through FYM to all crops

Table 2: Irrigation schedule of crops

System	Kharif		Rabi		Summer	
	SRI	CT	No mulch	Mulch	No mulch	Mulch
Rice-groundnut-fallow	10	8	8	7	-	-
Rice-*toria*-greengram	10	8	4	3	3	2

$$MWHC (\%) = ((B-C-D) / (C-A)) \times 100$$

The water use efficiency (WUE) is the system yield per unit depth of water required in a system and was expressed in kg REY ha-cm-1 (Stanhill, 1986).

$$\text{WUE (kg REY ha-cm}^{-1}) = \frac{\text{System yield (kg REY ha}-1)}{\text{Water requirement of the system (cm)}}$$

Results and Discussion

The effect of stand establishment technique on soil water holding capacity and water use efficiency at the end of 5th cropping cycle is depicted below.

Water Holding Capacity

Water holding capacity refers to the amount of water held between field capacity and wilting point. Soil "holds" water available for crop use, retaining it against the pull of gravity. This is one of the most important physical facts for agriculture. If the soil did not hold water, if water was free to flow downward with the pull of gravity as in a river, we would have to constantly irrigate, or hope that it rained every two or three days. There would be no reason to pre-irrigate. And there would be no such thing as dry-land farming. Soil texture and organic matter are the key components that determine soil water holding capacity.

Significant changes in soil water holding capacity were observed over the initial status of 37.6 percent due to the impact of crop establishment methods and addition of organic matter through mulching. Data pertaining to WHC (%) of soil is presented in Table 3. A comparison of rice establishment methods showed that WHC of soil of SRI (41.2 percent) method was significantly higher to a tune of 9.6 percent, over the initial value of 37.6 percent at the end of the 5th cropping cycle. System of rice intensification has a positive effect on water holding status of the soils thereby registering a gain of 6.9 per cent over the conventional system (38.5 percent) respectively (Fig. 2).

Table 3: Effect of crop establishment methods on soil water holding capacities.

Particular	% WHC
Method of rice establishment (E)	
SRI	41.2
CT	38.5
SEm (±)	0.13
CD (0.05)	0.47
Initial	37.6

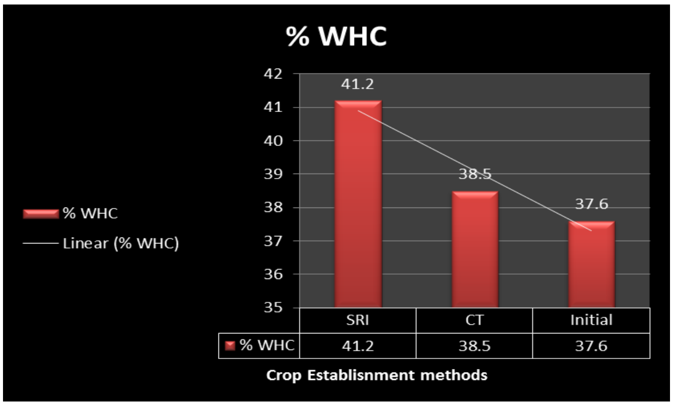

Fig 2: Effect of crop establishment methods on soil water holding capacities.

Water Use Efficiency

Water use efficiency (WUE) is defined as the amount of dry matter or yield produced per millimeter of rainfall. The key to optimizing yields is to make full use of all the moisture available. Data depicted in table 4 indicate higher water use efficiency (70.8 kg REY ha-cm^{-1}) from SRI method of stand establishment than CT (67.0 kg REY ha-cm^{-1}). The water use efficiency ranged between 54.5 kg REY ha-cm-1 to 86.0 kg REY hacm-1 for different rice based cropping systems. The highest water use efficiency was from SRI method. There was no significant difference in water use efficiency between the two rice based cropping systems. Mulching to *rabi* and summer crops increased water use efficiency by 14.8 per cent over non mulching (64.3 kg REY ha-cm-1) (Fig. 3).

Table 4: Comparison of crop establishment methods based on water use efficiency.

Particular	WUE, kg REY hacm^{-1}
Method of rice establishment	
SRI	70.8
CT	67.0

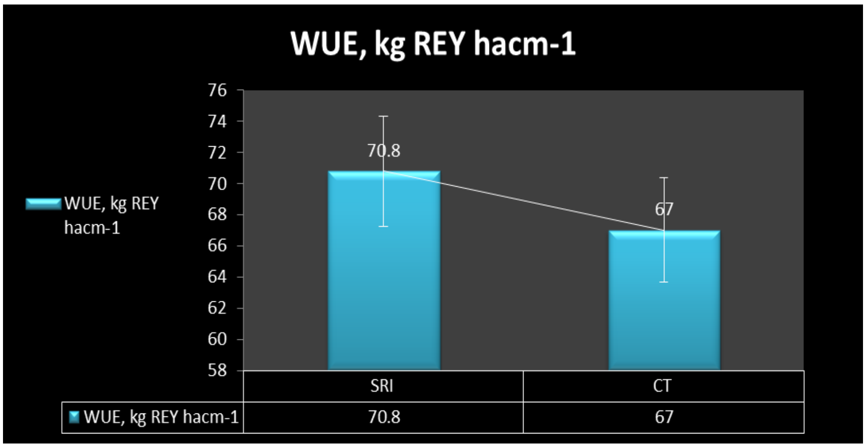

Fig 3: Comparison of crop establishment methods based on water use efficiency.

Discussion

The reduction in irrigation water requirements and improvement in water holding capacity of soil in through SRI adoption constitutes a remarkable increase in water use efficiency. Hence, SRI offers a valuable solution to attain "more crop per drop" of water, which is now a widely established objective of innovations in agricultural practices and technologies in light of growing pressures on water resources, mounting food needs of a growing world population and the large share of agriculture in total water consumption. Water holding capacity can be increased from two times to even six times (Ceesay *et al.*, 2006) [4]. Management practices designed to improve soil structure are the main way to improve WHC. Addition of organic matter through mulches increased the specific surface area resulting in increased WHC of each soil sample (Volk and Ullery., 1993; Gupta *et al.*, 1977) [24, 16]. The best option for a farmer is to increase their soil organic matter to increase the WHC of their farm soil. More water in the soil could save time, money and energy spent on frequently irrigating garden plants, pot plants, glasshouse plants and general horticulture.

Conclusion

Soil water holding capacity is the amount of water that a given soil can hold for crop use. Improved water holding capacity of soil significantly increased the water use efficiency of the system. It was noted that practising system of rice intensification not only improved the water holding capacity of soils and water use efficiency but also increased the yield, reduced number of irrigations or irrigation-hours per irrigation and per unit area (i.e., increase in water productivity) and improved seed quality. In addition to these private benefits, SRI embodies added societal or environmental benefits due to reductions in the use of environment-unfriendly inputs such as herbicides and fertilizers. Practice of system of rice intensification resulted in 9.6 percent increase in the water holding capacity over the initial status. The water holding capacity of the soil in the SRI method of crop establishment (41.2 percent) was significantly higher than the conventional system of establishment (37.6 percent) to a tune of 6.9 percent respectively. System of Rice Intensification was more resource use efficient with respect to water (70.8 kg REY ha cm^{-1}) as compared to the conventional system. So it can be concluded that practice of SRI along with organic mulching is one of the best possible options for improving water holding capacity of soils and water use efficiency of the system.

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