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Water and nitrogen use efficiency in SRI through AWD and LCC

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ABSTRACT

A farmer-participatory field experiment was conducted in Tripura, NE India to find out the relative efficiency of integrated use of leaf colour chart (LCC), alternate wetting and drying (AWD) and system of rice intensification (SRI). The rice was grown during the *rabi* (2012–13 to 2014–15) under two crop stand establishment methods of, system of rice intensification (SRI), and Conventional Rice Culture (CRC). The results of AWD for the water management in rice farming under SRI revealed that ~30% of irrigation water can be saved over conventional flooding method. The use of LCC was helpful to ascertain the amount of N fertilizer and its time of application for maintaining an optimal leaf N content and achieving higher rice yield. Agronomic efficiency (AEN) was significantly higher (73%), which resulted in more than 47% higher yield and N uptake over recommended N application. The adoption of AWD and N application with LCC (< 4) timing were the optimum and best methods of water and N management for transplanted rice under SRI.

Key words: Alternate wetting and drying, Nitrogen use efficiency, System of rice intensification, Water use efficiency

In rice production system, water and nitrogen (N) are main factors limiting the realization of yield potentials. Lowland rice fields have relatively high water requirements and many water-saving irrigation technologies have been developed to combat the increasing water scarcity in rice growing region. Alternate wetting and drying (AWD) method is increasingly being used in the parts of Asia to enhance water productivity and to reduce water use by 15–30% (Belder *et al.* 2005, Feng *et al.* 2007). Sustainability of rice yield can be maintained or even increased in systems of AWD as compared to conventional flood irrigation (Tan *et al.* 2012). Nitrogen fertilization in rice is expensive and N losses from the soil-plant system are large, resulting in low N recovery (<40%) (Nachimuthu *et al.* 2007). The optimum use of N fertilizer can be achieved by synchronising N supply with crop demand by measuring leaf N concentration under field condition. Leaf colour chart (LCC) provide a simple, quick, non-destructive and inexpensive method for estimating N of rice leaves. The system of root intensification (SRI) in which combined use of younger seedlings individually transplanted at a wider spacing, together with the adoption of intermittent irrigation with alternate wetting and drying were found productive in absolute fertilizer and water use savings with a greater plant stability (Chapagain and Yamaji 2010). Results of studies suggest that SRI increases N uptake and improve ammonia volatilization loss from rice soil at a relatively low N fertilizer rate (Thakur *et al.* 2010).

Current rice yields in farmer's field are far below their potential as both water and nitrogen inputs are not managed efficiently. Practices of AWD using low cost devices and use of LCC under SRI can be a cost-effective approach to resource-poor farmers. Hence, the present experiment was conducted with the objective to understand how integrated use of LCC, AWD and SRI interacted with water use efficiency (WUE) and nitrogen use efficiency (NUE) during crop growth for realizing sustainable rice yield.

MATERIALS AND METHODS

The field experiments were conducted for 3 years (2012–15) on the lowland rice farm of Sabrum, West Pilak and West Kalabaria villages, in south district of Tripura. The study area belongs to the Mid-Tropical Plain Zone (NEH-6) and lies between the north latitudes of 22°57′ N to 23°45′ N and the east longitudes of 91°19′ E to 91°53′ E. During the study period, the farm area had a mean monthly maximum temperature from 35.9°C in April to 25.2°C in January and a mean minimum temperature from 25.4°C in June to 10.1°C in January. The area had a mean total rainfall of 1900 mm, 80% of which occurred during the southwest monsoon period. The crop evapotranspiration of the district varied from 7.99 mm in April to 4.4 mm in December. The soil of the experimental field was strongly acidic with *p*H from 4.6–5.5. The texture were sandy clay loam having 5–11 g/

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kg organic carbon, 180–380 kg/ha alkaline permanganate oxidizable N, 18–34 kg/ha available Bray's P and 120–220 kg/ha ammonium acetate exchangeable K.

Management practices adopted: The rice cultivar (cv. Gomati/TRC 2005-1) was grown during *rabi* under two crop stand establishment methods of SRI, and conventional rice culture (CRC). The experiment was conducted in 20 m × 10 m plot size with three replications. In SRI, 14-day-old seedlings were transplanted at 25 cm × 25 cm spacing keeping one seedling per hill, while in CRC, 25-day-old seedlings were transplanted at 20 cm × 15 cm spacing keeping three seedlings per hill. Recommended dose of farmyard manure (10 t/ha), Nitrogen (40 and 80 kg/ha in SRI and CRC, respectively), phosphorus and potassium (20 and 40 kg/ha in SRI and CRC, respectively) fertilizer were applied as urea, single super phosphate and muriate of potash. Phosphorus and potassium fertilizer were applied as basal dose and N fertilizer was applied in 3 spilt doses (25% N as basal and 75% N as per LCC readings). Weeding in SRI treatment was done using cono-weeder at 15, 30, 45 and 60 days after transplanting (DAT), while the CRC plots were hand weeded at 20, 40 and 60 DAT. Need based plant protection measures were taken.

In the SRI plots, AWD irrigation management was applied after 3 days of transplanting and continues up to whole experiment period (125 days). AWD irrigation schedules were divided into two water regimes- (i) irrigation at 10 days after transplantation, and (ii) irrigation after 20 days as per Field Water Tube (FWT) indicator. The AWD irrigation was given when water level goes to 15 cm below soil surface till flowering and after flowering stage. However, during flowering stage soil was kept flooded (5 cm water above soil surface) for 10 days. FWT was observed at 5 days intervals and plant growth at 10 days interval throughout the experiment. Each FWT was attached with a ruler to measure the water level in the field (Fig 1). In case of CRC plots, 4–5 cm water was maintained from transplanting to grain filling stage. The field experiment was laid out in a randomized block design. The LCC developed by the International Rice Research Institute with six green shades panel was used in the experiment (Fig 1). LCC readings were taken at 7 days interval starting from 14 DAT and taken up to 65 DAT coinciding with the heading stage and last dose of nitrogen (25%).

All the data of rice for 3 years were analysed statistically. The agronomic efficiency (AEN), apparent recovery efficiency (REN), physiological efficiency (PEN) and partial factor productivity (PFPN) from applied N fertilizer were calculated as:

AEN = kg grain increase per kg N applied = (YN - Y0/FN)

REN = kg N taken up per kg N applied = (UN -U0)/FN

PEN = kg grain per kg N uptake = (YN - Y0 / (UN -U0)

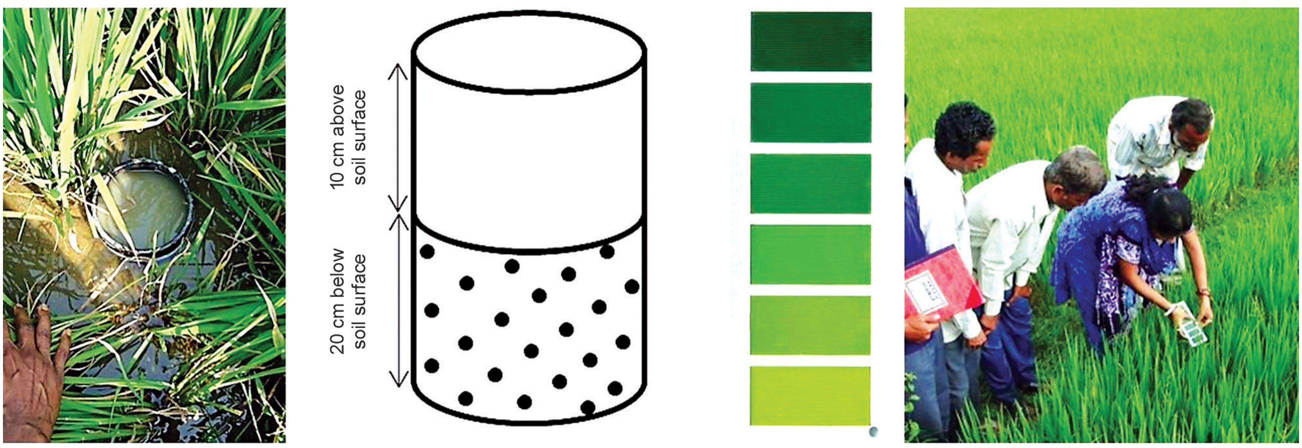
PFPN = kg rice grain yield per kg N applied = YN/FN

where YN, rice grain yield (kg/ha) at a certain level of applied fertilizer N (FN, kg/ha); Y0, rice grain yield (kg/ha) measured in a control plot with no N application; UN, total N in aboveground plant biomass at physiological maturity (kg/ha) in a plot receiving N without N addition.

The crop water requirement of rice was computed using CROPWAT 8.0 model. The overall water use efficiency (WUE) was determined by dividing the grain yield by the water used (sum of soil water at planting + soil water at harvest + irrigation water + effective rainfall) and expressed as kg/ha/mm.

RESULTS AND DISCUSSION

Water use efficiency and rice yield: AWD was evaluated in the paddy field to mitigate the impacts of water shortage during the dry season in rice cultivated areas along with SRI. On an average, it was found that the crop water demand for rice crop was about 309 mm and actual water used was 315–322 mm under SRI (AWD) and 328–333 mm in CRC system (Table 1). The irrigation supplies during that period were 300–310 mm and 410–445 mm for SRI (AWD) and CRC (flooded), respectively. There was a significant difference (100–135 mm) in the demand and supply of irrigation water in CRC system. Application



Field Water Tube (FWT) Leaf Colour Chart (LCC)

Fig 1 Field water tube (FWT) and leaf colour chart (LCC) used in the experiment

Table 1 Water and nitrogen use efficiency and net return as influenced by SRI (AWD) and CRC (Flooded)

Treatment and harvest year	Irrigation water applied (mm)	Water use efficiency (kg/ha/mm)	Total N applied (kg/ha)	N-use efficiency indices (kg/kg)				Grain yield (kg/ha)	Net Return (₹/ha) (B:C ratio)
				AEN	REN	PEN	PFPN		
SRI (LCC)									
2013	300	18.66	41	91.35	1.41	65.72	149	6010	34580 (1.95)
2014	310	18.79	39	90.15	1.39	64.49	148	5920	34020 (1.94)
2015	300	18.26	39	88.50	1.37	63.15	146	5860	33740 (1.92)
Mean	297	18.50	40	90.00	1.39	64.46	147	5900	33950 (1.94)
CO (P<0.05)	--	0.96	-	0.63	0.12	1.98	2.40	176	-
CRC (FP)									
2013	420	12.19	80	25.87	0.35	71.76	54.42	4060	23380 (2.50)
2014	410	12.15	80	23.76	0.34	69.80	53.12	4010	23100 (2.48)
2015	445	11.95	80	22.37	0.33	67.90	51.46	3930	22610 (2.47)
Mean	425	12.10	80	24.00	0.34	69.82	53.01	4000	23030 (2.48)
CD (P<0.05)	--	0.75	-	0.93	0.02	1.74	1.12	41.50	-

AEN, Agronomic Efficiency; REN, Apparent recovery efficiency; PEN, Physiological efficiency; PFPN, Partial factor productivity

of AWD in SRI system significantly reduced the irrigation water requirements by ~30% with a yield advantage of about ~47%.

AWD promoted the growth and development of deeper root system which was evidenced by the higher root volume (Table 2) thus makes the rice plant more tolerant to water stress condition (Yang *et al.* 2004, Thakur *et al.* 2010). WUE was significantly higher in the intermittent irrigation field i.e. 18.66–18.79 kg/ha/mm in SRI (AWD) as compared to 11.95–12.19 kg/ha/mm in CRC with conventional water management. A study revealed that the application of 5 cm depth of irrigation water when water level reached 10–15 below ground level, gave the highest grain yield and realized highest WUE as compared to continuous submergence (Oliver *et al.* 2008). AWD improved WUE and yield by increasing the proportion of productive tillers, reducing the angle of the topmost leaves thus allowing more light to penetrate the canopy and modifying shoot and root activity (Yang and Zhang 2010).

Nitrogen use efficiency: Increased availability of nitrogen was noticed in AWD conditions leading to higher uptake than the continuous flooding. Soil application of N as per LCC< 4, only 40 kg N/ha was required during entire growth which was 50% less to the recommended N (80 kg/ha). Use of more than 40 kg N/ha didn't affect the yield. Application of urea as top dressing before irrigation under AWD as per LCC readings could help to ensure the movement of N into the soil and minimised the loss through ammonia volatilization and consequently lead to a higher N uptake (Yang *et al.* 2004). The practice of AWD resulted in periodic aerobic soil conditions, thus stimulating sequential nitrification–denitrification (Peng *et al.* 2010). A positive and significant correlation (R^2 = 0.95) was observed between NUE and grain yield. The use of LCC was helpful to ascertain the amount of N fertilizer and its time of application for maintaining an optimal leaf N content and achieving high rice yield as well as split doses to different crop growth stages (Sathiya and Ramesh 2009). These results suggest that LCC-based management can be used for timing of N topdressing at a specific crop growth stage under AWD irrigation regime. Combination of AWD and LCC based N management can save irrigation water and N fertilizer while maintaining high yield under SRI as compared to CRC with fixed time and rate of nitrogen application (Kukal *et al.* 2005).

In SRI (AWD), agronomic N use efficiency (AEN), N recovery efficiency (REN) and partial factor productivity of N (PFPN) were significantly increased over conventional flooding (Table 1). Higher AEN and REN value may be attributed to maintain the pace in N supply and crop N demand during crop growth period, which in turn resulted in a significant increase in number of grain/panicle (151 grains/panicle) as compared to recommended N split (132 grains/panicle). On an average, AEN and REN were higher

Table 2 Comparison of average yield parameters as influenced by SRI (AWD) and CRC (Flooded)

Crop establishment nethod	Productive tillers/ m^2	No. of panicles/ m^2	No. of grain/ panicle	Root volume (cc)	1000 grain weight (g)	Harvest Index
SRI	272	219	151	58.6	18	0.45
CRC	225	192	132	42.0	16	0.41
SE+	6.68	1.25	6.98	3.27	0.82	0.01
CD (P<0.05)	14.71	2.74	15.35	7.19	1.80	0.02

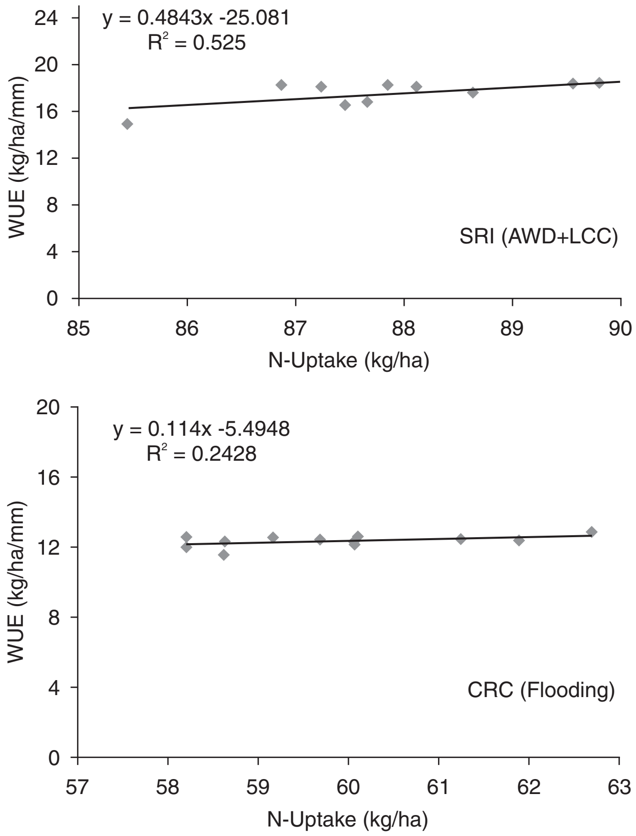


Fig 2 Relation between water-use efficiency and total N uptake under SRI and CRC crop establishment.

by about 73–75%, which resulted in more than 47% higher yield and N uptake over recommended N under CRC. Higher agronomic efficiency of N with high grain yield under AWD as compared to continuous flooding fields could be regarded as an indicator for efficient N management in rice (Yang *et al.* 2004). A probable explanation is that AWD regime leads to a higher harvest index (Table 2) which means less N to produce the biomass of vegetative tissues and more N to produce grain yield (Chu *et al.* 2015) resulting in a higher AEN (Yang *et al.* 2004). The higher AEN may also be attributed to a reduction in N application at the basal and early vegetative stages and a delayed in-season N application. Such N management can increase N uptake and accumulation in plants by reducing unproductive tillers and increasing dry matter accumulation during the grain filling period, leading to a higher AEN (Peng *et al.* 2010, Chu *et al.* 2015). The partial factor productivity (PFPN), which is a ratio of yield to the amount of applied N declines with increased N application. The PFPN is an aggregate efficiency index derived from uptake of N from soil and fertilizer from which plant is converted to grain yield.

Rice grown with AWD and SRI techniques contributed higher water productivity and show higher yield than CRC (Alam and Mondal 2003, Omwenga *et al.* 2014). This could be due to adequate water supply at right time for better root establishment, early tillering, nutrient mobilization and reduction in redundant vegetative growth (Yang and Zhang 2010, Chowdhury *et al.* 2014). A greater amount of N uptake was observed by rice when plants were grown under wider spacing with lower N rate under SRI than narrow spacing as practiced under CRC at higher N rate. These findings indicated that plant spacing could contribute to the N uptake pattern in enhancing NUE under SRI. Further, the coefficient of correlation between WUE and total N uptake was positive, irrespective of SRI (AWD) and CRC (Flooding) treatments (Fig 2); the relationship was stronger with the SRI (R^2=0.52) than CRC (R^2=0.24). The results indicated that WUE and NUE are determined not only by water regimes, but also by their interaction with N rates under both SRI and CRC system of rice cultivation. Both AEN and PFPN were much higher at SRI than at CRC. Therefore, we argue that the SRI (AWD) synergistically interacts with the N rate at early and late growth stages. Such a synergistic interaction could achieve the goal of increasing grain yield, WUE and NUE.

The optimal water and nitrogen use had produced significantly higher net returns with an additional income of about ₹10920/ha over CRC (Table 1). The farming cost also decreased in terms of two irrigations, 50% N fertilizer, fuel and labour due to adoption of SRI with AWD and LCC. FAO (2010) reported that the economic yield tends to be higher in AWD, as it decreases the cost of irrigation and nitrogen fertilizer, and in increase of grain yield.

Results of the study showed that continuous submergence is not an obligation in rice cultivation. Reducing ponded water depth from 5–7 cm to the level of soil saturation was found to be the best way to save water and increase water productivity. Current fertilizer N recommendations for rice crop do not match with the crop demand. Use of LCC helped for real time N management in order to increase N use efficiency and grain yield simultaneously. This study demonstrated that judicious use of water (AWD) and N management in real time significantly enhances the crop yield and profitability. It may be concluded that the adoption of AWD and N application with LCC (< 4) timing were the optimum and best methods of water and N management for transplanted rice under SRI.

REFERENCES

Alam M M and Mondal M K. 2003. Comparative water requirements and management practices for hybrid and inbred rice cultivation in Bangladesh. *Bangladesh Journal of Agriculture Science* **30**(2): 345–51.

Belder P, Spiertz J, Bouman B, Lu G and Tuong T. 2005. Nitrogen economy and water productivity of lowland rice under water saving irrigation. *Field Crop Research* **93**: 169–85.

Chapagain T and Yamaji E. 2010. The effects of irrigation method, age of seedling and spacing on crop performance, productivity and water-wise rice production in Japan. *Paddy Water Environment* **8**: 81–90.

Chowdhury M R, Kumar V, Sattar A and Brahmachari K. 2014. Studies on the water use efficiency and nutrient uptake by rice under system of intensification. *The Bioscan* **9**(1): 85–88.

Chu G, Wang Z Q, Zhang H, Liu L J, Yang J C and Zhang J H. 2015. Alternate wetting and moderate drying increases rice yield and reduces methane emission in paddy field with wheat straw residue incorporation. *Food Energy Security* **4**: 238–54.

Feng L, Bouman B, Tuong T, Cabangon R, Li Y, Lu G and Feng Y. 2007. Exploring options to grow rice using less water in northern China using a modelling approach I. Field experiments and model evaluation. *Agriculture Water Management* **88**: 1–13.

FAO. 2010. Climate-smart agriculture policies: practices and financing for food security, adaptation and mitigation. Food and Agriculture Organization, Rome, Italy.

Kukal S S, Hira A G S and Sidhu A A S. 2005. Soil matric potential-based irrigation scheduling to rice *(Oryza sativa)*. *Irrigation Science* **23**: 153–59.

Nachimuthu Gunasekher, Velu V, Malarvizhi P, Ramasamy S and Bose Jaykumar. 2007. Relationship between index leaf nitrogen and leaf colour chart (LCC) values in direct wet seeded rice (*Oryza sativa* L.). *Asian Journal of Plant Science* **6**: 477–83.

Oliver M M H, Talukder M S U and Ahmed M. 2008. Alternate wetting and drying irrigation for rice cultivation. *Journal of Bangladesh Agricultural University* **6**(2): 409–14.

Omwenga K G, Mati B M and Home P G. 2014. Determination of the effect of the system of rice intensification (SRI) on rice yields and water saving in Mwea Irrigation Scheme, Kenya. *Journal of Water Resource Protection* **6**: 895–901.

Peng S B, Buresh R J, Huang J L, Zhong X H, Zou Y B, Yang J C, Wang G H, Liu Y Y, Hu R F, Tang Q Y, Cui K H, Zhang F S and Dobermann A. 2010. Improving nitrogen fertilization in rice by site-specific N management, a review. *Agronomy of Sustainable Development* **30**: 649–56.

Sathiya K and Ramesh T. 2009. Effect of split application of nitrogen on growth and yield aerobic rice. *Asian Journal of Plant Science* **23**: 303–06.

Tan Xuezhi Shao, Dongguo Liu, Huanhuan Yang, Fengshun Xiao Chun and Yang Haidong. 2013. Effects of alternate wetting and drying irrigation on percolation and nitrogen leaching in paddy fields. *Paddy Water Environment* **11**: 381–95.

Thakur A K, Uphoff N and Antony E. 2010. An assessment of physiological effects of system of rice intensification (SRI) practices compared with recommended rice cultivation practices in India. *Experimental Agriculture* **46**: 77–98.

Yang C, Yang L, Yang Y and Zhu O. 2004. Rice root growth and nutrient uptake as influenced by organic manure in continuously and alternately flooded paddy soils. *Agriculture Water Management* **70**: 67–81.

Yang J C and Zhang J H. 2010. Crop management techniques to enhance harvest index in rice. *Journal of Experimental Botany* **61**: 3177–89.