

The Effects of Crop Establishment Method, Soil–Water Regime and Integrated Nutrient Management Practices on Sustainability of Rice Yield in North-Eastern India

A. K. Singh & Mandira Chakraborti

Agricultural Research

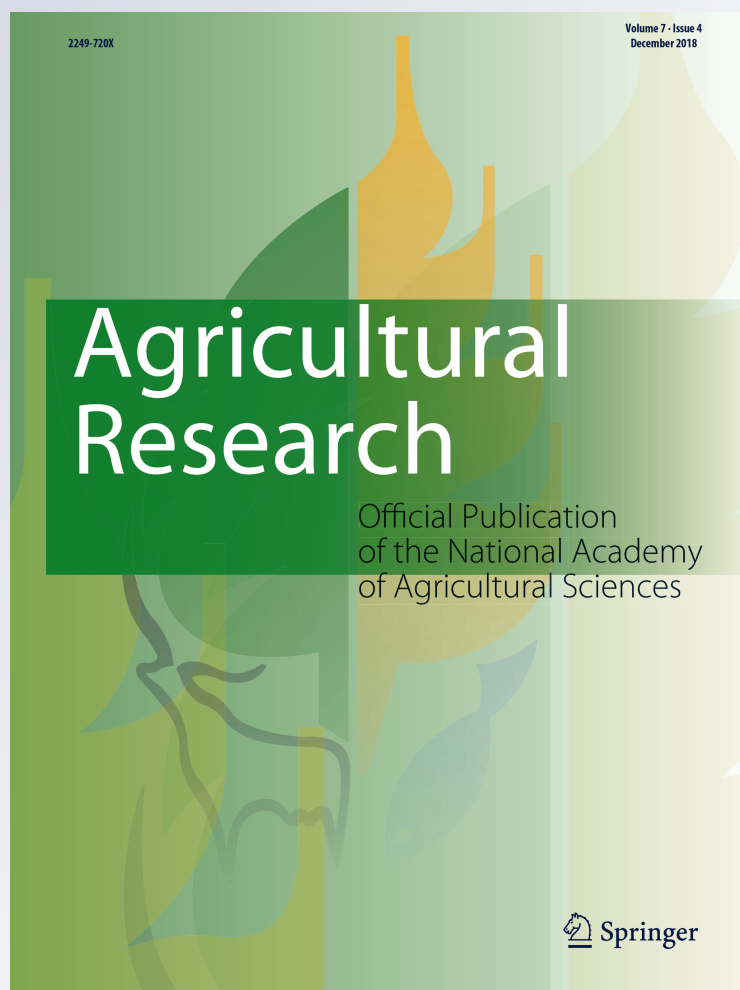
ISSN 2249-720X

Volume 7

Number 4

Agric Res (2018) 7:456–462

DOI 10.1007/s40003-018-0336-4



Your article is protected by copyright and all rights are held exclusively by NAAS (National Academy of Agricultural Sciences). This e-offprint is for personal use only and shall not be self-archived in electronic repositories. If you wish to self-archive your article, please use the accepted manuscript version for posting on your own website. You may further deposit the accepted manuscript version in any repository, provided it is only made publicly available 12 months after official publication or later and provided acknowledgement is given to the original source of publication and a link is inserted to the published article on Springer's website. The link must be accompanied by the following text: "The final publication is available at link.springer.com".

The Effects of Crop Establishment Method, Soil–Water Regime and Integrated Nutrient Management Practices on Sustainability of Rice Yield in North-Eastern India

A. K. Singh¹ · Mandira Chakraborti²

Received: 18 October 2016 / Accepted: 14 June 2018 / Published online: 4 July 2018
 © NAAS (National Academy of Agricultural Sciences) 2018

Abstract A field experiment was conducted in rice fields of the mid-tropical plain zone of north-eastern India with an aim to develop options through integrated management of soil, water, nutrition and plant for sustainable rice production. The experimental fields were managed in three transects by growing rice under the system of rice intensification (SRI), integrated crop management (ICM) and conventional rice culture (CRC) with fertiliser treatments of NPK_{100–100–100}; NPK_{100–100–100} + FYM; and NPK_{50–50–50} + FYM + biofertiliser. The results reveal that the SRI and ICM systems of rice culture give a good yield with better water use efficiency. The quantity of water required for producing one kilogram of rice was 1498 L in SRI and 1535 L in ICM compared to 1883 L in CRC. The requirement of fertiliser under SRI and ICM methods of transplanted rice was less than half of the fertiliser requirement of the CRC method. The soil–water regime, crop establishment method and integrated nutrient management (INM) practices significantly influenced the sustainability yield indices (85–99%) of rice in this climate scenario.

Keywords Lowland rice · Water use efficiency · Integrated nutrient management · Crop establishment method · North-eastern India

Introduction

During the Green Revolution era in India, the rate of growth in rice production was higher than the population growth and resulted in a surplus. But in the past decade, with climate change, production and productivity of rice have declined [4]. Rice production was affected by climate conditions, water availability, soil and other biotic and abiotic factors [26]. The wet season rice crop in North-eastern India is grown under an increasing rise in temperature and reduced water availability as a result of climate change [1, 6]. The increase in temperature, especially mean

minimum night temperature, has adverse effects on rice productivity as it reduces crop duration, increases respiration rate, alters photosynthate partitioning to grains, affects the survival and distribution of pest populations, hastens nutrient mineralisation in soils, decreases fertiliser-use efficiency and increases evapotranspiration [19, 27, 37]. Rice consumes almost 50% of irrigation water used for all crops and the declining availability of rainwater is a great threat to the rainfed rice cultivation systems of North-eastern India.

Rice is a staple food for people of North-eastern India in daily consumption as well as for household economy. Its cultivation covers more than 72% of the total grossed cropped area, and about 90% of the population depends on rice farming as the main source of livelihood, particularly in rural areas [9]. The rice production system in this part of country can be classified into two broad production systems, i.e. lowland rice and upland (dry land) rice cultivation. The majority of the production system is a single wet season cropping, particularly where there is no irrigation

✉ A. K. Singh
 singhak30@gmail.com

¹ Central Research Institute for Jute and Allied Fibres, Barrackpore, Kolkata 700120, India

² KVK, ICAR Research Complex for NEH Region, South Tripura 799144, India

supply [18]. The cropping calendar starts with the onset of the rainy season in late May to mid-June, followed by transplanting in late June to mid-July. However, the timing of practices depends on the rainfall distribution. Rice is produced with minimum inputs and a low-level technology. Inorganic nitrogen fertiliser is applied after transplanting, and the rate of application is rapidly increasing. Annual rice production remains variable as much of the rice is produced under rainfed conditions. Climate factors account for at least about 10% of the annual variability in rice production [31].

Lowland rice production has been affected by climate variability leading often to lower production, in particularly when rainfall is low or poorly distributed. Drought conditions have been observed during 2012–2014 especially in the early and later periods of the growing season. Therefore, it is to investigate how rice productivity performs under changing climate conditions and to develop recommendations based on integrated management of soil, water, nutrition and plant for sustainable rice production.

Materials and Methods

Study Area

Based on the soil-site characteristics and other relevant features, the soils of study area were classified into three transect as Transect-I (Typic Dystrudept in Dudhpuskarini village), Transect-II (Typic Kandudalfs in Matai village), and Transect-III (Aeric Fluvaquents in Garjee village), sited between 22°57'N to 23°45'N and 91°19'E to 91°53'E in South district of Tripura (India). Transects were selected on the basis of detailed geomorphic analysis [17]. According to National Agriculture Research Project [16] classification, the study area belongs to Mid-Tropical Plain Zone (NEH-6) of India. The data pertaining to soil-site characteristics are given in Table 1. These landforms reflect the differences in soil characteristics. The Alfisols (Transect-I) of the study area have very deep soil and inceptisols (Transect-II and Transect-III) with deep soil. The texture was sandy loam to sandy clay loam having 6–15 g/kg organic carbon, 186–480 kg/ha alkaline permanganate oxidisable N, 21 to 54.4 kg/ha available Bray's P and 116–340 kg/ha ammonium acetate exchangeable K. DTPA extractable Zn was in range of 0.06 to 1.10 mg/kg, and pH of the soil was strongly acidic (4.5 to 5.4). Climate of the study area is sub-humid with a wet monsoon and a dry season and rice is grown in the wet season.

The rice cultivar (*Gomati*) was grown under farmer's field condition during wet season (from year 2011 to 2014) under three crop stand establishment methods; (1) system of rice intensification (SRI); (2) integrated crop

management (ICM); and (3) conventional rice culture (CRC) with three fertiliser treatments: T1, NPK_{100–100–100}; T2, NPK_{100–100–100} + FYM; and T3, NPK_{50–50–50} + FYM + biofertiliser. Nitrogen (N), phosphorus (P) and potassium (K) fertiliser were applied as urea, single super phosphate (SSP) and muriate of potash (MOP). Phosphorus and potassium fertiliser were applied as basal dose and nitrogen fertiliser was applied in three split doses (@ 50% at basal and 25% each at tillering and panicle initiation stage). Biofertiliser (*Azotobacter*) was used as seed treatment @ 20 g per kg of seed. Fertiliser treatments were worked out from initial soil test value and requirement of crops as per plant population in each stand establishment methods (Table 2). Weeding in SRI and ICM treatment was done three times by Cono-weeder to incorporate weeds into the soil 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 all the treatments. In SRI, 10-day-old seedlings of the same rice variety were transplanted at 25 cm × 25 cm spacing keeping one seedling per hill, while in ICM, 20-day-old seedlings were transplanted at 20 cm × 20 cm spacing keeping two seedlings per hill. In CRC, 25-day-old seedlings were transplanted at 20 cm × 15 cm spacing keeping three seedlings per hill. The same practice of crop establishment was practiced every year. The soil was kept near saturated moisture condition throughout the vegetative phase in SRI and ICM system. A thin layer of 1–3 cm rainwater was maintained during the reproductive phase of rice. However, in CRC, 5–6 cm rainwater was maintained from transplanting to grain filling stage. The field experiment was laid out in a randomised block design. Observations on growth and yield characters were done at critical stages of crop growth. The water use efficiency (WUE) of rice crop was computed using CROPWAT 8.0 model [8]. Reference evapotranspiration (ET_o) estimation through CROPWAT 8.0 from limited climatic data was evaluated with that of a full set of climatic data under local climatic conditions for study area. The ET_o estimated from limited data has a good agreement with that of estimated ET_o from the full set of climatic data.

Sustainable Yield Index (SYI) for rice was computed using rice grain yield for soil units in different landforms as per equation, $SYI = (Y - SD)/Y_{max}$.

Where, 'Y' is the average yield, 'SD' is the standard deviation and 'Y_{max}' is the maximum observed yield from the year 2011 to 2014. In order to work out the variation in SYI due to various constraints under different soil-site conditions, statistical models were used.

Table 1 Initial soil-site characteristics of study area (Tripura, India)

Soil and climate parameters	Transect classification		
	Typic Dystrudept (Alfisols)	Typic Kandiuclalfs (Inceptisols)	Aeric Fluvaquents (Inceptisols)
Texture	Sandy loam	Clay loam	Sandy clay loam
pH	5.1–5.3	4.5–5.0	5.1–5.4
Organic carbon (g/kg)	0.69–0.75	0.75–1.50	0.6–0.96
Avail. N (kg/ha)	196–271	340–480	186–345
Avail. P (kg/ha)	21–24.8	25–45	30–54.4
Avail. K (kg/ha)	119–335	150–340	116–335
Avail. Zn (mg/kg)	0.06–0.90	0.50–1.00	0.45–1.10
Avail. Fe (mg/kg)	42–89	110–121	112–145
Rainfall (mm)	1940–2060	2100–2130	2180–2210
Maximum temperature (°C)	33–36	34–36	32–34
Minimum temperature (°C)	8–9	7–8	7–9
Humidity (%)	60–70	68–72	70–75

Table 2 Fertiliser treatments, seedling age and plant spacing under three stand establishment methods of transplanted rice

Treatment	Rate of fertiliser (kg/ha)		
	System of rice intensification (SRI)	Integrated crop management (ICM)	Conventional rice culture (CRC)
Age of seedlings (days)	10	20	30
No. of seedlings per hill	1	2	3
Spacing (cm)	25 × 25	20 × 20	20 × 15
Fertiliser treatment			
T_1 NPK _{100–100–100}	20:10:10	40:20:20	80:40:40
T_2 NPK _{100–100–100} + FYM	20:10:10 + 5000	40:20:20 + 5000	80:40:40 + 5000
T_3 NPK _{50–50–50} + FYM + biofertiliser	10:5:5 + 5000 + 0.2	20:10:10 + 5000 + 0.2	40:20:20 + 5000 + 0.2

Results

Rice Productivity during the year 2011 to 2014

With the System of Rice Intensification (SRI) technology, the maximum yield of rice recorded was 50.33, 49.70 and 49.67 q/ha and under Integrated Crop Management (ICM), maximum yield obtained was 54.10, 52.13 and 51.93 q/ha in Transect-I, Transect-II and Transect-III, respectively (Table 3). Whereas under Conventional Rice Culture (CRC) with flooded water condition, the rice yield varied between 41.67 to 49.67 q/ha, which was about 16 and 22–26% less than that of SRI under Transect-II and Transect-III, respectively. Similarly, average yield increased under ICM was 16–19 and 22–28% as compared to CRC under same soil Transects. Results have shown similar comparative advantages as reported by several researchers arising from SRI practice including higher yields [14, 18, 29, 35]. Study report from 17 countries

indicated that average rice grain yields were 68 q/ha for SRI as compared to just 39 q/ha for the recommended conventional rice management [7].

Grain yield of rice was significantly influenced due to application of fertiliser in combination with farmyard manure (FYM) and biofertiliser (Table 3). The maximum rice yield (54.10 q/ha) was recorded under ICM with Integrated Nutrient Management (INM) practices (NPK_{50–50–50} + FYM + biofertiliser). There was significant yield difference between the SRI and CRC rice establishment system under 'NPK_{50–50–50} + FYM + biofertiliser' in all the treatments of Transect-I. However, no significant variation in rice grain yield was observed under treatment 'NPK_{100–100–100}' and 'NPK_{100–100–100} + FYM'. Under Transect-II and Transect-III, significant yield difference was observed in all the rice establishment methods under treatment 'NPK_{50–50–50} + FYM + biofertiliser'. Setty et al. [25] also stated that the application of 50% recommended dose of nitrogen

Table 3 Grain yield and sustainability indices under various fertiliser treatment and crop establishment methods

Treatment	Transect classification								
	Typic Dystrudept			Typic Kandudalfs			Aeric Fluvaquents		
	Av. grain yield (q/ha)	SD	SYI	Av. grain yield (q/ha)	SD	SYI	Av. grain yield (q/ha)	SD	SYI
SRI									
T_1	46.17 ^a	1.04	0.89	44.83 ^a	0.29	0.89	46.03 ^a	0.42	0.92
T_2	47.00 ^a	0.50	0.92	45.37 ^a	0.78	0.90	46.53 ^a	0.95	0.91
T_3	50.33 ^b	1.53	0.97	49.70 ^b	0.61	0.99	49.67 ^b	0.57	0.99
ICM									
T_1	48.67 ^c	1.04	0.88	47.33 ^a	0.29	0.90	48.33 ^b	1.44	0.90
T_2	49.00 ^c	0.50	0.89	49.17 ^b	0.76	0.92	48.67 ^b	0.29	0.93
T_3	54.10 ^d	1.01	0.98	52.13 ^c	0.85	0.98	51.93 ^c	0.85	0.98
CRC									
T_1	46.03 ^a	0.42	0.91	38.67 ^d	0.58	0.89	39.67 ^d	0.58	0.93
T_2	46.53 ^a	0.95	0.92	38.97 ^d	2.52	0.85	38.00 ^d	1.73	0.87
T_3	49.67 ^b	0.57	0.98	42.67 ^a	1.53	0.96	41.67 ^d	1.15	0.97

Mean values in a column followed by a common letter are not significantly different at 5% level

through FYM and remaining 50% through inorganic fertilisers resulted in higher yield due to increased number of effective tillers per hill and filled grains per panicle but was statistically at par with NPK_{100–100–100} through inorganic sources of fertilisers.

Under different cultivation methods growth parameters like productive tillers (320–350 per m²), number of panicles (195–215 per m²), number of grain per panicle (172–173) and 1000 grain weight (23 g) were significantly superior in SRI and ICM over CRC. Nodal root development in SRI (60.7 cc) and ICM (52.1 cc) was better than the CRC method (43.8 cc) at the initial growth stage when soil nutrients and water were not limiting. Influence of different crop establishment practices on yield parameters is given in Table 4. In case of Transect-I (alluvium soil), flooded soil-favoured root length density in older seedlings (CRC) and grain yield was near to SRI and ICM system with fertiliser treatment of NPK_{100–100–100} and NPK_{100–100–100} + FYM. In case of Transect-II and

Transect-III, non-flooded soil improved the root growth in the subsoil layer, but more in younger seedlings (SRI and ICM) than older ones (CRC).

Among three rice establishment methods, ICM produced significantly higher grain yield (52.72 q/ha) followed by SRI (49.90 q/ha) compared to CRC (44.67 q/ha). In SRI, water use efficiency was 17.71 kg/ha/mm, whereas in case of ICM it was 14.66 kg/ha/mm (Table 5). WUE was higher in SRI and ICM treatment mainly due to larger reductions in quantity of water used. Water use efficiency was lowest in CRC system (11.52 kg/ha/mm).

Sustainable Yield Index (SYI) of Rice

The result of sustainability indices (SYI) revealed that yields of rice under ICM and SRI were higher than of CRC method. The SYI of rice varied from 0.85 to 0.99, indicating the minimum guaranteed yield that ranges from 85 to 99 per cent of the maximum observed yield (54.10 q/ha)

Table 4 Comparison of yield parameters as influenced by different crop establishment methods in rice

Stand establishment method	Productive tillers per m ²	No. of panicles per m ²	No. of grain per panicle	Root volume (cc)	1000 grain weight (g)	Straw yield (q/ha)	Grain yield (q/ha)
SRI	320	195	173	60.7	23	62.4	49.90
ICM	350	215	172	52.1	23	70.9	52.72
CRC	264	173	165	43.8	19	56.7	44.67
Mean ± SE	311 ± 25	194 ± 12	170 ± 2.51	52.2 ± 4.87	21.6 ± 1.33	63.3 ± 4.12	49.1 ± 2.35
CV %	14.02	10.81	2.56	16.18	10.67	11.28	8.31
C.D. ($P < 0.05$)	33.20	7.91	5.18	2.39	3.67	4.00	1.20

Data presented are mean value of best fertiliser treatment (NPK_{50–50–50} + FYM + biofertiliser) only

Table 5 Water use efficiency of paddy rice with different crop establishment system

Crop establishment system	Effective rainfall (mm)	Actual water requirement (mm)	Actual water use by crop (mm)	Average grain yield (q/ha)	Water use efficiency (kg/ha/mm ¹)	Litres of water (per kg grain)
SRI (Saturation)	1029	747.8	281.2	49.90	17.71	1498
ICM (Saturation)	1169	809.4	359.6	52.72	14.66	1535
CRC (Saturation)	1229	841.3	387.7	44.67	11.52	1883
Mean \pm SE	1142 \pm 59	799 \pm 27	342 \pm 32	49 \pm 2.35	14 \pm 14.6	1638 \pm 122
CV %	8.98	5.94	16.09	8.31	21.15	12.96

Data presented are mean value of best fertiliser treatment (NPK₅₀₋₅₀₋₅₀ + FYM + biofertiliser)

under ICM system of crop establishment (Table 3). Further, it was observed that INM treatment (NPK₅₀₋₅₀₋₅₀ + FYM + biofertiliser) recorded higher SYI compared to NPK₁₀₀₋₁₀₀₋₁₀₀ fertiliser treatment under all crop establishment methods. The minimum values of SYI were seen in soils of Transect-II (0.85) and Transect-III (0.87) under CRC system.

Discussion

Sustainability of crop depends on the climate, maintenance of productivity and quality of soil on a long-term basis through integrated land, water and crop management [13, 21]. Climate change makes the temperature and rainfall fluctuates, consequently, influencing soil evaporation and plant transpiration. A significant decreasing trend of monsoon-season rainfall (June to October) and a trend of higher temperature were noted in the study area during last 13 years (Fig. 1). Van de Geijn and Goudriaan [36] found that positive climate effects on crop growth can be adjusted by effective rooting depth, nutrients and improvement in water productivity. Increased grain yield (19–29%) under ICM and SRI over CRC practices was mainly due to the synergistic effects of modification in the cultivation

practices such as use of young 1 or 2 seedlings per hill and frequent loosening of the top soil to stimulate aerobic soil conditions [33]. Overall younger seedlings produced higher numbers of tillers than older seedlings, which might be due to less root damage and minimum transplanting shock, as younger seedlings can more easily establish themselves after transplanting in the main field [2, 12, 15, 30]. The nodal root from the coleoptilar node might have played a large role in the absorption of water and nutrients just after transplanting. Initial stage of seedling development favour more root formation for better establishment and water uptake [23]. Root elongation did not seem to be a problem under flooded soil conditions, but root initiation was restricted under flooding. Wider spacing in ICM and SRI methods facilitate the operation of cono-weeder resulting in the incorporation of weeds into the soil and also favour better aeration for beneficial microbial activity. On the other hand, lower yield in CRC is due to narrow spacing intern leads competition between nutrient and space.

Application of INM (NPK₅₀₋₅₀₋₅₀ + FYM + biofertiliser) improved the fertiliser use efficiency due to presence of FYM and biofertiliser in the system. It also favours the better crop growth [11] and produced the crop yield equivalent to NPK₁₀₀₋₁₀₀₋₁₀₀ resulting in reduced cost of cultivation. The fixation of applied P is a constraint in

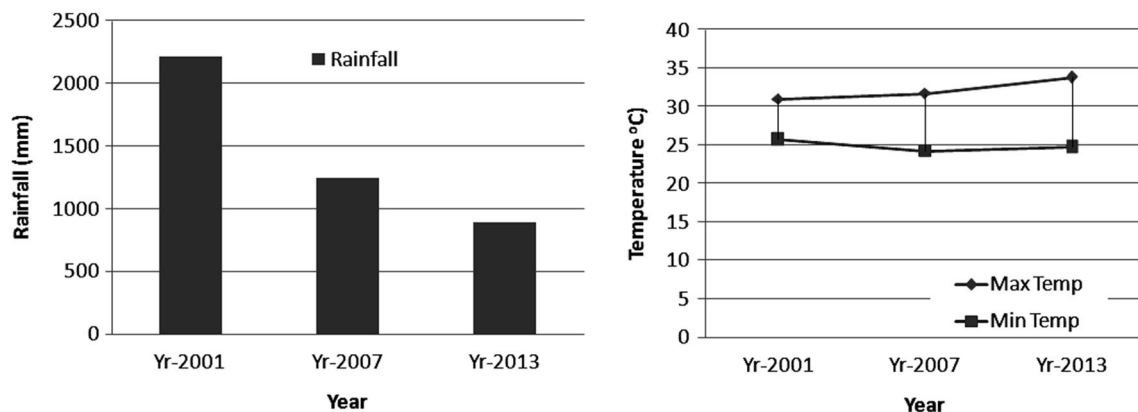


Fig. 1 Trends of rainfall and temperature during the year 2001–2013 in the study area

acidic soils and application of FYM enhances the rate of P mineralisation [28] and reduction in P adsorption [20]. The increase in rice grain yield even under CRC system with $\text{NPK}_{50-50-50} + \text{FYM} + \text{biofertiliser}$ application might be due to the preference of shoot growth over root growth in older seedlings and the dominance of NH_4^+ in the soil solution in the upper soil layers under reduced environment [24]. Although SRI and ICM practices of rice culture may reduce CH_4 emissions from rice fields, it may result in increased N_2O emissions [3]. The N_2O is having 310 times global warming potential than CO_2 . The appropriate combination of organic matter incorporation and N application may help in mitigation of N_2O emissions. Thus, use of 50% of N-chemical fertiliser with FYM and biofertiliser under INM practices may help to maximise the benefit of positive aspects and minimise the environmentally negative effects.

Farmers solely rely on rainfall in the study area for rice production. Management options for more efficient use of rainwater include crop scheduling and shifting away from continuously flooded (anaerobic) to partly aerobic rice and are important to improve the efficiency of water use [10]. The water requirement was about 50.67% less in SRI and 25% in ICM as compared to CRC. Similar observations were reported where 25 to 50% less water was required in SRI over conventional method [5, 22, 34]. Further, the quantity of water required for producing one kilogram of rice was found to be 1498 L in SRI and 1535 L in ICM, compared to 1883 L in flooded CRC. Thus, physical water requirements for the production were about 19–21 per cent higher in flooded CRC.

Sustainability Yield Index (SYI) is a qualitative measure to assess sustainability of agricultural practices and helps to find out the minimum guaranteed yield that can be obtained in terms of maximum observed yield of an area. The nearness of SYI to 1 indicates closeness to the ideal condition wherein the soil can sustain the potential yield over years and the deviation from 1 indicates losses to sustainability [32]. The results indicate that integrated nutrient management and transplantation of 1 or 2 younger seedlings with wider spacing under saturated water condition are important management practices in rice cultivation under changed climatic scenario as these significantly influence the SYI and sustain the potential yield of rice.

Conclusions

It can be concluded that crop establishment method, soil–water regime and INM practices are important as these significantly influence the sustainability yield indices of rice. Due to the wider spacing combined with younger aged seedlings in SRI and ICM, practices created favourable

growth conditions for rice plants to sustain the potential yield. Transplantation of two 20-days-old seedlings under ICM method was found more convenient as this system also have similar positive impact on production and yield as compared to SRI. The result of the study clearly indicated that amount of fertiliser under SRI and ICM methods of transplanted rice can be reduced to the half of the recommended fertiliser requirement of CRC method. Application of chemical fertiliser along with FYM and biofertiliser not only helped in improving the inherent fertility of soil but also reduces the cost of nutrient application. Physical water requirements for the rice production under SRI and ICM were also reduced to about 19–21 per cent. The fertiliser and water saved for rice can be effectively used for increasing the area under rice or other irrigated dry crops in the cropping sequence, thereby enhancing the system productivity.

References

1. Auffhammer M, Ramanathan V, Vincent JR (2006) Integrated model shows that atmospheric brown clouds and greenhouse gases have reduced rice harvests in India. In: Proceedings of National Academy of Sciences of the USA, pp 19668–19672
2. Ceesay M, Reid SW, Fernandes ECM, Uphoff NT (2006) The effect of repeated soil wetting and drying on low land rice yield with System of Rice Intensification (SRI) methods. *Int J Agric Sustain* 4:5–14
3. Chauhan BS, Mahajan G (2013) Strategies for boosting rice yield in the face of climate change in India. *J Rice Res* 1:1
4. Cruz RV, Harasawa H, Lai M, Wu S, Anokhin Y, Punsalma B, Honda Y, Jafari M, Li C, Ninh HN (2007) Asia Climate change 2007: impacts, adaptation and vulnerability. In: Parry ML, Canziani OF, Palutikof JP, Van der Linden PJ, Hanson CE (eds) Contribution of working group II to the fourth assessment report of the international panel on climate change. Cambridge University Press, Cambridge, pp 469–506
5. Chapagain T, 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 Environ* 8:81–90
6. Dey S, Tripathi SN (2008) Aerosol direct radiative effects over Kanpur in the Indo-Gangetic basin, northern India: long-term (2001–2005) observations and implications to regional climate. *J Geophys Res* 113:1–20
7. Fernandes ECM, Uphoff N (2002) Summary from conference reports. In: Uphoff N, Fernandes ECM, Yuan LP, Peng JM, Rafaralahy S, Rabenandrasana J (eds) Assessment of the system for rice intensification (SRI). Cornell International Institute for Food, Agriculture and Development, (CIIFAD), Ithaca, pp 33–39
8. Ghosh A, Jha KP (2002) Advances in rice production technology for rainfed lowland ecology in eastern India. *Indian Farm* 52:3–6
9. Hore DK (2005) Rice diversity collection, conservation and management in northeastern India. *Genet Resour Crop Evol* 52:1129–1140
10. Humphreys E, Masih I, Kukal SS, Turrall H, Sikka A (2006) Increasing field scale water productivity of rice–wheat systems in the Indo-Gangetic Basin. In: Proceedings of International Rice Congress, New Delhi

11. Gouranga Kar, Verma HN, Ravender Singh (2006) Effects of post-rainy season crop and supplemental irrigation on crop yield, water use efficiency and profitability in rainfed rice based cropping system of eastern India. *Agric Water Manag* 79:280–292
12. Kabir H, Uphoff N (2007) Results of disseminating the system of rice intensification with farmer field school methods in Northern Myanmar. *Exp Agric* 43:463–476
13. Kanwar JS (1994) Relevance of soil management in sustainable agriculture. Soil management for sustainable agriculture in dryland areas. Indian Society of Soil Science, New Delhi, pp 1–11
14. Mati BM, Wanjogu R, Odongo B, Home PG (2011) Introduction of the system of rice intensification in Kenya: experiences from Mwea irrigation scheme. *Paddy Water Environ*, 9:145–154
15. Abha Mishra, Salokhe VM (2008) Seedling characteristics and the early growth of transplanted rice under different water regimes. *Exp Agric* 44:1–19
16. NARP (1979) Agro-climatic zone specific research: Indian perspective under NARP. ICAR, New Delhi
17. NBSSLUP (1996) Soils of India: Soils of Tripura for optimising land use. National Bureau of Soil Survey and land Use Planning (ICAR), Nagpur
18. Pandey S, Sanamangkoun M (1998) Rainfed lowland rice in Laos: a socioeconomic benchmark study. IRRI, Los Baños
19. Peng S, Huang J, Sheehy JE, Laza RC, Visperas RM (2004) Rice yields decline with higher night temperature from global warming. In: *Proceedings of the National Academy of Sciences of the USA*, pp 9971–9975
20. Prasad J, Mathur BS (1997) Influence of long-term use of fertilizers. *Indian Soc Soil Sci* 45:24–27
21. Randhawa NS (1994) Retrospect and prospect of rainfed agriculture and watershed management in India. *Soil Management for Sustainable Agriculture in Dryland Areas*, Indian Society of Soil Science, New Delhi, pp 135–143
22. Randriamiharisoa R, Uphoff N (2002) Factorial trials evaluating the separate and combined effects of SRI practices. In: *Proceedings of an International Conference*, Ithaca, Sanya
23. Sasaki R, Hoshikawa K (1997) The role of crown roots from coleoptilar node in the rooting and development of transplanted rice nurdling seedlings. *Jpn J Crop Sci* 66:259–267
24. Sah RN, Mikkelsen DS (1983) Availability and utilization of fertilizer nitrogen by rice under alternate flooding II: effects on growth and nitrogen use efficiency. *Plant Soil* 75:227–234
25. Setty P, Bandi TK, Satnam Singh AG, Sanjay MT (2007) Influence of integrated nutrient management on growth and yield of hybrid rice under System of Rice Intensification (SRI) and Aerobic method of cultivation. In: *Proceedings of national symposium on system of rice intensification (SRI) in India-progress and prospects*, Agartala, India, pp 82–84
26. Schiller JM, Chaphengxay MB, Linnquist B, Rao SA (2006) Rice in Laos. International Rice Research Institute, Philippines
27. Sheehy J, Mitchell PL, Beerling DJ, Tsukaguchi T (1998) Temperature of rice spikelets: thermal damage and the concept of a thermal burden. *Agronomy* 18:449–460
28. Sarmah AC, Bordoloi PK (1994) Decomposition of organic matter in soils in relation to mineralization of carbon and nutrient availability. *Indian Soc Soil Sci* 42:199–203
29. Serpantie G, Rakotondramanana M (2013) Malagasy rice intensification, in practice. *Cahiers Agric* 22:401–410
30. Sinha SK, Talati J (2007) Productivity impacts of the system of rice intensification (SRI): a case study in West Bengal, India. *Agric Water Manag* 87:55–60
31. Singh AK, Chakraborti M, Datta M (2014) Efficient use of soil moisture and nutrients in rice based cropping systems under mid-tropical plain zone of India. *Rice Sci* 21(5):299–304
32. Singh RP, Das SK, Bhaskar Rao VM, Narayana Reddy M (1990) Towards sustainable dry land agriculture practices. CRIDA Report, Hyderabad
33. Stoop WA, Uphoff N, Kassam A (2002) A review of agricultural research issues raised by the system of rice intensification (SRI) from Madagascar: opportunities for improving farming systems for resource poor farmers. *Agric Sys* 71:249–274
34. Thiagarajan TM, Velu V, Ramasamy S, Durgadevi D, Govindarajan Priyadardhini R, Sudhalakshmi C, Senthilkumar K, Nisha PT, Gayathry G, Hengsdijk H, and Bindraban PS (2002) Effects of SRI practices on hybrid rice performance in Tamil Nadu, India, Water-wise rice production. In: *Proceedings of the international workshop on water-wise rice production*, Tamil Nadu, India, pp 19–127
35. Uphoff N, Anas I, Rupela OP, Thiagarajan TM (2009) Learning about positive plant-microbial interactions from the System of Rice Intensification. *Aspects Appl Biol* 98:29–53
36. Van de Geijn SC, Goudriaan J (1996) The effects of elevated CO₂ and temperature change on transpiration and crop water use. In: Bazzaz F, Sombroek WG (eds) *Global climate change and agriculture production*. Wiley, New York, pp 1–21
37. Welch J, Vincent JR, Auffhammer M, Moya PF, Dobermann A (2010) Rice yields in tropical/subtropical Asia exhibit large but opposing sensitivities to minimum and maximum temperatures. In: *Proceedings of the National Academy Science*, pp 14562–14567