Indian Journal of Agricultural Sciences **85** (5): 634–9, May 2015/Article

Productivity, profitability, nutrient uptake and soil health as influenced by establishment methods and nutrient management practices in transplanted rice (*Oryza sativa*) under hill ecosystem of North East India

RAKESH KUMAR[1], MANOJ KUMAR[2], AMIT KUMAR[3] and AVINASH PANDEY[4]

ICAR Research Complex for NEH Region, Nagaland Centre, Jharnapani, Nagaland 797 103

Received: 19 February 2014; Accepted: 18 November 2014

ABSTRACT

To evaluate the effect of different crop establishment methods and nutrient management practices in transplanted rice (*Oryza sativa* L.) under hill ecosystem, a field experiment was conducted at Agricultural Research Farm of Indian Council of Agricultural Research, Research Complex for North Eastern Hill Region, Jharnapani, Medziphema during *kharif* season of 2011 and 2012.Three crop establishment methods, viz. SRI (system of rice intensification), ICM (integrated crop management) and CTR (conventionally transplanted rice) were kept in main plots and five nutrient management practices, viz. control, 100% recommended dose of fertilizer (RDF), 100% RDF + 5 tonnes rice straw/ha, 100% RDN through FYM and 100% RDN through FYM + 5 tonnes rice straw/ha were allotted to sub-plots in a split-plot design and replicated thrice. The result showed that number of panicles/m^2, panicle length and test weight were recorded significantly higher under SRI followed by ICM and CTR, whereas, grain yield was recorded higher with ICM followed by SRI than CTR. Among the nutrient management practices, application of 100% RDF + 5 tonnes rice straw/ha recorded significantly higher yield attributes and grain yield of 4.61 and 4.73 tonnes/ha in year 2011 and 2012, respectively and which was followed by 100% RDN through FYM + 5 tonnes rice straw/ha. Higher nutrient uptake (NPK) by grain and straw as well as total uptake were recorded under ICM followed by SRI and CTR. Similarly, higher nutrient uptake by grain and straw was recorded with 100% RDF + 5 tonnes rice straw/ha. The Maximum gross income, net income, benefit: cost ratio were significantly higher in ICM followed by SRI and CTR. Similarly, the maximum gross income, net income and benefit: cost ratio was fetched with 100% RDF + 5 tonnes rice straw/ha followed by 100% RDF.

Key words: CTR, Economics, ICM, Net return, Nutrient management, Soil health, Yield

The existing system of rice (*Oryza sativa* L.) production, particularly green revolution technology is input intensive and favours cash rich farmers. Increasing prices of agricultural inputs prevent the poor farmers from completely adopting the modern production technologies. The excessive use of agrochemicals damages the soil biota. In such a situation, system of rice intensification (SRI), which is a low cost and high yielding system, might be a sustainable alternative to conventional paddy production (Batuvitage 2002). Numerous water-saving technologies for rice have been validated in Asia though they remain relatively untested and are not yet recommended. Of these, SRI has attracted the most attention. SRI techniques include the line transplanting of single young seedlings at wider spacing, mechanical weed control, alternate wetting and drying irrigation and application of organic amendments preferably compost or manure. SRI advocates argue these techniques provide very high yields and improve the water productivity (Uphoff *et al*. 2010). In India, where cultivable land is decreasing due to increasing demand of land from other sectors and where an increasing population is creating additional demand for foodgrains, farmers are adopting intensive tillage, more and more chemical fertilizers, more irrigation and excessive pesticides that have adverse impacts on the soil health and productivity of the crops. Poor farmers lost their interest in rice cultivation as declining the factor productivity and its profitability is in question with rise in input costs (Das *et al.* 2010). In this context, new technologies such as SRI and integrated crop management (ICM intermediate practice of SRI and CTR, i.e. 20 days seedling age, medium spacing 20 cm × 20 cm, single seedling/hill), appear to have potential that saves input, protect the environment and could improve the productivity and soil health (Sinha and Talati 2007). SRI principles encourage use of organic manure instead of inorganic fertilizers to

[1]Scientist (Agronomy) (e mail: rakeshbhu08@gmail.com), [2]Subject Matter Specialist (Agronomy) (e mail: mkumar_cprs@yahoo.co.in), KVK Longleng, [3]Scientist (Plant Breeding) (e mail: amit4118@gmail.com), [4]Scientist (Plant Breeding) (e mail: nashpgr@gmail.com), ICAR RC for NEH Region, Umaim, Meghalaya

harness the optimum crop potential. However, much of available literature suggests that integrated nutrient management with a judicious combination of organic manure and inorganic fertilizer as per resources available with the farmers is the best option for achieving the higher crop productivity (Aulakh and Grant 2008). Hence, there is a need to evaluate the individual and integrated effect of organic and inorganic fertilizers for SRI, ICM vis-à-vis CTR. Therefore, an attempt has been made to evaluate the effect of different crop establishment methods and nutrient management practices on productivity, profitability, nutrient uptake and soil health in transplanted rice under hill ecosystem of North East India.

MATERIALS AND METHODS

The field experiment was conducted at Agricultural Research Farm of Indian Council of Agricultural Research, Research Complex for North Eastern Hill Region, Nagaland Centre Jharnapani, Medziphema during *kharif* season of 2011 and 2012. The experimental site was located between 25.45° N latitude 93.53° E longitudes with a mean altitude of 295 m above mean sea level. The soil of experimental field was sandy loam and acidic in reaction (pH 5.3), high in organic carbon (0.93%), low in available N (225 kg/ha) and K (140 kg/ha) and medium in available P (12 kg/ha).The experiment was conducted in split plot design with three replications. The mean monthly average temperatures were varying from 20.3°C to 27.9°C in 2011 and 21.0°C to 28.4°C in 2012, respectively. Total rainfall received during the crop period was 1 442 mm and 1 160 mm in 2011 and 2012, respectively. However, rainfall distribution over month was better in 2012 as compare to 2011. The monthly rainfall was the maximum in month of June 2011 and July 2012. Three crop establishment methods, viz. SRI, ICM and CTR (conventionally transplanted rice) were kept in main plots and five nutrient management practices, viz. control, 100% recommended dose of fertilizer (RDF 120:60:40 NPK kg/ha), 100% RDF + 5 tonnes rice straw/ha, 100% RDN through FYM and 100% RDN through FYM + 5 tonnes rice straw/ha allotted to sub-plots in a split-plot design and replicated thrice. Farmyard manures was applied on the basis of N equivalent basis in 100% RDN. The gross and net plot sizes were 5 m × 5 m and 4 m × 4 m, respectively and treatments were superimposed in the same plot every year to study the cumulative effect of treatments. Nurseries for all the three establishment methods were sown on same day but transplanting date varied as per the requirement of different establishment methods. For SRI, 10 days old seedlings at single seedling/hill was used with 25 cm × 25 cm spacing while for ICM, 20 days old seedlings at 2 seedlings/hill with a spacing of 20 cm × 20 cm and for CTR, 30 days old seedlings at 3 seedlings/hill with the spacing of 20 cm × 15 cm was followed. A medium duration with high yielding rice variety RCM 11 was used as test crop. A nursery of a 100 m^2 area and 10-12 kg of good quality seeds were sufficient for 1 ha area with ICM method and a 50 m^2 nursery with 5-7 kg seeds was enough for SRI method. The seedlings attained one and a half leaf stage in about 10 days and young seedlings were transplanted by scooping the single seedlings for SRI and on 20^{th} day for ICM method (2-3 leaves). The supply of N, P and K was ensured through urea, di-ammonium phosphate (DAP) and muriate of potash (MOP) fertilizer. A half dose of N and full dose of P and K were applied as basal. Remaining half dose of N was applied in two equal splits at maximum tillering and panicle initiation stages. Two hand weeding (HWs) in CTR (20 and 45 days after transplanting (DAT) and two HWs (15 and 45 DAT) and one weeding with cono-weeder (30 DAT) was done in SRI and ICM methods. The complete recommended method of water management for SRI and ICM could not be followed due to high rainfall pattern. For easy irrigation and drainage of water, a channel of 30 cm width and 20 cm depth was provided around each individual plots. A continuous flooded water level of about 5±2 cm was maintained in the CTR plots. After the grain-filling stage, water from all the plots irrespective of establishment methods was drained out. Yield attributes such as panicles/ m, panicle length and weight, grains/panicle and test weight were recorded at maturity from randomly selected of five hills in each plot. The crop samples were subjected to the chemical analysis for N, P and K content. The samples were oven dried at 70-75°C for 72 hr and ground to pass a 20 mesh sieve. Total nitrogen and phosphorus content in plant was determined by using Kjeldahl and Vandate molybdate method, respectively. Potassium content of the plant sample was estimated by using a flame photometer. Total uptake of nitrogen, phosphorus and potassium by the crop was estimated employing dry matter yield and N, P and K content recorded. Surface soil samples collected from 0-15 cm depth were air dried in shade, sieved through 2 mm mesh and analyzed for soil physical and chemical properties. Soil organic carbon (SOC) was determined according to Walkley and Black (1934). Available N in soil was estimated according to (Subbiah and Asija 1973) by distillation of soil with alkaline potassium permanganate (0.32% $KMnO_4$). Available P (Olsen P) in soil was determined according to Olsen *et al.* (1954) extracting soil P in sodium bicarbonate ($NaHCO_3$). Available K (readily exchangeable plus water soluble K) in soil was extracted in neutral normal ammonium acetate (1 *N* CH_3COONH_4). Soil microbial biomass carbon (SMBC) was determined by ethanol-free chloroform fumigation extraction method. Gross return, net return and benefit: cost ratio in different nutrient management systems were derived by computing the prevailing price of input and output. The analysis of variance method (Gomez and Gomez 1984) was followed to statistically analyze the various data. The significance of different sources of variations was tested by error mean square of Fisher Snedecor's 'F' test at probability level (P =0.05).

RESULTS AND DISCUSSION

Yield attributes and yield

Yield attributes of rice, viz. panicle/m, grain filling

Table 1 Yield attributes of rice as influenced by establishment methods and nutrient management practices

Treatment	Panicles/m (No.)		Grain filling (%)		Panicle length (cm)		Panicle weight (g)		Grains/panicle (No.)		Test weight (g)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Establishment methods												
SRI	182.9	185.5	86.2	85.5	25.23	25.29	4.31	4.39	202.6	207.6	24.23	24.41
ICM	197.7	199.7	84.6	83.1	24.49	24.60	4.17	4.31	195.3	198.3	23.81	23.88
CTR	223.6	224.8	81.7	80.7	23.18	23.29	3.79	3.89	188.5	190.5	22.93	22.82
CD (*P*=0.05)	6.03	4.38	2.96	2.89	1.15	1.68	0.25	0.24	4.34	3.47	0.62	0.71
Fertility level												
Control	186.6	185.9	78.2	77.2	22.97	22.74	3.93	3.92	186.0	189.3	22.89	22.41
100% RDF	202.0	204.4	83.5	83.2	24.35	24.52	4.08	4.21	194.7	198.0	23.86	23.75
100% RDF + 5 tonnes rice straw/ha	208.4	211.0	87.6	88.1	25.43	25.60	4.28	4.42	202.6	205.9	24.16	24.50
100% RDN through FYM	203.5	206.0	85.2	82.2	24.28	24.44	4.06	4.19	194.4	197.8	23.58	23.74
100% RDN through FYM + 5 tonnes rice straw/ha	206.6	209.2	86.3	84.9	24.49	24.66	4.11	4.24	199.7	203.0	23.78	24.11
CD (*P*=0.05)	10.63	9.16	2.72	4.03	1.35	1.69	0.18	0.17	5.47	4.61	0.75	0.82

SRI-System of rice intensification; ICM-Integrated crop management; CTR- Conventially transplanted rice, RDF-RDNPK

(%), panicle length and weight, grains/panicle and test weight were significantly influenced by establishment methods and nutrient management practices (Table 1). Number of panicle/m was significantly higher in CTR followed by ICM and SRI, whereas grain filling (%), panicle length and weight, grains/panicle and test weight were significantly higher in SRI. All the yield attributes in relation to individual hill were recorded maximum under SRI followed by ICM and minimum with CTR. Significantly higher grain yield (4.41 and 4.47 tonnes/ha) was recorded with ICM which was statistically similar to SRI in both years, respectively (Table 2). Whereas, higher straw yield (5.48 and 5.51 tonnes/ha) was observed under SRI which was significantly superior over ICM and CTR during both the years. The higher grain yield in ICM was mainly due to higher number of panicles/m^2 as compared with SRI. Reddy *et al*. (2007) reported that SRI resulted increase in number of panicles/m^2 by 14.4%, grains/panicle by 16.8%, test weight by 2.9% and grain

Table 2 Yield and economics of rice as influenced by establishment methods and nutrient management practices

Treatment	Grain yield (tonnes ha)		Straw yield (tonnes ha)		Gross income (₹/ha)		Net income (₹/ha)		Benefit: cost ratio	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Establishment methods										
SRI	4.39	4.39	5.48	5.51	37 997	38 011	14 854	14 868	1.66	1.66
ICM	4.41	4.47	5.33	5.35	38 080	38 620	15 376	15 916	1.70	1.72
CTR	4.22	4.25	4.85	4.85	36 328	36 545	12 156	12 373	1.52	1.52
CD (*P*=0.05)	0.15	0.16	0.48	0.45	1 303	1 278	1 200	1 173	0.05	0.04
Fertility level										
Control	3.70	3.62	4.88	4.82	32 185	31 533	13 231	12 580	1.70	1.67
100% RDF	4.41	4.39	5.24	5.19	38 068	37 861	16 406	16 199	1.76	1.75
100% RDF + 5 tonnes rice straw/ha	4.61	4.73	5.44	5.51	39 774	40 787	17 114	18 127	1.76	1.80
100 % RDN through FYM	4.43	4.49	5.22	5.28	38 234	38 708	12 884	13 358	1.51	1.53
100% RDN through FYM + 5 tonnes rice straw/ha	4.53	4.61	5.31	5.38	39 081	39 739	11 007	11 665	1.39	1.42
CD (*P*=0.05)	0.17	0.19	0.19	0.20	1 395	1 540	1 418	1 540	0.07	0.07

SRI-System of rice intensification; ICM-Integrated crop management; CTR- Conventially transplanted rice, RDF-RDNPK yield by 16.6% over CTR. Rajendran *et al.* (2004) also reported that planting of 15 days old seedlings of rice gave 16-20% higher yield than 25 days old seedling because seedling mature later and delayed formation of tillers and time to recover from transplanting.

All the nutrient managements practices were recorded significantly higher values of yield attributes, viz. panicles/ m, grain filling (%), panicle length and weight, grains/ panicle and test weight compared to control (Table 1). The maximum values of these yield attributes were recorded with application of 100% RDF + 5 tonnes rice straw/ha, which was closely followed by 100% RDN through FYM + 5 tonnes rice straw/ha and higher than control. This might be due to more utilization of available plant nutrient in adequate amount, which result in ultimately higher grain filling (%), panicle length and weight, grains/ panicle and test weight and finally increased the crop productivity. Mirza *et al.* (2010) reported increase in number of tillers in rice plants due to integrated application of organic and inorganic nutrients. Among the nutrient management practices, application of 100% RDF + 5 tonnes rice straw/ha produced significantly higher grain yield 4.61 and 4.73 tonnes/ha in 2011 and 2012, respectively and which was followed by 100% RDN through FYM + 5 tonnes rice straw ha. Similarly, higher straw yield was also recorded with 100% RDF+5 tonnes rice straw/ha. This significant response might be due to enhanced nutrient availability to crop by the application of organic manures in combination with inorganic fertilizers. Higher grain and straw yield of rice with integrated application was also been reported by Das *et al*. (2013).

Nutrient uptake

Nutrient uptake (N, P and K) by grain and straw as well as total uptake by the rice crop were recorded significantly higher with ICM followed by SRI and CTR (Table 3 and 4). Total uptake of N, P and K were recorded higher in ICM as compared to SRI and CTR. Among the nutrient management practices, application of 100% RDF + 5 tonnes rice straw/ ha significantly improved NPK uptake by grain, straw and total uptake by rice crop as compared to other sources of nutrient management. This might be due to the initial quick availability of nutrient from inorganic source and later from an organic source, leading to an overall higher nutrient uptake (Das *et al*. 2010).

Economics

Gross income, net income, benefit: cost ratio was influenced by crop establishment methods and nutrient management practices during both the year (Table 2). The maximum gross income (₹ 38 350), net income (₹ 15 646) and benefit cost ratio (1.71) were recorded with ICM, which was at par with SRI but significantly higher than CTR. Whereas the minimum net return and benefit: cost ratio were recorded in CTR. Higher net return in ICM and SRI than CTR has been reported by Das *et al.* (2013). Among the nutrient management practices, the maximum gross income (₹ 38 234 and 38 708/ha), net income (₹ 12 884 and 13 358/ha) and benefit: cost ratio (1.51 and 1.53) was recorded with 100% RDF + 5 tonnes rice straw/ha followed by 100% RDF through chemical fertilizers in both the years. This might be due to higher productivity of the rice crop. Net income was recorded less in FYM or in

Table 3 Nutrient uptake of grain and straw as influenced by establishment methods and nutrient management practices

Treatment	Grain (kg/ha)						Straw (kg/ha)					
	N		P		K		N		P		K	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Establishment methods												
SRI	55.68	55.68	11.37	12.18	20.72	20.84	27.70	27.78	11.36	11.72	59.48	60.03
ICM	56.41	57.05	11.88	12.02	21.49	21.70	27.50	27.76	12.07	12.25	58.83	59.43
CTR	52.77	53.11	10.35	10.51	19.46	19.40	23.47	23.60	9.12	9.43	50.54	50.89
CD (*P*=0.05)	2.79	2.53	1.07	NS	0.91	0.71	3.45	6.94	1.73	2.05	4.52	3.92
Fertility level												
Control	45.63	44.60	8.39	8.01	15.98	15.36	22.47	21.77	8.91	8.69	49.67	48.49
100% RDF	55.63	55.21	11.02	11.36	21.46	21.25	26.11	25.91	11.06	11.28	55.84	55.93
100% RDF + 5 tonnes rice straw/ha	59.40	61.00	12.82	13.79	22.53	23.38	28.97	29.77	12.69	13.22	60.95	62.19
100% RDN through FYM	56.21	56.81	11.49	11.93	21.00	21.31	26.33	26.59	10.59	10.93	56.50	57.61
100% RDN through FYM + 5 tonnes rice straw/ha	57.88	58.77	12.29	12.75	21.82	21.94	27.26	27.87	11.00	11.55	58.47	59.68
CD (*P*=0.05)	2.02	2.28	0.66	0.58	1.00	1.14	1.52	1.64	0.82	0.85	2.93	2.71

SRI-System of rice intensification; ICM-integrated crop management; CTR- conventially transplanted rice, RDF-RDNPK

Table 4 Total nutrient uptake (kg/ha) by crop as influenced by establishment methods and nutrient management practices

Treatment	Total uptake (grain + straw)					
	N		P		K	
	2011	2012	2011	2012	2011	2012
Establishment methods						
SRI	83.38	83.47	22.73	23.90	80.20	80.87
ICM	83.92	84.80	23.96	24.26	80.32	81.13
CTR	76.24	76.71	19.47	19.94	70.00	70.29
CD (P=0.05)	2.78	6.02	2.54	3.25	5.12	4.09
Fertility level						
Control	68.10	66.38	17.30	16.70	65.64	63.85
100 % RDF	81.74	81.11	22.08	22.64	77.29	77.19
100 % RDF + 5 tonnes rice straw/ha	88.37	90.77	25.52	27.00	83.48	85.57
100% RDN through FYM	82.54	83.40	22.08	22.86	77.51	78.93
100% RDN through FYM 5 tonnes rice straw/ha	85.14	86.64	23.29	24.30	80.29	81.62
CD (P=0.05)	2.30	2.50	0.81	1.10	3.21	2.65

SRI-System of rice intensification; ICM-integrated crop management; CTR-conventially transplanted rice, RDF-RDNPK

Table 5 Soil health as influenced by establishment method and nutrient management practices (Pooled data of 2 years)

Treatment	SOC (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)	SMBC (µg/g/ soil)	BD (g/ cm)
Establishment methods						
SRI	0.78	167.27	18.48	176.30	142.01	1.28
ICM	0.77	165.02	17.22	175.99	141.35	1.28
CTR	0.78	166.49	16.91	175.18	141.67	1.27
CD (*P*=0.05)	NS	NS	0.88	NS	NS	NS
Fertility level						
Control	0.70	161.47	16.04	174.98	135.53	1.30
100 % RDF	0.78	165.00	17.09	175.71	141.97	1.29
100 % RDF + 5 tonnes rice straw/ha	0.81	169.23	18.34	175.79	144.36	1.27
100 % RDN through FYM	0.77	167.38	18.27	176.16	142.06	1.26
100 % RDN through FYM + 5 tonnes rice straw/ha	0.82	168.22	17.93	176.49	144.47	1.25
CD (*P*=0.05)	0.05	2.24	0.83	0.80	3.90	0.010

SRI-System of rice intensification; ICM-integrated crop management; CTR-conventially transplanted rice, RDF - RDNPK

combination of FYM and this might be due to FYM had more cost of cultivation. These results are in conformity with the findings of Kumar *et al*. (2013).

Soil health

Different establishment methods did not show any significant effect on soil fertility in terms of soil organic carbon (SOC), available N, K, BD and SMBC, whereas available P had significant effect which was recorded higher under SRI followed by ICM and CTR (Table 5). This might be due to use of cono-weeder under SRI, created better physico-chemical conditions, which enhance the soil microbial activities and P availability. Among the nutrient management practices, higher SOC (0.81%), available N (169.23 kg/ha), available P (18.34 kg/ha) and available K (175.79 kg/ha) were recorded with 100 % RDF + 5 tonnes rice straw/ha over control. Increase in available N and P might be due to the direct addition of N through rice straw and improved microbial activities, which might have converted organically bound N to inorganic forms. Increase in P availability might be due to the fact that organic materials form a cover on sesquioxides and thus reduce the phosphate fixing capacity of the soil and increased phosphorus solubilization for the native soil pool. The benefit of using organic manure like FYM was due to release of aliphatic and aromatic hydroxy acids and humates leads to higher availability of nutrients. The results corroborate with the similar findings of Das and Sinha (2004).

From the present investigation, it could be concluded that intermediate practice of ICM with recommended dose of NPK along with 5 tonnes rice straw/ha has greater potential than SRI as ICM produced higher productivity and profitability for the high rainfall zone of the Eastern Himalaya.

REFERENCES

Aulakh M S and Grant C A. 2008. *Integrated Nutrient Management for Sustainable Crop Production*. The Haworth Press, New York.

Batuvitage G P. 2002. Adaptation of the System of Rice Intensification in Sri Lanka. Cornell International Institute for Food, Agriculture and Development (on line), Internet http://ciiffad.cornel.edu/sri; 607-255-0831.

Das A, Patel D P, Munda G C, Ramkrushna G I, Kumar M and Ngachan S V.2013. Improving productivity, water and energy use efficiency in lowland rice (*Oryza sativa*) through appropriate methods and nutrient management practices in the mid altitude of North-East India. *Experimental Agriculture* doi: 10.1017/S0014479713000483

Das A, Tomar J M S, Ramesh T, Munda G C, Ghosh, P K and Patel D P. 2010. Productivity and economics of low land rice as influenced by N-fixing tree leaves under mid-altitude sub-tropical Meghalaya. *Nutrient Cycling in Agroecosystems* **87**: 9–19.

Das T and Sinha A C. 2004. Effect of organic materials and levels of nitrogen on yield attributes and yield of rice (*Oryza sativa* L.) under Terai region of West Bengal. *Environment and Ecology* **22** (2): 362–5.

Gomez K A and Gomez A A.1984. *Statistical Procedures for Agricultural Research,* 2nd edn. Wiley, New York.

Kumar M, Das A, Ramkrushna G I, Patel D P, Munda G C, Naropongla and Buragohain J.2013. Effect of nutrient sources and transplanting date on aromatic rice (*Oryza sativa*) under mid hills of north eastern India. *Indian Journal of Agronomy* **58** (3): 322–6.

Mirza H, Ahamed K U, Rahmatullah N M, Akhetar K N and Rahman M J. 2010.Plant growth characters and productivity of wetland rice (*Oryza sativa* L.) as affected by application of different manures. *Emirates Journal of Food and Agriculture* **22** (1): 46–58.

Olsen S R, Cole C W, Watanabe F S and Dean L A.1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular No. 939, pp 19–23.

Rajendran R, Balasubramanian V, Ravi V, Valliappan K, Jayaraj T and Ramanathan S. 2004. Nursery technology for early production of robust rice seedlings to transplant under integrated crop management. *International Rice Research Notes* **29** (2): 73–5.

Reddy M M, Reddy C V and Reddy P R. 2007. Status of SRI in Andhra Pradesh, problems and prospects. (*In*) *Second National Symposium on SRI*, 3-5 October 2007, Agartala, Tripura, India.

Sinha S K and Talati J. 2007. Productivity impacts of the system of rice intensification (SRI): a case study in West Bengal, India. *Agricultural Water Management* **87**: 55–60.

Subbiah B V and Asija G L. 1973. A rapid procedure for estimation of available nitrogen in soils. *Current Science* **28** (8): 259–60.

Uphoff N, Kassam A and Hardwood R. 2010. SRI as a methodology for raising crop and water productivity: productive adaptations in rice agronomy and irrigation water management. *Paddy Water Environment* **9**: 3–11.

Walkley A and Black I A. 1934. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* **37**: 29–37.