Indian Journal of Agronomy **60** (1): 1—19 (March 2015)

Review/Overview Article

System of rice (*Oryza sativa*) intensification for higher productivity and resource-use efficiency–A review

ANCHAL DASS[1], RAMANJIT KAUR[2], ANIL K. CHOUDHARY[3], V. POONIYA[4], RISHI RAJ[5] AND K.S. RANA[6]

ICAR-Indian Agricultural Research Institute, New Delhi 110 012

Received : December 2014; Revised accepted : March 2015

ABSTRACT

System of rice intensification (SRI) is a new method of rice (*Oryza sativa* L.) culture. This is an environment and ecology benign method that increases productivity and resource-use efficiency of irrigated rice by changing the way of managing soil, plants, water and nutrients. Emerged by chance in 1980s in Madagascar, it is now practiced on research farms and farmers' fields in about 60 countries world-over. A record yield of 19 tonnes/ha has been reported by China, while in India 50–100% increases in yield have been reported over conventional rice culture. As per the general notion, SRI is not cultivar-specific. However, differential yield responses of cultivars have been observed under SRI at different locations in the country. SRI has been found to enhance yield of hybrids, and long- and medium-duration cultivars more than those of short-duration improved cultivars, and hence these are found more suitable for cultivation under SRI. Yield enhancement with SRI was greater under constrained soil conditions like acidic soils, red lateritic soil, etc. Wider spacing is one of the important principles of SRI and influences growth and yield of rice. Initially, planting spacing ranging from 25 cm × 25 cm to 50 cm × 50 cm was prescribed, but lateron wide spread experiments across the world showed 25 cm × 25 cm to be the best planting spacing for SRI. However, some studies have suggested even lower spacing 20 cm × 20 cm to be ideal for SRI. Spacing of 25 cm × 25 cm seems to be better in *kharif* season, while in *rabi* season in southern India, 20 cm × 20 cm spacing appears to more rewarding than 25 cm × 25 cm. Seedling age of 10–12 days is invariably found suitable for transplanting to obtain higher yield and resource-use efficiency. Although under SRI yields were best when irrigations were scheduled at 3 days after disappearance of ponded water (DADPW), but larger water savings with some yield penalty suggests the delaying irrigations till 5 or 7 DADPW. Regarding nutrient management, it could be concluded that yield, profitability and resource-use efficiency from SRI under integrated nutrient management capsule consisting of 50% RDF + 50% nutrients from organic sources were either higher or equal to those obtained from the use of 100% RDF. Weeds infestation is more in SRI, which could be managed most economically by employing integrated weed management, using cono-weeder as one of the component.

Key words **:** Cultivar, Irrigation, Nutrient management, Rice yield, Seedling age, Spacing, System of rice intensification, Weed

Rice constitutes staple food for more than 50% of global population and its yearly production holds the key to world food security. Rice is particularly important in Asia that accounts for 90% of world's rice production and consumption. India ought to add 1.7 million tonnes of additional rice every year to ensure national food security (Dass and Chandra, 2013a). This puts a huge challenge to the rice scientists, famers and policy makers as the incremental rice productions are to be met from shrinking, depleting, polluting resources and changing climate situations. The conventional rice production cultures suffer from the limitations of yield stagnations, huge water requirement, multiple nutrient deficiencies, destruction of soil structure, and environmental problems. Of various research efforts made towards improving rice productivity and quality, SRI is the recent one. SRI has eked tremendous interest of scientists and this technology has been widely experimented in rice growing countries of world. Impressive yield gains with this technology have been reported by not only scientists from their on-station and on-farm trials but also by the farmers.

Higher yield with fewer inputs, like water, fertilizers, seed, labour, etc. have made SRI attractive and rewarding, particularly for the resource-poor small and marginal rice

[1, 2, 3]Senior Scientist, [4,5]Scientist, [6]Professor & Head, ICAR-Indian Agricultural Research Institute, New Delhi 110 012

farmers. It is also useful to resource-rich large farmers. With SRI, yields twice higher than the conventional transplanted rice yields have been frequently reported. The highest yield of 19 tonnes/ha with SRI has been reported from China. The physiological studies have demonstrated that SRI does not enhance rice plants' genetic potential, instead, it harnesses the synergy among certain management components and rhizosphere. It makes the rice plant to make better use of resources, like solar radiation, water, soil and soil nutrients and produce more quantity of grains with higher quality.

SRI Technology

SRI is basically a set of principles and ideas that are translated into agronomic practices. Now, SRI has acquired the status of 'yield enhancing and resource saving rice production technology'. SRI technology includes (i) transplanting of young seedlings that are 8–12 days old, in shallow (1–2 cm) submergence, (ii) sparse planting in a square geometry (25 cm × 25 cm or slightly more or less), (iii) providing intermittent irrigation and drainage during the vegetative stages to create soil aeration (iv) supplying nutrients from organic or organic + inorganic sources (v) controlling weeds mechanically (cono–weeding) or handweeding at 10–12, 22–25, and 40–42 days after transplanting (DAT) and (vi) transplanting completed quickly, preferably within 15 minutes of uprooting (maximum 30 minutes) and with roots placed horizontally (L-shaped) not bent upwards (J-shape) (Satyanarayana and Babu, 2004; Rabenandrasana, 1999).

History and spread of SRI

System of rice intensification was developed three decades before by the French Jesuit Father Henri de Laulanié in Madagascar in 1983, after having worked with farmers and experimenting with rice for about 20 years. This method of rice-growing led to tremendous yield enhancement in Madagascar. From there it took-off to different countries of the world in 2000.

However, until 1994, SRI was unknown to the rest of the world. It could receive the attention of the world's agricultural scientists only when the Cornell International Institute for Food, Agriculture and Development (CIIFAD) launched a collaborative project with Association Tefy Saina (ATS) to propagate the Madagascar innovations. In fact, credit of SRI spread goes to Dr. Norman Uphoff of Cornell (Cornell International Institute for Food and Agriculture, Ithaca, USA) for bringing SRI to the notice of others and promoting it in different parts of the world. Following his 3-year study of Malagassy farmers, Uphoff carried the idea to Asian farmers and from 1997 started to promote SRI in Asia (V & A Programme, 2009). Since 1999, with CIIFAD efforts, the local phenomenon grew to a global movement with farmers in 50 countries, especially in semi-arid regions. In Asia, along with India, China, Sri Lanka, the Philippines, Malaysia and Vietnam have made notable progress. Till 2013 more than 10 million farmers were benefitting from the adoption of SRI in 54 countries (*http://www.slideshare.net/SRI.CORNELL/1424-system-of-rice-intensification-research-a-review?next_ slideshow =1*) (Fig. 1).

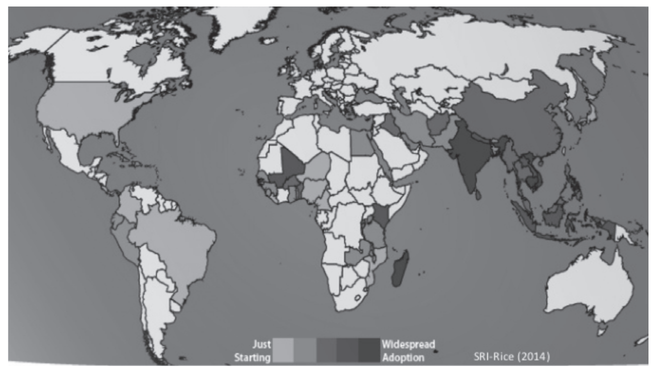
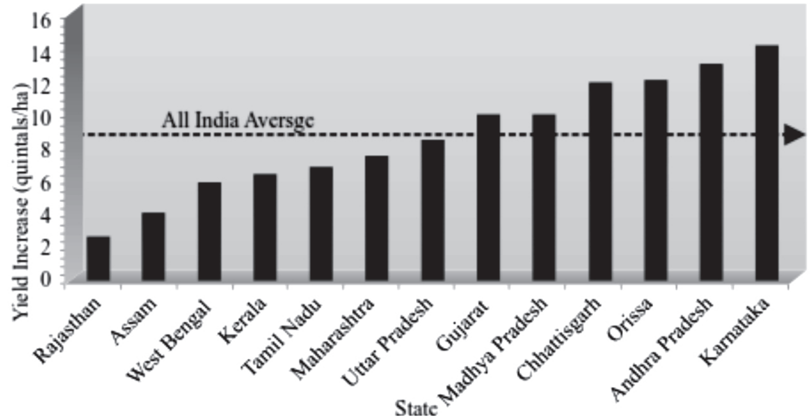


Fig. 1. Global spread and adoption of SRI.

In India SRI was introduced in 2000 as a promising alternative to high-water demanding conventionally transplanted rice. However, initially, SRI did not find adequate favour and support in India, which is reflected from the fact that Dr. T.M. Thiyagarajan of Tamil Nadu Agricultural University, Coimbatore, India was the only Indian representative at the 2002 International Conference on SRI. Dr. T.M. Thiyagarajan had first heard about SRI in 2000 from Dr. Ten Berge of Wageningen's Plant Research International and was interested in the soil aeration aspect of SRI, and its water-saving potential (Prasad, 2006). Now, SRI has reached to almost all states of India. During initial years of its introduction, lower yield in SRI compared to conventional transplanting were reported, but the careful research done in the immediate later years demonstrated convincingly higher yield with SRI in India also. This resulted in spread of SRI in different states of India; major states adopting or promoting SRI and yield increases over non-SRI rice yields have been shown in the Fig. 2.

Generally, SRI fields produced significantly higher yields but not in a uniform pattern across the states. The average yield increase with SRI technology is about 0.85 tonne/ha), which is 22% higher than in non-SRI fields. Madhya Pradesh, Gujarat and Odisha have registered 52, 54 and 33% increase in yields with SRI parcels. Maharashtra, Chhattisgarh, Andhra Pradesh, and Karnataka have the next highest yield increments with SRI–27, 24, 23 and 25%, respectively. Among the other major rice-growing states, only Rajasthan and Assam have



(Source: Palanisami *et al*., 2013)

Fig. 2. Major states adopting or promoting SRI and yield increases over non-SRI rice yields.

low absolute yield gains, but they still recorded a more than 12% increase over non-SRI parcels. Kerala, Tamil Nadu and West Bengal have recorded only moderate yield increases. Overall, only six states have experienced yield increases above the national average due to SRI (Palanisami *et al.*, 2013).

Important challenges vis-a-vis benefits with SRI

There is a generalized assumption that SRI culture does not require additional external inputs (Barrett *et al.*, 2004; Thakur, 2010; Glover, 2011). It is, however, generally held that SRI is more complex and labour–intensive. It is viewed that SRI requires more intensive field preparation, especially levelling to facilitate proper water control, as well as frequent (typically daily) visits to fields to check the water level (Barrett *et al.,* 2004). Regular and frequent weeding is also important, especially in the early transplanting stage, because weeds compete with seedlings in the field (Berkhout and Glover, 2011). Furthermore, increased labour demand for transplanting is often reported for carefully spaced and arranged transplanting.

While SRI practices involves more careful management, they facilitate achieving of greater yields than conventional management practices due to inherent synergistic effects, and on–farm trials have consistently shown remarkable yield increments in various countries (Uphoff *et al.*, 2002; Sato and Uphoff, 2007; Sinha and Talati, 2007; Stoop *et al*., 2002; Thakur, 2010; Thakur *et al.,* 2010a, b; Berkhout and Glover, 2011). Reduced water–use (30–50%), reduced cost of cultivation (23%), increase in household income and resilience against climate change are the other potential benefits of SRI. Globally, SRI is especially important in the water deficit regions as it requires 25–50% less water.

Components of SRI

Varieties

Crop duration, yield attributes and yield

It has been viewed that all existing varieties can be used in SRI though it is well established that varieties respond differentially to different agro–ecologies and management levels. It is possible that rice varieties should respond distinctively to SRI components like spacing, seedling age, water management, weed control practices, and nutrient management. A rice plant planted singly in SRI capitalizes on wider spacing to grow vigorously, produce more effective tillers and finally give higher yield. However, a variety with low tillering ability may not produce enough effective tillers under wider spacing to compensate for loss of population. Population in SRI is generally one-third to one-half of the recommended plant population and under such situations it is tillering ability of the variety, which helps produce desired number of effective tillers leading to higher yield (Dass and Chandra, 2013a; Hanamaratti *et al.,* 2006). Thus, it is important to find out and select those varieties that can adequately compensate the losses of plant population by exhibiting profuse tillering and are more responsive to SRI management.

Duration of cultivar is another important characteristic in realizing the higher yield with SRI. Long-duration varieties yielded more in SRI practice over short-duration varieties (Latif *et al.,* 2005). This could be due to the higher number of effective tillers, higher number of filled grains /plant and longer panicles (Viraktamath and Kumar, 2007). However, short-duration variety also performed satisfactorily under SRI along with long- and medium-duration varieties due to planting of young seedlings that provided adequate time to produce more tillers in the former (Babu, 2007). Poonam (2007) reported that in the wet season hybrid 'KRH 2' took the highest number of days to attain maturity (139 days), whereas in the dry season, 'CRHR 1' took the longest duration for maturity (150 days); the 'CRHR 5' (134 days) and 'PHB 71' (141 days) took the shortest duration for maturity in wet and dry season, respectively.

Under SRI method, variety 'PR 115' produced the highest number of panicles/m^2 (258) and test weight (24.3 g), variety '17A/R10' had the highest panicle weight (4.84 g), while variety 'HR 115' had the highest number of filled grains/panicle (178), which was equal to '17A/R10' but the lowest sterility percentage (Mahajan and Rao, 2009). In another study, increase in yield of 'Pusa Basmati 1' was attributed to increased grain number/panicle (Uprety *et al.,* 2003). Whereas, Poonam (2007) reported that among various rice hybrids evaluated at CRRI, Cuttack, most of the yield attributing characters were maximum with 'KRH 2' and 'CRHR 5' and minimum with 'CRHR 1'. Dass and Chandra (2013b) reported that in SRI, 'Hybrid 6444' produced 91–183 filled spikelets/panicle, which were higher than 'Pant Dhan 4'.

Mahajan and Rao (2009) reported that in Punjab among three varieties, viz., 'PR 115', 'HRI 152' and '17A/R10', evaluated under SRI method of cultivation, 'HRI 152' gave the highest grain yield (6.62 t/ha) which was significantly higher than '17A/R10' (5.20 t/ha). Whereas at Cuttack, Odisha, hybrid 'CRHR 5' recorded the maximum grain yield (5.69 and 7.16 t/ha), while 'CRHR 1' recorded maximum straw yield (8.59 and 9.33 t/ha) in wet and dry seasons, respectively, but grain: straw ratio and harvest index of 'KRH 2' were the maximum during both seasons (Poonam, 2007).

Yuan and Fu (1995) reported that rice hybrids contribute in enhancing rice yields to the extent of 30.5% or more in China, while Indian rice hybrids have shown a hike of 16–44% over conventional cultivars (Pillai, 1996), depending upon agro-climatic conditions. Dass and Chandra (2013a) reported that 'Hybrid 6444' and 'Pant Dhan 4' both gave ≥ 6 t/ha yield under SRI and just above 5 t/ha under conventional transplanting in *Tarai* soils of IGP. Hybrid 'TNRH 18' due to better growth, produced significantly higher straw yield than 'TNRH 10', 'TNRH 13' and a non–hybrid variety, 'Jaya', in silty clay loam soils of Nagpur, but gave lowest grain yield of 2.85 t/ha with lowest harvest index of 27.19%, whereas, among hybrids 'TNRH 10' gave the highest grain yield (4.35 t/ha) and harvest index (40.70%), which was however, statistically similar to non–hybrid 'Jaya' which gave the highest yield of 4.55 t/ha with a harvest index of 44.09% (Shrirame *et al*., 2000).

Data in table 1 depict the variable improvement in yield of different cultivars under SRI over conventional transplanting in different agro-climatic conditions. It is evident from the afore-cited studies that SRI enhanced yield of hybrids more than that of improved cultivars. Long-and medium-duration cultivars were benefited to a greater extent than the short-duration ones. At certain locations, yield potential of even local cultivars was impressively increased by SRI method (Avasthe *et al.*, 2012; Kumar *et al*., 2013). Further analysis of data revealed that yield enhancement by SRI was greater under constrained soil conditions like acidic soils, red lateritic soil, etc.

Nutrient uptake and grain quality

In general, nutrient accumulations and quality of grains differ among cultivars. This effect is further pronounced by SRI method. Awasthe *et al.* (2012) observed differential response of rice varieties to SRI for nutrient uptake; their study revealed that SRI under wider spacing (20 cm × 20 cm or 25 cm × 25 cm) enhanced the N, P and K uptake to a greatest extent in local cultivar 'Thulo Attey' followed by 'RC Maniphou-7' and 'RCPL 1-87-8', while nutrient accumulation in 'Pusa Sugandh-2' was considerably reduced by SRI compared to conventional transplanting. In *tarai* soils of Indo–Gangetic plains of India, 'Hybrid 6444' accumulated 63.6, 21.7 and 24 kg/ha, N, P and K, respectively, while 'Pant Dhan 4' showed corresponding uptake of 60.2, 23.6 and 25.4 kg/ha, and protein content was higher in 'Hybrid 6444' than 'Pant Dhan 4' (Dass and Chandra, 2012). Similarly, Ram *et al.* (2015) reported that quality parameters, *viz*., hulling, milling, head rice recovery and protein content were significantly higher in 'Hybrid PHB 71' than the inbred cultivar 'NDR 359'. Higher root growth, root activity, slow leaf-senescence, higher chlorophyll contents, photosynthetic rates and efficient transport of assimilates from source to sink have been held as the important factors for directly or indirectly contributing to the better grain quality of varieties responsive to SRI management (Satyanarayana *et al.,* 2007; Wang *et al.,* 2003).

Plant spacing

Tiller count, yield attributes and yield

Wider plant spacing is the key SRI–component which is considerably responsible for the higher performance of rice. The yield enhancement in wider spaced plants under SRI stems-out largely from the profuse tillering in the rice plants and conversion of a larger number of tillers into panicles, contributing 89% of the yield improvement (Baloch *et al*., 2002). Thus, maintaining a critical level of rice plant population in field is necessary to maximize grain yield. During early years of SRI development, a very wide plant spacing (50 cm × 50 cm) was considered viable for SRI (Fernandes and Uphoff, 2002), which however,

Table 1. Performance of rice cultivars under SRI and conventional transplanting (CT) in different climatic and edaphic conditions

Variety	Yield (t/ha)		Increase over CT (%)
	SRI	CT	
Climate: Sub–humid and sub–tropical, Pantnagar; Soils: TypicHapludoll, Mollisol (Dass and Chandra, 2013a)			
‘Pant Dhan 4’ (medium duration)	6.11	5.26	16.2
‘Hybrid 6444’ (medium duration)	6.09	5.19	17.3
Climate:Humid subtropical Banaras; Soils: Ustocherpts, alluvial plains (Ram *et al.,* 2014)			
'PHB 71' (Hybrid)	7.33	-	-
'NDR 359'	6.51	-	-
Climate: Per-humid, Tadong, Sikkim; Soils: Mid hill acidic soils (Avasthe *et al.,* 2012)			
'RCPL 1-87-8' (medium duration)	4.9	4.4	11.4
'Pusa Sugandh 2' (medium duration)	3.32	3.95	-18.5
'RC Maniphou 7' (long duration)	4.96	4.56	8.8
Local cultivar Thulo Attey (long duration)	3.52	2.26	55.8
Climate: Sub-tropical humid Chitwan, Nepal; Soil: Sandy loam, slightly acidic (Dhital, 2011)			
'Sabitri' (long duration)	6.91	3.96	74.5
'Loktantra' (medium duration)	6.55	3.68	78.0
'Radha 4 ' (short duration)	7.34	4.91	49.5
Climate: Hot & moist Sub-humid north central plateau agro-climatic zone of Odisha; Soil: Sandy clay loam in texture having pH 5.63 (Mohanty *et al.,* 2014)			
'Pratikshya'	6.65	5.64	17.9
Climate tropical Sirsi, District Uttar Kannada (Karnataka) Soil: Lateritic acid soils			
'Samba Masuhri' (BPT 5204)	4.07	3.68	10.6
Climate: Moderate, Red soils, Mughad, Dharwad (Kumar *et al.,* 2013)			
'PRH 10'	8.92	5.74	55.4
'DRRH 2'	10.97	6.82	60.9
'Sahyadri 3'	10.27	6.14	67.3
'MGD 101' (Local check)	8.38	4.13	102.9

implies a 6.25–fold decrease in plant density compared to 20 cm × 20 cm, and an equivalent increase in productivity per plant to obtain similar yields per unit area, which obviously proved impractical at large.

An ideal wider spacing (30 cm × 30 cm) increased the number of tillers/plant by 32.5 to 38.6% in SRI (Menete *et al.,* 2008), but due to greater tillering 40–50% tillers did not bear panicles resulting in lower number of effective tillers per unit area (Ceesay and Uphoff, 2003). Further reduction in plant spacing to 25 cm × 25 cm also produced lower number of effective tillers per unit area compared to closer spacing (20 cm × 20 cm or lower), but size of panicles, number of grains/panicle, panicle weight, 1000-grain weight were smaller due to competition among rice shoots for resources (light, water, and nutrients) including sink leading to inefficient grain filling and higher spikelet sterility under closer spacing (Jayawardena and Abeysekera, 2002; Verma *et al*., 2002; Cessay and Uphoff, 2003; Poonam and Rao, 2007; Latif *et al.,* 2009; Bommaysamy *et al*., 2010). All yield attributes, barring number of panicles/m^2, have been found better under wider spacing (Sharma and Masand, 2008; Hasanuzzaman *et al.* 2009; Chapagain and Yamaji, 2010) due to better root and shoot growth of individual hills. Thakur *et al*. (2010b) reported that the performance of individual hill was significantly improved under wider spacing (30 cm × 30 cm) compared with closely spaced hills (20 cm × 20 cm) in terms of root growth and xylem exudation rates, leaf number and leaf sizes, canopy angle and tiller production. Rice plants under shallow water depth with wetting and drying had better ontogenesis when seedlings are transplanted at low densities, compared to conventional water management (Lin *et al*., 2004). Wider spaced plants in SRI develop a healthy root system with higher dry root weights, root volume and better root: shoot ratio (Dass *et al.,* 2015), which cause increased accumulation of N and cytokinin transportation from roots to shoots, that under greater exposure to sunlight and circulatory air maintains higher rate of photosynthesis in rice plant (Jiang *et al.,* 1988; Uphoff, 2002; Ookawa *et al.,* 2003) and physiological activity of roots. Even in salt affected soil, wider spacing (30 cm × 30 cm) by virtue of better growth and development enabled rice plant to adapt well to decreased plant density (Menete *et al*., 2008).

Better yield attributes have been shown to result in higher grain yield, greater partitioning of dry matter in favour of grain, and water productivity under wider spacing (25 cm × 25 cm or higher) compared to narrower spacing. Many researchers have demonstrated the higher productivity of SRI under wider spacing in different regions

(Jayawardena and Abeysekera, 2002; Vijayakumar *et al.*, 2006; Krishna and Biradarpatil, 2009; Chapagain and Yamaji, 2010). However, there have been certain studies which reports at either equal or marginally higher yields from SRI when planted at closer spacing compared to wider spacing (Ceesay, 2002; Ceesay and Uphoff, 2003; Choudhury *et al.*, 2007; Hasanuzzaman *et al.*, 2009; Bommayasamy *et al.,* 2010; Thakur *et al.,* 2010a). In salt–affected soil also wider spacing of 30 cm × 30 cm reduced the yield of SRI rice by 2.2–11% over 20 cm × 20 cm spacing (Menete *et al*., 2008).

Overall, it has been found that under SRI method, 20 cm × 20 cm and 25 cm × 25 cm planting spacings sometimes return similar grain yield and sometimes different, however the yield differences between two spacings have been 5–10% only. In *kharif* season, 25 cm × 25 cm spacing seems to be better (Table 2) and in *rabi* season in southern and eastern India, 20 cm × 20 cm spacing appears to be more rewarding than 25 cm × 25 cm (Table 2). But both spacings are definitely better than conventional plant spacing of 20 cm × 10 cm. In *tarai* belt of Uttarakhand characterized by sub–humid and sub–tropical climate and Typic Hapludoll (Mollisol) soils, increase in yield with 25 cm × 25 cm spacing was higher compared to 20 cm × 20 cm, over closer spacing of 20 cm × 10 cm (conventional transplanting).

Nutrient uptake and grain quality

Plant spacing governs not only the growth and yield but also nutrient uptake and quality of produce. 'Pusa Basmati 1' accumulated 8.2, 13.9 and 6.8% higher amounts of N, P and K, respectively with 20 cm × 10 cm plant spacing (Jacob and Syriac, 2005). Singh and Sharma (1995) reported higher K uptake by rice with wider spacing of 25 cm than with 20 cm uniform rows. Spacing exerts impact not only on overall nutrient uptake but also on uptakes at different stages. Increasing plant spacing from 20 cm × 15 cm up to 20 cm × 20 cm or 20 cm × 25 cm significantly increased the grain protein content (Salem, 2006). Gunri *et al*. (2004) observed that the closer spacing (15 cm × 15 cm) proved better in terms of N–use efficiency and nitrogen uptake than the wider row spacing (20 cm × 15 cm). Similarly, at Port Blair, Andaman and Nicobar Islands, closer spacing of 20 cm × 20 cm resulted in significantly higher uptake of N, P and K than 25 cm × 25 cm and 30 cm × 30 cm spacings (Bommayasamy *et al.,* 2010). However, 20 cm × 15 cm plant geometry recorded higher N recovery (27.8%) than the other plant geometries. But, Salem (2006) in a 2 years study observed the higher protein content in rice grains with 20 cm × 25 cm spacing (av. 9.22) than 20 cm × 20 cm and 20 cm × 15 cm spacing. Dass and Chandra (2012) recorded significantly higher N, P and K uptake and milling recovery under 25 cm × 25 cm than 20 cm × 20 cm. Protein content was marginally higher in 25 cm × 25 cm than 20 cm × 20 cm.

Economics

Jacob and Syriac (2005) reported that at Vellayani, Kerala, transplanted scented rice, planted at 20 cm × 10 cm spacing gave the highest net returns (₹52,009/ ha) with a benefit: cost ratio of 1.69 and the 15 cm × 10 cm the lowest net returns (₹30,418/ha) and benefit: cost ratio (0.98). Likewise, hybrid rice 'Sahyadri' yielded the highest net returns (₹23,895/ha) under wider plant spacing of 20 cm × 20 cm (Powar and Deshpande, 2001). In *Trai* belt of Uttarakhand, a decrease in cost of cultivation by ₹1,000/ha mainly due to less cost involved in transplanting of rice seedlings and 5% increase in grain yield increased net returns by over ₹3000/ha under wider spacing (25 cm × 25 cm) compared to closer spacing of 20 cm × 20 cm (Dass and Chandra, 2012).

Seedling age

Planting of young (8–12 day-old) seedlings as single plant/hill is the most important principle of SRI, which accounts for more than 50% yield rises in SRI world-wide. Higher tiller production is pre-requisite for higher yields in SRI, as plant population in SRI is just one-third to half of the plant population in conventionally transplanted rice. Rapid crop establishment and avoidance of transplanting shock is advantageous in raising grain yields (Pasuquin *et al.,* 2008) and transplanting young seedlings as single plant/hill minimizes this shock and results in enhanced tiller development (San-oh *et al.,* 2006; Mishra and Salokhe, 2008). Younger seedlings establishes quickly in the main field and start growing at a faster rate compared to the conventional seedlings which remain in nursery-bed competing with one-another for four-five weeks before transplanting. Also, greater seedling age results in lower rice yield because older seedlings suffer from stem and root injury during pulling (Ashraf *et al*., 1999; Dizon *et al.,* 1996).

There have been experiments designed for the evaluation of age of rice transplants ranging from 6–30 days, with most researchers conducting experiments with an arbitrarily selected seedling age at transplanting between 8 and 16 days. The results were location-specific. In Sumatra, McHugh (2002) recorded the highest yields from 10-day-old transplants, while Makarim *et al.* (2002) reported that 15-day-old transplants out-yielded 21-day-old transplants, which was obvious as planting of aged seedlings singly reduces tillering and consequently yield. In Thailand, 12-day-old transplants consistently out-yielded 30-day-old transplants (Mishra and Salokhe, 2008).

Table 2. Yield comparison between SRI under variable plant spacings and conventional transplanting (CT)

Cultivation method	Spacing	Yield (t/ha)	Increase over CT (%)	Source(s)
Climate Pub–humid and sub–tropical, Pantnagar; Soils: Typic Hapludoll (Mollisols): Kharif season				Dass and Chandra (2013a)
SRI	20 cm × 20 cm	5.97	14.4	
	25 cm × 25 cm	6.23	19.3	
CT	20 cm × 10 cm	5.22	–	
Climate: Tropical; Soil: Sandy clay in texture, Killikulam, Tirunelveli, Tamil Nadu (Rabi season)				Bommayasamy *et al.*(2010)
SRI	20 cm × 20 cm	8.0	5.3	
	25 cm × 25 cm	7.6	0.0	
	30 cm × 30 cm	7.2	–5.3	
CT	20 cm × 10 cm	7.6	–	

In India, Manjunatha *et al*. (2010) reported 9 and 12 days seedlings, and Kumar *et al.* (2010) and Thakur *et al.* (2010a) 12-day old seedlings to be better for higher grain and straw yields under SRI. Similarly, a five year (2005-09) long experiment carried out by Deb *et al.* (2012) on lateritic soils of Bankura district of West Bengal revealed that young seedlings do not produce higher yields always and when seedlings are aged planting of multiple seedling transplants could produce similar yields as single seedling transplant of young seedlings for upland cultivars, but for low land cultivars, young seedlings (14-day old) yielded higher. In the northern Indo-Gangetic alluvial plains with sandy-clay-loam soil (Ustochrepts), 10-day old seedlings were found most suitable for higher growth, yield and nutrient uptakes under SRI (Shukla *et al.* 2014; Ram *et al*., 2014; Singh *et al.* 2013). However, Sharma and Kaur (2014) at PAU-Ludhiana, Punjab demonstrated completely opposite results; ten- day-old nursery transplanted in SRI gave the lowest paddy yield and the least water-use efficiency.

At Sindewahi district of Gujarat, 12- day-old seedlings produced the highest number of productive tillers/plant at harvest, leading to higher yield compared to other ages, while the youngest seedlings (8-day-old) flowered early (Kayande, 2012). In *rabi* season rice grown with SRI methods on sandy clay soil at Killikulam, Tamil Nadu, yields generated by 14-days-old seedlings were not statistically different from the yields obtained from conventional nursery with 21-day-old seedlings; number of seedlings/hill also did not bring-in any yield differences in SRI (Bommayasamy *et al*., 2010). However, Krishna and Biradarpatil (2009) observed higher grain yields with 12-day-old transplants than 8-, 16- and 25-day-old transplants at Gangavati, Karnataka. In temperate regions and during winter season in sub-tropical regions, growth of seedlings is slow due to low temperature and may take few more days to attain a size to be appropriate for transplanting. Thus where temperatures are low, 'young plants' may be 16–18 days old, even 20 days. The physical status of the plant is indicated by the number of leaves, and 'young' means between 2 and 3 leaves (Uphoff *et al.,* 2008). Overall, seedling age of 10-12 days is invariably found suitable for transplanting under SRI. Rice seedlings are known to lose much of their growth potential if transplanting is done after 15 days after emergence. Seedlings must be transplanted before the fourth phyllochron begins in order to retain tillering potential by the seedlings (Rafaralahy, 2002).

Irrigation effects

Yield

It has been well established that rice is not an aquatic plant and does not necessarily require flooding for producing best yields. However, standard rice cultivation practices around the world involve the continuous flooding and maintaining of standing water in rice field from transplanting till 15–20 days before maturity. This leads to huge water losses from rice fields through evaporation, seepage and deep percolation resulting in low water productivity. Rice cultivation has already been cognized as the main reason for alarming fall in groundwater level. For example, the sustainability of rice production in the northwestern part of IGP region (Punjab, Haryana, Western Uttar Pradesh, and Uttarakhand), is threatened by the growing scarcity of water (Singh, 2012; Dass *et al.*, 2015). Using water most efficiently and maintaining soil moisture around field capacity will serve the dual purpose of higher yields and saving of water (Borrel *et al.,* 1997; Singh and Ingram 2000)

Growing rice with SRI methods envisaging intermittent irrigation, offers efficient use of limited water and higher yield. There is substantial literature convincingly suggesting that rice grown with SRI methods give higher yields and water productivity. In SRI, cycles of repeated wetting and drying were found beneficial to rice plant growth through increased nutrient availability leading ultimately to higher grain yield (Ceesay and Uphoff, 2003;) There are visible gains in terms of yield enhancement and water saving with alternate wetting and drying and non-flooding conditions (Ceesay *et al.,* 2006; Kabir and Uphoff, 2007 and Sinha and Talati, 2007). But, implementation of such types of irrigation by the farmers is difficult primarily due to lack of reliable water source, little water control and water-use complies (McHugh *et al.,* 2002). At Hangzhou, China, Zhao *et al*. (2009) observed 21.5% increase in rice yield with SRI compared to traditional flooding though above- ground biomass was similar between SRI and conventionally flooded rice. Harvest index was also significantly higher with SRI. Tao and Ma (2003) and Zhong *et al.* (2003) observed 26–51 and 19% increase in yield from SRI, respectively, over traditional flooding. Under continuous flooded condition, rice yields tend to be very low on soils with unfavourable physico-chemical environment, particularly due to limited growth during the vegetative phase (Vizier, 1990). Yang *et al.* (2007) showed 7–11% increase in yield and upto 38% reduction in irrigation water by maintaining critical soil water potential at –15 KPa. Therefore, irrigation water input can be reduced by decreasing ponded water depths to soil saturation; water saving under saturated soil condition was on an average 23% with yield reduction of only 6% (Bouman and Tuong, 2001). These results clearly demonstrate the benefits of general alternate wetting and drying or intermittent irrigation. But the fact still remains to be analysed is what should be the duration of drying interval between two successive irrigations. Recently, there have been some studies which included evaluation of response of variable irrigation on rice grown employing SRI methods; the most prominent ones are reported here as follows (Table 3).

In mollisols of *tarai* belt of northern India, rice yield did not decrease significantly when irrigations were delayed from 1–3 DADPW, however further delay in irrigation to 5 DADPW, caused significant reduction in rice yields. Water productivity was greatest when irrigations were scheduled at 3 DADPW. Another interesting result of this study was that rice yields from SRI crop irrigated at 5 DADPW was 11.5% higher than from conventional transplanted rice irrigated at 1 DADPW (Dass and Chandra, 2013). This indicates that under water scarce conditions, irrigating SRI crop even at 5 DADPW offers substantial yield gain compared to CT. In eastern India, Thakur *et al.* (2014) reported that SRI grain yield and water productivity were the greatest at 3 DADPW (Table 3). In Southern Iraq also applying irrigation at 3 DADPW was the most rewarding irrigation schedule for SRI-rice in terms of yield and water productivity. In contrast, Dhar *et al.* (2008) reported that at Jammu, the maximum grain yield (5.29 t/ha) of rice under SRI methods was recorded when the crop was irrigated at 7 DADPW, which was significantly higher than the yield obtained from other treatments like alternate wetting and drying, applying irrigation at 3, 5 and 9 DADPW, but similar to the yield obtained from continuous submergence (4.93 t/ha).

Water saving in SRI compared to conventional transplanting

Water productivity of conventional transplanted rice is merely 20–30% (Walker and Rushton, 1984; Tuong and Bhuiyan, 1999). Zhao *et al*. (2009) found 40–47% reduction in water-use with SRI, 68–94% increase in water-use efficiency (WUE) and 100-130% increase in irrigation WUE compared to traditional flooding. Thiyagarajan *et al*. (2002) reported that applying limited irrigation (2 cm depth after development of surface cracks) to rice crop raised with conventional and young seedlings saved 56 and 50% water, respectively, without significant yield reductions. The corresponding water-use was 11,853 and 5,205 m^3/ha, and 13,347 and 6,699 m^3/ha for conventional and young seedlings, respectively. Irrigation 1 DADPW water saved 25% water without reduction in yield compared to continuous submergence (Ramamoorthy *et al.,* 1993). During a dry season, irrigation at saturation to 5 cm depth consumed only 47% of the water required by the continuous submergence (1850 mm), and in wet season too, there was a saving of 18% irrigation water (Mohandass *et al.,* 1987). They also reported that irriga-

Table 3. Effect of irrigation management on yield and water productivity (WP) of rice under system of rice intensification

Treatment	Southern Iraq, Silty clay-loam to clay loam soil		*Tarai* belt, Uttarakhand, India (Sandy loam soil)		Eastern India, Mendhasal Farm, Khurda, Odisha (Sandy clay loam)	
	Yield (t/ha)	WP (kg/m^3)	Yield (t/ha)	WP (kg/m^3)	Yield (t/ha)	WP (kg/m^3)
CWS	5.31	0.0665	-	-	5.46	0.524
1 DADPW	-	-	6.32	0.30	6.24	0.617
3 DADPW	6.56	0.165	6.16	0.32	6.35	0.647
5 DADPW	-	-	5.82	0.31	5.79	0.608
7 DADPW	5.07	0.229	-		4.28	0.457

CWS, Continuous water submergence; DADPW, days after disappearance of ponded water
(Source: Hameed *et al*., 2013; Thakur *et al*., 2014; Dass *et al*., 2015)

tion at saturation to 25% depletion of available soil moisture consumed the lowest irrigation water in summer (620 mm) and wet season (685 mm) with concomitant yield reduction of only 11%, but had higher WUE.

Chapagain and Yamaji (2010) observed that alternate wetting and drying can save a significant amount of irrigation water (28%) without yield reductions. Dhar *et al*., (2008) reported that irrigation at 5 DADPW saved 22.7% water with a slight reduction in grain yield compared to continuous submergence. During a low rainfall year in *Tarai* belt of India, the SRI crop irrigated at 5 DADPW (nine irrigations of 6 cm each) saved 25% irrigation water while producing 10.2% higher grain yield compared with conventional transplanting that required 12 irrigations (Dass and Chandra, 2013a). In eastern India, SRI practice with intermittent irrigation produced 49% higher grain yield with 14% less water than under continuous water submergence (Thakur *et al.,* 2014). In southern Iraq, 3-day interval irrigation in SRI led to about 50% saving of water, while also raised yields; with 7-day irrigation interval, although rice grain yield reduced by 6% (Table 3) but water consumption was lowered by three-quarters.

Overall, water saving of 20–50% has been achieved with SRI method. Although under SRI the best yields of rice were obtained when irrigations were applied at 3 DADPW, but water savings were larger with bearable yield reductions when irrigations were applied at 5 or 7 DADPW. The water so saved can be diverted to additional area for higher total rice production. As the water is becoming increasingly scarce world-over, irrigation options of 5 and 7 DADPW should be considered, even if these schedules do not maximize yields. These two schedules could support a larger area of production and greater total output of rice.

Weed management

The problem of weeds in SRI

Yield reductions in rice due to weeds can be as high as 80% (Babu *et al*., 1992) and rice grown with SRI can be no exception to this general trend. Rather, SRI is prone to greater infestation of weeds due to alternate wetting and drying conditions and planting of seedlings singly at wider spacing of 25 cm × 25 cm or more. Haden *et al.* (2007) pointed out weed infestation to be the most important problem of SRI, which has a significant influence in reducing the rice yields (Krupnik *et al*., 2012); the SRI yield reduction due to weed competition could be upto 69.15% (Babar and Velayutham, 2012a). Water productivity which is one of the key benefits of SRI reduced up to 38% compared to weed-free plots (Krupnik *et al.*, 2012). Hence, appropriate weed management practices are to be developed for controlling weeds in SRI.

Weed management strategies

Weeds have variable growth habits and life cycles so no single method can effectively control weeds in all situations. Thus, integrated weed management approach is the important requirement for sustainable rice production (Sridevi, 2013). A range of weed control strategies, which include competitive cultivars, flooding, hand weeding, mechanical cultivation, herbicide application (2, 4-D), mulching, and a combination of both hand weeding and herbicide have been used in SRI fields with varying economic costs and degrees of success (Randriamiharisoa, 2002; Latif *et al*., 2005; Haden *et al.*, 2007) and there have been deferential effects of weed control methods on suppression of weeds and improvement in yield (Hasanuzzaman *et al*., 2007; Riaz *et al.*, 2006).

Hand weeding and Cono-weeding in SRI

The general principle of controlling weeds in SRI is to use cono-weeder/ rotary hoe/power weeder to aerate the soil as well as control weeds. Operating weeder twice 10 and 20 days after transplanting (DAT) reduces the weed problem to a large extent. First weeding is advised to be done 10–12 DAT and the next weeding may be done at 10–15 days interval until crop reaches panicle stage. It has been observed that manual hand row weeder is useful in removing weeds up to 40 DAT, but this requires more labour. The advent of row weeding machine solved the problem of the intensive labour, but it can be run in SRI fields upto 30 DAT because profuse lateral vegetative growth of rice is vulnerable to the damage by the row weeding machine (Haden *et al.*, 2007). Moreover, weeders fail to remove all the weeds growing in intra-row spaces, which compete with rice plants; even some of the weeds are able to re-grow from their roots, particularly, rhizomatous weeds, sedges, etc. (IRRI, 2014).

However, the advantage of using mechanical weeder/ weeding machines include aeration of the soil during the weeding operation (Babar and Velayutham, 2012b), which allows oxygen to circulate within the soil (Dobermann, 2004), and emerging of new efficient roots from the rice roots which get pruned while running weeding tools also augment nutrient pool of the rhizosphere by effective recycling of depleted nutrients through incorporation of weeds *in-situ*. The increased root exudates provide greater source of food to soil micro-biome, which in turn, improve many soil properties. Uphoff (2002) reported that the mechanical hand weeder pruned some of the upper roots and encouraged deeper root growth. Randriamiharisoa (2002) noticed that the mechanical weeding using rotating hoe with small toothed wheels increased the soil pores so that roots and microbes could more easily gain access to oxygen and also significantly increase the tiller production.

The use of cono-weeder resulted in 10% grain yield increase during wet season, while the yield increase was only 3% in dry season than conventional method of weeding (Thiyagarajan *et al.,* 2002). Cono-weeding alone was found to contribute 17.43% for grain yield (Sridevi, 2006). The impact of cono-weeding in increasing the ammonical and nitrate nitrogen contents of the rhizosphere soils was evident only at harvest (37.9 ppm) and grain filling stages (49.6 ppm) respectively, while at the rest of the stages cono-weeding did not show any notable impact on the nitrogen fractions of the rhizosphere soil (Sudhalakshmi *et al*., 2005). Mrunalini and Ganesh (2008) opined that the implements like cono-weeder helped to save labour, time and reduced man-days required for weeding from 30 to 10 as the farmers become more experienced in handling the cono-weeder implement. Sudhalakshmi *et al*. (2005) pointed out the problems that are encountered in incorporation of weeds like *Cynodon* and sedges with underground stolons and rhizomes, which result in faster regeneration under mechanical weeding.

Weed management strategies in different rice growing regions

Yield and weed control efficiency effects of the potential weed control practices in different regions have been presented in tables 4 & 5. It is clear from the data that 4 cono-weedings are required for exploiting full yield potential of SRI. However, 3–4 weeding operations are nowhere possible due to constrained labour availability. Thus, the use of herbicides in SRI also assumes importance. It has been seen that a pre-or post emergence application of herbicide is sufficient to substitute 1–2 cono-weedings/hand weedings. In sandy-clay loam soil of Faisalabad, Pakistan, manual hoeing at 20, 40 and 60 DAT with weed control efficiency (WCE) of 85.1% was found to be the best option and hoeing with rotary hoe at 20, 40 and 60 DAT was the next best option for controlling weeds in SRI (Chadhar *et al.,* 2014). Herbicide application was also effective registering a WCE of 70%. In sandy loam soil in Myanmar, rotary weeding followed by hand weeding at 15 and 35 DAT resulted in 285.5% increase in yield over un-weeded check and showed the highest WCE of 96.9% (Thura, 2010).

Weed competitive cultivars

Competitive cultivars may offer eco-friendly suppression of weeds. However, Haden *et al.* (2007) reported that in the West Java province of Indonesia, despite the fact that there was 32.8% less weed biomass harvested from plots containing the competitive cultivar (Sarinah) as compared with the most common commercial variety (IR 64), this “weed suppressive effect” was not pronounced enough to influence the composition of the weed community to a significant degree.

Use of mulches

The SRI technique envisages less reliance on external inputs including herbicides. Thus, the use of mulch may

Table 4. Potential weed control options in SRI in different countries.

Region/ Country	Climate/ Soil-type	Treatments	Yield (t/ha)	Weed control efficiency (%)	Source(s)
Faisalabad, Pakistan	Hot desert climate; sandy-clay loam	i) Manual hoeing at 20, 40, 60 DAT	5.17	85	Chadhar *et al.* (2014)
		ii) Ortho-sulfamuron at 145 g a.i./ha (7 DAT)	4.76	70.29	
Myanmar	Sandy loam	i) Rotary weeding (fb) hand weeding at 15 and 35 DAT	5.86	98.22	Thura (2010)
		ii) Two hand weedings (21, 35 DAT)	5.59	96.65	
Raipur, Chhattisgarh, India	Sub-tropical	i) PE followed by PoE Fenoxaprop-p-ethyl + Ethoxysulfuron 15g /ha at 20, 35 DAT	5.19	74.8	Dewangan *et al.* (2011)
		ii) Fenoxaprop-p-ethyl 60 g/ha + Ethoxysulfuron 15 g/ha + manual weeding (two way) at 20, 35 DAT	4.83	70.9	
		iii) Mechanical weeding (2-way) -12, 25, 35 DAT	4.81	66.7	
		iv) HW at 20, 40 DAT	5.50	72.1	
Tarai Belt, India	Sub-humid and sub-tropical, Soil: Silty loam and alluvial in origin, Aquic Hapludoll	i) 4-cono-weeding (10, 20, 30, 40 DAT)	5.25	-	Roy *et al.,* (2015)
		ii) Pre-emergence application of Anilophos @ 1.5 kg a.i./ha + 2 cono-weeding (20, 40 DAT)	4.89	-	
		iii) Modified SRI (25 cm × 12.5 cm spacing) PE application of Anilophos @ 1.5 kg a.i./ha, 2 cono-weeding at 20, 40 DAT	5.23	-	

Table 5. Effect of various weed control practices on yield, economics and weed-control efficiency in SRI

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Cost of production (× 10³ ₹/ha)	Net returns (× 10³ ₹/ha)	Weed index	WCE (%)
Weedy check	2.95	3.47	27.67	17.38	40.95	0.00
Weed free (3 HW at 15, 30 & 45 DAT)	4.99	5.49	32.82	43.04	00.00	76.38
4 cono-weeding at 10, 20, 30 & 40 DAT	4.66	5.10	32.82	37.95	6.68	71.92
Butachlor @ 1.5 kg/ha at 5 DAT + 1 cono-weeding at 30 DAT	4.57	5.01	30.53	38.98	8.36	67.69
Butachlor @ 1.5 kg/ha at 5 DAT + 1 HW at 30 DAT	4.67	5.12	30.10	40.85	6.46	71.97
CD (P=0.05)	0.546	0.509	3.535	4.75	-	-

Source: Patel and Patel (2015)

be one alternative to the herbicides. In a region, where rice – rice cropping system is practiced, straw of preceding rice crop can be used as mulch in succeeding rice crop. About 4 tonnes of rice straw is enough for providing soil cover on 1 ha area (Devasinghe *et al*., 2011). Rice straw can remain in the field for a long time due to higher lignin and silica contents as well as low protein and digestibility (Hanafi *et al.*, 2012). Rice straw can be future natural herbicide because during its degradation (El-Shahawy *et al*., 2006; Kato-Noguchi and Ino, 2005), it releases phenolic compounds (caffeic, cinnamic, ferulic, p-coumaric, o-cowmaric and p-hydroxybenzoic acids) as the allelophathic compound (Chung *et al.*, 2003; El-Shahawy and Zydenbos, 2010) for weed suppression (Chung *et al.*, 2003; Devasinghe *et al.*, 2011). Wayayok *et al.* (2014) studied the effect of rice straw and plastic mulches and their results revealed that weed density was significantly reduced in the plot where rice straw mats were applied compared to control. Vegetative part of rice plant at maturity stage contains about 40% of nitrogen, 30–35% of phosphorus, 80–85 % of potassium and 40–50% of sulphur (Hanafi *et al*., 2012). Upon decomposition, rice straw returns nutrients back to the soil, add organic fertilizer (Nader and Robinsons, 2010) and provide feeds for the soil microbes (Bioflora, 2013) in the SRI fields. Thus, dosages of fertilizer nutrients can be cut by a substantial amount, which will reduce cost of production as well as lower water pollution. Not only rice straw, biomass of other crops like wheat straw, mustard straw or even tree biomass can also be used. But the challenge remains to be addressed is how to operate conoweeder or other weeding machines in rice-straw mulched SRI fields.

Nutrient management effects

Originally, nutrient supply in SRI was recommended to be through organic sources (FYM, or composts). However, 2 to 3 fold increase in rice yields with SRI as reported by some researchers (Ranjitha and Reddy, 2014) and 15–50% yield increase reported by many workers (Thakur *et al*. 2010; Zhao *et al*. 2010; Sinha and Talati, 2007; Senthilkumar *et al*., 2008; Dass and Chandra, 2013b; Dass and Chandra, 2015), and twice higher nutrient uptake (Table 6) are likely to require more nutrients compared to conventional transplanting (Barison and Uphoff, 2011). Thus, use of mineral fertilizers becomes important along with organics to get higher and sustainable yields from SRI. Even in Madagaskar, where SRI was discovered, use of mineral fertilizers was in practice**.** The

Table 6. Comparison between SRI and conventional transplanting for yield and nutrient uptakes

Treatment	Yield (t/ha)	Nutrient uptake (kg/ha)			
		N	P	K	Zn
Gangavati, Dharwad, Karnataka; Deep black clay (Calciustert)					
SRI	6.69	56.0	11.39	91.6	0.426
CT	3.68	31.4	6.15	50.4	0.229
Tarai Belt, Uttarakhand, India					
SRI	6.10	112.0	33.0	153.6	-
CT	5.22	94.8	26.0	128.4	-
Madagascar, South Africa					
SRI	6.36	95.07	21.03	108.64	-
CT	3.36	49.99	12.69	56.77	-

Source: Dass and Chandra (2012); Barison and Uphoff (2011), Weijabhandara *et al.* (2011)

mineral fertilizer is applied to feed the plant on short-term due to their greater solubility, and organic materials are used to enrich the soil system that feed the plant (Amir *et al*., 2011) making the combination a sustainable strategy on the long-term basis. The proportion of organic and inorganic supply of nutrient needs to be established before making any policy on nutrient management in new technology, SRI.

Yield and nutrient uptake

There is apprehension whether SRI crop requires lesser nutrients as it requires less water, and what should be nutrient management strategies for SRI? Ceesay (2011) concluded that in Gambia grain production can be significantly increased without higher application of inorganic fertilizer. However, Zhao *et al.* (2009) observed that the maximum yield (7.3 t/ha) from SRI resulted under the application of 80 kg N/ha, while under conventional flooding, the maximum yield (6.4 t/ha) was obtained with the use of 160 kg N/ha. However, Reddy *et al.* (2013) found that application of 100% recommended dose of NPK was more productive (Table 7).

At Varanasi, Uttar Pradesh, application of 75% RDF+45 kg N/ha through vermi-compost (VC) resulted in the highest grain yield and application of 45 kg N/ha either through FYM or VC led to higher NPK uptake in grain and straw (Srivastava *et al.*, 2014). Similarly in acidic sandy clay loam soil of Shyamakhunta, Mayurbhanj falling under north central plateau agro-climatic zone of Odisha, SRI with INM recorded the highest productivity (7.30 t/ha) and NPK uptake (Mohanty *et al*., 2014). In other parts of the country also integrated use of nutrients involving organic manures, chemical fertilizers and bio-fertilizers has been found to increase productivity and nutrient uptake in SRI (Bharathy, 2005; Raju *et al*., 2008; Borkar *et al*., 2008; Venkataviswanath *et al*., 2010; Weijabhandara *et al.,* 2011 and Chaudhary *et al*., 2014). (Tables 8). The studies of Chandrapala *et al*. (2010) revealed the highest nutrient uptake with NPK + Zn + S treatment followed by NPK + Zn, NPK + S and NPK + FYM; use of NPK + FYM, however, recorded the highest quantity of available N, P and K in the soil after crop harvest. Application of inorganic fertilizers alone in SRI method increased yield, but did not contribute to soil quality, which was a key factor in SRI performance (Stoop *et al*., 2002).

Some studies from various parts of the world revealed that 50% of nutrient demand of SRI could be replaced by organic sources of nutrients with no yield losses or even sometimes higher yield (Setty *et al*., 2007; Munda, *et al.,* 2007). Again, Hossain *et al*. (2003) from Mymensingh, Bangladesh reported the highest grain and straw yields under SRI method over conventional transplanting with 50% dose of N:P:K:S:Zn (30:20:20:5:2.5 kg/ha) through fertilizers + 50% through cow-dung @ 5t/ha) (organic fertilizer) treatment. On-farm trials in Indonesia showed that addition of 2 t/ha of organic matter and application of N by local recommendation produced significantly higher

Table 7. Effect of nutrient management on SRI yield and water productivity (WP)

Planting method	Grain yield (t/ha)	Grain weight/ hill (g)	Root dry weight (g)	WP (kg/m^3)
SRI-Organic	2.80	15.6	8.2	0.252
SRI-50% NPK	5.77	31.4	9.2	0.520
SRI-100% NPK	7.66	42.0	11.7	0.690
Traditional transplanting	6.48	22.6	3.2	0.371
CD (P=0.05)	0.507	2.41	0.241	0.028

Source: Reddy *et al.* (2013)

Table 8. Effect of nutrient management practices in SRI (mean of 2 seasons)

Treatment	Yield (t/ha)	Nutrient uptake (kg/ha)			
		N	P	K	Zn
100% RDF	7.95	69.5	14.2	113.9	0.558
75% RDF	6.49	54.3	10.7	83.7	0.361
75% RDF + biofertilizers	9.45	83.9	16.9	128.8	0.649
50% RDF	4.23	30.5	6.3	59.4	0.239
50% RDF + biofertilizer	5.32	41.9	8.8	72.4	0.321
CD (P=0.05)	0.11	4.7	1.0	7.3	0.082

Source: Weijabhandara *et al*. (2011), Dharwad, India grain yield over organics alone (Uphoff *et al*., 2002).

Economics

Cost on production gets escalated when higher amounts of organics like FYM or composts are purchased and added to soil. In most of the studies, higher gross returns have been reported with integrated use of organic and inorganic sources of nutrients, but net returns and benefit: cost ratio are invariably higher from the SRI method, where only chemical fertilizers are used (Bharathy, 2005; Borkar *et al*., 2008; Chandrapala *et al*., 2010). However, there are certain cases, where both gross and net returns were higher under INM. The use of 100 % RDF alongwith 30 kg N/ha through VC gave the highest net returns (₹59,804/ha) from SRI (Srivastava *et al.,* 2014). Mohanty *et al.* (2014) reported that SRI with INM mode of nutrition produced the highest gross returns (₹75,586/ha) and net return of (₹40,570/ha); but the net returns was at par with RDF (₹40,251/ha). Bhuva *et al.* (2006) revealed that SRI with INM (50% FYM + 50% RDF) and SRI with 100% organic manuring saved 28.6 and 34.3%, respectively, input cost over conventional transplanting with RDF.

Overall, SRI has been shown to be more profitable than conventional transplanting and farmers' traditional practices of rice cultivation. Data in table 9 provide the comparison between SRI and conventional transplanting for cost of production and net returns in some rice-growing countries. It is evident from the data that SRI increased net returns by 1.2 to 2.4 times that from conventional transplanting.

Thus, it is clear that yield, nutrient uptake, gross returns from SRI under integrated nutrient management capsule consisting of 50% RDF + 50% nutrients or N from organic sources were either higher or equal to those obtained from the use of 100% NPK, but net returns and benefit: cost ratio were mostly higher with 100% NPK and application of only organics even upto 10 t/ha as source of nutrients was inferior in terms of yield, nutrient uptake and net profit. However, keeping in view the fast depleting soil nutrients both macro-and micro-nutrients and beneficial effects of organics on soil health in the long-run, it is desirable to substitute 25–50% NPK with organic sources for higher and sustainable yields of SRI.

CONCLUSIONS

This review reveals differential response of SRI to management variables like, cultivar, planting spacing, seedling age, irrigation regimes, nutrient management and weed control practices. It has been generally believed that there are no specific varieties for SRI and all existing varieties can be used for growing rice with SRI method. Since contribution of effective tillers per unit area to rice yield is over 80% and SRI crop is planted at a wider spacing, varieties with greater tillering ability could be preferred over low tillering cultivars. For better establishment of crop, seedling age of 10–12 days is invariably found suitable for transplanting under SRI; 12-day old seedlings were particularly found suitable for *rabi* season rice. Wider spacing is an important component of SRI and most of the studies reviewed showed 25 cm × 25 cm and 20 cm × 20 cm to be ideal spacing for higher yield, nutrient uptake and grain quality under SRI. However, a few studies demonstrated higher yields from SRI under 30 cm × 30 cm plant spacing. Although under SRI the best yields of rice were obtained when irrigations were applied at 3 DADPW, but water savings were larger with some yield reductions when irrigations were applied at 5 or 7 DADPW. Thus when water is scarce, SRI rice may be irrigated at 5 and 7 DADPW. Regarding nutrient management in SRI, integrated nutrient management capsule consisting of 50 % RDF + 50% nutrients from organic sources appeared to be most suitable. Weeds infestation is greater in SRI, which can be managed by employing integrated weed management instead of using only cono-weeding or manual weeding.

Future Thrusts in SRI

1. It has been observed that about 50% of tillers under wider spacing do not produce panicles. Genetic and agronomic research interventions for converting greater number of tillers into productive ones, is an important issue that need to be addressed too.

Table 9. Comparison between SRI and conventional transplanting for cost of production and net returns in some of the rice growing countries

Cost of production/ net returns	India						Kenya		Sri Lanka		Nepal (*Tarai* region)	
	Pantnagar, Uttarakhand		Kanchipuram Tamil Nadu		Coimbatore, Tamil Nadu		SRI	FP	SRI	CT	SRI	CT
	SRI	CT	SRI	CT	SRI	CT						
Cost of cultivation (×10³₹/ha)	28.9	31.4	16.6	18.9	16.8	20.3	129.4*	133.5*	22. 7	19.2	23.2	23.1
Net returns (×10³₹/ha)	30.3	19.4	17.6	13.4	16.6	14.6	104.0	42.7	14.0	6.2	95.2	39.5

*Include cost of land hiring also

(Source: Namara *et al*., 2003; Barah, 2009; Dass and Chandra, 2012; Ndiiri *et al*., 2015; Uprety, 2015)

2. Interaction effects of cultivars, planting spacing, irrigation, nutrient management, weed management on SRI need to be studied further under different climatic and edaphic conditions.
3. The irrigation treatments applied in most of the studies have been scheduling of irrigation based on status of water ponding on soil surface or drying of soil surface. Soil and plant water status based irrigation need to be further evaluated. Thus, protocols for quickly and precisely determining soil and plant water status for precise irrigation scheduling in SRI need to be developed.
4. Certain sensors like moisture-meter, time-domain reflectometry (TDR), tensiometer are now available in the market, which need to be evaluated for irrigation scheduling in SRI.
5. Environmental foot prints of irrigation and nutrient management in SRI, like N_2O, methane emission, soil environment need to be investigated.
6. SRI suffers from severe infestation of weeds. Thus, new farmer-and eco-friendly approaches of weed management are required to be devised for feasible, efficient and cost effective weed management in SRI.

REFERENCES

Amir, K., Stoop, W. and Uphoff, N. 2011. Review of SRI modifications in rice crop and water management and research issues for making further improvements in agricultural and water productivity. *Paddy and Water Environment* **9**: 163–80.

Ashraf, M., Khalid, A. and Ali, K. 1999. Effect of seedling age and density on growth and yield of rice in saline soil. *Pakistan Journal of Biological Sciences* **2**: 860–862.

Avasthe, R.K., Verma, S., Kumar, A. and Rahman, H. 2012. Performance of rice varieties at different spacing under system of rice intensification in mid–hill acid soils of Sikkim Himalayas. *Indian Journal of Agronomy* **57**(1): 32–37.

Babar, S.R. and Velayutham, A. 2012a. Weed management practices on nutrient uptake, yield attributes and yield of rice under system of rice intensification. *Madras Agricultural Journal* **99**(1–3): 51–54.

Babar, S.R. and Velayutham, A., 2012b. Weed management practices on weed characters, plant growth and yield of rice under system of rice intensification. *Madras Agricultural Journal* **99**(1–3): 46–50.

Babu, D.P.S. 1992. Integrated weed management benefits from direct seeded upland rice. *Indian Journal of Agronomy* **42**(1): 7–8.

Babu, P.R. 2007. Response of rice varieties to SRI method of cultivation (ln) *Proceedings of 2nd National Symposium on SRI in India–Progress and Prospects.* October 3–5, 2007. Agartala, Tripura, pp. 57–58.

Baloch, A.W., Soomro, A.M., Javed, M.A., Ahmed, M., Bughio, H.R., Bughio, M.S. and Mastoi, N.N. 2002.Optimum plant density for high yield in rice (*Oryza sativa* L.). *Asian Journal of Plant Sciences* **1**: 25–27.

Barah, B.C. 2009. Economic and ecological benefits of system of rice intensification (SRI) in Tamil Nadu. *Agricultural Economics Research Review* **22**: 209–14.

Barison, J. and Uphoff, N. 2011. Rice yield and its relation to root growth and nutrient-use efficiency under SRI and conventional cultivation: an evaluation in Madagascar. *Paddy and Water Environment* **9**: 65–78.

Barrett, C.B., Moser, C.M., McHugh, O.V. and Barison, J. 2004. Better technology, better plots, or better farmers? Identifying changes in productivity and risk among Malagasy rice farmers. *American Journal of Agricultural Economics* **86**(4): 869–88.

Berkhout, E., and Glover, D. 2011. The evolution of the SRI as a socio–technical phenomenon. *A Report to the Bill & Melinda Gates Foundation. Wageningen, the Netherlands*: Wageningen University and Research Centre.

Bharathy, V.E. 2005. Effect of FYM and rotary weeding on crop yield in the SRI. *M.Sc. (Ag.) Thesis*. Acharya N. G. Ranga Agricultural University, Hyderabad, India.

Bhuva, N.P., Patel, R.R., Chauhan, N.P., Makwana, I.K., Mehta, A.M and Pathak, A.R. 2006. Performance of rice variety Gr-11 SRI (In) *Proceedings of National Symposium on System of Rice Intensification (SRI)–Present Status and Future Prospects*, November 17–18, 2006, Acharya N.G. Ranga Agricultural University, Hyderabad. pp. 65.

Bioflora, 2013. Definition of soil microbe groups. Retrieved from *http://www.bioflora.com/soil-microbes* on 22nd November, 2014.

Bommayasamy, N., Ravisankar, N. and Subramani, T. 2010. Influence of non–monetary inputs on growth and yield of rice under SRI. *Indian Journal of Agronomy* **55**(2): 95–99.

Borkar, L.S., Khawale, V.S., Raut, B., Patil, T.S and Kolte Harsha, S. 2008. Studies on spacing and nitrogen management under SRI. *Journal of Soils and Crops* **18**(2): 438–41.

Borrel, A., Garside, A., and Fukai, S.1997. Improving efficiency of water-use for irrigated rice in a semi-arid tropical environment. *Field Crops Research* **52**: 231–48.

Bouman, BAM and Tuong, T.P. 2001. Field water management to save water and increase its productivity in irrigated lowland rice. *Agricultural Water Management* **49**: 11–30.

Chadhar, A.R., Nadeem, M.A., Tanveer, A., and Yaseen, M. 2014. Weed management boosts yield in fine rice under SRI. *Planta Daninha, Viçosa-MG* **32**(2): 291–99.

Ceesay, M. 2002. Experiments with the system of rice intensification in the Gambia. (In) Uphoff, N., Fernandes, E.C.M., Yuan, L.P., Peng, J.M., Rafaralahy, S. and Rabenandrasana, J. (Eds.) Assessment of the system of rice intensification. *Proceedings of International Conference*. Sanya, China, April 1–4, 2002. pp. 56–57.

Ceesay, M. 2011. An opportunity for increasing factor productivity for rice cultivation in the Gambia through SRI. *Paddy and Water Environment* **9**: 129–35.

Ceesay, M. and Uphoff, N. 2003. The effects of repeated soil wetting and drying on lowland rice yield with system of rice intensification methods. *http/ciifad.cornell.edu.*

Ceesay, M., Reid, W.S., Fernandes, E.C.M. and Uphoff, N. 2006. The effects of repeated soil wetting and drying on lowland rice yield with system of rice intensification (SRI) methods. *International Journal of Agricultural Sustainability* **4**: 5–14.

Chandrapala, A.G., Yakadri, M., Mahender Kumar, R. and Bhupal R.G. 2010. Productivity and economics of rice (*Oryza sativa*) – maize (*Zea mays*) as influenced by methods of crop establishment, Zn and S application in rice. *Indian Journal of Agronomy* **55**(3): 171–76.

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 and Water Environment* **8**: 81–90.

Choudhury, B.U., Singh, A.K., Bouman, B.A.M. and Prasad J. 2007. System of rice intensification and irrigated transplanted rice: Effect on crop water productivity. *Journal of Indian Society of Soil Science* **55**(4): 464–70.

Chaudhary**,** S.K., Singh, S. P., Singh, Y. and Dharminder. 2014. Influence of integrated use of fertilizers and manures on SRI grown rice (*Oryza sativa*) and their residual effect on succeeding wheat (*Triticum aestivum*) in calcareous soil**.** *Indian Journal of Agronomy* **59**(4): 527–33.

Chung, I., Kim, K., Ahn, J., Lee, S., Kim, S., Hahn, S. 2003. Comparison of allelopathic potential of rice leaves, straw, and hull extracts on barnyard grass. *Agronomy Journal* **95**(4): 1,063–70.

Dass, A. and Chandra, S. 2012. Effect of different components of SRI on yield, quality, nutrient accumulation and economics of rice in *tarai* belt of northern India. *Indian Journal of Agronomy* **57**(3):250–54.

Dass, A. and Chandra, S. 2013a. Irrigation, spacing and cultivar effects on net photosynthetic rate, dry matter partitioning and productivity of rice under system of rice intensification in Mollisol of northern India. *Experimental Agriculture* **49**(4): 504–23.

Dass, A. and Chandra, S. 2013b. Panicle characteristics, yield and their correlation in system of rice (*Oryza sativa*) intensification and conventional transplanting under variable irrigation, spacing and varieties. *Indian Journal of Agronomy* **58**(1): 54–62.

Dass, A. and Dhar, S. 2014. Irrigation management for improving productivity, nutrient uptake, and water–use efficiency in system of rice intensification: A review. *Annals of Agricultural Research, New Series* **35**(2): 107–22.

Dass, A., Chandra, S., Choudhary, A.K., Singh, G. and Sudhishri, S. 2015. Influence of field re-ponding pattern and plant spacing on rice root-shoot characteristics, yield, and water productivity of two modern cultivars under SRI management in Indian Mollisols. *Paddy and Water Environment.* DOI 10.1007/s10333-015-0477-z.

Deb, D., Lässig, J. and Kloft, M. 2012. A critical assessment of the importance of seedling age in the system of rice intensification (SRI) in eastern India. *Experimental Agriculture* **48**(3): 326–46.

Devasinghe, D., Premarathne, K., Sangakkara, U., 2011. Weed management by rice straw mulching in direct seeded lowland rice (*Oryza sativa* L.). *Tropical Agricultural Research* **22**(3): 263–72.

Dewangan, D., Singh A.P., Nirala, H. and Verma, M. 2011. Effect of different weed management practices on weed density and weed dry matter production in system of rice intensification (SRI). *Indian Journal of Weed Science* **43**(3 and 4): 217–21.

Dhar, R., Gupta, N.K. and Samata, A. 2008. Effect of irrigation scheduling on the performance of *kharif* rice grown under different establishment methods. *Journal of Research SKUAST-Jammu* **7**(2): 277–80.

Dhital, K. 2011. Study on system of rice intensification in transplanted and direct–seeded versions compared with standard farmer practice in Chitwan, Nepal. *M.Sc. (Ag.) Thesis.* Tribhuvan University, Institute of Agriculture and Animal Sciences, Rampur, Chitwan, Nepal. 152 p.

Dizon, M.A., Gines, H.C., Redulia, C.A. and Cassman, K.G. 1996. Effect of transplanting practices on rice yield components. *Philippine Journal of Crop Science* **19**: 1–76.

Dobermann, A., 2004. A critical assessment of the system of rice intensification (SRI). *Agricultural Systems* **79**(3): 261–81.

El-Shahawy, T.A., El-Rokiek, K., Sharara, F., Khalaf, K., 2006. New approach to use rice straw waste for weed control. I. Efficacy of rice straw extract against broad and narrow leaved weeds in cucumber (*Cucumis sativa* L.). *International Journal of Agriculture and Biology (Pakistan)* **8**(2): 262–68.

El-Shahawy, T. A. and Zydenbos, S., 2010. Rice straw as an allelopathic agent for controlling weeds. (In) *17th Australasian Weeds Conference*. New Frontiers in New Zealand: Together we can Beat the Weeds. Christchurch, New Zealand, 26–30 September, 2010. 143–46.

Fernandes, E.C.M and Uphoff, N. 2002. Summary from conference reports. (In) Uphoff, N., Fernandes, E.C.M., Yuan, L.P., Peng, J.M., Rafaralahy, S. and Rabenandrasana, J. (Eds.). (In) *Proceedings of International Conference* on Assessment of the System of Rice Intensification. Sanya, China, April 1–4, 2002. pp. 33–39.

Glover, D. 2011. The system of rice intensification: Time for an empirical turn. *NJAS–Wageningen Journal of Life Sciences* **57**(1): 217–24.

Gunri, S.K., Pal, S.K. and Chaudhury, A. 2004. Effect of integrated nitrogen application on yield of rice in foot hill soil of West Bengal. *Indian Journal of Agronomy* **49**(4): 248–50.

Haden, V.R., Duxbury, J.M., DiTommaso, A. and Losey, J.E., 2007. Weed community dynamics in the system of rice intensification (SRI) and the efficacy of mechanical cultivation and competitive rice cultivars for weed control in Indonesia. *Journal of Sustainable Agriculture* **30**(4): 5–26.

Hameed, K.A., Jaber, F.A. and Mosa, A.J. 2013. Irrigation water-use efficiency for rice production in southern Iraq under system of rice intensification. *Taiwan Water Conservancy* **61**(4): 61–93.

Hanafi, E. M., El Khadrawy, H., Ahmed, W. and Zaabal, M. 2012. Some observations on rice straw with emphasis on updates of its management. *World Applied Sciences Journal* **16**(3): 354–61.

Hanamaratti, N.G., Salimath, P.M., Prashanthi, S.K., Raikar, S.D. and Angadi, V.V. 2006. Response of rice genotypes under direct seeded SRI in rainfed condition of Karnataka. (In) *National symposium on SRI– Present status and future prospects*. November, 17–18, 2006, Acharya N.G. Ranga Agricultural University, Hyderabad. pp. 70.

Hasanuzzaman, M., Nahar K. and Karim, M.R. 2007. Effectiveness of different weed control methods on the performance of transplanted rice. *Pakistan Journal of Weed Science Research* **13**(1–2): 17–25.

Hasanuzzaman, M., Rahman, M.L., Roy, T.S., Ahmed, J.U. and Zobaer, A.S.M. 2009. Plant characters, yield components and yield of late transplanted *aman* rice as affected by plant spacing and number of seedlings per hill. *Advances in Biological Research* **3**(5–6): 201–07.

Hossain, M.Z., Hossain, S.M.A., Anwar, M.P., Sarker, M.R.A and Mamun, A.A. 2003. Performance of 'BRRI Dhan 32' in SRI and conventional methods and their technology mixes. *Pakistan Journal of Agronomy* 2(4): 195–200.

IRRI, 2014. Weed control. Retrieved from *http:// www.knowledgebank.irri. org/ ericeproduction/* PDF_&_Docs/Weed_control.pdf, on 10 March, 2014.

Jacob, D. and Syriac, E.K. 2005. Performance of transplanted scented rice under different spacing and water management regimes in southern Kerala. *Journal of Tropical Agriculture* **43**(1–2): 71–73.

Jayawardena, S.N. and Abeysekera, S.W. 2002. Effect of plant spacing on the yield of hybrid rice. *Annals of the Sri Lanka Development and Agriculture* **4**: 15–20.

Jiang, C.Z., Hirasawa, T. and Ishihara, K. 1988. Physiological and ecological characteristics of high yielding varieties in rice plants. II. Leaf photosynthetic rate. *Japan Journal of Crop Science* **57**(1): 139– 45.

Kabir, H. and Uphoff, N. 2007. Results of disseminating the system of rice intensification with farmer field school methods in Northern Myanmar. *Experimental Agriculture* **43**(4): 463–76.

Kato-Noguchi, H. and Ino, T. 2005. Concentration and release level of momilactone B in the seedlings of eight rice cultivars. *Journal of Plant Physiology* **162**(9): 965–69.

Kayande, N.V., Kute, N.S., Katre, L.A. and Sawant, P.V. 2012. Influence of seedling age and spacing on yield of rice variety PKHMT. *Bioinfolet* **9**(4A): 470–72.

Krishna, A. and Biradarpatil, N.K. 2009. Influence of seedling age and spacing on seed yield and quality of short duration rice under system of rice intensification cultivation. *Karnataka Journal of Agricultural Sciences* **21**(1): 53–55.

Krupnik, T.J., Rodenburg, J., Haden, V.R., Mbaye, D. and Shennan, C. 2012. Genotypic trade-offs between water productivity and weed competition under the system of rice intensification in the Sahel. *Agricultural Water Management* **115**: 156–66.

Kumar, H.B.H., Deshpande, V.K., Vyakaranahal, B.S. and Hanamarahatti, N.G. 2013. Screening of selected promising rice hybrids under modified SRI method in upland ecosystem. *Bioinfolet* **10**(1A): 45–49.

Kumar, M.R., Surekha, K., Padmavathi, C., Subba Rao, L.V., Latha, P.C., Prasad, M.S., Babu, V.R., Ramprasad, A.S., Rupela, O.P., Goud, V., Raman, P.M., Somashekar, N., Ravichandran, S., Singh, S.P. and Viraktamath, B.C. 2010. Research experiences on system of rice intensification and future directions. *Journal of Rice Research* **2**: 61–71

Latif, M.A., Ali, M.Y., Islam, M.R., Badshah, M.A. and Hasan M.S. 2009. Evaluation of management principles and performance of SRI in Bangladesh. *Field Crops Research* **114**(2–3): 255–62.

Latif, M.A., Islam, M.R., Ali, M.Y. and Saeque, M.A. 2005. Validation of the SRI in Bangladesh. *Field Crops Research* **93**(2–3): 281–92.

Lin, X.Q., Zhou, W.J., Zhu, D.F. and Zhang, Y.P. 2004. Effect of water management on photosynthetic rate of leaves and water–use efficiency in paddy rice.*Chinese Journal of Rice Sciences* **18**: 333–38.

Mahajan, G. and Rao, P.S.S. 2009. Evaluation of system of rice intensification in irrigated agro–ecosystem of Punjab. *Journal of Research, Acharya N G Ranga Agri University* **37**(1 & 2): 1–6.

Makarim, A.K., Balasubramanian, V., Zaini, Z., Syamsiah, I., Diratmadja, I.G.P.A., Handoko, A., Wardana, I.P. and Gani, A. 2002. Systems of rice intensification (SRI): Evaluation of seedling age and selected components in Indonesia. In: *Water–Wise Rice Production*, pp 129–39 (Eds. B.A.M. Bouman, A. Hengsdijk, B. Hardy, P.S. Bindraban, T.P. Tuong and J.K. Ladha). Los Baños, Philippines: IRRI.

Manjunatha, B.N., Basavarajappa, R. and Pujari, B.T. 2010. Effect of age of seedlings on growth, yield and water requirement by different system of rice intensification. *Karnataka Journal of Agricultural Sciences* **23**(2): 231–34.

McHugh, O.V., Sttenhuis, T.S., Barison, J., Fernandes, E.C.M. and Uphoff, N. 2002. Farmer implementation of alternate wet-dry and non flooded irrigation practices in the system of rice intensification (SRI) (*In) Proceedings of the International Workshop on Water-wise Rice Production,* 8-11 April 2002, Los Baños, Philippines. Los Baños (Philippines): International Rice Research Institute. pp. 89–102.

Menete, M.Z.L., Vanes, H.M., Brito, R.M.L., De Gloria, S.D. and Famba, S. 2008. Evaluation of system of rice intensification component practices and their synergies on salt–affected soils. *Field Crops Research* **109**(1–3): 34–44.

Meyyappan, M., Ganapathy, M.Sriramachandrasekharan, M.V. and Sujatha S. 2013. Effect of age of seedlings and weed management practices on certain growth parameters of SRI. *Journal of Rice Research* **6**(1): 53–56.

Mishra, A. and Salokhe, V.M. 2008. Seedling characteristics and the early growth of transplanted rice under different water regimes. *Experimental Agriculture* **44**: 1–19.

Mohandass, S., Fadhakrishnan, R. and Sivanappan, R.K. 1987. Influence of moisture regime on 'IR 50'. *International Rice Research Newsletter* **12**(2): 46.

Mohanty, T.R., Maity, S.K. and Roul, P.K. 2014. Response of rice to establishment methods and nutrient management practices in medium land. *Oryza* **51**(2): 36–42.

Mollah, M.Z., Talukder, N.M., Islam, M.N., Rahman, M.A and Ferdous, Z. 2009. Effect of nutrients content in rice as influenced by zinc fertilization. *World Applied Sciences Journal* **6**(8): 1082–88.

Mrunalini, A., and Ganesh, M. 2008. Work load on woman using cono-weeder in SRI method of paddy cultivation. *Oryza* **45**(1): 58–61.

Munda, G.C., Das, A. and Patel, D.P. 2007. Performance of lowland rice (*Oryza sativa* L.) as influenced by stand establishment methods and nutrient management practices at mid altitude of Meghalaya. (In) *2nd National Symposium on System of Rice Intensification (SRI) in India -Progress and Prospects,* 3–5 October, Agartala, Tripura, India, pp 92–93.

Nader, G.A. and Robinsons, P.H. 2010. Rice producers' guide to marketing rice straw.*University of California, Agriculture and Natural Resources Publications 8425* pp1-10.

Namara, R.E., Weligamage, P. and Barker, R. 2003. Prospects for adopting system of rice intensification in Sri Lanka: A socio-economic assessment. Research Report 75, International Water Management Institute, Colombo, Sri Lanka, p. 56.

Ndiiri, J.A., Mati, B.M., Home, P.G., Odongo, B. and Uphoff, N. 2015. Benefit: cost analysis of paddy rice under the system of rice intensification in Mwea, Kenya. *file:///C:/Users/Admin/Downloads/862-3079-1-PB.pdf. Accessed on 24.3.2015.*

Ookawa, T., Naruoka, Y., Yamazaki, T., Suga, J. and Hirasawa, T. 2003. A comparison of the accumulation and partitioning of nitrogen in plants between two rice cultivars, *Akenohoshi* and *Nipponbare*, at the ripening stage. *Plant Production Science* **6:** 172–78.

Palanisami K., Karunakaran, K R., Amarasinghe, U., Ranganathan. C R. 2013. Doing different things or doing it differently ? Rice intensification practices in 13 States of India. *Economic & Political Weekly* XLVIII(8): 51–58.

Pasuquin, E., Lafarge, T. and Tubana, B. 2008. Transplanting young seedlings in irrigated rice fields: early and high tillering production enhanced grain yield. *Field Crops Research* **105**: 141–55.

Patel, K.M. and Patel M.M. 2014. Weed management in rice (*Oryza sativa L.*) under system of rice intensification technique. *Trends in Biosciences* **7**(5): 384–87.

Pillai, K.G. 1996. Current scenario in rice and prospects for sustainable rice production. *Fertilizer News* **41**(2): 15–33.

Poonam, A. 2007. Performance of rice hybrids under varying dates of planting during wet and dry seasons. *Ph.D. Thesis* submitted to Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, p. 147.

Poonam, A. and Rao, K.S. 2007. Comparative yield performance of system of rice intensification under different plant geometry and age of seedlings in coastal alluvial condition of Odisha. (In) *2nd National symposium on SRI in India: Progress and prospects*, 3–5 October, Agartala, Tripura, India. pp- 66.

Powar, S.L. and Deshpande, V.N. 2001. Effect of integrated agro–technology on 'Sahyadri' hybrid rice in medium black soil in high rainfall area. *Journal of Maharashtra Agricultural University* **26**(3): 272–76.

Prasad, C.S. 2006. *System of Rice Intensification in India: Innovation History and Institutional Challenges.* WWF Project 'Dialogue on water, Food and Environment' c/o ICRISAT, Hyderabad –502 324 and Xavier Institute of Management Xavier Square Bhubaneswar- 751 013, Odisha, p.79.

Rabenandrasana, J. 1999. The Madagaskar system of rice intensification: A revolution in rice production. (In) *Proceedings on "Enhancing Sustainability of the Rice Economy in the Philippines*", April 26–30, pp. 125–30.

Rafaralahy, S. 2002. An NGO perspective on SRI and its origin in Madagaskar. (In) *Assessment of SRI: Proceedings of International Conference,* Sanya, China, April 1–4, pp. 17–22.

Rajesh, V. and Thanunathan, K. 2003. Effect of seedling age, number and spacing on yield and nutrient uptake of traditional kambanchamba rice. *Madras Agricultural Journal* **90**(1–3): 47–49.

Raju, R.A and Sreenivas, Ch. 2008. Agronomic evaluation of system of rice intensification methods in Godavari delta. *Oryza* **45**(4): 280–83.

Ram, H., Singh, J.P., Bohra, J.S., Yadav., A.S. and Sutliya, J.M. 2015. Assessment of productivity, profitability and quality of rice (*Oryza sativa*) under System of Rice Intensification in eastern Uttar Pradesh. *Indian Journal of Agricultural Sciences* **85**(1): 38-42.

Ram, H., Singh, J.P., Singh, R.K., Bora, J.S. and Sutaliya, J.M. 2014. Effect of seedling age and plant spacing on growth, yield, nutrient uptake and economics of rice genotypes under system of rice intensification. *Indian Journal of Agronomy* **59**(2): 256–60.

Ramamoorthy, K., Selvaraj, K.V. and Chinnaswami, K.N. 1993. Varietal response of rice (*Oryza sativa*) to different irrigation regimes. *Indian Journal of Agronomy* **38**(3): 468–69.

Randriamiharisoa, H.W. 2002. Research results on biological nitrogen fixation with the system of rice intensification. (In) Uphoff, N., E.C.M. Fernandes, L. Yuan, J. Peng., S. Rafaralahy, and J. Rabenandrasana (Eds) *Proceedings of an International Conference on Assessments of the SRI*, Sanya, China, April 1-4, pp. 148–57.

Ranjitha, P. S. and Reddy, K.I. 2014. Effect of different nutrient management options on rice under SRI method of cultivation- A review. *International Journal of Plant, Animal and Environmental Sciences* **4**(1): 201–04.

Reddy, B.G.M., Ravishankar, Balaganhvi, S. and Joshi, V.R. 2013. Nutrient management of rice (*Oryza sativa*) under system of rice intensification (SRI). *Indian Journal of Agricultural Sciences* **83**(6): 591–94.

Riaz, M., Malik, A.M., Mahmood, T.Z. and Jamil, Y.M. 2006. Effect of various weed control methods on yield and yield components of wheat under different cropping patterns. *International Journal of Agriculture and Biology* **8**(5): 637-–40.

Roy, S., Bisht, P.S. Pandey, P.C., Paul, T. 2015. Assessment of age of seedling and weed management practices on rice yield under system of rice intensication. *Proceeding of the National Academy of Sciences, India, Section B Biological Sciences*. DOI 10.1007/s40011-015-0487-z .

Salem, A.K.M. 2006. Effect of nitrogen levels, plant spacing and time of farm yard manure application on the production of rice. *Journal of Applied Sciences and Research* **2**(11): 980–87.

San-oh, Y., Sugiyama, T., Yoshita, D., Ookawa, T. and Hirasawa, T. 2006. The effect of planting pattern on the rate of photosynthesis and related processes during ripening in rice plants. *Fields Crops Research* **96**: 113–24.

Sato, S. and Uphoff, N. 2007. A Review of on–farm evaluations of system of rice intensification methods in eastern Indonesia. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources* **54**: 1–12.

Satyanarayana, A., Thiyagarajan, T.M. and Uphoff, N. 2007. Opportunities for water saving with higher yield from the system of rice intensification. *Irrigation Science* **25**: 99–115.

Satyanarayana, A. and Babu, K.S. 2004. *Manual on System of Rice Intensification (SRI): A Revolutionary Method of Rice Cultivation*, Acharya N.G., Ranga Agricultural Unversity, Rajendranagar, Hyderabad, p.13.

Senthilkumar, K., Bindraban, P.S., Thiyagarajan, T.M., deRidder, N. and Giller, K.E. 2008. Modified rice cultivation in Tamil Nadu, India: yield gains and farmers, (lack of) acceptance. *Agricultural Systems* **98**: 82–94.

Setty, P.T.K., Bandi, A.G., Singh, S. and Sanjay, M.T. 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) 2nd *National Symposium on System of Rice Intensification (SRI) in India – Progress and Prospects.* 3–5 October, Agartala, Tripura, India, 82–84.

Sharma, P.K. and Kaur, J. 2014. Influence of age of rice nursery on productivity and water usage under different nitrogen levels and transplanting systems. *Journal of Research Punjab Agricultural University (India)* **51**(2): 132–35.

Sharma, P.K. and Masand, S.S. 2008. Evaluation of SRI in a high rainfall area of NW Himalayas. ***Oryza* 45(3):** 206–11.

Shrirame, M.D., Rajgire, H.J. and Rajgire, A.H. 2000. Effect of spacing and seedling number per hill on growth attributes and yield of rice hybrids under lowland condition. *Journal of Soils and Crops* **10**(1): 109–13.

Shukla, U.N, Srivastava, V.K., Singh, S., Sen, A. and Kumar, V. 2014. Growth, yield and economic potential of rice (*Oryza sativa*) as influenced by different age of seedlings, cultivars and weed management under system of rice intensification. *Indian Journal of Agricultural Sciences* **84**(5): 628–36.

Singh, H. and Ingram, K.T. 2000. Sensitivity of rice (*Oryza sativa* L.) to water deficit in three growth stages. *Crop Research* **20**(3): 355–59.

Singh, K., Singh, S R., Singh, J .K., Rathore, R S., Singh, S.P. and Roy, R. 2013. Effect of age of seedling and spacing on yield, economics, soil health and digestibility of rice (*Oryza sativa*) genotypes under system of rice intensification. *Indian Journal of Agricultural Sciences* **83**(5): 479–83.

Singh, K.N. and Sharma, S.N. 1995. Influence of fertility levels, spacing and weed management on the potassium uptake by direct seeded upland rice and weeds. *Agricultural Science Digest* **15**(1 and 2): 1–4.

Singh, Y.V. 2012. Crop and water productivity as influenced by rice cultivation methods and organic and inorganic sources of nutrient supply. *Paddy and Water Environment* **11**(1–4): 531–42.

Sinha, S.K. and Talati, J. 2007. Productivity impacts of the system of rice intensification: A case study in West Bengal, India. *Agricultural Water Management* **87**(1): 55–60.

Sridevi, V. 2006. Relative contribution of individual components of System of Rice Intensification (SRI) to the yield of rice. *M.Sc. (Ag.) Thesis*. Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India.

Sridevi, V., Jeyaraman, S., Chinnusamy, C. and Chellamuthu V. 2013. Weed management in lowland rice (*Oryza Sativa* L.) ecosystem: A review. *International Journal of Agricultural Science and Research* **3** (3): 13–22.

Srivastava V.K., Singh, J.K., Bohra, J.S. and Singh S.P. 2014. Effect of fertilizer levels and organic sources of nitrogen on production potential of hybrid rice (*Oryza sativa*) and soil properties under system of rice intensification. *Indian Journal of Agronomy* **59**(4): 607–12

Stoop, W.A., Uphoff, N. and Kassam, A. 2002. A review of agricultural research issues raised by the system of rice intensification from Madagascar: Opportunities for improving farming systems for resource–poor farmers. *Agricultural Systems* **71**(3): 249–74.

Sudhalakshmi, C., Velu, V. and Thiyagarajan, T.M. 2005. Weed management options on the dynamics of nitrogen fractions in the rhizosphere soil of rice hybrids. *Madras Agricultural Journal* **92**(7–9): 444–48.

Tao, S.S. and Ma, J. 2003. Improvement of the system of rice intensification (SRI) and its application in medium hybrid rice of the double cropping system. *Hybrid Rice* **18**: 47–48.

Thakur, A. 2010. Critiquing SRI criticism: Beyond scepticism with empiricism. *Current Science* **98**(10): 1,294–299.

Thakur, A.K., Mohanty, R.K., Patil, D.U. and Kumar, A. 2014. Impact of water management on yield and water productivity with system of rice intensification (SRI) and conventional transplanting system in rice. *Paddy and Water Environment* **12**: 413–24.

Thakur, A.K., Rath, S., Roychowdhury, S. and Uphoff, N. 2010a. Comparative performance of rice with SRI and conventional management using different plant spacings. *Journal of Agronomy and Crop Science* **196**(2): 146–59.

Thakur, A.K., Uphoff, N. and Antony, E. 2010b. An assessment of physiological effects of system of rice intensification practices compared with recommended rice cultivation practices in India. *Experimental Agriculture* **46**(1): 77–98.

Thiyagarajan, T.M., Senthilkumar, K., Bindraban, P.S., Hengsdijk, H., Ramasamy, S. Velu, V., Durgadevi, D., Govindarajan, K., Priyadarshini, R., Sudhalakshmi, C., Nisha, P.T., & Gayathry, C. 2002. Crop management options for increasing water productivity in rice. *Journal of Agricultural Resource Management* **1**(4): 169–81.

Thura, S. 2010. Evaluation of Weed Management Practices in the System of Rice Intensification (SRI). *M.Sc. (Agronomy) Thesis,* Submitted to the Postgraduate Committee of the Yezin Agricultural University, Myanmar.

Tuong, T.P. and Bhuiyan, S.I. 1999. Increasing water-use efficiency in rice production: Farm level perspectives. *Agricultural Water Management* **40**: 117–22.

Uphoff, N. 2002. System of rice intensification for enhancing the productivity of land labour and water. *Journal of Agricultural Resources and Management* **1**: 43–49.

Uphoff, N., Fernandes, E.C.M., Yuan, L.P., Peng, J.M., Rafaralahy, S. and Rabenandrasana, J. 2002. (In) *Proceedings of International Conference on Assessment of SR.,* Sanya, China, April 1–4, pp. 35

Uphoff, N., Kassam, A and Stoop, W. 2008. A critical assessment of a desk study comparing crop production systems: The example of the 'system of rice intensification' versus 'best management practice'. *Field Crops Research* **108**: 109–14

Uprety, D.C., Dwivedi, N., Jain, V., Mohan, R., Saxena, D.C., Jolly, M. and Paswan, G. 2003. Response of rice cultivars to the elevated CO_2. *Biologia Plantarum* **46**(1): 35–39.

Uprety, R. 2015. Economic analysis of System of Rice Intensification (SRI) methods in Morang district of Nepal, main season, 2005. *file:///C:/Users/Admin/Desktop/Agronomy%20SRI%20 review/nepupretyecon05%20nepal.pdf*. Accessed on 24.3.2015.

V & A Programme. 2009. *Vulnerability and Adaptation Experiences from Rajasthan and Andhra Pradesh: The System of Rice Intensification*, SDC V & A Programme, India.

Venkataviswanath, K., Veeraraghavaiah, R., Pullarao, Ch. and Lakshimi, G. V. 2010. Yield and nutrient uptake of rice (*Oryza sativa* L.) as influenced by interventions in nutrient management under the system of rice intensification. *The Andhra Agricultural Journal* **57**(2): 122–25.

Verma, A.K., Paclay, N. and Tripathi, S. 2002. Effect of transplanting spacing and number of seedlings on productive tillers, spikelet sterility, grain yield and harvest index of hybrid rice. *International Rice Research Newsletter* **27**(1): 51.

Vijayakumar, M., Ramesh S., Chandrasekaran B. and Thiyagarajan, T.M. 2006. Effect of SRI practices on yield attributes and yield and water productivity of rice. *Research Journal of Agricultural and Biological Sciences* **2**(6): 236–47.

Viraktamath, B.C. and Kumar, R.M. 2007. Research experiments on SRI – A summary of research papers submitted for the symposium. (In) *Proceedings of 2nd National symposium on system of rice intensification in India: Progress and prospects.* October 3–5, Agartala, Tripura. pp. 39– 41.

Vizier, J. F. 1990. Study of the dynamics of waterlogged environments: Physico-chemical approach. *Cahiers-ORSTOM, Pedologie (Journal)* **25**: 431–42

Walker, S.H. and Rushton, K.R. 1984. Verification of lateral percolation losses from irrigated rice fields by numerical model. *Journal Hydrology* **71**: 335–51.

Wang, S.H., Cao, W., Jiang, D., Dia, T.B. and Zhu, Y. 2003. Effects of SRI technique on characteristics and population development. *Chinese Journal of Rice Science* **19**(2): 31–36.

Wayayok, A., Soom, M.A. M., Abdan, K., and Mohammed, U. 2014. Impact of mulch on weed infestation in SRI farming. *Agriculture and Agricultural Science Procedia* **2:** 353–60.

Weijabhandara, D.M.D.I., Dasog, G.S., Patil, P.L. and Hebbar, M. 2011. Effect of nutrient levels on rice (*Oryza sativa* L.) under system of rice intensification and traditional methods of cultivation. *Journal of Indian Society of Soil Science* **59**(1): 67–73.

Yang, J., Liu, K., Wang, Z., Du, Y. and Yang, J. 2007. Water-saving and high-yielding irrigation for lowland rice by controlling limiting values of soil water potential. *Journal of Integrative Plant Biology* **49**: 1,445–54.

Yuan, L.P. and Fu, X. Q. 1995. Technology of Hybrid Rice Production. Food and Agriculture Organization of the United Nations, Rome Italy, p 62.

Zhao, L., Wu, L., Li, Y., Lu, X., Zhu, D. and Uphoff, N. 2009. Influence of the System of Rice Intensification on rice yield and nitrogen-and water-use efficiency with different N application rates. *Experimental Agriculture* **45**: 275–86.

Zhao, M., Wu, LH., Li, Y.S., Animesh, S., Zhu, D.F. and Uphoff, N., 2010. Comparisons of yield, water-use efficiency, and soil microbial biomass as affected by the system of rice intensification. *Communications in Soil Science Plant Analysis* **41**: 1–12.

Zhong, H.M., Huang, A.M., Liu, J.P., Li, J.N., Wu, F.B. and Ouyang, F.P. 2003. Analysis of the yield-increasing effects and economic benefits of system of rice intensification (SRI) in hybrid rice. *Hybrid Rice* **18**: 45–46.