

PERFORMANCE OF HYBRIDS/ HIGH YIELDING VARIETIES AND NUTRIENT MANAGEMENT IN SYSTEM OF RICE INTENSIFICATION – A REVIEW

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Received:16-09-2011

Accepted:11-01-2012

ABSTRACT

Rice is the staple cereal food grain of majority of India's over one billion population. As there is no scope to increase the area under rice, System of Rice Intensification (SRI) is considered as one of the technologies to increase the productivity. Contrary to this, SRI is showed by some workers as labour intensive, difficult to practice and on par to that of conventional method without any yield advantage. Nutrient management must be sound for achieving the yield potential of rice hybrids/ HYV's under SRI. The use of organic manures such as application of FYM has been proved to be viable component of INM for SRI.

Key words: Cultivars, FYM, Methods of Cultivation, Nutrient Management Options, System of Rice Intensification.

Rice, the staple cereal food grain of majority of India's over one billion population, contributes to nearly 44% of total food grain production. India has to produce 114 m t of rice by the year 2030 to meet the food grain requirement of burgeoning population. As there is no scope to increase the area under rice, System of Rice Intensification (SRI) is considered as one of the technologies to increase the productivity. Since rice is water intensive crop, water is becoming single most constraint to produce more rice to meet the increasing demand. So System of Rice Intensification (SRI) is introduced in India during 2000 as a viable alternative of rice cultivation that reduces about 30% of the water requirement when compared to traditional method. Contrary to this, SRI was also showed by some workers as labour intensive, difficult to practice and on par to that of conventional method without any yield advantage. However, while highlighting SRI, Uphoff *et al.* (2002) stated that the best SRI yields can be achieved with HYV's or hybrids but even traditional varieties can perform better under SRI. Nutrient management must be sound for achieving the yield potential of rice hybrids/ HYV's under SRI. Although use of chemical fertilizer is the fastest way of counteracting the pace of nutrient depletion the best course is to

practice Integrated Nutrient Management. This would harmoniously integrate the use of mineral fertilizer and organic manures to the extent possible without any detrimental effect on potential yield. The use of organic manures such as application of FYM has been proved to be viable component of INM for SRI.

Performance of Different Rice Cultivars (Hybrids/ Hyv's) Under SRI

Rice hybrids have a mean yield advantage of 10-15% over varieties (Yang *et al.*, 1999 and Hari Om *et al.*, 2000) since they possess a more vigorous and extensive root system and increased growth rate during vegetative period (Yamauchi, 1994) when grown under normal transplanting condition. Besides, rice hybrids exhibited highest yield potential even under SRI method, due to profuse tillering capacity, lodging tolerance, greater stress resistance and wide ecological adaptability (Yan Qingquan, 2002).

Plant height of the variety Tellahamsa was highly responsive to SRI over conventional method of cultivation at 41 DAS. However, this response was not consistent at later stages of crop growth. It was also observed that rice varieties Tellahamsa and BPT-5204 produced less of X matter m⁻² and less number dry effective tillers m⁻² (212 and 312; 355

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and 362 respectively) under SRI method of cultivation in comparison to conventional method (Krupakar Reddy, 2004).

Experience with SRI method suggests that average rice yields could be enhanced substantially without changing a cultivar (Wang Shao-hua *et al.*, 2002). Wang Shao-hua *et al.* (2002) reported that under SRI, population quality and biomass partitioning efficiency were found to increase distinctively and the grain yield was higher (11,750 kg ha⁻¹) than under conventional cultivation (11,497 kg ha⁻¹), irrespective of rice species. Subbalakshmi lokanadhan *et al.* (2007) from Tamil Nadu Agricultural University found that rice hybrid CORH-3 produced a grain yield of 8.14 t ha⁻¹ and straw yield of 11.20 t ha⁻¹ in SRI whereas it produced 6.78 t ha⁻¹ grain and 10.17 t ha⁻¹ straw in standard method. Similarly, Narsimha Reddy *et al.* (2006) reported that the hybrid KRH-2 and the variety RNR-23064 performed well under SRI method of cultivation recording a grain yield of 8.95 and 8.51 t ha⁻¹ respectively, while in conventional method of cultivation they gave 6.89 and 6.43 t ha⁻¹ respectively. The experiments conducted by Barah (2006) showed a yield advantage of 48% due to SRI with the rice hybrids PHB-71 and DRRH-1. The hybrids performed extremely well under SRI with 46-47% yield advantage and the hybrid KRH-2 was found superior to other cultivars with a grain yield of 7.95 t ha⁻¹ (Viraktamath, 2006). Subba Rao *et al.* (2007) observed significantly higher yield with SRI method over conventional method. Khan *et al.* (2009) reported that under SRI ecosystem, the rice hybrid PRH-10 recorded highest grain yield of 8.90 t ha⁻¹ followed by hybrid KRH-2 with 8.66 t ha⁻¹.

Among the cultivar groups, the performance of late and medium duration varieties and hybrids was found to be better as compared to early duration varieties. It is imperative that under SRI method, due to wider spacing, varieties with high tillering ability perform better as compared to the shy tillering genotypes (Kumar *et al.*, 2009). Uphoff, 2004 stated that rice hybrids produced around 15 t ha⁻¹ while HYV's had a yield potential of 6-12 t ha⁻¹ of grain when grown under SRI in Madagascar. Raghuvveer Rao *et al.* (2006) also from DRR reported that hybrids were found superior to HYV's as well as to basmati cultivar when grown under SRI, but in terms of dry matter production both were found at a par.

Sowmya (2008) suggested that in SRI method, the hybrid PSD-1 performed better than variety BPT – 5204 and gave significantly higher grain yield. Hybrid rice (PHB- 71) gave significantly higher grain yield (7869 kg ha⁻¹) and net returns (Rs. 26,944 ha⁻¹) than the variety (ADT 43) which recorded 6776 kg ha⁻¹ of grain yield and net returns of Rs. 20,656 ha⁻¹ (Thiyagarajan., 2007). Similarly Choudhary *et al.* (2010) found that rice hybrids like KRH-2, Arize 6444 and PHB – 71 produced 74.7, 65.5 and 56.0 per cent more grain yield respectively over a high yielding variety Indam 100-001.

SRI was not particularly variety sensitive and that advantage of the system can be well utilized by any variety during dry season as experienced at Maruteru, Andhra Pradesh, India (Satyanarayana *et al.*, 2004). Latif *et al.* (2005) found that while comparing the performance of short and long duration varieties, the long duration variety BRRI dhan 29 produced highest number of effective tillers m⁻² and also yielded highest (7.3 t ha⁻¹) than BRRI Hybrid dhan 1 (6.6 t ha⁻¹) with SRI practices. The variety Dhanrasi also performed better than other cultivars viz., Salivahana, Pranava, Swarna and Pooja under SRI (Ram *et al.*, 2006). Dakshina Murthy *et al.* (2006) observed higher yields with MTU-1010 and MTU 1001 when grown under SRI over normal transplanting method. While reporting the results of an experiment conducted by Subbaiah *et al.* (2006) at DRR, Rajendranagar, it was recorded that rice variety Krishnahamsa and local check variety M-7 recorded significantly higher grain yield under SRI method compared to other varieties. Babu (2007) observed that for SRI, the best varieties suitable for rabi season were NLR 3333057, NLR 33359 and NLR 34449. All the three varieties were of 115- 125 days duration indicating that the medium duration rice varieties perform well under SRI in rabi season. Venugopal Rao *et al.* (2007) stated that the variety MTU 1075 recorded highest grain yield of 6 t ha⁻¹ under SRI as against 5.5t ha⁻¹ in conventional method during kharif season.

Madhu Babu *et al.* (2007) reported that among the four rice varieties grown in SRI method of cultivation (BPT -5204, IR 64, MTU 1010 and Kaverisona), Kaverisona performed better in terms of both grain (7.6, 8.0, 8.3, 8.6 t ha⁻¹ respectively) and straw yields (9.3, 9.4, 9.8, 9.9 t ha⁻¹). Similarly the experiments conducted by Varaprasad *et al.*

(2007) also revealed the better performance of varieties BPT-5204, MTU 1061 and MTU 2077 under SRI method with an increased yield of 28, 21 and 24% respectively over farmers practice.

Krishna *et al.* (2008) noticed that the rice variety BPT -5204 took 106 days for 50 per cent flowering under SRI method as compared to 110 days under conventional method. The highest grain yield (7.2 t ha^{-1}) was recorded by Swarna than MTU 1061 (6.5 t ha^{-1}) variety under SRI method (Raju *et al.*, 2008). Mahajan and Sarao (2009) reported that the cultivar HR1 -152 produced significantly more seed yield of 6.6 t ha^{-1} than 17 A/R10 which yielded 5.2 t ha^{-1} in SRI method.

Effect of SRI on Growth

SRI method of cultivation create above-ground and below-ground environments that are more favourable for the rice plant's growth (Stoop *et al.*, 2002; Randriamiharisoa *et al.*, 2006). According to SRI concept, the reduction in achievable yield with conventional rice cultivation was mainly due to the degeneration of the root system (Kar *et al.*, 1999).

Suresh (2006) stated that in SRI method the yield potential is high owing to wider spacing, transplanting young and single seedling per hill and increased activity of soil biota. Thus the SRI method outperformed the NTP in terms of growth attributes, root growth and yield (Zamir Ahmed *et al.*, 2006).

Rabenandrasana (2002) reported that in SRI the full potential for the root growth was captured by alternative wetting and drying of the field with minimum number of irrigations, early and frequent weedings and incorporation of compost. Many species of bacteria and fungi produce phytohormones in the rhizosphere i.e. auxins, cytokinins, ethylene etc., that regulate and promote root growth (Arshad and Frankenberget, 1995).

The plant height (cm) was higher in standard method at tillering (58) and panicle initiation (69) stages and in SRI at flowering (81) and at maturity (83) (Subbalakshmi Lokanadhan *et al.*, 2007).

The plant height of the variety Tellahamsa was highly responsive to SRI over conventional method of cultivation at 41 DAS. But this response was not consistent at later stages of crop growth. Unlike this variety, BPT-5204 did not show a significant difference for plant height between SRI

and traditional cultivation method from 41 DAS until crop harvest (Krupakar Reddy, 2004).

Tao Longxing *et al.* (2002) from China National Rice Research Institute, Hangzhou reported that plant height of cultivar xieyou 9308 with SRI method was higher than that of standard method of rice cultivation although there was no significant difference in height for liangyou-peijiu cultivar. In terms of root growth there was a marked difference between SRI and traditional rice cultivation, SRI having a greater root growth. Root dry matter and root depth were also more in SRI compared to traditional rice. The total dry matter production of crop was higher with SRI than that of traditional rice, more significantly during the reproductive stage. Wang Shao- hua *et al.* (2002) found that at jointing stage, the dry matter accumulation under SRI (3916 kg ha^{-1}) was lower than that of conventional method (4096 kg ha^{-1}) while at heading and maturity stages, the dry matter production under SRI was higher than under conventional method. The study of Kewat *et al.* (2002) and Xiuming *et al.* (2004) also confirmed that dry matter accumulation increased by planting rice following SRI concept as compared to standard transplanting method. In another study, the highest dry matter production of 1330 g m^{-2} was recorded by SRI when compared to the dry matter production of 1104 g m^{-2} with conventional method at harvest (Singh *et al.*, 2006 a). Narendra Pandey and Om Prakash (2007) observed that the dry matter recorded by SRI at 60 DAT and at harvest were 16.55 and $39.53 \text{ g hill}^{-1}$ and were significantly superior to conventional method (14.10 and $36.67 \text{ g hill}^{-1}$) respectively. During *kharif* season, the combination of young seedling, one seedling, square planting and conoweeding significantly showed its superiority by registering taller plants, more tillers m^{-2} , more dry matter production, more root length, root dry weight and root volume in short duration rice variety ADT 43 (Sridevi and Chellamuthu, 2008). Borkar *et al.* (2008) stated that under SRI method, increased dry matter accumulation was due to adequate availability of nutrients through wider spacing which also produced higher number of effective tillers with increased LAI and less plant density. Similarly the plant dry weight was significantly higher under SRI method when compared to direct seeding and conventional transplanting method (Chandrapala *et al.*, 2010)

In contrast Wang Shao-hua *et al.* (2002) from Jiangsu Academy of Agricultural Sciences, Nanjing Agricultural University, reported that at heading and maturity stages, dry matter accumulation under SRI treatment were 10,479 and 19139 kg ha⁻¹ respectively, which were found slightly higher than that of normal rice cultivation (10136 and 18910 kg ha⁻¹). Krupakar Reddy (2004) also stated that rice varieties Tellahamsa and BPT-5204 produced low quantity of dry matter m⁻² by following SRI method of cultivation as compared to the standard method of cultivation.

Yan Qingquan (2002) opined that the tillering potential of rice could be fully achieved under SRI by adopting a spacing of 25cm x 25cm along with combined use of organic and inorganic nutrient sources. He also observed that wider spacing and transplanting 8-12 days old seedlings produced significantly higher number of effective tillers m⁻² over conventional method of transplanting at an age of 25-35 days with narrow spacing. Vishnudas (2003) observed that with SRI method, transplanting single seedling per hill at a distance of 25 cm x 25 cm or 30 cm x 30 cm gave up to 256 per cent more tiller production in different varieties of rice. In SRI planting strategy, there was less trauma to the root system and the plants recover from the shock of transplanting more quickly which preserve the potential of the plant for much greater tillering, faster root growth and grain filling (Uphoff, 2002). Similarly in SRI method, the increase in the productive tillers was to an extent of 217 per cent over conventional method due to more space available to the plants by planting in square method at 25 cm x 25 cm distance (Krishna *et al.*, 2008)

Hengsdijik and Bindraban (2001) reported that SRI method increased the number of tillers, productive tillers m⁻², number of grains panicle⁻¹ and 1000 grain weight over conventional method.

Singh *et al.* (2006 a) from DRR recorded higher mean maximum tiller number (544 m⁻²) under SRI, while the lowest number of tillers (443 m⁻²) was obtained with conventional transplanting. Dakshina Murthy *et al.* (2006) stated that despite higher number of tillers m⁻² recorded under normal transplanting during early stages compared to SRI, as the growth advanced the SRI method recorded higher number of tillers m⁻². In contrast Krupakar Reddy (2004) reported that in variety BPT-5204,

higher number of tillers was recorded by normal transplanting over SRI method during the entire crop growth period.

Effect of SRI on yield attributes and yield

Rajesh and Thanunathan (2003) and Uphoff (2001) observed that the roots of rice plants have least competition under wider spacing so that growth is stimulated by sunlight and space for the canopy expansion thereby increasing the yield attributes and yield.

Raju *et al.* (1989) recorded more filled grains per panicle and grain yield per plant under SRI method of cultivation. Abu Yamah (2002) also reported that in SRI method of rice cultivation, yield components like number of panicles m⁻² and grains per panicle were more with adoption of all recommended practices (448 and 122, respectively) over farmer's technique (338 and 95, respectively). Similar results were reported by Thiyagarajan (2002), (Raghuveer Rao *et al.*, 2006). Wang Shao-hua *et al.* (2002) reported that the percentage of productive tillers under SRI treatment was distinctively higher than that under conventional rice cultivation. Ang Shengfu (2004) observed that the effective panicles with SRI method at two spacings (33.3 cm x 33.3 cm and 40 cm x 40 cm) were 4.1 and 3.1 million ha⁻¹, respectively with an increase of 66.7 % and 26.5% over traditional rice cultivation method (2.4 million effective panicles ha⁻¹). Similarly, Singh *et al.* (2006 a) from DRR recorded higher panicle number (516 m⁻²) under SRI, while the lowest number of panicles (430 m⁻²) were observed with conventional transplanting. In contrast, Krupakar Reddy (2004) stated that the rice varieties Tellahamsa and BPT-5204 recorded significantly less number of effective tillers (212 and 312 respectively) at a spacing of 25 cm x 25 cm under SRI as compared to conventional method (355 and 462 respectively). Bisht *et al.* (2006) noticed that panicles were lowest (187 m⁻²) in SRI technology, however it was statistically at par with conventional method (227 m⁻²).

Avil Kumar *et al.* (2006) found that higher grain yield of rice in SRI was attributed to more number of panicles m⁻² (8-17%), more panicle length (8-11 %), higher number of filled grains per panicle (17-30%) coupled with lower unfilled grains per panicle (17-33%) over normal transplanting.

Krishna *et al.* (2006) noticed that productive tillers hill^{-1} (19.73) and filled spikelets panicle^{-1} (76.2) were higher in SRI method compared to conventional method. Subbalakshmi lokanadhan *et al.* (2007) reported that in hybrid CORH 3, panicle length and filled grains panicle^{-1} were higher in SRI (23.05 cm and 189 respectively) compared to standard method (21.87cm and 127 respectively). Similarly, Suresh (2006) concluded that SRI method would edge out conventional practices on account of higher number of effective tillers, greater panicle length, more number of grains per panicle and higher test weight.

Higher thousand grain weight (6.7%) and more biomass accumulation (20.1%) were reported by Ceesay and Uphoff (2003) in SRI method as compared to standard method. SRI method recorded more number of productive tillers, more number of filled spikelets and there was a slight increase in test weight also (Cheralu *et al.*, 2006). Ajay Kumar *et al.* (2007) found that SRI recorded the highest grain yield (6.10 t ha^{-1}) as compared to conventional practice of transplanting (3.9 t ha^{-1}) due to more number of panicles m^{-2} , panicle weight and 1000 grain weight. In contrast, Krupakar Reddy (2004) reported that the number of filled grains panicle^{-1} , 1000-grain weight and panicle length did not vary due to methods of cultivation (SRI and NTP).

Uphoff *et al.* (2002) reported that in Philippines, the yield with SRI was 6.8 t ha^{-1} compared to production level of 5.4 t ha^{-1} by farmers practice with an increase in the yield of 1.4 t ha^{-1} . The grain yields recorded under SRI ranged from 4,214 to $10,655 \text{ kg ha}^{-1}$ and those from conventional cultivation varied between 3,887 and $8,730 \text{ kg ha}^{-1}$ (Thiyagarajan 2002).

On farm trials conducted at Philippines by Robert Gasparillo (2003) revealed that a maximum yield of 7.4 t ha^{-1} with an average of 5.1 t ha^{-1} was obtained from comparative study between SRI and non-SRI. Cheralu *et al.* (2006) from Agricultural Research Station, Warangal, A. P., recorded a yield of 8.7 t ha^{-1} with SRI and 6.3 t ha^{-1} with normal method. Shrikanth *et al.* (2007) reported that grain yield in SRI method of cultivation (6.62 t ha^{-1} and 5.1 t ha^{-1}) was higher when compared to traditional rice planting techniques (5.9 t ha^{-1} and 4.3 t ha^{-1} respectively) in 2005 and 2006. The results of the experiment conducted by Avil kumar *et al.* (2006) RARS, Jagtial indicated that the crop under SRI

recorded 12% and 15% higher grain yield ($5,992$ and $5,614 \text{ kg ha}^{-1}$) during *kharif* and *rabi* respectively than that of normal transplanting ($5,350$ and $5,354 \text{ kg ha}^{-1}$). Similar results were observed by Balasubramanian and Devraj ., 2004; Satyanarayana *et al.*, 2004).

Ganesh *et al.* (2006) observed a yield advantage of 24 % with SRI method over conventional method. Similar yield advantage with SRI method over conventional practice was also noticed by other workers (Nissanka and Bandara (2004); Sameer Kumar *et al.*, 2006; Chaudhari *et al.*, 2006; Singh *et al.*, 2006 a; Sahadeva Reddy, 2007; Mahajan and Sarao ., 2009; Zode *et al.*, 2008 and Chandrapala *et al.*, 2010).

Contrary to these, Sheehy *et al.* (2004) stated that SRI has no major role in improving rice production and observations of very high yields in Madagascar probably are the consequence of some form of measurement error.

Stoop *et al.* (2002) stated that SRI is often presented as a very sophisticated and labour intensive approach, requiring strict water control (irrigation as well as drainage), well- levelled fields, ample supplies of compost or manure, and much labour to ensure timely transplanting and frequent weeding, both of which are the most critical field operations. The realities in the field, however, differed quite substantially from this presumed "ideal" image. Similarly, Dobermann (2003) observed that although yield advantages were claimed for SRI over conventional practice for the majority of the reports, there were also examples for no yield increase over control in Bangladesh, China, India, Myanmar, Nepal and Thailand.

Islam *et al.* (2005) from Bangladesh found that the yield potential of SRI method was at par with recommended transplanting method. The results of the study conducted by Dinesh kumar *et al.* (2006) showed a non-significant difference in grain yield of rice under both (SRI and conventional) methods of rice cultivation in the first year. However in second year conventional rice culture produced significantly much higher grain yield as compared to SRI. The results of trials conducted in Uttarakhand indicated non-significant difference between SRI and conventional method in terms of grain yield (Viraktamath and Mahender Kumar, 2007).

Latif *et al.* (2005) from Bangladesh Rice Research Institute (BRRI) reported that recommended management performed significantly better than SRI and resulted in higher grain yield (6.88 t ha^{-1}). Similarly Bisht *et al.* (2006) from GB Pant University of Agriculture and Technology stated that conventional transplanting resulted in highest grain yield (6.52 t ha^{-1}) which was statistically at par to SRI. The key reason for increased harvest index (HI) under SRI was due to less barren tillers and higher number of grains per fertile tiller (Khush, 1993). In contrast Krupakar Reddy (2004) concluded that the harvest index of Tellahamsa and BPT-5204 under SRI at a spacing of $25 \text{ cm} \times 25 \text{ cm}$ were on par with that of the same grown under normal transplanting method.

Effect of SRI on nutrient uptake

Barison (2002 b) observed variation in nutrient uptake between SRI management and conventional practices with the same variety wherein SRI management removed more N, P and K over conventionally grown rice. The larger canopies and well developed root system in SRI may lead to efficient and more effective N, P and K uptake than conventional system (Uphoff, 2005).

Vallois and Uphoff (2000) reported that N, P and K uptake was more with SRI than with conventional practices. Narendra Pandey and Om Prakash (2007) revealed that the N, P and K uptake of rice at crop harvest was higher under SRI method ($139.21, 36.27$ and $151.14 \text{ kg ha}^{-1}$) over conventional method ($124.78, 31.42$ and $131.08 \text{ kg ha}^{-1}$). Hugar *et al.* (2009) observed that during kharif season, SRI method recorded the maximum total uptake of nitrogen (268.5 kg ha^{-1}), phosphorus (67 kg ha^{-1}) and potassium (173 kg ha^{-1}) compared to normal method of planting ($224, 52.1$ and 153.9 kg ha^{-1} respectively). The increase in the nutrient uptake in SRI method may be attributed to large and more functional root system per unit area, which absorb the nutrient released and from native source as a result of solubilizing action of organic acids produced during decomposition of insitu incorporation of weeds and organic manures. SRI resulted in higher productivity during *Kharif* with comparable nutrient uptake and marginally higher nutrient use efficiency without depleting the soil available nutrients compared to standard transplanting, after two

seasons (Kumar *et al.*, 2009). In contrast, Krupakar Reddy (2004) reported that in variety BPT-5204 the total N uptake was less in SRI method compared to traditional method of rice cultivation. However the total uptake of P and K in both the methods of cultivation was at a par. Similarly Surekha *et al.* (2007) stated that SRI and conventional method were at a par with each other but significantly superior to eco-SRI with respect to N, P and K uptake.

Uphoff and Randriamiharisoa (2002) observed that mycorrhizal fungi that infect roots helped maintaining a balance in the supply of nutrients to the plants as well as provide valuable protective services. They increased the accessed soil volume by as much as 100 times compared with non-infected root. Plants with mycorrhizal fungi could grow well with just a fraction of the P required for unassisted plants. However, since fungi cannot survive under hypotoxic conditions, continuously irrigated rice had foregone the benefits of their associations for centuries, even millennia. They also observed that under SRI, increase in both vegetative and reproductive biomass was apparently attributable to more efficient acquisition of soil nutrients (N, P, K, Mg, Cu, Zn, Ca and Mo) and uptake of nutrients.

Effect of SRI on economics

SRI method has both yield advantage and economic advantage over conventional methods. The average increase in yield was 6-50 % and farmer's income was 4-82 % (Weixing *et al.*, 2004).

The International Institute of Water Management (IIWM) evaluation team compared the returns and stated that SRI rice farmers in Sri Lanka were more than 7 times less likely than conventional farmers to experience net economic loss in any particular season, because of higher yields and lower costs of production (Anthofer, 2004; Namara *et al.*, 2004).

Bruno Andrianaivo (2002) reported that SRI raises productivity of labour substantially. Net income from SRI was greater than normal cultivation method.

In SRI method, labour requirements typically diminish as farmers become familiar with the methods; eventually SRI can require less labour per ha (Barret *et al.*, 2004). However, Moser and Barret

(2002) reported that SRI was difficult to practice, because it required significant additional labour input at a time of the year when liquidity to hire the labour was low and family labour efforts were already high.

Field studies of labor requirements in Madagascar showed that SRI required an estimated 26-54% more labour than traditional cultivation methods (Mc Hugh, 2002; Barison, 2002 a; Rakotomalala, 1997). A net benefit of Rs. 18,700 ha⁻¹ was obtained in SRI over non SRI (Illuri *et al.*, 2004). Varghese *et al.*, 2005 reported 11% reduction in the cost of cultivation with SRI management compared to conventional system. Vishnudas (2006) from Wayanad, Kerala observed that the total income from SRI plots varied from Rs.10, 000 to 16,000 while that in conventional plots varied it from Rs.4, 400 to Rs.9, 600 per acre. The cost of production under SRI was half the cost of conventional cultivation (Singh *et al.*, 2006 b). The combination of young seedlings, single seedling, square planting and conoweeding contributed for the highest net return (12,574 Rs. ha⁻¹) and B:C ratio (1.87) compared to normal practice (Chellamuthu and Sridevi, 2006). Narendra Pandey and Om Prakash (2007) observed that the highest net returns (Rs. 27,468 ha⁻¹) were obtained under SRI, than those of other planting techniques (Standard transplanting, Random transplanting and Integrated Crop Management). Shrikanth *et al.* (2007) reported that net returns (Rs ha⁻¹) in SRI method of cultivation (27,486 and 18,816 respectively) were higher when compared to conventional rice planting techniques (22,728 and 13,385 respectively) in 2005 and 2006 years. Higher net profit of Rs 28,873 ha⁻¹ and B: C ratio of 2.16 was registered through increased grain yield with SRI. SRI method of cultivation recorded higher net income of Rs. 21,415 ha⁻¹ over farmers practice (Rs. 16,288 ha⁻¹), thus income increase was 31.5 per cent (Budhar and Mani, 2008). In contrast, Krupakar Reddy (2004) reported that BPT-5204 required an expenditure of Rs. 11,375 under SRI method as against Rs. 13,027 under traditional method. However the gross returns of Rs. 45,042 and net returns of Rs. 32,015 was accrued with traditional method over SRI method (Rs. 36,466 and Rs. 25,091 respectively). Anitha *et al.* (2007) stated that though the cost of cultivation was higher under conventional system, there was an increased grain

yield (4553 kg ha⁻¹), straw yield (4702 kg ha⁻¹) under conventional system of rice cultivation thereby the net return was higher (Rs. 14709 ha⁻¹) compared to SRI (Rs. 12331 ha⁻¹).

Influence of different nutrient management options under SRI on growth

Barison (2002 a) opined that application of well decomposed compost to rice in SRI system favored the improvement of better soil structure and supply of nutrients. It led to enhanced crop growth and biomass production. This enhanced growth parameters can be achieved by balanced fertilization accompanied by transplanting young seedlings in well drained soils to maintain tillering and rooting potential (Uphoff, 2001). Bua *et al.* (2002) reported that enhanced rate of application of nitrogen would improve the leaf area index and photosynthetic activity in System of Rice Intensification.

Gani *et al.* (2002) reported that full growth potential of 7 to 14 days seedlings could be exploited by addition of organic manures in conjunction with chemical fertilizers, rather than the application of individual sources alone.

Fertilizing soil with farmyard manure or compost would promote positive soil biological processes, enhance the availability of nutrients over a longer period to remove balanced nutrients for better growth and development (Mc Hugh *et al.*, 2002). Uphoff (1999) observed positive response with SRI in terms of plant height and biomass production with the application of recommended fertilizer over farmers practices.

Bharathy (2005) reported that at 60, 90 DAT and maturity, maximum plant height was recorded with application of FYM @ 10 t ha⁻¹ + 100 % RDF which was on par with 100 % RDF alone but was significantly superior to application of FYM alone (10 t ha⁻¹). Application of 50 % recommended dose of nitrogen (RDN) through poultry manure/FYM and remaining 50 % RDN through inorganic fertilizers resulted in significantly higher plant height (76.31 cm, 75.13 cm respectively) but was statistically on par with 100 % RDN through inorganic source of fertilizers (Prabhakara Setty *et al.*, 2007).

At 30, 60 and 90 DAT, maximum number of tillers (190, 397, 388 m⁻²) was recorded with application of 100 % RDF, followed by FYM @ 10 t ha⁻¹ + 100 % RDF (Bharathy 2005). Prabhakara

Setty *et al.* (2007) reported that application of 50 % recommended dose of nitrogen (RDN) through poultry manure / FYM and remaining 50 % RDN through inorganic fertilizers resulted in maximum number of tillers (46.03, 44.78 respectively) but was statistically on par with 100 % RDN through inorganic source of fertilizers. Plants grown under SRI method with FYM + RDF flowered and matured early as compared to application of fertilizer alone and the increase in productive tillers was 20 % with RDF over no fertilizer (Krishna *et al.*, 2008). Borkar *et al.* (2008) stated that the growth attributes like height of plants (64.02 cm, 63.94 cm), number of effective tillers plant⁻¹ (16.56, 15.70) and dry matter accumulation plant⁻¹ (35.23 g, 34.50 g) were the highest with the application of 100 % N through fertilizer than 50 % N through fertilizer + 50 % N through FYM.

Bharathy (2005) revealed that maximum dry matter of 55.0, 271.4, 548.9 and 1027.7 g m⁻² at 30, 60, 90 DAT and maturity, respectively was recorded with FYM @ 10 t ha⁻¹ + 100 % RDF, which was significantly superior over FYM @ 10 t ha⁻¹, but on par with 100 % RDF at all stages of crop growth. Application of 50 % recommended dose of nitrogen (RDN) through poultry manure/ FYM and remaining 50 % RDN through inorganic fertilizers resulted in greater dry matter (165.27, 163.60 g hill⁻¹ respectively) but was statistically on par with 100 % RDN through inorganic source of fertilizers (Prabhakara Setty *et al.*, 2007).

Influence of different nutrient management options under SRI on yield attributes and yield

In SRI practice, application of organic amendments in conjunction with inorganic fertilizer resulted in a positive correlation between the number of tillers per plant and the number of grains panicle⁻¹ (Uphoff, 1999).

Significantly higher effective tillers were observed with the application of FYM 10 t ha⁻¹ + 100 % RDF (337.1) over 100 % RDF (292.2) and FYM 10 t ha⁻¹ (261.7). The panicle length did not vary due to nutrient management practices. Maximum filled grains per panicle (111.5) were obtained with FYM 10 t ha⁻¹ + 100 % RDF followed by 100 % RDF alone and both were at a par with each other, but significantly superior over FYM alone (93.1) (Bharathy 2005).

Prabhakara Setty *et al.* (2007) reported that application of 50 % recommended dose of nitrogen (RDN) through poultry manure/FYM and remaining 50 % RDN through inorganic fertilizers resulted in higher number of effective tillers hill⁻¹ (35.88, 34.83 respectively) but was statistically on par with 100 % RDN through inorganic source of fertilizers. Similarly increased number of filled grains panicle⁻¹ were obtained with application of 50 % recommended dose of nitrogen (RDN) through poultry manure/FYM and remaining 50 % RDN through inorganic fertilizers (271.86, 265.56 g hill⁻¹ respectively) but was statistically on par with 100 % RDN through inorganic source of fertilizers.

Borkar *et al.* 2008 reported that yield contributing characters like test weight of grains were found higher with the application of 100 % N through fertilizer (17.81) which was on par with 50 % N through fertilizer + 50 % N through FYM (17.79).

The best results in terms of yield and soil quality was observed with the application of organic manures either alone or in conjunction with chemical fertilizers. Use of chemical fertilizers alone in SRI practice increased yield, but did not contribute to soil quality, which was a key factor in SRI performance (Stoop *et al.*, 2002).

Randrimbarisoa and Uphoff (2002) stated that SRI practices (young seedlings, one seedling per hill and aerated soil, added compost) gave an yield increase of 140 to 245 % over non- SRI practices (more mature seedlings, three seedlings per hill, saturated soil with NPK fertilizer).

The results of experiments conducted in Tamilnadu by Thiyagarajan (2002) revealed the superiority of SRI practice with younger seedlings, restricted irrigation (2 cm depth) and addition of green manure (6.25 t ha⁻¹) over traditional practice.

Experiments conducted by Barison (2002 b) in Madagascar showed that higher grain yield (6.26 t ha⁻¹) was obtained from plots with SRI method with the application of compost and was found superior to conventional rice cultivation.

On farm trials conducted on SRI proved that addition of 2 t ha⁻¹ of organic matter and application of N by local recommendation produced significantly higher grain yield over organics alone in Indonesia (Uphoff *et al.*, 2002). The yield was higher in SRI

system by 11% compared to that of normal method (Surendra Babu *et al.*, 2006).

Hossain *et al.* (2003) from Mymensingh, Bangladesh reported highest grain and straw yields under SRI method (5.6 and 5.98 t ha⁻¹ respectively) over conventional method with 50 % chemical (N: P: K: S: Zn at 30:20:20:5:2.5 kg ha⁻¹) + 50% (cowdung @ 5 t ha⁻¹) organic fertilizer treatment (5.04 and 5.67 t ha⁻¹ respectively).

Bharathy (2005) reported that in SRI, application of FYM 10 t ha⁻¹ + 100% RDF (100 N + 60 P₂O₅ + 40 K₂O kg ha⁻¹) gave higher grain yield (5050 kg ha⁻¹) over that of application of 100% RDF (4725 kg ha⁻¹) and FYM 10 t ha⁻¹ alone (4132 kg ha⁻¹).

Dinesh Kumar *et al.* (2006) reported that highest grain yield was recorded with 50% compost plus 50% NPK source, which was at a par with 50% FYM plus 50% NPK in the year 2004 and both produced significantly higher grain yield over FYM or compost or NPK fertilizer alone. However, in the year 2005, 50% compost plus 50% NPK proved better than all other nutrient sources and was best among all nutrient sources.

Prabhakara Setty *et al.* (2007) stated that in rice hybrid KRH-2 under SRI, application of 50 % nitrogen through FYM and 50 % nitrogen through inorganic sources recorded significantly higher grain and straw yield (8.35 and 8.58 t ha⁻¹ respectively) but was on par with the treatment of 100 % nitrogen supplied through inorganic sources.

Munda *et al.* (2007) concluded that among the nutrient management practices, application of 100 % NPK (80:60:40 kg ha⁻¹) + FYM @ 5 t ha⁻¹ resulted in significantly higher yield (47.57 and 55.28 q ha⁻¹ in 2005 and 2006 respectively), closely followed by 50 % NPK+ FYM @ 10 t ha⁻¹ and remained at a par with each other irrespective of the establishment methods (SRI, ICM and Conventional method). Combined application of FYM @ 5 t ha⁻¹ along with half recommended levels of nitrogen through chemical and gypsum at 1 t ha⁻¹ registered highest yield (7.6 t ha⁻¹) than application of pressmud at 5 t ha⁻¹ along with half recommended nitrogen through chemical and gypsum at 1 t ha⁻¹ (6.5 t ha⁻¹) (Raju *et al.*, 2008).

Limei Zhao *et al.* (2009) showed that the maximum yield obtained under SRI method was 7.3 t ha⁻¹ by applying 80 kg N ha⁻¹, while the maximum

yield under conventional flooding was 6.4 t ha⁻¹ using 160 kg N ha⁻¹.

Chandrapala *et al.* (2010) found that NPK + Zn + S treatment recorded the highest grain yield (5.30 t ha⁻¹) when compared to other treatments like NPK (4.10 t ha⁻¹), NPK + Zn (4.84 t ha⁻¹), NPK + S (4.78 t ha⁻¹), NPK + FYM (4.93 t ha⁻¹).

Venkata Viswanath *et al.* (2010) concluded better grain yield, straw yield and harvest index with the application of 125 % recommended dose of fertilizer for conventional rice along with 10 t or 5 t FYM ha⁻¹ under SRI.

Singh *et al.* (2006 b) stated that grain yield differences among different nutrient management options under SRI were non-significant. Harvest index did not differ significantly among nutrient management practices. However, highest value (45.2%) was observed with conjunctive use of organic and inorganic nutrient sources over their individual application of FYM 10 t ha⁻¹ and 100 % RDF (Bharathy 2005)

Influence of different nutrient management options under SRI on nutrient uptake

The higher nitrogen uptake by grain and straw (56.0 and 26.7 kg respectively) was observed with application of FYM @ 10 t ha⁻¹ + 100 % RDF. However, this was comparable with application of 100 % RDF alone. Similarly the highest P and K uptake (16.6 kg ha⁻¹ and 10.3 kg ha⁻¹ P; 18.9 and 127.1 ha⁻¹ K) in grain and straw, respectively was obtained with FYM @ 10 t ha⁻¹ + 100 % RDF, followed by 100 % RDF and lowest was with FYM @ 10 t ha⁻¹ (Bharathy 2005).

Total nitrogen uptake was maximum with the application of 100 % N through fertilizer (79.05 kg ha⁻¹) as compared to 50 % N through fertilizer + 50 % N through FYM (77.74 kg ha⁻¹) (Borkar *et al.*, 2008)

Among the different nutrient applications, NPK + Zn + S treatment recorded the highest nutrient uptake followed by NPK + Zn, NPK + S and NPK + FYM. Application of NPK + FYM recorded highest quantity of available soil N, P and K content after crop harvest (Chandrapala *et al.*, 2010).

Venkata Viswanath *et al.*, 2010 reported that at all the stages i.e. 30,60,90 DAP and at maturity, higher uptake of NPK was recorded by the application of 125 % RDF for conventional rice along

with 10 t FYM ha⁻¹, which was closely followed by that of the same level of RDF with 5 t FYM ha⁻¹ under SRI.

Influence of different nutrient management options under SRI on economics

Bharathy (2005) reported that gross returns were highest with FYM 10 t ha⁻¹ + 100 % RDF (Rs 30,839 ha⁻¹). However, net returns and benefit cost ratio was maximum with 100 % RDF (Rs 19,288 and 2.0 respectively) treatment.

Bhuva *et al.*, 2006 revealed that SRI with integrated nutrient management (50% FYM + 50% RD of NPK) and SRI with 100 % organic manuring saved 28.63% and 34.25% respectively, in input cost as compared to standard practice of transplanting with recommended fertilizer and cultural practices.

Application of 100 % nitrogen through fertilizer recorded maximum NMR (Rs 15331.80 ha⁻¹) and B:C ratio (2.08) when compared to that of 50 % N through fertilizer + 50 % N through FYM with a NMR of (Rs 9645 ha⁻¹) and B:C ratio (1.51) (Borkar *et al.*, 2008).

Chandrapala *et al.* (2010) found that application of NPK + Zn + S recorded higher mean values of net returns (Rs 58,982 ha⁻¹) and B:C ratio (1.99) followed by NPK + FYM (Rs 55,723 ha⁻¹ and 1.92).

CONCLUSION

The productivity of rice can be enhanced through formulating better production technologies like SRI with improved cultivars and efficient nutrient management practices.

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