

Performance of Rice under Different Systems of Cultivation: A Review

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ABSTRACT

*Transplanting after repeated puddling is the conventional method of rice (*Oryza sativa* L) growing which is not only intensive water user but also cumbersome and laborious. Different problems like lowering water table, scarcity of labour during peak periods, deteriorating soil health demands some alternative systems of rice cultivation to sustain productivity of rice as well as natural resources. During the past years efforts have been tried to find out alternatives to the traditional method of rice cultivation. System of rice intensification and drum seeding a resource conservation methods were found to be an efficient alternative to increase the rice production as it require less water, less seed, reducing cost of cultivation and saving labor over time. Systems of rice cultivation offers certain advantages viz., it is less drudgery, early crop maturity, better soil physical conditions for following crops and less methane emission.*

Keywords: *Systems of rice cultivation, System of rice intensification, Aerobic rice, Direct seeded rice and Drum seeding.*

INTRODUCTION

Food security within Asia is challenged by rising food demand and threatened water availability. Growth of population and arithmetic increase in cereal production take flight a vast gap in food supply. Rapidly depleting water resources threaten the sustainability of the irrigated rice and hence the food security and livelihood of rice producers and consumers (Bouman & Tuong, 2000). Rice, as a submerged crop, is a prime target for water conservation because it is the most widely grown of all crops under

irrigation. To produce 1 kg of grain, farmers have to supply 2-3 times more water in rice fields than other cereals (Barker et al., 2000). In Asia, more than 80 per cent of the developed freshwater resources are used for irrigation purposes; about half of which is used for rice production (David, 2004). More than 400 million people in rice-producing areas of America, Asia and Africa still suffer due to chronic food scarcity, with the demand for food predictable to extend by an additional 38 per cent by 2050.

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In Asia, more than 2 billion people are getting 60 to 70 per cent of their energy requirement from rice and its derived products. There is also much evidence that water scarcity already prevails in rice-growing areas, where rice farmers need technologies to cope with water shortage and ways must be sought to grow rice with lesser amount of available water (Tuong & Bouman, 2002). The challenge is to develop novel technologies and production systems that would allow rice production to be maintained or increased at the face of declining water availability. Several strategies are in vogue to reduce rice water requirements, such as system of rice intensification (SRI), aerobic rice, drum seeding, direct seeded rice (DSR) *etc.*, under the conditions explained above to generate more information on the performance of this paper discusses performance of rice under different systems of cultivation

1. Growth parameters of rice under different systems of cultivation

1.1 Plant height

The field experiments conducted on clay loam soils at Indian Institute of Rice Research (IIRR), Rajendranagar, Hyderabad, during *khari* seasons of 2015 and 2016 revealed that during both the years of the study, significantly higher plant height was recorded in mechanized SRI and it was on par with normal transplanting method (Thirupathi, 2017). Among the different establishment methods studied, SRI machine transplanting recorded higher plant height compared to other methods *i.e.*, wet seeding, drum seeding, line planting and SRI square planting (Senthilkumar, 2015). A study conducted at 60 locations in East Sikkim by Mohanty et al. (2014) revealed that system of rice intensification had higher plant height (145.7 cm) compared to traditional random planting (134.33 cm). Planting of rice by self-propelled rice transplanter recorded significantly taller plants as compared to other establishment methods studied (Swain et al., 2013). At Madurai, Tamil Nadu, Rajendran et al. (2013) revealed that system of rice intensification method had significantly taller plants (91.6

cm) over machine planted (82.4 cm) on sandy clay loam soils. Singh et al. (2013) noticed that system of rice intensification with 12 days old seedlings performed better and recorded higher plant height at all the growth stages of rice. Ali et al. (2012) conducted an experiment on effect of different planting methods on clay soil at Rice Research Institute, Pakistan and reported that mechanized transplanting recorded higher plant height than the other methods tested.

Hameed et al. (2011) reported that significant differences were noticed in average plant height in SRI plots as compared to non-SRI plots. System of rice intensification recorded higher plant height over conventional method in Chiba Prefecture, Japan (Chapagain et al., 2011). Among the different establishment methods, the highest mean plant height (78.5 cm) was recorded with normal transplanting followed by transplanter and SRI methods which recorded higher plant height than zero tillage, drum seeder and aerobic methods (Hugar et al., 2009a). Manjunatha et al. (2009) concluded that both manual and mechanical transplanting methods remained on par with mean plant height of 46.9 and 45.5 cm, respectively at Gangavathi, Karnataka. System of rice intensification recorded significantly higher plant height (97.7 cm) as compared to normal transplanting (90.5 cm) at DRR, Hyderabad (Chandrapala, 2009). A study on the rice establishment methods at Dharwad, Karnataka by Wijebandara et al. (2009) revealed that SRI recorded significantly higher plant height (91.8 cm) as compared to conventional method (76.5 cm). The results of a study conducted on economic effect of different plant establishment techniques on rice production at Lahore revealed that more plant height was recorded by transplanted rice than direct seeded rice (Awan et al., 2007).

1.2 Number of tillers

Among the different rice cultivation methods, machine transplanting recorded significantly higher number of tillers m^{-2} compared to drum seeding and was on par with conventional transplanting (Sathish et al., 2017). Sharma et al. (2016) reported that among the rice

establishment methods, System of Rice Intensification (SRI) and wet seeding after puddling produced significantly more productive tillers m^{-2} than the conventional transplanting method. The maximum number of tillers were recorded with line sowing (216) followed by drum seeding (178), SRI (137) and the least were recorded with transplanting (125) (Arunbabu and Satya, 2014). Sanjeev et al. (2014) from Patna, Bihar revealed that transplanting by self-propelled transplanter *i.e.*, Mechanical Transplanting (MT) though statistically at par with the manual transplanting, produced significantly higher number of effective tillers m^{-2} (212) over Zero Tilled (ZT) rice and other methods of seeding. At Mwea Irrigation Agricultural Development (MIAD) Centre Research Station, Kenya, Omwenga et al. (2014) observed that system of rice intensification produced more tillers $hill^{-1}$ (55) as compared to the conventional method of growing rice (25). System of rice intensification was found to be highly significant at both 5 and 1 per cent level of significance with respect to number of tillers over traditional random planting in East Sikkim (Mohanty et al., 2014).

An experiment carried out at IARI, New Delhi by Singh et al. (2013) revealed that, number of total tillers $hill^{-1}$ was higher in system of rice intensification as compared to conventional planting method. Machine transplanting of rice recorded maximum number of tillers m^{-2} followed by broadcasting, conventional transplanting and drum seeding at Kampasagar, Telangana (Pasha et al., 2014). Gopalakrishnan et al. (2013) from Hyderabad reported that system of rice intensification produced higher number of tillers m^{-2} over other management practices. Self propelled rice transplanter registered significantly higher number of tillers m^{-2} (349.3) over eight establishment methods studied in Odisha (Swain et al., 2013). Ali et al. (2012) conducted an experiment with different planting methods at Rice Research Institute, Lahore, Pakistan and revealed that the highest number of productive tillers m^{-2} were recorded with dry seeding followed by mechanized

transplanting. Among the different establishment methods the maximum number of total tillers m^{-2} were observed in SRI method followed by transplanter and the lower was in the case of zero tillage (Hugar et al., 2009b). At Ganagvati, Karnataka manual transplanted and mechanical transplanted rice had performed equally better in respect of number tillers $hill^{-1}$ (Manjunatha et al., 2009). Krishna et al. (2008) reported that SRI method produced 15.3 per cent more number of tillers than conventional transplanting. Singh et al. (2006) recorded higher tiller number under SRI, while the lowest number of tillers were under NTP at Directorate of Rice Research (DRR), Hyderabad. Murthy et al. (2006) found higher number of tillers in conventional transplanting during early stages compared to SRI method. Hossain et al. (2003) reported that at Mymensingh, Bangladesh, SRI method produced higher number of tillers $hill^{-1}$ compared to conventional transplanting. Hengsdijik and Bindraban (2001) reported that SRI method produced more number of productive tillers m^{-2} than normal transplanting (NTP).

1.3 Dry matter production

Senthilkumar (2015) reported that SRI machine transplanting produced significantly higher dry matter production of rice than the other establishment methods. Hussain et al. (2012) in Jammu & Kashmir observed that transplanting of one or two seedlings $hill^{-1}$ recorded significantly higher dry matter production and accumulation compared to 3 seedlings $hill^{-1}$ in system of rice intensification. Chandrapala et al. (2010) observed that at heading and maturity stages, dry matter accumulation under SRI was 10,479 and 19,139 $kg\ ha^{-1}$ respectively, which was found to be higher than that under NTP (10,136 and 18,910 $kg\ ha^{-1}$, respectively). System of rice intensification recorded significantly higher dry matter production over normal transplanting and aerobic technique at Kathalagere, Karnataka (Pradeep, 2009). Experiments conducted at Crop Research Centre, Pantnagar, Uttarakhand on different establishment methods by Singh et al. (2009)

revealed that the highest dry matter at harvest was recorded with mat-type transplanter method than manual transplanting and direct sowing. System of rice intensification recorded significantly higher dry matter production and accumulation over normal practice (Borkar et al., 2008). Singh et al. (2006) recorded higher dry matter production under SRI, while the lowest dry matter production was under NTP at Directorate of Rice Research (DRR), Hyderabad. The line planting (13.5 t ha^{-1}) registered significantly higher dry matter production at harvest as compared to random transplanting (13.2 t ha^{-1}) and direct sowing (12.1 t ha^{-1}) (Anbumani et al., 2004). Senthilkumar (2002) indicated that there was increased dry matter production under SRI practice.

1.4 Phenology

Mohanty et al. (2014) in East Sikkim noticed that the crop duration for the same variety was reduced by at least 15 days by adoption of system of rice intensification as compared to traditional method of rice cultivation which helps the farmers to go for second crop after rice well in advance. SRI management method reduced the days to flowering by 10 days and days to harvest by 8 days compared to conventional method (Chapagain et al., 2011). Raju and Sreenivas (2008) reported that the panicle emergence was slightly delayed by 5-6 days under SRI than under conventional system due to lack of puddling. SRI plots took significantly lesser number of days (4-5) for flowering and maturity as compared to traditional method of planting in BPT-5204 variety (Krupakar, 2004). Paladugu et al. (2004) observed that the rice varieties attained 50 per cent flowering early under SRI as compared to normal cultivation at Maruteru, Andhra Pradesh during dry season.

2 Physiological studies of rice under different systems of cultivation

2.1 Physiological growth parameters

System of rice intensification recorded significantly higher leaf area index (5.6) than machine planting (5.0) at Madurai, Tamil Nadu (Rajendran et al., 2013). Hussain et al. (2012) in Jammu & Kashmir observed that

transplanting of one or two seedlings hill^{-1} produced significantly higher leaf area index compared to 3 seedlings hill^{-1} in system of rice intensification. System of rice intensification recorded significantly higher leaf area, leaf area index and leaf area duration over normal transplanting and aerobic technique at Kathalagere, Karnataka (Pradeep, 2009). Single seedling hill^{-1} in SRI method recorded higher crop growth rate over three seedlings hill^{-1} , although it recorded lower LAI (Obulamma et al., 2002).

2.2 SPAD chlorophyll meter reading (SCMR)

SPAD chlorophyll meter reading (SCMR) is an indication of the light transmittance characteristics of the leaf which is dependent on the leaf chlorophyll content. Thakur et al. (2013) reported that SPAD values decreased with increase in age of the crop *i.e.*, from tillering to grain filling stage. Higher leaf nitrogen and chlorophyll contents during the ripening stage in SRI plants reflected delayed leaf-senescence, extension of improved root-shoot activities. Abdellah et al. (2011) also observed similar decrease in chlorophyll content under moderate and severe water stress situations. Mishra and Salokhe (2010) found that, the high chlorophyll content with wider spacing was attributed to higher root - oxidation activity. Geethalakshmi et al. (2009) reported that soil and plant analysis development meter (SPAD) values at flowering were higher under SRI and transplanted rice compared to aerobic rice and AWD. Water stress decreased chlorophyll content in rice leaves (Zhu and Huang, 1994; Peng and Bouman, 2007). Reddy et al. (2003) reported significant negative correlation between SCMR and SLA, genotypes with high SCMR had greater photosynthetic capacity and thereby assimilated more carbon per unit land area, which might have influenced seed yield (Latha, 2004).

2.3 Specific leaf area (SLA)

Bindhu et al. (2002) provided evidence that the relationship between WUE and SLA was predominantly due to a strong association between SLA and leaf nitrogen, which has

strong positive linkage with SCMR. Dingkuhn et al. (2001) found that there is a strong case for SLA being responsible to a large extent for varietal differences in tillering ability and LAI in rice. High SLA is a major factor enabling early ground cover and light interception; therefore, it determines potential growth in many situations. Specific leaf area is one of the physiological traits in plant growth analysis and is the ratio of leaf area to its dry weight. The SLA is often considered as an indirect measure of leaf expansion. The SLA was negatively related to WUE and was positively related to Harvest Index, suggesting that selection for low SLA might result in the production of more dry matter with minimal influence on pod weight in groundnut (Wright et al., 1988). Higher SLA means higher leaf area per unit biomass and a larger surface area for transpiration. On the other hand, if SLA is higher, the leaf thickness would be less and hence the capacity of photosynthesis would be smaller.

2.4 Relative water content (RWC)

The plants grown under well-watered conditions had higher RWC (70 %) than the plants suffered from water deficit (59 %). RWC was closely associated with the root length of rice seedlings (Sanusan et al., 2010). Relative water content is often considered as an appropriate measure of plant water status and is considered to be a sensitive index of plant water content especially when plants are exposed to cellular water deficit conditions (Painwadu et al., 2009; Sheeba et al., 2010). Vanitha (2008) indicated that RWC is positively correlated with root traits such as root length, dry root weight and root: shoot ratio suggesting that selection based on days to attain 70 per cent RWC is highly fruitful in developing drought tolerant genotypes as it will bring simultaneous improvement of these traits. Liu et al. (2004) reported the positive correlation between RWC and leaf water potential. RWC was strongly associated with grain yield under rainfed conditions. This indicates that maintenance of higher water status under drought plays an important role in building grain yield (Ravindra et al., 2004).

Singh et al. (2004) reported that the positive relationship of RWC could be used as reliable and simple screening technique for vegetative stress. Mean leaf relative water content across the DH lines of rice declined to 68 per cent under stress (Babu et al., 2003). Maintenance of higher water status under drought play a central role in stabilizing the various plant processes and yield (Kumar and Kujar, 2003). At RWC of below 80 per cent changes in metabolism become marked, with cessation of photosynthesis, much increased respiration and accumulation of proline and abscissic acid (Cabuslay et al., 2002). Maintenance of plant water status is more important than plant functions, which controls crop performance under drought. Leaf water potential is closely related to leaf RWC, but it is confounded by osmotic adjustment, stronger correlations might be found between yield and RWC under water stress near flowering was necessary but not sufficient to ensure good yield (Lafitte, 2002). Naidu et al. (2001) reported from the studies that RWC of leaves and leaf area were decreased and seed yield was also decreased drastically as the crop was subjected to progressive drought. Enhanced RWC helped the plants to perform the physiological processes like stomatal conductance, photosynthesis, transpiration, biochemical metabolism to continue more effectively even under low moisture condition (Rekika et al., 2000).

3. Yield parameters of rice under different systems of cultivation

Kumhar et al. (2016) reported that the higher yield parameters, viz., effective tillers, length of the panicle, weight of the panicle and number of filled grains per panicle were recorded in line transplanting technique. Among the different production systems viz., wet seeding, drum seeding, random planting, line planting, SRI square planting and SRI machine planting, the maximum yield characters viz., number of panicles m^{-2} (238 and 224), number of grains panicle⁻¹ (218 and 204) and panicle length (26 and 27 cm) were recorded under SRI machine planting during *kharif* and *rabi* seasons respectively and it was

comparable with SRI square planting method (Senthilkumar, 2015). At Kampasagar, Telangana, Pasha et al. (2014) revealed that machine transplanting recorded significantly higher number of panicles m^{-2} (364 and 336), panicle length (23.61 and 18.50 cm) and total grains panicle⁻¹ (158 and 149) during 2011 and 2012, respectively over broadcasting and drum seeding methods but which was on par with conventional transplanting. Mechanical transplanting and manual transplanting were on par with each other in terms of number of filled grains panicle⁻¹ and test weight but was significantly superior over zero tilled rice and direct wet sown method (Sanjeev et al., 2014). Significantly higher panicle length (23 cm), number of grains panicle⁻¹ (120.33) and test weight (20.67 g) were recorded in SRI method as compared to traditional methods (Mohanty et al., 2014).

In Mwea Irrigation Agricultural Development (MIAD) Centre Research Station, Kenya, Omwenga et al. (2014) revealed that the system of rice intensification produced more panicles hill⁻¹ (51) compared to the conventional method of growing rice (21) and the SRI method recorded a higher percentage of grain filling (81.5 %) than conventional method (75.1 %). A trial conducted in Orissa on sandy clay loam soils by Thakur et al. (2013) revealed that the number of panicles m^{-2} , spikelet number panicle⁻¹, per cent of filled spikelets and 1000 grain weight were increased significantly under SRI method to the tune of 15.5 per cent, 27.8 per cent, 9.7 per cent and 3.5 per cent respectively as compared to transplanted flooded rice (TFR). Rajendran et al. (2013) observed that the higher panicle length (21.9 cm) and total number of grains panicle⁻¹ (123) were recorded in system of rice intensification as compared to machine planting (21.0 cm and 108, respectively). Pasha et al. (2012) reported that significantly higher panicle length (22.5 cm) was recorded with mechanical transplanter as compared to farmers practice (16.8 cm). Lower sterility percentage and higher number of grains panicle⁻¹ were

observed in system of rice intensification over conventional methods at four locations in Neku region of Iraq (Hameed et al., 2011).

The experiment was conducted at DRR, Hyderabad with sandy clay loam soils by Chandrapala (2009) and reported that number of panicle m^{-2} did not vary significantly due to crop establishment methods (SRI, direct sowing and normal transplanting) further he reported that highest number of filled grains panicle⁻¹ and 1000 grain weight were recorded by SRI (121.4 and 21.93 g) method over the direct sowing (106.7 and 21.43 g) and normal transplanting (110.0 and 21.11 g) and these were found significantly at par. A experiment was conducted at Gangavathi, Karnataka by Manjunatha et al. (2009) and observed that in both manual and mechanical transplanting, number of panicles m^{-2} (468.2 & 478.4) and test weight (23.3 & 23.1 g, respectively) remained on par. Hugar et al. (2009b) at Kathalagere, Karnataka, under irrigated conditions on red clay loam soils tested different establishment methods and reported that SRI method recorded significantly higher panicle length (23.5 cm), number of seeds panicle⁻¹ (94.5) and 1000 grain weight (27.5 g) as compared to other methods of cultivation. Lokanadhan et al. (2007) from Tamil Nadu Agricultural University found that rice hybrid, CORCH-3 produced higher panicle length and filled grains panicle⁻¹ (23.05 cm and 189, respectively) in SRI method as compared to standard transplanting (21.087 cm and 127, respectively).

SRI proved to be superior to traditional method in the yield attributes of rice viz., number of total grains panicle⁻¹, filled grains panicle⁻¹ and 1000 grain weight (Choudhury et al., 2007). The yield parameters viz., panicles m^{-2} , filled grains panicle⁻¹, per cent grain filling, test weight and grain weight panicle⁻¹ were maximum with machine planted rice followed by manual planted rice in Sirsi hill zone of Karnataka (Manjappa and Kataraki, 2004).

Anbumani et al. (2004) reported that line planting registered significantly more number of panicles m^{-2} (267.8) and number of filled grains panicle $^{-1}$ (133.1) compared to random transplanting (261.2 and 130.8) and direct sowing (244.7 and 123.4). Hossain et al. (2003) reported that at Mymensingh, Bangladesh, SRI method produced longer panicles (25.7 cm), higher number of grains panicle $^{-1}$ (142.3) and 1000 grain weight (21.4 g) as compared to conventional transplanting. Rice established through drum seeder recorded significantly more number of panicles m^{-2} than transplanted rice (Narasimman et al., 2000 and Subbaiah et al., 2000). The yield parameters were not affected by different methods of crop establishment *viz.*, transplanting, sowing sprouted seeds in lines manually and drum seeding of sprouted seeds (Santhi et al., 1998). Bhuiyan et al. (1995) noticed that wet seeded rice had consistently higher number of panicles per unit area, lower number of spikelets per panicle, higher percentage of filled grains and 24 per cent higher grain yield than transplanted crop.

4. Grain and straw yield of rice under different systems of cultivation

Field experiments conducted on clay loam soils at Indian Institute of Rice Research (IIRR), Rajendranagar, Hyderabad, during *kharif* seasons of 2015 and 2016, revealed that among the different establishment methods, mechanized system of rice intensification (6420, 6224 and 6121, 5926 kg ha $^{-1}$) recorded significantly higher grain yield and straw yield over drum seeding method (5663, 5524 and 6882, 6500 kg ha $^{-1}$) but it was comparable with normal transplanting (6121, 5926 and 7333, 6959 kg ha $^{-1}$) during both 2015 and 2016 (Thirupathi, 2017). At Hyderabad, Telangana, Sathish et al. (2016) reported that Machine transplanting recorded higher grain and straw yields (6088 and 6954 kg ha $^{-1}$ respectively) which was significantly superior to drum seeding method (5308 and 6295 kg ha $^{-1}$, respectively). However conventional transplanting method (5926 and 6886 kg ha $^{-1}$) was found on par to machine transplanting method with 2.7 and 1.0 per cent variation

respectively. Study conducted on farmers fields in Visakhapatnam of Andhra Pradesh on red clay loam soils indicated that the average grain yield for three years in mechanized paddy cultivation and mechanized paddy cultivation with incorporation of *Dhaincha* before direct sowing of paddy seed was enhanced by 10 and 14 per cent respectively when compared with farmers practice (Malleswara et al., 2014). A similar study was carried at 60 locations in East Sikkim showed that system of rice intensification recorded 25.44 per cent higher grain yield over traditional random planting (Mohanty et al., 2014).

In Patna, Bihar on clay loam soils a field experiment was conducted by Sanjeev et al. (2014) revealed that transplanting by self-propelled transplanter *i.e.* mechanical transplanting though statistically at par with the manual transplanting, produced significantly higher grain and straw yield over zero tilled rice and direct wet sown rice. Pasha et al. (2014) at Kampasagar, Telangana revealed that higher grain (6222 kg ha $^{-1}$) and straw yields (6547.5 kg ha $^{-1}$) were obtained with machine transplanting over conventional transplanting, broadcasting and drum seeding methods. At Kharagpur, Odisha, Swain et al. (2013) observed that self propelled rice transplanter recorded higher grain and straw yields (3.95 and 4.49 t ha $^{-1}$, respectively) over other establishment methods. Field experiment was conducted at Madurai during *rabi* 2007-08 and 2008-09 seasons, by Rajendran et al. (2013) and observed significantly higher grain and straw yields (7424 and 8971 kg ha $^{-1}$, respectively) in system of rice intensification over machine transplanting (5899 and 7017 kg ha $^{-1}$). Dinesh et al. (2013) reported that the highest grain yield of rice was obtained with SRI method, which was significantly higher than conventional rice cultivation and aerobic cultivation at Research Farm of Indian Agricultural Research Institute, New Delhi. Grain yield was found to be significantly higher in SRI method compared to best management practices at Hyderabad (Gopalakrishnan et al., 2013).

Jagtap et al. (2012) from Dapoli, Maharashtra reported that transplanted rice produced significantly higher grain and straw yield compared to pre-monsoon dibbling seeds, dibbling of seeds with the onset of monsoon, transplanting of seedlings by Thomba Method and SRI techniques. Venkateswarlu et al. (2011) reported that 13 per cent higher grain yield and 22 per cent higher straw yield was observed in machine planting than manual planting and this was due to the early age of seedlings planted. Geethalakshmi et al. (2011) revealed that among the different methods of rice cultivation, SRI method recorded higher grain yield followed by puddle transplanted rice. Jayadeva et al. (2010) at Kathalagere, Karnataka, in red clay loam soils observed that SRI technique registered significantly higher grain and straw yields (10331 and 11183 kg ha⁻¹, respectively) compared to normal transplanting (8954 and 9902 kg ha⁻¹, respectively) and aerobic (7800 and 8956 kg ha⁻¹, respectively) condition.

Grain yield was found to be highest in transplanting with Japanese manual transplanter (8.03 t ha⁻¹) over other methods of establishments at PAU, Ludhiana (Anoop et al., 2010). System of rice intensification had shown significantly higher grain yield (6140 kg ha⁻¹) and straw yield (9306 kg ha⁻¹) over aerobic and conventional methods at Kathalagere, Karnataka, in red clay loam soils during summer season (Hugar et al. 2009b). A study conducted by Pradeep (2009) also indicated that SRI establishment technique recorded significantly higher grain yield (4435.5 kg ha⁻¹) and straw yield (5660 kg ha⁻¹) as compared to normal transplanting (4252.2 and 5979.5 kg ha⁻¹, respectively) and aerobic method (3650.5 and 4881.6 kg ha⁻¹, respectively). Wijebandara et al. (2009) at Dharwad, Karnataka obtained significantly higher grain yield (66.9 q ha⁻¹) and straw yield (81.8 q ha⁻¹) in SRI method as compared to conventional method (36.8 q ha⁻¹ and 44.6 q ha⁻¹, respectively). Abeywardena et al. (2009) at Nugegoda, Sri Lanka observed that SRI method gave five and ten times higher grain yield than that of standard transplanting and broadcasting, respectively.

Manjunatha et al. (2009) concluded that grain and straw yield in both manual and mechanical transplanting remained on par with mean grain yield of 53.77 and 54.01 q ha⁻¹, straw yield of 72 and 64.3 q ha⁻¹, respectively at Gangavathi, Karnataka. Singh et al. (2006) reported that maximum grain yield was recorded in mechanical transplanting followed by manual transplanting, direct dry sowing and direct sprouted sowing. Latif et al. (2005) at Comilla, Bangladesh recorded significantly higher yield (5.95 t ha⁻¹) in SRI method compared to farmer's practice (5.5 t ha⁻¹). A field experiment was conducted in hill zone of Karnataka by Manjappa and Kataraki (2004) and noticed that the maximum grain yield (7432 kg ha⁻¹) was recorded with machine planting followed by manual planting (7371 kg ha⁻¹) which were on par with each other but significantly superior over broadcasting and drum seeding methods. Hossain et al. (2003) opined that at Mymensingh, Bangladesh, SRI method produced higher grain (5.67 t ha⁻¹), straw (5.98 t ha⁻¹) and biological (11.65 t ha⁻¹) yields over conventional transplanting. Hussain et al. (2003) reported that grain (5.6 t ha⁻¹) and straw yields (6.0 t ha⁻¹) were higher in SRI method (3.65 t ha⁻¹) compared to NTP method (4.29 t ha⁻¹). Prasad et al. (2001) from Pusa, Bihar reported that transplanted rice recorded the highest grain and straw yields as compared to dry seeding and puddled sowing of sprouted seeds.

5. Water productivity and water use efficiency of rice under different systems of cultivation

A field experiment was conducted during *kharif* 2014 at Agricultural Research Institute - Rajendranagar, Hyderabad, Telangana with three cultivation systems and five irrigation regimes by Sathish et al. (2017a) and they reported that significantly higher water use efficiency (4.7 kg ha mm⁻¹) was recorded in case of machine transplanting as compared to drum seeding (4.0 kg ha mm⁻¹) and was on par with conventional transplanting (4.6 kg ha mm⁻¹). Omwenga et al. (2014) in Mwea Irrigation Agricultural Development (MIAD) Centre Research Station, Kenya on vertisol

revealed that water productivity was significantly higher in SRI method (0.84 kg m^{-3}) over conventional rice production (0.40 kg m^{-3}). SRI method utilized 3.4 and 4.3 per cent lower total quantity of water over NTP during *kharif* and *rabi*, respectively and recorded increased water productivity (WP) of 57.1 and 34 per cent during *kharif* and 51.1 and 33.3 per cent during *rabi* over NTP and mechanized transplanting, respectively (Shantappa, 2014).

Water use efficiency (WUE) in conventional transplanted rice is only 20 - 30 per cent. However, SRI could improve WUE by 68 - 94 per cent and irrigation WUE by 100 - 130 per cent over traditional flooding (Dass & Dhar, 2014). Irrigation water savings averaged 31 per cent and 37 per cent during *kharif* and *rabi* seasons, respectively in system of rice intensification over best management practices at Hyderabad, on sandy clay loam soils (Gopalakrishnan et al., 2013). Senthikumar and Thilagam (2012) conducted an experiment at Varappur village, Tamil Nadu during *kharif* season and reported that water saving was up to 35 per cent in drum seeder than other methods because of early maturity of crop. Elamathi et al. (2012) reported that, SRI method recorded WUE of $4.93 \text{ kg ha mm}^{-1}$ while it was only $3.09 \text{ kg ha mm}^{-1}$ under NTP and saved 50 to 60 per cent water, without decline in yield. There was a 24 per cent saving of irrigation water in SRI method, while land productivity and water productivity were increased by 71 per cent and 90 per cent, respectively as compared to the conventional flooded system on vertisol in Mwea Irrigation Agricultural Development (MIAD) Centre Research Station, Kenya (Nyamai et al., 2012).

Changing water management from CF to SRI with AWD had the potential to reduce irrigation input. Water requirement was less under SRI (850 mm) as compared to conventional (1180 mm) and higher WUE ($7.31 \text{ kg ha mm}^{-1}$) as compared to NTP ($4.5 \text{ kg ha mm}^{-1}$). The water productivity in SRI was found to be 1389 liters kg^{-1} as against 2,274 liters kg^{-1} in NTP (Pandian, 2012). Jayadeva et al. (2010) reported that SRI technique was

resulted in higher water use efficiency ($64.87 \text{ kg ha cm}^{-1}$) than aerobic method ($60.62 \text{ kg ha cm}^{-1}$) and normal transplanting ($47.94 \text{ kg ha cm}^{-1}$). The total water productivity of the SRI method was 29 per cent higher as compared to conventional method (Kumar et al., 2009). Thiyagarajan et al. (2007) observed that SRI method saved irrigation water up to 56 per cent as compared to conventional method in Tamil Nadu. A field experiment carried out at IARI, New Delhi on clay loam soils by Choudhury et al. (2007) revealed that SRI yielded on par with that of TPR treatment (5.4 t ha^{-1}) but required 23 per cent less irrigation water input during the crop growth period.

Water saving in SRI method was to the tune of 30 to 40 per cent over conventional rice cultivation (Kumar et al., 2006). Gill et al. (2006) reported that the direct seeded rice crop was supplied with 108, 114 and 108 cm irrigation water when sown on 1 June, 10 June and 20 June respectively. The corresponding water applied to transplanted crop was 132, 120 and 118 cm when transplanted on 25 June, 5 July and 15 July, respectively. The water productivity of direct seeded rice was higher (0.40 to 0.46 kg m^{-3}) compared to transplanted rice (0.29 to 0.39 kg m^{-3}), thus showing superiority in productivity and saving in irrigation water under direct seeded rice. Murthy et al. (2006) revealed that SRI cultivation utilized 1130 mm of water which was 11.3 per cent lesser compared to recommended transplanting (1270 mm).

6. Nutrient uptake and nutrient use efficiency of rice under different systems of cultivation

Hassan and Upasani (2015) reported that the mean uptake of nitrogen, phosphorus and potash by weeds were 11.28, 1.80 and 15.65 kg ha^{-1} at 70 DAS in different methods of rice establishment. Uptake of nitrogen, phosphorus and potassium by rice at flowering and harvesting was found to be the maximum with transplanting method, which was comparable with semi - dry system, while, the lowest uptake was associated with broadcasting of sprouted seed, which was however, on par with drum seeding of sprouted seed (Sandhya

et al., 2014). Thakur et al. (2013) conducted experiments during the dry season on sandy clay loam soils and found that the nitrogen uptake by rice plants differed significantly among the different cultivation practices and N application rates. N uptake across the four N rates was significantly higher under SRI method than transplanted flooded rice by 51.8 per cent.

System of rice intensification recorded higher mean N, P and K (121.5, 20.04 and 90.33 kg ha⁻¹, respectively) uptake at 50 per cent flowering over direct sown rice (107.09, 17.80 and 79.5 kg ha⁻¹, respectively) in DRR farm at ICRI, Hyderabad (Chandrapala, 2009). Hugar et al. (2009b) studied the uptake of nutrients (N, P & K) in different establishment methods and reported that during *kharif* season, SRI method recorded maximum total uptake of nitrogen (268.5 kg ha⁻¹), phosphorus (67 kg ha⁻¹) and potassium (173 kg ha⁻¹) as compared to normal transplanting (224, 52.1 & 153.9 kg ha⁻¹, respectively). Similarly during summer season SRI method recorded higher uptake of total N, P & K (199.6, 50.7 & 119.3 kg ha⁻¹, respectively) compared to normal transplanting (186.7, 44 & 118.2 kg ha⁻¹, respectively).

7. Economics of rice under different systems of cultivation

Kaur and Singh (2016) reported that benefit accrued was more in case of dry-DSR methods than wet-DSR method and manual transplanting in puddled field. In Patna, Bihar, Sanjeev et al. (2014) observed that mechanical rice transplanter saved 94 per cent time and 72 per cent of cost which was followed by direct wet seeding (88 % time and 64.6 % of cost). Mohanty et al. (2014) also concluded that although the cost of production of SRI method and TRP was same, SRI realized 61.23 per cent higher net returns over traditional rice planting method. The benefit cost ratio of 1.70 was also higher than the TRP (1.47). In Hisar, Haryana, experiments were conducted in farmers fields from 2006 to 2010 by Kamboj et al. (2013) and stated that higher yields were obtained in conventional puddled transplant

rice and mechanical transplanted rice (MTR) systems, the MTR system helped in reducing labour requirement and ultimately, profit to the farmers. Ali et al. (2012) observed that both drilling (Drill-Dry-DSR and Bed-Dry-DSR) and broadcasting of DSR (dry and soaked seed) were considered to be superior and economical than conventional transplanting.

Veeresh et al. (2011) from Raichur, Karnataka noted that among the methods of planting, sowing of sprouted seeds resulted in more net returns and B:C ratio when compared to direct seeding and transplanting. The average labour input in rice transplanter was 30 man h ha⁻¹ compared to 126 man h ha⁻¹ in hand transplanting. The total cost of transplanting in rice transplanter decreased by 25.70 per cent as compared to normal transplanting at Rice Research Institute of Iran (RRII), Guilan (Alizadeh et al., 2011). Venkateswarlu et al. (2011) reported that the higher net income (₹ 62295 ha⁻¹) was recorded with machine planting which was 29 per cent more compared to manual planting (₹ 48458 ha⁻¹). The reduced cost of cultivation, increased grain as well as straw yield resulted in better cost benefit ratio of 1:2.47 with machine planting than 1:2.11 recorded with manual planting. Machine planting is a viable alternative at times of scarce availability and higher cost of labour.

Rashid et al. (2010) found that the cost of transplanting was ₹ 8000 acre⁻¹ in traditional method, while in machine transplanting it was only ₹ 3000 acre⁻¹ including cost of raising nursery. Hugar et al. (2009a) reported that among the different establishment methods SRI method realized the maximum gross returns (₹ 1,17,432 ha⁻¹ yr⁻¹), net profit (₹ 79,912 ha⁻¹ yr⁻¹) and B:C ratio (2.13). The lower gross returns (₹ 63,512 ha⁻¹ yr⁻¹), net profit (₹ 36,312 ha⁻¹ yr⁻¹) and B:C ratio (1.33) were recorded in zero tillage method. Manjunatha et al. (2009) reported that the mean gross returns remained on par between the manual and mechanical transplanting (₹ 33,872 and 34,209 ha⁻¹, respectively). Further it was reported that the cost of transplanting was very low in

mechanical transplanting (₹ 789 ha⁻¹) as compared to manual transplanting (₹ 1625 ha⁻¹) at Gangavati, Karnataka. In Dharmapuri district of Tamil Nadu, SRI method of cultivation recorded higher net income (₹ 21,415 ha⁻¹) over farmers practice (₹ 16,288 ha⁻¹) and the increase in income was 31.5 per cent (Budhar and Mani, 2008).

The SRI method of establishment technique recorded significantly higher gross income, net income and B:C ratio (2.84) as compared to normal transplanting and aerobic method on red clay loam soils of Kathalagere, Karnataka (Jayadeva & Prabhakara, 2008). The net returns in SRI method of cultivation (₹ 27,486 ha⁻¹ and ₹ 18,816 ha⁻¹, respectively) remained higher when compared to conventional rice planting techniques (₹ 22,728 ha⁻¹ and ₹ 13,385 ha⁻¹) in 2005 and 2006 (Chitale et al., 2007). Higher gross and net returns were realized with machine transplanting (₹ 51874 and 40265 ha⁻¹) followed by manual transplanting (₹ 49971 and 36824 ha⁻¹) being at par each other. The lowest gross and net returns were obtained with broadcast seeding and drum seeding in hill zone of Karnataka (Manjappa and Kataraki, 2004). Narasimman et al. (2000) concluded that among the different establishment methods, direct seeding recorded the highest benefit cost ratio of 2.4 as compared to 1.6 for line transplanting and 1.3 for random transplanting.

8. Energetics of rice under different systems of cultivation

Bhora and Kumar (2015) compared energy use pattern in different crop establishment methods of rice and revealed that the highest input energy was consumed in manually transplanted rice compared to mechanically transplanted rice, direct seeding of sprouted seed by drum seeder and direct seeding under zero till condition. However, the output energy was the highest in mechanical transplanting closely followed by manual transplanting of rice, direct seeding by drum seeder and the lowest was in direct dry seeding by zero till drill rice. Babu et al. (2014) revealed that system of rice intensification recorded

significantly higher gross energy output (124.9 GJ ha⁻¹), net energy output (115.8 GJ ha⁻¹), energy use efficiency (13.82 %), energy productivity (1.03 kg MJ⁻¹) and energy intensity in economic terms (4.11 MJ ₹⁻¹). SRI method recorded significantly higher energy output as compared to normal transplanting (Kumar et al., 2009). Mohanty et al. (2014) revealed that the conventional transplanting used the maximum energy followed by drum seeding and the least energy was expended by SRI method of cultivation for production of rice.

Das et al. (2014) reported that the energy input was highest under conventional rice culture followed by integrated crop management and SRI. The pooled energy output and output/input ratio was the highest under conventional method followed by SRI. Brar et al. (2011) reported that the transplanted *basmati* rice (TPBR) gave 4.3 and 2.8 per cent higher energy output than direct seeded *basmati* rice (DSBR), irrespective of crop establishment methods. Jayadeva and Prabhakara (2008) reported that the SRI establishment technique recorded significantly higher energy output ratio (15.78) compared to transplanting (13.98) and aerobic (12.42) techniques. The increase in energy output: input ratio was mainly due to higher biomass production and total energy output.

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