2. REVIEW OF LITERATURE

Rice is one important cereal crop which plays a key role in food security. It is consumed by nearly half the world’s population, grown in at least 114 countries and many people are engaged in rice cultivation around the world. The work of previous researchers and scientists relevant to the present investigation and on allied aspects have been gleaned from the available literature from different sources over the years and collected, collated and presented in a systematic way in this chapter.

2.1 Origin of system of rice intensification (SRI) and its genesis in India

The system of rice intensification, or SRI, is a system that has evolved over the last few decades of the 20th century and offers a radical departure in the way of growing more rice with fewer inputs. It is a fascinating case of rural innovation that has been developed by Fr. Henri de Laulané, a Fresh priest with a background in agriculture and passion for rural development, whose keen observation of deviant practice and continued experimentation led to SRI emerging over a decade with six principles of growing rice that were different, often radically, from conventional rice cultivation techniques. These six basic principles, perfected over a period of time in Madagascar, surprisingly gave very high yields, in some instances close to 20 tonnes per hectare, with much reduced inputs of seed, water, fertilizers and pesticides.

Laulanie presented his results after nearly twenty years of work for the first time publicity in a seminar in 1989 to a large group of individuals like representatives from NGOs, Govt. extension agents, scientists etc. One of the fall outs of the seminar was the setting up the Association Tefy Saina (ATS) in 1990 that was established as a NGO to give practical effect to his ideas. The association’s Malagasy name literally means, in English, to built the human spirit through a change in mentality. This concept places men and women at the centre of a development process, emphasizing self help rather than dependency. The association was to provide a permanent platform of information exchange for autonomous rural development that brought together farmers, engineers, state extension agents and NGO technicians. This vision of ATS in getting various players in the sector together is often not sufficiently appreciated in the SRI literature that has in many instances tended to get carried away
by the high yields of SRI, ignoring the institutional process that enabled this innovation.

SRI, however was unknown to the rest of the world. In 1994, an integrated conservation and development project (ICDR), Ranomafana National park, made it possible for Tefy Saina to begin working with the Cornell International Institute for food, Agriculture and development (CIIFAD) to disseminate and evaluate SRI and other technological innovations in that region. With the continuous work of this important partnership what until 1999 was a local phenomenon became a global movement with farmers in 22 countries taking to SRI in varying degrees. This spread is remarkable. Considering that SRI met with and still meets with stiff resistance from the agricultural research establishment and has but little formal support in most countries. Resistance to SRI has been on the methodology which scientists struggle to understand and perceptions of SRI as backward. Following its rapid spread especially in Asia, it was possible for CIIFAD and Tefy Saina to held an International Conference on SRI in China in 2002 to pool ion experiences from 15 countries. It was hosted by Prof. Yuan Long Ping, Director of the China National Hybrid Research and Development Centre and popularly known as the hybrid rice who had demonstrated the merits of SRI at his centre.

Unlike other rice-growing nations India had a rather delayed start in SRI. T.M. Thiagarajan of the TNAU, Coimbatore was the lone Indian representative at the 2002 International Conference on SRI. He was interested in the soil aeration aspects of SRI, and its water saving potential. The modified SRI practice that was evaluated by TNAU used three of the SRI principles (single seedlings, wider spacing and use of mechanical weeder) but it used water saving through modified SRI recommendations. The results indicated considerable water saving through modified SRI and reduction of seed costs, no significant increase in yields (Thiagarajan, 2002) rather lesser than conventional rice yields in most of the cases. These initial results would have been sufficient reason for rejecting SRI as an option for rice India. However, choices made by farmers and other actors are often complex than mere economics and productivity considerations.

The complexity of SRI in India bringing to the fore the almost parallel movements in SRI, one by the state agencies and the other by civil society.In state like Tamil Nadu,
the region that is credited with bringing SRI to India. SRI is referred to by these actors differently, the state agencies and research establishment refer to it as Thirunthia Nel Sekupali (transformed rice cultivation) whereas, NGOs have been popularizing as Ottarai Naatu Nadavu (single seedling method).

Following Thiagarajan’s Norman Uphoff visited India in May 2002 to represent the prospects of SRI to agricultural officials in the southern states of AP and Tamil Nadu. Later in the year, in November 2002, Uphoff made a presentation on SRI at the II\textsuperscript{nd} International Agronomy Congress held in New Delhi as well as to top officials in the consequently, The Acharya N G Ranga Agriculture University in Hyderabad sent its director of extension and a regional director of research to Sri Lanka in January 2003, a visit that was a land mark in the history of SRI in India. Alapati Satyanarayan, the director of extension, an initial skeptic of SRI, returned with a passionate zeal and emerged as one of SRI’s strongest proponents, not only in India, but also in debates on SRI throughout the world. By this time in Tamil Nadu, a state that was facing a crisis due to declining rice production owing partly to reduced inflows in the Cauvery basin, the trials at TNAU attracted official attention. The Ministry of Agriculture visited TNAU’s SRI plot in October 2002, following which the State Govt. made a grant of over $ 50000 for SRI promotion and evaluation in the Cauvery delta and the Govt.

Speaking to various farmers, scientists and people involved in rice cultivation in India it is apparent that SRI is not something altogether new to India. It does seem to fellow some prevalent practices on dry land farming. Many SRI innovators referred R.H. Richaria’s work on rice and biodiversity in the context of SRI. Clonal propagation, a technique that first developed by Richaria in the 1960s at the Central Rice Research Institute, Cuttack. Richaria then was of course unaware of the possibilities that SRI offered and it is probable that the combination and synergistic ideas of SRI might have yielded better results to Richaria and other farmers keen on biodiversity conservation and native varieties of rice.

The small union territory of Pondicherry in southern India, a small dot on the rice map of India is perhaps the earliest place to have experimented with SRI. Auroville, the international commune that has been in the forefront for reclaiming degraded land and one of leaders in sustainable agriculture, was among the first civil organization in India to have taken up SRI. In 2002 another big NGO, the Chennai based M.S.
Swaminathanan Research Foundation (MSSRF) tried SRI on small plots in its biovillage. SRI in Karnataka too originated from civil society and have been led by a network of the organic farming community that includes several NGOs and some of the country leading organic farmer. Similarly there have been efforts of civil society involvement in SRI in Andhra Pradesh and West Bengal. In Odisha, two NGOs have been spreading SRI in different parts of the state- Sambhab in eastern and southern Odisha and PRADAN in northern Odisha.

In all these efforts by civil society the source of information in the first few years has not been from the rice establishment but from the fellow farmers, the internet, a combination of the two and by practical experimentation. The early adoption of SRI were often farmers with a difference, not all were traditional farmers or from farming families, in fact some received information on SRI from non-farmers who were enthused by what SRI seemed to represent namely a shift towards sustainable methods of farming and less reliance on chemical inputs.

2.2 System of Rice Intensification

Laulanié, 1993a; Laulanié, 1993b; Uphoff, 2001; Stoop et al., 2002; Uphoff et al., 2002; Stoop, 2003; Uphoff, 2003; Horie et al., 2005 described the system of rice intensification and suggested that SRI represents an integrated and agro-ecologically sound approach to irrigated rice (Oryza sativaL. var. indica) cultivation, which may offer new opportunities for location-specific production systems of small farmers. Batuvitage (2002) reported that SRI method of rice cultivation does not require the application of agrochemicals or pesticides, the plants raised under SRI method are able to resist damage from pests and diseases, making agrochemicals usually unnecessary. Dobermann (2004) reported that although yield advantages were claimed for SRI over conventional practice; there were also examples of no yield increase over control in Bangladesh, China, India, Myanmar, Nepal and Thailand. SRI is a designer innovation that efficiently uses scarce land, labour, capital and water resources, protects soil and groundwater from chemical pollution, and is more accessible to poor farmers than input-dependent technologies that require capital and logistical support (Uphoff, 2004). SRI methods can lead to superior phenotypes and agronomic performance for a diverse range of rice genotypes (Lin et al., 2005, Lin et al., 2006). Raju and Srinivas in 2008 from their agronomic
evaluation of SRI in Godavari delta reported that the panicles m\(^{-2}\), the filled grains panicle\(^{-1}\) and ultimately the grain yield were significantly higher across seven varieties of paddy viz. MTU 1071, Samba Mahsuri, MTU 1032, MTU2716, MTU 7029 and Indra. Irrespective of the varieties, significantly higher values of root weight and root volume were also noticed than conventional method. The highest grain yield (7.2t/ha) was recorded with MTU 7029 in SRI method.

Uphoff and Randriamharisoa (2002) reported success of SRI is based on the synergetic development of both tillers and roots. With more vigorous root growth plants can become stronger and taller and better access to the nutrients and water, they need to produce more tillers and more yield (Uphoff, 2001). Consequently with well proliferated root growth Barison (2002) reported 91% increase in N and K uptake compared with conventionally grown rice plants in conjunction with a 90% increase in grain yield and 66% increase in P uptake under SRI methods.

### 2.3 Effects of age of seedlings

Uphoff (2002) reported that in SRI, very seedlings should transplanted quickly and carefully so that the root tips do not bend upward resume quick downward growth to have more number of phyllochron for massive tillering. Ros et al. (1998) suggested that SRI practices lead to increased shoot and root dry matter accumulation by protecting root system during transplanting.

Horie et al. (2005) suggested that early transplanting under SRI method of rice cultivation provides longer vegetative growth period, and single seedling per hill reduces the competition and helps to minimize the shading effect on lower leaves. This helps lower leaves to remain photo synthetically active and root activity remains higher for a longer period due to the plants enhanced supply of oxygen and carbohydrates to the roots.

Transplanting rice seedlings at younger age has been supported by many researchers (Ota, 1975 and Yamamito et al.,1995). This practice captures the benefit of early phyllochron stages (less than four leaves) having higher potential to produce more tillers per plant (Katayama, 1951). Similarly (Stoop et al., 2002) reported that SRI method of rice cultivation resulted in highest grain yield when young seedlings are transplanted less than 15 days old seedlings and preferably 8-12 days i.e. before the
start of the fourth phyllocrom. This preserve plants positional for tillering and root growth that is compromised by late transplanting (Uphoff, 2001; Randriamiharisoa and Uphoff, 2002). The experiment conducted insandy clay loam soil at Madurai under TNAU, Kavitha et al. (2010) observed significantly higher plant height, LAI, dry matter accumulation, panicle length, productive tillers, total grains panicle\(^{-1}\), grain yield and straw yield under SRI method of rice cultivation with 14 days old seedlings. Vijay Kumar et al. (2004) conducted field experiments at TNAU, using 21 days old seedlings (conventional) and 14 days old seedlings (dapog nursery) with three different spacing of 15 X 10, 20 X 20 and 25 X 25 cm. They clearly observed that the yield attributes like panicle length, number of panicles hill\(^{-1}\), total number of grains panicle\(^{-1}\) as well as grain yield were significantly higher in the treatments involving 14 days old seedlings than that with 21 days old seedlings. Though not significant, this has reflected nearly 4% increase in the yield hill-1 over older seedlings. Similar response of younger seedlings were also reported by Kumar and Shiving (2004).

In sandy loam soil of Bhubaneswar, Roul et al. (2008) observed significantly higher number of ear bearing tillers, length of panicle and grain yield in SRI rice when transplanted with 12 days old seedlings under both organic and inorganic sources of nutrition than conventional transplanting with 25 days old seedlings. Similarily in the same type of soil at Shalimar, J & K, Singh et al. (2012) experienced that the crop grown with 20 days old seedlings registered significantly higher effective tiller m\(^{-2}\), spikelets panicle\(^{-1}\) and number of grains panicle\(^{-1}\) over 35 and 50 days old seedlings. Similarly Krishna et al. (2009) reported that under SRI system, the 12 days old seedlings produced more number of productive tillers hill\(^{-1}\) at harvest as compare to 8, 16 and 25 days old seedlings. The younger seedling (8 days) flowered early but the twelve days old seedlings recorded higher grain yield ha\(^{-1}\). Manjunatha et al. (2010) experienced that the younger seedlings of 9 days old registered higher grain yield (6.01 t ha\(^{-1}\)) as compared to 12, 15 and 18 and 21 days old seedlings. In subsequent years Hussain et al. (2012) also observed that, 14 age of seedlings produced similar grain and straw yields was that with 21 days old seedlings but convincingly higher than that with 28 and 35 days old seedlings. The magnitude of increase in the grain yield due to 14, 21 and 28 days old seedlings was to the tune of 13.1%, 12.6% and 6% over 35 days old seedlings during 2007 whereas 14.3%, 14.5% and 8%, respectively during 2008. Kewat et al. (2002) revealed that, transplanting of 21 and 28
day old seedlings registered significantly higher grain and straw yields, net monetary returns and benefit cost ratio than transplanting of thin and lanky seedlings of 14 days old seedling in hybrid rice.

2.3.1 Effect on growth

Singh et al. (2008) observed no significant difference in plant height between SRI (93.3 cm) and standard transplanting method (87.1 cm), but both were significantly higher than line sowing by drum seeder. In another study by Sharma and Masand (2008) to compare the performance of SRI vis-a-vis conventional transplanting revealed that SRI produced taller plants by 14.1 cm than conventionally transplanted rice. Shekhar et al. (2009) from their experiment reported that, under same date of nursery sowing the plants under SRI were taller by 7.4 cm than conventional transplanting. Mankotia et al. (2009) from their experiment found higher plant height (107.4 cm) in conventionally transplanted rice than drum seeded rice (102.7 cm). On the contrary, Bommayasamy et al. (2010) from their experiment from Kilikulam, Tamilnadu found that, closure spacing (20x20 cm) produced significantly taller plants (92.5 cm) as compared to other two spacing (25x25 cm and 30x30 cm), which produced plants of 85.45 cm and 81.55 cm height, respectively. However, Geethalakshmi et al. (2011) recorded significantly higher shoot (85.2 and 86.6 cm) length at maturity under SRI in both the years of experiment which was comparable with transplanted rice (86.4 and 85.8 cm) and wet seeded rice (82.7 and 81.2 cm).

Stoop et al. (2002) opined that in a crowded environment with serious competition for nutrient and energy among plants, more tillers will not lead to increased production. Singh et al. (2008) reported that in SRI method total tillers m⁻² (338) were significantly higher than normal transplanting and line sowing by drum seeder method which produced 301 and 275 tillers m⁻², respectively. Hugar et al. (2009) recorded higher numbers of tillers m⁻² (448) under SRI with 12 days old seedlings planted at 25 cm x 25 cm that was significantly greater than other methods in summer season in Karnataka. Wijebandara et al. (2009) concluded that, rice seedlings transplanted before the fourth phyllocron stage produced highest number of tillers by exploiting the maximum potential for tillering. Thakur et al. (2011), based on their experiment conducted in a sandy clay loam soil at Bhubaneswar found that, the number of tillers per hill in System of Rice Intensification (SRI) was approximately
1.5 times higher than conventional transplanting (CT) which varied from 12 - 16 and 5 – 15 in SRI and CT, respectively. Geethalakshmi et al. (2011) found that rice under SRI produced more number of tillers m⁻² (414 and 448) as compared to that of conventional transplanting (391 and 410) and wet seeded rice (387 and 438) during two subsequent years of experimentation.

Zeng et al. (2002) reported increased root volume, root length and root dry weight of rice crop due to availability of sufficient nutrients, light intensity and water under SRI due to wider spacing and less plant population per unit area. Villela et al. (1996) reported that root length decreased by 20.5 and 16.8 % by 50 days seedling over direct sowing (0 age of seedling) and 20 days old seedling, respectively. Barrison (2002) found greater root growth of plants under SRI at lower depth as well as below 30 cm depth due to alternate wetting and drying of soil which led to greater root penetration. Longxing et al. (2002) reported higher root dry weight per plant (13.2 g and 9.8 g) under SRI as compared to 8.2 g and 7.6 g in traditional method of flooded rice irrigation (TRC) in two rice hybrids, respectively. Doberman (2004) attributed vigorous plants with larger root systems in SRI to alternate wetting and drying method of irrigation resulting improved oxygen supply to rice roots thereby increasing the aerenchyma formation and causing a stronger and healthier root system with potential advantage and better nutrient uptake. Sinha and Talati (2007) also found extensive and strong root system under SRI and so more effort was needed to uproot SRI plants. Similar results of higher root volume (75.0 cc hill⁻¹) and root dry weight (33.6 g hill⁻¹) under SRI method have been reported by Roul et al. (2008) as compared to conventional method which were reported to be 32.0 cc hill⁻¹ and 16.5 g hill⁻¹ for root volume and root dry weight, respectively. Raju and Sreenivas (2008) from their experiment on SRI involving var. Swarna found higher root volume (85.1 cc hill⁻¹), root weight (17.91 g hill⁻¹) as compared to 35.6 cc hill⁻¹ and 8.90 g hill⁻¹ of root volume and root weight in conventional transplanting, respectively. Rice seedlings transplanted before the fourth phyllocron stage could produce highest number roots by exploiting the maximum potential for rooting Wijebandara et al. (2009). Singh et al. (2012) reported that root length, root weight and root volume significantly decreasing with increasing the age of seedling.

Shukla et al. (1999) found that square planting of Kranti with 15 x 15 cm spacing was more effective in dry matter production (1235 g m⁻²) at harvest along with high
values of CGR (1771 g m\(^{-2}\) day\(^{-1}\)), NAR (0.40 mg m\(^{-2}\) day\(^{-1}\)) and RGR (0.0466 g g\(^{-1}\) day\(^{-1}\)) at 60 DAT than those of rectangular planting (22.5x10 cm). Shao-hua et al. (2002) revealed 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 methods. Longxing et al. (2002) reported that, SRI produced higher plant dry weight than TRC. Subbulakshmi et al. (2008) reported that line transplanting produced higher LAI (5.46) and dry matter production (10,836 kg ha\(^{-1}\)) at harvest than drum seeding which produced LAI of 5.13 and dry matter production of 10155 kg ha\(^{-1}\). Singh et al. (2008) observed that in SRI method, LAI and dry matter accumulation were significantly higher than normal transplanting and line sowing by drum seeder method.

Wang and Sun (1990) noticed that duration can be curtailed by 7-15 days in direct seeded rice compared to transplanted rice. Mankotia et al. (2009) found that, conventionally transplanted crop took more number of days to maturity (114 days) than drum seeded rice (109 days). Longxing et al. (2002) reported that, the yellow leaf sheath in the base of the stem appeared later with SRI, which indicated delaying of leaf senescence under SRI. Rani et al. (2008) revealed that in drum seeder method the crop came to maturity 10 days earlier than conventional and SRI method. Shekhar et al. (2009) reported that, under same date of nursery sowing the plants under SRI matured seven days earlier (117 days) compared to conventional transplanting (124 days). Krishna and Biradrapatil (2009) reported that transplanting of young seedlings (8 day old) resulted in early flowering (90.5 days) as compared to 25 day old seedlings which flowered in 94.5 days. Similar results of reduction in crop duration under SRI have been reported by Ramaprasad et al. (2008) and Kushwah et al. (2012).

Sridevi and Chellamuthu (2008) reported that, during Kharif season, the combination of young seedling, one seedling, square planting and cono weeding (YOSC) significantly shown 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. Shahane et al. (2012) reported that, the plant growth parameters like plant height, tillers, dry matter accumulation and leaf area index (LAI) were significantly higher in conventionally transplanted rice (CT) compared to
SRI method at 30 DAT, but these parameters are statistically comparable at 60 and 90 DAT and at crop harvest.

2.3.2 Effect on yield attributes and yield

UpendraRao et al. (2013) reported that, the higher tiller to panicle conversion ratio (83.1%), higher spikelet fertility (82.9%), significantly higher grain yield (20.3%) and matures early by 3-4 days with system of rice intensification compared to traditional farmers practice. Nissanka and Bandara (2004) reported 9 and 12% more grain yield in SRI compared to conventional transplanting and direct sowing methods, respectively. Raju and Srinivas (2008) revealed that, variety Swarna produced significantly higher yield (7.24 t ha⁻¹) under SRI compared to conventional transplanting (CT) (5.64 t ha⁻¹) in Godavari Delta. Sharma and Masand (2008) reported that, SRI with young seedlings (7 to 12 days old) at 15 cm x 15 cm and 30 cm x 30 cm spacing recorded 20 and 13 per cent more rice grain yield, respectively than conventional transplanting (2 to 3 seedlings per hill of 22 to 28 day old and at 15 cm x 15 cm spacing). They also found higher grains panicle⁻¹ (79) at 30 cm x 30 cm spacing than at 15 cm x 15 cm spacing (70). From the same experiment they also found that wider spacing at 30 cm x 30 cm produced higher 1000 grain weight (21.67 g) than at 15 cm x 15 cm spacing (20.42 g). Rani et al. (2008) reported that SRI produced more number of productive tillers m⁻² (415), total number of grains panicle⁻¹ (256) and grain yield (7.5 t ha⁻¹) followed by drum seeding and conventional method which produced 380 and 312 number of productive tillers m⁻², 199 and 173 number of grains panicle⁻¹ and 5.8 and 5.6 t ha⁻¹ grain yield, respectively. However, Singh et al. (2008) reported that SRI produced more number of panicles m⁻² (318), fertile grains panicle⁻¹ (98.3), 1000-grain weight (24.76 g) and grain yield (5.02 t ha⁻¹) followed by conventional method and drum seeding which produced 278 and 253 number of panicles m⁻², 92.13 and 91.50 number of grains panicle⁻¹, 24.41 and 24.25 thousand-grain weight and 4.33 and 3.52 t ha⁻¹ grain yield, respectively.

Subbulakshmi et al. (2008) recorded significantly higher filled grains panicle⁻¹ (92.2), grain yield (5496 kg ha⁻¹) and straw yield (6388 kg ha⁻¹) under line transplanting than drum seeding which produced 90.7 numbers of filled grains panicle⁻¹, 4574 and 5447 kg ha⁻¹ grain and straw yield, respectively. On the contrary, Manjunath et al. (2009) reported that direct wet seeding by drum seeder resulted in higher mean grain yield of three years (61.88 q ha⁻¹) compared to normal transplanting (56.59 q ha⁻¹). The mean
numbers of panicles m$^{-2}$ (541), mean panicle length (29.39 cm) were significantly more in case of drum seeding as compared to normal transplanting which produced 519 number of panicles m$^{-2}$ and panicle length 19.19 cm, respectively. The mean straw yield was however, higher in case of transplanting method of establishment (6.83 t ha$^{-1}$) than drum seeding (6.53 t ha$^{-1}$).

Sekhar et al. (2009) found that, under same date of nursery sowing SRI outperformed CT by registering higher panicle weight (3.75 g) as against 2.85 g in case of CT which well compensated production of lesser number of panicles m$^{-2}$ (203) in SRI as compared to 244 in CT. On an average, SRI produced significantly more grain yield (6.43 t ha$^{-1}$) compared to CT (5.81 t ha$^{-1}$). Mankotia et al. (2009) revealed that conventionally transplanted rice produced better yield (3.98 t ha$^{-1}$) than drum seeded rice (3.37 t ha$^{-1}$). From the same experiment, it was also reported that conventional transplanting (CT) produced higher panicle weight (2.92 g), grains panicle$^{-1}$ (76), 1000 grain weight (23.8 g) and harvest index (44.4 %) than drum seeded rice which produced figures of 2.80 g, 68 numbers, 23.7 g and 39.9 % panicle weight, grains panicle$^{-1}$, 1000 grain weight and harvest index, respectively. However, the number of panicles m$^{-2}$ were higher (272.1) in case of drum seeded rice as compared to 238.8 in case of CT. Similar results of higher grain (55.29 q ha$^{-1}$) and straw (63.94 q ha$^{-1}$) yields were reported in case of normal transplanting compared to grain yield of 50.62 q ha$^{-1}$ and straw yield of 58.57 q ha$^{-1}$ in drum seeding (Yadav et al., 2010). Hugar et al. (2009) reported that, SRI with 25 cm x 25 cm spacing and 12 day old seedlings gave higher number of effective tillers m$^{-2}$ (376.5), panicle length (23.5 cm) and number of grains panicle$^{-1}$ (94.5) resulting in significantly higher grain yield (6140 kg ha$^{-1}$) and straw yield (9286 kg ha$^{-1}$).

Chandrapal et al. (2010) from their experiment conducted at DRR farm, Hyderabad found that plant dry weight, grains panicle$^{-1}$, 1000 grain weight and biological yield of rice crop was significantly higher under SRI method during both the years of experiment when compared with direct sowing of sprouted seeds and conventional transplanting method. On an average, SRI produced significantly higher rice grain yield by 15.5 and 18.8 % over DS and CT, respectively in both the years. Bommayasamy et al. (2010) reported that, closure spacing of 20 cm x 20 cm had higher number of productive tillers m$^{-2}$ (491); but it registered lower numbers of filled grains panicle$^{-1}$ (116.7).
Geetalakshmi *et al.* (2011) from their experiment conducted at wetland farm, TNAU, Coimbatore reported that, among the different rice crop establishment methods, SRI registered significantly larger number of productive tillers m$^{-2}$ (383 and 416), than other rice establishment methods such as conventional transplanting (354 and 374) and wet seeded rice (361 and 402) which were comparable to each other. SRI also registered higher number of filled grains panicle$^{-1}$ (117.8 and 130.8) followed by CT (110.8 and 121.9) and wet seeded rice (102.5 and 94.8). SRI also recorded significantly higher grain yield (6014 and 6682 kg ha$^{-1}$) followed by transplanted rice (5732 and 6262 kg ha$^{-1}$) and wet seeded rice (5175 and 5500 kg ha$^{-1}$). Thakur *et al.* (2011) reported that all the rice varieties of different duration produced significantly higher yields (by an average of 28 % ) under SRI practice compared to the CT. Medium duration rice varieties *Lalat* and *Surendra* gave 36 and 42 % more grain with SRI management than when grown under conventional transplanting system, respectively. However, from the same experiment they found that conventional transplanting (CT) produced significantly higher straw yield than SRI. They also reported significantly higher harvest index for SRI (47%) compared to CTS (39%). There was a 10 % increase in panicle length and 33 % increase in number of grains panicle$^{-1}$ under SRI as compared to CT. Also 1000 grain weight and grain filling percentage were significantly higher in SRI than CT for all the varieties tested such as *Khandagiri, Lalat, Surendra, Savitri* and *CRHR-7*.

### 2.3.3 Effect on soil physico-chemical properties

Budhar *et al.* (2006) reported that SRI method improved soil quality, which promotes stronger root and canopy growth with increased grain yield. Alternate wetting and drying in SRI method increased soil microbial biomass and released organic P from it (Yang *et al.*, 2004; Turner and Haygarth, 2011). Singh *et al.* (2008) revealed that total uptake of nitrogen (104.8 kg ha$^{-1}$), phosphorus (20.74 kg ha$^{-1}$) and potassium (125.8 kg ha$^{-1}$) were maximum in SRI followed by conventional transplanting and drum seeder which exhibited total uptake of 87.75 and 70.91 kg ha$^{-1}$ nitrogen, 16.82 and 13.36 kg ha$^{-1}$ phosphorus and 105.88 and 86.49 kg ha$^{-1}$ potassium, respectively. The aerobic soil conditions benefited both root and soil biota. The later mobilized soil nutrients through N-fixation and P solubilization by bacteria and nutrient and water access through micorrhizal fungi (Randriamiharisoa *et al.*, 2006). Mishra and Salokhe (2008) found that, young seedlings of 12 days old in wet or dry seed bed
performed better in respect of greater uptake of plant nutrient than old seedlings of 24 days when transplanted in either flooded or non flooded soils under SRI method.

Yadav et al. (2010) from their experiment revealed that, N, P and K uptake by rice was significantly influenced by crop establishment methods. In the first year of experiment in 2003, transplanting and drum seeding were at par with each other regarding uptake of N, P and K. However, in the second year of experiment in 2004, the uptake of N, P and K being 96.53, 19.68 and 33.18 kg ha\(^{-1}\), respectively were significantly superior to that of drum seeding which produced uptake values of 88.40, 18.00 and 30.37 kg ha\(^{-1}\), respectively. Similarly protein content in grain (7.53 %) under conventional transplanting was significantly higher than drum seeding method (7.26 %) in the first year of experiment.

### 2.4 Effect of nutrient management practices on rice

#### 2.4.1 Effect on growth

Alagesan (1997); Arun Kumar et al. (2011) revealed that the positive correlation between nitrogen application and formation of productive tillers. Use of higher dose of nitrogen, phosphorus and potassium through organic sources produced higher number of panicles and thousand grain weight (Dhurandher et al., 1999). Bhattacharyya et al. (2002) reported significant variation in dry matter accumulation in rice between the treatments involving manures and fertilizers, where cow dung manure (CDM) + urea (U) was closely followed by Municipal solid waste compost (MSWC) + Urea (U) but resulted in significant increase in dry matter than their individual applications. Leaf area index (LAI) at 60 days after transplanting (DAT) showed significantly highest value against CDM + U followed by MSWC + U and fertilizer alone. Similar response was also noted in case of crop growth rate (CGR). Apparently, a corresponding increase in dry matter accumulation occurred with increase in LAI and CGR in CDM + U followed by MSWC + U and fertilizer alone. Beneficial effects of such integration of manures and fertilizers having more potential role than applying either manures or fertilizers alone has been reported by Singh and Deka (1990). Bhadoria et al. (2003) from their experiment in an acid lateritic soil found higher plant height (104.3 cm, 107 cm), more tillers m\(^{-2}\) (301.9, 309.7), higher LAI (3.79, 3.92) and higher dry matter (779.3 g m\(^{-2}\), 801.5 g m\(^{-2}\)) under integrated nutrient management (FYM + chemical fertilizer) than plant height (97.2 cm and
96.6 cm), tillers m$^{-2}$ (259.6 and 251.8), LAI (3.44 and 3.41) and dry matter (645.6 and 627.4 g m$^{-2}$) under chemical fertilizer alone in both the years of experiment.

Mandal and Adhikary (2005) reported higher plant height with the treatment receiving 50% nitrogen through inorganic fertilizers and 50% through FYM followed by the treatments with 75% nitrogen through inorganic fertilizers and 25% through FYM, which were significantly higher than all other treatments. But, significantly lowest plant height was with the treatments that received 50% nitrogen through inorganic fertilizers and 50% through neem cake. Mankotia (2007) from his experiment found that application of 5 t FYM ha$^{-1}$ + 50 % NPK (45:20:20 kg N: P$_2$O$_5$ : K$_2$O) gave significantly taller rice plants (97.9 cm) as compared to 91.3 cm in no manure + 100 % NPK (90:40:40) fertilized plots. Hussain et al. (2009) from a field investigation conducted in the temperate conditions in the Kashmir valley to ascertain the best nutrient management strategy in SRI, found that SRI with NPK (inorganic fertilizers with different proportions of nitrogen, phosphorous and potassium) as well as FYM led to superior plant height and tillers hill$^{-1}$ over the recommended N practices and the conventional method of cultivation. Shekhar et al. (2009) revealed that, the uptake of N, P and K with SRI than conventional transplanting.

Radhakumari and Reddy (2011) reported that supply of 100 % N through fertilizer to rice was found to be superior to other nutrient management practices such as 50 % RDF + 50 % N through FYM and 100 % N through FYM application in rice which produced LAI (5.72, 5.31 and 4.82) and tillers m$^{-2}$ (466, 427 and 378), respectively.

### 2.4.2 Effect on yield attributes and yield

Garcia et al. (1994) found that uninhibited growth of SRI during the vegetative stage led to superior biological yield than that of transplanted rice. Islam (1999) stated that in the SRI method plant spacing of 25×25cm$^2$ or 20×20cm$^2$, yields were about the same (9.5 t ha$^{-1}$ and 9.2 t ha$^{-1}$, respectively) but with spacing of 30×30cm$^2$, the yield increased up to 10.5 t ha$^{-1}$. Bhadoria et al. (2003) reported that the number of panicle m$^{-2}$ (265.1) recorded in the combined nutrient sources (FYM + chemical fertilizers) was statistically at par with application of chemical fertilizer alone (238). However, in the second year, combined nutrient management (FYM + chemical fertilizers) produced 269.2 number of panicle m$^{-2}$ which was significantly higher than of chemical fertilizer alone (234.7 panicles m$^{-2}$). Also from the same experiment he
reported that, combined nutrient management (FYM + chemical fertilizers) produced significantly higher grain yield (4.5 t ha\(^{-1}\)) than chemical fertilizers alone (3.6 t ha\(^{-1}\)) in the second year of experiment. The extent of increase (average of two years) in grain yield of rice with addition of organic matter treatments in combination with chemical fertilizers ranged from 4.3 to 26.4 %. However, there was no difference as regards grains panicle\(^{-1}\) and test weight among different nutrient sources during both the years. Mandal and Adhikary (2005) reported that application of nitrogen 50% through inorganic fertilizers and 50% through FYM resulted significantly more number of effective tillers per plant, number of grains per panicle, 1000 grain weight and grain yield which was comparable with 75% nitrogen through inorganic fertilizers and 25% through FYM. However, highest straw yield was obtained in plots receiving 75% nitrogen through inorganic fertilizers and 25% through FYM, which was significantly higher than all other treatments. The lowest grain and straw yield was with the treatments that received 50% nitrogen through inorganic fertilizers and 50% through neem cake. The highest yield of rice was also reported when fertilizers were applied in combination with FYM (Laxminarayana, 2006). Arun Kumar et al.(2011) from their experiment reported that the number of productive tillers hill\(^{-1}\), filled grain panicle\(^{-1}\), panicle length, panicle weight and thousand grain weight significantly difference due to integrated nutrient management and further reported that the grain yield was significantly influenced by the same treatment in SRI. Hussain et al. (2012) revealed that, transplanting 1 or 2 seedlings hill\(^{-1}\) produced similar growth, yield attributes and yields but significantly higher than the 3 seedlings hill\(^{-1}\).

Mankotia (2007) from his experiment reported higher panicles m\(^{-2}\) (282.7), panicle weight (2.05 g), straw yield (4.87 t ha\(^{-1}\)) and grain yield (3.23 t ha\(^{-1}\)) in case of 50 % NPK + 5 t FYM ha\(^{-1}\) as compared to 277.5 number of panicles m\(^{-2}\), 1.79 g panicle\(^{-1}\), 4.7 t ha\(^{-1}\) straw yield and 2.84 t ha\(^{-1}\) grain yield in case of 100 % NPK through chemical fertilizer only. Pramanick et al. (2007) from a two year experiment conducted in the alluvial soils of lower Gangetic plain of West Bengal found highest grain yield of rice (30.9 q ha\(^{-1}\)) in recommended doses of N, P and K treatment followed by integrated use of FYM and NPK (FYM 10 t ha\(^{-1}\) + 60:30:30) treatment (29.1 q ha\(^{-1}\)), followed by only organic treatments (27.2 q ha\(^{-1}\)) under FYM at 5 t ha\(^{-1}\) + neem cake at 0.2 t ha\(^{-1}\), 26.5 q ha\(^{-1}\) under FYM at 5 t ha\(^{-1}\) + neem cake at 0.1 t ha\(^{-1}\), 25.5 q ha\(^{-1}\) under FYM at 10 t ha\(^{-1}\)). Straw yield also followed the same trend.
Harvest index, number of panicles m$^{-2}$ and number of filled grains panicle$^{-1}$ were also influence by different nutrient management practices where higher values were recorded under application of chemical fertilizers only. Barla and Kumar (2011) revealed that, increased the crop vigour, higher panicle size with more number of filled grains panicle$^{-1}$ in SRI Practice.

Raju and Sreenivas (2008) reported that, combination of organic and inorganic fertilizers produced significantly higher yield than sole chemical fertilizers. 50 % N through FYM (5 t ha$^{-1}$) + 50 % N through fertilizer produced significantly more yield (6.13 t ha$^{-1}$) compared to sole chemical fertilizer (120:60:40 kg N: P$_2$O$_5$:K$_2$O) which produced yield of 4.32 t ha$^{-1}$ under SRI method. Singh et al. (2009) from their experiment at Jorhat, Assam during wet season reported that, application of 50 % N (inorganic) + 50 % N through FYM + PK (inorganic and adjusted) produced higher grain yield (3.79 t ha$^{-1}$) and higher straw yield (4.54 t ha$^{-1}$) than 100 % RDF (60: 20:40 NPK ha$^{-1}$) which produced grain and straw yields of 3.04 and 3.91 t ha$^{-1}$, respectively. Barik and Gulati (2009) reported significantly higher number of effective tillers m$^{-2}$ and grain and straw yield in case of 50% RDF + vermicompost @ 10 t ha$^{-1}$ in comparison to 100% RDF.

Radhakumari et al. (2011) revealed that, supply of 100 % N through fertilizer only to rice was found to be superior to other nutrient management practices such as 50 % RDF + 50 % N through FYM and 100 % N through FYM application in rice which produced dry matter (11546, 10839 and 10142 kg ha$^{-1}$), number of panicles m$^{-2}$ (420, 378 and 333), total number of grains panicle$^{-1}$ (100.2, 84.9 and 77.9), test weight (23.6, 23.3 and 22.9 g), grain yield (5454, 5090 and 4710 kg ha$^{-1}$), straw yield (7649, 6977 and 6345 kg ha$^{-1}$) and harvest index (42.6, 42.2 and 41.6 %), respectively.

2.4.3 Effect of nutrient on soil physico-chemical properties

Sudha and Chandini (2005) reported that, the available N (272.85 kg ha$^{-1}$) and K (218.28 kg ha$^{-1}$) was higher in plots supplied with vermicompost @ 5 t ha$^{-1}$ and P (33.89 kg ha$^{-1}$) was higher in plots supplied with FYM @ 10 t ha$^{-1}$ as compared to values of N (256.48 kg ha$^{-1}$), P (29.46 kg ha$^{-1}$) and K (187.52 kg ha$^{-1}$), respectively in plots supplied with RDF only. Sarangi (2008) from his experiment in an acid upland soil reported that, there was improvement of soil pH (5.35), organic carbon (0.77%)
and total N (0.81%) with application of 50% RDF + 5 t FYM ha\(^{-1}\) which were significantly higher than pH (4.85), organic carbon (0.52%) and total N (0.76%) obtained with application of RDF only over initial values of 5.03, 0.62 and 0.65, respectively to preceding rice crop. Sudha and Chandini (2005) reported that, the continuous use of organic manure, neem cake, FYM and vermicompost can improve the microbial activity in soil and these improving the soil fertility in short run and have not indicated yield advantage.

Upadhyay et al. (2011) at the end of five cropping cycles found that, application of organic manures resulted in higher soil organic carbon, available N, P, K and maximum beneficial micro-organisms than chemical fertilizers and the soil bulk density was lowered significantly under organic nutrient management. Garnayak et al. (2012) reported that, application of 50 % RDF coupled with 50 % recommended N through green manuring of azolla at Bhubaneswar produced about 7 % higher yield over 100 % NPK in a long term plot experiment on “Integrated nutrient supply system in rice-rice crop sequence” conducted during 1983-84 to 2011-12 (29 years). Long term addition of organic matter in conjunction with inorganic fertilizers improved the soil pH and this might be due to the stabilizing effect of organic matter on soils because of its buffering capacity. On the contrary, continuous application of inorganic fertilizers decreased the pH of the soils, which might be due to the formation of some inorganic acids. Similarly, incorporation of organic matter over the years resulted in gradual build up of organic carbon content of soils and the increase over control was to the tune of 40 to 74 %. Dass and Chandra (2012) reported that, the uptake of nutrients, especially N and P in grains and straw were higher with irrigation at 1 and 3 DADSW (Days After Disappearance of Standing Water), which enhanced grain protein and milling percentage.

2.5 Weed management in SRI

The field dries up and as a consequence of alternate dry and wetting, an aggressive flush of both terrestrial and aquatic weeds come up in the early stage of crop growth (Sharma et al., 1999). Sridevi and Chellamuthu (2008) reported that, during Kharif season, the combination of young seedling, one seedling, square planting and cono weeding significantly shown 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.
To control weeds, use of a mechanical weeder is recommended, starting after 10 days after transplanting, with additional weedings every 10–12 days until the canopy closed. One or two weedings is usually sufficient to control most weeds. Soil aeration appears to stimulate the growth of aerobic bacteria and fungi and associated organisms in the soil food web. Planting in a square pattern allows farmers to weed in perpendicular directions, which achieves more and better soil aeration. These practices are all known to have positive effects on yield (Horie et al., 2005). Initial growth of weeds are controlled by mechanical weeding (cono weeder) which also helps in incorporation of weed biomass and maintains proper aeration in soil (Satyanarayan et al., 2007). However, additional weedings are seen to boost yield by 0.5–1.0 tonnes. Vijayakumar et al. (2006) also found significant yield increase of 9.7% (20 x 20 cm\(^2\) plant density) and 11.1% (25 x 25 cm\(^2\) plant density) due to weeder use when compared to conventional weeding (herbicide + hand weeding) with 14-day-old seedlings and limited irrigation. Additional weeding can add as much as t ha\(^{-1}\) to the yield, which substantially increases the profitability of SRI (Uprety, 2005). Several analyses have shown that additional weeding beyond the first two can add 0.5 to 2.5 t ha\(^{-1}\) to final yield. In one Madagascar community, farmers who did not do mechanical weeding got 6.0 t ha\(^{-1}\), farmers who did one or two weedings got 7.5 t ha\(^{-1}\), but the farmers who weeded three 17 times averaged 9.2 t ha\(^{-1}\), and the farmers who were weeding four times got 11.8 t ha\(^{-1}\) (Uphoff, 2003). Kavitha et al. (2010) reported that 14 days old seedlings recorded lower total weed population and weed dry matter production there by reduced nutrient removal by weeds, comparatively higher number of total weed population was noticed with 22 days old seedlings, pre-emergence application of pretilachlor followed by one mechanical weeding at 30 DAT resulted in greater reduction in the population of grasses, sedges and broad leaved weeds. Thiyagarajan (2002) opined that the maximum yield (7612 kg ha\(^{-1}\)) was obtained for the modified SRI practice with young seedlings, restricted irrigation, addition of green manure and incorporation of weeds, soil aeration with cono weeder during Rabi (Samba) season with CORH-2 (hybrid) at Coimbatore. Rice weeds are at present the major biotic constraint to increased rice production worldwide. The importance of their control has been emphasized in the past by various authors (De Datta and Baltazar, 1996). Unchecked weed compete with rice plants for light, nutrients and moisture resulting reduction of grain yield up to 80 % (Sinha Babu et al., 1992). Estimation of yield losses caused by
competition from weeds ranges from 30-100% (Dobermann and Fairhurst, 2000). Yield loss in rice crop due to weed range from 10-50 % (Singh and Singh, 1993). In lowland or puddled conditions, broad-leaved weeds are the main problem. Maximum grain yield (64 q ha\(^{-1}\)) was obtained in weed-free plots and minimum (35 q ha\(^{-1}\)) in weedy plots.

### 2.6 Effect of SRI on economics

Arumainathan (1997) reported that higher total monetary return, net return and rupee invested with wider spacing compared to closer spacing. Illuri et al. (2004) reported that there was no significant difference in cost of cultivation between SRI and non SRI but significant difference was found in terms of net returns between SRI (₹ 27 923 ha\(^{-1}\)) and non SRI (₹ 9 222 ha\(^{-1}\)) at Andhra Pradesh during wet season. A net benefit of ₹ 18 700 ha\(^{-1}\) was obtained in SRI. Andrianaivo (2002) obtained significantly higher net returns of $250 under SRI cultivation when compared to traditional method ($210). The higher net returns was due to efficient use of resources, better yield levels with SRI method than traditional method of cultivation. Cost of cultivation showed marked variation due to plant spacing. Maximum cost (₹ 15085 ha\(^{-1}\)) was incurred under the close spacing (20 x 10 cm\(^2\)) which reduced correspondingly with further widening in plant spacing (Kewat et al., 2002). Andrianaiva (2002) reported that SRI enhanced labour productivity substantially. Net income from SRI was far greater than traditional cultivation. Krupakar Reddy (2004) recorded higher net return (₹ 34889 ha\(^{-1}\)) compared to traditional method (₹ 23 889 ha\(^{-1}\)). The cost of production under SRI was half the cost of the conventional cultivation (Singh et al., 2006). The combination of young seedlings, single seedling, square planting and cono weeding registered the highest net return (₹ 12574 ha\(^{-1}\)) and B:C ratio (1.87) compared to normal practice (Chellamuthu and Sridevi, 2006). The positive point for the spread of SRI for rice hybrid is saving of ₹ 1500 ha\(^{-1}\) in the seed cost besides saving of water to an extent of 30 to 50 per cent (Viraktamath, 2006). Transplanting with 12 day old seedling at one seedling hill\(^{-1}\) under SRI recorded highest net profit (₹ 40773 ha\(^{-1}\)) and B:C ratio of 3.95 (Rajasekhar Reddy et al., 2006). Vijayakumar et al., (2006) reported that higher labour productivity of ₹ 4.05 was obtained in SRI method. Hussain et al. (2012) revealed that, the highest net returns of ₹ 51,900 was realized by planting two seedlings hill\(^{-1}\) and among the age of seedling the highest net return
of ₹53,400 was realized for 14 days old seedling which was comparable with 21 days old seedlings. Rao et al. (2013) revealed that, the SRI practice recorded about ₹9000-12000 higher gross returns compare to farmers practice and was found significantly superior over both farmers practice and recommended practice during the both the year of study at Maruteru, Andhra Pradesh.