A COMPARATIVE STUDY OF NUTRIENT MANAGEMENT IN PADDY UNDER SRI AND TRADITIONAL METHODS OF CULTIVATION

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I. INTRODUCTION

Rice commends recognition as a supreme commodity to mankind, because rice is truly life, a culture, a tradition and a means of livelihood to millions. It is an important staple food providing 66-70 per cent body calorie intake of the consumers. The United Nations General Assembly, in a resolution declared the year of 2004 as the "International Year of Rice", which has tremendous significance to food security. It very eloquently upheld the need to heighten awareness of the role of rice in alleviating poverty and malnutrition (Barah and Pandey, 2005).

Rice is the staple food for about 50 per cent of the world's population that resides in Asia, where 90 per cent of the world's rice is grown and consumed. In Asia, India has the largest area under rice (41.66 million ha) accounting for 29.4 per cent of the global rice area. Of the total area, about 46 per cent is irrigated, 28 per cent is rainfed lowland, 12 per cent is rainfed upland and 14 per cent is flood prone. Rice is one of the largest traded commodities in the world with a total quantity touching 16.4 million tonnes. The southeast countries account for about 40 per cent of the rice trade in the world (Mangala Rai, 2004).

The world paddy production was 614.65 million tonnes in 2004-05, covering an area of 153.51 million ha with an average yield of 3.87 tonnes per ha. Developing countries contributed about 90 per cent of the total world rice production.

India ranked first in area under paddy (41.66 million ha) and second in terms of production (85.31 million tonnes) during 2004-05 and it stood next only to China in the world. But, the yield levels in India were low at 2.047 tonnes per ha compared to other major rice producing countries viz., Japan (6.52 t/ha), China (6.24 t/ha) and Indonesia (4.25 t/ha). About 67 per cent of the area under paddy in India is under HYV's.

The green revolution of 1960's was oriented towards high input usage particularly fertilizers, irrigation and plant protection chemicals. As a result of excessive use of these inputs the cost of cultivation escalated. This is more so in irrigated crops like paddy. The spectacular increase in production of paddy was restricted to irrigated belts of the country. The skewed distribution of green revolution results and increased costs of cultivation have given alarming signals to the future needs of food security.

To assure food security in the rice consuming countries of the world, rice production should be increased by 50 per cent in these countries by 2025. This additional rice will have to be produced on less land with less usage of water, labour and chemicals (Zheng *et al*., 2004). Similarly, to achieve the projected targets of 680 and 771 million tonnes by 2015 and 2030, respectively, the productivity of rice has to be increased through adoption of suitable and newer technologies (Badawi, 2004).

The System of Rice Intensification (SRI), developed in Madagascar over a 20 year period and synthesized in the early 1980s by Father Henri de Laulanie, offers opportunities to researchers and farmers to expand their understanding of potentials already existing in the rice genome (Stoop *et al*., 2002; Uphoff and Randriamiharisoa, 2002). The SRI is a new methodology for increasing the productivity of irrigated rice by changing the management of plants, soil, water and nutrients resulting in both healthy soil and plants, supported by greater root growth and the soil microbial abundance and diversity.

The SRI was recently introduced into India and slowly gaining momentum since 2003. If SRI were to be applied with the water now being used for rice irrigation, it would be able to increase irrigated area by atleast 50 per cent, leading to 50 per cent increase in rice production (Thakkar, 2005).

Fertilizer is one of the inputs which brings quantum jump in the yield of rice. The nutrient uptake by rice plant is different from other field crops. To improve the production efficiency of rice and to synchronize the application of nutrients with the demand of the plant, it is necessary to apply required dose of NPK fertilizer.

Nitrogen is known as the key nutrient of rice production. It is one of the most important and essential nutrient which directly influences the growth, development, yield and quality of rice. Nitrogen applied in lowland rice is lost from soil through leaching and denitrification. The next limiting nutrient which reduces the productivity of rice is phosphorus as it is required for cell division, seed formation, crop maturation, root growth and development. The phenomenon of grain filling is influenced by potassium fertilization.

Among the micronutrients, zinc is the most important essential plant nutrient, whose widespread deficiency has become serious nutritional problem in rice limiting its yield. Zinc deficiency in rice appears right from seedling stage in nursery and three weeks after transplanting in transplanted plot, if the soil is deficient in zinc.

Biofertilizers, an alternate low cost resource have gained prime importance in recent decades and they play a vital role in maintaining long-term soil fertility and sustainability. Among the nitrogenous biofertilizers in rice field *Azospirillum* has been recognized as an important diazotroph colonizing root environment of cereal crops. It fixes atmospheric N_2, enhances uptake of nutrients and also produces plant growth promoting substances. The N_2 fixing ability of *Azospirillum* is 25 to 30 kg N per ha per season. Thus, it can save 25 per cent of fertilizer nitrogen. Phosphatic biofertilizers solubilize fixed insoluble forms of phosphorus already present in the soil and make it available for use of plants. Bacteria like *Bacillus megatherium* var. phosphaticum, *Pseudomonas fluorescens*, fungi like *Penicillium digitatum* and *Aspergillus niger* are found to have a strong phosphate dissolving ability.

Information on nutrient dynamics in SRI method of cultivation is scanty. Hence, the present investigation was taken up with the following main objectives.

1. To compare the growth and yield of rice under SRI and traditional methods of cultivation as influenced by nutrient levels and biofertilizers.
2. To study the nutrient uptake of paddy under SRI and traditional methods of cultivation as influenced by nutrient levels and biofertilizers.
3. To study the N dynamics in SRI and traditional methods of cultivation as influenced by nutrient levels and biofertilizers at different depths during different stages of crop growth.

II. REVIEW OF LITERATURE

The pertinent literature on the performance of rice under SRI and traditional methods of cultivation under different fertilizer levels are reviewed in this chapter in addition to a brief review on the System of Rice Intensification.

System of Rice Intensification (SRI)

Traditionally rice is cultivated under submergence where in the poor soil aeration used to affect adversely the crop growth and yields (Drew, 1983).

Ramakrishnayya *et al.* (1990) reported increased duration of submergence resulted in reduction of oxygen supply and lead to poor nitrogen uptake and photosynthesis.

Father Henri de Laulanie, who developed SRI in Madagascar observed two things *viz.,* (a) rice plants have very great tillering potential and b) the best yields of rice are obtained with soil aeration. Based on these observations, he formulated the following principles (Uphoff and Randriamiharisoa*,* 2002).

i) Rice is not an aquatic plant : Eventhough rice can survive under flooded conditions, most of the rice plant's roots remain in top 6 cm of soil and most of them degenerated by the time rice plants entered into reproductive phase under continuous submergence.

ii) Rice seedlings lose much of their growth potential if they are not transplanted before the start of fourth phyllochron of growth (*i.e.,* 15 days after emergence). So early transplanting should be done.

iii) Trauma to seedlings and roots should be minimized during transplanting

iv) Wider spacing of plants lead to greater root growth and tillering

v) Soil aeration and organic matter create beneficial conditions for plant root growth, plant vigour and health, to resist damage from pests and diseases.

Based on the above principles, the following practices are developed under the SRI.

1. Transplanting very young seedlings of 8-12 days old with just two small leaves
2. Transplanting seedlings carefully and quickly to have minimum trauma to the roots
3. Transplanting singly, only one seedling per hill instead of 3-4 together, which causes root competition
4. Widely spaced to encourage greater root and canopy growth
5. Transplanting in a square pattern 25 cm x 25 cm or wider spacings of 30 cm x 30 cm, 40 cm x 40 cm even up to 50 cm x 50 cm with the best quality soil
6. Keeping the soil well drained than continuously flooded upto vegetative growth period
7. Early and frequent weeding with rotary weeder
8. Application of organic manures

These practices should be combinedly followed to achieve better results. The SRI is promoted by the Association Tefy Saina, an NGO in Madagascar and the Cornell International Institute for Food and Agriculture Development (CIIFAD) in USA. The SRI is now under practice in 32 countries around the world (CIIFAD Country Report, 2005).

SRI method differs from normal method of rice cultivation as given below.

1. Nursery management: Raised seed bed should be prepared by mixing FYM in the soil either on polythene cover, banana sheaths etc. or on soil itself.

a. Seed rate: Five kgs of seed per hectare is sufficient as against 50-62.5 kg per hectare in normal rice.

b. Age of the seedlings: Transplanting should be done with 8-12 days aged seedlings with two small leaves as against 25 days and above in normal rice.

2. Transplanting: Seedlings should be removed carefully from the nursery without disturbing the roots of the plant along with mud and single plant should be transplanted in the main field. Water in the main field should be drained before transplanting.

3. Wide spacing: Wider spacing of 25 cm $\times$ 25 cm in square pattern should be maintained for aeration and for easy intercultural operations as against 33 hills per m^2 in traditional method.

4. Weeding: Naturally weed growth is more in these fields because there is no stagnated water, weeding should be done with rotary weeder/conoweeder for at least four times with an interval of 10 days starting from tenth day after planting. It churns the soil and the weeds are incorporated in the soil, which in turn are useful as organic manure. It increases soil aeration and soil health.

5. Water management: The soil should be kept moist but not saturated by providing alternative wetting and drying.

6. Manures and fertilizers : More of organic manures (10 t/ha) should be used and chemical fertilizers should be reduced.

2.1 Growth and yield components of rice

2.1.1 Effect of N, P, K and Zn on growth components of rice

Rice grown under SRI principles was found to produce more tillers per hill than those under conventional system *i.e.,* upto 70 tillers by the 75^{th} day after transplanting (MSSRF, 2002).

Enhanced root activity (root oxygenation ability) was observed during the entire growth period particularly 2 times and 2.9 times more at heading and maturity stages, respectively, under the SRI (12 to 13 day old seedlings) over that under traditional cultivation (28 to 30 day old seedlings). Increase in accumulation of soluble sugars, non-protein nitrogen, MDA and proline content levels were 61.5, 23.4, 108.8 and 26.5 per cent, respectively, with SRI than under traditional rice cultivation (TRC). The total translocation of nitrogen from leaves, stems and sheaths was 66.9 per cent higher with SRI than TRC (Wang *et al.,* 2002).

Tao *et al.* (2002) reported higher plant height and leaf area with 15 day old seedlings than 30 day old seedlings at planting. Further, they reported 10-15 cm deeper root system with the planting of 15 day old seedlings than that with 30 day old seedlings. No significant difference, however, was observed between 10 day old seedlings and 20 day old seedlings regarding plant height and tillers/m^2 by Chris *et al.* (2002).

Sengthong (2002) from Laos observed that 9 day old seedlings produced 43 tillers per hill compared to 28 and 23 tillers per hill produced by 12 and 18 day old seedlings, respectively. Similarly, Yamah (2002) reported 20-69 tillers per hill by planting 10 day old seedlings compared to 8-9 tillers per hill by planting 30 day old seedlings.

Barison (2002) observed that root growth was restricted to top 20 cm soil, when 25 and 45 day old seedlings were transplanted compared to root growth beyond 30 cm soil depth when 8 day old seedlings were transplanted.

Mulu (2004) reported shorter length of phyllochrons and more tillering when younger plants (8 and 15 days old seedlings) were transplanted than those when older plants (20 and 25 days old seedlings) were planted.

Sarath and Thilak (2004) reported four times higher total dry weight at maturity from planting of 8 day old seedlings than from 21 day old seedlings on account of increased tillering but not plant height. Further, they reported leaf area of 0.48 m^2 at heading stage in plots where 8 day old seedlings were used compared to 0.1 m^2 where 21 day old seedlings were used.

Sengthong (2002) reported increased tillering with increase in plant spacing from 25 cm x 25 cm to 40 cm x 40 cm, but not beyond.

Devasenamma *et al.* (1999) reported that nitrogen application caused significant variation in total dry matter production over control at all the crop growth stages. There was significant increase in total dry matter production with successive increase in levels of nitrogen up to 180 kg per ha at all stages of crop growth.

Kumari *et al.* (2000) conducted a field experiment to study the effect of different levels of nitrogen on growth of rice. They observed taller plants at higher level of nitrogen application *i.e.* 120 kg/ha. Dry matter production also increased with increased level of nitrogen.

Somasundaram *et al.* (2002) observed significant increase in plant height, leaf area index and dry matter accumulation with each successive increase in N level from 0 to 150 kg/ha. Addition of N from 100 to 150 kg/ha did not significantly improve the above parameters. However, maximum values for growth parameters were recorded at 125 kg N/ha.

Reddy *et al.* (1984) and Alam and Azmi (1984) reported that dry matter, plant height and number of tillers increased significantly with increasing phosphorus.

Pawar and Chavan (1996) studied the response of rice to different sources of complex phosphatic fertilizers in lateritic soils and reported that the treatment nitrophosphate produced significantly higher number of tillers/hill. Urea ammonium phosphate and urea + single super phosphate were next in performance and at par with each other.

Singh *et al.* (1999) reported that plant height increased significantly up to 30 kg P_2O_5/ha and difference between 30 and 60 kg P_2O_5/ha were non-significant but were significantly superior over control (P_0) in rice-cowpea sequence.

Hati and Misra (1982) studied the effect of levels of potash on dry matter of rice. They used four levels of K (0, 30, 60, 90 and 120 kg/ha) as muriate of potash. They reported that potash treatments effected significant variations in the dry matter at 60 days and at harvest. The dry matter increased significantly with increase in level of potash up to 60 kg K/ha. A decline in the dry matter was observed at 120 kg K/ha.

Ravi and Rao (1992) conducted a field experiment to study the effect of graded levels of potassium and times of application, with three levels of potassium (0, 60 and 120 kg/ha) and four schedules of application (All basal, half as basal + half at 30 DAT, half as basal + half at PI stage and 1/3 equally as basal, at 30 DAT and at PI stage). They observed that dry matter production significantly increased at 90 DAT and at harvest due to levels of potassium only. A significant superior LAI was obtained.

Bohra and Doerffling (1993) revealed that increasing levels of K application improved plant height, tiller number and shoot dry weight at flowering. However significant difference was observed only in the sensitive variety IR-28, whereas K_{50} and K_{75} treatments produced significantly higher value than the K_0 treatment.

Sriramachandrasekharan and Mathan (1988) conducted a field experiment to study the influence of zinc sources on the growth characters *viz.*, plant height, number of tillers/hill and root characters. Application of zinc increased plant height, number of tillers, root length, root volume and root weight and root length density. Application of zincated urea alone or in combination with zincated suphala were on par in regard to character studied.

Maji and Bandyopadhyay (1990) studied the response of rice to zinc in coastal saline soils. They used two levels of zinc (6.8 and 13.6 kg/ha) and reported that a decreasing trend in dry matter was observed with higher doses of zinc.

2.1.2 Yield components and yield of rice as influenced by N, P, K and Zn

Cultivation of rice under the principles of SRI *i.e.,* transplantation of 8-day old seedlings at 25 cm x 25 cm spacing resulted in 2-4 times more yield than under conventional practices (Uphoff, 2001).

Transplanting of 8 day old seedlings @ one per hill at a spacing of 25 cm x 25 cm followed by two to three weedings at 10 day interval starting from the 10^{th} day, the farmers in Madagascar got yield upto 10-15 t/ha and even more than that under wider spacing of 50 cm x 50 cm fertile soils (Berkelaar, 2001).

The highest grain yield was recorded under the SRI with L-shape root placement than that under conventional cultivation with J-shape root placement (Hossain *et al.,* 2003).

Natarajan (2004) reported 50-60 tillers per hill with a yield of 250 g per plant and the cost of cultivation of Rs. 1000/acre under the SRI compared to Rs. 4310/acre under conventional method of cultivation.

With the practice of SRI, 46 per cent lesser seed rate, 50 per cent lesser expenditure on chemical fertilizers. 71 per cent decrease in labour requirement and 41-130 per cent increase in yield were reported from Cambodia (Yang and Suon, 2004; Jurgen, 2004; Illuri *et al.,* 2004).

The yield of Njavara, a medicinal rice variety grown in Kerala, India, was increased by threefold under the SRI, compared to the yield obtained under traditional system of cultivation. The net profit per hectare was Rs. 80,000/acre as its price was Rs. 45 to Rs. 55/kg because of its high content of amino acid methionine (Rekha, 2004).

At Maruteru in Andhra Pradesh, Paladugu *et al.* (2004) observed increase in number of ear-bearing tillers (167.5%), fertile grains per panicle (29%), spikelet fertility (6.4%), 1000 grain weight (1.7%) and yield (922 kg/ha) under the SRI over those under traditional method of cultivation.

About 28 per cent to 49.8 per cent increase in grain yield, 49 to 54 per cent increase in straw yield, up to 95 per cent saving in seeds and upto 50 to 70 per cent saving in water were reported from India and other countries (Thakkar, 2005; CIIFAD Country Report, 2005).

Wang *et al.* (2002) reported higher spikelet number per panicle and productive tillers per hill from planting of 12-13 days old seedlings than from planting of 28-30 days old seedlings.

Yamah (2002) reported 3 fold increase in panicles per hill and significant increase in spikelets per panicle from planting of 10 day old seedlings over those from planting of 30 day old seedlings. Grain yield also increased by 2-fold in plots planted with 8 day old seedlings compared to that of 21 day old seedlings.

Randriamiharisoa (2002) reported higher yield (5.3 t/ha) with 8 day old seedlings compared to 2.7 t/ha with 16 day old seedlings on clay soil.

Randriamiharisoa and Uphoff (2002) reported the results of factorial trials. In Madagascar, three ages of seedlings (8, 16 and 20 days old) were evaluated under different combinations of water management (aerated and saturated soil), plant density (one and three seedlings per hill) and fertilization (compost vs NPK 16-11-12). Among all the practices studied by them, planting of younger seedlings (8 day old) @ one per hill and maintained in aerated soil with the use of compost had resulted in 140 per cent to 245 per cent increase in grain yield.

Mulu (2004) reported higher number of filled spikelets per panicle with 8 day old seedlings (265.7) compared to 234.9, 233.5 and 212.9 with 15, 20 and 25 day old seedlings, respectively. Similarly, Sarath and Thilak (2004) recorded the highest grain number per panicle (290) and yield (7.6 t/ha) with 8 day old seedlings compared to that (242 and 6.9 t/ha, respectively) with 21 day old seedlings.

Uphoff (2005) also reported the highest yield (6437 kg/ha) with the use of younger seedlings (14 day old) compared to that (5212 kg/ha) with the use of older seedlings (33 day old).

Sebastien (2002) from Madagascar reported increase in panicles per hill, grains per panicle and yield with increasing plant spacing from 25 cm x 25 cm to 50 cm x 50 cm. In contrary, Chris *et al.* (2002) recorded more effective tillers per m^2 and yield in 30 cm x 30 cm planting than in 40 cm x 40 cm planting.

Robert (2002) reported maximum yield of 5.1 t/ha with 25 cm x 25 cm spacing compared to the yields of 4.7, 3.5 and 2.7 t/ha with 15 cm x 15 cm, 33 cm x 33 cm and 40 cm x 40 cm spacings, respectively. Yuan (2002) reported 21.3 per cent yield increase with 33 cm x 33 cm spacing over that of 16 cm x 26 cm planting. However, no difference between yields of 25 cm x 25 cm and 30 cm x 30 cm planting was found (Randriamiharisoa and Uphoff, 2002).

Uphoff (2005) observed more number of productive tillers per hill (23.4), percentage of filled grains (30%) and yield (6.6 t/ha) by planting seedlings at 20 cm x 15 cm spacing compared to 40 cm x 40 cm spacing. But, higher number of filled grains was observed in the widest spacing *i.e.,* 40 cm x 40 cm.

Raju *et al.* (2004) studied a wide range of plant age (0 to 24 days) and plant spacing (20 cm x 15 cm, 25 x 25 cm, 50 cm x 25 cm and 50 cm x 50 cm) using different varieties of rice in West Godavari district of Andhra Pradesh and concluded that planting of 8 day old seedlings at 25 cm x 25 cm spacing was better for all the varieties studied. The rice variety, BPT-5204, however, gave good yields even upto 14 days of seedling age.

Thakkar (2005) reported 28 per cent higher grain yield with planting of 14 day old seedlings at a spacing of 20 cm x 20 cm than planting of 21 day old seedlings at 15 cm x 15 cm spacing.

McHugh *et al.* (2002) observed that primary drawbacks reported by farmers with implementing alternate wetting and drying and non-flooding irrigation were the lack of reliable water source, little water control and water use conflicts. SRI was associated with a significantly higher grain yield of 6.4 t/ha compared with 3.4 t/ha from conventional practices. On SRI plots, grain yields were 6.7 t/ha for alternate wetting and drying irrigation, 5.9 t/ha with non-flooding irrigation and 5.9 t/ha for continuously flooded.

Ceesay and Uphoff (2003) reported that among water management practices proposed for the System of Rice Intensification (SRI), cycles of repeated wetting and drying were found beneficial to rice plant growth through increased nutrient availability leading ultimately to higher grain yields.

Murthy and Murthy (1978) observed significant increase in the yield when nitrogen rate increased from 60 to 120 kg ha^{-1}. Increase in the grain yield was due to increase in total dry matter $hill^{-1}$, panicle m^{-2}, spikelets m^{-2} and high leaf area index.

Anil *et al.* (1989) reported that grain yield significantly increased with increasing nitrogen levels up to 120 kg N/ha. Whereas, Singundhupe and Rajput (1989) indicated that application of nitrogen significantly increased both grain and straw yields up to 150 kg N/ha compared with unfertilised treatment.

Pandey and Tripathi (1994) reported that the grain yield was significantly higher at 120 kg N/ha than at lower levels owing to significant increase in panicles/m^2 and panicle weight.

Krishnan *et al.* (1994) revealed a linear rice response with increasing N levels though the grain yield continued to increase up to 240 kg N/ha. The yield increase per kg of N was the highest from 0-60 kg N/ha (31.3 kg N^{-1}) followed by 60-120 kg N/ha (21.51 kg N^{-1}). Beyond 180 kg N/ha, the yield increase was not significant and registered only 0.5 kg increase for each kg of N applied.

Mutanal *et al.* (1997) reported that the application of nitrogen through nimin coated urea proved superior than through prilled urea, tar coated urea and large urea granules. The optimum dose was 75 kg N/ha, which recorded higher return compared with 50 and 100 kg N/ha.

Latchanna *et al.* (1989) reported that number of panicles per m^2 increased by 9.5, 15, 18 and 20 per cent with 20, 40, 60 and 80 kg P_2O_5/ha application over control. Application of phosphorus also resulted in increased number of filled grains per panicle, 1000 grain weight, grain and straw yields, however the increase was marked up to 40 kg P_2O_5/ha only.

Annadurai and Palaniappan (1994) reported that application of graded level of phosphorus (0, 9.5, 19 and 38 kg P_2O_5/ha) significantly improved the number of productive tillers and 1000 grain weight which in turn increased the yield of IR-20 rice variety.

Singh *et al.* (2000) conducted field experiments to study the response of rice to 4 levels of P_2O_5, *viz.*, 0, 30, 60 and 90 kg P_2O_5/ha. They found that both rice grain and straw yields increased with graded levels of P_2O_5 applications. There was significant response to applied P up to 60 kg P_2O_5/ha.

Singh *et al.* (1976) working with traditional varieties reported that application of K_2O at 120 kg/ha at the transplanting gave the highest straw yield, but split application *viz.*, at transplanting, tillering and panicle initiation gave the highest grain yield.

Bhargava *et al.* (1985) reported a progressive increase in response to K_2O. At 60 kg K_2O/ha, the increase in yield was about 6-8 kg grain/kg in rice. The yield response in most soils was significant at 40 to 60 kg K_2O/ha.

Ravi and Rao (1992) conducted a field experiment to study the effect of graded levels of potassium and times of application with three levels of potassium (0, 60, 120 kg/ha) and four schedules of applications (all basal, half as basal + half at 30 DAT, half as basal + half at PI stage and 1/3 equally as basal, at 30 DAT and at PI stage). They reported that maximum test weight, number of filled grains/panicle and yield were obtained due to application of potassium in two equal splits as basal and at PI stage.

Raju *et al.* (1999) reported that rice yield and its attributing characters responded favourably to higher dose (60 kg K_2O/ha) of K, but not at lower doses (40 kg/ha) except when the entire dose was applied at panicle initiation stage. In general, K fertilization showed beneficial effect on grain, tillering and harvest index and reduced the duration of crop.

Gill and Hardeep (1978) reported that application of zinc sulphate at 20 kg/ha increased the productive tillers, panicle length and number of grains per panicle in rice. Whereas, Patel (1979) observed that application of 0-25 kg $ZnSO_4$/ha increased 1000 grain weight, number of effective tillers per plant, fertile spikelets per panicle and panicle length.

Uddin *et al.* (1981) found that with increase in the levels of $ZnSO_4$ application number of effective tillers, plant height, panicle length, number of grains per panicle and 1000 grain weight was increased. Saravanan and Ramanathan (1986) reported that 25 kg $ZnSO_4$/ha is the optimum rate for rice grown on Cauvery delta clay loam soils.

Ingle *et al.* (1997) reported that application of 15 kg Zn/ha through zinc sulphate with N, P, K (100:50:50) fertilizers gave the highest grain and straw yields of paddy and was found significantly superior over control and other treatments.

Kumar *et al.* (1998) studied the effect of Zn application on yield attributing characters and yield of rice. Application of 25 kg $ZnSO_4$/ha in transplanted field or spraying standing crop with 0.5 per cent $ZnSO_4$ solution three weeks after transplanting or dipping seedling roots in 2 per cent ZnO suspension were equally effective in correcting zinc deficiency. Zinc application in transplanted field in general improved yield attributes like number of panicles, test weight, panicle length and fertile spikelets significantly.

2.1.3 Combined effect of NPK and Zn

Sikdar and Gupta (1979) observed that spikelet sterility was higher at 100 kg N + 50 kg P_2O_5 + 50 kg K_2O ha^{-1} as compared to 50 kg N + 25 kg P_2O_5 + 25 kg K_2O ha^{-1}. But, the spikelets $panicle^{-1}$, grain yield and 1000 grain weight were higher with higher dose of fertilizers.

Venkateswarlu and Singh (1980) observed higher grain yield with 120 kg N + 60 kg P_2O_5 + 45 kg K_2O ha^{-1} followed by 80 kg N + 40 kg P_2O_5 + 30 kg K_2O ha^{-1}. Yield attributes like number of effective tillers m^{-2}, panicle weight, grains $panicle^{-1}$ and test weight were increased with increase in the fertility level.

Chandrashekarappa (1985) reported that application of 100 kg N, 100 kg P_2O_5 and

50 kg K_2O ha^{-1} gave the highest grain yield. This was on par with 100 kg N, 50 kg P_2O_5 and 50 kg K_2O ha^{-1}. The increase in yield was due to increased dry matter production, plant height, leaf area index, leaf area duration, number of tillers $hill^{-1}$ and to some extent panicle length and 1000 grain weight.

Rao and Shukla (1996) conducted a field experiment during *kharif* seasons at BHU, Varanasi revealed that highest grain yield of rice was obtained with ammonium polyphosphate (APP) applied at 90 kg P_2O_5 ha^{-1} in combination with 30 kg $ZnSO_4$ ha^{-1}. Among the sources of phosphorus tested, APP followed by UNP recorded the highest grain yield over DAP. Increasing the doses of phosphorus significantly increased the grain yield. Increasing the zinc sulphate up to 30 kg/ha significantly improved the grain yield. Similar trend was observed in respect of all the growth characters studied.

2.1.4 Effect of biofertilizers on crop growth

Biofertilizers are inputs containing microorganisms which are capable of mobilizing nutritive elements from non-usable form to usable form through biological processes. *Azospirillum* is an important nitrogen fixing biofertilizer, whose application increases grain yield of cereals by 5-20 per cent. Phosphorus solubilizing bacteria solubilize insoluble/fixed forms of phosphorus into forms which are readily taken by the plants.

2.1.4.1 Effect of *Azospirillum* on crop growth

Tien *et al.* (1979) reported the excretion of auxins particularly IAA, gibberellins and cytokinins of *Azospirillum brasilense*.

Nayak *et al.* (1986) reported that inoculation of rice with *Azospirillum* increased the production of tillers, plant height and early reproductive stage. Purushothaman *et al.* (1987) reported that inoculation of *Azospirillum brazilense* strain sp. 7 increased the germination, seed vigour index of cv. IR50 and cv. Co-40. It also increased the shoot and root length, number of primary roots and dry weight of seedlings.

Singh *et al.* (1989) reported that two strains of *Azospirillum* in maize showed at 35°C a better growth of both plant and bacteria above which reduced plant height. Stancheva and Dinev (1992) reported that the interaction between *Azospirillum brasilense* and the maize root system increased the plant biomass.

2.1.4.2 Effect of PSB on crop growth

Gaur and Singh (1982) observed that inoculation of *Bacillus polymyxa* along with rock phosphate increased the dry matter of rice plants.

Datta *et al.* (1982) reported that there was an increase in dry matter of rice (Jaya and IR-8) due to inoculation with phytohormone producing P solubilizing bacteria *Bacillus firmis* inoculated along with rock phosphate and superphosphate.

2.1.5 Effect of biofertilizers on yield and yield components

2.1.5.1 Effect of *Azospirillum*

Rao *et al.* (1979) reported that *Azospirillum* inoculation significantly increased the grain yield of rice variety Pusa 2-21 at 0, 40 and 60 kg N/ha.

Rao *et al.* (1983) observed a statistically significant positive yield response to inoculation with *Azospirillm* sp. at different levels of N fertility over three consecutive seasons. The response of *Azospirillum* was more pronounced at 30 and 40 kg N/ha of fertilizer N than at a higher level. Although the mean yields of both grain and straw were increased by inoculation with *Azospirilum*, the interaction between N fertilizers and inoculation was not statistically significant.

Azospirillum inoculation significantly increased the filling rate of grains and grain yield per plant in rice (Watanabe and Lin, 1984).

Field experiments carried out in Tamil Nadu with rice (ADT 36) revealed that inoculation with *Azospirillum brasilense* increased grain yield upto 22 per cent and straw yield by 8 to 41 per cent (Gopalaswamy and Vidhyasekaran, 1987). The number of productive tillers, grain yield and straw yield in rice cultivars ADT 36, IR50 and ADT37 were also increased by inoculation of *Azospirillum* (Gopalaswamy and Vidhyasekaran, 1988).

Mahapatra and Sharma (1988) reported that dipping roots of rice seedlings in 2 per cent solution of *Azospirillum* increased the yield of 200 kg/ha over uninoculated treatment.

Azospirillum inoculation was found to be beneficial for upland rice (Purushothaman, 1988). The grain and straw yield of direct sown rice were increased by seed treatment and soil application of *Azospirillum* (Gopalaswamy *et al*., 1989).

Kumar and Balasubramanian (1989) reported that 25 to 50 kg N/ha can be saved by *Azospirillum* inoculation in rice cultivation.

Jayaraman (1990) studied the comparative efficiency of different biofertilizers *viz*., *Azospirillum*, *Azolla* and blue green algae with and without sub-optimal levels of N (0, 15, 75 kg/ha) and recommended level of N revealed that the application of 75 kg N/ha supplemented by *Azospirillum* or *Azolla* or bluegreen algae was found to be more efficient in influencing the grain yield. It showed a significant increase in *kharif* rice and the increased yield was statistically on par in *rabi* rice as compared to the application of recommended level of 100 kg N alone/ha.

Govindan and Bagyaraj (1995) studied the field response of wetland rice to *Azospirillum* inoculation and reported that *Azospirillum* inoculation enhanced shoot and root growth, grain and straw yield. Recommended dose of fertilizer N + inoculation gave maximum grain yield. At 75 per cent N and 50 per cent N level inoculation resulted in significant increase in straw yield. At 25 per cent and 0 N, the effect of inoculation on straw yield was not significantly difference from their respective uninoculated controls.

2.1.5.2 Effect of PSB

Sharma and Singh (1971) reported that inoculation with phosphobacteria and application of bone meal to soil increased the grain yield of rice.

Datta *et al.* (1982) reported that there was increase in grain yield of rice (jaya and IR-8) due to inoculation with phytohormone producing P solubilizing bacteria *Bacillus firmis* inoculated along with rock phosphate and superphosphate.

Gaur and Singh (1982) obtained increased yield of rice by inoculation of seedling roots with *Bacillus polymyxa* along with rock phosphate. The yield with 60 kg rock phosphate with the above culture was as good as super phosphate applied at 60 kg P_2O_5/ha.

Mohod *et al.* (1991) reported that the P-solubilizing cultures (*Pseudomonas striata* and *Bacillus polymyxa*) significantly increased the number of grains/panicle, weight of 1000 grains, grain weight/panicle, grain yield and straw yield of rice variety KJP-184. The cultures were more efficient with rockphosphate than with super phosphate.

2.1.5.3 Combined effect of *Azospirillum* and PSB

Kundu and Gaur (1984) in a green house eperiment observed that by inoculating rice seedlings with mixed cultures of *Azotobacter chrococcum*, *Pseudomonas striata* and *Aspergilus awamori* increased the grain yield with and without chemical fertilizers over the control. The response due to mixed culture inoculation was more than single cultures showing the synergistic effect of two types of organisms. The results indicate that the mixed culture inoculation can be used safely for better yields and is superior over single culture inoculations.

Arangarasan *et al.* (1998) studied the field response to inoculation with diazotrophic bacteria *viz*., *Azospirillum lipoferum*, *Herbaspirillum seropedicae* and phosphorus solubilizing bacteria *Bacillusmegatherium* var. Phosphaticum in rice. In inoculated treatments with the two bacteria cultures, increase in shoot and root length, 1000 grain weight and grain yield were recorded over uninoculated control. Coinoculation resulted in increased grain yield by 9-14 per cent over control.

2.2 Nutrient uptake of paddy

Knowledge of uptake and concentration of nutrients in plant parts at different stages of crop growth will help in arriving at the optimum requirement of the nutrients for the crop plants.

2.2.1 Nutrient uptake as influenced by nutrients N, P, K and Zn

Uphoof and Randriamiharisoa (2002) reported increase in both vegetative and reproductive biomass was apparently attributed to more efficient acquisition of soil nutrients (N, P, K, Mg, Cu, Zn, Ca and Mo) rather than fixation of dinitrogen by rhizobia that grow as endophyte in rice roots. Similarly, Barison (2002) observed 91 per cent increase in N and K uptake and 66 per cent increase in P uptake with SRI compared to conventional method of cultivation.

Among different spacings (20 cm x 20 cm, 25 cm x 25 cm, 30 cm x 30 cm, 35 cm x 35 cm and 40 cm x 40 cm) tested under SRI, 35 cm x 35 cm spacing recorded significantly higher N uptake than others and the remaining spacings were at par in their influence on N uptake. However, there was no such influence on P and K uptake under SRI (Reddy, 2004).

Magdoff and Bouldin (1970) documented substantial increases in root Biological Nitrogen Fixation (BNF) when aerobic and anaerobic soil horizons are mixed together continuously in rice.

Barison (2002) found that plants of the same variety took 90 per cent more N, K and 60 per cent more P under SRI management compared with those conventionally grown, with no change in harvest index.

Uphoff and Randriamiharisoa (2002) observed that mycorrhizal fungi that “infect” roots help maintain a balance in the supply of nutrients to the plant as well as provide valuable protective services. They can increase the accessed soil volume by as much as 100 times compared with non-infected root. Plants with mycorrhizal fungi can grow well with just a fraction of the P required for unassisted plants. However, since fungi cannot survive under hypoxic conditions, continuously irrigated rice has forgone the benefits of their associations for centuries, even millennia. They also observed that under SRI, increase in both vegetative and reproductive biomass was apparently attributable to more efficient acquisition of soil nutrients (N, P, K, Mg Cu, Zn, Ca and Mo) rather than to BNF of rhizobia that grow as endophyte in rice roots.

Barison (2002) reported that N, P and K uptake was more with SRI than with conventional cultivation practices.

Padmaja (1977) reported that nitrogen concentration in both grain and straw increased with increasing concentration of nitrogen in the root medium.

Dubey and Bisen (1989) reported that nitrogen uptake increased significantly with increased levels of nitrogen in grain and straw. Increase in N uptake by grain and straw was observed with increasing level of nitrogen.

Sagar and Reddy (1995) reported that the uptake of phosphorus and potassium in grain and straw of rice was significantly increased with the split application of higher levels of nitrogen.

Rao *et al.* (1988) reported that application of 60 kg P_2O_5 ha^{-1} significantly increased the nitrogen, phosphorus and potassium in grain and straw over 30 kg P_2O_5 ha^{-1}.

Subbaiah (1991) indicated consistent increase in N, P and K uptake with increased levels of P which was attributed due to effective absorption and higher dry matter accumulation brought out by P nutrition.

Mongia *et al.* (1998) conducted a green house experiment to study the effect of phosphatic fertilizers and liming on rice in acid sulphate soils. They concluded that phosphate application resulted in both increased P content and uptake but at each P level, application of lime further increased P content and uptake. P application reduced the Al and Fe content of both grain and straw, but increased the Mn content.

Vijayan and Sreedharan (1972) conducted a field experiment to study the effect of levels and times of application of potash on IR-8. They reported that the content of K in the grain and straw were highest at the maximum level of 80 kg/ha of K applied and the best time of application of K was found to be half at planting and the other half at the active tillering stage.

Velayutham *et al.* (1992) reported that the split application of potassium increased the NPK uptake and the yield of low land rice. The uptake of potassium and grain yield were found to be maximum under the treatments receiving 125 kg K_2O/ha in three equal splits at basal, maximum tillering and panicle primordium initiation stages.

Upadhyay (1994) reported that N, P and K content and uptake in both grain and straw were not appreciably influenced due to various levels of potash. P uptake (52.8 kg/ha) by rice crop increased significantly upto 25 kg K_2O/ha over control.

Panda *et al.* (1999) reported that application of K at 40 kg/ha recorded significantly higher N, P and K uptake over that of no K. The additional increase in N, P and K uptake over control was 1, 0.4 and 2.21 kg respectively.

Pal *et al.* (2000) reported that significant differences were recorded in K uptake by rice grain due to splitting of K levels over basal and these followed the same trend in the case of rice yield.

Reddy and Murthy (1988) reported that the phosphorus uptake by rice increased with increase in levels of N, P and K fertilizer. Differences in P uptake due to varieties and fertilizer levels were significant.

Sharma and Mittra (1989) reported that uptake of N, P and K increased significantly with increasing N levels. Application of P resulted in marginal increase in nutrient uptake.

Rajkhowa and Baroova (1991) reported that the highest grain yield and N, P and K uptake were recorded in treatment with 100 per cent recommended fertilizer than fifty or seventy five per cent.

Bellakki *et al.* (1997) observed that increase in RDF (recommended dose of fertilizer) level from 50 to 125 per cent resulted in an increase of N uptake from 42.00 to 71.51 kg/ha by grain and from 29.49 to 50.77 kg/ha by straw during *kharif* 1992-93. similarly uptake of P and K also increased significantly upto 125 per cent NPK dose over control.

Ilangovan and Palaniappan (1987) reported that application of Zn significantly increased the NPK uptake and Zn uptake in rice. Soil application of Zn-DAP, especially 6 per cent grade, was efficient and economic in meeting the Zn nutrition of rice in a Zn deficient low land rice soil.

Saravanan and Ramanathan (1988) conducted a field experiment with seven levels of $ZnSO_4$ (0, 12.5, 25.0, 37.5, 50.0, 62.5 and 75 kg/ha) to study the effect of zinc application on its availability and yield of rice. They observed that the uptake of Zn by rice increased with the increased level of Zn application. Similar observations were made by Ingle *et al.* (1997).

Kumar and Singh (1979) conducted a field experiment to study the effect of different doses and methods of zinc application on zinc status of rice plants. Maximum zinc content under all the treatments was observed at active tillering stage. With advancement in age, the zinc concentration in plant declined. Zinc application in nursery gave maximum concentration of zinc in the treatment of root dipping in ZnO suspension irrespective of zinc application in transplanted field at all the stages. Under transplanted condition, the similar trends were observed with little variations.

2.2.2 Effect of biofertilizers on nutrient uptake

2.2.2.1 Effect of *Azospirillum*

Prasad and Singh (1984) reported the combined effect of inoculation of *Azospirillum* and incorporation of azolla in rice in pot culture. Incorporation of azolla as a green manure, inoculation of seedlings with *Azospirillum* and or application of N increased growth, nutrient uptake and yield of rice.

Govindan and Bagyaraj (1995) conducted an experiment to study the response of rice to *Azospirillum* inoculation at graded levels of nitrogen fertilizers and found that Azospirilum enhanced grain yield, straw yield and N uptake of field grown wetland rice.

2.2.2.2 Effect of PSB

Sharma and Singh (1971) reported that the incorporation of phosphobacterium culture along with superphosphate + ammonium sulphate increased the uptake of N and P_2O_5 in grain as compared to the application of superphosphate + ammonium sulphate.

Datta *et al.* (1982) reported that phosphobacteria in combination with rock phosphate and super phosphate increased the uptake of phosphorus by rice.

Mohod *et al.* (1989) reported that P solubilizing culture alone or in combination with phosphatic fertilizers increased the P uptake in rice plant. The beneficial effects of culture was greater with rock phosphate than single superphosphate.

Mohod *et al.* (1991) reported that the phosphorus solubilizing culture significantly increased the N uptake in rice cv. KJT-184. The beneficial effects of culture was greater with rockphosphate than single super phosphate.

2.2.2.3 Combined effect of *Azospirillum* and PSB

Kundu and Gaur (1984) in a green house experiment observed that inoculating rice seedlings with mixed cultures of *Azotobacter chrococcum*, *Pseudomonas striata* and *Azpergillus awamori* increased the N and P uptake in rice.

2.3 Dynamics of nitrogen in rice

2.3.1 Exchangeable soil NH_4-N and NO_3-N and rice growth

Exchangeable NH_4-N is an important source of N that is easily available to wetland rice. In paddy soils, it occurs in two forms namely adsorbed on to cation exchange sites in soil and in soil solution. Approximately 2 to 20 per cent of exchangeable NH_4-N in soil is present in soil solution (Okajima and Imai, 1973 and Shoji *et al.*, 1974).

Keerthisinge *et al.* (1985) reported that NH_4-N decreased continually with crop growth and the decrease is reflected in increased N uptake by rice crop and conducted that exchangeable and in some cases non-exchangeable NH_4-N are important sources of easily available N to wetland rice.

Many researchers have reported the existence of a relationship between the amount of exchangeable NH_4-N in soil and rice growth (Shoji *et al.*, 1974, 1986 and Wada *et al.*, 1989). Mengel *et al.* (1986) reported that initial exchangeable soil NH_4^+ behaved like fertilizer N and found a linear relation between N uptake by the crop and initial NH_4-N + fertilizer N. Similarly, Chakraborthy and Mandal (1992) reported that the different fractions of N such as NH_4, NO_3 and NHLN contents in soil at 15, 30 and 45 days after transplanting had significant correlation with grain yield. Toriyama (1994) reported that higher amounts of NH_4-N in soil solution led to a higher tiller number and a larger amount of N in rice. Similar observations were reported by Sasaki *et al.* (2002).

Das *et al.* (1998) reported that the NO_3-N content of the soil recorded a lower value compared with NH_4-N content which may be due to prevailing anaerobic condition of rice soil. The soil NO_3-N also declined with the duration of submergence because of its loss through microbially controlled denitrification.

The soil exchangeable NH_4-N content was higher during summer and Kuruvai seasons than that of the Thaladi season due to the higher temperature prevailed during summer and Kuruvai seasons which might have favoured higher mineralization of soil organic N (Velu and Ramanathan, 1999).

Das and Saha (2004) revealed that single inoculation of Azotobacter and Azospirillum highly stimulated the exchangeable NH_4-N while their combined inoculation remarkably augmented the accumulation of soluble NO_3^- -N in the rhizosphere soils of rice.

Among the three N forms, NH_4-N content in the leachate was proportionately higher than the other form, because in wetland soil, very little amount of NH_4-N is oxidized to NO_3-N due to the reduced conditions and the mineralization of the fertilizer N proceeds upto the formation of NH_4-N only (Suresh *et al.*, 1994).

III. MATERIAL AND METHODS

The particulars relating to the geographical set up of the study area, collection and preparation of the soil samples and the analytical methods adopted in the investigation are briefly presented in this chapter.

3.1 Experimental site

The experiment was conducted at Agricultural Research Station, Gangavati of University of Agricultural Sciences, Dharwad during late *rabi* 2005-06. The station is situated in the Northern Dry Zone of Karnataka between 15^0 –15' – 40" North latitude and 76^0 – 31' – 40" East longitude at an altitude of 419 m above the mean sea level. The station comes under Tungabhadra command area representing the irrigated transplanted rice belt.

3.2 Climatic conditions

The weather data of the station during the crop growth period is presented in Table 1. The mean maximum temperature varied from 29.6 to 42.1^0C and the mean minimum temperature varied from 16.6 to 27.3^0C. No rains were received during the crop growth period.

3.3 Soil characters of the experimental site

The soil of the experimental site was medium deep black clay. Before start of experiment, composite soil samples from the surface 0 to 20 cm depth were collected and analysed for physical and chemical characteristics. The soil analysis data is presented in Table 2.

3.4 Experimental details

Crop	: Rice
Variety	: KRH-2
Spacing	: SRI method - 25 × 25 cm
	Traditional method – 20 × 10 cm
RDF	: 150:75:75:25 kg N, P_2O_5, K_2O and $ZnSO_4$ per ha
Design	: Split plot
Replications	: 3
Plot size	: 5 × 4 m
Date of nursery establishment	: 31-12-2005
Harvesting	: 09-05-2006

3.5 Cultural practices

Cultural practices for rice were followed as per the package of practices. Seedlings were raised in the nursery bed. In SRI method of cultivation 10 day old seedlings were transplanted in the main field with one seedling per hill and one month old seedlings were transplanted in traditional method of cultivation. Seedlings of respective treatments were inoculated with biofertilizers slurry. After inoculation, seedlings were transplanted. A fertilizer dose of N:P:K:Zn = 150:75:75:25 kg per ha was given as per the package of practice recommendation. Fertilizers were given in the form of urea, DAP, MOP and $ZnSO_4$ as per the recommendation in the respective treatments.

Plate 1: General view of the experimental site

Table 1: Weather data of Agricultural Research Station, Gangavati

Months	Temperature (^0C)		Relative humidity (%)	
	Maximum	Minimum	Maximum	Minimum
November	29.60	17.06	74.56	56.20
December	31.29	16.88	79.20	51.35
January	31.48	17.11	78.67	45.45
February	33.17	16.60	72.03	39.03
March	35.80	20.60	76.40	42.48
April	41.20	25.30	78.50	43.70

Table 2: Physical and chemical characteristics of experimental site

Sl. No.	Characteristics	Value
I.	Particle size analysis	
1.	Sand (%)	27.5
2.	Silt (%)	26.5
3.	Clay (%)	46.0
4.	Textural class	Clay
II.	Chemical properties	
1.	pH (1:2.5)	8.39
2.	EC (dS/m)	0.18
3.	OC (%)	0.69
4.	N (kg/ha)	168
5.	P_2O_5 (kg/ha)	13.84
6.	K_2O (kg/ha)	174

Legend

I. Main plot : Methods of cultivation

M1 - SRI

M2 - Traditional

II. Sub-plot : Fertilizer levels

S_1 -100% RDF

S_2 -75% RDF

S_3 -75% RDF + Biofertilizer

S_4 -50% RDF

S_5 -50% RDF + Biofertilizer

RDF – 150: 75: 75: 25kgN, P_2O_5, K_2O and $ZnSO_4$ per ha

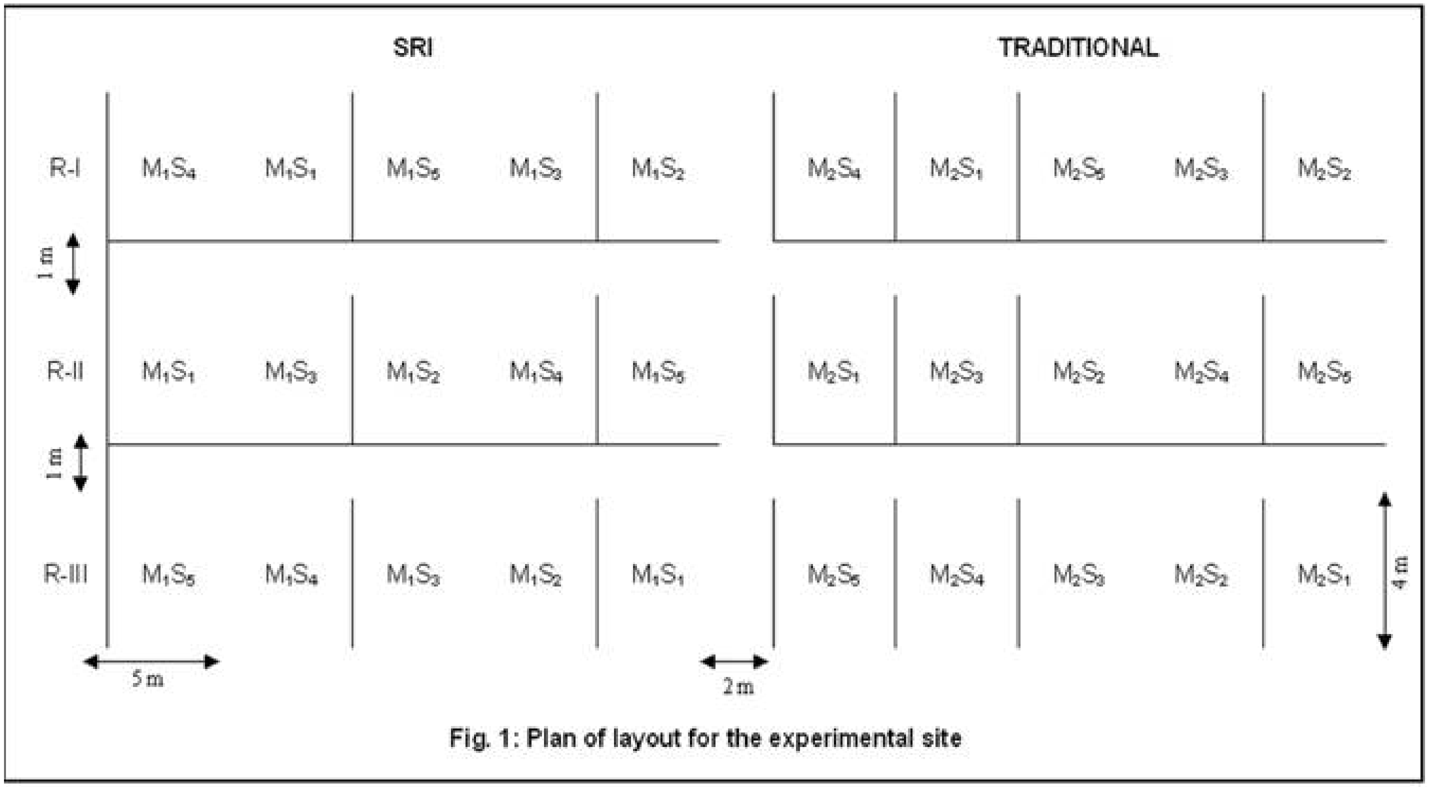

Fig. 1: Plan of layout for the experimental site

Plant protection measures were also taken as per the recommendation. The crop was harvested on attaining physiological maturity. First the ring line plants were harvested and bulked, then plants in the net plot area were harvested treatment-wise and kept separately for drying. Hand threshing and winnowing was done to separate the grains. After thorough sun drying weight was recorded treatment-wise for grain and straw, respectively.

3.6 Collection of experimental data

3.6.1 Soil sampling

Soil samples from treatment plots at specified stages were drawn using a tube auger, dried in shade, powdered and sieved to pass through 2 mm sieve. The fine earth samples were stored in separate containers and used for various analyses.

Soil samples were drawn at four stages (30th, 60th, 90th day after transplanting and at harvest). At each stage sampling was done before fertilizer application.

For the analysis of NH_4-N and NO_3^-N, wet samples were collected from three different depths i.e., 0-20, 20-40 and 40-60 cm at 30, 60 and 90 days of transplanting and at harvest.

3.7 Growth parameters

Five hills per plot were selected randomly in the net plot and tagged for recording observations at four stages (30th, 60th, 90th day after transplanting and at harvest).

3.7.1 Plant height

The plant height of five hills were measured from the ground level to tip of the top most leaf at early stages (30, 60 and 90 DAT), upto the tip of main panicle at maturity and the average height was expressed in centimeters.

3.7.2 Number of tillers per hill

The number of tillers from five hills was counted and the average was worked out.

3.7.3 Number of tillers per m^2

The number of tillers per m^2 was worked out with the help of quadrat.

3.7.4 Dry matter production

The plant samples were partitioned into leaf, stem, panicle and root depending upon the growth stage of the plants and were dried in oven at 65 – 70^{0}C to constant weight and the dry weight was recorded. The average of five hills were taken as the dry matter production per hill and is expressed in quintals per ha.

3.8 Yield and yield parameters

The panicles from the randomly selected and tagged five hills for taking biometric observations at harvest were used and the following observations on yield components and yield were recorded.

3.8.1 Panicle length

Panicle length from five tillers selected from randomly labelled plants in each plot was recorded from base to the tip of the panicle. The mean value was calculated and expressed in centimeters.

3.8.2 Number of grains per panicle

Ten panicles were selected randomly from five labelled hills and then grains were separated and counted. The mean value was worked out and recorded as number of grains per panicle.

3.8.3 Test weight (1000-grain weight)

One thousand grains were counted from randomly selected five hills per each treatment and their weight was recorded and expressed in grams.

3.8.4 Grain yield

The grains were separated by threshing separately from each net plot and were dried under sun for three days. Later winnowed and cleaned and then weight of the grains per net plot was recorded. From the net plot values, the grain yield per ha was computed and expressed in quintals per hectare.

3.8.5 Straw yield

Straw from each net plot was dried under sun for 10 days, weight was recorded on complete drying and expressed in quintals per hectare.

3.8.6 Harvest index

The harvest index was worked out from grain and straw yields using the formula given by Donald (1962).

$$\text{Harvest index} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

3.9 Chemical analysis of soil samples

3.9.1 NH_4-N and NO_3^-N content

The wet soil samples were collected at different stages of crop from different depths and were separately analysed for NH_4-N content by distillation with NaOH and NO_3^-N by devardas alloy reduction method as suggested by AOAC (1978).

3.9.2 Available nitrogen

Available nitrogen was estimated by alkaline $KMnO_4$ method where the organic matter in soil is oxidized with hot alkaline $KMnO_4$ solution. The ammonia evolved during oxidation is distilled and trapped in boric acid mixed indicator solution. The amount of NH_3 trapped is estimated by titrating with standard acid (Subbaiah and Asija, 1956).

3.9.3 Available phosphorus

Available phosphorus was extracted with sodium bicarbonate (0.5 M) at pH 8.5 (Olsen's reagent) and the amount of P in the extract was estimated by chlorostannous reduced phosphomolybdate blue colour method using sepctrophotometer at wave length of 660 nm (Jackson, 1973).

3.9.4 Available potassium

Available K was extracted with neutral normal ammonium acetate and determined using flame photometer (Jackson, 1973).

3.10 Chemical analysis of plant samples

The plant samples collected at different growth stages (30, 60, 90 DAT and at harvest) were dried in hot air oven at 65^0C. Further, the samples were milled to considerable fineness in a willey mill and stored in butter cover for further analysis.

3.10.1 Digestion of the plant samples

Half a gram of 100 mm mesh passed powdered plant sample was predigested with concentrated HNO_3 overnight. Further, predigested samples were treated with diacid (HNO_3 :

$HClO_4$ in 10:4 ratio) mixture and kept in sand bath for digestion. After complete digestion, in 6N HCl it was transferred to the 100 ml volumetric flask through Whatman No. 42 filter paper by thoroughly washing with double distilled water.The volume was made to 100ml and preserved for following analysis.

3.10.1.1 Phosphorus

Phosphorus in plant sample was determined by Vanadomolybdo-phosphoric yellow colour method (Jackson, 1973).

3.10.1.2 Potassium

The potassium content in the digested sample was determined by flamephotometer after making appropriate dilution (Jackson, 1973).

3.10.1.3 Nitrogen

Half a gram of powdered plant sample was digested with concentrated H_2SO_4 and digestion mixture ($CuSO_4$ + Se powder + K_2SO_4). The digest was transferred to microkjeldhal distillation flask and the liberated ammonia in the presence of alkali was collected in 2 per cent boric acid mixed indicator solution and then titrated against standard acid (Jackson, 1973).

3.10.2 Nutrient uptake (kg/ha)

The nutrient uptake by rice at 30, 60, 90 DAT and at harvest was worked out using the following equation.

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Nutrient content} \times \text{Dry matter production (q/ha)}}{100}$$

3.11 Statistical Analysis

The experimental data obtained was subjected to statistical analysis adopting Fischer's method of analysis of variance as outlined by Gomez and Gomez (1984).The critical difference (CD) values are given wherever the 'F' test was found significant.

IV. EXPERIMENTAL RESULTS

A field experiment was conducted at Agricultural Research Station, Gangavati, University of Agricultural Sciences, Dharwad during late *rabi* 2005-06 to investigate the nutrient management in paddy under SRI and traditional method of cultivation. The results of the experiment are presented in this chapter under the following heads.

4.1 Effect of fertilizer levels on growth and yield of rice under SRI and traditional methods of cultivation

4.2 Nutrient content of rice at different growth stages under SRI and traditional methods of cultivation as influenced by nutrient levels

4.3 Nutrient uptake of rice at different growth stages under SRI and traditional methods of cultivation as influenced by nutrient levels

4.4 Available soil N, P and K at different growth stages under SRI and traditional methods of cultivation as influenced by nutrient levels

4.5 Dynamics of N under SRI and traditional methods of cultivation as influenced by nutrient levels in rice at different depths during different stages of crop growth

4.1 Effect of fertilizer levels on growth and yield of rice under sri and traditional methods of cultivation

4.1.1 Growth parameters of rice

4.1.1.1 Plant height (cm)

The data pertaining to plant height at 30, 60, 90 DAT and at harvest is presented in Table 3.

The rice crop had grown taller with the advancement in age and the increase being more rapid upto flowering stage (90 DAT). Plant height was recorded significantly more in SRI method of cultivation (56.3, 74.0, 89.1, 92.4 cm at 30, 60, 90 DAT and at harvest, respectively) over traditional method of cultivation (39.2, 54.8, 73.6, 79.7 cm at 30, 60, 90 DAT and at harvest, respectively).

Treatment T_3 (75% RDF + biofertilizers) recorded the highest plant height (63.1, 78.1, 96.2 and 99.3 cm at 30, 60, 90 DAT and at harvest, respectively) at all the growth stages. It was significantly superior over all other treatments.

Treatment T_1 (RDF) recorded the second highest plant height and it was followed by T_2, T_5 and T_4. The treatment T_4 (50% RDF) accounted for the lowest plant height (32.9, 50.9, 68.2 and 70.0 cm at 30, 60, 90 DAT and at harvest, respectively) at all the growth stages. The treatment T_3 was on par with T_1 and T_5 was on par with T_4 at 90 DAT.

Interactions were found to be non-significant at 30, 60 and 90 DAT while it was significant at harvest. Treatment T_3 (75% RDF + biofertilizers) under SRI method of cultivation recorded the highest plant height (107.9) at harvest while the treatment T_4 (50% RDF) under traditional method of cultivation accounted for the lowest plant height.

4.1.1.2 Number of tillers per hill

Data pertaining to the number of tillers per hill is given in Table 4. The number of tillers per hill showed progressive increase upto 90 DAT and thereafter it showed slight decrease with increase being more rapid upto 60 DAT.

Comparatively higher number of tillers was noticed in SRI method of cultivation compared to traditional method of cultivation at all the growth stages. SRI method of cultivation recorded 27.8, 61.6, 63.2, 61.5 tillers at 30, 60, 90 DAT and at harvest, respectively while traditional method registered 16.9, 20.0, 21.8, 20.1 tillers at 30, 60, 90 DAT and at harvest, respectively.

Table 3: Effect of SRI and Traditional (TRA) methods of cultivation and fertilizer levels on plant height (cm)

Treatments	30 DAT			60 DAT			90 DAT			At harvest		
	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean
T_1-RDF	65.7	49.6	57.6	81.1	63.0	72.0	97.5	85.1	91.3	101.2	88.7	94.9
T_2-75% RDF	56.5	36.7	46.6	73.0	54.3	63.7	87.8	75.2	81.5	90.4	84.6	87.5
T_3-75% RDF + BF	71.8	54.4	63.1	88.8	67.4	78.1	103.1	89.2	96.2	107.9	90.8	99.3
T_4-50% RDF	38.7	27.0	32.9	60.4	41.4	50.9	75.8	60.6	68.2	76.6	63.5	70.0
T_5-50% RDF + BF	48.9	28.2	38.5	66.6	47.8	57.2	81.5	57.9	69.7	85.9	70.8	78.4
Mean	56.3	39.2	47.7	74.0	54.8	64.4	89.1	73.6	81.4	92.4	79.7	86.0

For comparing means of	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%
Method of cultivation (M)	0.666	4.052	0.072	0.439	1.618	9.842	1.113	6.774
Treatment (T)	1.856	5.561	1.480	4.434	2.916	8.739	1.016	3.043
M × T	2.624	NS	2.093	NS	4.124	NS	1.436	4.304

Table 4: Effect of SRI and Traditional (TRA) methods of cultivation and fertilizer levels on number of tillers

Treatments	30 DAT			60 DAT			90 DAT			At harvest		
	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean
T_1-RDF	34.3	20.0	27.1	70.0	23.0	46.5	71.6	25.3	48.5	69.6	22.3	46.0
T_2-75% RDF	26.3	15.0	20.6	59.6	18.0	38.8	62.0	19.6	40.8	60.0	18.0	39.0
T_3-75% RDF + BF	40.3	26.0	33.1	75.0	29.0	52.0	78.0	31.0	54.5	75.3	29.3	52.3
T_4-50% RDF	17.3	10.0	13.6	48.0	13.3	30.6	50.0	15.3	32.6	47.6	14.0	30.8
T_5-50% RDF + BF	21.0	13.6	17.3	55.3	16.6	36.0	54.6	17.6	36.1	55.0	17.0	36.0
Mean	27.8	16.9	22.4	61.6	20.0	40.8	63.2	21.8	42.5	61.5	20.1	40.8

For comparing means of	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%
Method of cultivation (M)	0.386	2.348	0.216	1.315	0.579	3.525	0.081	0.491
Treatment (T)	1.119	3.354	0.963	2.886	1.269	3.804	1.145	3.431
M × T	1.583	NS	1.362	4.082	1.795	5.379	1.619	4.853

The treatment T_3 (75% RDF + biofertilizers) recorded the maximum number of tillers per hill (33.1, 52.0, 54.5, 52.3 at 30, 60, 90 DAT and at harvest, respectively) at all the growth stages, it was significantly superior over other treatments followed by T_1, T_2, T_5 and T_4. Treatment T_5 was on par with T_2 at all the growth stages. At all the growth stages, treatment T_4 (50% RDF) registered the lowest number of tillers (13.6, 30.6, 32.6, 30.8 at 30, 60, 90 DAT and at harvest, respectively).

Interaction effects were found to be significant at 60, 90 DAT and at harvest. Among the interactions the treatment T_3 receiving 75% RDF + biofertilizers under SRI method of cultivation registered significantly higher number of tillers per hill, while the treatment T_4 receiving 50% RDF under traditional method of cultivation recorded lowest number of tillers per hill.

4.1.1.3 Dry matter production (q/ha)

The data on dry matter production is presented in Table 5. The dry matter production of the crop increased with age. At 30 DAT, significantly higher dry matter of the crop was recorded in SRI method (49.2 q/ha) over the traditional method (23.1 q/ha). Treatment T_3 (75% RDF + biofertilizers) recorded the highest value of dry matter (48.9 q/ha) and it was significantly superior over all other treatments and was followed by T_1, T_2, T_5 and T_4. Treatment T_4 (50% RDF) recorded the lowest value of 23.4 q per ha. The trend remained same at 60, 90 DAT and at harvest.

At 60 DAT, SRI method recorded significantly higher dry weight (106.8 q/ha) over traditional method of cultivation (46.0 q/ha). Among the treatments, T_3 (75% RDF + biofertilizers) recorded the highest dry weight (90.4 q/ha) and it was on par with T_1 (85.9 q/ha). Treatments T_4 and T_5 were on par with each other. Treatment T_4 recorded the lowest dry weight (63.4 q/ha).

At 90 DAT, dry matter production was higher under SRI method (128.2 q/ha) compared to traditional method of cultivation (52.1 q/ha). Treatment T_3 (75% RDF + biofertilizers) recorded the highest dry weight (118.1 q/ha) and it was on par with T_1 (109.9 q/ha) followed by T_2, T_5, T_4. Treatment T_4 (50% RDF) recorded the lowest dry weight (65.0 q/ha).

At harvest, there was no significant difference among the methods of cultivation in grain dry matter production. Significantly higher straw yield was recorded in SRI method (98.6 q/ha) over traditional method of cultivation (63.3 q/ha). Treatment T_3 (75% RDF + biofertilizers) recorded the highest grain dry matter (66.7 q/ha), which was on par with T_1 followed by T_2, T_5 and T_4. Treatments T_4 and T_5 were on par with each other. Treatment T_4 (50% RDF) recorded the lowest grain dry matter (32.7 q/ha). The highest straw dry matter (111.9 q/ha) was recorded in treatment T_3 (75% RDF + biofertilizers) which was on par with T_1. Treatments T_2 and T_5 were on par with each other. Treatment T_4 (50% RDF) recorded the lowest straw dry matter (57.5 q/ha) and T_5 and T_4 were at par.

Interaction effects were found to be significant at 30 DAT. At 30 DAT, treatment T_3 (75% RDF + biofertilizers) under SRI method was significantly superior over all other treatments while treatment T_4 (50% RDF) under traditional method recorded the lowest value.

4.1.2 Yield and yield components of rice

4.1.2.1 Number of productive tillers

The data on number of productive tillers per hill and number of productive tillers per m^2 is furnished in Table 6.

Comparatively higher number of productive tillers per hill was noticed in SRI method of cultivation (47.5) as compared to traditional method of cultivation (13.8). The treatment T_1 (RDF) recorded the highest number of productive tillers per hill (40.3), which was on par with treatment T_3 (39.8). The treatment T_4 (50% RDF) recorded the lowest number (20.6).

Among different interactions, the treatment T_1 (RDF) under SRI method recorded the highest number of productive tillers per hill (64.6), while the treatment T_4 (50% RDF) under traditional method recorded the lowest number of productive tillers per hill (9.0).

Table 5: Effect of SRI and Traditional (TRA) methods of cultivation and fertilizer levels on dry matter production (q/ha)

Treatments	30 DAT			60 DAT			90 DAT			At harvest					
										Grain			Straw		
	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean
T_1-RDF	58.9	31.7	45.3	115.5	56.4	85.9	146.6	73.2	109.9	76.7	43.6	60.1	124.2	74.6	99.4
T_2-75% RDF	48.1	22.0	35.1	106.5	44.1	75.3	127.3	50.4	88.8	54.7	29.8	42.2	85.4	57.4	71.4
T_3-75% RDF + BF	64.1	33.8	48.9	120.4	60.4	90.4	155.1	81.1	118.1	83.8	49.6	66.7	133.1	90.6	111.9
T_4-50% RDF	34.8	12.1	23.4	93.0	33.8	63.4	97.6	22.6	65.0	43.2	22.3	32.7	72.3	42.6	57.5
T_5-50% RDF + BF	40.2	16.2	28.2	98.7	35.3	67.0	114.6	33.6	74.1	48.3	25.7	37.0	77.8	51.4	64.6
Mean	49.2	23.1	36.2	106.8	46.0	76.4	128.2	52.1	91.2	61.3	34.2	48.8	98.6	63.3	80.9

For comparing means of	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%
Method of cultivation (M)	0.484	2.943	2.406	14.638	0.976	5.940	5.556	NS	1.721	10.471
Treatment (T)	0.839	2.514	2.645	7.928	3.931	11.779	2.243	6.721	3.406	14.432
M × T	1.186	3.555	3.741	NS	5.559	NS	3.172	NS	4.816	NS

Table 6: Effect of SRI and Traditional (TRA) methods of cultivation and fertilizer levels on productive tillers per hill and productive tillers per m^2

Treatments	Productive tillers per hill			Productive tillers per m^2		
	SRI	TRA	Mean	SRI	TRA	Mean
T_1-RDF	64.6	16.0	40.3	1004.6	658.0	831.3
T_2-75% RDF	44.6	12.3	28.5	793.3	749.6	771.5
T_3-75% RDF + BF	60.6	19.0	39.8	1056.3	703.3	879.8
T_4-50% RDF	32.3	9.0	20.6	674.0	465.3	569.3
T_5-50% RDF + BF	35.3	13.0	24.1	735.3	515.0	625.1
Mean	47.5	13.8	30.7	852.7	618.2	735.5

For comparing means of	SEm±	CD at 5%	SEm±	CD at 5%
Method of cultivation (M)	0.170	1.032	8.746	53.217
Treatment (T)	1.622	4.860	24.154	72.382
M × T	2.294	6.874	34.159	102.364

Significantly higher number of productive tillers per m^2 was noticed in SRI method of cultivation (852.7) over traditional method of cultivation (618.2).

Among the treatments, T_3 (75% RDF + biofertilizers) recorded the highest number of productive tillers per m^2 (879.8), which was on par with treatment T_1 (RDF) followed by T_2 and T_5. Treatment T_4 (50% RDF) recorded the lowest number of productive tillers per m^2 (569.3).

Among the interactions, treatment T_3 (75% RDF + biofertilizers) under SRI method of cultivation recorded the highest number of productive tillers per m^2 (1056.3), while T_4 (50% RDF) under traditional method registered the lowest number (465.3).

4.1.2.2 Mean panicle length (cm), grains per panicle and test weight (g)

Data pertaining to mean panicle length, grains per panicle and test weight is presented in Table 7.

Not much variation in methods of cultivation and among the treatments was noticed with respect to panicle length. The highest panicle length was recorded in T_3 (29.5 cm), which was on par with T_1 and T_5. Treatment T_4 (50% RDF) recorded the lowest panicle length (23.9 cm). Interaction effects were found to be non-significant.

Significantly higher number of grains per panicle was recorded in SRI method (247.0) over traditional method of cultivation (123.6). Among the treatments, the number of grains per panicle varied from 208.0 (T_3) to 167.0 (T_4). Treatment T_3 (75% RDF + biofertilizers) was significantly superior over other treatments followed by T_1, T_2, T_5 and T_4. Interaction effects were found to be non-significant.

The 1000-grain weight was recorded higher in SRI method of cultivation (31.5 g) as compared to traditional method of cultivation (22.8 g). The 1000-grain weight varied from 33.4 (T_3) to 20.5 g (T_4). Treatments T_1 and T_3 were on par with each other, while T_2 and T_5 were on par with each other. Interaction effects were found to be non-significant.

4.1.3 Grain yield, straw yield and harvest index (q/ha)

Results of the yield and harvest index are given in Table 8. Significantly higher grain yield was recorded in SRI method of cultivation (80.1 q/ha) over traditional method of cultivation (45.4 q/ha). The highest grain yield was recorded in treatment T_3 (86.9 q/ha) followed by T_1, T_2, T_5 and T_4. Treatment T_4 recorded the lowest grain yield (41.1 q/ha) as compared to other treatments. Among the interactions, T_3 (75% RDF + biofertilizers) under SRI method registered the highest grain yield (109.4 q/ha) whereas T_4 (50% RDF) under traditional method recorded the lowest grain yield (29.9 q/ha).

SRI method of cultivation recorded comparatively higher straw yield (96.6 q/ha) over traditional method of cultivation (53.7 q/ha).

Among the treatments, T_3 (75% RDF + biofertilizers) recorded the highest straw yield (103.5 q/ha) followed by T_1, T_2, T_5 and T_4. Treatment T_4 (50% RDF) recorded the lowest straw yield of 49.5 q per ha. Interaction of T_3 (75% RDF + biofertilizers) under SRI method (128.5 q/ha) was found to be significantly superior over all other treatments and treatment T_4 (50% RDF) under traditional method (33.4 q/ha) recorded the lowest straw yield.

Harvest index of rice in the experiment ranged from 0.490 to 0.433. There was no significant variation in harvest index of rice due to methods of cultivation and fertilizer levels.

4.2 Nutrient content of rice at different growth stages under sri and traditional methods of cultivation as influenced by traditional methods of cultivation as influenced by nutrient levels

4.2.1 Nitrogen content (%)

Data on nitrogen content is presented in Table 9. The nitrogen content of plant was higher in SRI method compared to traditional method at all the growth stages. The nitrogen content of rice was highest at 30 DAT in all the treatments and after that it showed a gradual decrease upto 90 DAT. At harvest nitrogen content in grain was higher than that in straw.

Table 7: Effect of SRI and Traditional (TRA) methods of cultivation and fertilizer levels on panicle length (cm), grains per panicle and test weight (g)

Treatments	Panicle length (cm)			Grains per panicle			Test weight (g)		
	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean
T_1-RDF	29.7	28.0	28.9	259.6	138.3	199.0	38.6	26.5	32.5
T_2-75% RDF	28.5	26.3	27.4	240.6	119.0	179.8	29.6	22.3	26.0
T_3-75% RDF + BF	30.6	28.4	29.5	270.3	145.6	208.0	40.2	26.6	33.4
T_4-50% RDF	24.5	23.2	23.9	228.6	105.3	167.0	22.7	18.3	20.5
T_5-50% RDF + BF	26.4	25.6	26.0	235.6	109.6	172.6	26.6	20.4	23.5
Mean	27.9	26.3	27.1	247.0	123.6	185.3	31.5	22.8	27.2

For comparing means of	Panicle length SEm±	Panicle length CD at 5%	Grains per panicle SEm±	Grains per panicle CD at 5%	Test weight SEm±	Test weight CD at 5%
Method of cultivation (M)	0.214	1.300	6.247	38.007	0.269	1.636
Treatment (T)	0.808	2.422	2.417	7.242	1.475	4.419
M × T	1.143	NS	3.418	NS	2.085	NS

Table 8: Effect of SRI and Traditional (TRA) methods of cultivation and fertilizer levels on grain yield (q/ha), straw yield (q/ha) and harvest index

Treatments	Grain yield (q/ha)			Straw yield (q/ha)			Harvest index		
	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean
T_1-RDF	96.5	52.5	74.5	118.3	64.4	91.3	0.447	0.453	0.450
T_2-75% RDF	76.6	43.6	60.1	90.3	47.0	68.6	0.453	0.490	0.472
T_3-75% RDF + BF	109.4	64.5	86.9	128.5	78.5	103.5	0.460	0.453	0.457
T_4-50% RDF	52.2	29.9	41.1	65.5	33.4	49.5	0.443	0.453	0.448
T_5-50% RDF + BF	65.7	36.8	51.2	80.3	45.1	62.7	0.460	0.433	0.447
Mean	80.1	45.4	62.8	96.6	53.7	75.1	0.453	0.457	0.455

For comparing means of	SEm$\pm$	CD at 5%	SEm$\pm$	CD at 5%	SEm$\pm$	CD at 5%
Method of cultivation (M)	0.103	0.629	1.024	6.230	0.003	NS
Treatment (T)	1.310	3.926	1.539	4.613	0.007	NS
$M \times T$	1.853	5.552	2.177	6.524	0.010	NS

Table 9: Effect of SRI and Traditional (TRA) methods of cultivation and fertilizer levels on nitrogen content (%) in rice

Treatments	30 DAT			60 DAT			90 DAT			At harvest					
										Grain			Straw		
	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean
T_1-RDF	2.39	2.35	2.37	1.38	1.35	1.36	1.15	1.11	1.13	1.28	1.27	1.27	0.74	0.70	0.72
T_2-75% RDF	2.37	2.32	2.34	1.34	1.31	1.32	1.10	1.06	1.08	1.26	1.23	1.24	0.69	0.66	0.67
T_3-75% RDF + BF	2.46	2.40	2.43	1.47	1.45	1.46	1.19	1.15	1.17	1.35	1.33	1.34	0.78	0.72	0.75
T_4-50% RDF	1.71	1.69	1.70	1.11	1.08	1.09	0.81	0.79	0.80	1.09	1.06	1.07	0.59	0.57	0.58
T_5-50% RDF + BF	2.18	2.10	2.14	1.23	1.21	1.22	0.99	0.97	0.98	1.29	1.20	1.24	0.68	0.62	0.65
Mean	2.22	2.17	2.20	1.30	1.28	1.29	1.05	1.01	1.03	1.25	1.21	1.23	0.69	0.65	0.67

For comparing means of	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%
Method of cultivation (M)	0.001	0.006	0.002	0.012	0.004	0.023	0.002	0.011	0.005	0.028
Treatment (T)	0.007	0.022	0.004	0.013	0.005	0.015	0.004	0.013	0.004	0.011
M × T	0.010	NS	0.006	NS	0.007	NS	0.006	0.018	0.005	0.016

At 30 DAT, the plant N content varied from 2.43 per cent in T_3 to 1.70 per cent in T_4. Treatment T_3 (75% RDF + biofertilizer) recorded the highest value followed by T_1, T_2, T_5 and T_4. Treatment T_4 (50% RDF) recorded the lowest value. The same trend was noticed at 60, 90 DAT and at harvest stage. At 60 DAT, N content in plant ranged from 1.46 to 1.09 per cent and at 90 DAT, it ranged from 1.17 to 0.80 per cent. At harvest, N content in grain varied from 1.34 to 1.07 per cent and in straw varied from 0.75 to 0.58 per cent. The interactions were found to be significant at harvest.

The treatment T_3 (75% RDF + biofertilizer) under SRI method recorded the highest value while T_4 (50% RDF) under traditional method recorded the lowest value in both grain and straw.

4.2.2 Phosphorus content (%)

Data on phosphorus content is given in Table 10. The cultivation method did not affect P content in rice at 60 DAT and at harvest. At 30 and 90 DAT, plant P content was higher in SRI method (0.42% and 0.29%) compared to traditional method of cultivation (0.39%, 0.26%).

At 30 DAT, the plant P content recorded the maximum value and thereafter it showed a gradual decrease upto 90 DAT in all the treatments. At harvest stage, the P content in grain was higher than P content in straw.

At 30 DAT, the P content varied among the treatments ranging from highest value of 0.46 per cent (T_3) to lowest value of 0.36 per cent (T_5). T_3 (75% RDF + biofertilizers) was followed by T_1, T_2, T_4, T_5. Interaction effects were found to be non-significant.

At 60 DAT, the P content ranged from 0.39 (T_3) to 0.26 per cent (T_5). Treatments T_1 and T_2 were on par with each other. All the treatments were significantly higher over T_5.

Among the interactions, treatment T_3 (75% RDF + biofertilizers) under SRI method recorded significantly higher P content (0.41%).

At 90 DAT, the P content ranged from 0.34 per cent (T_3) to 0.24 per cent (T_4). Treatments T_1 and T_2 were on par with each other and treatments T_4 and T_5 were on par with each other. Interactions were found to be non-significant.

At harvest, P content in grain ranged from 0.30 per cent (T_3) to 0.24 per cent (T_4). Treatments T_4 and T_5 were on par with each other. Among the interactions, treatment T_3 (75% RDF + biofertilizers) under SRI method recorded highest value of 0.31 per cent. The P content in straw varied from 0.15 per cent (T_3) to 0.12 per cent (T_4). Treatment T_1 and T_2 were on par with each other. Interaction effects were found to be non-significant.

4.2.3 Potassium content (%)

Data pertaining to potassium content is given in Table 11. The cultivation method did not affect K content in rice at 30, 90 DAT. At 60 DAT and at harvest in grain and straw plant K content was higher in SRI method (1.40%, 0.43% and 1.11%) compared to traditional method of cultivation (1.39%, 0.41% and 1.07%).

Potassium content was highest at 30 DAT in all the treatments and after that it showed a gradual decrease upto 90 DAT. K content in straw was higher than that in grain.

At 30 DAT K content varied from 1.75 per cent (T_3) to 1.46 per cent (T_4). Treatment T_3 (75% RDF + biofertilizers) was followed by T_1, T_2, T_5 and T_4. Interaction effects were found to be non-significant.

At 60 DAT, K content varied from 1.60 per cent (T_3) to 1.27 per cent (T_4). Treatment T_3 (75% RDF + biofertilizers) recorded the highest per cent of K followed by T_1, T_2, T_5 and T_4. Among the interactions, treatment T_3 (75% RDF + biofertilizers) under SRI method of cultivation was found to be significantly superior.

The highest per cent of K at 90 DAT was found in T_3 (1.30%) followed by T_1, T_2, T_5 and T_4. Treatment T_4 (50% RDF) recorded the lowest K content (0.95%). Interaction effects were found to be non-significant.

Table 10: Effect of SRI and Traditional (TRA) methods of cultivation and fertilizer levels on phosphorus content (%) in rice

Treatments	30 DAT			60 DAT			90 DAT			At harvest					
										Grain			Straw		
	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean
T_1-RDF	0.45	0.42	0.43	0.35	0.34	0.34	0.30	0.29	0.29	0.29	0.27	0.28	0.15	0.13	0.14
T_2-75% RDF	0.42	0.37	0.40	0.38	0.33	0.35	0.29	0.25	0.27	0.28	0.24	0.26	0.15	0.14	0.14
T_3-75% RDF + BF	0.48	0.45	0.46	0.41	0.38	0.39	0.36	0.32	0.34	0.31	0.30	0.30	0.16	0.15	0.15
T_4-50% RDF	0.39	0.37	0.38	0.31	0.29	0.30	0.25	0.23	0.24	0.24	0.24	0.24	0.12	0.12	0.12
T_5-50% RDF + BF	0.37	0.35	0.36	0.26	0.26	0.26	0.27	0.24	0.25	0.24	0.24	0.24	0.14	0.13	0.13
Mean	0.42	0.39	0.40	0.34	0.32	0.33	0.29	0.26	0.28	0.27	0.25	0.26	0.14	0.13	0.14

For comparing means of	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%
Method of cultivation (M)	0.001	0.006	0.004	NS	0.003	0.020	0.002	NS	0.005	NS
Treatment (T)	0.005	0.014	0.004	0.011	0.004	0.012	0.003	0.008	0.003	0.008
M × T	0.007	NS	0.005	0.015	0.006	NS	0.004	0.011	0.004	NS

Table 11: Effect of SRI and Traditional (TRA) methods of cultivation and fertilizer levels on potassium content (%) in rice

Treatments	30 DAT			60 DAT			90 DAT			At harvest					
										Grain			Straw		
	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean
T_1-RDF	1.72	1.73	1.72	1.48	1.48	1.48	1.27	1.23	1.25	0.47	0.45	0.46	1.16	1.16	1.16
T_2-75% RDF	1.66	1.65	1.65	1.37	1.31	1.34	1.17	1.11	1.14	0.41	0.41	0.41	1.11	1.07	1.09
T_3-75% RDF + BF	1.76	1.74	1.75	1.58	1.62	1.60	1.32	1.29	1.30	0.50	0.47	0.48	1.20	1.17	1.18
T_4-50% RDF	1.47	1.46	1.46	1.27	1.28	1.27	0.97	0.94	0.95	0.36	0.35	0.35	0.96	0.95	0.96
T_5-50% RDF + BF	1.56	1.55	1.56	1.33	1.28	1.30	1.07	1.07	1.07	0.41	0.39	0.40	1.10	1.01	1.06
Mean	1.63	1.63	1.63	1.40	1.39	1.40	1.16	1.13	1.14	0.43	0.41	0.42	1.11	1.07	1.09

For comparing means of	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%
Method of cultivation (M)	0.009	NS	0.001	0.008	0.010	NS	0.002	0.013	0.006	0.034
Treatment (T)	0.010	0.031	0.007	0.020	0.007	0.020	0.004	0.013	0.005	0.016
M × T	0.015	NS	0.010	0.029	0.010	NS	0.006	NS	0.007	0.022

The concentration of K in grain varied from 0.48 (T_3) to 0.35 (T_4) per cent. Treatment T_3 (75% RDF + biofertilizers) was followed by T_1, T_2, T_5 and T_4. Interaction effects were found to be non-significant.

In straw, treatment T_3 (1.18%) recorded the highest K content and it was followed by T_1, T_2, T_5 and T_4. Treatment T_4 (50% RDF) recorded the lowest K content of 0.96 per cent. Among the interactions, the treatment T_3 (1.20%) under SRI method of cultivation was found to be significantly superior over other interactions. The treatment T_4 (50% RDF) under traditional method of cultivation recorded the lowest value of K content in rice straw (0.95%).

4.3 Nutrient uptake of rice at different growth stages under sri and traditional methods of cultivation as influenced by nutrient levels

4.3.1 Nitrogen uptake (kg/ha)

The data on uptake of N by rice at 30, 60, 90 DAT and grain and straw at harvest is presented in Table 12.

The nitrogen uptake increased steadily with the age of the crop.

Significantly higher uptake of nitrogen was noticed in SRI method of cultivation as compared to traditional method of cultivation at all the growth stages.

SRI method recorded the uptake of 112.2, 140.9, 137.5, 78.0, 70.2 kg per ha while traditional method recorded 52.2, 57.9, 55.6, 42.2, 42.4 kg per ha at 30, 60, 90 DAT and at harvest by grain and straw, respectively.

Application of 75 per cent RDF + biofertilizers recorded significantly higher uptake of nitrogen (119.7, 129.9, 138.8, 89.6, 84.8 kg/ha at 30, 60, 90 DAT and at harvest by grain and straw, respectively) at all growth stages. The treatment receiving 50 per cent RDF accounted for the lowest uptake (40.1, 68.4, 48.6, 35.4, 33.4 kg/ha at 30, 60, 90 DAT, grain and straw at harvest, respectively) at all growth stages.

At all the growth stages, treatment T_3 (75% RDF + biofertilizers) was significantly superior over all other treatments. Treatment T_3 (75% RDF + biofertilizers) was followed by T_1, T_2, T_5 and T_4 at 30, 60, 90 DAT and at harvest. The method of cultivation did not affect N uptake by grain at harvest. Treatment T_3 (75% RDF + biofertilizers) recorded the highest N uptake by grain and it was significantly superior over all other treatments. Treatment T_3 was followed by T_1, T_2, T_5 and T_4. But, the treatments T_2 and T_5 were on par with each other. The same trend was observed in the straw N uptake.

In the study, the interaction effects were not significant at 60, 90 DAT and in grain at harvest. Among the interactions, at 30 DAT and in straw at harvest T_3 treatment under SRI method was found to be significantly superior over all other treatments, while the treatment T_4 (50% RDF) under traditional method recorded lowest uptake.

4.3.2 Phosphorus uptake (kg/ha)

Data pertaining to phosphorus uptake is given in Table 13. The P uptake steadily increased with the age of the crop.

Significantly higher uptake of phosphorus was noticed in SRI method as compared to traditional method at all growth stages. SRI method recorded the uptake of 21.1, 36.9, 37.9, 17.1, 14.5 kg per ha, while traditional method recorded 9.4, 15.1, 14.7, 9.0, 8.7 kg per ha at 30, 60, 90 DAT and grain, straw of harvest, respectively.

Application of 75 per cent RDF + biofertilizers recorded significantly higher uptake of phosphorus (22.9, 36.1, 38.3, 20.4, 17.5 kg/ha at 30, 60, 90 DAT, grain and straw of harvest, respectively) at all growth stages. The treatment receiving 50 per cent RDF accounted for the lowest uptake (8.9, 14.7, 7.8 and 6.9 kg/ha at 30, 90 DAT, grain and straw of harvest, respectively).

Table 12: Effect of SRI and Traditional (TRA) methods of cultivation and fertilizer levels on nitrogen uptake (kg/ha) in rice

Treatments	30 DAT			60 DAT			90 DAT			At harvest					
										Grain			Straw		
	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean
T_1-RDF	141.1	74.7	107.9	160.1	76.2	118.2	169.4	81.2	125.3	98.7	54.0	76.3	92.0	52.6	72.3
T_2-75% RDF	114.5	51.1	82.8	142.7	57.8	100.2	140.7	53.4	97.0	68.9	36.4	52.7	59.2	38.1	48.6
T_3-75% RDF + BF	158.1	81.3	119.7	176.9	82.9	129.9	184.5	93.2	138.8	113.1	66.0	89.6	103.9	65.7	84.8
T_4-50% RDF	59.6	20.7	40.1	103.2	33.6	68.4	79.4	17.9	48.6	47.2	23.6	35.4	42.7	24.2	33.4
T_5-50% RDF + BF	87.7	33.4	60.5	121.4	39.2	80.3	113.7	32.6	73.2	62.4	31.0	46.7	53.2	31.7	42.5
Mean	112.2	52.2	82.2	140.9	57.9	99.4	137.5	55.6	96.6	78.0	42.2	60.1	70.2	42.4	56.3

For comparing means of	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%
Method of cultivation (M)	1.114	6.778	1.880	11.440	0.342	2.078	6.745	NS	0.877	5.337
Treatment (T)	1.921	5.758	3.572	10.705	3.958	11.862	2.831	8.483	2.496	7.478
M × T	2.717	8.143	5.052	NS	5.598	NS	4.003	NS	3.529	10.576

Table 13: Effect of SRI and Traditional (TRA) methods of cultivation and fertilizer levels on phosphorus uptake (kg/ha) in rice

Treatments	30 DAT			60 DAT			90 DAT			At harvest					
										Grain			Straw		
	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean
T_1-RDF	26.5	13.3	19.9	40.3	19.2	29.7	46.9	21.2	34.1	22.1	11.7	16.9	18.6	9.7	14.1
T_2-75% RDF	20.2	8.5	14.3	40.4	14.5	27.4	36.9	13.5	25.2	15.3	7.1	11.2	13.0	8.0	10.5
T_3-75% RDF + BF	30.7	15.1	22.9	49.3	23.0	36.1	50.8	25.8	38.3	26.0	14.8	20.4	21.2	13.9	17.5
T_4-50% RDF	13.4	4.4	8.9	28.8	9.8	19.3	24.2	5.2	14.7	10.2	5.3	7.8	8.6	5.2	6.9
T_5-50% RDF + BF	14.9	5.6	10.2	25.9	9.2	17.6	30.8	8.1	19.5	11.7	6.2	8.9	10.9	6.7	8.8
Mean	21.1	9.4	15.2	36.9	15.1	26.0	37.9	14.7	26.3	17.1	9.0	13.0	14.5	8.7	11.6

For comparing means of	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%
Method of cultivation (M)	0.203	1.235	1.165	7.087	0.849	5.163	1.425	NS	0.602	3.664
Treatment (T)	0.332	0.995	1.016	3.045	1.462	4.382	0.694	2.080	0.485	1.453
M × T	0.470	1.408	1.437	4.306	2.068	NS	0.982	2.941	0.685	NS

At all the growth stages, treatment T_3 (75% RDF + biofertilizers) was significantly superior over all other treatments. At 30 DAT, T_3 was followed by T_1, T_2, T_5 and T_4. At 60 DAT, T_2 was on par with T_1 and T_4 was on par with T_5. At 90 DAT, T_3 and T_1 were at par.

The method of cultivation did not affect the P uptake by grain at harvest. The treatment T_3 (75% RDF + biofertilizers) recorded the highest P uptake by grain and it was significantly superior over all other treatments. Treatment T_3 was followed by T_1, T_2, T_5 and T_4. Treatments T_4 and T_5 were on par with each other. The same trend was also observed in the P uptake by straw.

In the study, the interaction effects were not significant at 90 DAT and in straw at harvest.

Among the interaction effects, the effect due to SRI method and treatment T_3 (75% RDF + biofertilizers) recorded the maximum P uptake at 30, 60 DAT and in grain of harvest.

4.3.3 Potassium uptake (kg/ha)

Data pertaining to potassium uptake is given in Table 14. A steady increase was noticed in K uptake with the age of the crop.

Significantly higher uptake of potassium was noticed in SRI method of cultivation as compared to traditional method of cultivation at all growth stages.

SRI method recorded the uptake of 82.0, 151.6, 150.6, 27.1, 111.1, while traditional method recorded 38.4, 65.6, 61.7, 14.6, 69.4 kg per ha at 30, 60, 90 DAT and grain and straw at harvest, respectively.

Application of 75 per cent RDF + biofertilizers recorded significantly higher uptake of potassium (86.6, 144.3, 155.1, 32.7, 132.9 kg/ha at 30, 60, 90 DAT and grain and straw at harvest, respectively) at all growth stages. The treatment receiving 50 per cent RDF accounted for the lowest uptake (34.2, 80.9, 55.0, 11.6, 55.3 kg/ha at 30, 60, 90 DAT, grain and straw at harvest, respectively) at all growth stages.

At all growth stages, T_3 (75% RDF + biofertilizers) was significantly superior over all other treatments. Treatment T_3 was followed by T_1, T_2, T_5 and T_4. Method of cultivation did not effect the K uptake by grain at harvest. At 60 DAT, T_4, T_5 were on par with each other. Treatment T_3 recorded the highest K uptake by grain and it was significantly superior over other treatments. Treatment T_3 was followed by T_1, T_2 and T_5 and T_4. But, the treatments T_2 and T_5 were on par with each other. The same trend was also noticed in the straw K uptake.

Interactions were not significant at 60, 90 DAT and in straw at harvest. Among the interactions, the effect due to SRI method and treatment which received 75 per cent RDF + biofertilizers recorded the maximum K uptake at 30 DAT and grain of harvest.

4.4 Available soil N, P and K at different growth stages under sri and traditional methods of cultivation as influenced by nutrient levels

4.4.1 Available nitrogen (kg/ha)

The available soil N did not vary significantly between SRI and traditional method at 30 and 60 DAT. At 90 DAT and harvest SRI method recorded significantly higher available soil N (196.6, 192.2 kg/ha) than traditional method (187.9 and 182.0 kg/ha) (Table 15).

At 30 DAT, treatment T_3 (75% RDF + biofertilizers) recorded higher available N but remained on par with T_1. The treatments T_2 and T_5 were on par with each other. Treatment T_4 (50% RDF) recorded the lowest value of available soil N. Same trend was followed at 60, 90 DAT and at harvest. Interaction effects were not significant at all the growth stages.

4.4.2 Available phosphorus (kg/ha)

The available soil P did not vary significantly between SRI and traditional method at 60 DAT and at harvest. AT 30 and 90 DAT, SRI method recorded significantly higher available soil P (16.7 and 13.1 kg/ha) than traditional method (Table 16).

Table 14: Effect of SRI and Traditional (TRA) methods of cultivation and fertilizer levels on potassium uptake (kg/ha) in rice

Treatments	30 DAT			60 DAT			90 DAT			At harvest					
										Grain			Straw		
	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean
T_1-RDF	101.8	54.9	78.4	171.6	83.6	127.6	187.2	90.6	138.9	36.0	19.9	27.9	144.2	87.0	115.6
T_2-75% RDF	79.8	36.4	58.1	145.9	57.8	101.8	148.9	56.2	102.5	22.5	12.1	17.3	95.4	61.4	78.4
T_3-75% RDF + BF	114.3	58.8	86.6	190.3	98.2	144.3	205.3	104.9	155.1	41.9	23.4	32.7	159.8	106.0	132.9
T_4-50% RDF	51.0	17.5	34.2	118.5	43.3	80.9	88.7	21.3	55.0	15.5	7.7	11.6	69.9	40.7	55.3
T_5-50% RDF + BF	63.1	24.6	43.8	131.6	45.3	88.4	123.1	35.7	79.4	19.7	9.9	14.8	86.2	52.1	69.1
Mean	82.0	38.4	60.2	151.6	65.6	108.6	150.6	61.7	106.2	27.1	14.6	20.9	111.1	69.4	90.3

For comparing means of	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%
Method of cultivation (M)	0.903	5.496	3.295	20.049	1.425	8.672	2.315	NS	2.169	13.198
Treatment (T)	1.444	4.327	3.872	11.603	5.466	16.379	1.039	3.112	3.921	11.750
M × T	2.042	6.120	5.476	NS	7.730	NS	1.469	4.401	5.545	NS

Table 15: Effect of SRI and Traditional (TRA) methods of cultivation and fertilizer levels on available soil nitrogen (kg/ha)

Treatments	30 DAT			60 DAT			90 DAT			At harvest		
	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean
T_1-RDF	226.5	214.9	220.7	239.5	232.8	236.1	218.5	207.7	213.1	216.2	200.5	208.4
T_2-75% RDF	201.8	187.7	194.7	215.4	211.8	213.6	193.5	185.1	189.3	188.5	179.5	184.0
T_3-75% RDF + BF	229.6	219.8	224.7	244.5	233.6	239.0	218.1	211.4	214.8	214.2	205.4	209.8
T_4-50% RDF	172.6	167.3	169.9	187.7	184.2	185.9	168.1	158.5	163.3	161.8	153.1	157.4
T_5-50% RDF + BF	193.7	186.5	198.1	208.2	203.5	205.8	185.1	176.8	180.9	180.3	171.4	175.9
Mean	204.8	195.2	200.0	219.0	213.1	216.1	196.6	187.9	192.3	192.2	182.0	187.1

For comparing means of	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%
Method of cultivation (M)	1.892	NS	1.000	NS	1.321	8.039	1.267	7.706
Treatment (T)	3.842	11.514	3.830	11.477	3.768	11.290	3.569	10.696
M × T	5.434	NS	5.416	NS	5.328	NS	5.048	NS

Table 16: Effect of SRI and Traditional (TRA) methods of cultivation and fertilizer levels on available soil phosphorus (kg/ha)

Treatments	30 DAT			60 DAT			90 DAT			At harvest		
	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean
T_1-RDF	19.3	18.4	18.9	16.4	15.5	16.0	15.4	14.9	15.1	14.8	13.5	14.1
T_2-75% RDF	15.7	15.6	15.6	12.7	11.5	12.1	13.0	11.6	12.3	12.3	10.8	11.6
T_3-75% RDF + BF	20.4	19.5	19.9	17.4	16.5	16.9	15.5	14.6	15.0	14.9	13.8	14.3
T_4-50% RDF	13.6	12.6	13.1	10.7	9.6	10.1	10.2	9.6	9.9	8.3	8.6	8.5
T_5-50% RDF + BF	14.5	14.1	14.3	12.5	11.8	12.1	11.4	11.3	11.3	10.5	10.9	10.7
Mean	16.7	16.0	16.4	13.9	13.0	13.4	13.1	12.4	12.7	12.1	11.5	11.8

For comparing means of	**SEm±**	**CD at 5%**	**SEm±**	**CD at 5%**	**SEm±**	**CD at 5%**	**SEm±**	**CD at 5%**
Method of cultivation (M)	0.073	0.444	0.442	NS	0.096	0.582	0.196	NS
Treatment (T)	0.689	2.065	0.539	1.616	0.420	1.259	0.384	1.151
M × T	0.975	NS	0.762	NS	0.594	NS	0.543	NS

Table 17: Effect of SRI and Traditional (TRA) methods of cultivation and fertilizer levels on available soil potassium (kg/ha)

Treatments	30 DAT			60 DAT			90 DAT			At harvest		
	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean
T_1-RDF	252.7	248.6	250.7	237.3	230.6	233.9	225.8	222.4	224.1	218.4	216.8	217.6
T_2-75% RDF	220.5	217.9	219.2	202.5	200.2	201.4	180.0	192.1	186.0	189.3	187.6	188.5
T_3-75% RDF + BF	262.7	259.1	260.9	243.5	243.3	243.4	232.5	230.6	231.5	226.3	218.8	222.5
T_4-50% RDF	163.5	158.0	160.7	148.3	139.2	143.8	139.5	131.7	135.6	133.5	125.1	129.3
T_5-50% RDF + BF	190.1	182.4	186.2	175.5	172.0	173.8	166.1	159.2	162.6	157.6	147.0	152.3
Mean	217.9	213.2	215.5	201.4	197.1	199.2	188.8	187.2	188.0	185.0	179.1	182.0

For comparing means of	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%
Method of cultivation (M)	0.698	4.248	0.214	1.303	0.112	0.680	0.046	0.278
Treatment (T)	1.384	4.149	4.019	12.045	4.116	12.334	4.244	12.718
M × T	1.958	NS	5.684	NS	5.821	NS	6.002	NS

At 30 DAT, treatment T_3 (75% RDF + biofertilizers) recorded higher available P (19.9 kg/ha), but remained on par with T_1 (18.9 kg/ha). The treatments T_2 and T_5 were on par with each other. Treatment T_4 recorded the lowest value of 13.1 kg per ha. The same trend was noticed at 60, 90 DAT and at harvest also. The interaction did not influence the available soil P at all the growth stages.

4.4.3 Available potassium (kg/ha)

Significantly higher available soil K was recorded under SRI method (217.9, 201.4, 188.8, 185.0 kg/ha at 30, 60, 90 DAT and at harvest, respectively) compared to traditional method (213.2, 197.1, 187.2, 179.1 kg/ha at 30, 60, 90 DAT and at harvest, respectively) (Table 17).

At 30 DAT, treatment T_3 (75% RDF + biofertilizers) recorded the highest available soil K (260.9 kg/ha). Treatment T_3 was followed by T_1, T_2, T_5 and T_4. Treatment T_4 (50% RDF) recorded the lowest value of 160.7 kg per ha.

At 60 DAT, treatment T_3 (75% RDF + biofertilizers) recorded the highest value (243.4) which was on par with T_1 (233.9 kg/ha). Treatment T_4 recorded the lowest value of 143.8 kg per ha. Treatment T_1 was followed by T_2 and T_5. Same trend was followed at 90 DAT and at harvest also. Interactions were found to be non-significant at all the growth stages.

4.5 Dynamics of N under sri and traditional methods of cultivation as influenced by nutrient levels in rice at different depths during different stages of crop growth

4.5.1 Ammonical nitrogen (mg/kg)

4.5.1.1 NH_4N at 0-20 cm depth (Table 18)

At all the growth stages, traditional method was found to be significantly superior over the SRI method. Traditional method recorded higher ammonical N (50.8, 41.3, 34.0, 25.5 mg per kg at 30, 60, 90 DAT and at harvest, respectively).

Among the treatments, the treatment T_3 recorded significantly higher NH_4-N at all growth stages (58.8, 46.7, 40.9, 30.2 mg per kg at 30, 60, 90 DAT and at harvest, respectively). Treatment T_3 (75% RDF + biofertilizers) was on par with T_1 at 30, 60 and 90 DAT. The treatment T_4 recorded the lowest value (24.6, 20.7, 16.6, 12.5 mg per kg at 30, 60, 90 DAT and at harvest, respectively).

The interaction effect due to cultivation methods and fertilizer levels was found to be significant with respect to NH_4-N.

At 60 DAT, the effect due to traditional method and treatment T_3 recorded maximum NH_4N (52.8 mg/kg). The same level of interaction recorded highest NH_4-N at 90 DAT (44.3 mg/kg) and at harvest (32.5 mg/kg). The effect due to cultivation methods and fertilizer levels was found to be non-significant at 30 DAT.

4.5.1.2 NH_4N at 20-40 cm depth (Table 19)

The ammonical N at 20 to 40 cm depth was less compared to 0 to 20 cm depth. At all the growth stages, traditional method was found to be superior over the SRI method. Traditional method recorded high ammonical N (37.4, 29.8, 26.2, 19.1 mg per kg at 30, 60, 90 and at harvest, respectively) as compared to SRI method (27.8, 22.5, 16.4, 11.9 mg/kg at 30, 60, 90 DAT and at harvest, respectively).

Among the treatments, treatment T_3 (75% RDF + biofertilizers) recorded significantly higher NH_4-N at all growth stages (43.7, 38.3, 30.9, 21.3 mg per kg at 30, 60, 90 DAT and at harvest, respectively). There was a significant difference among the treatments at all growth stages. Treatment T_3 (75% RDF + biofertilizers) was followed by T_1, T_2, T_5 and T_4. Treatment T_4 recorded the lowest value of NH_4-N.

The interaction effects due to cultivation method and fertilizer levels was found to be significant with respect to NH_4-N. At all the growth stages, the effect due to traditional method and treatment T_3 recorded the maximum NH_4-N. The interaction was found to be significantly superior over other treatments.

Table 18: Effect of SRI and Traditional (TRA) methods of cultivation and fertilizer levels on NH_4-N in soil at 0-20 cm depth (mg/kg)

Treatments	30 DAT			60 DAT			90 DAT			At harvest		
	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean
T_1-RDF	46.9	64.3	55.6	35.0	50.9	43.0	36.4	41.4	38.9	20.1	34.6	27.4
T_2-75% RDF	43.4	51.9	47.6	42.0	47.1	44.6	25.6	37.8	31.7	23.6	27.3	25.5
T_3-75% RDF + BF	49.3	68.3	58.8	40.6	52.8	46.7	37.5	44.3	40.9	27.9	32.5	30.2
T_4-50% RDF	19.4	29.7	24.6	18.0	23.5	20.7	13.8	19.4	16.6	10.8	14.1	12.5
T_5-50% RDF + BF	25.5	39.7	32.6	21.2	32.4	26.8	17.8	27.4	22.6	14.5	19.1	16.8
Mean	36.9	50.8	43.8	31.4	41.3	36.3	26.2	34.0	30.1	19.4	25.5	22.5

For comparing means of	30 DAT SEm±	30 DAT CD at 5%	60 DAT SEm±	60 DAT CD at 5%	90 DAT SEm±	90 DAT CD at 5%	At harvest SEm±	At harvest CD at 5%
Method of cultivation (M)	0.187	1.139	0.930	5.659	0.266	1.617	0.090	0.548
Treatment (T)	1.824	5.467	1.310	3.924	0.382	1.146	0.205	0.614
M × T	2.580	NS	1.852	5.550	0.541	1.621	0.290	0.868

Table 19: Effect of SRI and Traditional (TRA) methods of cultivation and fertilizer levels on NH_4-N in soil at 20-40 cm depth (mg/kg)

Treatments	30 DAT			60 DAT			90 DAT			At harvest		
	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean
T_1-RDF	36.6	48.7	42.6	24.8	35.4	30.1	15.5	35.4	25.4	12.3	20.1	16.2
T_2-75% RDF	29.6	42.9	36.2	21.7	32.0	26.9	13.5	26.0	19.7	10.1	24.3	17.2
T_3-75% RDF + BF	38.1	49.3	43.7	33.6	42.9	38.3	24.3	37.5	30.9	15.9	26.6	21.3
T_4-50% RDF	14.6	19.9	17.2	13.9	17.2	15.6	12.5	13.5	13.0	8.9	10.7	9.8
T_5-50% RDF + BF	20.0	26.2	23.1	18.6	21.5	20.1	16.0	18.7	17.3	12.6	13.9	13.2
Mean	27.8	37.4	32.6	22.5	29.8	26.2	16.4	26.2	21.3	11.9	19.1	15.5

For comparing means of	30 DAT SEm±	30 DAT CD at 5%	60 DAT SEm±	60 DAT CD at 5%	90 DAT SEm±	90 DAT CD at 5%	At harvest SEm±	At harvest CD at 5%
Method of cultivation (M)	0.052	0.318	0.130	0.790	0.148	0.903	0.603	3.671
Treatment (T)	0.209	0.626	0.312	0.934	0.285	0.854	0.542	1.623
M × T	0.296	0.886	0.441	1.320	0.403	1.207	0.766	2.296

Table 20: Effect of SRI and Traditional (TRA) methods of cultivation and fertilizer levels on NH_4-N in soil at 40-60 cm depth (mg/kg)

Treatments	30 DAT			60 DAT			90 DAT			At harvest		
	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean
T_1-RDF	26.1	36.2	31.1	17.0	24.5	20.7	11.9	15.0	13.4	10.1	12.6	11.4
T_2-75% RDF	20.6	26.1	23.3	13.7	22.2	18.0	8.8	14.0	11.4	5.5	9.8	7.6
T_3-75% RDF + BF	23.7	38.2	31.0	18.2	33.2	25.7	11.9	24.5	18.2	8.7	15.9	12.3
T_4-50% RDF	11.9	14.9	13.4	10.7	14.5	12.6	8.6	12.2	10.4	5.9	8.0	6.9
T_5-50% RDF + BF	18.5	19.6	19.0	14.6	18.8	16.7	10.2	16.6	13.4	7.9	10.1	9.0
Mean	20.1	27.0	23.6	14.8	22.6	18.7	10.3	16.4	13.4	7.6	11.3	9.4
For comparing means of	SEm±	CD at 5%		SEm±	CD at 5%		SEm±	CD at 5%		SEm±	CD at 5%	
Method of cultivation (M)	0.372	2.264		3.007	NS		0.376	2.287		0.395	2.402	
Treatment (T)	0.654	1.968		0.327	0.979		0.234	0.702		0.447	1.340	
M × T	0.925	2.772		0.462	1.384		0.331	0.992		0.632	1.895	

4.5.1.3 NH_4N at 40-60 cm depth (Table 20)

The ammonical N content decreased with the depth at all the growth stages. The traditional method was found to be superior over the SRI method at all growth stages. The traditional method recorded higher ammonical N (27.0, 16.4, 11.3 mg/kg at 30, 90 DAT and at harvest, respectively) as compared to SRI method (20.1, 10.3, 7.6 mg/kg at 30, 90 DAT and at harvest, respectively).

Among the treatments, treatment T_3 recorded significantly higher NH_4-N at all growth stages (31.0, 25.7, 18.2, 12.3 mg/kg at 30, 60, 90 DAT and at harvest, respectively).

At 30 DAT, treatments T_1 and T_3 were found to be on par with each other. At 90 DAT, treatments T_1 and T_5 were found to be on par with each other. At harvest, T_2 and T_4 were at par.

The interaction effects due to cultivation method and fertilizer levels was found to be significant with respect to NH_4-N. At all the growth stages, the effect due to traditional method and treatment T_3 recorded the maximum NH_4-N. The interaction was found to be significantly superior over all other treatments.

4.5.2 Nitrate nitrogen (mg/kg)

4.5.2.1 NO_3N at 0-20 cm depth (Table 21)

At all growth stages, SRI method was found to be significantly superior over the traditional method. SRI method recorded higher NO_3^-N (27.8, 22.2, 16.5, 11.2 mg/kg) as compared to traditional method (20.4, 14.6, 10.0, 7.3 mg/kg at 30, 60, 90 DAT and at harvest, respectively).

Among the treatments, treatment T_3 (75% RDF + biofertilizers) recorded significantly higher NO_3^-N at all growth stages (31.5, 25.9, 18.0, 12.5 at 30, 60, 90 DAT and at harvest, respectively).

At 30 DAT, T_1 and T_3 were found to be on par with each other. At 90 DAT, T_1 and T_5 were at par and at harvest T_2 and T_4 were at par.

The interaction effects due to cultivation method and fertilizer levels was found to be significant with respect to NO_3^-N. At all growth stages, the effect due to SRI method and treatment T_3 recorded the maximum NO_3^-N. The interaction was found to be superior over all other combinations.

4.5.2.2 NO_3N at 20-40 cm depth (Table 22)

The NO_3^-N content was found to increase from 0 to 20 cm to 20 to 40 cm depth. At all the growth stages, SRI method was found to be superior over traditional method. SRI method recorded higher NO_3^-N (50.4, 41.3, 34.0, 25.5 mg per kg at 30, 60, 90 DAT and at harvest, respectively) as compared to traditional method (37.0, 31.9, 26.4, 19.5 mg/kg at 30, 60, 90 DAT and at harvest, respectively).

Among the treatments, T_3 (75% RDF + biofertilizers) recorded significantly higher NO_3^-N at all growth stages (58.9, 48.0, 41.6, 30.0 mg/kg at 30, 60, 90 DAT and at harvest, respectively). There was a significant difference among the treatments at all growth stages. Treatment T_3 was followed by T_1, T_2, T_5 and T_4. Treatment T_4 recorded the lowest value of NO_3^-N.

The interaction effects due to cultivation method and fertilizer levels was found to be significant with respect to NO_3^-N. At all the growth stages, the effect due to SRI method and treatment T_3 (75% RDF + biofertilizers) recorded the maximum NO_3^-N. The interaction was found to be significantly superior over other combinations.

4.5.2.3 NO_3N at 40-60 cm depth (Table 23)

The NO_3^-N was found to decrease from 20-40 to 40-60 cm depth. The SRI method was found to be superior over the traditional method at all growth stages. The SRI method recorded higher NO_3^-N (37.5, 31.2, 25.4, 17.7 mg/kg) as compared to traditional method (27.6, 21.4, 14.6 and 11.2 mg/kg at 30, 60, 90 DAT and at harvest, respectively).

Table 21: Effect of SRI and Traditional (TRA) methods of cultivation and fertilizer levels on NO_3^-N in soil at 0-20 cm depth (mg/kg)

Treatments	30 DAT			60 DAT			90 DAT			At harvest		
	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean
T_1-RDF	36.5	26.5	31.5	24.3	15.9	20.1	15.3	11.2	13.3	12.3	9.4	10.9
T_2-75% RDF	29.7	20.4	25.0	21.6	14.2	17.9	14.1	8.4	11.3	9.3	5.3	7.3
T_3-75% RDF + BF	38.5	24.5	31.5	33.4	18.5	25.9	24.8	11.3	18.0	16.3	8.8	12.5
T_4-50% RDF	14.8	12.5	13.6	13.6	10.4	12.0	12.3	8.3	10.3	8.4	5.4	6.9
T_5-50% RDF + BF	19.6	18.4	19.0	18.3	14.2	16.2	16.1	10.7	13.4	9.6	7.7	8.6
Mean	27.8	20.4	24.1	22.2	14.6	18.4	16.5	10.0	13.2	11.2	7.3	9.2

For comparing means of	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%
Method of cultivation (M)	0.096	0.585	0.185	1.125	0.369	2.246	0.136	0.825
Treatment (T)	0.324	0.972	0.391	1.171	0.470	1.409	0.145	0.434
M × T	0.459	1.374	0.553	1.657	0.665	1.993	0.205	0.614

Table 22: Effect of SRI and Traditional (TRA) methods of cultivation and fertilizer levels on NO_3^-N in soil at 20-40 cm depth (mg/kg)

Treatments	30 DAT			60 DAT			90 DAT			At harvest		
	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean
T_1-RDF	62.6	47.2	54.9	50.7	34.4	42.5	41.6	25.4	33.5	34.6	20.6	27.6
T_2-75% RDF	52.3	43.4	47.8	47.4	42.4	44.9	36.8	36.4	36.6	27.4	24.6	20.0
T_3-75% RDF + BF	68.4	49.4	58.9	52.5	43.6	48.0	44.7	38.6	41.6	32.6	27.5	30.0
T_4-50% RDF	29.7	19.5	24.6	23.6	17.8	20.7	19.4	13.4	16.4	13.5	10.5	12.0
T_5-50% RDF + BF	39.2	25.5	32.3	32.5	21.2	26.9	27.6	18.4	23.0	19.5	14.2	16.9
Mean	50.4	37.0	43.7	41.3	31.9	36.6	34.0	26.4	30.2	25.5	19.5	22.5

For comparing means of	30 DAT SEm±	30 DAT CD at 5%	60 DAT SEm±	60 DAT CD at 5%	90 DAT SEm±	90 DAT CD at 5%	At harvest SEm±	At harvest CD at 5%
Method of cultivation (M)	0.278	1.694	0.290	1.766	0.923	5.614	0.602	3.664
Treatment (T)	0.607	1.819	0.498	1.491	0.383	1.148	0.345	1.034
M × T	0.858	2.573	0.704	2.109	0.542	1.623	0.488	1.462

Table 23: Effect of SRI and Traditional (TRA) methods of cultivation and fertilizer levels on NO_3^-N in soil at 40-60 cm depth (mg/kg)

Treatments	30 DAT			60 DAT			90 DAT			At harvest		
	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean	SRI	TRA	Mean
T_1-RDF	48.5	36.5	42.5	33.6	21.0	27.3	24.5	15.2	19.8	20.4	12.2	16.3
T_2-75% RDF	43.3	29.4	36.4	39.4	23.6	31.5	32.4	13.4	22.9	18.9	9.4	14.1
T_3-75% RDF + BF	49.7	38.4	44.0	43.6	28.2	35.9	38.5	16.6	27.5	24.5	16.2	20.3
T_4-50% RDF	19.6	14.3	16.9	18.4	14.8	16.6	13.5	12.4	12.9	10.4	8.4	9.4
T_5-50% RDF + BF	26.5	19.5	23.0	21.3	19.5	20.4	18.3	15.5	16.9	14.2	9.8	12.0
Mean	37.5	27.6	32.6	31.2	21.4	26.3	25.4	14.6	20.0	17.7	11.2	14.4

For comparing means of	30 DAT SEm±	30 DAT CD at 5%	60 DAT SEm±	60 DAT CD at 5%	90 DAT SEm±	90 DAT CD at 5%	At harvest SEm±	At harvest CD at 5%
Method of cultivation (M)	0.108	0.655	1.252	7.617	0.753	4.583	0.044	0.270
Treatment (T)	0.478	1.432	1.291	3.869	1.009	3.023	0.242	0.725
$M \times T$	0.676	2.025	1.826	5.471	1.427	4.275	0.342	1.025

Among the treatments, treatment T_3 (75% RDF + biofertilizers) recorded significantly higher NO_3^-N at all growth stages (44.0, 35.9, 27.5, 20.3 mg/kg at 30, 60, 90 DAT and at harvest, respectively). Treatment T_3 (75% RDF + biofertilizers) was found to be significantly superior over all other treatments at all growth stages. Treatment T_3 was followed by T_1, T_2, T_5 and T_4. Treatment T_4 recorded the lowest value of NO_3^-N (16.9, 16.6, 12.9, 9.4 mg/kg at 30, 60, 90 DAT and at harvest, respectively).

The interaction effects due to cultivation method and fertilizer levels was found to be significant with respect to NO_3^-N. At all growth stages the effect due to SRI method and treatment T_3 (75% RDF + biofertilizer) recorded the maximum NO_3^-N. The interaction was found to be significantly superior over other combinations.

V. DISCUSSION

A field experiment was conducted at Agricultural Research Station, Gangavati, University of Agricultural Sciences, Dharwad during late *rabi* 2005-06 to study the effect of methods of cultivation and fertilizer levels on growth, yield and uptake of paddy. The results obtained from the present investigation are discussed here under different subheads.

5.1 Effect of fertilizer levels on growth and yield of rice under SRI and traditional methods of cultivation

5.2 Nutrient content of rice at different growth stages under SRI and traditional methods of cultivation as influenced by nutrient levels

5.3 Nutrient uptake of rice at different growth stages under SRI and traditional methods of cultivation as influenced by nutrient levels

5.4 Available soil N, P and K at different growth stages under SRI and traditional methods of cultivation as influenced by nutrient levels

5.5 Dynamics of N under SRI and traditional methods of cultivation as influenced by nutrient levels in rice at different depths during different stages of crop growth

Weather condition during crop growth period was favourable. There was no outbreak of pests and diseases on large scale.

5.1 Effect of fertilizer levels on growth and yield of rice under sri and traditional methods of cultivation

5.1.1 Effect on growth components

From the experimental results, it was observed that the growth parameters such as plant height, number of tillers per hill, dry matter production were higher in the SRI method as compared to the traditional method. Planting younger seedlings at their second or third phyllochron stage did not disturb the rapid tillering and rooting which begins at the fourth phyllochron stage (Berkelaar, 2001 and Uphoff, 2001). Increase in number of tillers per m^2 by planting younger seedlings was observed by a number of researchers (Yamah, 2002, Sengthong, 2002 and Mulu, 2004).

Rice seedlings planted carefully at younger stage under SRI might have recovered fast enough due to lower transplanting shock and started absorbing nutrients and water to support faster growth and hence higher dry matter production was observed. Similarly, higher shoot dry matter production with planting of younger seedlings than with older seedlings was also reported by Berkelaar (2002), Barison (2002), Wang *et al.* (2002) and Sarath and Thilak (2004). Planting younger seedlings at wider spacing might have resulted in more root growth which might have penetrated deep into the soil to exploit more nutrients and water resulting in increased number of tillers, shoot and root dry matter production.

Among the different growth parameters plant height in all the treatments increased more rapidly upto flowering stage and then showed a gradual decrease. It is but natural that the growth diminishes as the crop enters the reproductive stage. Application of 75 per cent RDF + biofertilizers (T_3) recorded the maximum plant height (63.1, 78.1, 96.2, 99.3 cm at 30, 60, 90 DAT and at harvest, respectively) at all growth stages.

The lowest plant height was recorded due to application of 50 per cent RDF (T_4) (32.9, 50.9, 68.2, 70.0 at 30, 60, 90 DAT and at harvest, respectively) at all growth stages. The highest plant height in treatment receiving 75 per cent RDF + biofertilizers (T_3) was because of fertilizer dose and continuous supply of additional amount of nutrients throughout its growth stage as a result of inoculation of biofertilizers (*Azospirillum* and phosphobacteria). Leaching loss of nutrients must have been minimized by use of biofertilizers, which have an ability to mobilize nutritionally important elements from non-usable forms to usable forms.

Plate 2a. Grown up nursery ready for transplanting

Plate 2b. Strong and well spread root under SRI method

Plate 2c. 75%RDF+Biofertilizersunder SRI method

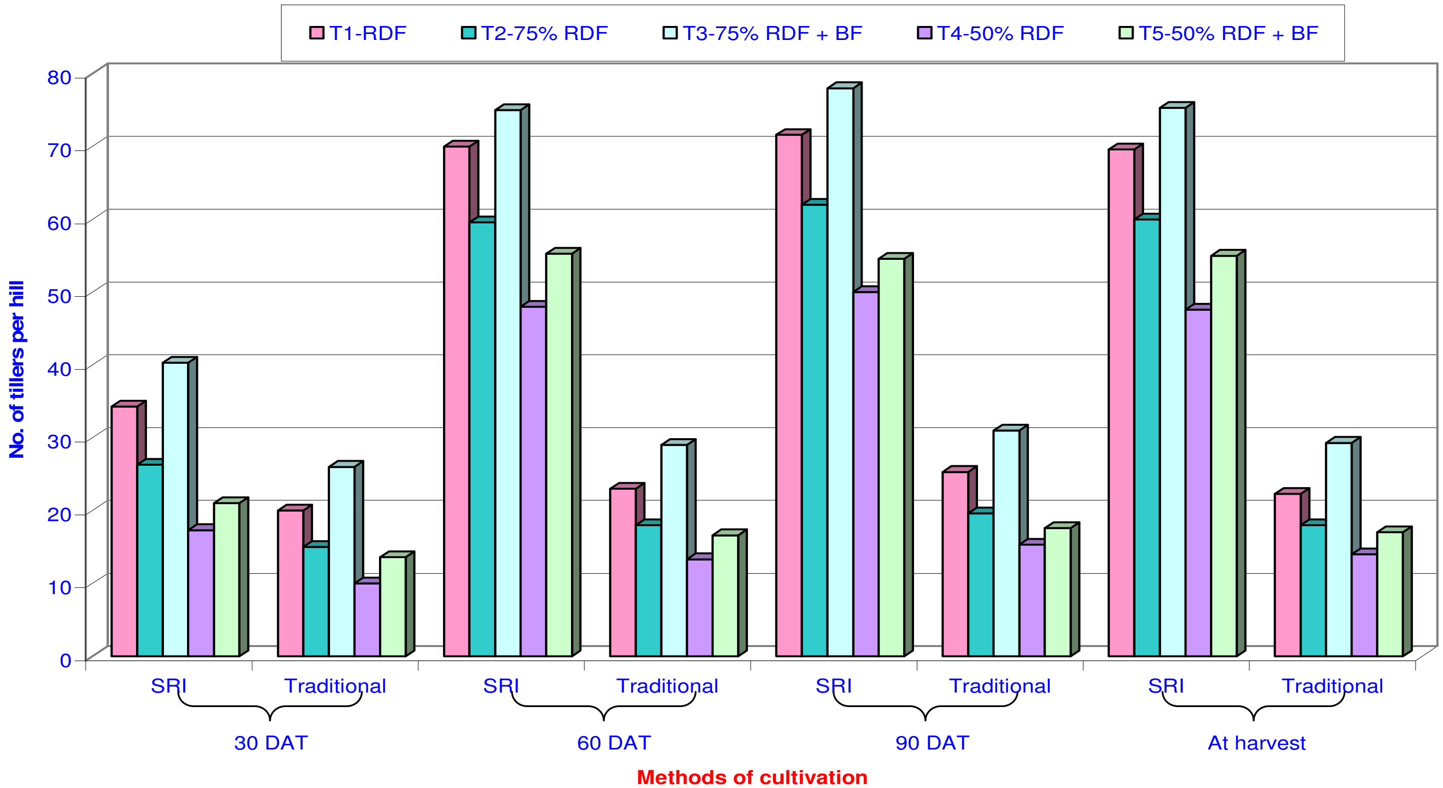

Fig. 2: Effect of SRI and Traditional methods of cultivation and fertilizer levels on number of tillers

Fig. 2: Effect of SRI and traditional methods of cultivation and fertilizer levels on number of tillers

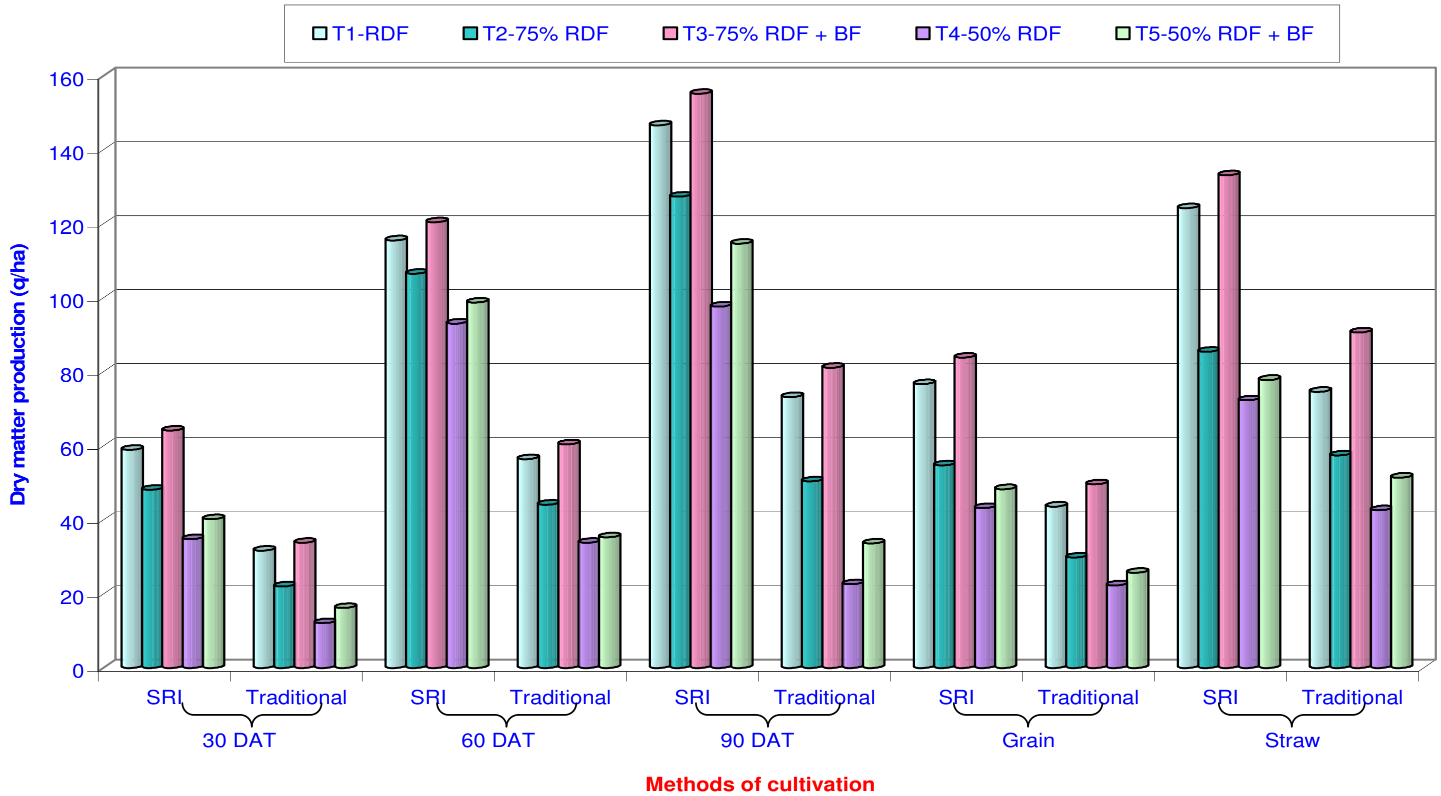

Fig. 3: Effect of SRI and Traditional methods of cultivation and fertilizer levels on dry matter production (q/ha)

Fig.3: Effect of SRI and traditional methods of cultivation and fertilizer levels on dry matter production (q/ha)

Azospirillum inoculation enhanced the nitrogen availability to rice plants as it can fix 10 to 20 kg N per ha. According to Tien *et al.* (1979) in addition to its high N fixation. *Azospirillum* is known to synthesize growth substances such as IAA and other auxins and vitamin B which might have also helped in increasing the plant height.

Inoculation of phosphobacteria converted insoluble form of P into soluble forms and made them available to plants which resulted in increased plant height. Eventhough, potassium was not considered to be necessary for promoting the vegetative growth it might be possible that this nutrient had an indirect effect in increasing the uptake of nitrogen which in turn might have increased the plant height (Halvin *et al*., 1965). The favourable effect of zinc might be due to its direct influence on the quantity of auxin production, which inturn enables the plants to grow better. These findings were in accordance with the findings of Srinivasan and Naidu (1998). They reported that higher shoot length in zinc treated plots may be due to auxin production. The combined application of NPK, $ZnSO_4$ and biofertilizers had beneficial effect over their single application. This may be due to supply of major and micronutrients (N, P, K and Zn) along with the growth promoting substances. Biofertilizers enhanced the mobility of zinc which in turn increased its availability. Jeyabal and Kuppuswamy (1998) reported that the application of $ZnSO_4$ along with *Azospirillum* increased the plant height. Similar increase in plant height due to $ZnSO_4$ @ 30 kg per ha was reported by Arya and Singh (2001). The beneficial effects of nitrogen + zinc could be attributed to the synergistic effect between these nutrients and continuous and enhanced nitrogen supply resulting in highest plant height (Ram *et al*., 1995).

The number of tillers per hill increased upto 90 DAT and thereafter a decrease was observed. The decrease in number of tillers at harvest could be due to senescence of secondary tillers. The highest number of tillers per hill was recorded due to application of 75 per cent RDF + biofertilizers (T_3) at all the growth stages (33.1, 52.0, 54.5, 52.3 at 30, 60, 90 DAT and at harvest, respectively). This can be attributed to adequate supply of nutrients. Inoculation of biofertilizers enhanced the number of tillers.

Number of tillers was also influenced by zinc application. This might be due to high auxin production. These findings are in accordance with Reddy *et al.* (1984).

Results on dry matter production indicated that it increased as the crop growth advanced. Treatment T_3 (75% RDF + biofertilizers) recorded the highest dry matter at all growth stages of the crop. Combined application of nutrients and biofertilizers caused significant variation in total dry matter production over other treatments.

With respect to dry matter production RDF (T_1) was on par with 75 per cent RDF + biofertilizers (T_3) at 60, 90 DAT and in grain of harvest. Nitrogen imparts vigorous vegetative growth resulting in high dry matter. These findings are in accordance with the findings of Devasenamma *et al.* (1999). *Azospirillum* inoculation resulted in a constant supply of additional nitrogen throughout the growth period of the crop. The beneficial effects of *Azospirillum* can be attributed to a combination of; increased associative biological nitrogen fixation in the rhizosphere, production of plant growth promoting substances that favour rice growth and nutrient utilization and increased nutrient availability through solubilizaton of immobilized nutrients by inoculated bacteria.

All these resulted in vigorous plant growth and high dry matter production.

Charyulu *et al.* (1985) reported that there was significant effect of inoculation with *Azospirillum* at high nitrogen levels. Application of inorganic phosphate with P solubilizing bacteria resulted in better root growth and better availability of phosphorus which resulted in higher dry matter production. The results indicated that inoculation of biofertilizers in combination with micronutrients showed increased dry matter production (Mudenoor, 2002). It is due to synergistic effect between biofertilizers and zinc which increased the availability of nitrogen, phosphorus, potassium and zinc.

As zinc is a part of various enzymes and hormones, it favoured increased synthesis of enzymes and hormones along with the metabolization of major nutrients which would inturn promote growth components. Sarkar *et al.* (1998) reported that use of increased doses of $ZnSO_4$ increased the shoot dry matter production in wheat. The treatment T_4 (50% RDF) recorded the lowest dry matter due to less number of tillers per hill as it received less nutrients and no biofertilizers.

5.1.2 Effect on yield components

SRI method recorded higher productive tillers per hill and productive tillers per m^2 than those observed in traditional method. Similar higher effective tillers per hill by planting younger seedlings were also recorded by Yamah (2002), Mulu (2004) and Sarath and Thilak (2004). Not much variation in methods of cultivation and among the treatments was noticed with respect to panicle length. Higher number of grains per panicle and 1000-grain weight was recorded in SRI method as compared to traditional method of cultivation. It might be due to the favourable soil condition created due to the alternate wetting and drying in SRI method.

Among the treatments, the treatments RDF (T_1) and 75 per cent RDF + biofertilizers (T_3) were at par with respect to number of productive tillers per hill and productive tillers per m^2 and thousand grain weight. The availability of required quantity of nitrogen for long time was probably responsible for producing more number of effective tillers. Kumari *et al.* (2000) reported that productive tillers significantly increased with increased levels of N upto 120 kg per ha. Treatment T_3 (75% RDF + biofertilizers) showed highest number of grains per panicle over other treatments. The increase in yield components with *Azospirillum* inoculation might have been due to the atmospheric N fixing capacity of *Azospirillum* and this fixed N was made available to the crop throughout the crop period. Inoculation of PSB increased the availability of insoluble P and gave a constant supply of P throughout the crop growth. Ishizuka (1971) opined that P play an important role in the translocation of assimilates to the panicles and also as a constituent of protoplasm. This explains the reason for the increased length of the panicle, panicle weight and number of grains per panicle. Venkateswarlu and Singh (1980) recorded similar findings. It was observed that application of zinc increased the number of panicles per m^2. This may be due to enhanced activity of metallo enzymes like protinase and peptidase. These findings were in accordance with those of Sriramachandrasekharan and Mathan (1988). Khnda and Dixit (1995), who reported that favourable effect of combined application of N and Zn on yield components might be due to the increased vigour, photosynthate accumulation and better translocation of photosynthates to the sink.

5.1.3 Effect on grain yield, straw yield and harvest index

Higher grain yield was recorded by planting younger seedlings with control over water (SRI) than that recorded by planting older seedlings under submergence (traditional). The higher grain yield recorded in the former might be the resultant of increased yield attributing characters such as effective tillers per hill and higher filled grains per panicle, which resulted due to planting of younger seedlings. Straw yield also followed similar trend as that of grain yield. Many researchers reported increased grain and straw yields by planting younger seedlings than older seedlings (Randriamiharisoa, 2002, Randriamiharisoa and Uphoff, 2002, Yamah, 2002, Mulu, 2004, Sarath and Thilak, 2004 and Uphoff, 2005). There was no significant variation in harvest index of rice due to methods of cultivation and fertilizer levels.

Overall it can be concluded that planting younger seedlings singly i.e., before starting of fourth phyllochron carefully and quickly after removing from nursery might not have suffered from transplanting shock much and recovered rapidly to result in increased root growth to support for increased tillering and shoot dry matter production. The increase in shoot dry matter production might have supported improvement in yield components such as effective tillers per hill or tillers per m^2, filled grains per panicle and ultimately lead to increased yields.

Maximum grain yield of 86.9 q per ha was obtained by the application of 75 per cent RDF + biofertilizers and lowest yield of 41.1 q per ha was recorded in T_4 (50% RDF). The increased yield was due to higher magnitude of yield components i.e., more number of effective tillers, better panicle length, number of grains per panicle and 1000-grain weight.

Kumari *et al.* (2000) reported that increased N levels from 40 to 120 kg per ha brought about significant increase in grain yield. The increase in yield due to biofertilizer inoculants may not be solely due to N fixation or phosphate solubilization, but because of several other factors such as release of growth promoting substances, control of plant pathogens, proliferation of beneficial organisms in the rhizosphere. These findings are in accordance with Kundu and Gaur (1984). PSB solubilizes inorganic phosphates in the soil

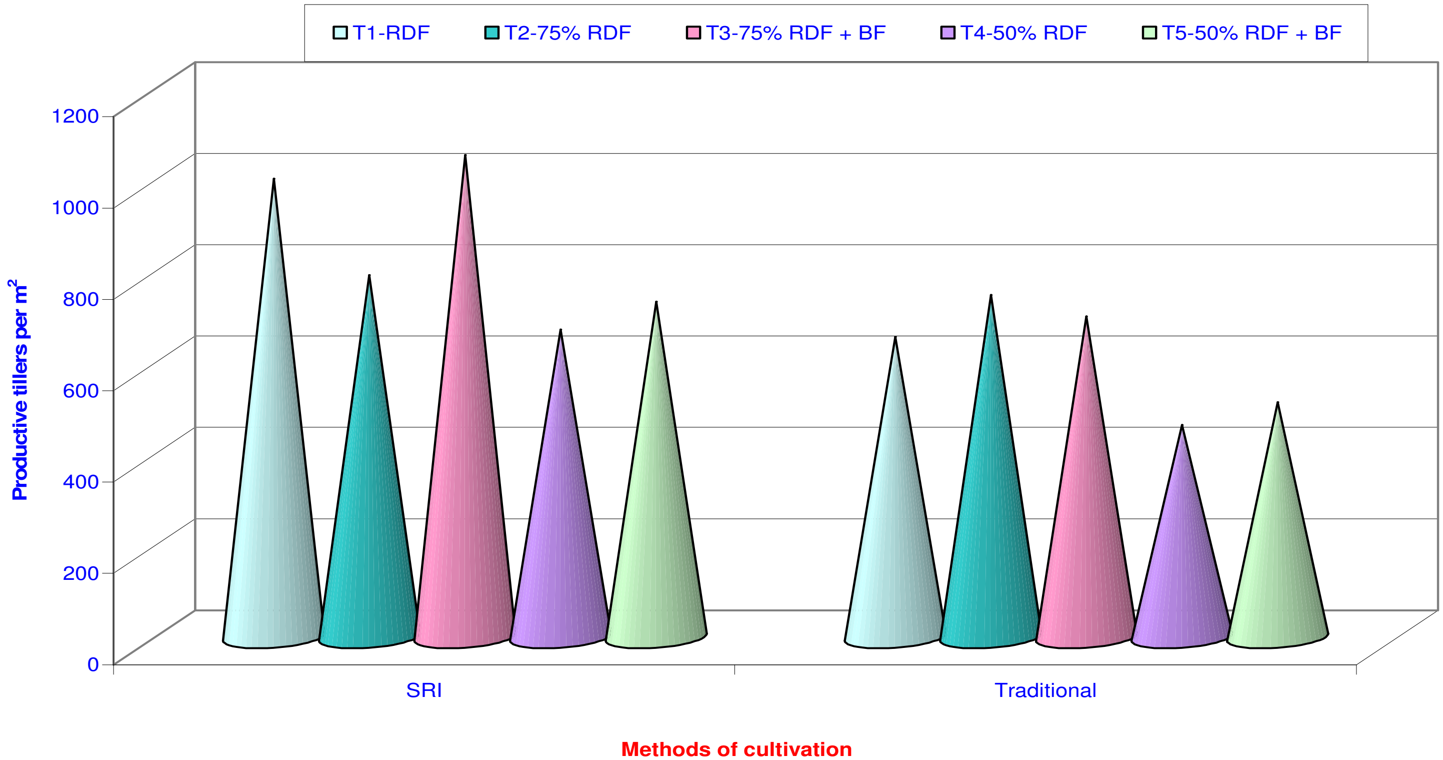

Fig. 4: Effect of SRI and Traditional methods of cultivation and fertilizer levels on productive tillers per m^2

Fig. 4: Effect of SRI and traditional methods of cultivation and fertilizer levels on productivetillers per m^2

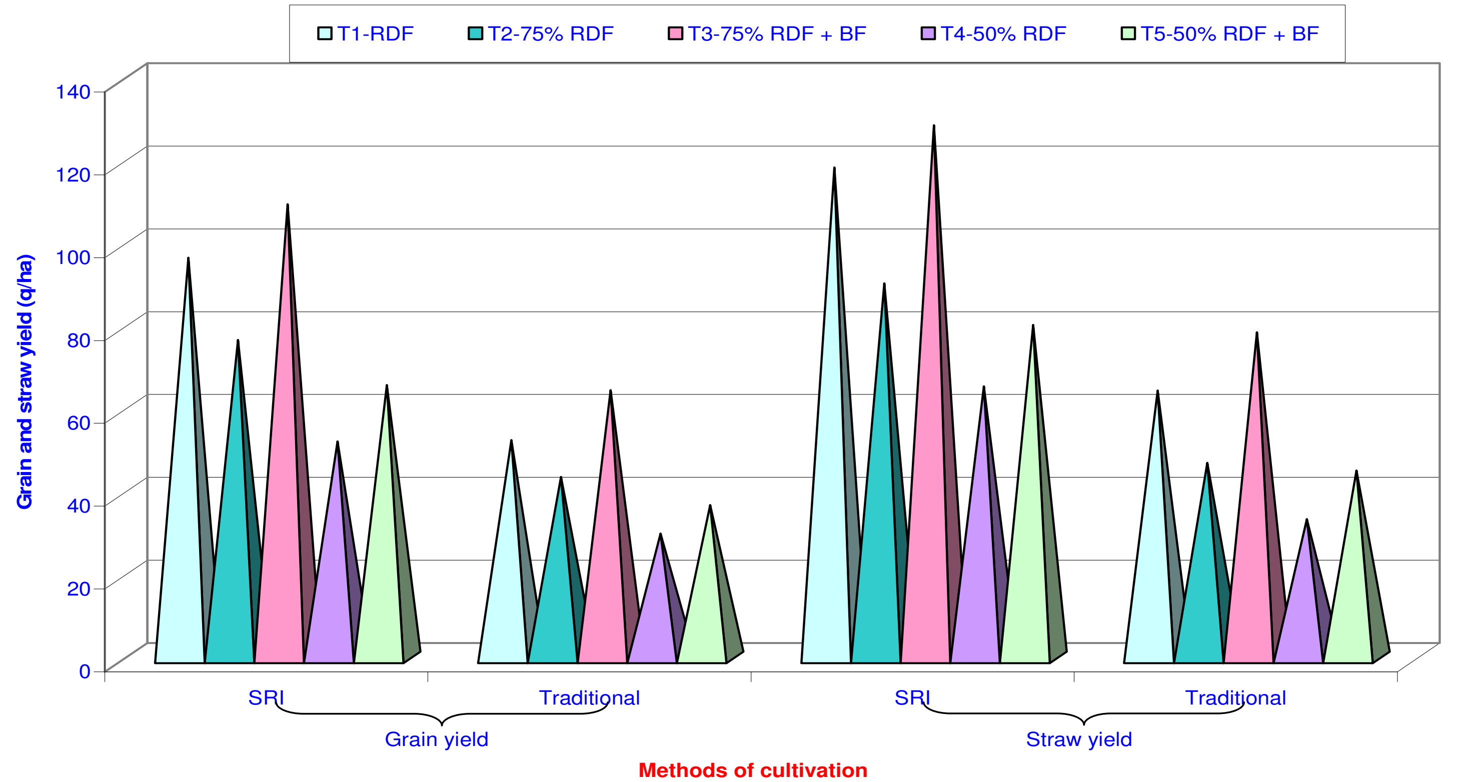

Fig. 5: Effect of SRI and Traditional methods of cultivation and fertilizer levels on Grain yield and straw yield (q/ha)

Fig. 5: Effect of SRI and Traditional methods of cultivation and fertilizer levels on Grain yield and straw yield (q/ha)

and make them available to the crop, which resulted in better yield. It also produced a phytohormone IAA which increased its capacity of nutrient extraction from the soil. These findings were in accordance with Datta *et al.* (1982). The response to mixed culture inoculation was more than that for single culture, showing the synergistic effect of two types of organism. The significant response was mainly due to the supply of two major nutrients N and P. Application of Zn had significantly increased the grain yield. Sriramachandresekharan and Mathan (1988) reported that application of Zn irrespective of Zn sources increased the number of panicles per m^2. This is due to enhanced activity of the metallo enzymes like protinases and peptideses. The accelerated physiological activities might be the probable reason for higher yield.

The yield obtained by combined application of biofertilizers and $ZnSO_4$ @ 25 kg per ha was significantly higher than individual application indicating the synergistic effect of Zn and the activity of microorganisms.

Straw yield ranged from 103.5 to 49.5 q per ha. The increase in straw yield might be due to high N through RDF and biofertilizers. Nitrogen is known to promote tillering, improve length and width of leaves, which inturn increases the plant height and dry matter which are responsible for increase in straw yield. Yoshida (1977) opined that N obtained at early growth stages resulted in the production of more straw than grain. Harvest index did not show any significant difference between the methods of cultivation and treatments.

5.2 Nutrient content of rice at different growth stages under sri and traditional methods of cultivation as influenced by nutrient levels

The N content of plant was higher in SRI method compared to traditional method at all growth stages. It might be due to favourable soil condition which enhanced nutrient uptake as well as better growth and activity of roots. Application of 75 per cent RDF + biofertilizers (T_3) recorded the highest N content at all the growth stages due to the increased supply of N through inorganic fertilizers and biofertilizers. N content of rice was significantly affected by successive stages of plant growth. At 30 DAT, it showed the highest N content. N content at 60 and 90 DAT decreased due to dilution effect, caused by higher dry matter production in comparison to absorption and mobilization of N towards developing grains.

Lal and Mahapatra (1975) reported that N content in plants decreases with increased age as N is absorbed vigorously at early stages of growth due to greater cell division and accumulation of protein at panicle primordial stage and after flowering the rate of absorption decreases due to decreased root activity and increased dry weight of plants.

P content also followed the same trend as that of N content. The cultivation method did not affect the P content in rice at 60 DAT and at harvest. Application of 75 per cent RDF + biofertilizers (T_3) recorded the highest P content. Reddy and Murthy (1988) reported that high P content in grain was an indicative of preferential migration of this nutrient. Singh *et al.* (2000) reported that content of P in plants appeared to be related to the initial available P content of the soil. Potassium concentration also followed the same trend with highest K concentration at 75 per cent RDF + biofertilizers (T_3). The cultivation method did not affect K content in rice at 30 and 90 DAT. The highest K content was observed at 30 DAT and nutrient content decreased at 60 and 90 DAT due to dilution effect. Concentration of K was higher in straw than in grain. This may be due to lesser migration of this nutrient.

5.3 Nutrient uptake of rice at different growth stages under sri and traditional methods of cultivation as influenced by nutrient levels

Significantly higher uptake of N, P and K was noticed in SRI method of cultivation as compared to the traditional method of cultivation at all growth stages. Alternate wetting and drying might have improved the soil aeration and thus root activity to improve the uptake of nutrients under SRI. Increased root dry matter and root volume might have exploited more soil volume for nutrient absorption.

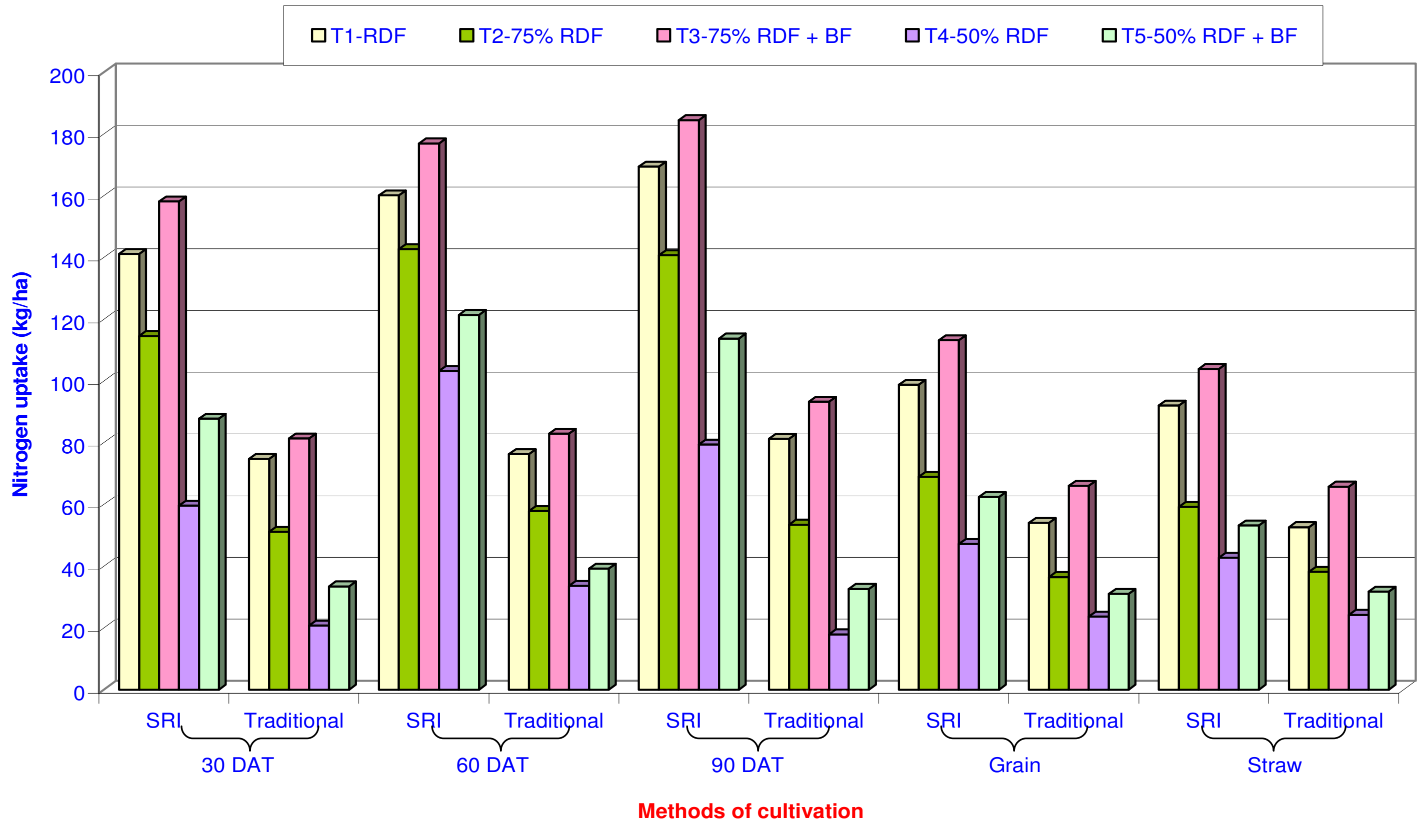

Fig. 6: Effect of SRI and Traditional methods of cultivation and fertilizer levels on nitrogen uptake (kg/ha) in rice

Fig. 6: Effect of SRI and traditional methods of cultivation and fertilizer levels on nitrogen uptake (kg/ha) in rice

Uphoff and Randriamiharisoa (2002) also observed that SRI provides soil conditions that are favourable for the mycorhizal fungi and many soil microbes, which enhances the nutrient uptake by rice.

The nitrogen uptake by plant however increased with the growth of the crop. Application of 75 per cent RDF + biofertilizers (T_3) recorded the highest uptake at all growth stages. The increase in dry matter accounted for the increased uptake. Application of nitrogenous fertilizers along with *Azospirillum* resulted in higher dry matter production. Inoculation of PSB also increased the uptake of N. Sundararao and Sinha (1963) reported significant increase in total N uptake by wheat due to application of phosphobacteria. Ilangovan and Palaniappan (1987) reported that application of Zn significantly increased NPK uptake. Ram *et al.* (1995) reported that the beneficial effect of N + Zn could be attributed to the synergistic effect between these nutrients and continuous and enhanced nitrogen supply. Mudenoor (2002) reported that inoculation of *Azospirillum* along with added Zn showed significantly higher shoot and root N content and uptake.

Application of 75 per cent RDF + biofertilizers (T_3) recorded the highest P uptake at all growth stages. The P uptake increased with the growth of the crop. This was due to the increased dry matter production. Application of water soluble phosphate and inoculation with PSB increased the P uptake.

Inoculation of PSB enhanced the P uptake due to solubilization of insoluble phosphate. A variety of mechanisms are ascribed in the solubilization and mineralization of insoluble and organic P sources such as production of aliphatic, aromatic acids, phytases and phospholipids.

Mohod *et al.* (1989) reported that PSB culture alone or in combination with phosphatic fertilizers increased the P uptake in rice. Sharma and Singh (1971) reported that the incorporation of phosphobacteria culture along with super phosphate and ammonium sulphate increased the uptake of N and P in grain as compared to the application of super phosphate plus ammonium sulphate.

Combined application of biofertilizers and $ZnSO_4$ enhanced the P uptake. This is mainly due to effect of biofertilizers and $ZnSO_4$ on dry matter production.

Application of 75 per cent RDF + biofertilizers recorded the highest uptake of K at all stages of crop growth. These results corroborate with the findings of Panda *et al.* (1999).

Application of biofertilizers enhanced the K uptake. This might be due to synergistic effect between N and K. Application of Zn in general enhanced K uptake. These findings are in accordance with the findings of Dwivedi and Takkar (1974).

5.4 Available soil N, P and K at different growth stages under sri and traditional methods of cultivation as influenced by nutrient levels

5.4.1 Available soil N

The available soil N did not vary significantly between SRI and traditional method at 30 and 60 DAT. At 90 DAT and at harvest, SRI method recorded significantly higher available N than traditional method. It might be due to higher N loss under traditional method through denitrification and leaching. Milka *et al.* (2000) revealed that N losses from nearly saturated soil were 14 per cent lower than from flooded soil.

Application of 75 per cent RDF + biofertilizers (T_3) recorded the higher available N and remained on par with RDF (T_1). The available N content at harvest was more than the initial status in treatments T_3, T_1 and T_2. Depletion of N was found in 50 per cent RDF (T_4) due to lack of sufficient N to crop. In T_3, the increase was due to enhanced microbial activity due to inoculation and in T_1 due to recommended level of N application dose.

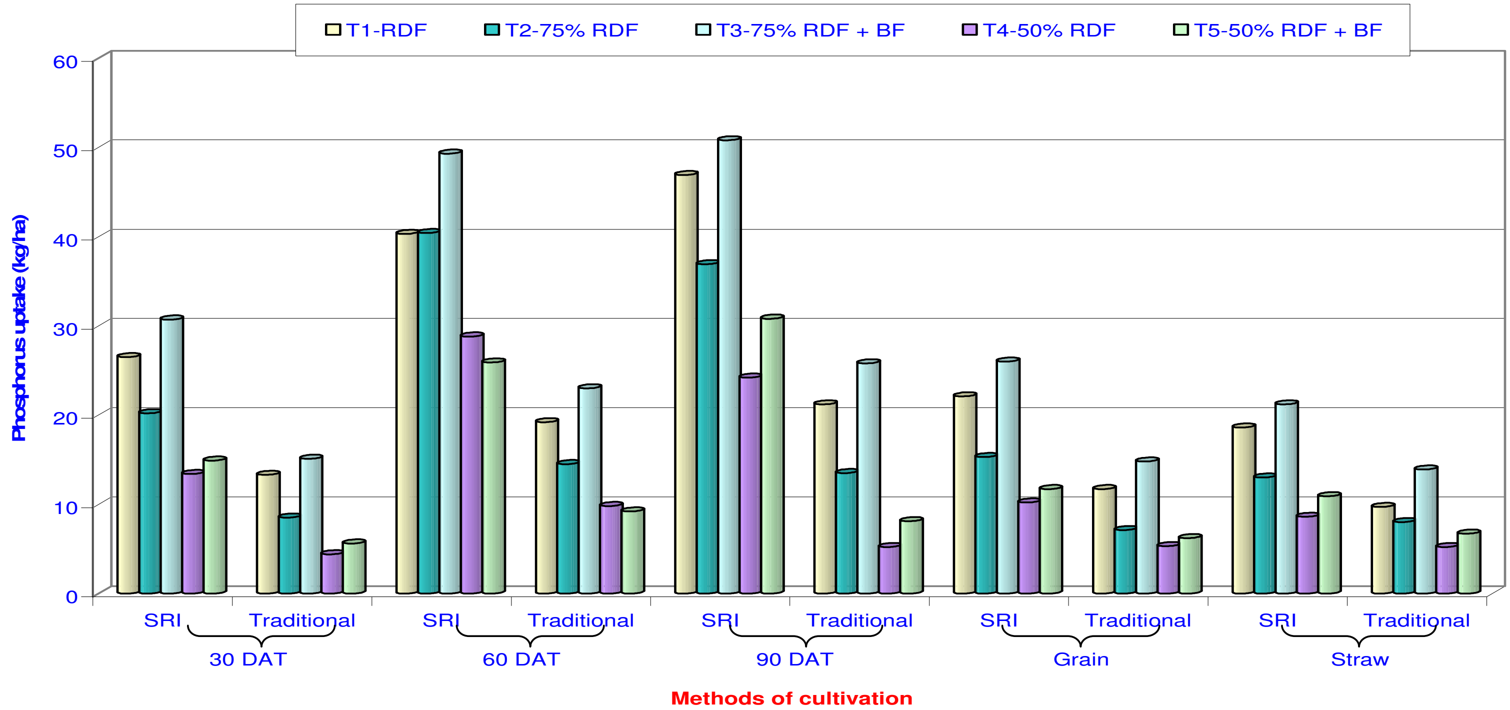

Fig. 7: Effect of SRI and Traditional methods of cultivation and fertilizer levels on phosphorus uptake (kg/ha) in rice

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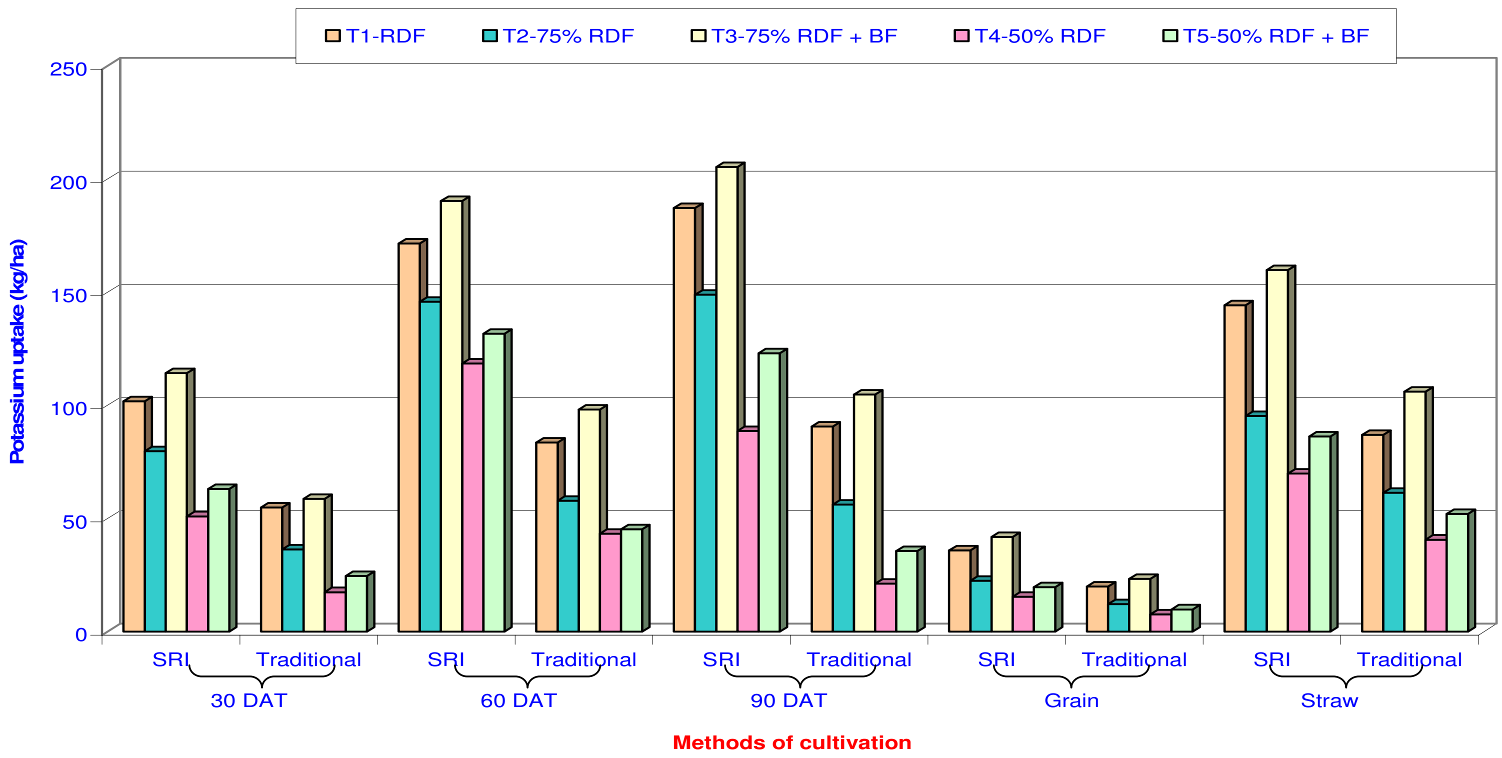

Fig. 8: Effect of SRI and Traditional methods of cultivation and fertilizer levels on potassium uptake (kg/ha) in rice

Fig. 8: Effect of SRI and Traditional methods of cultivation and fertilizer levels on potassium uptake (kg/ha) in rice

5.4.2 Available soil P

The soil available P did not vary significantly between SRI and traditional method at 60 DAT and at harvest. At 30 and 90 DAT SRI method recorded significantly higher available P than traditional method which might be due to favourable soil condition under SRI method.

Application of 75 per cent RDF + biofertilizers (T_3) recorded the highest available P in soil, which was on par with T_1. At harvest stage, the available P content in soil was higher than initial status in T_3 and T_1. Treatments T_2, T_4 and T_5 accounted for a slightly lower P content than initial status. In T_3 application of phosphatic fertilizer along with PSB resulted in an increase in available P in soil. PSB inoculation resulted in greater mobilization of insoluble inorganic P and mineralization of organic P. These findings are in accordance with Mohod *et al.* (1989).

5.4.3 Available soil K

Significantly higher available soil K was recorded under SRI as compared to traditional method. Among the treatments, T_3 (75% RDF + biofertilizers) recorded the highest available soil K followed by T_1 and T_2. At harvest stage, the available K content in soil increased from its initial status in all treatments except T_4 and T_5. Since, T_4 and T_5 received only 50 per cent of recommended K it led to depletion of available soil K.

5.5 Dynamics of N under sri and traditional methods of cultivation as influenced by nutrient levels in rice different depths during different stages of crop growth

5.5.1 Ammonical nitrogen

The exchangeable NH_4^+ is an important source of N that is easily available to the wetland rice. Among the two methods of cultivation NH_4-N content was found to be higher under traditional method than SRI method at all the growth stages and at different depths. In SRI method, the soil is partially aerobic and is supported by a relatively higher nitrification of applied fertilizer, whereas in traditional method under reduced condition (anaerobic) N mineralziation can not proceed past the ammonical stage due to absence of oxygen which is necessary for microbial conversion of ammonia to nitrate. Thus, there was a higher content of ammonical N under traditional method. These results are in accordance with the findings of Milka *et al.* (2000).

In the present study, NH_4-N content decreased as the growth advanced. The depletion in NH_4-N with advance in crop growth may be attributed to increased crop growth resulting in decreased NH_4-N concentration. Keerthisinghe *et al.* (1985) reported continuous decrease in exchangeable NH_4-N with advancement of crop growth.

With increase in depth the NH_4-N content decreased. It may be attributed to its low mobility of NH_4-N.

Among the treatments, 75 per cent RDF + biofertilizers (T_3) recorded higher NH_4-N content. It was on par with RDF (T_1) only at 0 to 20 cm depth.

Inoculation of *Azospirillum* highly stimulates the availability of exchangeable NH_4-N in the rhizosphere soils of rice. This pointed out that inoculation of *Azospirillum* induces the activity of ammonifying bacteria resulting in greater mineralization of organic N in rhizosphere soils (Ghosh *et al.*, 1998).

Das and Saha (2004) found that single inoculation of Azotobacter and *Azospirillum* highly stimulate the exchangeable NH_4-N in rhizosphere soils of rice. The accumulation of NH_4-N decreased at maturity stage of the crop due to higher nitrification.

5.5.2 Nitrate nitrogen

The NO_3^-N concentration was found to be higher under SRI method of cultivation compared to traditional method. In SRI method, the partial aerobic soil supported relatively high nitrification resulting in high concentration of NO_3-N. According to Milka *et al.* (2000) the N losses from nearly saturated soil were 14 per cent lower than from flooded soils. Moreover, higher rates of denitrification in flooded condition might have reduced NO_3-N content. In

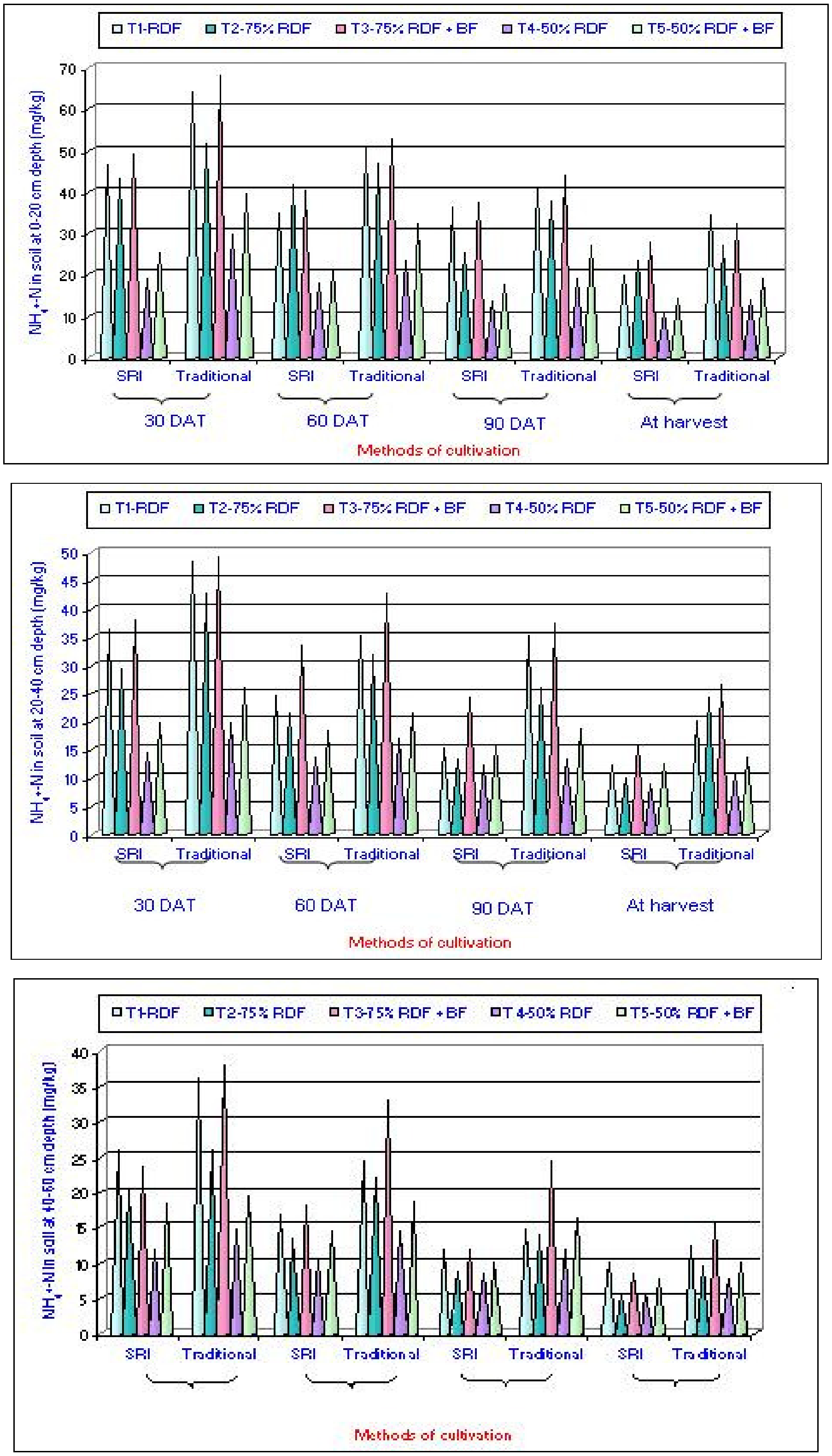

Fig. 9: Effect of SRI and Traditional methods of cultivation and fertilizer levels on NH_4-N in soil (mg/kg)

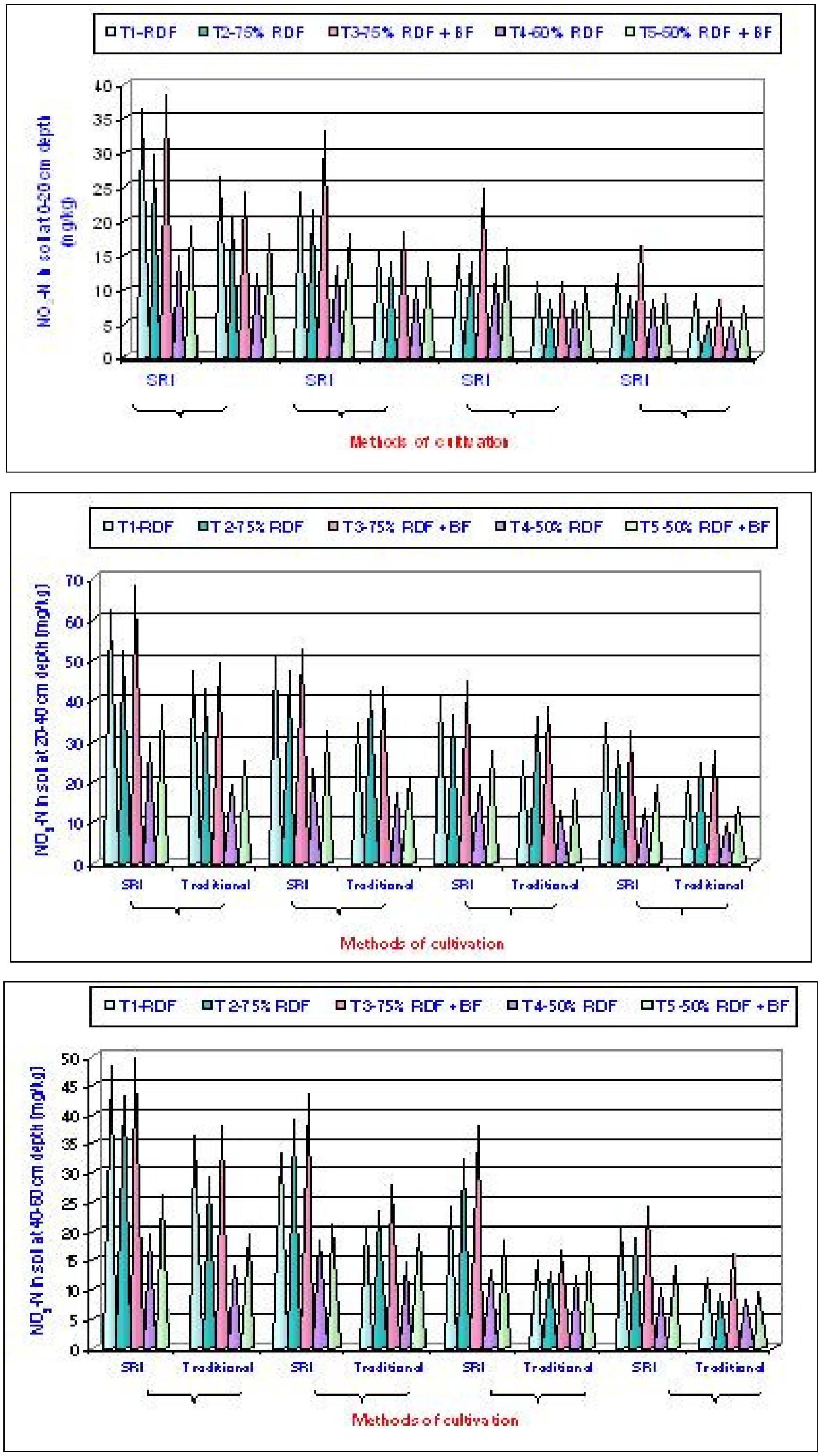

Fig. 9: Effect of SRI and Traditional methods of cultivation and fertilizer levels on NO_3- N in soil (mg/kg)

flooded condition N mineralization cannot proceed past the ammonia stage due to absence of oxygen which is necessary for the conversion of ammonia to nitrate.

NO_3-N content decreased as the growth advanced. Depletion of NO_3-N with advance in crop may be attributed to increased crop uptake of N and loss of N through denitrification.

There was an increase in NO_3-N content with increase in depth upto 20 to 40 cm and thereafter it decreased. The NO_3-N content in the 40 to 60 cm depth was more than 0 to 20 cm depth. This may be attributed to the high mobility of NO_3-N from surface to deeper layers (leaching) along with the percolating water after irrigation.

Among the treatments, the treatment receiving 75 per cent RDF + biofertilizers recorded high NO_3-N content. This may be attributed to the high microbial conversion of ammonia to nitrate.

VI. SUMMARY

A field experiment was conducted at Agricultural Research Station, Gangavati, University of Agricultural Sciences, Dharwad during late *rabi* 2005-06 to study the nutrient management in paddy under SRI and traditional methods of cultivation with the following objectives.

1. To compare the growth and yield of rice under SRI and traditional methods of cultivation as influenced by nutrient levels and biofertilizers.
2. To study the nutrient uptake of paddy under SRI and traditional methods of cultivation as influenced by nutrient levels and biofertilizers.
3. To study the N dynamics in SRI and traditional methods of cultivation as influenced by nutrient levels and biofertilizers at different depths during different stages of crop growth.

The field experiment was laid out on medium, deep black clay soil at Agricultural Research Station, Gangavathi. Split plot design was adopted and the treatments were replicated thrice. The treatments consisted of two methods of cultivation (SRI and traditional) as main plots and five fertilizer levels (100% RDF, 75% RDF, 75% RDF + biofertilizers, 50% RDF, 50% RDF + biofertilizers) as subplots.

Data pertaining to growth parameters *viz.,* plant height, number of tillers per hill, number of tillers per m^2, dry matter production and yield parameters *viz.,* panicle length, number of grains per panicle, test weight, grain yield, straw yield and harvest index were collected at 30, 60, 90 DAT and at harvest

Soil and plant samples were drawn at 30, 60, 90 DAT and at harvest for various analysis. Chemical analysis of available N, P and K, NH_4^-N and NO_3^-N in soil and N, P and K in plant was carried as indicated in Material and Methods.

The inferences and conclusion drawn from the experimental results are presented in this chapter.

- ✓ Significantly taller plants, higher number of tillers and dry matter percentage was noticed in SRI method of cultivation at all the growth stages of crop as compared to traditional method.
- ✓ SRI method of cultivation recorded significantly higher grain yield and yield attributes compared to traditional method of cultivation.
- ✓ Significantly higher concentration of plant N, P and K was noticed in SRI method as compared to traditional method.
- ✓ Significantly higher uptake of N, P and K was noticed in SRI method as compared to traditional method.
- ✓ SRI method registered higher available N, P and K in soil compared to traditional method.
- ✓ Higher concentration of NH_4-N was registered in traditional method while higher concentration of NO_3^-N was registered in SRI method at all depths.
- ✓ Application of 75 per cent RDF + biofertilizers recorded significantly taller plants, number of tillers per hill at all the growth stages. The least was recorded by treatment T_4 (50% RDF).
- ✓ The dry matter production increased rapidly in all the treatments from early stage to harvest. Highest dry matter was noticed in treatment which received 75 per cent RDF + biofertilizers.
- ✓ The yield components viz., number of productive tillers per hill, number of productive tillers per m^2, panicle length, number of grains per panicle, 1000-grain weight and yield were highest with the application of 75 per cent RDF + biofertilizers.

- ✓ Significantly higher concentration of plant N, P and K was recorded in treatment T_3 (75% RDF + biofertilizers), while lowest was recorded in treatment T_4 (50% RDF).
- ✓ Application of 75 per cent RDF + biofertilizers recorded significantly higher uptake of NPK at all growth stages of crop. Lowest uptake was recorded in T_4 (50% RDF) which had not received biofertilizers.
- ✓ Available N, P and K in soil were higher in treatment T_3 (75% RDF + biofertilizers) and lowest N, P and K values were obtained in T_4 (50% RDF).
- ✓ Treatment T_3 registered significantly higher readily available NH_4-N and NO_3^-N contents at all growth stages.

Future Line Of Work

- Rice yields all over the world have leveled out under the present system of flooded cultivation. We need to be looking for alternatives to existing practices with an open mind.
- SRI is still evolving and it is hoped that the scientific community will collaborate in further refining the SRI practices and working out the scientific reasons for the reported higher productivity.
- Planting young seedlings carefully and at wider spacing gives the plant more time and space for tillering and root growth. Careful water management keeping the field wet and not flooded gives better yield as it supports healthy root growth.
- This practice should be encouraged everywhere as the whole world is facing water shortages. Weeding rice fields with a rotary weeder helps by churning the soil and incorporating the weed biomass as it aerates the root zone.

Therefore, seeing the overall benefits, the SRI needs to be evaluated further and refined to suit local environments.

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A COMPARATIVE STUDY OF NUTRIENT MANAGEMENT IN PADDY UNDER SRI AND TRADITIONAL METHODS OF CULTIVATION

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ABSTRACT

A field experiment was conducted at Agricultural Research Station, Gangavati, University of Agricultural Sciences, Dharwad during late *rabi* 2005-06 to compare the growth, yield, nutrient uptake and N dynamics of paddy under SRI (System of Rice Intensification) and traditional methods of cultivation as influenced by nutrient levels and biofertilizers. The experiment was laid out on medium deep black clay soil by adopting split plot design and the treatments were replicated thrice. The treatments consisted of two methods of cultivation (SRI and traditional) as main plots and five fertilizer levels (100% RDF, 75% RDF, 75% RDF + biofertilizers, 50% RDF, 50% RDF + biofertilizers) as subplots.

Significantly taller plants, higher number of tillers and higher dry matter production were noticed in SRI method of cultivation at all growth stages as compared to traditional method. SRI method recorded higher grain yield and yield attributes compared to traditional method of cultivation. Significantly higher concentration of plant N, P and K, higher uptake of N, P and K and higher available N, P and K in soils were noticed in SRI method as compared to traditional method. Higher concentration of NH_4-N was registered in traditional method while higher concentration of NO_3-N was registered in SRI method at all depths.

Application of 75% RDF + biofertilizers resulted in significantly taller plants, higher number of tillers per hill, highest dry matter and higher grain yield and yield attributes. Significantly higher concentration of plant N, P and K, higher uptake of N, P and K and available N, P and K in soil were recorded in treatment receiving 75% RDF + biofertilizers. The same treatment also registered significantly higher readily available NH_4-N and NO_3-N contents at all stages. But, the lowest values were obtained in the treatment receiving 50% RDF.