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SITE SPECIFIC NUTRIENT MANAGEMENT FOR SEMI-DRY RICE OF RAMANATHAPURAM DISTRICT, TAMIL NADU

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TAMIL NADU AGRICULTURAL UNIVERSITY

MADURAI – 625 104

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Thesis submitted in partial fulfillment of the requirements for the degree of
DOCTOR OF PHILOSOPHY (Agriculture) in Soil Science and Agricultural Chemistry
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(R. DHANASEKARA PANDIAN)

ABSTRACT

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Soil nutrient database of semi-dry rice soils of Ramanathapuram district was created by collecting 129 and 126 soil samples from 22 and 21 villages of Paramakudi block and Ramanathapuram block, respectively. Two major soil profiles of soil series viz., Paramakudi and Thirupullani were studied and characterized. The soil nutrient database was used to identify soil-related constraints to be addressed to maximise rice productivity. Also 70 ground water samples were collected and characterized to assess their suitability for supplemental irrigation to semi-dry rice during drought condition.

In Paramakudi soil series, the surface texture was sandy clay followed by clay in all the sub-horizons. The bulk density of the horizons was 1.40 to 1.48 (Mg/m^{-3}), soil pH was neutral; EC varied between 1.5 and 1.90 dSm^{-1} with low organic carbon, low available N and P and high in available K status. In all the horizons free $CaCO_3$ varied between 1.51 and 1.96 per cent which indicated the calcareous nature of soil series. The CEC of different horizons varied between 30.6 and 49.7 cmol (p^+) kg^{-1} with BSP of 88.8 to 98.9 per cent, respectively.

The Thirupullani soil series which is predominant in Ramanathapuram block had loamy sand as texture in surface horizons followed by sandy clay loam and sandy loam subsurface horizon. Due to the presence of cemented hard pan in

subsurface horizon, soil become impervious and the monsoon rain gets stagnated which favours semi-dry rice cultivation. The bulk density of different horizons varied between 1.6 and 1.72 Mg m^{-3}. Soil pH was neutral; EC varied from 1.3 to 1.8 dSm^{-1}, with low organic carbon status and low available nitrogen content. In the surface A_p horizon available P content was medium while available K content was high in all the horizons, the CEC varied from 8.11 to 21.65 cmol (p^+) kg^{-1}, with BSP of 74.11 to 85.05 per cent.

Site Specific Nutrient Management (SSNM) approach, a plant-based approach developed by IRRI, Philippines was used to optimise fertilizer N, P and K requirement of semi-dry rice for a yield target. To develop SSNM methodology, one on-station experiment each at ARS, Paramakudi and CSRC, Ramanathapuram was conducted during 2011-12 with two on-farm trials each at Paramakudi and Ramanathapuram blocks respectively. The treatments include nutrient omission plots viz., PK (-N), NK (-P), NP (-K), NPK, NPK with organic manure (FYM@12.5 t ha^{-1}) and farmers fertilizer practice (FFP) with four replications. The test crop rice (ADT45) was grown during October-January 2011-12. Based upon the nutrient omission plot yield, SSNM package for yield target of 4.0 and 3.5 t ha^{-1} was developed for Paramakudi and Ramanathapuram blocks, respectively and test verified during October-January 2012-13.

In Paramakudi block, during 2011-12, application of NPK with FYM recorded the maximum mean plant height of 35.3 cm (AT) and 68.3 cm (PI), more number of mean total and productive tillers of 14.2 (PI) and 9.60 (PI) respectively, highest DMP of 3484 (AT) and 6784 (PI) kg ha^{-1}, more thousand grain weight of 22.0 g and higher grain and straw yield of 3526 and 4130 kg ha^{-1} respectively. Likewise, maximum total N uptake of 64.6 kg ha^{-1} (PI) and 98.1 kg ha^{-1} (PH), total P uptake of 16.7, 34.7 and 41.7 kg ha^{-1} in AT, PI and PH stages and total K uptake of 56.7,114.5 and 148.3 kg ha^{-1} respectively were recorded under NPK +FYM treatment. Also, NPK along with organic manure application recorded the highest total mean factor productivity (TFP) of 25.7 kg per kg of nutrient applied, mean partial factor productivity (PFP) of 47.0 kg per kg of N and mean agronomic efficiency of 25.3 kg yield increase per kg of N, respectively. This was followed by, either NPK alone (or)

FFP which recorded next best values in all the above parameters in all the on station and on farm experiments.

In Ramanathapuram block during 2011-12, application of NPK with FYM recorded the maximum mean plant height of 35.8 cm (AT) and 71.7 cm (PI), more number of total and productive tillers of 11.4, 14.9 and 12.6 at AT, PI and PH stages, respectively. The highest DMP of 2132 and 5629 kg ha^{-1} at AT and PI respectively, more thousand grain weight of 20.5 g and highest grain yield of 3246 kg ha^{-1} respectively were recorded under NPK+FYM. The maximum total N uptake of 28.3 (AT), 65.1 (PI) and 93.1 kg ha^{-1}(PH) respectively, the highest total P uptake of 8.5, 27.4 and 33.9 kg ha^{-1} in AT, PI and PH stages respectively and K uptake of 32.8, 103.2 and 109.2 kg ha^{-1} at AT, PI and PH stages respectively were recorded in NPK+FYM. Also the maximum mean TFP of 23.60 kg per kg of nutrient applied, mean PFP of 42.23 kg per kg of N applied, mean AE of 22.96 kg per kg of N applied and mean RE of 0.40 kg of N uptake per kg of N applied were recorded in NPK+FYM treatment respectively. This was followed by, either NPK alone (or) FFP which recorded the next best values in all the experiments.

In Paramakudi block, during 2012-13, the SSNM package recorded the highest mean plant height of 33.9 cm (AT) and 75.4 cm (PI), more number of mean total productive tillers of 11.0 15.5 and 12.8 at AT, PI and PH respectively. The highest mean DMP of 3771 (AT) and 7032 (PI) kg ha^{-1} more mean thousand grain weights of 22.5 g and highest mean grain and straw yield of 3922 and 4440 kg ha^{-1} respectively were recorded under SSNM treatment. Likewise, highest mean total N uptake of 46.3 kg ha^{-1} (AT), 68.7 kg ha^{-1}(PI) and 105.1 kg ha^{-1} (PH), mean total P uptake of 15.9 , 37.7 and 47.9 kg ha^{-1} and mean K uptake of 62.4, 118.2, and 141.1 kg ha^{-1} in AT, PI and PH stages respectively were recorded with SSNM based NPK application. The SSNM package and NPK+FYM recorded the highest mean TFP with 24.83 and 25.03 kg per kg of nutrient applied respectively; NPK alone and NPK +FYM @12.5 $t.ha^{-1}$ recorded highest mean PFP with 43.76 and 45.9 kg per kg of N applied, mean AE with 21.4 and 23.53 kg per kg of N applied and mean RE with 0.38 and 0.43 kg of N uptake per kg of N applied respectively.

In Ramanathapuram block during 2012-13, SSNM package recorded the maximum mean plant height of 34.0 cm (AT) and 75.6 cm (PI), more number of

mean total productive tillers of 10.6,16.0 and 14.2 at AT, PI and PH respectively highest mean DMP of 2800 and 5826 kg ha^{-1}, at AT and PI respectively, more mean grain weight of 23.9 g and maximum mean grain and straw yield of 3433 kg ha^{-1} 4326 kg ha^{-1} respectively and the highest mean total N uptake of 36.7 kg ha^{-1} (AT), 50.5 kg ha^{-1} (PI) and 94.4 kg ha^{-1} (PH), mean total P uptake of 10.4, 27.5, and 44.1 kg ha^{-1} and mean total K uptake of 41.6,91.6 and 110.2 kg ha^{-1} at AT,PI and PH stages respectively. TFP of 23.20 kg per kg of nutrient applied, RE of 0.38 and 0.40 were recorded in SSNM treatment.

In 2011-12, in Paramakudi block mean indigenous N supply (INS), mean indigenous P supply (IPS) and mean indigenous K supply(IKS) were 59.3, 26.9 and 92.9 kg ha^{-1},while in Ramanathapuram block, mean INS, IPS and IKS were 55.8, 21.5 and 84.1 kg ha^{-1} respectively. In 2012-13, in Paramakudi block, mean INS, IPS and IKS were 67.8, 35.6 and 107.9 kg ha^{-1} respectively while in Ramanathapuram block, mean INS, IPS and IKS were 57.0, 29.7 and 88.2 kg ha^{-1} respectively

In Paramakudi block, mean N, P and K requirement of rice were 37.3, 12.8 and 35.7 kg t^{-1} during 2011-12, while it was 39.9, 13.9 and 36.8 kg t^{-1} during 2012-13. Similarly in Ramanathapuram block, mean N, P and K requirement of rice were 36.7, 10.8 and 36.4 kg t^{-1} while it was 31.1, 12.9 and 32.3 kg t^{-1}in during 2012-13 respectively.

For a yield target of 4.0 t ha^{-1}, in Paramakudi block, mean N, P and K fertilizer requirement was 150, 20 and 30 kg ha^{-1}. In Ramanathapuram block, for a yield target of 3.5 t.ha^{-1} N, P and K requirement was 140, 20 and 30 kg ha^{-1} respectively.

Hence application of NPK + FYM@12.5 t.ha^{-1} with SSNM package for semi-dry rice will increase rice yields by 0.5 to 1.0 t.ha^{-1} which will give additional profit of Rs. 5000 to Rs. 10,000 per ha. Also application of $FeSO_4$ or $ZnSO_4$ as soil application in deficient areas with supplemental irrigation with best available ground water will increase yields of semi-dry rice of Ramanathapuram district.

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CHAPTER I

INTRODUCTION

For more than half of humanity in this planet earth, rice is life. It is the grain that has shaped the cultures, diets, and economies of billions of people in Asia. For them, life without rice is simply unthinkable. Between now and 2020, 1.2 billion new rice consumers will be added in Asia (TARF). Feeding these people will require the greatest effort in the history of agriculture: rice production must be increased by one third from today's 320 million tonnes to 420 million tonnes. Farmers will have to grow an extra 3.7 million tonnes every year at the very time that rice land is decreasing and the remaining fields seem to be wearing out.

In coastal Tamil Nadu, rice is grown under upland condition wherein, rice is grown as pre-monsoon direct sown with dry seeding during September-October. The Ramanathapuram district is a dry district where non-system tank is the major source of irrigation; hence rainfall is the most decisive factor (Selvaraj and Ramasamy, 2006). Apart from drought, other abiotic stress like salinity, low soil fertility, less water holding capacity and imbalanced use of fertilizers, etc, are the major reason for low yields in semi-dry rice soils, which is the livelihood for farmers living in an area of 73,550 ha in Ramanathapuram district of Tamil Nadu.

In coastal areas, rice is grown as direct sown dry seeded rice during pre-monsoon season viz., September second week onwards at Paramakudi block and October first week onwards at Ramanathapuram block. In Paramakudi block, semidry rice is grown with supplemental irrigation either through tanks or underground marginally saline water. But in Ramanathapuram block, the underground water is poor quality viz., high SAR saline or alkali in nature which could not be used for supplemental irrigation (AICRP, 2000-2002). Hence when the monsoon recedes early during flowering stage (December second week onwards) rice yields are drastically affected. Therefore managing abiotic stress of drought and imbalanced fertilization with selection of good cultivars and creating awareness among farmers of above technologies will increase rice yields of semi dry rice. There is a scope to increase yield by 0.5 to 1.0 t ha^{-1} with supplemental irrigation combined with balanced

fertilization which will increase net profit of farmers by Rs.5000 to Rs.10000 per ha (FAO,1999).

The site specific nutrient management (SSNM) is a plant-based approach which optimises the fertilizers N, P and K requirement for a yield target using nutrient omission plots. The SSNM approach developed by International Rice Research Institute, Philippines and test verified in more than 200 on-farm trials at Cauvery delta in irrigated transplanted rice. The SSNM strategy include field and season specific fertilizer rates, which are calculated after taking into account the indigenous soil nutrient supply, plant nutrient demand and interaction among N,P and K (Fairhurst, 2000). The SSNM approach aims to increase farmers profit through, i) increased yield of rice per unit of applied fertilizer, ii) higher rice yields iii) reduced disease and insect damage and also eliminate waste of fertilizer by preventing excessive rate of fertilization. Sasaki, (2001) reported that under SSNM for rice, yield advantage varied between 0.31 t ha^{-1} in the first year (+6 per cent) and 0.41 t ha^{-1} in the second year (+8 per cent). Hence, this SSNM approach is used to optimise fertilizer N, P and K for semi dry rice for the first time in Ramanathapuram district.

IFAD (1992) suggested that the key to nutrient management in direct seeded rice is the basal application of P and split application of N during panicle initiation and heading stages. It was recommended that full basal application of P, half N and K at 15 days after sowing and the remaining N and K at 45 DAS was on par with the application of full P and K and half N basally and the remaining N applied at 45 DAS. Kim and Bajitz (1995) reported that in aerobic soils Fe oxidation by root released O_2 reduces rhizosphere soil pH and limits deficiency of Zn from highly insoluble fractions for availability to the rice plant. Basal application of Zn @ 25-50 kg ha^{-1} as $ZnSo_4$ is recommended. Pal *et al*., (2008) reported that under aerobic condition, deficiency of iron is more pronounced due to oxidation of available (Fe^{2+}) form to unavailable (Fe^{3+}) form in soil. Yadav *et al.,* (2011) reported that application of 50 kg ha^{-1} with 2 foliar sprays @ 2 per cent $FeSO_4.7H_2O$ results in higher yield.

In semi-dry rice soils of Ramanathapuram district, rice yield varied between 2.5 to 3.0 t ha^{-1} under farmers fertilizer practices (FFP) with yield potential up to 4.0 t ha^{-1} under best management practices. Hence to bridge this yield gap of 1.0 t ha^{-1}, one on-station and two on farm trials were conducted during 2011-12 and

2012-13 at two domains viz., Paramakudi block with sandy clay loam to clayey texture and Ramanathapuram block with sandy to loamy sand surface texture with sandy clay loam sub horizon with hard pan which enables water stagnation and successful raising of semidry rice in Ramanathapuram district..

In coastal soils of Tamil Nadu where rice is grown under semi dry condition, resource inventory of both soil and ground water, rainfall distribution, its harvesting and recycling for supplemental irrigation or conjunctive use with poor quality water, use of high yielding cultivars like Anna 4 will enhance the rice yields and net income of the resource poor farmers of this region.

Hence this study was planned with the following objectives.

- To create the soil nutrient database of semi-dry rice soils of Ramanathapuram district
- To create and validate the Site Specific Nutrient Management (SSNM) for semi-dry rice.
- To evaluate the effect of Site Specific Nutrient Management on yield, nutrient uptake and use efficiency by semi-dry rice.
- To evaluate the effect of Site Specific Nutrient Management on indigenous nutrient supply and nutrient requirement of rice.

CHAPTER II

REVIEW OF LITERATURE

In Ramanathapuram district and other coastal areas of Tamil Nadu rice is grown under semi-dry condition with pre-monsoon sowing with average yields of 3-4 t ha^{-1}.The main reasons for low yield are abiotic stress like drought, low soil fertility, imbalanced fertilization, etc. Hence literature pertinent to above aspects including Site Specific Nutrient Management (SSNM) were reviewed and presented in this chapter.

2.1. Coastal saline soils

Environmental factors favourable to salinization are arid and semi-arid climates with evapotranspiration volumes greater than precipitation amounts for at least part of the year (aridic, ustic or xeric soil water regimes), most saline soils are also sandy and these saline sandy soils can be deleterious to plants and result in low yields, due to low fertility, high soluble salts especially sodium chloride, low water holding capacity and low cation exchange capacity. Rice is the major crop that is cultivated in most of the coastal areas during the northeast monsoon season.

Ponnamperuma (1972) found that saline soils vary widely in their chemical and physical properties as well as hydrology. Relevant parameters include the content and nature of salts, the distribution of salts in the surface horizon, the soil pH, the nature and content of clay, the organic matter content, the nutrient content, the water regime relief and the temperature. In coastal saline soils, the problem is further complicated by inundation through backwash from sea, tidal waters, wind borne salts and underground intrusion of sea water in sub soils (Agarwal, 1983).

Bandyopadhyay and Bandyopadhyay (1983) reported that the salinity of the soil varies with the season. It reaches the maximum between January and May and decreases thereafter with the onset of monsoon. This cyclic salt accumulation and intermittent flood make these regions predominant in rice cultivation. Coastal saline soils are characterized by clay loam either along with silt or sand with electrical conductivity ranging from 0.5 to 9.2 and with sodium as dominating salts (Bandyopadhyay and Sen, 1987).

Biswas and Bhattacharya (1987) observed that salinity is the major limiting factor towards increasing productivity in coastal soils. Rice is grown as a major crop in most of the coastal areas during the north east monsoon season (Kothandaraman, 1987).

Biswas *et al.* (1990) observed that coastal saline soils generally have highly saline shallow underground water table with gradual upward movement of saline water during summer months and subsequent evaporation of the water that contributes to soil salinity during dry periods.

2.1.1. Nutrient status of coastal saline soils

The coastal zone of Tamil Nadu is subjected to heavy rainfall resulting in leaching of nutrients particularly nitrogen and potassium leading to poor soil fertility, low pH, high Al and Fe content, low available phosphorus and low to medium available potassium. 'Zn' deficiency is another important problem in these soils. Rice is the main crop in this ecosystem and the low fertility status of these soils results in low production of rice.

2.1.1.1. Organic manure application

Combined use of organic manures (FYM, green manure etc.) and fertilizers is also recommended. The use of green manures either alone or in combination with mineral fertilizers was very important for efficient nitrogen management of saline and alkaline soils

Regular application of FYM to saline soil gradually increased the yield of crops. Interestingly, addition of organic matter to saline soil improved soil physical condition including ability to leach the salts from soil profile which improved the yield of crops (Saravanan *et al.*, 1991).

Patil *et al.* (1991) suggested that it is important that regular application of organic manure to saline and alkali soils is an urgent need for sustainable productivity and improvement of fertility and physico-chemical properties of saline and alkali soils.

Integrated nutrient management with organic matter as one of the major inputs has more often been used for low input sustainable agriculture on saline and

alkali soils. Use of FYM, green manure, bio-fertilizers, etc., in addition to NPK fertilizers resulted in significant increases in yield and nutrient uptake by crops (Sahu *et al.,* 1996).

Mirza *et al.* (2010) reported that the increase in plant height, number of tillers per hill, spikelet number per panicle, grain yield and 1000-grain weight in response to application of organic and chemical fertilizers is probably due to enhanced availability of nutrients.

Mirza *et al.* (2010) reported increase in number of tillers in rice plants due to influence of fertilizer combinations, according to them, more number of tillers per square meter might be due to the more availability of nitrogen which plays a vital role in cell division. Organic sources offer more balanced nutrition to the plants, especially micro nutrients which positively affect number of tillers in plants (Siavoshi *et al.,* (2011).

Salem (2006) reported that application of FYM along with nitrogen fertilizer significantly increased number of panicles per square meter, panicle length, panicle weight, number of filled grains/panicle, and 1000 grain weight and grain yield in rice.

Luong and Heong (2005) observed that excess application of inorganic fertilizers is not necessary to produce effective tillers if we can supplement it from organic manures, which also help in providing essential micronutrients to the plants. Organic sources offer more balanced nutrition to the plants, especially micro nutrients which positively affect number of tiller in plants (Miller, 2007).

Luong and Heong (2005) resembled that reduction in unfilled grain percentage, increase in grain weight of rice with application of organic manure. Bala *and* Hossain (2008) suggested application of Mo with organic matter to produce highest number of panicle / hill, spikelets / panicle and grains.

2.1.1.2. Nitrogen

Bandyopadhyay *et al.* (1990) reported that nitrogenous fertilizers play a very important role in utilizing salt affected soils (saline and sodic or alkali soils) for improving crop yield, since most of the salt affected soils are deficient in nitrogen. Due to low vegetative cover the N content is low in salt affected soils. Further, due to

high rates of decomposition in arid and semi-arid regions the organic matter content of most of the inland salt affected soils in India is very low.

Chawla (1969) observed that the organic matter content in alkali soils of Punjab was 0.23-0.56% and significant negative correlation between pH and available nitrogen was reported. Less nodulation and lower nitrogen content in nodules of *Casuarina equisetifolia* grown in alkali soils. Because of high pH and salt concentration the transformations and mineralization of nitrogen from soil organic matter are slower in salt affected soils (Batra and Abrol, 1986)

Kanvar *et al*. (1965) reported that N content in salt affected soils of Punjab and Haryana was lower than the normal soils and most of the soils were low in organic-N and nitrate-N. They observed that nitrogen content in soil decreased with depth and nitrate form of nitrogen dominated over the ammoniacal form.

Bandyopadhyay and Bandyopadhyay (1983) observed that the rate of mineralization of nitrogen was slowed down by increase in soil salinity and ECe above 10 dSm^{-1} was more harmful. The rate of conversion of one form of nitrogen to other forms is also quite slow in salt affected soils. It was observed that hydrolysis of urea to ammonium nitrogen was much slowed down with increase in soil pH.

Rao (1984) observed that significant negative correlation between soil pH and activity of urease and dehydrogenase enzymes in alkali soil of karnal, urease activity has been shown positively correlated with organic carbon, silt plus clay content and total nitrogen.

Bandyopadhyay and Sen (1987) observed that volatilization loss of N from urea and ammonium sulphate increased with increase in salinity of soil. Volatilization losses of ammonium sulphate were higher during first few weeks.

CSSRI suggested that alkali soils generally needed 20-25 % more nitrogen than normal soils for the same cropping system. Due to the rapid enzymatic hydrolysis of urea in alkali soils, the released NH_3 tend to escape into the atmosphere.

2.1.1.3. Phosphorus

Bandyopadhyay and Biswas (1988) observed that coastal saline soil was rich in Ca-P,in calcareous alkaline soils, phosphorous tends to form di-calcium phosphate and then octa calcium phosphate thus reducing the availability of P.

Chhabra *et al.* (1981) observed that while working on alkalis soils the amount of P observed by soil was function of ESP/pH and amount of P absorbed by soil decreased significantly (r = -0.91 to -0.97) with increase in ESP although the soil showed net release of P with ESP.

In acid sulphate soils of the coastal regions phosphorus deficiency become one of the most limiting factors for growth of crops. High acidity condition of soil increased solubility of aluminum and iron thus, inducing acute deficiency of phosphorus. The use of rock-phosphate under acid sulphate soil was beneficial but the use of single super-phosphate was highly beneficial to yield (Bandyopadhyay *et al.*, 1990).

Both rice and wheat responded to added phosphorous. Application of 60 kg P_2O_5 ha^{-1} in wheat and 30 kg ha^{-1} in rice appeared most promising dose. Residual effects of phosphorous were also well marked (Ponnamperuma, 1974).

The critical values at which crop respond to applied P vary greatly with the nature of the soil (clay content) and stage of its reclamation, initial soil-test value, crop to be grown and the type of amendment used for reclamation (Swarup and Sarkar, 1974).

Results of a long term fertility experiment conducted on a gypsum-amended alkali soil (texture loam, pH 9.2, ESP 32) with rice-wheat and pearl millet-wheat cropping system and NPK fertilizer use showed that phosphorous applied at a rate of 22 kg P ha^{-1} to either or both rice and wheat crop in the system significantly increased the grain yield of rice when Olsen's extractable P (0-15cm soil) had decreased from the initial level of 33.6 kg ha^{-1} to12.7 kg P ha^{-1} which was very close to the widely used critical soil text value of 11.2 kg P ha^{-1}. Though wheat responded to applied P when available P level decreased close to 8.7 kg ha^{-1} pearl millet did not respond to applied P at this level of critical soil-test value.

Rice and wheat responded to P application in pyrite-amended alkali clay-loam soil (pH 9.3, ECe 3.42 $dSm^{-1,}$ CEC 20.1 m.e.100 g^{-1} and ESP 46.7) testing low in available P (4.63) (Tiwari *et al.*,1989).

In a long term study which reported that coastal saline soils of West Bengal initially did not respond to P application as the soil was rich in available P. The use of

organic matter is very beneficial for P management of saline and alkali soils the use of green manures increased the available P content of soil and the efficiency of single super phosphate and rock phosphate and rock phosphate and increased the yield of crops (Bandyopadhyay and Maji, 1989).

2.1.1.4. Potassium

Salt affected soils, both in alluvial and black soil region in India, are generally rich in available potassium. The availability of potassium in salt affected soil depends primarily on the parent materials, weathering conditions and type and amount of clay minerals (Acquaye *et al.*, 1974).

It was reported that most of the coastal saline soils of Orissa and West Bengal were rich in both available and non-available forms of K and there might not be any depletion of available K content of soil even after repeated crop cultivation without K fertilizer (Bandyopadhyay and Maji, 1989).

In the micaceous soils of the indo-gangetic plains, crop response to applied potassium fertilizers has not been observed even after nearly 15 years of rice-wheat cropping. Thus, it has been suggested that most of the saline and alkali soils can be cultivated without K fertilizers which may not have any adverse effect on soil fertility and crop yield (Swarup and Sarkar, 1974).

2.1.1.5. Micronutrients

The most important factors influencing micronutrient availability in salt affected soils are pH, soil texture, organic matter, calcareousness and salinity of soil. It is observed that each unit increase in pH reduces the solubility of divalent cations by 100 times and that of trivalent cations by 1000 times (Lindsay, 1978).

High and positive correlation was noted between soil organic matter contents and available micronutrient contents. A negative correlation between pH and available Cu in the sodic soils of Uttarpradesh was observed (Agarwal *et al.*, 1977).

Studies at CSSRI, Karnal have shown that many of the alkali soils were deficient in Zn and application of 45 Kg zinc sulphate per ha increased the yield of rice on soil having pH 10.2. The deficiency of Fe, Mn and Cu are also quite frequent

in alkali soils normal soils. Very low amount of exchangeable Mn in the salt affected soils of Rajasthan, Punjab and U.P. was reported (Kanwar and Randhava, 1974).

Flooding or poor drainage conditions, as found in many saline and alkali soils, have profound influence on the availability of several micronutrients, particularly Fe and Mn. The coastal saline soils are normally well supplied with available Fe, Mn, Cu and B but many are deficient in Zn and Mo (Maji *et al.* 1992).

Chatterjee and Das (1964) found that there was more ammonium acetate extractable zinc in soils with pH below 6.0 and its content decreased as pH rise above 7.0.Sandy coastal alluvium of Tamil Nadu is low in total P_2O_5 and lime and fair in total K_2O and organic carbon.

2.2. Direct Seeding of rice (DSR)

Asian rice systems are undergoing various types of change in response to economic factors and technological opportunities in farming. One such change has been a shift from transplanting to direct-seeding methods for rice establishment. While the rising cost of labor has provided economic incentives for direct seeding, the availability of short-duration rice varieties and chemical weed control methods has made such a shift economically profitable.

In the future, in addition to the rising cost of labor, rice farmers of Asia will have to deal with an anticipated increasing scarcity of irrigation water as the demand for water from the urban and industrial sectors expands. Direct-seeding methods, especially dry seeding, may help in achieving higher water-use efficiency.

2.2.1. Potential advantages of direct seeding

- Depending on the nature of the production system, direct seeding can reduce the labor requirement by as much as 50%.
- In situations where no substantial reduction in labor requirement occurs, direct seeding can still be beneficial because the demand for labor is spread out over a longer time than with transplanting, which needs to be completed within a short time.

- Direct seeding can also reduce the risk by avoiding terminal drought that lowers the yield of transplanted rice, especially if the latter is established late due to delayed rainfall.
- Direct seeding can facilitate crop intensification.

Erguiza *et al.* (1990) noted that the farmers with smaller families in relation to the size of the farm can prefer direct seeding to deal with the labour shortage. Farm-level studies have shown that transplanting tends to be the dominant method in bottom lands where water accumulates from neighbouring fields while direct seeding is practiced in higher fields (Pandey and Velasco,1999).

Tuong *et al.* (2000) suggested that DSR is established earlier than transplanted rice without growth delays from transplant injury. This hastens physiological maturity and reduces vulnerability to late-season drought.

Pandey and Velasco (1999) reported that in recent years, there has been a shift from TPR to DSR cultivation in several countries of Southeast Asia. They also noted that dry seeding has been the principal method of rice establishment since the 1950s in developing countries.

2.2.2. Crop establishment for dry direct-seeded rice

Commonly reported constraints to achieving higher productivity in dry-seeded rice involve delays in land preparation leading to late crop establishment, excessive weed infestation, uneven crop emergence, and poor water control.

2.2.2.1. Soil tillage

The objective of soil tillage in dry direct-seeded rice is to prepare a suitable seedbed by (1) destroying weeds and incorporating crop residues and manure, (2) improving soil aeration, (3) improving infiltration capacity, and (4) improving seed-soil contact by changing the aggregate distribution (Morris 1982).

Morris and Moody (1982) stated that in view of the significant weed infestation problems often encountered in dry seeded rice, weed control is frequently viewed as the primary objective of tillage

Rijk (1986) stated that Tillage operations can also prevent emergence of weeds and improve soil structure in specific situations, such as breaking up impermeable soil layers. Apart from irrigation pumping, soil tillage is often the first farm operation that is mechanized as it requires the highest amount of energy in agriculture. Trafficability is a measure of how well the soil will support the equipment used during tillage to operate the equipment effectively (Krause and Lorenz, 1984).

CIAP (1998) reported that One particular problem in rainfed lowlands is unlevelled land, which makes it more difficult to have an even crop establishment across fields, particularly under direct seeding.

Hoogmoed (1999) suggested that the suitability of soils to mechanized tillage can be characterized by the workability (or tillability) and trafficability of a soil. Workability can be defined as the relative ease by which a soil can be manipulated for a specific purpose; it is a measure of how much energy is required for tillage

Lantican *et al.* (1999) studied the relationship between land-leveling precision and grain yield in the same study area in the Philippines and concluded that yield for DSR was significantly correlated with precision of land leveling. Mean standard deviation for land leveling precision was 8 cm and farmers lost 925 kg ha^{-1} of yield because of land-level deficiencies.

Rickman *et al.* (1999) compared crop yields of transplanted and dry-seeded rice on 14 farms in Battamba, Cambodia, and concluded that levelling increased crop yields significantly for both transplanted and dry-seeded fields

2.2.2.2. Mechanical row seeding

The most widespread method for establishing dry direct-seeded rice is broadcasting seed by hand on tilled soil. Mechanical row seeding (i.e., using some type of mechanical implement to place the seed under the soil surface) can considerably reduce labour requirements of establishing dry-seeded rice and further improve emergence by placing seeds at a more uniform depth in the seedbed.

Seko (1954) reported that Lodging was divided into four types and, among them, two types of lodgings, root lodging and culm breaking, mostly occurred in

direct seeding cultivation. Lodging of rice plant at milky stage decreased grain yield 34 % in Korea (Lee *et al.*, 1991).

Ogata and Matsue (1996) reported that Lodging results in substantial yield reductions due to decreased photosynthesis by self-shading, and hampered grain quality due to increased colouring and decreased taste. DSR is more susceptible to lodging during ripening than TPR (Setter *et al.*, 1997)

Yamauchi (1995) reported that problems such as drought, salinity, crabs, birds, rats, and weeds are also more common among seedlings established from direct seeding. Some of the problems are reduced if seeds are planted deeper in the soil. He also observed that if seeds are placed at shallower depths, rice seedlings may not be able to emerge and crop establishment may be poor.

Tarashima *et al*. (1998) showed that machine drilling seed reduced lodging to less than 10%. When the seed was partially incorporated using drag harrows after broadcasting, 15% of the total crop lodged. In the same trial, 45% of the non incorporated dry-seeded crop lodged.

Rickman *et al.* (1999) reported that crop lodging is a significant problem in dry seeded rice. Lodging was reduced by partially incorporating the seed by harrows or by using a seed drill.

2.2.3. Enhancing the performance of dry-seeded rice

2.2.3.1. Seed priming

Seed priming with appropriate chemicals can be an effective option to cope with erratic rainfall when seeding has to be carried out early and seeds are likely to be exposed to droughts.

Primed seeds are those that undergo controlled hydration- dehydration pre-treatment before sowing. During hydration, seeds are allowed to absorb moisture to a point just prior to germination. After this period, seeds are dried to their original moisture content and stored before sowing.

Singh *et al.* (2000) reported that soaking seeds of three upland rice varieties in water for 24 hrs, followed by air drying, improved stand establishment by 23 to 43

per cent, compared with non-primed seeds, and grain yield by 11 to 24 per cent over three consecutive years.

Evidence is accumulating from recent research in a range of crop species and countries showing that fast germination, early emergence, and vigorous seedling growth may result in higher yielding crops (Harris 1996).

Harris and Jones (1997) showed that priming for 24 hrs effectively speeded up germination among a range of diverse upland rice cultivars. That Early emergence of a vigorous crop stand provides better root anchorage and improves nutrient absorptive capacity (Watanabe, 1997).

Tuong *et al.* (2000) found that to combat weed infestation, farmers in the Mekong Delta plant dry-seeded rice at a high density of up to 600 seeds m^{-2}. A plant density that is too high, however, may lead to increased early dry matter production but reduced grain yields. He also noted that Time of seeding may therefore influence weed infestation in dry-seeded rice because field hydrology changes with seeding dates.

Harris (1996) reported that On-farm priming in DSR has increased the rate of germination and emergence (by 1-3 days), resulting in more uniform and vigorous seedling growth.

Mohanasarida and Mathew (2005) found that Priming with 0.05 per cent Imidacloprid (N-[1-[(6-Chloro-3-pyridyl) methyl]-4, 5-dihydroimidazol-2-yl] nitramide) resulted in the highest seedling density during the early vegetative phase of semi-dry rice, with comparable results from NaCl (0.5 per cent), KCl (2 per cent) and the bio-fertilizer *Azospirillum* (2 per cent).

Farooq *et al.* (2011) reported that Osmo-hardening with KCl or $CaCl_2$ improved germination and emergence, allometry, kernel yield, and grain quality in direct seeded medium grain and fine grain aromatic rice compared with traditional farmer seed-soaking, which resulted in poor and erratic emergence of seedlings followed by poor crop performance.

Rickman *et al*. (1999) reported that in direct seeded fine grain rice, osmo-hardening with $CaCl_2$ had the best kernel yield (2.96 t ha^{-1} vs. 2.11 t ha^{-1}, untreated

control), straw yield (10.13 t ha^{-1} vs. 9.35 t ha^{-1}) and harvest index (22.61 per cent vs.18.91 per cent). Moreover, osmo-hardening with $CaCl_2$ improved P, Ca and K uptake, closely followed by osmo-hardening with KCl. Thus, osmo-hardening with $CaCl_2$ or KCl can improve crop stands, growth, yield and quality in DSR culture in farmers' fields.

2.2.3.2. Seeding rate and time of seeding

Naranswamy *et al.* (1982) have indicated that rice paddy yield can be improved by increasing plant density and early sowing. Optimum plant population contributes to high yield, which relates directly to seeding density and not to tillering ability (Janoria 1989).

Park (1991) indicated that rice yield can be improved by increasing plant density and early sowing. Studies have shown that it is possible to increase rice yield at farm level by about 50-60% by ensuring an optimum plant density (Miller *et al.,* 1991).

2.2.4. Specific genotypic characters required for direct seeding

Janoria (1989) reported that Early planting of photoperiod-insensitive cultivars would allow the crop to mature early to escape late-season drought. The use of photoperiod insensitive genotypes provides an opportunity to develop high-yielding cultivars. Early planting of photoperiod-insensitive and early heading rice varieties with better drought tolerance are better suited for dry-seeded rice, such as IR36 with 105days duration and good drought tolerance.

Mackill and Redona (1997) reported that A few characters are specifically required under direct seeding for rainfed lowland rice. These characters are associated with direct-seeding conditions and include photoperiod insensitivity, good competitive ability against weeds, seedling vigor including submergence tolerance, and lodging resistance.

Wong and Morooka (1996) reported that cultivar selection based on an ideal type has contributed remarkably to increased rice yield. Rice cultivars with fewer tillers, lower panicle weights with thick roots and culms are suitable for DSR. The modern semi-dwarf cultivars have a short mesocotyl, and this is disadvantageous for

good crop establishment, especially when seeds are drilled deeper in the soil (Fukai, 1999).

2.2.4.1. Seedling vigor

Seshu *et al.* (1988) stated that Seed vigor affects seedling establishment in all cereal crops, particularly in direct- seeded rice. Plants from low-vigor seeds showed delayed flowering, fewer panicles and filled grains, and lower grain yield than those from high-vigor seeds of the same variety (IRRI 2003).This is a particularly important genotypic character for rainfed direct seeding where water control is limited. Seedling vigor is the plant's ability to emerge rapidly from the soil or water and cover the ground fast. It is often determined as shoot length at particular days after seeding.

2.2.4.2. Competitive ability against weeds

Weeds are a major problem for direct-seeded rice, where the opportunity to control water is limited. Competitive cultivars are able to reduce weed biomass compared with non competitive cultivars. Competitiveness against weeds may be measured by the ratio of yield or biomass under unweeded and weeded conditions.

Garrity *et al.* (1992) found that large genotypic variation in competitiveness against weeds under both upland and lowland conditions. Several plant characters have been identified for strong competitiveness: tall plants, good tillering ability, and high leaf area index Bastiaans *et al.* (1997).

Fischer *et al.* (1997) reported that in which 10–14 semi dwarf cultivars were compared under competition with Echinochloa colona (L.), rice biomass was negatively correlated with weed biomass. Characters associated with rice competitiveness may be determined without weeds in some cases, such as rice plant height.

Dingkuhn *et al.* (1990) found quick-maturing cultivars to be rather susceptible to weed competition under upland conditions.

2.2.5. Yield reduction

Upasena (1980) reported that if weeds are not adequately controlled in the early stages of crop establishment, yield loss in broadcast rice may be severe.

Bhagat *et al*. (1998) observed that the degree of weed infestation in dry-seeded rice depends on the hydrological conditions of the field at the time of seeding and on tillage activities. High weed infestation is the major bottleneck in DSR especially in dry field conditions.

Tuong *et al.* (1995) noted that time of seeding may therefore influence weed infestation in dry-seeded rice because field hydrology changes with seeding dates.

Johnson *et al.* (1999) studied the management effects of 10 weeds in five farmers' fields in DSR and reported average yield losses of 49 per cent if weeds were not controlled. Critical periods for 95 per cent weed control were estimated to be 29-32 DAS in the wet season and 4-83 DAS in the dry season. In wet-seeded and dry-seeded rice, weed growth reduced grain yield by up to 53 and 74%, respectively (Ramzan, 2003).

Pellerin and Webster (2004) observed that several pre-emergence herbicides including Butachlor, Thiobencarb, Pendimethalin, Oxadiazon, Oxyfluorfen and Nitrofen, alone or supplemented with hand weeding, resulted in good weed control as expressed by reduced weed density and improved yields.

Singh *et al.* (2005) observed that in India, densities of barnyard grass, climbing dayflower (*Commelina diffusa* L.) and purple nut sedge (*Cyperus rotundus* L.) increased in DSR compared with TPR in field experiments from 2000 to 2004.

Allard *et al.* (2005) observed that weed species such as barnyard grass and Asian spangle-top (*Leptochloa chinensis* L.) become more prevalent within a few years of adopting direct-seeded rice. Estimated losses from weeds in rice are around 10 per cent of total production grain yield; however, such losses can be much higher Rao and Moody,(2007).

2.2.6. Nutrient dynamics in direct-seeded rice

Understanding nutrient management issues specific to direct-seeded rice, particularly in rainfed lands, is becoming important because of the continuous expansion of area under this culture. Approaches to nutrient management of direct-seeded rice depend on rainfall patterns, methods of direct seeding, soil type, and

soil/crop management. Rice soil in aerobic and reduced phases greatly differs in physical and chemical characteristics.

2.2.6.1. Nitrogen

Ponnamperuma (1974) reported that since nutrients are delivered to the roots primarily by mass flow and diffusion, the lower moisture content in the aerobic phase reduces the nutrient supply to the roots. Nitrogen is one of the yield limiting nutrients affecting growth and quality in rice systems (Nambiar and Ghosh, 1984).

Rao (1984) reported that an analysis across 14 locations of the All-India Coordinated Rice Improvement Project indicated that N application to direct-seeded lowland rice was beneficial only up to 40 kg N ha^{-1}. Most nutrient research on direct-seeded rice in the rainfed lowlands is on N.

Dingkuhn *et al.* (1990) stated that general recommendations for NPK fertilizers are similar to those in puddled transplanted rice, except that a slightly higher dose of N (22.5-30 kg ha^{-1}) is suggested in DSR.

Direct seeded rice soils are often exposed to dry and wet conditions and difference in N dynamics and losses pathways often results in different fertilizer recoveries in aerobic soils (De Datta *et al*. 1988).

Nitrogen application has great impact on crop yield in rice when acquired during early and mid tillering stages to produce high number of panicles and obtain optimum spikelets per panicle and high percentage of filled spikelet's (Murty *et al.,* 1986).

George *et al.* (1993) observed that dry seeding rice before the onset of rains enables the crop to use this soil nitrate. Further, soil nitrate as well as legume-fixed N can be accumulated in a post rice legume crop.

Applying 40 kg N ha^{-1} in three equal splits, with the latter two splits applied at panicle initiation and heading, resulted in higher grain yield and higher N accumulation (Deka and Bhattacharyya, 1994),

Bufogle *et al.* (1997) concluded that Split application is one of strategies for efficient use of N fertilizers throughout the growing season by synchronizing with

plant demand, reducing denitrification losses and improved N uptake for maximum straw and grain yield, and harvest index in DSR.

Hussain and Naqvi (1998) found that as a result of hot climatic conditions and high pH in calcareous soils of Pakistan, 22-53% of applied N is lost as ammonia volatilization. NUE ranges from 30-45% under traditional rice system (Zia *et al.*, 1997).

Linwattana (2001) reported the highest grain yield, crop growth parameters, and N uptake by direct-seeded lowland rice consistently across seasons and varieties when 60 kg N ha^{-1} was applied in three splits-15 kg each at 15 and 30 d after emergence (DAE) and the remaining 30 kg ha^{-1} at 45 DAE or at panicle initiation. Other split combinations produced significantly lower yields.

Shoji *et al.* (1992) found that slow-release (SRF) or controlled-release N fertilizers (CRFs) offer the advantage of a "one-shot dose" of N and because of their delayed release pattern may better match crop N demand to reduce its losses and labour cost.

Bouman (2002) found that the alternating moist and dry soil conditions during the growing season in DSR can stimulate nitrification and denitrification processes, resulting in a loss of N through NO_3 and N_2O. Moreover, the relatively low uptake of N by DSR under aerobic conditions can cause low fertilizer-N recovery. Split application of K has also been suggested for direct seeding in medium-textured soil (Philippines Rice 1995).

Zhang *et al.* (1998) concluded that absence of transplanting, shallow roots under direct seeded conditions results in low N uptake during early growth stages. They also indicated that high yielding rice cultivars usually exhibit vigorous vegetative growth under direct seeded condition and perform poorly during reproductive stages due to N deficiency.

Beldar *et al.* (2005) compared flooded and aerobic rice systems for crop performance using 150 kg ha^{-1} N applied in three splits and found decreased growth, yield and low N fertilizer recoveries under aerobic condition. He also reported that only 22 per cent of the 150 kg N ha^{-1} applied to DSR was taken up by the crop and 31 per cent was left in the soil and roots after harvest. Higher N losses accounted were

gaseous in their study and it was also suggested to optimize the dose and time of N application.

Ravigopal *et al.* (2010) reported that N management of zero till rice during 2008-2009 in Bihar (India) with two distinct cultivars and five nitrogen doses showed that the grain yield was maximum at N dose of 180 kg ha^{-1} for both varieties (Pusa Basmati 1 and Rajendra Mahsuri) in both years compared to lower doses (60 and 120 kg ha^{-1}) as well as of higher doses up to 240 kg ha^{-1}. N application time should be balanced to fulfill the crop requirement before and after anthesis (Mahajan *et al.* 2011).

Kamboj *et al.* (1999) reported that the general recommendation is to apply a full dose of P and K and one-third N as basal at the time of sowing. Split applications of N are necessary to maximize grain yield and to reduce N losses. The remaining two-third dose of N should be applied in splits and top-dressed in equal parts at active tillering and panicle initiation stages

H. U. Rehman *et al.* (1988) concluded that two or three N equal splits applied at sowing, tillering or anthesis increased growth attributes, dry matter accumulation and yield due to better crop nutrition and reduced N losses.

2.2.6.2. Phosphorus

De Datta (1986) reported that higher biomass production and more effective extraction of soil P via rhizosphere acidification and the formation of fine root hairs may induce P deficiency, as observed in Japan.

IFAD (1992) suggested that the key to nutrient management in direct-seeded rice is the basal application of P and split application of N at panicle initiation and heading. Results of studies on fertilizer management practices for lowland dry direct-seeded rice showed that the recommended full basal application of P, half N and K at 15 days after sowing (DAS), and the remaining N and K at 45 DAS was on a par with the application of full P and K and half basal N, with the remaining N applied at 45 DAS.

Alam and Ladha (1997) found that The use efficiency of P in a rice cropping system can be improved markedly by choosing a proper crop sequence and the crop to be supplied with P in that sequence

Patil *et al.* (1998) observed that direct-seeded rice performs better than transplanted rice at lower P application levels. This better performance has been attributed to more efficient P extraction because of the lowering of the rhizosphere pH to about 4 by rice root exudates under aerobic conditions. Young roots in the rice plant develop fine root hairs in aerobic soil, which may further contribute to better P use (Singh *et al.*, 1999).

2.2.6.3. Potassium

Mahanta (1993) observed a response by direct-seeded rice to 60 kg K_2O ha^{-1} in the first year, but no response in the second year.

Ladha *et al.* (2011) reported that in these soils, K can be split, with 50% as basal and 50% at early panicle initiation stage.

2.2.6.4. Micronutrients

Ponnamperuma (1974) reported that in direct seeding, availability of several nutrients including N, P, S and micronutrients such as Zn and Fe, is likely to be a constraint. Loss of N due to denitrification, volatilization and leaching is likely to be higher in Dry-DSR than in CT-TPR (Singh and Singh 1988).

Kim and Bajita (1995) reported that in aerobic soils, Fe oxidation by root-released oxygen reduces rhizosphere soil pH and limits release of Zn from highly insoluble fractions for availability to the rice plant. Basal application of zinc to the soil is found to be the best and to avoid its deficiency, application of 25–50 kg ha^{-1} zinc sulphate heptahydrate is recommended. However, if a basal application is missed, the deficiency can be corrected by topdressing up to 45 days. For foliar application, spray of 0.5% zinc sulphate two to three times at intervals of 7-15 days just after the appearance of deficiency symptoms is recommended.

Mandal *et al.* (2000) reported that reasons for Zn deficiency in rice fields include low redox potential, high carbonate content and high pH. The timing and source of Zn application may influence Zn uptake in DSR.

Gao *et al.* (2006) stated that Micronutrient deficiencies are of concern in DSR – imbalances of such nutrients (e.g. Zn, Fe, Mn, S and N) result from improper and imbalanced N fertilizer application while for high yield.

Pal *et al.* (2008) reported that under aerobic condition, deficiency of iron (Fe) is more pronounced due to oxidation of available ferrous form to unavailable ferric form in soil. For correction of Fe deficiency drilling of 0.5 kg of librel Fe into the soil at sowing time has been found quite promising. Foliar application, however, was observed to be superior to soil application. Foliar-applied Fe is easily translocated acropetally and even re-translocated basipetally. A total of 9 kg Fe ha^{-1} in three splits (40, 60, and 75 DAS) as foliar application (3% of $FeSO_4.7H_2O$ solution) has been found to be effective.

Yadav (2011) reported that application of 50 kg ha^{-1} + 2 foliar spray of 2% $FeSO_4.7H_2O$ results in higher grain yield, returns and benefit cost ratio and was comparable to sole soil application of 100 kg $FeSO_4.7H_2O$ ha^{-1} and 3 foliar spray of 2% $FeSO_4.7H_2O$. The crop quickly oxidizes iron sulphate applied under aerobic condition into ferric forms (Fe^{3+}) that is not taken up. After 30 - 35 days of sowing, libmix @ 2 gm per liter of water is sprayed to overcome the deficiencies of Zinc and Iron. To overcome sulphur deficiency, ground application of 2 kg $acre^{-1}$ of librel sulphur needs to be done.

2.2.7. Precise water management

Lantican *et al.* (1999) found that Bund management also plays an important role in maintaining uniform water depth and limiting water losses via seepage and leakage.

Balasubramanian (1999) reported that precise water management, particularly during crop emergence phase (first 7-15 days after sowing), is crucial in direct seeded rice. In northwest India using DSR into non-puddled soils saved 35-57% water.

Gupta *et al.* (2003) conducted an experiment in these trials; soils were kept near saturation or field capacity unlike the flooded conditions used in puddled-transplanted systems. In small plot DSR trials, the irrigation requirement decreased by 20%. DSR on raised beds decreased water use by 12–60%, and increased yield by 10% as compared to TPR, in trials at both experimental stations and on-farm.

There are few reports evaluating mulching for rice, apart from those from China, where 20–90% input water savings and weed suppression occurred with plastic and straw mulches in combination with DSR compared with continuously flooded TPR (Lin, 2003).

Kamboj *et al.* (1999) reported that water productivity in DSR was 0.35 and 0.76 as compared to 0.31 and 0.57 under TPR during 2002 and 2003, respectively, indicating better water-use efficiency.

Bouman *(*2007) reported that from sowing to emergence, the soil should be kept moist but not saturated to avoid seed rotting. After sowing in dry soil, applying a flush irrigation to wet the soil if it is unlikely to rain followed by saturating the field at the three-leaf stage is essential.

Gopal *et al.* (2010) have recommended avoiding water stress and keeping the soil wet at the following stages, tillering, panicle initiation, and grain filling. Water stress at the time of anthesis results in maximum panicle sterility. He also observed that during active tillering phase i.e. 30-45 days after sowing (DAS) and reproductive phase (Panicle emergence to grain filling stage) optimum moisture (irrigation at 2-3 days interval) is required to be maintained to harvest optimum yields from DSR crop. Irrigation can also be delayed for around 7-15 days depending on soil texture and water table conditions to facilitate deeper rooting and to make seedlings resistant to drought.

Gathala *et al.* (2011) reported that in a 6-year study conducted in Modipuram, India on sandy-loam soil, it was observed that Dry-DSR can be irrigated safely at the appearance of soil hairline cracks.

2.3. Rainfall

Among the various meteorological parameters, rainfall plays a significant role in determining the sowing time for crops.

Rainfall is the most critical risk in drought-prone areas. Rainfall risk could be both covariate (a systemic risk) and individual specific, depending on the onset date of monsoon and rainfall distribution across crops, soil types and regions. Being the

most limited production factor in drylands, rainfall has an essential role in determining the cropping pattern.

Season and crop report indicated that the agricultural sector in Tamil Nadu is subjected to erratic monsoon seasons. This is a major factor for high yield risk in rainfed crops, making farmers extremely vulnerable to yield (and income) losses.

In Tamil Nadu, rainfall is the most crucial factor for adoption of modern technological inputs, specifically, inorganic fertilizers. Many studies proved that crop response to fertilizer is higher in irrigated areas as reflected in the strong correlation between irrigation water and fertilizers (Season and Crop Report, 2010-11.Tamil Nadu).

Ramanathapuram is a dry district where non-system tank is the major source of irrigation; hence, rainfall pattern is the most decisive factor. In Coimbatore and Thiruvallur, wells are the major source of irrigation and the effect of rainfall failure is lower compared to Ramnad .Fertilizer use in rainfed areas was reduced due to rainfall shortage. Yield variability was higher (44 percent to 60 percent) in drought-prone areas. Yield loss due to risk of rainfall failure was higher in HYVs compared to landraces. A 10-percent increase in risk resulted in 5.4-percent decline in yield of modern varieties in Ramnad district (Selvaraj and Ramasamy, 2006).

Fugile, (1992) reported that farmers in the rainfed areas are operating at sub-optimal level of production. About 90 percent were inefficient since crop yields were lower than the optimal yield. Farmers incurred an additional cost of Rs 899 to increase yield by 228 kg ha^{-1}.

Ramasamy and Babu (2003) reported that rainfall, ground water availability, reservoir levels, and crop conditions determine the nature and extent of drought in Tamil Nadu. Drought occurs frequently in Tamil Nadu and in the sample districts of Ramnad, Thiruvallur, Coimbatore, and Sivagangai. He also estimated that rice production loss due to erratic rainfall can be as high as 30 percent of the state total rice production, valued at Rs. 8.521 billion, which accounts for 5.54 percent of the state's GDP.

Tamil Nadu experienced seven drought years during the last 30 years. Over the same period, Ramnad suffered from drought for six years; Tiruvallur, seven; and

Coimbatore, eight. During the normal period, the average rainfall is 965 millimeters (mm) but during drought, rainfall is 694 mm, representing a 39-percent water shortfall (Selvaraj and Ramasamy, 2006)

IRRI reported that if the rice crop depends solely on rainfall, it needs no less than 30 centimeters per month (cm/month) of rainfall over the entire growing period. Tamil Nadu usually receives only 10 to 20 cm/month of rainfall for four to eight consecutive months. In both cropping seasons, high water deficiency was observed in all the drought-prone districts which indicate the prevalence of drought in the said districts. Rice is predominantly grown during the northeast monsoon period in the rainfed areas.

Asaduzzaman (1979) mentioned that there is a big yield gap between irrigated and dryland or rainfed areas. Although use of HYVs has spread to dryland areas, adoption of associated technologies has been poor. Rainfall fluctuations could be responsible for 50 pe rcent of variability in yields (National Commission of Agriculture).

2.4. Quality of Irrigation Water

Water is a precious resource on earth and no water could be condemned as unfit for use, particularly for irrigation in raising agricultural crops. The ability lies in understanding the various constituents of water, and assessing its suitability for crop growth crop growth and attaining economic yield and at the same time with minimum disturbance to soil characteristics.

2.4.1. Methods for Assessing the Quality of Irrigation Water

Various methods have been evolved to find the quality of irrigation water. The important criteria that are usually considered in the evaluation of irrigation water are.

- Total concentration of soluble salts present in the irrigation water
- Sodium content in relation to other cations
- The presence of toxic elements

Bijendra Singh and Ramphool Singh (1994) classified the ground water of Jodhpur, Jiselimar, Barmer, and Bikanes districts in the arid zone of Rajasthan into

five classes based on total dissolved solids chloride and total hardness, sulphates and into three classes based on pH value.

Gopalswamy *et al.* (1973) classified the well waters of various blocks of Pollachi division of Coimbatore district based on the standard USSL. They suggested ways and means of using the low quality irrigation waters by adopting suitable soil management practices. Doneen's criteria were a better index than USSL system in assessing the quality irrigations waters of Coimbatore district (Sivanappan *et al.* 1970).

Gupta (1974) reported that Quality of irrigation water based on the water tables its fluctuation, depth of aquifers, salinity, SAR, RSC, Boron, nature of soil, climate crop growth etc. The suitability index of drainage water for irrigation based on Sodium absorption ratio (SAR) Salinity, pH, Soil texture ratings and plant tolerance classes etc. (Hamid and Hamid 1974).

Singh and Karkar (1977) carried out a survey of irrigation water in Khara and Majra are of Amristar district and based on their finding they divided into four zones. 1. Low Salinity and Low RSC waters. 2. Low Salinity and Low to medium RSC waters. 3. Low Salinity and Medium to high RSC waters. 4. Low of medium salinity and high RSC waters.USDA rating system has limited applicability to Indian condition.

Gupta (1979) proposed that depending upon soil texture and crop tolerance, the irrigation water into five classes based on the adjusted SAR, boron, electrical conductivity to determine the suitability for irrigation. When the residual sodium carbonate (RSC) is alone taken for consideration 41 present of the water were found suitable for irrigation, 36 per cent were marginal and the rest were unsuitable.

2.4.2. Parameters that determine the quality of irrigation water and their effect On soils

The chemical composition that determines the quality of irrigation waters are pH, electrical conductivity and total soluble salts, carbonates, bicarbonates, chloride and sulphates, nitrates, Boron, calcium, magnesium, potassium and sodium.

2.4.2.1. pH

Joshi (1956) adopted the suitability criteria of irrigation water on the basis of pH and EC. The majority of well waters of Hosur taluk were found suitable for irrigation based on the pH, soluble salts and Boron contents.

Gandhi and Paliwal (1973) found that there was highly significant correlation between pH value of the irrigation water and that of the soluble carbonate and bicarbonate of surface and sub-surface irrigated soils of Nagaur district, Rajasthan.

2.4.2.2. Electrical Conductivity and Total Soluble Salts

Dass and Mehta (1963) reported that Relationship between EC and Total soluble salts was positively correlated in underground waters of Rajasthan. EC is highly correlated with TSS, CI, SO_4, HCO_3, Na, Mg and SAR (Mondal and Jain 1986).

Gajbhiye *et al.* (1973) reported that studies on well of waters of Bikaner districts of Rajastan revealed close relationships between EC and Boron and SAR. The EC of the waters of Bharatpur district of Rajasthan was significantly correlated with cations, anions, SAR and Boron content (Sinsinwar and Vijaysingh 1984).

Singh and Bhumbla (1968) reported that Electrical conductivity of irrigation water and E.C of various types of soils were significantly correlated with ESP of soils. The irrigation water (EC 18.5 dSm^{-1}) did not give result in any accumulation of salt on light textured soils of Agra region (Tripati *et al.*, 1971).

Paniswamy and Dhanapalanmosi (1973) found that the red soils of Tamil Nadu having lower CEC values showed a high ESP and consequently very badly affected by saline waters when compared to black soil.

Palival and Gandhi (1973) reported that the electrical conductivity of the soil was less than waters used for irrigation and obtained positive significant correlation between electrical conductivity of the irrigation water and the surface (r=0.855) and subsurface (r=0.880) soils.

Gupta and Yadav (1986) analysed the crop yield data in relation to different degree of salinity of irrigation waters pertaining to different agro climatic and soil conditions in India. They worked out the critical limits for EC is above which yield

decrease by 10, 25 and 50 per cent. There was more salt built up with saline water than with SAR values and Ca: Mg ratios (Kumar *et al.* 1986).

2.4.2.3. Residual Sodium Carbonate

Kanwar and Kanwar (1971) found that pH, Na and Cl of the saturation extract and exchangeable Ca, Mg of the soils decreased with an increase in RSC. RSC from CO_3 was more harmful than HCO_3.

Lal and Lal (1977) found that the adverse effect of RSC was more in a light soil than heavy soil.RSC of irrigation water and ESP of soils having a significant positive correlation.

Krishnamoorthy (1979) reported that high RSC water was grouped under unsuitable class and when used for irrigation may lead to the development of alkali in normal irrigated soil. Mali *et al.* (1980) proposed the EC and hydraulic conductivity of soil tended to decrease with an increased level of Residual Sodium Carbonate. The $CaCO_3$ tended to increased with an increased level of RSC.

Vinaysingh *et al.* (1986) reported that RSC level increased the electrical conductivity of soil and the accumulation of salts in soil increased with increased RSC level of irrigation water.

2.4.2.4. Soluble Sodium Percentage (SSP)

Razumora (1973) reported that Na and salinity hazards were associated with SSP excess of fifty per cent and with Cl^- contains that exceeded fifty per cent of the total anionic content in irrigation water of kaibyshav Transvolga, Russia.

A significant positive correlation between ESP of soils and the water properties viz., SAR, HCO_3, RSC and SSP. there is a general correlation between SSP of irrigation water and that of saturation extract of soil only for 24-48 cm depth (Vyas *et al.,* 1982) .

2.4.2.5. Sodium Adsorption Ratio (SAR)

Manchanda and Kanwar (1971) reported that EC and SAR of irrigation water and irrigated soils were interrelated. The soil pH, E.C, water soluble anions and

cations and ESP increased with increase SAR of irrigation water whereas exchangeable calcium and magnesium decrease.

Gajbhiye *et al.* (1973) reported that the boron was significantly correlated between EC and SAR of irrigation water of Bikaner district of western Rajasthan. The waters of similar EC values, the accumulation of salts in the soil increase with an increase in the clay and with increasing SAR of waters (Lal and Singh 1974).

Gupta (1983) observed that adverse effect of RSC increase with increase in SAR. The chemical composition of irrigation water reveals that Mg/Ca ratio is generally less than one and mostly it varies from 0.2 to 0.5. the SAR of water increased as the HCO_3 concentration decreased after the equilibration of water with $CaCO_3$ and vice versa (Jain *et al*.2012).

2.4.3. Chemical composition of irrigation water

2.4.3.1. Carbonate and Bicarbonate

Mondal and Jain (1986) studied the irrigation waters of Rajasthan and obtained a close correlation between bicarbonate and electrical conductivity. The chloride and sodium were the dominant ions having high E.C, while bicarbonate rich water has low E.C (Paliwal and Gandhi 1972).

Paliwal and Gandhi (1973) reported that the pH of the soil and water was interrelated and correlated with CO_3 and HCO_3 content. When two Rhodesian soils with irrigation water having high bicarbonate, low SAR and no RSC and found that $CaCO_3$ and $MgCO_3$ were deposited in the soil and the PH as well as the ESP of both soils increased. Such in increase was greater in the sandy than clayey soil.

Gupta (1980) pointed out that irrigation with bicarbonate waters having RSC up to 10 me/l can be practiced continually without any problem on sandy loam calcareous soils, provided the SAR of the water is less than ten, in areas such as Karnal where high rainfall occurs.

2.4.3.2. Chloride

Krishnamoorthy (1970) observed a positive correlation between chloride and Electrical conductivity of irrigation waters of Kovilpatti taluk. Gupta (1986) reported that there is positive correlation between sodium and chloride ions.

Gopalachari *et al.* (1968) found that the ground water was rich in chloride and soluble salts in the low-lying soil of east Godavari district in Andhra Pradesh. The water containing chlorides and total soluble salts gradually rises to the soil surface and consequently get absorbed by the plant.

Ploegmann (1973) made a study in which 700 mm of water of average chloride concentration (57 mg Cl^- l)was applied to a clay and a sandy soil and found that an increase of 0.89 and 1.32 mg of chloride, respectively, per mm of water.

Patel *et al.* (1993) noticed that the value of chloride tend to increase with increase in electrical conductivity. The electrical conductivity had a high correlation with chloride ions that present in water.

2.4.3.3. Calcium and Magnesium

Natani *et al.* (1966) observed a significant correlation between Magnesium and RSC of irrigation water of Chambal command area. In Jaipur district of Rajasthan, 95 per cent of water samples have more magnesium when compared to Calcium. He also noticed that there is a positive correlation between E.C and sodium, calcium and magnesium content of well waters of Nagpur district.

2.4.3.4. Potassium

Kanwar and Deo (1969) proposed that potassium acts on the same way as that of Na, but its effect were not so pronounced when compared to Na, concentration of potassium would be more effective in keeping down the adsorption of Na.

2.4.3.5. Sodium

In a study of irrigation waters of Sathanur ayacut area, the harmful effects of sodium in the irrigation water which may be allowed to pass in earthen channels through bags containing gypsum admixture with coarse sand to remove the harmful effect of sodium Thiyagarajan *et al.*, (1976).

Gupta and Yadav (1986) reported that low salinity waters may be dominant in sodium bicarbonate, high salinity waters will be found dominant in sodium chloride.

2.4.3.6. Effect of cationic composition of irrigation water on soil properties

Sankaranarayana and Ganu (1963) reported that irrigated soils contained more of exchangeable Mg (where the irrigation water was high in Mg) and notably more exchangeable Na than unirrigated soils. Irrigation waters of Rajasthan had preponderance of Mg^{++} over Ca^{++} resulting in large accumulation of Mg^{++} in soil solution.

Palanisamy and Dhanabalan (1973) reported that high proportion of Na^{+} in irrigation water caused a high content of Na^{+} in the exchange complex of the soil.ESP of black cotton soils with sodium hazards of stream waters of Tungabhadra river valley project (left canal) area and found that all the stream waters were doubtful quality for irrigation.

Sharma *et al.* (1981) reported that the continuous irrigation with saline water on a normal black cotton soil, increase the salt concentration and exchangeable Na in the soil. This was more in the upper 0-15 cm soil depth as compared to 15-30 cm and 30-45 cm depth.

Poonia *et al.* (1974) reported that there was higher salt accumulation in soil when irrigated with saline water. The alkalinity in the red soil region seems to have formed due to irrigation with saline waters (Agarwal and Ramamoorthy 1974)

Lal and Singh (1974) found that the waters having similar E.C, the accumulation of salts in the soil increased with an increase in the clay and SAR of waters. heavy textured soils showed more of salinity hazard as compared to kaolinite and illite type light textured soils when irrigated water having an EC of 2250 micro mhos/cm (Agarwal and Ramamoorthy 1974).

Chatterjee *et al.* (1975) reported that possibility of 73.3 to 87.7 per cent reduction in salinity of the soil having provision of good drainage by the application of the irrigation water having E.C ranging from 0.73 to 3.70mmhos/cm.

2.4.4. Effect of irrigation water quality on crop growth

Lad and La1 (1977) reported that the reduction in grain and straw yield of wheat and barley with increasing level of Residual Sodium Carbonate (RSC) in water may be attributed to the fact that pH and Residual Sodium Carbonate(RSC) of the soil

also increased which in turn caused nutritional disturbances resulting into reduced growth and yield.

Mali *et al.* (1980) reported that the reduction in total uptake of phosphorus, potassium and calcium is quite natural because the grain and straw yields and the content of P, K and Ca decreased with a rise of Residual Sodium Carbonate (RSC) in water. The total uptake of sodium increased in spite of the reduction in the yields with increasing RSC of water. It is due to increase in sodium content of grain and straw of wheat and barley.

Tomar and Yadav (1989) noticed that the growth tree seedling, especially root development was reduced as Electrical Conductivity of irrigation water gets increased.

Girdhar (1988) reported that the sodium accumulation in rice plant increased and K/Na ratio decreased with an increase in soil salinity concentration of Na was greater at maturity than at tillering or at flowering stage but the per cent increase in the sodium content was significantly higher at flowering stage than at tillering or at maturity stage. Salinity increased the Nitrogen content of the rice plant but at the same time the content of plant in different plant parts were not affected by salinity.

Sharma *et al.* (1981) proposed that low phosphorus uptake as observed and physiological aberration and disorder are responsible for considerable reduction in grain yield due to higher salinity of irrigation water. Water stress prevents transferring nutrients to plants.

Doberman and Fairhurst (2000) reported that rice is a very sensitive crop to salinity. Salinity affects 19.5 per cent of irrigated and 2.1 per cent of dry land agriculture across the globe (FAO 1988). Salinity stress caused reduction in leaf water potential, evapotranspiration, stomatal conductance, leaf area and yield of plants.

Lal and Singh (1974) proved that EC threshold of local varieties yield loss to be 1 to 2 dSm^{-1}. Drought and salinity are major factors limiting rice production in rainfed ecosystems, and they are increasing in importance in irrigated environments as a result of water shortages and poor maintenance of infrastructure.

Vyas *et al.* (1982) found that salinity is an ever-present threat to crop yields, especially in countries where irrigation is an essential aid to agriculture. Salinity imposes two constraints on plants: the hyper osmotic effect (especially short-term stress) due to lower soil water potential and the hyper ionic effect (especially long-term stress) due to direct toxicity of ions over metabolism and nutrition of plants.

Belder *et al.* (2005) noted that several studies have been carried out to better understanding of rice reaction to drought stress and finding new solution for mitigating the effects of the new condition. He also reported that which results in decrease of tillerings numbers, leaf area, dry matter, filled grains, and number of panicle, kernel weight and yield, so it is recommend avoiding long drought period for decreasing water use.

2.5. Site Specific Nutrient Management (SSNM)

Crop response to fertilizer application is not always easy to predict, due to the effects of seasonal and year to year variation in climate (particularly solar radiation) and spatial and temporal variation of indigenous soil nutrient supplies. Both factors lead to large difference among sites, seasons and years in optimal rates of fertilizer inputs. Fertilizer management in rice production is drawing attention among farmers, especially under current climate change situation. Efficient fertilizer management under environment-friendly condition is crucial to increase rice production worldwide.

Balasubramanian *et al.* (1999) reported that Progress has been made in recent years in developing field and season specific nutrient management approaches, as alternatives to blanket recommendation for nitrogen, phosphorus and potassium fertilizer.

Fairhurst (2000) revealed that one of the most important alternative management approaches is the Site Specific Nutrient Management approach. It was developed to increase mineral fertilizer use efficiency and achieve balanced plant nutrient and supply the nutrient as and when needed by the rice crop. The SSNM strategies include field and season-specific fertilizer rates, which were calculated after taking into account of indigenous soil nutrient supplies, plant nutrient demand and interactions among nitrogen (N), phosphorus (P) and potassium (K).

The SSNM approach aims to increase farmers profit through,

- Increased yield of rice per unit of applied fertilizer,
- Higher rice yields
- Reduced disease and insect damage and also eliminates wastage of fertilizer by preventing excessive rate of fertilization and by avoiding fertilization, when the crop does not requires nutrient inputs. It also ensures that N, P and K are applied in the ratio required by the rice crop.

Sasaki (2001) noted that conventional application of nitrogen fertilizer results in very low yields at low-fertility sites, as well as late heading and lodging of rice plants. The yield advantages with SSNM were similar in both high and low yielding seasons and increased due to greater experience from 0.31 t ha^{-1} in the first year (+ 6 per cent) to 0.41 t ha^{-1} in the second year (+ 8 per cent). With the exception of the first crop, grain yields in SSNM plots were consistently higher when compared with the FFP treatment and the plant uptake of N, P and K was greater with SSNM compared with FFP (Dobermann *et al.*, 2002).

Witt and Dobermann (2002) resembled that this management strategy were tested for rice in several Asian countries in co-operation with IRRI Because the investment was not costly, financial profitability of rice farming by SSNM was found to be higher than that of farmer fertilizer practice (FFP). The average grain yield increase was 0.36 t ha^{-1} or 7 per cent greater with SSNM compared to FFP.

The conversion rate of nutrient uptake to grain yield was similar for P and K and the difference between SSNM and FFP treatment was small. More detailed analysis indicated that, while nutrient uptake was sufficient to achieve the yield goal of almost 80 per cent of the potential yield. The actual yields in SSNM were about 67 per cent of potential yield compared to 62 per cent in FFP. It is likely that further yield increase will only be achieved if all aspects of crop, nutrient and pest management are improved simultaneously.

Fairhurst and Witt (2002) revealed that The SSNM can be used, where the areas having one or more of the following characteristics,

- Insufficient or unbalanced use of fertilizer.

- Occurrence of nutrient deficiency symptoms.
- Occurrence of pest problems linked to nutrient imbalance or overuse of fertilizer nitrogen.
- Inefficient fertilizer N use because of high total N rates or inadequate splitting and timing.
- · Evidence of strong mining of soil indigenous P or K

Toriyama *et al.* (2003) revealed that The SSNM has many advantages over conventional management in terms of uniformity in product quality for achieving uniform growth and yield of rice and proper application rates of agricultural inputs, such as fertilizer and agricultural chemicals.

2.5.1. Main Features of SSNM

- ★ Optimal use of existing indigenous nutrient sources such as crop residues and manures.
- ★ Application of N. P and K fertilizer is adjusted to the local and season-specific needs of the crop.
- ★ Use of omission plots to determine the P and K fertilizer required to meet the crop needs.
- ★ Local recommendation for application of zinc, sulphur and micronutrient
- ★ Selection of the most economic combinations of available fertilizer sources.

2.5.1.1. Crop Nutrient Requirement

Witt and Dobermann (2002) observed that the rice plant growth is limited solely by nutrient supply, the optimal nutritional balance is achieved with an uptake of about 15 kg N, 2.6 kg P and 15 kg K i.e. 15 kg N, 6 kg P_2O_5 and 18 kg K_2O per ton of grain yield. These nutrient uptake rates are valid for yield goals that reach 70 to 80 per cent of yield maximum. Thereafter, the amount of nutrients required to produce an additional tonne of grain yield increase due to decreasing internal nutrient use efficiency.

Witt and Dobermann (2002) noted that the plant nutrient requirements for a particular yield goal may be smaller in a high yielding season than in a low yielding one i.e. the 80 kg N required to support a yield goal of 5.5 t ha^{-1} at a yield maximum

10 t ha^{-1}, but 100 kg N would be required for the same (5.5 t ha^{-1}) yield goal at a yield maximum of 6 t ha^{-1}.

Witt and Dobermann (2002) revealed that Because of moderate to high N efficiency can be reached with improved nutrient management under field conditions, soil P and K fixation is low to moderate, K losses due to leaching are small and get about 4 to 5 t ha^{-1} of straw for each harvest. So, this SSNM concept is valid for modern, high yielding varieties with a harvest index ratio of grain to dry matter of about 0.5, because of this reason the SSNM practice can be recommended for rice cropping system.

Toriyama *et al.* (2003) revealed that in the Site Specific Nitrogen Management, the mean uptake rate of soil nitrogen was 6.0 g N m^{-2} and the internal N efficiency in SSNM reached 51 kg grain produced per kg plant N uptake, which is 85 per cent of the theoretical optimum of 67 kg grain per kg fertilizer that can be achieved with optimal crop and nutrient management.

2.5.1.2. Time of Nutrient Application in SSNM

The potential indigenous nutrient supply of N (INS), P (IPS) and K (IKS) is defined as the amount of each nutrient taken up by the crop from indigenous sources, when all other nutrients are amply supplied and other limitations to growth are removed.

Fairhurst and Witt (2002) reported that Nitrogen could be applied based on leaf color chart (LCC) reading, which can be taken once in every 7 to 10 days interval starting from 14 days after transplanting for transplanted rice or 21 days after seeding for direct wet seeded rice. The last reading is taken at first flowering and respective amount of nitrogen could be applied based on the LCC reading.

The phosphorus applied to rice has a residual effect on the succeeding crop but direct application to each crop is more efficient. Phosphorus fertilizers should be incorporated in the soil before seeding or transplanting.

The total amount of K fertilizer to be applied is small; it can be applied at seeding or transplanting. For larger applications (40 to 120 kg K_2O ha^{-1}), application can be often two splits, 50 per cent as basal application and 50 per cent at panicle initiation stage.

2.5.2. Indigenous Nutrient Supply

Witt and Dobermann (2002) reported that the Site specific fertilizer requirement is the estimation of the indigenous nutrient supply of N, P and K defined as the total amount of the particular nutrient that is available to the crop from the soil during a cropping cycle, when other nutrients are non-limiting. The indigenous nutrient derived from soil, incorporated crop residues, water and atmospheric deposition it is estimated by measuring plant nutrient uptake by omission plot technique. The indigenous nutrient supply is measured in units that can be directly used for fertilizer calculations (kg nutrient per ha or kg nutrient per crop).

Dobermann *et al.* (2003) observed that Indigenous nutrient supply measurement is that it integrates the supply of truly plant-available nutrient forms across the effective rooting depth under field condition. This includes readily available nutrient pools that are typically extracted with soil tests but also more slowly available nutrient pools and nutrients supplied from other indigenous sources in flooded rice fields.

To obtain reliable plant based estimates of indigenous nutrient supplies using omission plots, the following points should be considered. (1) Use certified seed, (2) Manage the omission plot with proper crop care (water, weed, pest and disease control), (3) Take measurement in a season with favorable climatic conditions and low pest pressure to minimize the effect of yield limiting factors other than the nutrient under test.

Wang *et al.* (2001) revealed that Indigenous supply can be approximated by only measuring plant nutrient accumulation with the above ground biomass in a nutrient omission plot. This approach was successfully used in recent studies on Site Specific Nutrient Management in irrigated rice.

2.5.2.1. Estimation of indigenous nutrient supply from omission plot technique

Dobermann *et al.* (1996) revealed that unless there is a deficiency, vascular K or straw K concentrations continue to respond to variations in external K supply but have little effect on K concentrations in the grain or grain yield itself. About 80 per cent of the above ground plant K is contained in vegetative plant parts of rice where it is mainly stored in the central vacuoles of cells (Witt *et al.*, 1999).

Dobermann and Fairhurst (2000) estimated the soil nutrient supply from grain yield in omission plot, assuming an average uptake of 15 kg N, 2.6 kg P and 15 kg K to harvest per tonne of grain per hectare. In some case of grain yield measurement in the omission plot predicting from indigenous phosphorus supply (IPS) and indigenous potassium supply (IKS) were 2.9 kg P and 15.8 kg K per tonne of grain yield. They also observed, only P and K applied plot (+ PK), the mean grain yield was higher (0.3 Mg ha^{-1}) than the fertilizer omission plot (-F).

In the area of K deficiency or low soil K status, the IKS prediction was only 11.3 to 13.1 kg K per tonne of dry matter production. This gives an idea, for using total dry matter (grain plus straw) instead of grain yield which did not significantly improve prediction of IPS or IKS.

Witt and Dobermann (2002) observed that the soil nutrient supply can be estimated directly from plant nutrient uptake in omission plots as an alternative soil testing. This helps to see the farmers for the particular nutrient deficits in their field. The required rate of P or K fertilizer can be calculated from the deficit in yield between the respective omission plots and a fully fertilized plot with no nutrient limitation and consequently helps to ensure that P and K are applied in the ratio required by the crop.

Dobermann *et al.* (2003) suggested that therefore estimates of IKS based on grain yield measurement tend to be less accurate than those for nutrient that are mostly stored in grain i.e. N and P.

2.5.3. Management of N, P and K in SSNM

The management of N involves visual indicators of deficiency, while the management of P and K primarily involves in preventing deficiency in the soil rather than treating observable deficiency symptoms in the crop.

2.5.3.1. Nitrogen

The management of N is based on Leaf Colour Chart (LCC). The LCC can be successfully adopted and used in irrigated and favorable rain-fed rice ecosystem. The commonly used LCC is developed by Crop Resources and Management Network (CREMNET) for International Rice Research Institute (IRRI), which as 15 long charts

with a scale of 6 strip colour gradient. The colour scale is made of plastic, resistant to sunshine damage and light reflectable. The strip colour lines arranged like leaf veins and scored from 1 (yellowish green) to 6 (deepest dark green). A simple instruction sheet is present in the back side is in local language will go with the chart to help the farmer to determine the correct time and quantity of nitrogen application to rice crop. The critical LCC reading is 3 for direct seeded semi-dwarf indica varieties, LCC 4 for transplanted semi-dwarf indica varieties and hybrid. A predetermined amount of fertilizer N can be applied when the colour of rice leaves falls below a critical LCC threshold that indicates N deficiency and requires immediate N fertilizer application to prevent yield losses and it is also known as "Real time N management'. This Real-time N management reduces N fertilizer needs, increases N-use efficiency and reduces the crop's susceptibility to pests and diseases.

Furuya (1987) studied that farmers generally use leaf colour as a visual and subjective indicator of the N status for rice and to determine the need for fertilizer N application. It is an inexpensive, simple and easy to use for measuring the leaf greenness and it was developed from a Japanese prototype and it was devised by Fuji Film Company especially for rice leaf colour. This leaf colour chart is used to monitor plant N status during the seasons and as a decision aid to plan fertilizer N as top dressing.

Peng *et al.* (1995) resembled that this is the important tool, which offer the best way for monitoring the N status of the rice crop and apply N only if the crop requires N and the leaf N content is closely related to photosynthetic rate and biomass production.

Johnkutty *et al.* (2000) observed that the fertilizer N saving from 50kg in ADT 36 rice during Kuruvai season to 70 kg N ha^{-1} during Thaladi season in the real time N management and the critical LCC score helps to avoid over application of N to rice crop.

2.5.3.2. Phosphorus

The phosphorus management is to prevent P deficiency rather than treating P deficiency symptoms. If low soil P supply is the reason, the targeted yields are not achieved; management must focus on the buildup and maintenance of adequate soil-

available P levels to ensure that P supply does not limit crop growth and N-use efficiency.

P is not easily lost from the system, but inputs from sources such as irrigation water and straw are generally small. P fertilizer application has residual effects that can last several years and maintenance of soil P supply requires long term strategies tailored to site-specific conditions that consider P inputs from all sources.

Fairhurst and Witt (2002) observed that sustainable P management may require the application of fertilizer P, even if a direct yield response to P application is not expected. In some soils, the indigenous P supply would decline only after a few seasons if fertilizer P was not applied. A suitable maintenance strategy would then have to balance the nutrient removal with grain and straw to replenish the soil P reserves.

Management of P

Theoretically, fertilizer P application would not be required if a yield response were not expected for the selected yield target (i.e. yield target = yield in nutrient omission plot). This zero-P fertilizer strategy results in mining the soil of P reserves and may affect yields in the medium to long term, especially if other nutrient sources such as straw or manure are not applied.

To prevent mining of soil P reserves, the following rules can also be applied, as suggested by Fairhurst and Witt (2002).

- If most of the straw is retained in the field (harvest panicles only) and nutrient input from manure is small, apply at least 4 kg P_2O_5 ha^{-1} for each tonne of grain harvested to replenish P removed with grain.
- If most of the straw is removed from the field and nutrient input from other sources (manure, water and sediment) is small, apply at least 6 kg P_2O_5 ha^{-1} for each tonne of grain harvested to replenish P removed with grain and straw.

P applied to rice has a residual effect on the succeeding crop but direct application to each crop is more efficient. Phosphorus fertilizers should be incorporated in the soil before seeding or transplanting.

2.5.3.3. Potassium

The general strategy for K management follows the same principles given for P, but the K uptake requirement of rice is much greater than for P. After harvest, more than 80 per cent of K taken up by rice remains in the straw, making straw an important input source to consider when calculating fertilizer K requirements.

Fairhurst and Witt (2002) noted that in Indian condition, both low yielding and high yielding season most of the rice straws are removed because of surface cut leaving less than 10 per cent straw in the field. It is nearly about 0 to 1 tonne of straw so, the indigenous K supply would decline only after a few seasons if fertilizer K was not applied.

Management of K

A general rule, where the soil K supply is small, applies 30 kg fertilizer K_2O ha^{-1} for each ton of target grain yield increase over the K omission plot yield.

Fairhurst and Witt (2002) observed that in the short term fertilizer K application would not theoretically be required if a yield response is not expected for the selected yield target i.e. yield target is equals to the yield of K omission plot yield. Substantial mining of soil K reserves may affect yields in the medium to long term, especially if most straw is removed and other nutrient sources are not applied.

To prevent mining of soil K reserves, they suggest the following rules,

- If most of the straw is retained in the field i.e. only harvest the panicles and the nutrient input from manure is small, apply at least 3.5 kg K_2O $ha^{-1}$for each tonne of grain harvested to replenish K removed with grain.
- If most of the straw is removed from the field and nutrient input from other sources i.e manure, water and sediment is small, apply at least 12 kg K_2O ha^{-1} for each tonne grain harvested to replenish K removed with grain and straw.

Fairhurst and Witt (2002) revealed that when the total amount of K fertilizer to be applied is small, it can all be applied at seeding or transplanting. For larger applications (40 to120 kg K_2O ha^{-1}) apply in two splits i.e. 50 per cent as basal application before crop establishment or within the first 2 week after crop establishment and 50 per cent at panicle initiation. With large applications (more than

120 kg K_2O ha^{-1}) apply in three splits i.e. 1/3 as basal, l/3 at panicle initiation and 1/3 at heading to first flowering stage.

2.5.3.4. Effect of fertilizer practices on nutrient content and uptake

2.5.3.4.1. N supply at different growth stages of rice

Yamauchi (1995) observed that high N content during the middle of the growing stage ensures the number of spikelet required to achieve high yield, but may cause lodging and poor filling of grains. In the tillering stage, top dressing of N found to increase the number of panicle per unit area**.**

Patnaik and Rao (1979) reported that the application of 75 per cent of total N at puddling or through suitable splits during vegetative growth period and 25 per cent of total N at panicle initiation stage was found successful.

Vinaysingh and Jaiprakash (1979) noted that inadequate N supply at any critical physiological stage may retard the growth and yield of rice. It has been reported that the efficiency of absorbed N for grain production depends on the stage of crop development and the nitrogen supply.

Thiyagarajan *et al.* (1994) showed that the first N application could be delayed to the time up to which native soil N supply could maintain the required leaf N concentration.

2.5.3.4.2. Nitrogen content and uptake

Singh and Sinha (1975) reported that uptake of N in grain and straw increased due to application of K and N uptake in three seasons found that N uptake in rice increased with N levels.

Subbiah and Prasada Rao. (1983) noticed that phosphorus application enhanced the N uptake of rice. The uptake of N and P was greatly influenced by applied P over no P but there was not much influence by time and method of P application in rice (Jayaraman, 1990).

Pandey *et al.* (1991) reported that the short duration genotypes generally had lower N uptake than medium and long duration genotypes. The uptake of N, P and K increased with application of N.

Vijayalakshmi *et al.* (1992) observed that two peaks in the rate of N content and uptake one at the maximum tillering stage and another at panicle development stage. Sivasamy *et al.* (1994) observed that the maximum N accumulation in rice was slower between active tittering and panicle initiation stage, the splitting of N application in this stage may increase the N accumulation.

Sharma *et al.* (1994) observed that Application of urea at 14 DAT showed maximum uptake of N and minimum when it was applied basally 50 per cent N.

Shukla and Sharma (1994) recorded a progression increase in N uptake by grain and straw individually as well as total with the increasing rate of N application from 0 to 150 kg N ha^{-1}.

Some genotypes absorb similar amounts of N but produce different grain yield or total dry matter, but variability in N uptake and gain yield among genotype was decreased at low N level. The N content in rice grain and straw was significantly higher in the fertilizer treatments than in control (Jagadeeswari 1997).

2.5.3.4.3. Phosphorus content and uptake

Kolambe and Patel (1994) reported that phosphorus uptake were maximum with 90 kg P_2O_5 ha^{-1}. Phosphorus application enhanced the available P, but not the available N and K (Marilyn, 2000).

Jagadeeswari (1997) observed that the P content in rice grain and straw was significantly higher in fertilized plots than control. The P content was 0.27 per cent in control and 0.52 per cent in NPK treatment, 0.42 per cent in NP and 0.40 per cent in NK treatment in rice grain and a similar pattern was also observed in rice straw.

Rattan and Singh (1997) observed that P content in rice grain and straw under the treatment receiving P fertilizers were significantly higher than in the treatment without P. the uptake of P increased with the increase in quantities of nutrients applied to the kharif crop.

Ganauri Singh *et al.* (2000) observed that application of 90 kg P_2O_5 ha^{-1} increased P uptake both in grain and straw, which lead to higher P content in straw and grain.

2.5.3.4.4. Potassium content and uptake

Lekha (1987) observed that P application influenced the K uptake at panicle initiation. Salam and Subramanian (1988) noticed that .The K content and uptake also increased with levels of N.

Senthilkumar (1998) recorded significantly higher potassium content in NPK treated plots (0.20 per cent), NP (0.19 per cent) and NK (0.24 per cent) over control (0.13 %) in rice grain.

2.5.3.4.5. Grain and Straw yield

Sharma (1994) observed that application of urea 14 days after transplanting gave significantly higher grain yield of 19.3 per cent over and above of the existing practice of urea application i.e. at the time of transplanting.

Dawe and Moya (1999) concluded that the causes of yield decline in several long term experiments were associated with a decrease in the effective N supply from soil although the total soil N remain constant or increase.

The SSNM treatment performed better than FFP and reported an average grain yield of 7.8 t ha^{-1} in Kuruvai and the straw yield increased significantly in NPK fertilizer treated plot. He also reported a significant higher grain yield in NPK (4.2 t ha^{-1}), NP (3.63 t ha^{-1}), and NK (3.63 t ha^{-1}) treated plots over control (2.83 t ha^{-1}) (Donna, 2000).

Kumar *et al.,* (2000) recorded an average grain yield of 4.8 t ha^{-1} in the rice varieties with SPAD based management compared with 4 and 4.4 t ha^{-1} for fixed N rate of 90 and 135 kg N ha^{-1}.

2.5.3.4.6. Yield attributes

Cassman *et al.* (1996) found that higher number of productive tillers was obtained by the application of 120 kg N ha^{-1}. The panicle numbers m^{-2} increased with increasing level of nitrogen up to 120 kg N ha^{-1}.

Natarajan and Manickam (1991) reported that the graded levels of fertilizer N had manifested a linear response in terms of grain yield. The higher biomass production can translate into higher grain yield depends on numerous factors, including crop management, climate and genotype.

Vijayalakshmi *et al.* (1992) attributed the ability to produce more panicle number and spikelet density and not the test grain weight to the better performance of rice cultivars at higher N levels. The normal practice of split application of N (50:25:25) recorded minimum value of panicle number and spikelet number

Balasubramaniam *et al.* (1999) observed that grain yield is mainly determined by the number of panicle per unit area and the number of spikelets per panicle. Panicle number increased with higher N application and conversely, spikelet number per panicle decreased with increased levels of N application and in modern varieties only the panicle density was increased due to N fertilization, but in traditional varieties the grain yield was increased through increase in panicle density and spikelet number.

Wopereis *et al.* (1999) observed that the percentage of unfilled grains per panicle was found to increase with the level of N application due to spikelet sterility problems and also observed that the dry matter production and the grain yield were found to be strongly correlated. He also noted that Dry matter yield in rice was found to increase during the vegetative phase and started decreasing from flowering onwards Total dry matter production gradually increasing with crop age and reached its maximum at harvest

Thiyagarajan *et al.* (1994) noted that the total dry matter production was increased in general with increasing level of N application only up to 150 kg N ha^{-1}, beyond 150 kg N ha^{-1}, the dry matter production exhibited a plateau.

The response of rice to N levels was conspicuous up to 150 kg ha^{-1}beyond which the response decreased and the split application of nitrogen resulted in higher number of tillers as compared to a single application (Alam *et al.*, 2005).

Aruna (2001) found that the yield attributing characters like panicle m^{-2}, grains per panicle and thousand grain weights increased with increasing dose of N application.

In the above review of literature, it was concluded that there is scope to increase the yield of semi-dry rice grown at Ramanathapuram district of Tamil Nadu through site specific nutrient management (SSNM) approach using nutrient omission plots.

CHAPTER III

MATERIALS AND METHODS

The present study was taken up to study the soil related constraints and to increase the rice yields under semi-dry condition through nutrient optimization using site specific nutrient management (SSNM). The methodology followed in collection of profile, surface soil and ground water samples, experimental details, analytical procedures for soil, water and plant samples, statistical scrutiny and interpretation of results are briefly discussed in this chapter.

3.1. Description of study area

The Ramanathapuram district of Tamil Nadu where semi-dry rice is grown in an extent of 73,550 ha was the study area. Two domains viz., Paramakudi block and Ramanathapuram block were selected which varied in soil and rainfall characteristics. From the two domains, 22 and 21 villages were selected and 129 and 126 surface soil samples,respectively were collected to assess the soil related constrains. The location map of sampling villages is given in Fig.1 and the geospatial co-ordinates of all the soil sampling villages are given Table 2. Similarly 70 ground water samples were collected to assess their suitability for supplemental irrigation to semi-dry rice. Two soil profiles were dug; horizon wise samples collected, morphological study made and the soil profile sketch with diagram are given in Fig.2 and 3 for Paramakudi series and Thirupullani series, respectively.

The normal annual rainfall of Ramanathapuram district is 827 mm, most of which is received during north east monsoon, that onsets from September-October onwards. The rainfall distribution pattern for the last five years and annual rainfall distribution during 2011-12 and 2012-13 are given in Fig.4.

3.2. Description of on-station and on-farm trials

3.2.1. Paramakudi block

The Paramakudi block of Ramanathapuram district has net cropped area of 92,849 ha in which semi-dry rice is grown on 48,534 ha. To optimize the nutrient requirement of semi-dry rice, one on-station experiment at Agricultural Research

Station (ARS), Paramakudi and two on-farm trials were conducted in farmer's field at Vilathur and Oorakudi village during the late *kuruvai* season of October to January during 2011-2012 and 2012-13 using nutrient omission plot technique.

3.2.2. Ramanathapuram block

The Ramanathapuram block has a total net cropped area of 68,584 ha of which semi-dry rice is grown on 28,127 ha. In this block, to optimize the nutrient requirement of semi-dry rice one on-station experiment at Coastal Saline Research Centre(CSRC), Ramanathapuram and two on-farm trials at Keelakkarai and Mandivalasai villasai village were conducted during late *kuruvai* season of October to January during 2011-2012 and 2012-13, using nutrient omission plot technique.

The details of both on-station and on-farm trials are as follows:

Details of field experiment	**Location I**	**Location II**
On-station experiments	ARS, Paramakudi (9° 05'N 78° 55'E)	CSRC, Ramanathapuram (9° 32'N 78° 83'E)
On-farm trials	Vilathur(OFT-1) Oorakudi (OFT-2)	Keelakkarai(OFT-1) Mandivalasai(OFT-2)
Soil series	Paramakudi soil series (*Typic chromustert)*	Thirupullani soil series (*Fluventic haplustalf)*
Crop	Rice	Rice
Variety	ADT 45	ADT 45
Duration	Short duration (110 days)	Short duration (110 days)
Season	Late *kuruvai* (Oct-Jan 2011-12 and 2012-13)	Late *kuruvai* (Oct-Jan 2011-12 and 2012-13)
Design	Randomized block design (RBD)	Randomized block design (RBD)
Replications	4	4
Plot size	(5 x 5) m = 25m^2	(5 x 5) m = 25m^2
Spacing	22 x 22 cm	22 x 22 cm

Initial soil fertility status of site

Sl. No.	Soil parameters	Paramakudi-ONS	OFT-1	OFT-2	Ramanathapuram-ONS	OFT-3	OFT-4
A. Particle size distribution							
1	Coarse sand (%)	17.76	21.45	23.4	14.75	12.45	12.52
2	Fine sand (%)	26.21	25.63	24.6	65.25	68.36	65.36
3	Silt (%)	10.36	10.2	11.55	11.84	10.32	13.65
4	Clay (%)	44.12	42.36	40.2	7.16	8.63	7.48
5	Texture	Sandy clay	Sandy clay	Sandy clay	Loamy sand	Loamy sand	Loamy sand
B. Physical properties							
6	Bulk density (Mg m^{-3})	1.44	1.41	1.39	1.6	1.5	1.5
7	Particle density (Mg m^{-3})	2.47	2.35	2.43	2.35	2.25	2.42
8	Infiltration rate (cm/hr)	0.22	0.2	0.26	42.59	43.6	45.44
C. Physico- chemical properties							
9	Soil reaction (pH)	7.6	7.9	8.1	7.8	7.2	8.1
10	EC (dSm^{-1})	1.3	1.1	1.5	1.5	1.2	1.3
11	CEC(cmol (p^+) kg^{-1})	45.32	44.63	44.96	12.36	9.63	10.22
D. Available nutrient status							
12	Organic carbon (%)	0.09	0.1	0.12	0.16	0.1	0.15
13	$KMnO_4$-N (kg ha^{-1})	230	244	249	210	182	196
14	Olsen-P (kg ha^{-1})	9.2	10.2	10.9	11.2	10.2	10.9
15	NH_4OAc-K(kg ha^{-1})	462	452	468	325	340	336
16	DTPA extractable Zn	0.78	0.63	0.7	1.3	0.96	1.23
17	DTPA extractable Fe	7.6	6.53	6.2	12.9	11.2	10.7
18	DTPA extractable Cu	2.2	2.1	2.2	1.7	1.65	1.5
19	DTPA extractable Mn	8.5	6.86	7.53	6.14	6.33	5.85
E. Total nutrient status							
20	Nitrogen (%)	0.057	0.063	0.068	0.056	0.036	0.044
21	Phosphorus (%)	0.052	0.042	0.039	0.023	0.013	0.019
22	Potassium (%)	0.19	0.12	0.15	0.23	0.14	0.21
23	Zinc (ppm)	38.32	25.63	28.6	50.75	49.3	53.66
24	Iron (ppm)	11964	9568	10988	5638	4869	3975
25	Copper (ppm)	30.63	35.71	35.96	28.7	25.4	28.3
26	Manganese (ppm)	135	113	127	121	104	115

3.2.3. Experimental details The on-station (ONS) and on-farm trials (OFT) were laid out in a Randomized block design (RBD) with six treatments during 2011-12 and seven treatments during 2012-13 with four replications. The details of the experiments were as follows:

3.2.4. Experimental layout (on-station and on-farm trials during 2011-12)

R_1T_1	**R_3T_5**	**R_2T_3**	**R_4T_1**
R_1T_4	**R_3T_1**	**R_2T_5**	**R_4T_3**
R_1T_2	**R_3T_4**	**R_2T_2**	**R_4T_5**
R_1T_3	**R_3T_2**	**R_2T_4**	**R_4T_2**
R_1T_5	**R_3T_3**	**R_2T_1**	**R_4T_4**

Treatment details (on-station and on-farm trials)

T_1 : PK (P_2O_5 @ 25 kg ha^{-1} and K_2O @ 37.5 kg ha^{-1})

T_2 : NK (N @ 75 kg ha^{-1} and K_2O @ 37.5 kg ha^{-1})

T_3 : NP (N @ 75 kg ha^{-1} and P_2O_5 @ 25 kg ha^{-1})

T_4 : NPK (N @ 75 kg ha^{-1}, P_2O_5 @ 25 kg ha^{-1} and K_2O @ 37.5 kg ha^{-1})

T_5 : NPK (T_4) + FYM @ 12.5 t. ha^{-1}

T_6 : Farmer's fertilizer practice (120 kg N, 50 kg P_2O_5 and 50 kg K_2O) – (From adjacent farmer's field).

(Recommended Dose of Fertilizers: NPK @ 75:25:37.5 kg ha^{-1} as N: P_2O_5: $K_2O.ha^{-1}$)

3.2.5. Experimental layout (on-station and on-farm trials during 2012-13)

R_1T_1	R_3T_6	R_2T_3	R_4T_1
R_1T_4	R_3T_1	R_2T_5	R_4T_3
R_1T_6	R_3T_4	R_2T_2	R_4T_6
R_1T_3	R_3T_2	R_2T_4	R_4T_2
R_1T_5	R_3T_3	R_2T_6	R_4T_4
R_1T_2	R_3T_5	R_2T_1	R_4T_5

Treatment details (on-station and on-farm trials)

T_1 : PK (P_2O_5 @ 25 kg ha^{-1} and K_2O @ 37.5 kg ha^{-1})

T_2 : NK (N @ 75 kg ha^{-1} and K_2O @ 37.5 kg ha^{-1})

T_3 : NP (N @ 75 kg ha^{-1} and P_2O_5 @ 25 kg ha^{-1})

T_4 : NPK (N @ 75 kg ha^{-1}, P_2O_5 @ 25 kg ha^{-1} and K_2O @ 37.5 kg ha^{-1})

T_5 : NPK (T_4) + FYM@12.5 $t.ha^{-1}$

T_6 : SSNM

T_7 : Farmer's fertilizer practice (120 kg N, 50 kg P_2O_5 and 50 kg K_2O)-from adjacent farmers field

(Recommended Dose of Fertilizers: NPK @ 75: 25: 37.5 kg ha^{-1} as N: P_2O_5: K_2O)

Fertilizer application

The fertilizer N was applied as urea in three equal splits at active tillering, panicle initiation and flowering stages. The entire dose of P was applied as single superphosphate as basal (enriched with FYM @ 1:4) and potassium was applied as murate of potash in two equal splits at active tillering and panicle initiation stages respectively.

The farmers fertilizer practice (FFP) was recorded from the field adjacent to experimental area where fertilizer dose of N, P_2O_5 and K_2O @ 120: 50: 50 kg ha^{-1} was followed. A basal dose of 25 kg N, 25 kg P_2O_5 and 12.5 kg K_2O ha^{-1}were applied. The remaining N and K were given in two equal splits at active tillering and panicle initiation stages respectively.

3.2.6. Semi-dry rice cultivation

Dry ploughing was given to get fine tilth and gypsum @ 1 t/ha was applied basally to avoid soil crusting and soil hardening problem. Perfect land leveling was given for efficient weed and water management.Seed rate of @ 75kg/ha dry seed were used with seed hardening with 1% KCl for 16 hours (seed and KCl solution 1:1) and shade dried to enable the seed to withstand early moisture stress under semi-dry condition. The pre monsoon sowing with seed drill was done with 20 cm inter row spacing with a depth of 3-5 cm. First hand weeding was done between 15 and 21 days after germination. Second weeding was done at 30 - 45 days after first weeding (or) pendimethalin @1kg a.i /ha was applied.

3.3. Biometric observations

3.3.1. Growth attributes

In the net plot, five numbers of hills were selected randomly and tagged for recording biometric observations. The plant height and total number of tillers were taken at three critical stages *viz.*, active tillering, panicle initiation and post harvest. The yield parameters like number of total tillers and productive tillers, length of panicle, 1000 grain weight, grain and straw yield were recorded at harvest stages of the crop.

3.3.1.1. Plant height

The height of the tagged plants were measured from the ground level to the tip of the top most fully opened leaf or flag leaf at tillering, flowering and at harvest stages and the mean values of three replications were expressed in cm.

3.3.1.2. Number of tillers

The number of tillers plant^{-1} was measured at respective intervals as mentioned earlier and expressed in numbers plant^{-1}.

3.3.1.3. Dry matter production (DMP)

Five plants were randomly selected from sampling area and they were pulled out at tillering and flowering stages. The samples were dried in shade and again oven dried at 60°C till a constant weight was obtained. The dry weight was recorded using an electronic top pan balance and the dry matter was expressed in kg ha^{-1}.

3.3.1.4. Thousand grain weight

A sample of grains from the yield of each plot was drawn and 1000 well filled grains were counted, weighed and expressed as test weight in grams.

3.4. Yield

3.4.1. Grain yield

Grains from each net plot were cleaned; sun dried and weighed at 14 per cent moisture content and the grain yield was expressed in kg ha^{-1}.

3.4.2. Straw yield

The straw obtained from each net plot area was sun dried and weighed. The straw yield was expressed in kg ha^{-1}.

3.5. Computation of derived parameters

3.5.1. Total factor productivity (TFP)

$$\text{Total factor productivity (TFP)} = \frac{\text{Grain yield in treated plot (kg ha}^{-1}\text{)}}{\text{Total nutrients applied (NPK) (kg ha}^{-1}\text{)}}$$

3.5.2. Partial factor productivity (PFP)

Partial factor productivity (PFP) = kg grain per kg of nutrient applied

$$\text{For N applied plot } (PFP_N) = \frac{\text{Grain yield in N applied plot (kg ha}^{-1}\text{)}}{\text{Fertilizer N applied (kg ha}^{-1}\text{)}}$$

3.5.3. Agronomic efficiency (AE)

Agronomic efficiency (AE) = kg grain yield increase per kg of nutrient applied

$$\text{For N applied plot } (AE_N) = \frac{\text{(Grain yield in N applied plot – Grain yield in N}_0\text{ plot) (kg ha}^{-1}\text{)}}{\text{Fertilizer N applied (kg ha}^{-1}\text{)}} \times 100$$

3.5.4. Recovery efficiency (RE)

Recovery efficiency (RE) = kg nutrient taken per kg of nutrient applied

$$\text{For N applied plot } (RE_N) = \frac{\text{(Uptake of N in N applied plot – Uptake of N in N}_0\text{ plot) (kg ha}^{-1}\text{)}}{\text{Fertilizer N applied (kg ha}^{-1}\text{)}}$$

3.5.5. Indigenous nutrient supply

The indigenous nutrient supply is the amount of each nutrient taken up by the crop from indigenous sources when sufficient amounts of all other nutrients are supplied and other limitations are removed. The indigenous nutrient supply was calculated as follows:

Indigenous nitrogen supply (INS) = Total N uptake in N omission plot i.e., N uptake in PK plot.

Indigenous phosphorus supply (IPS) = Total P uptake in P omission plot i.e., P uptake in NK plot

Indigenous potassium supply (IKS) = Total K uptake in K omission plot
i.e., K uptake in NP plot

3.5.6. Fertilizer requirement of rice

The fertilizer N requirement of rice as per the SSNM approach was computed as per Buresh *et al.* (2005) as follows:

$$\text{Fertilizer N (kg ha}^{-1}) = \frac{\text{(Attainable yield target – N limiting yield)}}{AE_N} \times 1000$$

The attainable yield target was 4.0 and 3.5 t ha^{-1} in Paramakudi block and Ramanathapuram block respectively. The N limiting yield and agronomic efficiency for N (AE_N) were used to compute fertilizer N requirement for rice. Similarly for the same yield target, fertilizer P_2O_5 and K_2O requirement were computed as per Witt *et al*. (2002) (Tables 3 and 4).

Table 3. Guidelines for the application of fertilizer P_2O_5 to rice according to yield target and P-limited yield in P omission plots (Witt *et al*., 2002)

Yield target (t ha^{-1}) →	**4**	**5**	**6**	**7**	**8**
P- limited yield (t ha^{-1}) ↓	**Fertilizer P_2O_5 rate (kg ha^{-1})**				
3	20	40	60		
4	15	25	40	60	
5	0	20	30	40	60
6	0	0	25	35	45
7	0	0	0	30	40
8	0	0	0	0	35

Table 4. Guidelines for the application of fertilizer K_2O to rice according to yield target and K- limited yield in K omission plots (Witt *et al.*, 2002)

Rice straw inputs	Yield target (t ha^{-1})↓	4	5	6	7	8
	K- limited yield (t ha-1)→	Fertilizer K_2O rate (kg ha^{-1})				
Low (<1t ha^{-1})	3	45	75	105		
	4	30	60	90	120	
	5		45	75	105	135
	6			60	90	120
	7				75	105
	8					90
Medium (2 to 3 t ha^{-1})	3	30	60	90		
	4	0	35	65	95	
	5		20	50	80	110
	6			35	65	95
	7				50	80
	8					65
High (4 to 5 t ha^{-1})	3	30	60	90		
	4	0	30	60	90	
	5		0	30	60	90
	6			10	35	70
	7				25	55
	8					40

3.5.7. Computation of irrigation water quality

i. The residual sodium carbonate (RSC) value, (Eaton,1950) was calculated using the formula,

$$\mathbf{RSC = (CO_3^{-2} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})}$$

ii. The soluble sodium percentage(SSP)value, (Eaton,1950) was calculated as,

$$\mathbf{SSP = (Na^{+} \times 100) / (Ca^{2+} + Mg^{2+} + Na^{+})}$$

iii. The sodium adsorption ratio (SAR), (Richards, 1954) was worked out using the formula.

$$\mathbf{SAR = Na^{+} / \sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

iv) The potential salinity of the irrigation water(Doneen,1975) was calculated as, **potential salinity=Cl+1/2 SO_4**

3.6. Collection, processing and analysis of soil, ground water and plant samples

3.6.1. Soil sample

A total number of two fifty five surface, composite soil samples (0-15cm) were collected from the semi-dry rice cultivating areas of district. The samples were dried in shade and gently powdered with wooden mallet and passed through 2 mm sieve and stored in polythene containers for analysis.

3.6.2. Ground water samples

Seventy ground water samples were collected in plastic container from different bore wells of semi-dry rice cultivating areas of Ramanathapuram district. The plastic container safely handled, transferred and stored in appropriate place of analytical lab for further chemical analysis.

3.6.3. Plant sampling

Plant samples of five hills were collected carefully with roots in each plot at critical stages of crop growth. The roots were cleaned with tap water and subsequently with distilled water to remove the adhering soil. In the tillering and flowering stages, the roots and shoots were amalgamated. At harvest, the grain and straw were separated. These plant samples were dried in shade and oven dried at 65 °C. Then the samples were ground separately in a wiley mill using stainless steel blades and used for nutrient analysis. At harvest stage, the dry matter was partitioned into grain and straw and analyses were carried out accordingly. The grain samples were powdered separately. All the processed plant samples and grain samples were preserved for chemical analysis.

Table 5. Analytical methods for soil and plant and water samples

S. No.	Parameter	Methodology	Authors
I. Soil analysis			
1	Soil survey	-	Soil survey staff (1966)
2	Pedon description and sample collection	-	Anon.(1966)
A.	**Physical properties**		
3	Soil colour	Munsell colour chart	Pendleton and Nickerson (1951)
4	Bulk density	Cylinder method	Dakshinamoorthy and Gupta (1968)
5	Textural analysis	International pipette method	Piper (1966)
B.	**Chemical properties**		
6	Soil pH	Potentiometry – 1:2 soil water ratio	Jackson (1973)
7	Electrical conductivity	Conductometry – 1:2 soil water ratio	Jackson (1973)
8	Organic carbon and organic matter	Chromic acid digestion method	Walkley and Black (1934)
9	Total N	Kjeldahl method	Piper (1966)
10	Total P	-	Pemberton (1945)
11	Total K	-	Stanford and English (1949)
12	Available N	Alkaline permanganate method	Subbiah and Asija (1956)
13	Available P	Colorimetric, 0.5 M $NaHCO_3$ extract, ascorbic acid method	Olsen *et al.* (1954)
14	Available K	Flame photometer, neutral normal ammonium acetate extraction	Stanford and English (1949)
15	Available Fe,Cu, Zn, and Mn	DTPA extract – Atomic absorption spectrophotometer	Lindsay and Norvell (1978)
16	Total Fe,Cu, Zn, and Mn	Atomic absorption spectrophotometer	Jackson (1973)
17	Cation exchange capacity	Neutral normal NH_4OAC leaching and washing with C_2H_5OH	Schollenberger and Dreibelbis (1930)
18	Free $CaCO_3$	Rapid titration method	Piper (1966)
II. Plant Analysis			
1	Total nitrogen	Kjeldahl digestion and distillation	Jackson (1973)
2	Total phosphorus	Vanadomolybdate yellow colour method	Jackson (1973)
3	Total potassium	Concentration of K in triacid extract by flame photometry	Piper (1966)
4	Micronutrients (Fe, Cu, Zn and Mn)	Triple acid extract	Piper (1966)

Table 5. Analytical methods for water sample

S.NO	Details of analysis	Methods followed	Reference
1	Reaction (pH)	Using glass electrode	Piper, 1966
2	Electrical conductivity(EC)	Using conductivity bridge	Piper, 1966
3	Carbonate and bicarbonate	Volumetric	Richards, (1954)
4	Chloride	Volumetric	Richards, (1954)
5	Sulphate	Volumetric	Jackson, (1973)
6	Calcium plus Magnesium	Versanate titration	Richards, (1954)
7	Potassium	Flame photometry	Stanford and English (1949)
8	Sodium	Flame photometry	Stanford and English (1949)

3.7. Statistical analysis

The data on various soil properties were statistically scrutinised for establishing the relationship between different parameters of the soil and irrigation waters working out simple correlation as described by Fisher (1938).The various biometric observations, the yield of dry matter at each physiological stage and the yield of grain and straw recorded at harvest, the analytical values of different estimations of plant and the computed data such as uptake were subjected to statistical scrutiny as per the standard procedures outlined by Gomez and Gomez (1976).

CHAPTER IV

RESULTS

To characterize the semi-dry rice growing soils of Ramanathapuram district two soil profiles of Paramakudi and Thirupullani soil series, 255 village wise surface soil samples were collected and characterized to assess the soil related constrains which affects the semi-dry rice yields of Ramanathapuram district. Also on-station and on-farm trials were laid out to find out the yield gap between farmers fertilizers practice (FFP) and recommended dose of nutrient application for semi-dry rice and develop SSNM strategy to bridge the yield gap and increase the rice yields under semi-dry condition. The experimental data generated in the above study were tabulated and presented in this chapter.

4.1. SOIL PROFILE CHARACTERISTICS OF SEMI-DRY RICE GROWING SOILS OF RAMANATHAPURAM DISTRICT

To characterize the semi-dry rice grown soils of Ramanathapuram district two domains viz., Paramakudi and Ramanathapuram were selected and two soil profiles were dug to characterize the major soil series of each domain. The profiles were dug at the location of Oorakudi village (9°55’ and 7°53’) of Paramakudi block and in Mammathukadai village (9°28’ and 7°83’) of Ramanathapuram block. The morphological, physical and chemical characteristics of the two profile studied viz., Paramakudi series and Thirupullani series are given in Tables 6 and 7 respectively. The profile diagram and photograph of the soil profiles are given in Fig. 2 and 3.

In Paramakudi soil series, the surface texture was sandy clay followed by clay in all the sub horizons; The bulk density of the horizons varied between 1.40 and 1.48 (Mg/m^{-3}); soil pH was neutral, EC varied between 1.5 and 1.90 dS m^{-1} with low organic carbon, low available N and P and high in available K status. In all the horizons free $CaCO_3$ varied between 1.51 and 1.96 per cent which indicates the calcareous nature of soil series. The CEC of different horizons varied between 30.6 and 49.7 cmol (p^+) kg^{-1} with BSP of 88.8 to 98.9 per cent, the total major and micro nutrient content and available nutrient status are given in Tables 6.

Thirupullani soil series which was predominant in Ramanathapuram block had loamy sand in texture in surface A_p and A_{12} horizons followed by sandy clay loam in B_{21t} horizons and sandy loam in B_{22t} horizon. Due to the presence of cemented hard pan in B_{21t} horizon soil become impervious and the monsoon gets stagnated which favours for semi-dry rice cultivation. The bulk density of different horizons varied between 1.6 and 1.72 Mg/m^{-3}. Soil pH was neutral, EC varied from 1.3 to 1.8 dS m^{-1}, with low organic carbon and available nitrogen content. In the surface A_p horizon available P content was medium while available K content was high in all the horizons, the CEC varied from 8.11 to 21.65 cmol (p^+) kg^{-1},with BSP of 74.1 to 85.1 per cent and the total major and micro, available major and micro nutrient status are given in Tables 7.

4.2. Soil nutrient data base

To create the village wise soil nutrient database of semi-dry soils of Ramanathapuram district 129 soil samples were collected from 22 villages of Paramakudi block and 126 soil samples from 21 villages were collected in Ramanathapuram block. The soil samples were analyzed for soil pH, EC, organic carbon, available N, P, K and available Fe, Mn, Zn and Cu respectively.

4.2.1. Soil reaction (pH)

The frequency distribution of soil pH of semi-dry rice soils of Paramakudi and Ramanathapuarm blocks are given in Tables 8. The range of soil pH for Paramakudi block varied between 6.10 and 8.40 with a mean of 7.32. In the 22 villages, all the 129 samples recorded neutral soil pH.

In Ramanathapuram block, of the 126 soil samples collected from 21 villages, the frequency distribution of soil pH was 66 per cent were neutral, while 18 per cent were acidic and 16 per cent alkaline.The village wise distribution of acidic pH was Sakkarkottai (34 per cent) T.pattanam (75 per cent), Kalari (50 per cent), Ekkudi (67 per cent), Nallankudi (83 per cent), Pullankudi (20 per cent) and Ammari (20 per cent).Similarly the village wise distribution of soil alkalinity was Sakkarkottai (17 per cent), Peruvayal (60 per cent), N.Mangalam (60 per cent), RM.B.Tank (20 per cent), Karendal (43 per cent), Ragupuram (20 per cent), Pullandai

(17 per cent), Anjamadai (50 per cent), Setukal (14 per cent), Vallam (17 per cent) and Mudalur (17 per cent) respectively.

4.2.2. Electrical conductivity (EC)

The frequency distribution of EC in semi-dry rice soils of Ramanathapuaram district is given in Tables 9. In Paramakudi block, the range of EC varied between 0.97 and 1.28 dSm^{-1} with a mean of 1.12 dS m^{-1}. Of the 129 soil samples, 95 per cent recorded medium salinity (1-4 dS m^{-1}) while 5 per cent were the non saline (<1.0 dS m^{-1}). The villages of Pothuvakudi (16%), V.kurichi (40%), Nagatchi (37%) and Erumpoor (25%) were the non saline soil.

In Ramanathapuram block, the range of EC varied from 0.12 to 4.71dS m^{-1} with a mean of 1.82 dS m^{-1}. Of the 126 soil samples, 52 per cent were medium saline, 40 per cent were non saline and rest of 8 per cent was saline respectively. The villages of Sakkarkottai (33%), Kalari (67%), U.K.mangai (14%), Ekkudi (86%), Nallankudi (86%), Ammari (100%), Peruvayal (60%), Pasalai (100%), Karendal (28%), Ragupuram (20%), Pullandai (100%), Setukal (28%), Vallam (17%) and Mudalur (100%) were non saline soils.

The villages of Sakkarkotai (33%), R.S.Madai (84%), T.pattanam (100%), Kalari (14%), U.K.Mangai (86%), Maruthur (100%), Ekkudi (14%), Nallankudi (14%), Pullankudi (80%), Peruvayal (40%), N.Manglam (80%), RM.B.Tank (80%), Karendal (44%), Ragupuram (80%), Anjamadai (100%), Setukal (58%) and Vallam (83%) of Ramanathapuram block were medium saline while Sakkarkotai (34%), R.S.Madai (16%), Pullankudi (20%), N.Manglam (20%), RM.B.Tank (20%), Karendal (28%) and Setukal (14%) were saline EC (>4.0 dS m^{-1}) soil respectively.

4.2.3. Organic carbon (OC)

The frequency distribution of organic carbon status of semi-dry rice soils of Ramanathapuram district is given in Tables 10. In Paramakudi block, the range of OC varied between 0.03 and 0.73 per cent with a mean of 0.27 per cent. Of the 129 soil samples, 96 per cent recorded low OC status while 4 per cent recorded the medium OC status.

In Ramanathapuram block the range of OC varied from 0.03 to 1.35 per cent with a mean of 0.42 per cent. Of the 126 soil samples, 64 per cent were low, 27 per cent were medium and 9 per cent were high in OC status. The village wise distribution of high OC status was as follows: Sakkarkotai (17%), Kalari (33%), U.K.mangai (14%) and Ragupuram (20%).

4.2.4. Available N

The frequency distribution of available N status of semi-dry rice soils of Ramanathapuram district is given in Tables 11. In Paramakudi block, the range of values for available N varied between 118 and 280 kg ha^{-1} with a mean of 217 kg ha^{-1}. Of the 129 soil samples, 97.9 per cent recorded low available N while 2.1 per cent recorded the medium available N status.

In Ramanathapuram block the range of available N varied from 76 to 354 kg ha^{-1} with a mean of 198 kg ha^{-1} respectively. Of the 126 soil samples, 95.8 per cent were low and 4.2 per cent were medium in available N status. The village wise distribution of medium available N status was as follows: Kalari (33%), U.K.mangai (14%), R.M.B.tank (10%) and Ragupuram (33%).

4.2.5. Available P

The frequency distribution of available P status of semi-dry rice soils of Ramanathapuram district is given in Tables 12. In Paramakudi block, the range of values for available P varied between 5.0 and 29.0 kg ha^{-1} with a mean of 10.1 kg ha^{-1}. Of the 129 soil samples, the per cent distribution of available P status was 86.1 per cent low available P while 11.7 per cent recorded the medium in available P status and 2.2 per cent registered the high available P status respectively. In Paramakudi block, following villages recorded cent per cent low available P status:Parthibanur, Perungarai, Kamuthakudi, Puthukudi, M.puram, Kavanur, Ariyanenthal, Kalaiyur, Ariyakottai and Smaputhur.

In Ramanathapuram block, the range of available P varied from 5.0 to 16 kg ha^{-1} with a mean of 9.6 kg ha^{-1} respectively. Of the 126 soil samples, 79.9 per cent were low and 20.1 per cent were medium in available P status. In Ramanathapuram block, following villages cent per cent low available

P status : T. Pattanam, Kalari, Nallankudi, Peruvayal, N. Mangalam, Pasalai and Karendal.

4.2.6. Available K

The frequency distribution of available K of semi-dry rice soils of Ramanathapuram district is given in Tables 13. In Paramakudi block, the range of values for available K varied between 408 and 596 kg ha^{-1} with a mean of 506 kg ha^{-1} respectively, with 100 per cent of samples recording high available K status.

In Ramanathapuram block recorded high available K status of all the 126 soil samples. The range of available K status varied from 229 to 557 kg ha^{-1} with a mean of 338 kg ha^{-1} respectively. Of the 126 soil samples except the villages of Pullandai (20%), Ammari (40%) and Peruvayal (100%) which recorded medium available K status, the remaining villages consisting 88 per cent recorded high available K status.

4.2.7. Available micronutrient status

4.2.7.1. Available Fe

The frequency distribution of available Fe for semi-dry rice soils of Ramanathapuram district is given in Tables 14. In Paramakudi block, the range of values for available Fe varied between 0.06 and 44.8 ppm with a mean of 5.05 ppm respectively. Of the 129 soil samples, 64.4 per cent were deficient of available Fe status for the threshold of 6.3 ppm for calcareous soils. The villages of Kulavipatti, Melayakudi and Ariyanenthal recorded 100 per cent deficiency which in Kamuthakudi, Oorapuli, Nagatchi and Erumpoor more than 80 per cent of sampls were deficient of available Fe status

In Ramanathapuram block, the range of values for available Fe status varied from 3.42 to 100.4 ppm with a mean of 14.5 ppm respectively. Of the 126 soil samples, except the villages of Sakkarkotai (11%), Kalari (11%) and R.M.B.tank (20%) all other 18 villages which comprising 97.4 per cent of soil samples recorded sufficient available Fe status for the threshold of 3.7 ppm for non calcareous soil. The spatial distribution of different levels of available Fe status of Ramanathapuram district is given in Fig.12, Fig.12.a and Fig.12.b respectively.

4.2.7.2. Available Mn

The frequency distribution of available Mn for semi-dry rice soils of Ramanathapuram district is given in Tables 15. In Paramakudi block, the range of values for available Mn varied between 0.22 and 53.80 ppm with a mean of 5.77 ppm respectively. Of the 129 soil samples, 17.4 per cent were deficient in available Mn. The village wise distribution of deficient in available Mn was in Parthibanur (17%), Pothuvakudi (33%), Kulavipatti (14%),Vilathur (50%), Melayakudi (67%), Kavanoor (50%), Pamboor (33%), Kalaiur (67%), Oorapuli (17%), Ariyakottai (20%) and Ulakatchi (14%) respectively.

In Ramanathapuram block, the range of values for available Mn varied between 0.30 and 79.16 ppm with a mean of 13.23 ppm respectively. Of the 126 soil samples, except the villages of Sakkarkotai (33%) and R.S.Madai (33%) all other 20 villages which comprising 96.8 per cent of soil samples were sufficient in available Mn content.

4.2.7.3. Available Zn

The frequency distribution of available Zn status of semi-dry rice soils of Ramanathapuram district is given in Tables 16. In Paramakudi block, the range of values for available Zn varied between 0.34 and 1.80 ppm with a mean of 0.72 ppm respectively. Of the 129 soil samples, 88.2 per cent were deficient in available Zn with the following villages recording 100 per cent Zn deficiency: Parthibanur, Pothuvakudi, Kulavipatti, Vilathur, Melayakudi, Kavanoor, Venthoni, Kalaiur, Nagatchi, Kiliyur, Keelanotchi, Smaputhur, Ulakatchi and Erumpoor recording 100 per cent Zn deficiency respectively.

In Ramanathapuram block, the range of values for available Zn varied between 0.03 and 3.30 ppm with a mean of 0.85 ppm respectively. Of the 126 soil samples, 85 per cent were deficient in available Zn status with villages of Maruthur, Peruvayal, Pasalai, Ragupuram, Pullandai and Anjamadai recording 100 per cent Zn deficiency.

4.2.7.4. Available Cu

The frequency distribution of available Cu of semi-dry rice soils of Ramanathapuram district is given in Tables 17. In Paramakudi block the range of

values for available Cu varied between 0.56 and 2.94 ppm with a mean of 1.81 ppm respectively. Except the villages of Kalaiur (33%), Ariyakottai (20%) and Kiliyur (11%) remaining 97 per cent of samples were sufficient in available Cu status.

In Ramanathapuram block, the range of values for available Cu status varied between 0.26 and 4.28 ppm with a mean of 1.60 ppm respectively. Of the 126 soil samples, 32.8 per cent were deficient in available Cu and their villages of Sakkarkottai (50%), T.Pattanam (50%), Peruvayal (50%), RM.B.Tank (60%), Pasalai (50%), Ragupuram (80%), Pullandai (50%) and Anjamadai (67%) were deficient available Cu status.

4.3. Assessment of ground water quality

The semi-dry rice in both Paramakudi and Ramanathapuram blocks are sown during 2-3rd week of September and 1-2nd week of October as direct seeded pre-monsoon sowing respect with the onset of north east monsoon. The directly seeded rice are germinated and mostly which grown with supplemental irrigation through tanks in Paramakudi block while it is completely rainfed in Ramanathapuram block. When the north east monsoon recedes early during December 2nd week onwards the standing rice will be in the flowering stage which needs supplemental irrigation either through tank (or) underground water. To assess the suitability of underground water, 70 ground water samples were collected from both Paramakudi and Ramanathapuram block and their quality was assessed using CSSRI, criteria. The assessment of ground water quality of semi-dry rice soils of Ramanathapuram district is given in Tables 18.

The frequency distribution of EC, RSC and SAR with respect to different quality of ground water is given in Tables.19. Of the 70 ground water samples, 5 were good (3.2%), 36 samples were marginally saline (53.3%), 25 were high SAR saline (37.5%) and 4 were alkali (5.5%) category. The good water samples recorded the mean value of 1.8 dSm^{-1}, 1.1 meq/l and 5.1of EC, RSC and SAR respectively. In high SAR saline category of the 25 samples, the mean values were 3 dSm^{-1}, 0.4 meq/l and 13.5 of EC, RSC and SAR respectively. And the alkali category the mean values were 2.9 dSm^{-1}, 4.6 meq/l and 8.3 of EC, RSC and SAR respectively.

In Paramakudi block, the block wise of different quality of ground water is given in Tables 20.Of the 40 water samples, 7.5 per cent were good, 80 per cent were

marginally saline,5 per cent were high SAR saline and 7.5 were alkali in nature. Hence both this good and marginally saline quality of ground water can be safely used for supplemental irrigation.

In Ramanathapuram block, of the 30 ground water samples, 26.6 per cent were marginally saline, 70 per cent were high SAR saline, and 3.4 per cent were alkali in nature respectively. Hence in Ramanathapuram block, 73.4 per cent of ground water samples comprising high SAR saline and alkali which cannot be used as supplemental irrigation. . Percent distribution of different ground water quality of Ramanathapuarm block is given in Fig.20.

4.4. Effect of nutrient omission on biometric observations of semi-dry rice

The SSNM technique was used to optimize the fertilizers N, P and K requirement of rice by using nutrient omission plots. Hence in Ramanathapuram district where semi-dry rice is grown on more than 75,000 ha in two domains viz., Paramakudi and Ramanathapuram blocks were related in each one on-station (ONS) experiments and two on-farm trials (OFT) using nutrient omission plots were conducted during 2011-2012 respectively. Also including SSNM package developed in on station experiment at Paramakudi with two on-farm trials and three on-farm trials at Ramanathapuram were conducted during 2012-13 to validate the SSNM package developed.

4.4.1. Effect of nutrient omission on plant height (cm) at active tillering stage

The effect of nutrient omission on plant height at active tillering stage during 2011-12 and 2012-13 are given in Tables 21 and 22, respectively. During 2011-12 in Paramakudi block, in ONS1 and both OFTs, application of NPK with organic manure recorded the highest plant height of 35.3 cm which was on par with application of NPK alone or FFP. In Ramanathapuram block, in ONS2 experiment, application of NPK with organic manure recorded significantly highest plant height of 36.2 cm. But in both OFT3 and OFT4, application of NPK with organic manure recorded the higher plant height of 35.5 and 35.6 cm respectively, which was on par with NPK alone and FFP recorded the plant height of 34.4 and 34.4 cm and 34.6 and 34.5 cm respectively. In Ramanathapuram block during 2011-12, the N omitted treatment recorded the lowest plant height of 28.4, 27.9 and 28.1 cm in ONS2, OFT3 and OFT4 respectively.

Similarly during 2012-13 in Paramakudi block, in ONS1, SSNM treatment recorded significantly highest plant height of 33.9 cm. But in both OFT1 and OFT2 either SSNM (or) NPK with organic manure application which were on par with NPK alone and FFP recorded the highest plant height of 33.9 cm respectively. Similarly in Ramanathapuram block, in all the trials, SSNM treatment were on par with NPK with organic manure application which recorded the highest plant height of 34.0 cm. During 2012-13 also in both Paramakudi and Ramanathapuram block N omitted treatment registered the lowest plant height of 26.4 and 26.3 cm respectively.

4.4.2. Effect of nutrient omission on plant height (cm) at panicle initiation stage

The effect of nutrient omission on plant height at panicle initiation stage during 2011-12 and 2012-13 are given in Tables 23 and 24 respectively. During 2011-12 in Paramakudi block, in ONS1 and OFT1, application of NPK with organic manure recorded the highest plant height of 72.6 and 67.0 cm respectively, but in OFT2 the NPK alone showed the maximum plant height of 66.5 cm. In ONS1 and OFT1 the P omission plot, K omission plot, NPK alone and FFP were on par with NPK with organic manure application but in OFT2 NPK with organic manure application and FFP were on par with NPK alone treatment respectively. In Ramanathapuram block, in ONS2 experiment and OFT3 application of NPK with organic manure recorded significantly highest plant height of 73.8 and 71.5 cm respectively. But in OFT4, FFP recorded the higher plant height of 70.3 cm which was on par with NPK alone, NPK with organic manure application

Similarly during 2012-13 in Paramakudi block, in ONS1 and both OFTs, application of NPK as per the SSNM approach showed significantly highest plant height of 75.5, 75.6 and 75.1 cm respectively which was on par with NPK alone, NPK with organic manure and FFP. But additionally K omitted treatment in OFT2 and P omitted treatment in ONS1 were on par respectively. Similarly in Ramanathapuram block, SSNM treatment recorded the maximum plant height of 76.4, 75.6 and 75.6 cm in OFT3, OFT4 and OFT5 respectively. The NPK with organic manure application, NPK alone, FFP and K omitted treatment were on par in OFT3 and OFT4 in addition to P omitted treatment which was on par in OFT5 respectively. During 2012-13 in both Paramakudi and Ramanathapuram blocks, N omitted treatment recorded the lowest plant height of 65.3 and 64.2 cm respectively.

4.4.3. Effect of nutrient omission on total tillers (nos.) at active tillering stage

The effect of nutrient omission plot on total tillers at active tillering stage during 2011-12 and 2012-13 are given in Tables 25 and 26 respectively. During 2011-12 in Paramakudi block, in ONS1 and OFT2, application of NPK with organic manure recorded the maximum total tillers of 10.5 and 11.8 respectively, but in OFT1, the NPK alone showed the maximum of total tillers of 11.7. In OFT1, the FFP was on par to NPK with organic manure application but in ONS1 the NPK alone and FFP were on par with NPK organic manure application. In Ramanathapuram block, in ONS2 experiment and OFT4, application of NPK with organic manure recorded significantly highest total tillers of 10.3 and 11.2 respectively. But in OFT3 application of NPK with organic manure on par with FFP recorded total tillers of 12.6. In Ramanathapuram block, NPK with organic manure application recorded the maximum mean of total tillers of 11.4.

Similarly, during 2012-13, in Paramakudi block, in ONS1 and both OFT1 and OFT2, the SSNM approach recorded maximum total tillers of 10.9, 11.1 and 10.9 respectively. This is noted as NPK with organic manure application on par with FFP, in ONS1 and NPK with organic manure application alone in OFT1 and OFT2 respectively. In Paramakudi block, the highest mean of total tillers of 11.0 in SSNM approach.

Similarly, in Ramanathapuram block, SSNM treatment recorded the maximum total tillers of 9.9. This was followed by NPK with organic manure application on par with NPK alone and FFP in OFT3. But in OFT4, NPK with organic manure application showed the highest number of total tillers of 10.4. In OFT5, the SSNM recorded maximum of 10.1 which was on par with FFP and NPK with organic manure application. In Ramanathapuram block, SSNM approach recorded the maximum total tillers mean of 10.6 respectively.

4.4.4. Effect of nutrient omission on total tillers (nos.) at panicle initiation stage

The effect of nutrient omission on total tillers at panicle initiation stage during 2011-12 and 2012-13 are given in Tables 27 and 28 respectively. During 2011-12 in Paramakudi block, in OFT1 and OFT2, FFP recorded the maximum total tillers of 15.2 and 14.1 respectively. This was followed by NPK with organic manure

application. But in ONS1 the NPK with organic manure application recorded the maximum total tillers of 14.9, this was followed by NPK alone and FFP were on par. In Paramakudi block, NPK with organic manure application and FFP recorded the total tillers of 14.2 each. In Ramanathapuram block, in ONS2 experiment and OFT3, application of NPK with organic manure recorded significantly highest total tillers of 14.9 and 15.6 respectively. But in OFT4, FFP recorded the maximum total tillers of 14.8. NPK alone and FFP were on par, K omitted, NPK alone and FFP were on par and K omitted, NPK alone and NPK with organic manure application were on par in ONS2, OFT3 and OFT4 respectively. In Ramanathapuram block, NPK with organic manure application recorded the maximum mean of total tillers 14.9 at panicle initiation stage.

Similarly, during 2012-13, in Paramakudi block, in ONS1 and both OFTs, SSNM approach recorded significantly maximum total tillers of 15.7, 15.2 and 15.6 respectively. This was followed by NPK with organic manure application in ONS1, FFP on par with NPK with organic manure application recorded of 15.5 in SSNM treatment. Similarly in Ramanathapuram block, SSNM approach recorded the maximum total tillers of 15.8, 16.2 and 16.0 in OFT3, OFT4 and OFT5 respectively. This was followed by NPK with organic manure application, NPK alone and FFP which were on par. But in OFT4 and OFT5, NPK alone, NPK with organic manure application and FFP which were on par respectively. In Ramanathapuram block, SSNM based NPK application recorded the maximum mean of total tillers with 16.0 respectively.

4.4.5. Effect of nutrient omission on total productive tillers (nos.) at panicle initiation stage

The effect of nutrient omission on total productive tillers at panicle initiation stage during 2011-12 and 2012-13 are given in Tables 29 and 30 respectively. During 2011-12, in Paramakudi block, in ONS1 and OFT1, NPK with organic manure application recorded the maximum total productive tillers of 10.9 and 9.50 respectively while in OFT2; FFP recorded the maximum productive tillers of 9.90. This was followed by in ONS1 and OFT1, NPK alone and FFP which were on par and in OFT2, K omission, NPK alone and NPK with organic manure application were on par. In Ramanathapuram block, in ONS2 experiment and OFT3 application of

NPK with organic manure recorded significantly highest total productive tillers of 11.8 and 13.2 respectively. But in OFT4, FFP recorded the maximum total productive tillers of 12.8. In ONS2 and OFT3, FFP which were on par with NPK alone recorded next best total productive tillers. In Ramanathapuram block, NPK with organic manure application recorded the maximum mean total productive tillers of 12.6 at panicle initiation stage.

Similarly during 2012-13 in Paramakudi block, in ONS1 and both OFT1 and OFT2, the SSNM approach recorded significantly maximum total productive tillers of 12.8, 12.8 and 12.8 respectively. This was followed by NPK with organic manure application and FFP which were on par in both OFT1 and OFT2. The SSNM approach recorded maximum mean of total productive tillers of 12.8. Similarly in Ramanathapuram block, SSNM approach recorded the maximum mean of total productive tillers of 14.0 and 14.7 in OFT3 and OFT4 respctively. In OFT5, NPK with organic manure application and SSNM which were on par recorded total productive tillers of 13.9 each. In OFT4 and OFT5, NPK alone, NPK with organic manure and FFP which were on par. But in OFT3, NPK with organic manure application and FFP were on par. In Ramanathapuram block, SSNM approach recorded the maximum number of total productive tillers of 14.2 respectively.

4.4.6. Effect of nutrient omission on DMP (kg ha^{-1}) at active tillering stage

The effect of nutrient omission on DMP at panicle initiation stage during 2011-12 and 2012-13 are given in Tables 31 and 32 respectively. During 2011-12, in Paramakudi block, in ONS1 and OFT2, NPK with organic manure application recorded the maximum DMP of 3422 and 3510 kg ha^{-1}. But in OFT1, FFP recorded the maximum of DMP of 3645 kg ha^{-1} respectively. This was followed by NPK alone and FFP which were on par, NPK alone and NPK with organic manure application were on par. In Paramakudi block, NPK with organic manure application recorded the maximum mean DMP of 3484 kg ha^{-1}. In Ramanathapuram block, in OFT3 and OFT4, FFP recorded significantly highest DMP of 2245 and 2092 kg ha^{-1} respectively. But in ONS2, application of NPK with organic manure recorded the maximum of DMP with 2159 kg ha^{-1}. FFP were on par in OFT3 and OFT4 this was followed by NPK with organic manure application. In Ramanathapuram block, NPK

with organic manure application recorded the maximum mean of DMP of 2132 kg ha^{-1}at active tillering stage.

Similarly during 2012-13 in Paramakudi block, in ONS1 and both OFTs, the SSNM approach recorded significantly maximum DMP of 3688, 3758 and 3867 kg ha^{-1} respectively. This was followed by NPK alone, NPK with organic manure application and FFP which were on par in ONS1 and NPK with organic manure application and FFP which were on par in OFT1. The highest mean of 3771 kg ha^{-1} was recorded in SSNM approach. Similarly in Ramanathapuram block, SSNM approach recorded significantly the maximum DMP in all the OFT3, OFT4 and OFT5 with 2981, 2540 and 2878 kg ha^{-1} respectively. In Ramanathapuram block, SSNM based NPK application recorded significantly the maximum mean DMP of 2800 kg ha^{-1}.

4.4.7. Effect of nutrient omission on DMP (kg ha^{-1}) at panicle initiation stage

The effect of nutrient omission on DMP at panicle initiation stage during 2011-12 and 2012-13 are given in Tables 33 and 34 respectively. During 2011-12 in Paramakudi block, in ONS1 and OFT2, NPK with organic manure application recorded the maximum DMP of 6943 and 6732 kg ha^{-1} but in OFT1, FFP recorded the maximum DMP of 6889 kg ha^{-1}. In ONS1, this was followed by NPK alone and FFP which were on par. In Paramakudi block, NPK with organic manure application recorded the maximum dry matter production of 6784 kg ha^{-1}. In Ramanathapuram block, in ONS2 and OFT4, NPK with organic manure application recorded significantly highest DMP of 5986 and 5012 kg ha^{-1} respectively. But in OFT3, FFP recorded the maximum DMP of 5964 kg ha^{-1}. In ONS2 and OFT4, this was followed by NPK alone and FFP which were on par. In Ramanathapuram block, NPK with organic manure application recorded the maximum of DMP of 6289 kg ha^{-1} at panicle initiation stage.

Similarly, during 2012-13 in Paramakudi block, in ONS1 and both OFTs, SSNM approach recorded significantly maximum DMP of 7040, 7058 and 6998 kg ha^{-1} respectively. This was followed by NPK alone, NPK with organic manure application and FFP were on par in ONS1; NPK alone, NPK with organic manure application and FFP which were on par in OFT1 and OFT2 respectively. The highest

mean of 7032 kg ha^{-1} noted in SSNM approach in Paramakudi block. In Ramanathapuram block, SSNM approach recorded the maximum DMP of 5684, 5897 and 5896 kg ha^{-1}in OFT3, OFT4 and OFT5 respectively. NPK alone, NPK with organic manure application and FFP which were on par in all the OFTs. In Ramanathapuram block SSNM based NPK application recorded the maximum DMP of 5826 kg ha^{-1}.

4.5. Effect of nutrient omission on yield and yield attributes of semi-dry rice

4.5.1. Effect of nutrient omission on 1000 grain weight

The effect of nutrient omission plot on 1000 grain weight during 2011-12 and 2012-13 is given in Tables 35 and 36 respectively. In Paramakudi block, application of NPK with organic manure recorded maximum 1000 grain weight of 22.3 and 22.4 g in ONS1 and OFT2. But in OFT1, FFP based NPK application recorded the maximum 1000 grain weight of 22.7g. Similarly in 2011-12 in Ramanathapuram block, application of NPK with organic manure recorded significantly highest 1000 grain weight of 20.2, 21.2 and 20.0 g in OFT3, OFT4 and OFT5 respectively.

Similarly during 2012-13 in Paramakudi block, SSNM package recorded significantly higher 1000 grain weight of 22.1, 22.8 and 22.7 g in ONS1, OFT1 and OFT2 respectively. In ONS1 and OFT2, except N omitted treatment all the treatments were on par with SSNM approach based NPK application respectively. During 2012-13 in Ramanathapuram block, the SSNM based NPK application recorded the maximum 1000 grain weight of 23.1, 23.9 and 24.9 g in OFT3,OFT4 and OFT5 respectively.

4.5.2. Effect of nutrient omission on grain yield

The effect of nutrient omission on rice grain yield of semi-dry rice during 2011-12 is given in Tables 37 and 38 respectively. In Paramakudi block, application of NPK with organic manure recorded the highest grain yield of 3488, 3591 and 3499 kg ha^{-1} in ONS1, OFT1 and OFT2 respectively. This was followed by NPK alone which on par with FFP in all the trials of Paramakudi block. In Paramakudi block, application of NPK with organic manure application recorded about 7.2 per cent higher grain yield than NPK alone. Compared to FFP, NPK with organic manure application recorded 5.4 per cent higher rice grain yield. In Paramakudi block

compared to NPK alone, PK (-N), NK (-P) and NP (-K) plots recorded -51.5,-35.4 and -19.8 per cent low grains yields respectively. Similarly during 2011-12, in Ramanathapuram block application of NPK with organic manure recorded significantly highest grain yield of 3369, 3124 and 3245 kg ha^{-1} in ONS2, OFT3 and OFT4 respectively. In all the trials, NPK with organic manure application, NPK alone and FFP application which were on par. The application of NPK with organic manure recorded 6.4 and 5.1 per cent higher grain yield than NPK alone and FFP respectively. In Ramanathapuram block, compared to NPK alone, PK (-N), NK (-P) and NP (-K) omission plots recorded -50.2, -33.3 and -23.9 per cent lower yields.

Similarly during 2012-13 in Paramakudi block, SSNM package recorded significantly highest grain yield of 3975, 3844 and 3948 kg ha^{-1} in ONS1, OFT1 and OFT2 respectively. This was followed by NPK with organic manure which was on par with FFP. In both OFTs, application of NPK alone recorded significantly lower grain yield than NPK with organic manure (or) SSNM (or) FFP. In general in Paramakudi block, against the target of 4t ha^{-1} the SSNM package could achieve 3.9 tonnes ha^{-1} which is 13.5 per cent higher than FFP. Also compared to NPK alone, SSNM package recorded 19.4 per cent higher yield and NPK with organic manure recorded 4.7 per cent higher yields. Also compared to NPK alone, PK (-N), NK (-P) and NP (-K) omission plots recorded -48.9,-21.3 and -10.6 per cent lower yields. During 2012-13 in Ramanathapuram block, also the SSNM package recorded significantly higher rice grain yield of 3467, 3422 and 3410 kg ha^{-1} in OFT3, OFT4 and OFT5 respectively. This was followed by application of NPK with organic manure which was on par with FFP. In general in Ramanathapuram block, SSNM package recorded 7.2 and 14.2 per cent higher grain yield than FFP and NPK alone treatment. Compared to NPK alone, PK (-N), NK (-P) and NP (-K) omission plots recorded -39.2,-18.0 and -9.2 per cent lower grain yield respectively.

4.5.3. Effect of nutrient omission on straw yield

The effect of nutrient omission on straw yield during 2011-12 and 2012-13 is given in Tables 39 and 40 respectively. In Paramakudi block, in ONS1 and OFT1, application of NPK with organic manure recorded highest straw yield of 4092 and 4176 kg ha^{-1} respectively; this was followed by NPK alone and FFP which were on par in all the trials. In Paramakudi block, application of NPK with organic manure

recorded about 2.5 per cent higher straw yield than FFP. Similarly in 2011-12 in Ramanathapuram block, application of NPK with organic manure recorded significantly highest straw yield of 4196 kg ha^{-1} in ONS2 and both OFTs recorded the maximum straw yield of 4012 and 3986 kg ha^{-1}in FFP respectively.

Similarly during 2012-13 in Paramakudi block, SSNM package recorded significantly highest straw yield of 4549, 4315 and 4456 kg ha^{-1} in ONS1, OFT1 and OFT2 respectively. In both OFT1 and OFT2, application of NPK alone recorded significantly lower straw yield than NPK with organic manure (or) SSNM (or) FFP. In general in Paramakudi block, SSNM package could increase the straw yield by 5 per cent higher than FFP. During 2012-13 in Ramanathapuram block, the SSNM package recorded significantly higher rice straw yield of 4396 and 4370 kg ha^{-1} in OFT3 and OFT5 respectively. In general in Ramanathapuram block, SSNM package recorded about 2 per cent higher straw yield than FFP.

4.6. Nutrient uptake by semi-dry rice

4.6.1. Total N uptake (kg ha^{-1}) at active tillering stage

The effect of nutrient omission on total N uptake at active tillering stage by semi-dry rice for 2011-12 and 2012-13 are given in Tables 41 and 42 respectively. During 2011-12 in Paramakudi block, in ONS1, application of NPK with organic manure recorded significantly higher total N uptake of 42.3 kg ha^{-1} while in OFT1 and OFT2 the FFP recorded the highest total N uptake of 47.2 and 45.4 kg ha^{-1} respectively. In Paramakudi block, total N uptake was higher in FFP followed by NPK with organic manure application and NPK alone at active tillering stage respectively. Similarly in Ramanathapuram block, during 2011-12, application of NPK with organic manure recorded highest total N uptake of 30.7 kg ha^{-1} in ONS2 experiments. But in OFT3 and OFT4 the FFP recorded maximum total N uptake of 27.5 and 29.2 kg ha^{-1} respectively. In general in Ramanathapuram block, during 2011-12 the total N uptake was higher in NPK with organic manure application followed by FFP and NPK alone at active tillering stage.

In 2012-13 at active tillering stage, the SSNM treatment recorded significantly highest total N uptake of 45.9, 46.0 and 46.9 kg ha^{-1} in ONS1, OFT1and OFT2 respectively. This was followed by NPK with organic manure application which was

on par with FFP and NPK alone. In general in Paramakudi block, the total N uptake was higher in SSNM followed by FFP, NPK with organic manure application and NPK alone. Similarly in Ramanathapuram block, SSNM treatment recorded significantly higher total N uptake of 47.3, 29.3 and 33.6 kg ha^{-1} in OFT3, OFT4 and OFT5 respectively. In all the three OFTs, this was followed by either NPK with organic manure application (or) FFP which were on par.

In Ramanathapuram block, in general in all the three OFTs, NPK alone recorded the lowest total N uptake among the NPK applied. In general total N uptake was higher in SSNM treatment followed by FFP (or) NPK with organic manure application respectively.

4.6.2. Total N uptake (kg ha^{-1}) at panicle initiation stage

The effect of nutrient omission plot on total N uptake at panicle initiation stage of semi-dry rice for 2011-12 and 2012-13 are given in Tables 43 and 44 respectively. During 2011-12, in Paramakudi block, in ONS1, OFT1 and OFT2, application of NPK with organic manure recorded significantly higher total N uptake of 66.1, 63.3 and 64.4 kg ha^{-1} this was followed by the FFP and NPK alone which recorded a total N uptake with 64.0 and 63.7 kg ha^{-1}, 62.3 and 59.3 kg ha^{-1} and 61.6 and 61.7 kg ha^{-1} in ONS1, OFT1 and OFT2 respectively. In Paramakudi block, total N uptake was higher in NPK with organic manure application followed by FFP and NPK alone at panicle initiation stage. Similarly, in Ramanathapuram block, during 2011-12, application of NPK with organic manure recorded highest total N uptake of 61.2 and 69.6 kg ha^{-1} in ONS and OFT4 respectively. But in OFT3, the FFP recorded the maximum total N uptake of 64.9 kg ha^{-1}. In general in Ramanathapuram block, at panicle initiation stage during 2011-12 the total N uptake was higher in NPK with organic manure application followed by FFP and NPK alone.

In 2012-13, at panicle initiation stage the SSNM treatment recorded significantly highest total N uptake of 68.6, 69.7 and 67.7 kg ha^{-1} in ONS1, OFT1 and OFT2 respectively. This was followed by NPK with organic manure application which is on par with FFP and NPK alone in ONS1 and FFP was on par with NPK with organic manure application and NPK alone in both OFTs. In general in Paramakudi block, the total N uptake was higher in SSNM followed by FFP, NPK

with organic manure application and NPK alone. Similarly in Ramanathapuram block, SSNM treatment recorded significantly higher total N uptake of 54.4, 46.6 and 50.5 kg ha^{-1} in OFT3, OFT4 and OFT5 respectively. In all the three OFTs, this was followed by either NPK with organic manure application (or) FFP which were on par. In Ramanathapuram block in general total N uptake was higher in SSNM treatment followed by FFP (or) NPK with organic manure application.

4.6.3. Total N uptake (kg ha^{-1}) at harvest stage

The effect of nutrient omission plot on total N uptake at harvest stage by semi-dry rice during 2011-12 and 2012-13 are presented in Tables 45 and 46 respectively. During 2011-12 in Paramakudi block, in ONS1 and OFT2 application of NPK with organic manure recorded the higher total N uptake of 108.4 and 95.5 kg ha^{-1},FFP was on par in ONS1 but in OFT1 the NPK alone recorded the maximum total N uptake of 93.8 kg ha^{-1} followed by the FFP and NPK with organic manure application. In Paramakudi block, total N uptake was higher in NPK with organic manure application followed by FFP and NPK alone. Similarly in Ramanathapuram block, during 2011-12, application of NPK with organic manure recorded highest total N uptake of 96.2 and 89.7 kg ha^{-1} in ONS2 and OFT4 respectively. But in OFT3, the FFP recorded the maximum total N uptake of 94.6 kg ha^{-1}. In general in Ramanathapuram block, at harvest stage during 2011-12 the total N uptake was higher in NPK with organic manure application followed by FFP and NPK alone.

In 2012-13 at harvest stage the SSNM treatment recorded significantly highest total N uptake of 98.3, 111.1 and 105.8 kg ha^{-1} in ONS1, OFT1 and OFT2 respectively, in addition, FFP was on par. This was followed by NPK with organic manure application which were on par with FFP and NPK alone in ONS1 and FFP on par with NPK with organic manure application and NPK alone in both OFTs. In general in Paramakudi block, the total N uptake was higher in SSNM followed by FFP, NPK with organic manure application and NPK alone. Similarly in Ramanathapuram block, SSNM treatment recorded significantly higher total N uptake of 96.1, 93.4 and 93.7 kg ha^{-1} in OFT3, OFT4 and OFT5 respectively. In OFT3, this was followed by NPK with organic manure application showed the total N uptake of 86.3 kg ha^{-1} but in OFT4 the FFP and NPK with organic manure were on par and in OFT5 the FFP, NPK with organic manure and NPK alone were on par. In

Ramanathapuram block, In general total N uptake was higher in SSNM treatment followed by NPK with organic manure application and FFP respectively.

4.6.4. Total P uptake (kg ha^{-1}) at active tillering stage

The effect of nutrient omission on total P uptake at active tillering stage of semi-dry rice for 2011-12 and 2012-13 are given in Tables 47 and 48 respectively. During 2011-12 in Paramakudi block, in ONS1 and OFT2, application of NPK with organic manure recorded significantly higher total P uptake 15.7 and 17.4 kg ha^{-1} respectively, while in OFT1 the FFP recorded the highest total P uptake of 17.5 kg ha^{-1}. In Paramakudi block, total P uptake was higher in NPK with organic manure application followed by FFP and NPK alone at active tillering stage. Similarly in Ramanathapuram block during 2011-12, application of NPK with organic manure recorded highest total P uptake 8.81 kg ha^{-1} in ONS2 experiments. But in OFT3 and OFT4 the FFP recorded the maximum total P uptake of 8.85 and 8.78 kg ha^{-1} respectively. In general in Ramanathapuram block, at active tillering stage during 2011-12 the total P uptake was higher in NPK with organic manure application followed by FFP and NPK alone.

In 2012-13 at active tillering stage the SSNM treatment recorded significantly highest total P uptake of 15.6 and 16.4 kg ha^{-1} in ONS1 and OFT2 respectively. But in OFT1 the NPK with organic manure application recorded the higher P uptake of 15.7 kg ha^{-1}. In both OFTs, the NPK with organic manure application and FFP were on par. In general in Paramakudi block, the total P uptake was higher in SSNM followed by NPK with organic manure application, FFP and NPK alone. Similarly in Ramanathapuram block, SSNM treatment recorded significantly higher total P uptake of 11.09, 9.14 and 10.9 kg ha^{-1} in OFT3, OFT4 and OFT5 respectively. In all the three OFTs, this was followed by either NPK with organic manure application (or) FFP which were on par. In general total P uptake was higher in SSNM treatment followed by NPK with organic manure application and FFP.

4.6.5. Total P uptake (kg ha^{-1}) at panicle initiation stage

The effect of nutrient omission on total P uptake at panicle initiation stage on semi-dry rice for 2011-12 and 2012-13 are given in Tables 49 and 50 respectively. During 2011-12 in Paramakudi block, in ONS1, OFT1 and OFT2, application of NPK

with organic manure recorded significantly higher total P uptake of 35.2, 34.5 and 34.3 kg ha^{-1} followed by the NPK alone and FFP. In Paramakudi block, total P uptake was higher in NPK with organic manure application followed by NPK alone and FFP at panicle initiation stage. Similarly in Ramanathapuram block, during 2011-12, application of NPK with organic manure recorded highest total P uptake of 27.5 and 26.4 kg ha^{-1} in ONS2 and OFT4 respectively. But in OFT3 the FFP recorded the maximum total P uptake of 28.6 kg ha^{-1}. In general in Ramanathapuram block, at panicle initiation stage during 2011-12 the total P uptake was higher in NPK with organic manure application followed by FFP and NPK alone.

In 2012-13 at panicle initiation stage, in Paramakudi block, the SSNM treatment recorded significantly highest total N uptake of 36.2 and 38.7 kg ha^{-1} in ONS1 and OFT1. But in OFT2 the FFP recorded maximum total P uptake of 38.7 kg ha^{-1} respectively. This was followed by NPK with organic manure application which was on par with FFP and NPK alone in ONS1. In general in Paramakudi block, the total P uptake was higher in SSNM followed by FFP, NPK with organic manure application and NPK alone. Similarly in Ramanathapuram block, SSNM treatment recorded significantly higher total P uptake of 28.0, 27.3 and 27.3 kg ha^{-1} in OFT3, OFT4 and OFT5 respectively. In Ramanathapuram block, in all the three OFTs, NPK alone recorded the lowest total P uptake among the NPK applied treatments. In general, total P uptake was higher in SSNM treatment followed by NPK with organic manure application and FFP.

4.6.6. Total P uptake (kg ha^{-1}) at harvest stage

The effect of nutrient omission on total P uptake at harvest stage on semi-dry rice for 2011-12 and 2012-13 are presented in Tables 51 and 52 respectively. During 2011-12, in Paramakudi block, in ONS1 and both the OFTs, application of NPK with organic manure recorded the higher total P uptake of 43.7, 39.7 and 41.6 kg ha^{-1} respectively. In addition NPK alone and FFP were on par in ONS1 and OFT1, but in OFT2, the FFP was on par. In Paramakudi block, total P uptake was higher in NPK with organic manure application followed by FFP and NPK alone at harvest stage. Similarly in Ramanathapuram block during 2011-12, application of NPK with organic manure recorded the highest total P uptake of 35.1 and 33.1 kg ha^{-1} in ONS2 and OFT4 respectively. But in OFT3 the FFP recorded the maximum total P uptake of

34.5 kg ha^{-1}. In general in Ramanathapuram block at harvest stage during 2011-12 the total P uptake was higher in NPK with organic manure application followed by FFP and NPK alone.

In 2012-13 at harvest stage the SSNM treatment recorded significantly highest total P uptake of 40.2, 49.9 and 53.7 kg ha^{-1} in ONS1, OFT1 and OFT2 respectively. This was followed by NPK with organic manure application which was on par with FFP and NPK alone in ONS1 and OFT1; but FFP on par with NPK with organic manure application in OFT2. In general in Paramakudi block, the total P uptake was higher in SSNM followed by FFP, NPK with organic manure application and NPK alone. Similarly in Ramanathapuram block, SSNM treatment recorded significantly higher total P uptake of 44.9, 44.1 and 43.5 kg ha^{-1} in OFT3, OFT4 and OFT5 respectively. In OFT4 and OFT5 the FFP was on par with SSNM treatment. In Ramanathapuram block, in all the three OFTs, NPK alone recorded the lowest total P uptake among the NPK applied treatment. In general total P uptake was higher in SSNM treatment followed by NPK with organic manure application and FFP.

4.6.7. Total K uptake (kg ha^{-1}) at active tillering stage

The effect of nutrient omission on total K uptake at active tillering stage on semi-dry rice for 2011-12 and 2012-13 are given in Tables 53 and 54 respectively. During 2011-12 in Paramakudi block, in ONS1 and OFT2, application of NPK with organic manure recorded significantly higher total K uptake 55.4 and 59.3 kg ha^{-1} respectively, while in OFT1 the FFP recorded the highest total K uptake of 59.4 kg ha^{-1}. In Paramakudi block, total K uptake was higher in NPK with organic manure application followed by FFP and NPK alone at active tillering stage. Similarly in Ramanathapuram block during 2011-12, application of NPK with organic manure recorded highest total K uptake 33.7 kg ha^{-1} in ONS2 experiment. But in OFT3 and OFT4, the FFP recorded the maximum total K uptake of 35.0 and 32.8 kg ha^{-1} respectively. In general, in Ramanathapuram block, at active tillering stage during 2011-12 the total K uptake was higher in NPK with organic manure application followed by FFP and NPK alone.

In 2012-13 in Paramakudi block, at active tillering stage, the SSNM treatment registered significantly highest total K uptake of 60.3, 63.5 and 63.5 kg ha^{-1} in ONS1,

OFT1 and OFT2 respectively. In OFT1 and ONS1 the NPK alone and FFP were on par with NPK with organic manure application and in OFT2, NPK with organic manure application were on par with FFP respectively. In general in Paramakudi block, the total K uptake was higher in SSNM followed by NPK with organic manure application and FFP. In Ramanathapuram block, the SSNM treatment recorded significantly higher total P uptake of 47.3, 34.9 and 42.7 kg ha^{-1} in OFT3, OFT4 and OFT5 respectively at active tillering stage. In all the three OFTs, this was followed by either NPK with organic manure application (or) FFP which were on par. In Ramanathapuram block, in all the three OFTs, NPK alone recorded the lowest total K uptake among the NPK applied treatments. In general, total K uptake was higher in SSNM treatment followed by NPK with organic manure application (or) FFP.

4.6.8. Total K uptake (kg ha^{-1}) at panicle initiation stage

The effect of nutrient omission on total K uptake at panicle initiation stage on semi-dry rice for 2011-12 and 2012-13 are given in Tables 55 and 56 respectively. During 2011-12 in Paramakudi block, in ONS1, OFT1 and OFT2, application of NPK with organic manure recorded significantly higher total K uptake of 120.1, 109.5 and 113.7 kg ha^{-1}, followed by the NPK alone and FFP which recorded of total K uptake of 114.9 and 113.8 kg ha^{-1}; 95.8 and 101.8 kg ha^{-1} and 111.0 and 107.2 kg ha^{-1} respectively. In Paramakudi block, total K uptake was higher in NPK with organic manure application followed by FFP and NPK alone at panicle initiation stage. Similarly in Ramanathapuram block, during 2011-12 application of NPK with organic manure recorded highest total K uptake of 105.3 kg ha^{-1} in ONS2. But the FFP recorded the maximum total K uptake of 104.4 and 102.7 kg ha^{-1} in OFT3 and OFT4 respectively. The NPK alone and NPK with organic manure application which were on par with FFP. In general in Ramanathapuram block, at panicle initiation stage during 2011-12 the total K uptake was higher in NPK with organic manure application followed by FFP and NPK alone.

In 2012-13 at panicle initiation stage, the SSNM treatment recorded significantly highest total K uptake of 118.5, 119.3 and 117.0 kg ha^{-1} in ONS1, OFT1 and OFT2 respectively. This was followed by NPK alone and NPK with organic manure application were on par with FFP in both OFTs but in ONS1, NPK alone and FFP were on par with NPK with organic manure application. In general in

Paramakudi block, the total K uptake was higher in SSNM followed by FFP, NPK with organic manure application and NPK alone. Similarly in Ramanathapuram block, SSNM treatment recorded significantly higher total K uptake of 91.6, 91.4 and 91.6 kg ha^{-1} in OFT3, OFT4 and OFT5 respectively. In Ramanathapuram block in all the three OFTs, NPK alone recorded the lowest total K uptake among the NPK applied treatment. In general total K uptake was higher in SSNM treatment followed by FFP and NPK with organic manure application.

4.6.9. Total K uptake (kg ha^{-1}) at harvest stage

The effect of nutrient omission on total K uptake at harvest stage on semi-dry rice for 2011-12 and 2012-13 are presented in Tables 57 and 58 respectively. During 2011-12, in Paramakudi block, in ONS1 and both the OFTs, application of NPK with organic manure recorded the higher total K uptake of 163.5, 140.1 and 141.2 kg ha^{-1} respectively. But in OFT2, NPK alone and FFP were on par. In Paramakudi block, total K uptake was higher in NPK with organic manure application followed by FFP and NPK alone at harvest stage. Similarly in Ramanathapuram block during 2011-12 application of NPK with organic manure recorded highest total K uptake of 115.2 kg ha^{-1} in ONS2. But in OFT3 and OFT4 the FFP recorded the maximum total K uptake of 110.1 and 105.5 kg ha^{-1} respectively. In both OFTs, NPK alone and NPK with organic manure application were on par. In general in Ramanathapuram block, at harvest stage during 2011-12 the total K uptake was higher in NPK with organic manure application followed by FFP and NPK alone.

In 2012-13 at harvest stage the SSNM treatment recorded significantly highest total K uptake of 133.0, 148.8 and 141.5 kg ha^{-1} in ONS1, OFT1 and OFT2 respectively. In both OFTs, NPK with organic manure application and FFP were on par. But in ONS1, NPK alone was on par with NPK with organic manure application and FFP. In general in Paramakudi block, the total K uptake was higher in SSNM followed by FFP, NPK with organic manure application and NPK alone. Similarly in Ramanathapuram block, SSNM treatment recorded significantly higher total K uptake of 112.9, 109.8 and 107.9 kg ha^{-1} in OFT3, OFT4 and OFT5 respectively. In OFT4 and OFT5 the NPK with organic manure application and FFP were on par. In general total K uptake was significantly higher in SSNM treatment followed by NPK with organic manure application and FFP respectively.

4.7. Indigenous nutrient supply (kg ha^{-1}) in semi-dry rice soils of Ramanathapuram district during 2011-12

4.7.1. Indigenous nitrogen supply (INS)

The indigenous nutrient supply (kg ha^{-1}) in semi-dry rice soils of Ramanathapuram district is given in Tables 59 and 60 for the period of 2011-12 and 2012-13 respectively. In 2011-12, in Paramakudi block, the indigenous nitrogen supply was 66.7, 55.5 and 55.8 kg ha^{-1}in ONS1, OFT1 and OFT2 with a mean of 59.3 kg ha^{-1}. Similarly in Ramanathapuram block the INS varied between 44.2, 64.2 and 59.1 kg ha^{-1}in ONS2, OFT3 and OFT4 with a mean of 55.8 kg ha^{-1}.

Similarly in 2012-13, in Paramakudi block, the indigenous nitrogen supply was 60.2, 74.9 and 68.3 kg ha^{-1}in ONS1, OFT1 and OFT2 respectively with a mean of 167.8 kg ha^{-1}. In Ramanathapuram block, indigenous nitrogen supply varied between 53.3, 59.8 and 58.0 kg ha^{-1}in OFT3, OFT4 and OFT5 respectively with a mean of 57.0 kg ha^{-1}

4.7.2. Indigenous phosphorus supply (IPS)

In 2011-12, in Paramakudi block, the indigenous phosphorus supply was 28.2, 26.5 and 26.0 kg ha^{-1}in ONS1, OFT1 and OFT2 with a mean of 26.9 kg ha^{-1}. Similarly in Ramanathapuram block, the the indigenous phosphorus supply varied between 18.8, 22.7 and 22.9 kg ha^{-1}in ONS2, OFT3 and OFT4 with a mean of 21.5 kg ha^{-1}.

Similarly in 2012-13 in Paramakudi block the indigenous phosphorus supply was 30.1, 36.8 and 39.8 kg ha^{-1}in ONS1, OFT1 and OFT2 respectively with a mean of 35.6 kg ha^{-1}. In Ramanathapuram block, the indigenous phosphorus supply varied between 28.1, 28.8 and 32.1 kg ha^{-1} in OFT3, OFT4 and OFT5 respectively with a mean of 29.7 kg ha^{-1}.

4.7.3. Indigenous potassium supply (IKS)

In 2011-12, in Paramakudi block, the indigenous potassium supply was 94.3, 82.3 and 101.9 kg ha^{-1} in ONS1, OFT1 and OFT2 with a mean of 92.9 kg ha^{-1}. Similarly in Ramanathapuram block, the indigenous potassium supply varied between 69.4, 94.7 and 88.4 kg ha^{-1} in ONS2, OFT3 and OFT4 with a mean of 84.1 kg ha^{-1}.

Similarly in 2012-13, in Paramakudi block, the indigenous potassium supply varied as 100.9, 112.5 and 110.2 kg ha^{-1}in ONS1, OFT1 and OFT2 with a mean of 107.9 kg ha^{-1} respectively. In Ramanathapuram block indigenous potassium supply varied between 83.4, 88.7 and 92.4 kg ha^{-1}in OFT3, OFT4 and OFT5 respectively with a mean of 88.2 kg ha^{-1}.

4.8. Nutrient requirement (kg t^{-1}) of semi-dry rice

Based upon the nutrient uptake and yield obtained from the nutrient omission plots the nutrient requirement was computed in kg t^{-1} for semi-dry rice during 2011-12 and 2012-13 which is given in Tables 61 and 62 respectively. In Paramakudi block, during 2011-12, the N requirement of semi-dry rice was 44.5, 34.7 and 32.8 kg t^{-1} in ONS1, OFT1 and OFT2 respectively with a mean of 37.3 kg t^{-1}. The P requirement was 12.2, 13.2 and 13.0 kg t^{-1} in ONS1, OFT1 and OFT2 respectively with a mean of 12.8 kg t^{-1}. The K requirement of semi-dry rice was 34.9, 32.9 and 39.2 kg t^{-1} in ONS1, OFT1 and OFT2 respectively with a mean of 35.7 kg t^{-1}.

In Ramanathapuram block, during 2011-12, the N requirement was 29.5, 43.8 and 36.9 kg t^{-1} in ONS2, OFT3 and OFT4 with a mean of 36.7 kg t^{-1} respectively. The P requirement was 9.0, 12.0 and 11.5 kg t^{-1} in ONS2, OFT3 and OFT4 respectively with a mean of 10.8 kg t^{-1}. The K requirement was 30.2, 45.1 and 34.0 kg t^{-1} in ONS2, OFT3 and OFT4 respectively with a mean of 36.4 kg t^{-1}.

Similarly in 2012-13 in Paramakudi block, the N requirement was 35.4, 41.6 and 42.7 kg t^{-1} in ONS1, OFT1 and OFT2 with a mean of 39.9 kg t^{-1}. The P requirement was 12.0, 14.2 and 15.3 kg t^{-1} in ONS1, OFT1 and OFT2 with a mean of 13.9 kg t^{-1}.The K requirement was 33.6, 37.5 and 39.3 kg t^{-1} in ONS1, OFT1 and OFT2 with a mean of 36.8 kg t^{-1}.

In Ramanathapuram block, the N requirement was 29.6, 33.2 and 30.5 kg t^{-1} in OFT3, OFT4 and OFT5 with mean of 31.1 kg t^{-1} respectively. The P requirement was 12.2, 13.1and 13.4 kg t^{-1} in OFT3, OFT4 and OFT5 respectively with a mean of 12.9 kg t^{-1}. The K requirement was 30.9, 31.7 and 34.2 kg t^{-1} in OFT3, OFT4 and OFT5 respectively with a mean of 32.3 kg t^{-1}.

4.9. Total factor productivity (TFP), Partial factor productivity (PFP), Agronomic efficiency (AE) and Recovery efficiency (RE) of semi-dry rice

4.9.1. Total factor productivity (TFP)

To assess the efficiency of different combination of N, P and K application, the different use of efficiencies were calculated and given in Tables 63 and 64 for the period of 2011-12 and 2012-13 respectively. In 2011-12, in Paramakudi block, among different combination of N,P and K the TFP was highest in NPK with organic manure applied treatment which recorded 25.4, 26.1 and 25.5 kg grain per kg of nutrient applied in ONS1, OFT1 and OFT2 respectively. This was followed by NPK alone and FFP recorded the lowest TFP. Similarly in Ramanathapuram block, NPK with organic manure applied treatment which recorded the highest TFP of 24.5, 22.7 and 23.6 kg grain per kg of nutrient applied in ONS2, OFT3 and OFT4 respectively. This was followed by NPK alone and FFP recorded the lowest TFP respectively.

In 2012-13, in Paramakudi block, the SSNM recorded the highest TFP of 26.7 kg grain per kg of nutrient applied in ONS1 but in OFT1 and OFT2, the NPK with organic manure application which recorded the maximum TFP of 24.2 and 24.8 kg grain per kg of nutrient applied respectively. This was followed by SSNM approach, NPK alone and FFP. Similarly in Ramanathapuram block, SSNM treatment recorded the highest TFP of 23.9 and 23.4 kg grain per kg of nutrient applied in OFT3 and OFT4 but in OFT5 the NPK with organic manure application showed the maximum TFP of 23.9 kg of grain per kg of nutrient applied. This was followed by NPK with organic manure application, NPK alone and FFP in OFT3 and OFT4 respectively.

4.9.2. Partial factor productivity (PFP)

In 2011-12, in Paramakudi block, among different combination of N, P and K, the PFP was maximum in NPK with organic manure applied treatment which recorded 46.5, 47.9 and 46.7 kg of grain per kg of N applied in ONS1, OFT1 and OFT2 respectively. This was followed by NPK alone and FFP recorded the lowest PFP. Similarly in Ramanathapuram block, NPK with organic manure applied treatment which recorded the highest PFP of 44.9, 41.6 and 43.2 kg of grain per kg of N applied in ONS2, OFT3 and OFT4 respectively. This was followed by NPK alone and FFP recorded the lowest PFP respectively (Tables 58 and 59).

In 2012-13, in Paramakudi block, the NPK with organic manure application recorded the highest PFP of 47.9, 44.3 and 45.5 kg of grain per kg of N applied in ONS1, OFT1 and OFT2 respectively. This was followed by NPK alone, SSNM approach and FFP. Similarly in Ramanathapuram block, NPK with organic manure application recorded the highest PFP of 41.7, 42.5 and 43.8 kg of grain per kg of N applied in OFT3, OFT4 and OFT5.This was followed by NPK alone, SSNM approach and FFP respectively.

4.9.3. Agronomic efficiency (AE)

In 2011-12, in Paramakudi block, among different combination of N, P and K, the AE was maximum in NPK with organic manure applied treatment which recorded 26.4, 26.2 and 23.2 kg increase in grain per kg of N applied in ONS1, OFT1 and OFT2 respectively. This was followed by NPK alone and FFP recorded the lowest AE among the N, P and K applied treatments. Similarly in Ramanathapuram block, NPK with organic manure applied treatment recorded the highest AE of 24.4, 22.6 and 21.9 kg increase in grain per kg of N applied in ONS2, OFT3 and OFT4 respectively. This was followed by NPK alone and FFP recorded the lowest TFP respectively.

In 2012-13, in Paramakudi block, the NPK with organic manure application recorded the highest AE of 25.4, 20.8 and 24.4 kg increase in grain per kg of N applied in ONS1, OFT1 and OFT2 respectively. This was followed by NPK alone, SSNM approach and FFP in ONS1 and OFT2, but SSNM showed maximum efficiency next to NPK with organic manure application in OFT1.Similarly in Ramanathapuram block, NPK with organic manure application recorded the highest AE of 17.8, 18.5 and 18.6 kg increase in grain per kg of N applied OFT3, OFT4 and OFT5.This was followed by SSNM approach, NPK alone, and FFP respectively.

4.9.4. Recovery efficiency (RE)

In 2011-12 in Paramakudi block, among different combination of N, P and K, the RE was maximum in NPK alone which recorded 0.64 and 0.51 kg of N uptake per kg of N applied in ONS1, and OFT1 respectively but in OFT2, the NPK with organic manure applied treatment showed the maximum efficiency of 0.53 kg of N uptake per kg of N application respectively. This was followed by NPK with organic manure application and FFP recorded the lowest RE. Similarly in Ramanathapuram

block, NPK with organic manure applied treatment recorded the highest RE of 0.44 and 0.39 kg of N uptake per kg of N applied in ONS2 and OFT4 but in OFT3 the NPK alone showed the maximum efficiency of 0.38 kg of N uptake per kg of N applied respectively (Tables 58 and 59)

In 2012-13, in Paramakudi block, the NPK with organic manure application recorded the highest RE of 0.46, 0.41 and 0.42 kg of N uptake per kg of N applied in ONS1, OFT1 and OFT2 respectively. This was followed by NPK alone, SSNM approach and FFP in ONS1, OFT1and OFT2 respectively. Similarly in Ramanathapuram block, NPK with organic manure application recorded the highest RE of 0.37 and 0.39 kg of N uptake per kg of N applied in OFT4 and OFT5 but in OFT3 the maximum RE was recorded in SSNM approach with 0.45 kg of N uptake per kg of N applied and comparable RE was recorded with NPK alone and SSNM approach in OFT5.

4.10. Fertilizer N, P and K prescription for semi-dry rice

Based upon the N, P and K limiting yield recorded during 2011-12, at on-station and on-farm trials the yield target of 4.0 and 3.5 t.ha^{-1} for Paramakudi and Ramanathapuram blocks as per SSNM approach which was validated during 2012-13 (Table 60).

The fertilizer N prescription for Paramakudi block varied between 120 and 185 kg ha^{-1} with mean of 150.6 kg ha^{-1}, while P and K prescription was 20 and 30 kg ha^{-1} in each all the on-farm trials using this fertilizer N, P and K, yield target of 4.0 t.ha^{-1} was achieved with variation of 0.75 to 4.0 per cent in Paramakudi block. In Ramanathapuram block, fertilizer N prescription varied between 96 to 159 kg ha^{-1} with a mean of 137.6 kg ha^{-1} while P and K prescription was 20 and 30 kg ha^{-1} for a yield target of 3.5 t.ha^{-1} was achieved with variation of 1.1 to 2.6 per cent in Ramanathapuram block. Hence apart from optimised N, P and K fertilizer application which solved the soil fertility constrains, solving other abiotic stress especially drought through supplemental irrigation, choice of suitable varieties and creating awareness among farmers on the above aspects will pave the way to increase rice yields of Ramanathapuram districts which are grown in semi-dry condition.

CHAPTER V

DISCUSSION

A soil nutrient database of semi-dry rice grown soils of Ramanathapuram was created by collecting 129 and 126 soil samples from 22 and 21 villages of Paramakudi and Ramanathapuram blocks respectively to assess the soil related constraints. Also to optimize fertilizer N,P and K requirement, Site specific nutrient management (SSNM) approach through nutrient omission plots was used through one on-station and two on-farm trials at Paramakudi and Ramanathapuram block each. The results emanated in the above study are discussed in this chapter.

5.1. Soil nutrient database of semi-dry rice soils

5.1.1. Soil pH

The range of soil pH for Paramakudi block varied between 6.10 and 8.40 with a mean of 7.32. In the 22 villages, all the 129 samples recorded neutral soil pH. In Ramanathapuram block, of the 126 soil samples collected from 21 villages, the soil pH was 66, 18 and 16 per cent neutral, acidic and alkaline respectively. The high BSP of 88.8 to 98.9 per cent in Paramakudi block, and 74.1 and 85.1 in Ramanathapuram block were responsible for neutral pH. The occurrence of ground water quality viz., high SAR saline and alkali make the surface soil alkaline in soil pH. The pH values were generally higher in these soils than the normal soils which increased with the fineness of texture in these soils, confirming the report of Ramasharma *et al.* (1985). The higher pH in Paramakudi series might be the effect of high amount of fine clay and total clay, ESP and water soluble HCO_3 etc., as remarked by Bhargava *et al*. (1976). Generally, the soil pH was increasing with depth due to the solubility of salts moving with water as regulated by the clay distribution pattern and compaction in different sub horizons. These results were in line with the report of Kadrekar (1980) and Nandha and Pradhan (1985). The spatial distribution of soil pH of semi-dry rice grown soils of Ramanathapuram district is given in Fig.5.

The slight increasing pH with depth is due to the movement of salts as a function of clay; in line with the pH in series (along with high clay content) will result in the slow drainage especially during rainy seasons. The pH will influence the nutrient

availability in soils indicated by the negatively and significant correlation with available Zn and available Cu and positively and significantly correlated with available Fe and available Mn.

5.1.2. Electrical conductivity

In Paramakudi block, the range of soil EC varied between 0.97 and 1.28 dSm^{-1} with a mean of 1.12 dSm^{-1}. Of the 129 soil samples, 95 per cent recorded medium salinity (1-2 dSm^{-1}) while 5 per cent were non saline soil. In Ramanathapuram block, EC varied between 0.12 and 4.71 dSm^{-1} with the mean of 1.82 dSm^{-1}. Of the 126 soil samples, 40, 52 and 8 per cent were non-saline, medium saline and saline respectively. The occurrence of poor quality ground water viz., marginally saline, were responsible for making surface soil slightly saline in soil EC due to its capillary rise during drought condition. Also, fairly high EC was due to its fine texture and aridity as reported by Jain (1981).There was a significant and positive correlation between EC and free $CaCO_3$ (0.402**). The high free $CaCO_3$ in Paramakudi series might be due to insufficient of water for dissolving and leaching and higher clay content to prevent movement of Ca with depth (Krishnan and Perumal, 1950). The spatial distribution of soil EC of semi-dry rice grown soils of Ramanathapuram district is given in Fig.6.

5.1.3. CEC and exchangeable cations

The relatively higher CEC in Paramakudi soils might be due to high clay content and probably montmorillonitic type of clay minerals present in the series. The high exchangeable Ca and Mg were due to the basic igneous rock source of the alluvium from which these soils were derived and arid environment existing in this tract. This was in accordance with Sanyasiraju and Durairaj (1954). Because of relatively the finest texture, slow movement of water through the horizons, capillary rice of Na^+ through water evaporation in summer, inadequacy of water to leach out the Na^+ and montmorillonitic type of clay minerals led to high exchangeable cations as in corroboration with the conclusions of Sandhu *et al*. (1981).The highest exchangeable K in Paramakudi series could be explained by the high K releasing power of minerals in these soils of probably montmorillonitic clay mineral under sodic environment favouring easy build up of exchangeable available K^+ (Pal and Mondal, 1980).

5.1.4. Organic carbon (OC)

In Paramakudi block, the range of OC varied between 0.03 and 0.73 per cent with a mean of 0.27 per cent. Of the 129 soil samples, 96 per cent were low in OC status while 4 per cent were medium in OC status. In Ramanathapuram block, the range of OC varied from 0.03 to 1.35 per cent with a mean of 0.42 per cent. Of the 126 soil samples, 64, 27 and 9 per cent were low, medium and high in OC status respectively. The arid climate, coarse texture of soils, low addition of organic manures, single rainfed rice crop which leaves low amount of crop residue were the reasons for low OC status. Because of high pH and salt concentration the transformations and mineralization of nitrogen from soil organic matter were slower in salt affected soils (Batra and Abrol. 1986).The C/N ratio was mostly narrow in these soils with noticeable increasing trend with depth having a relative wider ratio in coarse textured soils than in finer textured soils. The reason for wider C/N ratio with depth in profile would be the due to solubulization of organic matter and loss or faster decomposition of organic matter in this very arid situation (Dixit and Lal, 1974). The spatial distribution of soil organic carbon status of semi-dry rice grown soils of Ramanathapuram district is given in Fig.7.

5.1.5. Available Nitrogen

In Paramakudi block, the range of values for available N varied between 118 and 280 kg ha^{-1} with a mean of 217 kg ha^{-1}. Of the 129 soil samples, 97.9 per cent recorded low available N while 2.1 per cent recorded the medium in available N status. In Ramanathapuram block, the range of available N varied from 76 to 354 kg ha^{-1} with a mean of 198 kg ha^{-1} respectively. Of the 126 soil samples 95.8 per cent were low and 4.2 per cent medium in available N status. The available N content in salt affected soils of Punjab and Haryana was lower than the normal soils and most of the soils were low in organic-N and nitrate-N and nitrogen content in soil decreased with depth and nitrate form of nitrogen dominated over the ammoniacal form (Kanwar and Singh, 1961). Also the rate of mineralization of nitrogen was slowed down by increase in soil salinity and ECe above 10 dSm^{-1} (Bandyopadhyay and Bandyopadhyay, 1983). The available N status of these soils was grouped under low category, pointing out the need of judicious application of N fertilizer along with organic manures to get satisfactory returns.

The decreasing trend of available N with depth in profile pointed out their association with higher organic matter in surface then sub surface soil (Kuldeepsingh *et al*., 1990). The relatively maximum of N status in Ramanathapuram block might be due to the result of better fertilizer practices, cultivation and land use. These soils were low in available N status needing adequate N supply for better crop yields. While applying N fertilizers to these coarse textured soils, enhanced number of splits should be followed to make it available to crops. Further it was better to mix high clay containing vertisol (Karambai) at 100 $t.ha^{-1}$ in order to enable these soils retain the nutrients without much loss for long period as recommended by Murugesan (1996). The spatial distribution of soil available N status of semi-dry rice grown soils of Ramanathapuram district is given in Fig.8.

5.1.6. Available Phosphorus

In Paramakudi block the range of values for available P varied between 5.0 and 29.0 kg ha^{-1} with a mean of 10.1 kg ha^{-1}. Of the 129 soil samples, the per cent distribution of available P status was 86.1, 11.7 and 2.2 per cent were low, medium and high in available P status respectively. In Ramanathapuram block, the range of available P varied from 5.0 to 16 kg ha^{-1} with a mean of 9.6 kg ha^{-1} respectively. Of the 126 soil samples, 79.9 and 20.1 per cent were low and medium available P status respectively. Generally the low to medium available P in the soil stressing the need for judicious P fertilization through enriched FYM. The low organic matter status, calcareousness nature of Paramakudi series, low P fertilization rates of rainfed rice were the main reasons for low available P status.

The decreasing trend of P with depth indicated the quick absorption and fixation of available P in the clay and organic matter complex in top layers of the profile, falling in line with the findings of Sengupta (1969) leading to restriction in P movement in soil. In calcareous alkaline soils, phosphorous tends to form di-calcium phosphate and then octa-calcium phosphate thus reducing the availability of P (Bandyopadhyay and Biswas, 1988).

In Ramanathapuram block, the range of available P varied from 5.0 to 16 kg ha^{-1} with a mean of 9.6 kg ha^{-1} respectively. Of the 126 soil samples, 79.9 per cent were low and 20.1 per cent medium in available P status. Generally, the low to

medium available P in the soil stressing the need for judicious P fertilization by deep placement as crop age advances and needing adequate P supply to better the crop yields in this drought prone tract. The spatial distribution of soil available P status of semi-dry rice grown soils of Ramanathapuram district is given in Fig.9.

5.1.7. Available Potassium

In Paramakudi block, the range of values for available K varied between 408 and 596 kg ha^{-1} with a mean of 506 kg ha^{-1} respectively and 100 per cent of sample recording high available K status. In Ramanathapuram block, the range of available K status varied from 229 to 557 kg ha^{-1} with a mean of 338 kg ha^{-1} respectively. Of the 126 soil samples, 88 per cent were high in K status. High BSP, high clay content of Paramakudi series, dominant clay minerals like illite or montmorillite were responsible for high available K status of soils. The increasing trend of available K^+ with depth in profile of salt affected soils indicated the translocation of K with clay in saline-alkaline environment (Kansal and Sehkon, 1976). Salt affected soils, both in alluvial and black soil region in India, are generally rich in available potassium. The availability of potassium in salt affected soil depends primarily on the parent materials, weathering conditions and type and amount of clay minerals (Acquaye *et al.,* 1974). It was reported that most of the coastal saline soils of Orissa and West Bengal were rich in both available and non-available forms of K and there might not be any depletion of available K content of soil even after repeated crop cultivation without K fertilizer (Bandyopadhyay and Maji, 1989). Another fact of interest was also derived from the K distribution pattern in these salt-affected soils that since K moved in the profile, judicious split application of K fertilizers might do well in supplying the required level at the rhizosphere and preventing loss below the root zone of crops.

In Ramanathapuram block, the range of available K status varied from 229 to 557 kg ha^{-1} with a mean of 338 kg ha^{-1} respectively. Of the 126 soil samples, 88 per cent were high in K status. The available K in soils having a increasing trend with depth probably due to the presence of K bearing minerals progressively with depth and degree of weathering of K minerals, falling in line with the findings of Ranganathan and Satyanarayanan (1980). The spatial distribution of soil available K status of semi-dry rice grown soils of Ramanathapuram district is given in Fig.10.

5.1.8. Available micronutrients

The most important factors influencing micronutrient availability in salt affected soils are pH, soil texture, organic matter, calcareousness and salinity of soil. It was observed that each unit increase in pH reduces the solubility of divalent cations by 100 times and that of trivalent cations by 1000 times (Lindsay, 1972).

5.1.8.1. Available Fe

In Paramakudi block, the range of values for available Fe varied between 0.06 and 44.8 ppm with a mean of 5.05 ppm respectively. Of the 129 soil samples, 64.4 per cent were deficient in available Fe status for the threshold of 6.3 ppm for calcareous soils. In Ramanathapuram block the range of values for available Fe status varied from 3.42 to 100.4 ppm with a mean of 14.5 ppm respectively. Of the 126 soil samples, 97.4 per cent of soil samples were recorded sufficient available Fe status. The calcareous nature of Paramakudi series led to 64.4 per cent Fe efficiency compared to 97.4 per cent sufficiency of available Fe in Ramanathapuram block where soils were non calcareous. Both the total and available forms of Fe followed a general increasing trend with depth in the profile as reported by Mayalagu (1981) and Dubey *et al*. (1981). As per the recommendation of Anon (1997) these salt affected soils were less than the critical value of available Fe necessitating the application of Fe as $FeSO_4$ (easily available form) adequately. The spatial distribution of available Fe status of semi-dry rice grown soils of Ramanathapuram district is given in Fig.11.

5.1.8.2. Available Mn

In Paramakudi block, the range of values for available Mn varied between 0.22 and 53.80 ppm with a mean of 5.77 ppm respectively. Of the 129 soil samples, 82.6 per cent were sufficient in available Mn. In Ramanathapuram block, the range of values for available Mn varied between 0.30 and 79.16 ppm with a mean of 13.23 ppm respectively. Of the 126 soil samples, 96.8 per cent of soil samples were sufficient in available Mn content. Both total and available Mn exhibited a general increasing trend with depth in profile as that of Fe distribution due to possibly similar reasons given under Fe. The reason for higher total and available Mn under finer texture soils would be possibly the contribution by clay under saline-alkaline conditions as reported by Singh (1970) and Dubey *et al*. (1981). The available Mn

was correlated with clay positively due to the strong dependence of available Mn on clay soils (Singh, 1970). The spatial distribution of available Mn status of semi-dry rice grown soils of Ramanathapuram district is given in Fig.12.

5.1.8.3. Available Zn

In Paramakudi block, the range of available Zn varied between 0.34 and 1.80 ppm with a mean of 0.72 ppm respectively. Of the 129 soil samples, 88.2 per cent were deficient in available Zn. Low organic matter content of soils and high pH were reason for high Zn deficiency with Paramakudi and Ramanathapuram blocks. In Ramanathapuram block, the range of available Zn varied between 0.03 and 3.30 ppm with a mean of 0.85 ppm respectively. Of the 126 soil samples, 85 per cent were deficient. Both the total and available forms of Zn revealed a general decreasing trend with depth in the salt-affected soil. The similarity to organic carbon pattern of distribution due to probably bonding with organic matter complex.

The pH was negatively correlated with available Zn, while the available Zn was positively correlated with total Zn. The decreasing pattern of depth wise distribution of both total and available Zn in this soil might be due to the effect of fixation of Zn with organo-clay complex, revealing the quick adsorption of Zn to organic matter and clay and slow permeability of Zn in soil (Balasundaram *et al*., 1973) and (Rajagopal *et al*., (1984). The spatial distribution of available Zn status of semi-dry rice grown soils of Ramanathapuram district is given in Fig.13.

5.1.8.3. Available Cu

In Paramakudi block, the range of available Cu varied between 0.56 and 2.94 ppm with a mean of 1.81 ppm respectively. Of which, 97 per cent of samples were sufficient in available Cu status. In Ramanathapuram block, the range of available Cu varied between 0.26 and 4.28 ppm with a mean of 1.60 ppm respectively. Of the 126 soil samples, 32.8 per cent were deficient in available Cu. The fine textured soils had high Cu than the coarse textured soils probable due to high organic carbon associated in the clay (Prasad, 1981).

In Ramanathapuram block, both the forms of Cu generally decrease with depth. The decrease in copper content with depth might be due to its fixation by organo-clay complex confirming the results of Rajagopal *et al*. (1984). The reason for the least

amount of available Cu in this soil could be due to highly leached and coarse texturedness of it having very less organic carbon. The deficiency for Cu in this tract stressing the necessity of adequate Cu fertilization either by placement or foliar application. The spatial distribution of available Cu status of semi-dry rice grown soils of Ramanathapuram district is given in Fig.14.

5.2. Assessment of ground water quality of semi-dry rice cultivating areas of Ramanathapuram district

Of the 70 ground water samples, 5 were good (3.2%), 36 samples were marginally saline (53.3%), 25 were high SAR saline (37.5%) and 4 were alkali (5.5%) category. In Paramakudi block, Of the 40 water samples, 7.5 per cent were good, 80 per cent were marginally saline, 5 per cent were high SAR saline and 7.5 were alkali in nature. In Ramanathapuram block, of the 30 ground water samples, 26.6 per cent were marginally saline, 70 per cent were high SAR saline, and 3.4 per cent were alkali in nature respectively. Poor quality aquifers, sea water inundation, were the reasons for poor quality waters. In Paramakudi block, 87.5 per cent ground waters were suitable for supplemental irrigation which could be exploited to increase rice productivity. But in Ramanathapuram block, 73.4 per cent of ground water were either high SAR saline or alkali, thus unsuitable for supplemental irrigation. The per cent distribution of different ground water quality of Paramakudi and Ramanathapuram blocks are given in Fig.15 and 16 respectively.

5.3. Effect of nutrient omission on biometric observations of semi-dry rice

5.3.1. Plant height

During 2011-12 in the Paramakudi and Ramanathapuram block application of NPK with organic manure recorded highest plant height at active tillering and panicle initiation stages. This is due to the response to the organic manure application as FYM @ 12.5 $t.ha^{-1}$ .In Paramakudi and Ramanathapuram blocks, 96 and 64 per cent of the soil sample are low in organic manure status, which responded to organic manure application.The increase in plant height, number of tillers per hill, spikelet number per panicle, grain yield and 1000-grain weight in response to application of organic and chemical fertilizers were probably due to enhanced availability of nutrient (Mirza *et al*., 2010).

In 2012-13, in both the Paramakudi and Ramanathapuram blocks, SSNM treatment recorded the highest plant height at both active tillering and panicle initiation stages. In SSNM the fertilizer NPK were computed, based upon nutrient omission plots. This SSNM includes assessing indigenous nutrient supply and application of NPK in correct quantity, in correct time and in correct form or source. Hence, this enables to record the highest plant height in both stages of semidry rice crops. Hence, to maximize the rice productivity under semidry condition, application of organic manure based upon local availability combined with application of fertilizer NPK through SSNM approach can be followed.

5.3.2. Total tillers

During 2011-12, in both the blocks, NPK with organic manure application recorded the maximum total tillers, which ranged between 10.5 and 11.8. Similarly, in 2012-13, Paramakudi and Ramanathapuram blocks, SSNM treatment recorded the maximum mean total tillers, which ranged between 10.9 and 11.1. Similar to plant height application of organic manure with NPK increased the total tillers due to addition of organic manure which improved the soil fertility and had the positive effect on biometric observation total tillers count.

In 2011-12, more number of total tillers good response to organic manure application as the initial organic carbon content of soil were low in 96 and 64 per cent in Paramakudi and Ramanathapuram blocks respectively. Similarly, 2012-13, SSNM treatment which favours the application of correct quantity of fertilizer N, P and K in correct time, right form favours the more number of total tillers, which lead to higher productivity. Cassman *et al*. (1996) found that higher number of productive tillers was obtained by the application of 120 kg N ha^{-1}. The panicle numbers m^{-2} increased with increasing level of nitrogen up to 120 kg N ha^{-1}.

Hence, application of organic manure, based upon local availability to semidry rice soil in Ramanathapuram district, which coupled with fertilizer NPK application through SSNM favours higher yields by improving the biometric parameters like total number of tillers/hill. Mirza Hasanuzzaman *et al*. (2010) reported increase in number of tillers in rice plants due to the influence of fertilizer combinations. According to them, more number of tillers per square meter might be due to the more availability of

nitrogen which plays a vital role in cell division. Organic sources offer more balanced nutrition to the plants, especially micro nutrients which positively affect number of tillers in plants.

5.3.3. Dry matter production

During 2011-12, in Paramakudi and Ramanathapuram blocks, application of NPK with organic manure recorded the maximum mean DMP of 3484 and 2132 kg ha^{-1} at active tillering stage respectively. Similarly, at panicle initiation stage, in both Paramakudi and Ramanathapuram blocks, NPK with organic manure application recorded maximum mean dry matter production 6784 and 5629 kg ha^{-1} respectively. Similar to other biometric parameters, application of organic manure as FYM @ 12.5 t ha^{-1} which favored the high dry matter production as good response under this organic carbon status of soil as discussed earlier. Hence, application of organic manure based upon local availability has to be recommended to enhance yield of semi dry rice. Salem (2006) reported that application of FYM along with nitrogen fertilizer significantly increased the number of panicles per square meter, panicle length, panicle weight, number of filled grains/panicle, and 1000 grain weight and grain yield in rice.

In 2012-13, both Paramakudi and Ramanathapuram blocks, SSNM application recorded the highest dry matter production in active tillering and panicle initiation stages as discussed earlier.In SSNM approach, application of correct dose of fertilizer, correct time and sources enhance the dry matter production which led to higher grain yield.

Thiyagarajan *et al.* (1994) noted that the total dry matter production increased in general with increasing level of N application only up to 150 kg N ha^{-1}, beyond which the dry matter production exhibited a plateau.

Aruna (2001) found that the yield attributing characters like panicle m^{-2}, grains per panicle and thousand grain weights increased with increasing dose of N application. Hence, to enhance the rice production in semi dry condition the SSNM approach could be recommended.

5.3.4. Thousand grain weight

In 2011-12, in both Paramakudi and Ramanathapuram blocks, NPK with organic manure application recorded the maximum 1000 grain weight of 22.0 g and 20.5 g respectively. Effect of nutrient omission plot on 1000 grain weight of semidry rice during 2011-12 and 2012-13 are given in Fig.17 and 18 respectively.

In 2012-13, in both Paramakudi and Ramanathapuram blocks, SSNM recorded maximum 1000 grain weight of 22.5 g and 23.9 g respectively. As discussed earlier, in both the years and both the locations application of organic manure coupled with NPK through SSNM enhanced to the biometric parameters and finally the grain yield.Luong and Heong (2005) observed reduction in unfilled grain percentage, increase in grain weight of rice with organic manure application.

5.4. Effect of nutrient omission on grain and straw yield of semi dry rice

In 2011-12, in both the blocks, NPK with organic manure application significantly recorded higher mean grain yield of 3526 and 3246 kg ha^{-1} in Paramakudi and Ramanathapuram blocks respectively. In Paramakudi block, application of organic manure with NPK recorded 7.2 and 5.4 per cent higher grain yield compared to NPK alone and FFP respectively. Similarly, in Ramanathapuram block, application of NPK with organic manure recorded 6.4 and 5.1 per cent higher grain yield than NPK alone and FFP respectively. Effect of nutrient omission plot on grain yield of semidry rice during 2011-12 and 2012-13 are given in Fig.19 and 20 respectively.

Similarly, in both Paramakudi and Ramanathapuram blocks, application of NPK with organic manure recorded the highest straw yield. Hence, the necessity and positive effect of organic manure application was well established. As the organic carbon status of Paramakudi block was low, its application in any form, based upon the local availability which enhances the soil fertility, improved the biometric parameters and finally rice yields. The organic manures application helped in providing essential micronutrients to the plants (Islam *et al*., 2008).

In 2012-13, in both the blocks, SSNM recorded the highest mean grain yield of 3922 and 3433 kg ha^{-1} in Paramakudi and Ramanathapuram blocks respectively. In Paramakudi block against the target of 4 t ha^{-1}, as the SSNM package achieved

3.9 t ha^{-1},which was 13.5 per cent higher than FFP. Also, compared to NPK alone, the SSNM package recorded 19.4 per cent higher grain yield. Sharma (1994) observed that application of N 14 days after transplanting gave significantly higher grain yield of 19.3 per cent over and above of the existing practice of N application i.e. at the time of transplanting.

In general, in Ramanathapuram block, SSNM package achieved 7.2 and 14.2 per cent higher grain yield than FFP and NPK alone treatment respectively. Also in 2012-13, in both Paramakudi and Ramanathapuram blocks, SSNM treatment recorded the highest straw yield. Effect of nutrient omission plot on straw yield of semidry rice during 2011-12 and 2012-13 are given in Fig.21 and 22 respectively.

Guanghuo Wang *et al*, (2001) reported that the performance of SSNM was tested for four successive rice crops. Compared with the current farmers' fertilizer practice (FFP), average grain yield increased from 5.9 to 6.4 Mg ha^{-1} while plant N, P, and K uptake increased by 8 to 14%. The gross return over fertilizer cost was about 10% greater with SSNM than with FFP. Also a significant higher grain yield was reported in NPK (4.2 t ha^{-1}), NP (3.63 t ha^{-1}), and NK (3.63 t ha^{-1}) treated plots over control (2.83 t ha^{-1}) (Donna, 2000).

Balasubramaniam *et al.*, (1999) observed that grain yield was mainly determined by the number of panicle per unit area and the number of spikelets per panicle. Panicle number increased with higher N application and conversely, spikelet number per panicle decreased with increased levels of N application and in modern varieties only the panicle density was increased due to N fertilization, but in traditional varieties the grain yield was increased through increase in panicle density and spikelet number.

Kumar *et al*. (2000) recorded an average grain yield of 4.8 t ha^{-1} in the rice varieties with SPAD based N management compared with 4 and 4.4 t ha^{-1} for fixed N rate of 90 and 135 kg N ha^{-1} respectively.

In SSNM, where fertilizer NPK was applied in correct quantity, in correct time and correct source by assessing the indigenous nutrient supply. Hence, combining organic manure application with fertilizer NPK through SSNM can be recommended to improve soil fertility of semi dry rice which increases the rice yields.

5.5. Total N, P and K uptake

5.5.1. Total N uptake

In 2011-12, in both the Paramakudi and Ramanathapuram blocks, application of NPK with organic manure recorded the highest total N uptake at active tillering, panicle initiation and at harvest stages respectively. At harvest, NPK with organic manure application recorded highest mean total N uptake of 98.1 and 93.1 kg ha^{-1} at Paramakudi and Ramanathapuram blocks respectively. Similarly, 2012-13, in Paramakudi and Ramanathapuram blocks, SSNM treatment recorded the highest total N uptake at active tillering, panicle initiation and at harvest stages respectively. At harvest, SSNM treatment recorded highest mean total N uptake 105.1 and 94.4 kg ha^{-1} at Paramakudi and Ramanathapuram blocks respectively. Patnaik and Rao (1979) reported that the application of 75 per cent of total N at suitable splits during vegetative growth period and 25 per cent of total N at panicle initiation stage was found successful. Singh and Sinha (1975) reported that uptake of N in grain and straw increased due to application of K and N uptake in three seasons found that N uptake in rice increased with N levels Effect of nutrient omission plot on total N uptake at harvest stage of semidry rice during 2011-12 and 2012-13 are given in Fig.23 and 24 respectively.

In Ramanathapuram district, application of organic manure in semi dry rice soils which improved the soil fertility, dry matter production, N content and finally increased the total N uptake. Pandey *et al*. (1991) reported that the short duration genotypes generally had lower N uptake than medium and long duration genotypes. The uptake of N, P and K increased with application of N. The SSNM treatment due to correct quantity of NPK application at right time through right sources improved the total N uptake. Hence, for the semi dry rice soils of Ramanathapuram district, application of local organic manures with NPK through SSNM approach can be recommended.

5.5.2. Total P uptake

During 2011-12, in Paramakudi and Ramanathapuram blocks, application of NPK with organic manures recorded the highest total P uptake at active tillering and panicle initiation and harvest stages respectively. At harvest, application of NPK with

organic manure recorded the highest mean total P uptake of 41.7 and 33.9 kg ha^{-1} at Paramakudi and Ramanathapuram blocks respectively. Application of organic manure in semi dry rice soil increased the soil fertility, dry matter production, and phosphorus content in plants. Effect of nutrient omission plot on total P uptake at harvest stage of semidry rice during 2011-12 and 2012-13 are given in Fig.25 and 26 respectively.

During 2012-13, in Paramakudi and Ramanathapuram blocks, the SSNM treatment recorded the highest total P uptake at active tillering, panicle initiation and at harvest stages respectively. At harvest, the SSNM treatment recorded the highest mean total P uptake of 47.9 and 44.1 kg ha^{-1} in Paramakudi and Ramanathapuram blocks respectively. The SSNM treatment due to the application of correct quantity of NPK at right time through right sources which improved the total P uptake. Hence, for the semi dry rice soils of Ramanathapuram district, application of local organic manures with NPK through SSNM approach is recommended.

5.5.3. Total K uptake

During 2011-12, in Paramakudi and Ramanathapuram blocks, application of NPK with organic manures recorded the highest total K uptake at active tillering and panicle initiation and harvest stages respectively. At harvest, application of NPK with organic manure recorded the highest mean total K uptake of 148.3 and 109.2 kg ha^{-1} at Paramakudi and Ramanathapuram blocks respectively. Application of organic manure in semi dry rice soil increased the soil fertility, dry matter production, and potassium content in plants. Effect of nutrient omission plot on total K uptake at harvest stage of semidry rice during 2011-12 and 2012-13 are given in Fig.27 and 28 respectively.

During 2012-13, in Paramakudi and Ramanathapuram blocks, the SSNM treatment recorded highest total K uptake at active tillering, panicle initiation and at harvest stages. At harvest, the SSNM treatment recorded the highest mean total K uptake of 141.1 and 110.2 kg ha^{-1} in Paramakudi and Ramanathapuram blocks respectively. In SSNM treatment application of correct quantity of NPK at right time through right sources improved the total P uptake. Hence, for the semi dry rice soils of Ramanathapuram district, application of local organic manures with NPK through SSNM approach is recommended.

5.6. Indigenous nutrient supply

In 2011-12, the indigenous mean N, P and K supply were 59.3, 26.9, 92.9 kg ha^{-1} and 55.8, 21.5, 84.1 kg ha^{-1} for Paramakudi and Ramanathapuram blocks respectively. Similarly, in 2012-13, INS, IPS, IKS were 67.8, 35.6, 107.9 and 57.0, 29.7, 88.2 kg ha^{-1} for Paramakudi and Ramanathapuram block respectively. Dobermann and Fairhurst (2000) estimated the soil nutrient supply from grain yield in omission plot, assuming an average uptake of 15 kg N, 2.6 kg P and 15 kg K to harvest per tonne of grain per hectare. In some case of grain yield measurement in the omission plot predicting from indigenous phosphorus supply (IPS) and indigenous potassium supply (IKS) were 2.9 kg P and 15.8 kg K per tonne of grain yield. They also observed, only P and K applied plot (+ PK), the mean grain yield was higher (0.3 Mg ha^{-1}) than the fertilizer omission plot (-F). Indigenous nutrient supply (kg ha^{-1}) in semi-dry rice soils of Ramanathapuram district during 2011-12 and 2012-13 are given in Fig.29 and 30 respectively.

Application of organic manure to enrich indigenous nitrogen supply and enriched FYM to increase the IPS are to be taken up. As, both the Paramakudi soil series and Thirupullani soil series were high in available K status, the IKS is higher than INS respectively.

5.7. Nutrient requirement of semi dry rice

In 2011-12, the mean NPK requirement of semi dry rice were 37.3, 12.8, 35.7 and 36.7, 10.8, 36.4 kg t^{-1} at Paramakudi and Ramanathapuram blocks respectively. In 2012-13 mean NPK requirements were 39.9, 13.9, 36.8 and 31.1, 12.9, 32.3 kg t^{-1} at Paramakudi and Ramanathapuram blocks respectively. Witt and Dobermann (2002) observed that the rice plant growth is limited solely by nutrient supply, the optimal nutritional balance is achieved with an uptake of about 15 kg N, 2.6 kg P and 15 kg K i.e. 15 kg N, 6 kg P_2O_5 and 18 kg K_2O per ton of grain yield. These nutrient uptake rates are valid for yield goals that reach 70 to 80 per cent of yield maximum (potential yield). Thereafter, the amount of nutrients required to produce an additional tonne of grain yield increase due to decreasing internal nutrient use efficiency. Nutrient requirement (kg t^{-1}) of semi-dry rice during 2011-12 and 2012-13 are given in Fig.31 and 32.

In this study, the N and K requirement were two times higher; P requirement was four times higher than irrigated normal rice soils. Hence, under semi-dry condition, abiotic stress due to drought may be prevalent. Hence the total NPK uptake could not be transformed into economical yield. Hence, studies are to be taken up, to improve the nutrient use efficiency through better source to sink relationship which will improve the rice yield on semi dry conditions further.

5.8. Different use efficiency of semi dry rice

5.8.1. Total Factor Productivity (TFP)

Application of NPK with organic manure recorded the highest mean TFP of 25.7 and 23.6 kg of grain per kg of nutrient applied during 2011-12 and 25.0 and 23.3 kg of grain per kg of nutrient applied during 2012-13 at Paramakudi and Ramanathapuram blocks respectively. Total factor productivity (TFP), Partial factor productivity (PFP), Agronomic efficiency (AE) and Recovery efficiency (RE) of semi-dry rice during 2011-12 and 2012-13 are given in Fig.33 and 34.

5.8.2. Partial Factor Productivity (PFP_N)

Application of NPK with organic manure recorded the highest (PFP) of 47.0 and 43.2 kg of grain per kg of N applied during 2011-12 and 45.9 and 42.7 kg of grain per kg of N applied during 2012-13 at Paramakudi and Ramanathapuram blocks respectively.

5.8.3. Agronomic Efficiency (AE)

The application of NPK with organic manure recorded the highest AE of 25.3 and 23.0 kg grain increase per kg of N applied during 2011-12 at Paramakudi and Ramanathapuram blocks respectively. During 2012-13, at Paramakudi and Ramanathapuram blocks, the application of NPK with organic manure recorded the highest AE of 23.50 and 18.30 kg grain increase per kg of N applied respectively.

5.8.4. Recovery Efficiency (RE)

Application of NPK alone recorded the highest RE of 0.56 kg of N uptake per kg of N applied during 2011-12 at Paramakudi block, while in Ramanathapuram block, NPK with organic manure application recorded the highest RE of 0.40 kg of N uptake per kg of N applied during 2011-12. During 2012-13, application of NPK and

organic manure recorded mean RE of 0.43 and 0.40 kg of N uptake per kg of N applied at Parakakudi and Ramanathapuram blocks respectively.

Hence, improving the organic carbon status of semi dry soil through organic manure application is the pre-requisite to improve the rice yield and different nutrient use efficiency of semi-dry rice grown in Ramanathapuram districts.

5.9. Nutrient limiting yield

In 2011-12, compared to NPK alone, PK (-N), NK (-P) and NP (-K) plots recorded -51.5, -35.4 and -19.8 per cent and -50.2, -33.2, and -23.9 per cent lower grain yields at Paramakudi and Ramanathapuram blocks respectively.

Similarly, during 2012-13, in Paramakudi block, compared to NPK alone, PK (-N), NK (-P) and NP (-K) plots recorded -48.9, -21.3, -10.6 per cent and -39.2, -18 and -9.2 per cent lower grain yield at Ramanathapuram blocks respectively.

Hence, in N omitted plots yield reduction varied between -39.2 and -51.5 per cent which will be roughly 1.6 to 2.0 t ha^{-1}. Similarly, P omitting yield varied between -18.0 and -35.4 per cent, which will be 0.8-1.3 t ha^{-1}. Similarly, K omitting yield varied between -9.2 and -23.9 per cent which will be approximately 0.22-0.75 t ha^{-1}. In General, NPK limiting yields were lowest than average of NPK alone by half for nitrogen, 1/3rd for P and 1/4th for K. This was mainly due to low organic carbon, low available N and P status and high available K status of semi dry rice soil of Ramanathapuram district respectively. Hence improving the indigenous N and P supply through organic manure application and enriched FYM is to be recommended to enhance yields of semi-dry rice.

5.10. Fertilizer N, P and K prescription for semi-dry rice

The fertilizer N prescription for Paramakudi block varied between 120 and 180 kg ha^{-1} with a mean of 150.6 kg ha^{-1}, while P and K prescription was 20 and 30 kg ha^{-1} for a yield target of 4 t ha^{-1}. In the on station and on farm trials at yield target of 4 t ha^{-1} was achieved with a negative variation of -0.75 to -4.0 per cent.

The fertilizer N prescription of Ramanathapuram block was 140 kg ha^{-1} with P and K prescription of 20 and 30 kg ha^{-1} respectively for the yield target of 3.5 t ha^{-1} which was achieved with variation of -1.12 to -2.6 per cent in all the on station and on

farm trials. Compared to blanket recommendation 75 kg of N per ha, the SSNM prescription was 2 times higher, while P and K prescription 20 and 30 kg per ha which were lower than general recommendation of 25 and 37.5 kg P_2O_5 and K_2O per ha respectively. Hence, fertilizer N use efficiency has to be increased through applying maximum quantity of organic manure and other integrated nutrient management (INM) practices.

Hence application of recommended quantity of organic manures compiled with NPK application through SSNM can be recommended to enhance yields of semi-dry rice. Also application of micro nutrients especially Fe and Zn at Paramakudi and Zn at Ramanathapuram is to be recommended. Finally during drought, supplemental irrigation with best available ground water to be given up to enhance yields of semi-dry rice.

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Table 21: Effect of nutrient omission on plant height (cm) at active tillering stage of semi-dry rice during 2011-12

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	ONS2	OFT3	OFT4	Mean
T_1 [-N]	26.8	28.6	27.7	27.7	28.4	27.9	28.1	28.1
T_2 [-P]	30.4	29.2	29.8	29.8	28.5	29.5	29.4	29.1
T_3 [-K]	33.4	32.6	33.0	33.0	29.8	32.4	32.2	31.4
T_4 [+NPK]	34.8	34.2	34.5	34.5	34.2	34.4	34.4	34.3
T_5 [NPK+OM]	35.0	35.7	35.3	35.3	36.2	35.5	35.6	35.8
T_6 [FFP]	34.6	36.0	35.3	35.3	31.7	34.6	34.5	33.6
SEd	**1.0**	**0.92**	**0.84**	**-**	**0.93**	**0.95**	**0.75**	**-**
CD (0.05)	**2.2**	**2.0**	**1.8**	**-**	**2.0**	**2.0**	**1.6**	**-**

Table 22: Effect of nutrient omission on plant height (cm) at active tillering stage of semi-dry rice during 2012-13

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	ONS2	OFT3	OFT4	Mean
T_1 [-N]	25.6	27.2	26.4	26.4	26.1	26.4	26.5	26.3
T_2 [-P]	28.6	27.2	27.9	27.9	29.6	28.3	28.2	28.5
T_3 [-K]	30.1	32.2	31.2	31.2	31.3	31.2	31.4	31.2
T_4 [+NPK]	31.3	33.6	32.4	32.4	32.0	32.3	32.6	32.3
T_5 [NPK+OM]	32.0	34.0	33.0	33.0	33.4	33.0	33.3	33.1
T_6[SSNM]	33.9	33.9	33.9	33.9	34.2	34.0	34.0	34.0
T_7 [FFP]	31.3	33.9	32.6	32.6	32.2	32.5	32.8	32.5
SEd	**0.85**	**0.9**	**0.88**	**-**	**1.2**	**1.1**	**1.1**	**-**
CD (0.05)	**1.8**	**1.9**	**1.8**	**-**	**2.5**	**2.3**	**2.3**	**-**

Table 23: Effect of nutrient omission on plant height (cm) at panicle initiation stage of semi-dry rice during 2011-12

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	ONS2	OFT3	OFT4	Mean
T_1 [-N]	63.7	61.2	60.4	61.8	55.2	52.8	54.2	54.1
T_2 [-P]	68.6	64.6	60.7	64.6	66.0	62.8	59.5	62.8
T_3 [-K]	70.2	64.6	62.8	65.9	70.2	65.6	63.5	66.4
T_4 [+NPK]	71.9	66.1	66.5	68.2	71.9	69.3	68.1	69.8
T_5 [NPK+OM]	72.6	67.0	65.4	68.3	73.8	71.5	69.7	71.7
T_6 [FFP]	71.8	65.2	64.9	67.3	71.9	71.1	70.3	71.1
SEd	**1.9**	**1.6**	**1.7**	**-**	**2.4**	**1.7**	**1.7**	**-**
CD (0.05)	**4.1**	**3.4**	**3.6**	**-**	**5.0**	**3.6**	**3.7**	**-**

Table 24: Effect of nutrient omission on plant height (cm) at panicle initiation stage of semi-dry rice during 2012-13

Treatments	Paramakudi				Ramanathapuram			
	ONS	OFT1	OFT2	Mean	OFT3	OFT4	OFT5	Mean
T_1 [-N]	65.5	64.5	65.9	65.3	61.2	64.5	64.3	64.2
T_2 [-P]	70.7	71.1	70.4	70.7	71.0	70.8	70.8	70.7
T_3 [-K]	71.3	71.6	71.7	71.5	73.3	71.9	72.0	72.2
T_4 [+NPK]	72.9	73.9	72.6	73.1	74.4	73.4	73.5	73.4
T_5 [NPK+OM]	73.1	74.3	73.3	73.6	74.9	73.8	74.0	73.9
T_6[SSNM]	75.5	75.6	75.1	75.4	76.4	75.6	75.6	75.6
T_7 [FFP]	72.9	73.7	73.6	73.4	74.4	73.6	73.7	73.8
SEd	**2.4**	**1.9**	**1.8**	**-**	**2.0**	**2.1**	**2.4**	**-**
CD (0.05)	**5.0**	**4.0**	**3.8**	**-**	**4.2**	**4.5**	**5.0**	**-**

Table 25: Effect of nutrient omission on total tillers (nos) at active tillering stage of semi-dry rice during 2011-12

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	ONS2	OFT3	OFT4	Mean
T_1 [-N]	4.61	4.90	5.40	4.97	4.33	5.86	6.22	5.47
T_2 [-P]	6.80	5.40	7.80	6.67	7.33	8.23	7.63	7.73
T_3 [-K]	8.54	9.40	7.90	8.61	7.95	9.41	9.55	8.97
T_4 [+NPK]	10.2	11.7	9.80	10.6	8.94	10.8	10.1	9.94
T_5 [NPK+OM]	10.5	9.3	11.8	10.5	10.3	12.6	11.2	11.4
T_6 [FFP]	10.4	11.1	10.9	10.8	8.84	12.2	10.5	10.5
SEd	**0.31**	**0.34**	**0.27**	**-**	**0.28**	**0.29**	**0.33**	**-**
CD (0.05)	**0.67**	**0.72**	**0.57**	**-**	**0.6**	**0.63**	**0.7**	**-**

Table 26: Effect of nutrient omission on total tillers (nos) at active tillering stage of semi-dry rice during 2012-13

Treatments	Paramakudi				Ramanathapuram			
	ONS	OFT1	OFT2	Mean	OFT3	OFT4	OFT5	Mean
T_1 [-N]	6.35	6.50	6.28	6.38	5.73	6.35	6.22	6.13
T_2 [-P]	7.53	7.61	7.59	7.58	7.68	8.44	7.96	7.62
T_3 [-K]	8.44	8.24	8.42	8.37	8.12	9.56	8.86	8.30
T_4 [+NPK]	8.96	9.01	8.34	8.77	8.92	9.98	8.90	8.68
T_5 [NPK+OM]	9.22	10.1	10.3	9.90	9.34	10.4	9.86	9.86
T_6[SSNM]	10.9	11.1	10.9	11.0	9.9	10.0	10.1	10.6
T_7 [FFP]	8.90	8.95	9.34	9.06	8.91	10.2	10.0	9.10
SEd	**0.28**	**0.28**	**0.27**	**-**	**0.26**	**0.27**	**0.25**	**-**
CD (0.05)	**0.59**	**0.59**	**0.56**	**-**	**0.55**	**0.56**	**0.52**	**-**

Table 27: Effect of nutrient omission on total tillers (nos) at panicle initiation stage of semi-dry rice during 2011-12

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	ONS2	OFT3	OFT4	Mean
T_1 [-N]	8.08	9.40	8.00	8.49	6.45	8.54	7.21	7.40
T_2 [-P]	9.88	9.20	8.70	9.26	10.5	13.4	11.6	11.9
T_3 [-K]	11.6	10.5	10.9	11.0	11.0	14.7	13.7	13.1
T_4 [+NPK]	13.3	11.8	12.7	12.6	12.6	15.0	14.0	13.8
T_5 [NPK+OM]	14.9	13.9	13.9	14.2	14.9	15.6	14.2	14.9
T_6 [FFP]	13.2	15.2	14.1	14.2	12.2	15.1	14.8	14.0
SEd	**0.39**	**0.35**	**0.3**	**-**	**0.36**	**0.35**	**0.39**	**-**
CD (0.05)	**0.84**	**0.75**	**0.63**	**-**	**0.76**	**0.74**	**0.83**	**-**

Table 28: Effect of nutrient omission on total tillers (nos) at panicle initiation stage of semi-dry rice during 2012-13

Treatments	Paramakudi				Ramanathapuram			
	ONS	OFT1	OFT2	Mean	OFT3	OFT4	OFT5	Mean
T_1 [-N]	9.63	10.2	9.85	9.90	8.23	9.14	10.1	9.16
T_2 [-P]	11.4	12.2	12.4	12.0	11.1	13.2	12.5	12.3
T_3 [-K]	11.9	12.2	12.3	12.1	12.6	14.8	14.4	13.9
T_4 [+NPK]	12.6	12.2	12.6	12.5	13.5	15.8	15.0	14.7
T_5 [NPK+OM]	14.0	12.6	13.5	13.4	13.9	15.9	15.4	15.1
T_6[SSNM]	15.7	15.2	15.6	15.5	15.8	16.2	16.0	16.0
T_7 [FFP]	12.7	13.9	14.3	13.6	13.6	15.5	15.8	15.0
SEd	**0.35**	**0.34**	**0.41**	**-**	**0.34**	**0.54**	**0.51**	**-**
CD (0.05)	**0.74**	**0.72**	**0.86**	**-**	**0.71**	**1.1**	**1.1**	**-**

Table 29: Effect of nutrient omission on total productive tillers (nos) at panicle initiation stage of semi-dry rice during 2011-12

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	ONS2	OFT3	OFT4	Mean
T_1 [-N]	5.89	5.50	6.10	5.83	6.12	7.22	6.42	6.59
T_2 [-P]	7.11	6.90	6.60	6.87	7.69	9.20	9.35	8.75
T_3 [-K]	7.90	7.10	7.90	7.63	7.96	10.9	10.3	9.69
T_4 [+NPK]	9.40	8.70	7.90	8.67	10.5	12.1	11.7	11.5
T_5 [NPK+OM]	10.9	9.50	8.40	9.60	11.8	13.2	12.7	12.6
T_6 [FFP]	9.30	9.10	9.90	9.43	9.99	12.7	12.8	11.8
SEd	**0.25**	**0.26**	**0.27**	**-**	**0.31**	**0.34**	**0.33**	**-**
CD (0.05)	**0.55**	**0.56**	**0.58**	**-**	**0.67**	**0.72**	**0.71**	**-**

Table 30: Effect of nutrient omission on total productive tillers (nos) at panicle initiation stage of semi-dry rice during 2012-13

Treatments	Paramakudi				Ramanathapuram			
	ONS	OFT1	OFT2	Mean	OFT3	OFT4	OFT5	Mean
T_1 [-N]	7.30	7.41	7.66	7.46	7.21	8.21	9.12	8.18
T_2 [-P]	9.23	9.54	9.51	9.43	9.45	10.6	11.2	10.4
T_3 [-K]	10.2	10.8	10.4	10.5	11.1	12.2	12.8	12.1
T_4 [+NPK]	11.0	11.2	11.2	11.1	11.7	13.4	13.6	12.9
T_5 [NPK+OM]	11.9	11.4	11.7	11.7	12.5	14.5	13.9	13.6
T_6[SSNM]	12.8	12.8	12.8	12.8	14.0	14.7	13.9	14.2
T_7 [FFP]	11.2	12.0	11.9	11.7	11.9	13.8	13.5	13.1
SEd	**0.32**	**0.35**	**0.36**	**-**	**0.38**	**0.5**	**0.47**	**-**
CD (0.05)	**0.68**	**0.73**	**0.76**	**-**	**0.79**	**1.1**	**1.00**	**-**

Table 31: Effect of nutrient omission on DMP (kg ha^{-1}) at active tillering stage of semi-dry rice during 2011-12

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	ONS2	OFT3	OFT4	Mean
T_1 [-N]	1951	1986	2015	1984	1148	1247	1122	1172
T_2 [-P]	2376	2249	2457	2361	1325	1641	1476	1481
T_3 [-K]	2611	2978	2733	2774	1496	1984	1625	1702
T_4 [+NPK]	3393	3425	3289	3369	1976	2044	1931	1984
T_5 [NPK+OM]	3422	3521	3510	3484	2159	2148	2088	2132
T_6 [FFP]	3264	3645	3496	3468	1896	2245	2092	2078
SEd	**81.7**	**87.6**	**91.7**	**-**	**53.7**	**56.9**	**57.7**	**-**
CD (0.05)	**174**	**187**	**195**	**-**	**114**	**121**	**123**	**-**

Table 32: Effect of nutrient omission on DMP (kg ha^{-1}) at active tillering stage of semi-dry rice during 2012-13

Treatments	Paramakudi				Ramanathapuram			
	ONS	OFT1	OFT2	Mean	OFT3	OFT4	OFT5	Mean
T_1 [-N]	2034	2014	2156	2068	1675	1443	1681	1600
T_2 [-P]	2459	2678	2546	2561	1923	1673	1884	1827
T_3 [-K]	2986	2896	2843	2908	2234	1988	2345	2189
T_4 [+NPK]	3489	3562	3251	3434	2468	2045	2389	2301
T_5 [NPK+OM]	3521	3647	3592	3587	2631	2248	2579	2486
T_6[SSNM]	3688	3758	3867	3771	2981	2540	2878	2800
T_7 [FFP]	3420	3604	3740	3588	2563	2348	2558	2490
SEd	**100.4**	**87.4**	**86.6**	**-**	**75.2**	**56.1**	**74.5**	**-**
CD (0.05)	**211**	**184**	**182**	**-**	**158**	**118**	**157**	**-**

Table 33: Effect of nutrient omission on DMP (kg ha^{-1}) at panicle initiation stage of semi-dry rice during 2011-12

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	ONS2	OFT3	OFT4	Mean
T_1 [-N]	5466	5234	5463	5388	3149	3861	3245	3418
T_2 [-P]	5992	5648	5879	5840	3974	4863	3864	4234
T_3 [-K]	6433	6124	6485	6347	4125	5242	4215	4527
T_4 [+NPK]	6837	6345	6683	6622	5468	5648	4856	5324
T_5 [NPK+OM]	6943	6678	6732	6784	5986	5888	5012	5629
T_6 [FFP]	6894	6689	6532	6705	5347	5964	4978	5430
SEd	**196**	**155**	**170**	**-**	**166**	**137**	**112**	**-**
CD (0.05)	**418**	**330**	**362**	**-**	**353**	**291**	**239**	**-**

Table 34: Effect of nutrient omission on DMP (kg ha^{-1}) at panicle initiation stage of semi-dry rice during 2012-13

Treatments	Paramakudi				Ramanathapuram			
	ONS	OFT1	OFT2	Mean	OFT3	OFT4	OFT5	Mean
T_1 [-N]	5555	5642	5519	5572	3645	4322	4255	4074
T_2 [-P]	6074	5982	5948	6001	4138	4642	4968	4583
T_3 [-K]	6657	6247	6420	6441	4367	5314	5347	5009
T_4 [+NPK]	6899	6648	6534	6694	4986	5399	5547	5311
T_5 [NPK+OM]	6946	6891	6687	6841	5264	5614	5678	5519
T_6[SSNM]	7040	7058	6998	7032	5684	5897	5896	5826
T_7 [FFP]	6901	6945	6942	6929	5056	5688	5746	5497
SEd	**200**	**166**	**163**	**-**	**140**	**146**	**139**	**-**
CD (0.05)	**421**	**348**	**343**	**-**	**294**	**308**	**293**	**-**

Table 35: Effect of nutrient omission on 1000 grain weight (gm) of semi-dry rice during 2011-12

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	ONS2	OFT3	OFT4	Mean
T_1 [-N]	18.0	18.6	19.0	18.5	16.6	17.6	16.8	17.0
T_2 [-P]	18.8	19.4	18.2	18.8	17.2	18.5	17.0	17.6
T_3 [-K]	19.5	20.1	20.8	20.1	17.8	19.6	18.4	18.6
T_4 [+NPK]	20.6	19.9	21.3	20.6	18.2	20.0	19.4	19.2
T_5 [NPK+OM]	22.3	21.4	22.4	22.0	20.2	21.2	20.0	20.5
T_6 [FFP]	20.8	22.7	21.8	21.8	18.1	20.5	19.6	19.4
SEd	**0.64**	**0.71**	**0.54**	**-**	**0.65**	**0.60**	**0.66**	**-**
CD (0.05)	**1.4**	**1.5**	**1.2**	**-**	**1.4**	**1.3**	**1.4**	**-**

Table 36: Effect of nutrient omission on 1000 grain weight (gm) of semi-dry rice during 2012-13

Treatments	Paramakudi				Ramanathapuram			
	ONS	OFT1	OFT2	Mean	OFT3	OFT4	OFT5	Mean
T_1 [-N]	18.2	19.2	18.6	18.7	17.2	17.5	18.6	17.8
T_2 [-P]	19.3	19.3	19.9	19.5	19.7	18.4	20.1	19.4
T_3 [-K]	19.5	20.2	20.3	20.0	20.1	20.2	22.5	20.9
T_4 [+NPK]	19.9	19.7	19.8	19.8	22.3	21.6	23.2	22.4
T_5 [NPK+OM]	20.1	21.5	20.6	20.7	22.9	23.1	23.7	23.2
T_6[SSNM]	22.1	22.8	22.7	22.5	23.1	23.9	24.9	23.9
T_7 [FFP]	20.2	20.9	21.3	20.8	22.3	23.4	23.8	23.2
SEd	**0.65**	**0.7**	**0.8**	**-**	**0.63**	**0.6**	**0.6**	**-**
CD (0.05)	**1.4**	**1.5**	**1.7**	**-**	**1.33**	**1.2**	**1.3**	**-**

Table 37: Effect of nutrient omission on grain yield (kg ha^{-1}) of semi-dry rice during 2011-12

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	ONS2	OFT3	OFT4	Mean
T_1 [-N]	1507	1625	1762	1631	1537	1422	1596	1518
T_2 [-P]	2325	1984	2073	2127	2106	1953	2045	2035
T_3 [-K]	2706	2473	2574	2584	2311	2107	2546	2321
T_4 [+NPK]	3397	3243	3209	3283	3123	2986	3045	3051
T_5 [NPK+OM]	3488	3591	3499	3526	3369	3124	3245	3246
T_6 [FFP]	3208	3341	3317	3289	3068	3045	3159	3091
SEd	**80.8**	**79.4**	**103.5**	**-**	**82.7**	**63.3**	**69.1**	**-**
CD (0.05)	**172**	**169**	**221**	**-**	**176**	**135**	**147**	**-**

Table 38: Effect of nutrient omission on grain yield (kg ha^{-1}) of semi-dry rice during 2012-13

Treatments	Paramakudi				Ramanathapuram			
	ONS	OFT1	OFT2	Mean	OFT3	OFT4	OFT5	Mean
T_1 [-N]	1686	1763	1586	1678	1788	1796	1890	1825
T_2 [-P]	2453	2648	2645	2582	2348	2245	2455	2349
T_3 [-K]	2986	2978	2847	2937	2678	2763	2741	2727
T_4 [+NPK]	3459	3128	3265	3284	3024	2976	3012	3004
T_5 [NPK+OM]	3588	3320	3415	3441	3124	3186	3288	3199
T_6[SSNM]	3975	3844	3948	3922	3467	3422	3410	3433
T_7 [FFP]	3499	3356	3512	3456	3110	3210	3286	3202
SEd	**99.9**	**78.4**	**81.3**	**-**	**83.3**	**79.0**	**88.2**	**-**
CD (0.05)	**210**	**164**	**171**	**-**	**175**	**165**	**185**	**-**

Table 39: Effect of nutrient omission on straw yield (kg ha^{-1}) of semi-dry rice during 2011-12

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	ONS2	OFT3	OFT4	Mean
T_1 [-N]	2125	2097	1983	2068	2039	2248	2456	2248
T_2 [-P]	2924	3071	3142	3046	2569	2678	2845	2697
T_3 [-K]	3392	3271	3345	3336	2866	2897	3012	2925
T_4 [+NPK]	3902	4010	3991	3968	4029	3869	3425	3774
T_5 [NPK+OM]	4092	4176	4123	4130	4196	3978	3678	3951
T_6 [FFP]	3980	3892	4217	4030	4010	4012	3986	4003
SEd	**115**	**89.6**	**92.0**	**-**	**103**	**102**	**87.2**	**-**
CD (0.05)	**246**	**191**	**196**	**-**	**220**	**217**	**186**	**-**

Table 40: Effect of nutrient omission on straw yield (kg ha^{-1}) of semi-dry rice during 2012-13

Treatments	Paramakudi				Ramanathapuram			
	ONS	OFT1	OFT2	Mean	OFT3	OFT4	OFT5	Mean
T_1 [-N]	2256	2365	2456	2359	2268	2456	2143	2289
T_2 [-P]	3121	3256	3125	3167	3108	3410	3352	3290
T_3 [-K]	3248	3345	3369	3321	3368	3612	3589	3523
T_4 [+NPK]	4162	3999	4256	4139	4135	3944	4057	4045
T_5 [NPK+OM]	4267	4028	4298	4198	4214	4127	4239	4193
T_6[SSNM]	4549	4315	4456	4440	4396	4212	4370	4326
T_7 [FFP]	4215	4138	4369	4241	4158	4367	4213	4246
SEd	**124.0**	**102.5**	**107.4**	**-**	**107.6**	**98.2**	**99.4**	**-**
CD (0.05)	**260.5**	**215.5**	**225.7**	**-**	**226.1**	**206.3**	**208.9**	**-**

Table 41: Effect of nutrient omission on total N uptake (kg ha^{-1}) at active tillering stage of semi-dry rice during 2011-12

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	ONS2	OFT3	OFT4	Mean
T_1 [-N]	21.1	20.7	21.4	21.1	11.6	13.1	13.4	12.7
T_2 [-P]	26.6	25.1	27.0	26.3	14.9	18.8	18.9	17.5
T_3 [-K]	30.6	34.0	30.8	31.8	18.4	23.0	23.8	21.7
T_4 [+NPK]	41.1	40.6	39.1	40.3	27.0	24.1	26.6	25.9
T_5 [NPK+OM]	42.3	42.8	43.5	42.9	30.7	25.7	28.4	28.3
T_6 [FFP]	39.8	47.2	45.4	44.1	25.4	27.5	29.2	27.4
SEd	**1.0**	**1.2**	**1.4**	**-**	**0.63**	**1.0**	**1.1**	**-**
CD (0.05)	**2.2**	**2.6**	**3.0**	**-**	**1.3**	**2.2**	**2.4**	**-**

Table 42: Effect of nutrient omission on total N uptake (kg ha^{-1}) at active tillering stage of semi-dry rice during 2012-13

Treatments	Paramakudi				Ramanathapuram			
	ONS	OFT1	OFT2	Mean	OFT3	OFT4	OFT5	Mean
T_1 [-N]	20.8	21.8	22.5	21.7	25.3	14.8	17.6	19.2
T_2 [-P]	28.5	31.5	29.6	29.9	29.2	18.3	21.2	22.9
T_3 [-K]	34.9	34.7	33.8	34.5	29.3	22.3	26.9	26.2
T_4 [+NPK]	41.1	42.6	38.6	40.8	38.2	23.1	27.5	29.6
T_5 [NPK+OM]	41.7	43.9	43.0	42.8	40.8	25.5	29.9	32.1
T_6[SSNM]	45.9	46.0	46.9	46.3	47.3	29.3	33.6	36.7
T_7 [FFP]	40.4	43.7	45.3	43.1	39.7	26.9	29.7	32.1
SEd	**1.0**	**1.6**	**1.5**	**-**	**1.1**	**0.93**	**0.98**	**-**
CD (0.05)	**2.1**	**3.3**	**3.2**	**-**	**2.3**	**2.0**	**2.1**	**-**

Table 43: Effect of nutrient omission on total N uptake (kg ha^{-1}) at panicle initiation stage of semi-dry rice during 2011-12

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	ONS2	OFT3	OFT4	Mean
T_1 [-N]	44.7	44.4	44.6	44.6	19.3	37.5	41.0	32.6
T_2 [-P]	53.1	50.5	50.1	51.2	28.8	48.4	45.7	41.0
T_3 [-K]	58.7	57.7	58.2	58.2	33.8	55.2	58.0	49.0
T_4 [+NPK]	63.7	59.3	61.7	61.6	51.8	60.7	63.4	58.6
T_5 [NPK+OM]	66.1	63.3	64.4	64.6	61.2	64.4	69.6	65.1
T_6 [FFP]	64.0	62.3	61.6	62.6	50.2	64.9	67.1	60.7
SEd	**1.6**	**2.2**	**2.3**	**-**	**1.2**	**1.8**	**1.5**	**-**
CD (0.05)	**3.4**	**4.7**	**5.0**	**-**	**2.5**	**3.9**	**3.2**	**-**

Table 44: Effect of nutrient omission on total N uptake (kg ha^{-1}) at panicle initiation stage of semi-dry rice during 2012-13

Treatments	Paramakudi				Ramanathapuram			
	ONS	OFT1	OFT2	Mean	OFT3	OFT4	OFT5	Mean
T_1 [-N]	46.8	50.3	47.7	48.3	26.0	30.1	30.2	28.8
T_2 [-P]	55.4	55.9	53.8	55.0	28.2	32.4	36.3	32.3
T_3 [-K]	62.1	58.6	60.8	60.5	31.5	37.7	40.2	36.5
T_4 [+NPK]	65.0	63.7	61.2	63.3	39.2	40.0	42.9	40.7
T_5 [NPK+OM]	67.2	67.5	63.4	66.0	43.3	41.9	44.7	43.3
T_6[SSNM]	68.6	69.7	67.7	68.7	54.4	46.6	50.5	50.5
T_7 [FFP]	65.4	68.1	66.0	66.5	42.0	44.2	46.4	44.2
SEd	**1.9**	**2.2**	**2.0**	**-**	**1.2**	**1.7**	**1.5**	**-**
CD (0.05)	**4.1**	**4.6**	**4.1**	**-**	**2.4**	**3.6**	**3.2**	**-**

Table 45: Effect of nutrient omission on total N uptake (kg ha^{-1}) at harvest stage of semi-dry rice during 2011-12

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	ONS2	OFT3	OFT4	Mean
T_1 [-N]	66.7	55.5	55.8	59.3	64.2	61.3	59.1	61.5
T_2 [-P]	92.3	66.5	71.7	76.9	57.0	71.5	68.3	65.6
T_3 [-K]	104.0	82.6	85.1	90.6	59.9	82.0	78.0	73.3
T_4 [+NPK]	104.7	93.8	94.9	97.8	89.0	89.8	85.4	88.1
T_5 [NPK+OM]	108.4	90.4	95.5	98.1	96.2	93.4	89.7	93.1
T_6 [FFP]	105.2	93.6	94.5	97.8	85.0	94.6	88.7	89.4
SEd	**2.9**	**3.1**	**3.4**	**-**	**2.3**	**3.1**	**2.5**	**-**
CD (0.05)	**6.2**	**6.7**	**7.3**	**-**	**4.9**	**6.7**	**5.2**	**-**

Table 46: Effect of nutrient omission on total N uptake (kg ha^{-1}) at harvest stage of semi-dry rice during 2012-2013

Treatments	Paramakudi				Ramanathapuram			
	ONS	OFT1	OFT2	Mean	OFT3	OFT4	OFT5	Mean
T_1 [-N]	60.2	74.9	68.3	67.8	53.3	59.8	58.0	57.0
T_2 [-P]	78.3	87.8	83.0	83.0	64.3	67.9	71.7	68.0
T_3 [-K]	89.2	93.3	93.9	92.1	68.2	79.4	79.2	75.6
T_4 [+NPK]	93.7	100.7	95.8	96.7	80.6	82.0	84.3	82.3
T_5 [NPK+OM]	94.8	105.9	99.6	100.1	86.3	87.5	87.6	87.2
T_6[SSNM]	98.3	111.1	105.8	105.1	96.1	93.4	93.7	94.4
T_7 [FFP]	93.8	108.1	105.0	102.3	81.7	88.3	89.4	86.5
SEd	**2.3**	**2.6**	**3.0**	**-**	**2.2**	**2.9**	**2.8**	**-**
CD (0.05)	**4.9**	**5.4**	**6.3**	**-**	**4.7**	**6.1**	**5.8**	**-**

Table 47: Effect of nutrient omission on total P uptake (kg ha^{-1}) at active tillering stage of semi-dry rice during 2011-12

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	ONS2	OFT3	OFT4	Mean
T_1 [-N]	7.90	8.18	8.44	8.18	4.36	4.41	4.56	4.45
T_2 [-P]	6.60	7.05	7.21	6.95	2.96	3.59	3.74	3.43
T_3 [-K]	11.2	13.9	12.3	12.5	5.77	7.28	7.56	6.87
T_4 [+NPK]	14.9	14.1	15.9	15.0	7.79	7.64	7.93	7.79
T_5 [NPK+OM]	15.7	17.2	17.4	16.7	8.81	8.14	8.53	8.49
T_6 [FFP]	14.2	17.5	16.5	16.1	7.51	8.85	8.78	8.38
SEd	**0.36**	**0.56**	**0.5**	**-**	**0.25**	**0.27**	**0.3**	**-**
CD (0.05)	**0.76**	**1.2**	**1.1**	**-**	**0.54**	**0.58**	**0.64**	**-**

Table 48: Effect of nutrient omission on total P uptake (kg ha^{-1}) at active tillering stage of semi-dry rice during 2012-13

Treatments	Paramakudi				Ramanathapuram			
	ONS	OFT1	OFT2	Mean	OFT3	OFT4	OFT5	Mean
T_1 [-N]	8.38	7.83	8.76	8.32	5.41	4.75	5.16	5.11
T_2 [-P]	7.67	8.07	7.79	7.84	5.42	4.25	5.29	4.99
T_3 [-K]	12.5	11.7	11.6	12.0	7.24	6.92	7.95	7.37
T_4 [+NPK]	14.7	14.5	13.5	14.2	8.22	7.32	8.46	8.00
T_5 [NPK+OM]	14.9	15.7	15.3	15.3	9.68	8.07	9.59	9.11
T_6[SSNM]	15.6	15.6	16.4	15.9	11.09	9.14	10.9	10.4
T_7 [FFP]	14.4	15.1	16.2	15.2	8.71	8.74	9.69	9.05
SEd	**0.45**	**0.55**	**0.51**	**-**	**0.29**	**0.22**	**0.32**	**-**
CD (0.05)	**0.95**	**1.16**	**1.07**	**-**	**0.60**	**0.47**	**0.68**	**-**

Table 49: Effect of nutrient omission on total P uptake (kg ha^{-1}) at panicle initiation stage of semi-dry rice during 2011-12

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	ONS2	OFT3	OFT4	Mean
T_1 [-N]	25.8	24.4	25.3	25.2	13.5	17.3	16.2	15.7
T_2 [-P]	20.1	19.3	18.5	19.3	11.1	14.8	12.6	12.8
T_3 [-K]	31.0	30.1	31.0	30.7	17.8	24.5	22.4	21.6
T_4 [+NPK]	34.0	31.5	33.5	33.0	24.5	27.1	25.2	25.6
T_5 [NPK+OM]	35.2	34.5	34.3	34.7	27.5	28.3	26.4	27.4
T_6 [FFP]	33.3	33.1	31.4	32.6	23.5	28.6	26.2	26.1
SEd	**0.94**	**1.5**	**1.4**	**-**	**0.5**	**0.7**	**0.90**	**-**
CD (0.05)	**2.0**	**3.1**	**3.1**	**-**	**1.1**	**1.5**	**1.9**	**-**

Table 50: Effect of nutrient omission on P uptake (kg ha^{-1}) at panicle initiation stage of semi-dry rice during 2012-13

Treatments	Paramakudi				Ramanathapuram			
	ONS	OFT1	OFT2	Mean	OFT3	OFT4	OFT5	Mean
T_1 [-N]	26.9	28.9	27.5	27.8	15.0	18.0	17.9	17.0
T_2 [-P]	20.8	22.5	19.5	20.9	12.3	14.4	17.3	14.7
T_3 [-K]	33.0	31.4	33.1	32.5	18.4	22.6	23.4	21.5
T_4 [+NPK]	34.8	34.8	34.4	34.7	21.4	23.8	24.1	23.1
T_5 [NPK+OM]	35.6	36.5	36.7	36.2	24.6	24.8	25.6	25.0
T_6[SSNM]	36.2	38.7	38.3	37.7	28.0	27.3	27.3	27.5
T_7 [FFP]	34.9	37.3	38.7	37.0	22.3	25.0	26.6	24.6
SEd	**0.93**	**1.3**	**1.24**	**-**	**0.62**	**0.87**	**0.88**	**-**
CD (0.05)	**2.0**	**2.7**	**2.6**	**-**	**1.3**	**1.8**	**1.8**	**-**

Table 51: Effect of nutrient omission on total P uptake (kg ha^{-1}) at harvest stage of semi-dry rice during 2011-12

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	ONS2	OFT3	OFT4	Mean
T_1 [-N]	29.3	27.2	27.6	28.0	17.3	23.4	23.0	21.2
T_2 [-P]	28.2	26.5	26.0	26.9	18.8	22.7	22.9	21.5
T_3 [-K]	37.7	35.0	37.3	36.7	22.8	29.9	30.0	27.6
T_4 [+NPK]	41.4	38.2	38.5	39.4	31.2	32.6	32.0	31.9
T_5 [NPK+OM]	43.7	39.7	41.6	41.7	35.1	33.5	33.1	33.9
T_6 [FFP]	41.1	39.1	39.8	40.0	30.0	34.5	32.7	32.4
SEd	**1.1**	**1.1**	**1.2**	**-**	**0.7**	**1.2**	**0.8**	**-**
CD (0.05)	**2.3**	**2.4**	**2.5**	**-**	**1.5**	**2.6**	**1.8**	**-**

Table 52: Effect of nutrient omission on total P uptake (kg ha^{-1}) at harvest stage of semi-dry rice during 2012-13

Treatments	Paramakudi				Ramanathapuram			
	ONS	OFT1	OFT2	Mean	OFT3	OFT4	OFT5	Mean
T_1 [-N]	28.6	36.3	38.3	34.4	26.4	28.6	28.6	27.9
T_2 [-P]	30.1	36.8	39.8	35.6	28.1	28.8	32.1	29.7
T_3 [-K]	36.6	40.6	46.2	41.1	31.9	36.4	37.2	35.2
T_4 [+NPK]	38.5	44.2	48.3	43.7	37.3	38.5	39.6	38.5
T_5 [NPK+OM]	39.1	47.1	49.6	45.2	40.0	40.7	40.9	40.5
T_6[SSNM]	40.2	49.9	53.7	47.9	44.9	44.1	43.5	44.1
T_7 [FFP]	38.5	46.5	52.9	46.0	37.8	42.2	41.2	40.4
SEd	**1.0**	**1.4**	**1.3**	**-**	**1.0**	**1.1**	**1.0**	**-**
CD (0.05)	**2.2**	**3.0**	**2.7**	**-**	**2.1**	**2.3**	**2.2**	**-**

Table 53: Effect of nutrient omission on total K uptake (kg ha^{-1}) at active tillering stage of semi-dry rice during 2011-12

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	ONS2	OFT3	OFT4	Mean
T_1 [-N]	27.9	27.8	30.0	28.6	16.7	18.6	18.0	17.8
T_2 [-P]	35.9	36.5	38.0	36.8	18.6	24.6	23.8	22.3
T_3 [-K]	35.5	39.9	35.5	37.0	18.1	24.6	23.6	22.1
T_4 [+NPK]	54.0	57.5	49.7	53.7	30.0	31.3	29.6	30.3
T_5 [NPK+OM]	55.4	55.3	59.3	56.7	33.7	33.1	31.6	32.8
T_6 [FFP]	51.9	59.4	57.7	56.3	28.4	35.0	32.8	32.1
SEd	**1.3**	**1.9**	**1.8**	**-**	**0.7**	**1.2**	**1.1**	**-**
CD (0.05)	**2.7**	**4.1**	**3.7**	**-**	**1.5**	**2.5**	**2.2**	**-**

Table 54: Effect of nutrient omission on total K uptake (kg ha^{-1}) at active tillering stage of semi-dry rice during 2012-13

Treatments	Paramakudi				Ramanathapuram			
	ONS	OFT1	OFT2	Mean	OFT3	OFT4	OFT5	Mean
T_1 [-N]	31.7	32.3	35.1	33.0	25.3	19.1	23.4	22.6
T_2 [-P]	38.6	43.7	41.7	41.3	29.2	22.5	27.0	26.2
T_3 [-K]	42.4	41.1	43.4	42.3	29.3	25.6	30.5	28.5
T_4 [+NPK]	55.1	58.2	53.4	55.6	38.2	27.8	34.3	33.4
T_5 [NPK+OM]	56.4	60.2	58.8	58.5	40.8	30.8	37.2	36.3
T_6[SSNM]	60.3	63.5	63.5	62.4	47.3	34.9	42.7	41.6
T_7 [FFP]	54.4	59.8	61.1	58.5	39.7	32.5	37.3	36.5
SEd	**1.6**	**2.1**	**2.3**	**-**	**1.1**	**1.1**	**1.4**	**-**
CD (0.05)	**3.3**	**4.4**	**4.8**	**-**	**2.3**	**2.4**	**3.0**	**-**

Table 55: Effect of nutrient omission on K uptake (kg ha^{-1}) at panicle initiation stage of semi-dry rice during 2011-12

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	ONS2	OFT3	OFT4	Mean
T_1 [-N]	83.8	81.1	82.6	82.5	51.0	64.9	64.4	60.1
T_2 [-P]	93.5	89.1	89.4	90.7	65.6	81.7	83.2	76.8
T_3 [-K]	69.5	69.8	87.6	75.6	59.0	81.7	78.1	72.9
T_4 [+NPK]	114.9	95.8	111.0	107.2	93.0	96.6	96.0	95.2
T_5 [NPK+OM]	120.1	109.5	113.7	114.5	105.3	101.9	102.5	103.2
T_6 [FFP]	113.8	101.8	107.2	107.6	89.8	104.4	102.7	99.0
SEd	**2.9**	**3.7**	**4.4**	**-**	**2.6**	**4.2**	**3.8**	**-**
CD (0.05)	**6.2**	**7.9**	**9.4**	**-**	**5.5**	**8.9**	**8.1**	**-**

Table 56: Effect of nutrient omission on K uptake (kg ha^{-1}) at panicle initiation stage of semi-dry rice during 2012-13

Treatments	Paramakudi				Ramanathapuram			
	ONS	OFT1	OFT2	Mean	OFT3	OFT4	OFT5	Mean
T_1 [-N]	91.8	93.6	90.6	92.0	55.9	63.2	63.7	60.9
T_2 [-P]	100.9	98.7	97.1	98.9	63.6	68.8	75.0	69.1
T_3 [-K]	88.3	87.0	91.0	88.8	62.1	74.4	78.4	71.6
T_4 [+NPK]	115.1	110.7	108.3	111.4	79.4	81.7	85.0	82.0
T_5 [NPK+OM]	116.6	116.0	111.1	114.6	81.7	85.7	87.1	84.8
T_6[SSNM]	118.5	119.3	117.0	118.2	91.6	91.4	91.6	91.6
T_7 [FFP]	115.3	117.2	116.1	116.2	78.1	89.1	88.1	85.1
SEd	**3.1**	**3.3**	**3.2**	**-**	**2.0**	**3.4**	**2.6**	**-**
CD (0.05)	**6.6**	**7.0**	**6.8**	**-**	**4.2**	**7.2**	**5.5**	**-**

Table 57: Effect of nutrient omission on total K uptake (kg ha^{-1}) at harvest stage of semi-dry rice during 2011-12

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	ONS2	OFT3	OFT4	Mean
T_1 [-N]	100.2	85.8	92.5	92.8	55.7	78.4	73.6	69.2
T_2 [-P]	123.8	105.4	109.4	112.9	71.8	88.6	84.8	81.7
T_3 [-K]	94.3	82.3	101.9	92.9	69.4	94.7	88.4	84.1
T_4 [+NPK]	152.2	132.3	137.1	140.5	102.8	106.3	101.3	103.5
T_5 [NPK+OM]	163.5	140.1	141.2	148.3	115.2	107.7	104.8	109.2
T_6 [FFP]	151.7	128.8	140.5	140.4	98.9	110.1	105.5	104.9
SEd	**4.4**	**3.0**	**2.9**	**-**	**2.4**	**2.5**	**2.5**	**-**
CD (0.05)	**9.4**	**6.4**	**6.2**	**-**	**5.1**	**5.2**	**5.4**	**-**

Table 58: Effect of nutrient omission on total K uptake (kg ha^{-1}) at harvest stage of semi-dry rice during 2012-2013

Treatments	Paramakudi				Ramanathapuram			
	ONS	OFT1	OFT2	Mean	OFT3	OFT4	OFT5	Mean
T_1 [-N]	94.5	112.1	103.9	103.5	70.1	72.5	71.7	71.4
T_2 [-P]	107.0	119.9	114.2	113.7	80.4	81.4	84.4	82.1
T_3 [-K]	100.9	112.5	110.2	107.9	83.4	88.7	92.4	88.2
T_4 [+NPK]	127.5	136.8	128.4	130.9	97.9	97.7	99.1	98.2
T_5 [NPK+OM]	129.1	143.4	133.2	135.2	103.8	102.4	102.4	102.9
T_6[SSNM]	133.0	148.8	141.5	141.1	112.9	109.8	107.9	110.2
T_7 [FFP]	127.4	145.2	138.7	137.1	99.1	104.9	103.0	102.3
SEd	**3.2**	**3.5**	**3.3**	**-**	**2.7**	**2.5**	**2.3**	**-**
CD (0.05)	**6.7**	**7.4**	**6.9**	**-**	**5.6**	**5.3**	**4.9**	**-**

Table 59: Indigenous nutrient supply (kg ha^{-1}) in semi-dry rice soils of Ramanathapuram district during 2011-12

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	ONS2	OFT3	OFT4	Mean
INS	66.7	55.5	55.8	59.3	44.2	64.2	59.1	55.8
IPS	28.2	26.5	26.0	26.9	18.8	22.7	22.9	21.5
IKS	94.3	82.3	101.9	92.9	69.4	94.7	88.4	84.1

Table 60: Indigenous nutrient supply (kg ha^{-1}) in semi-dry rice soils of Ramanathapuram district during 2012-13

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	OFT3	OFT4	OFT5	Mean
INS	60.2	74.9	68.3	67.8	53.3	59.8	58.0	57.0
IPS	30.1	36.8	39.8	35.6	28.1	28.8	32.1	29.7
IKS	100.9	112.5	110.2	107.9	83.4	88.7	92.4	88.2

Table 61: Nutrient requirement (kg t^{-1}) of semi-dry rice during 2011-12

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	ONS2	OFT3	OFT4	Mean
N	44.5	34.7	32.8	37.3	29.5	43.8	36.9	36.7
P	12.2	13.2	13.0	12.8	9.0	12.0	11.5	10.8
K	34.9	32.9	39.2	35.7	30.2	45.1	34.0	36.4

Table 62: Nutrient requirement (kg t^{-1}) of semi-dry rice during 2012-13

Treatments	Paramakudi				Ramanathapuram			
	ONS1	OFT1	OFT2	Mean	OFT3	OFT4	OFT5	Mean
N	35.4	41.6	42.7	39.9	29.6	33.2	30.5	31.1
P	12.0	14.2	15.3	13.9	12.2	13.1	13.4	12.9
K	33.6	37.5	39.3	36.8	30.9	31.7	34.2	32.3

Fig.5. Spatial distribution of Soil pH of semi-dry rice grown soils of Ramanathapuram district

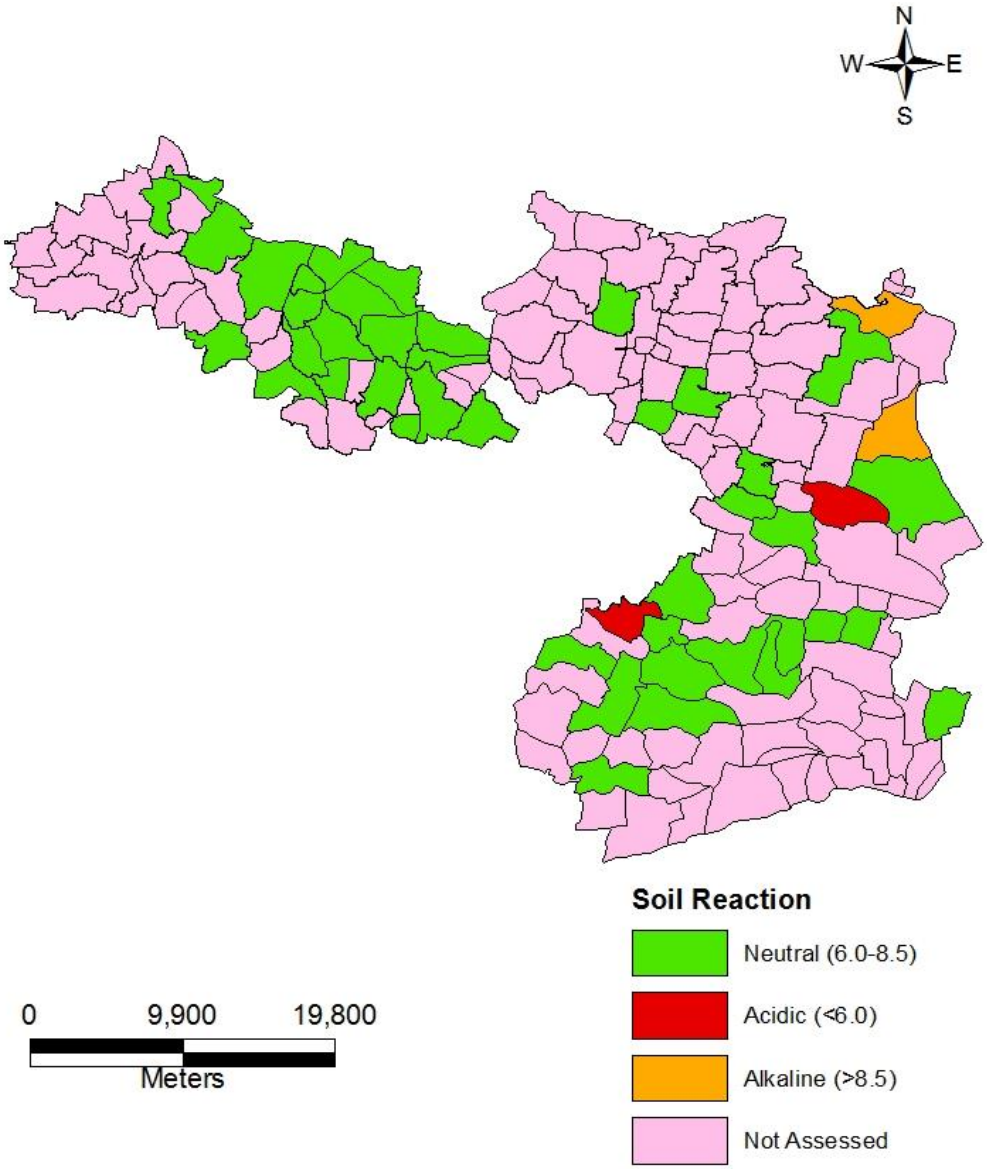


Fig.6. Spatial distribution of soil EC of semi-dry rice grown soils of Ramanathapuram district

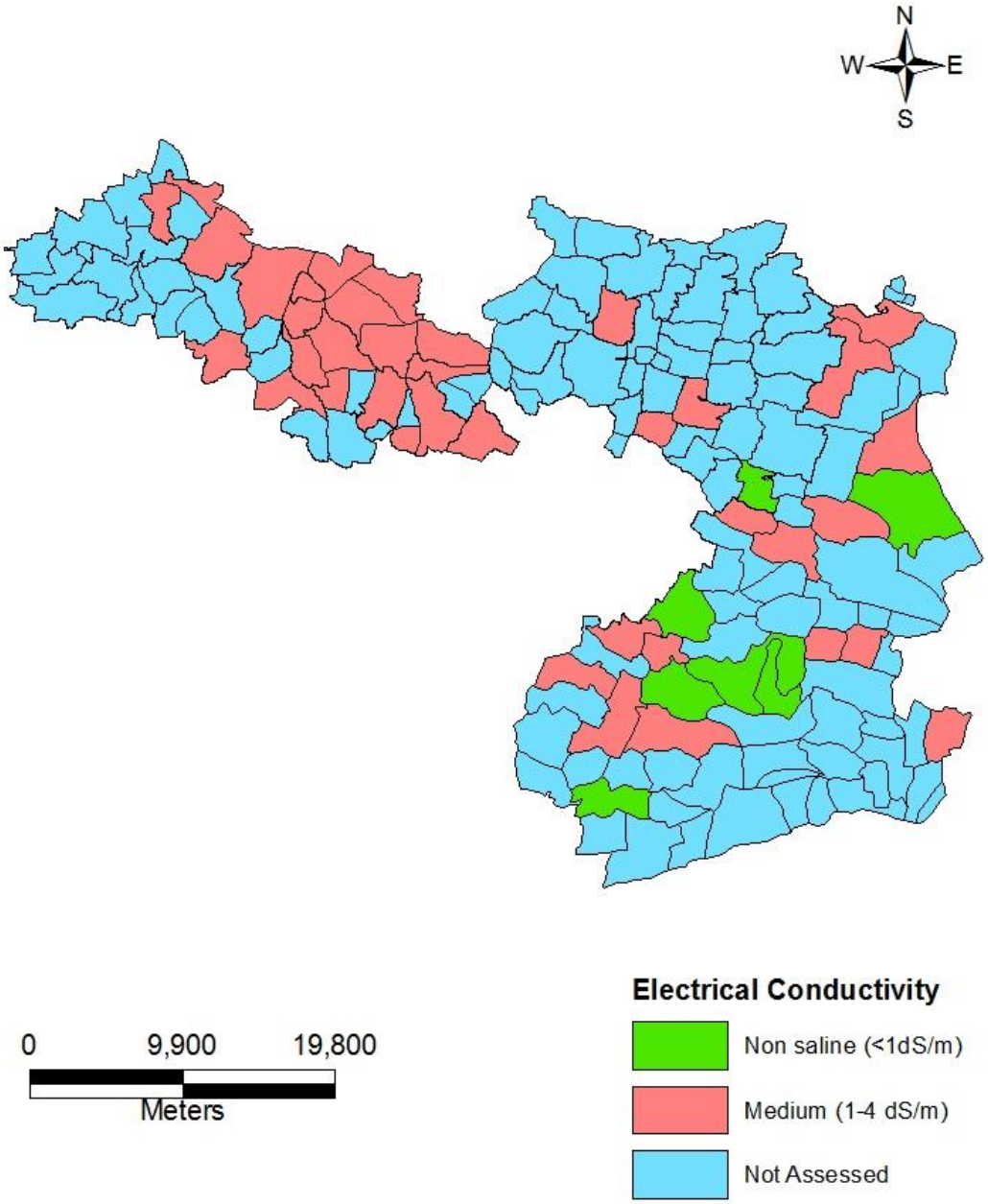


Fig.7. Spatial distribution of soil organic carbon status of semi-dry rice grown soils of Ramanathapuram district

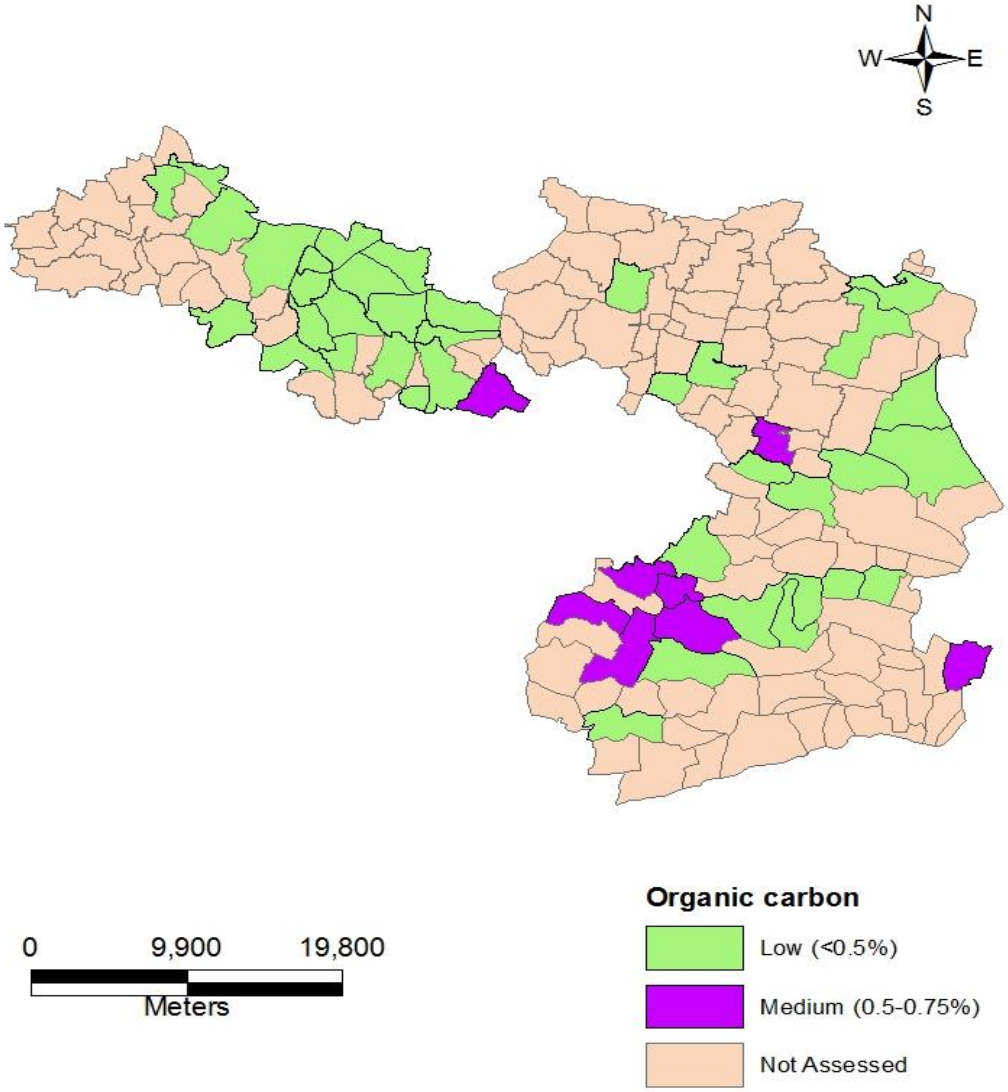


Fig.8. Spatial distribution of soil available N status of semi-dry rice grown soils of Ramanathapuram district

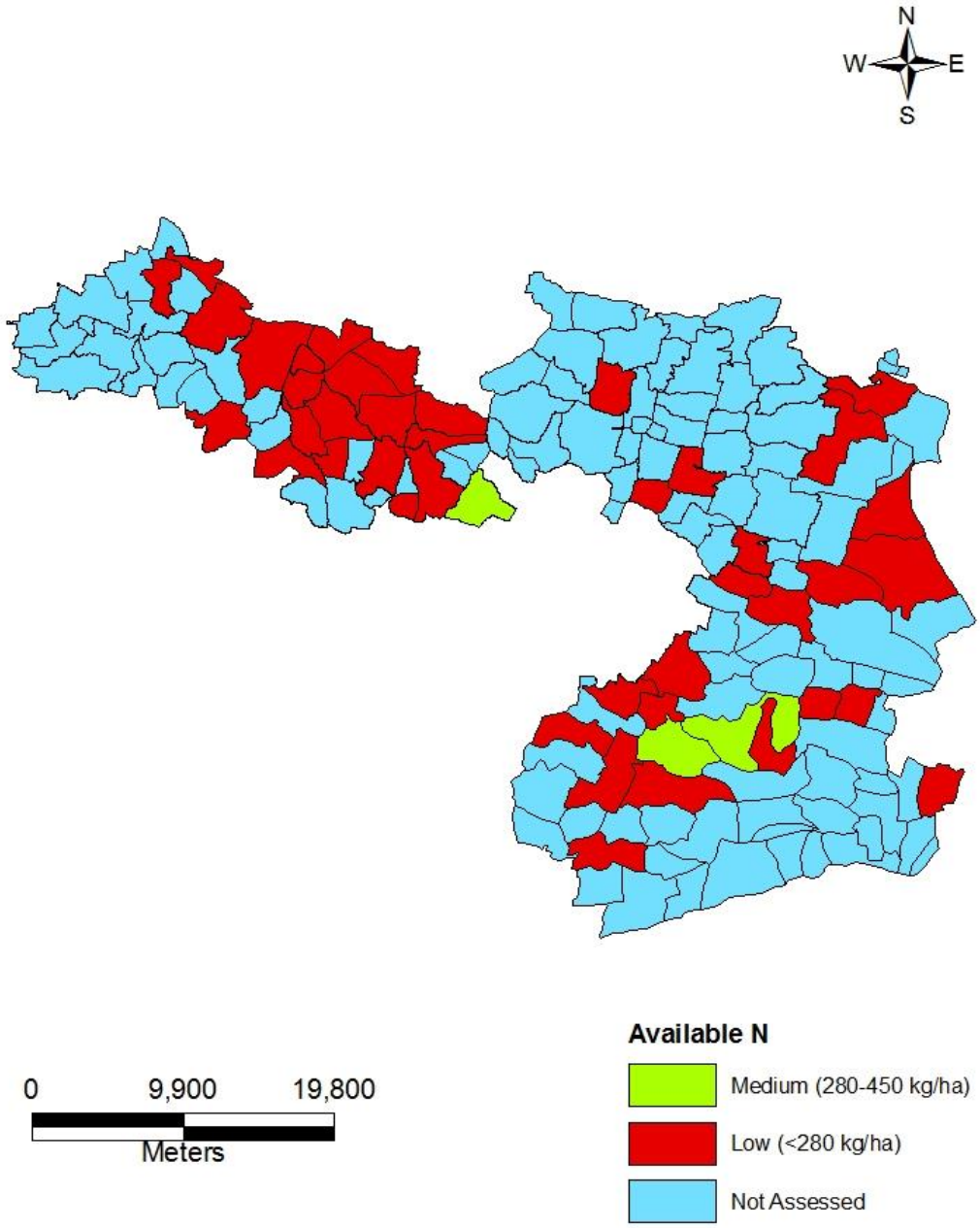


Fig .9. Spatial distribution of soil available P status of semi-dry rice grown soils of Ramanathapuram district

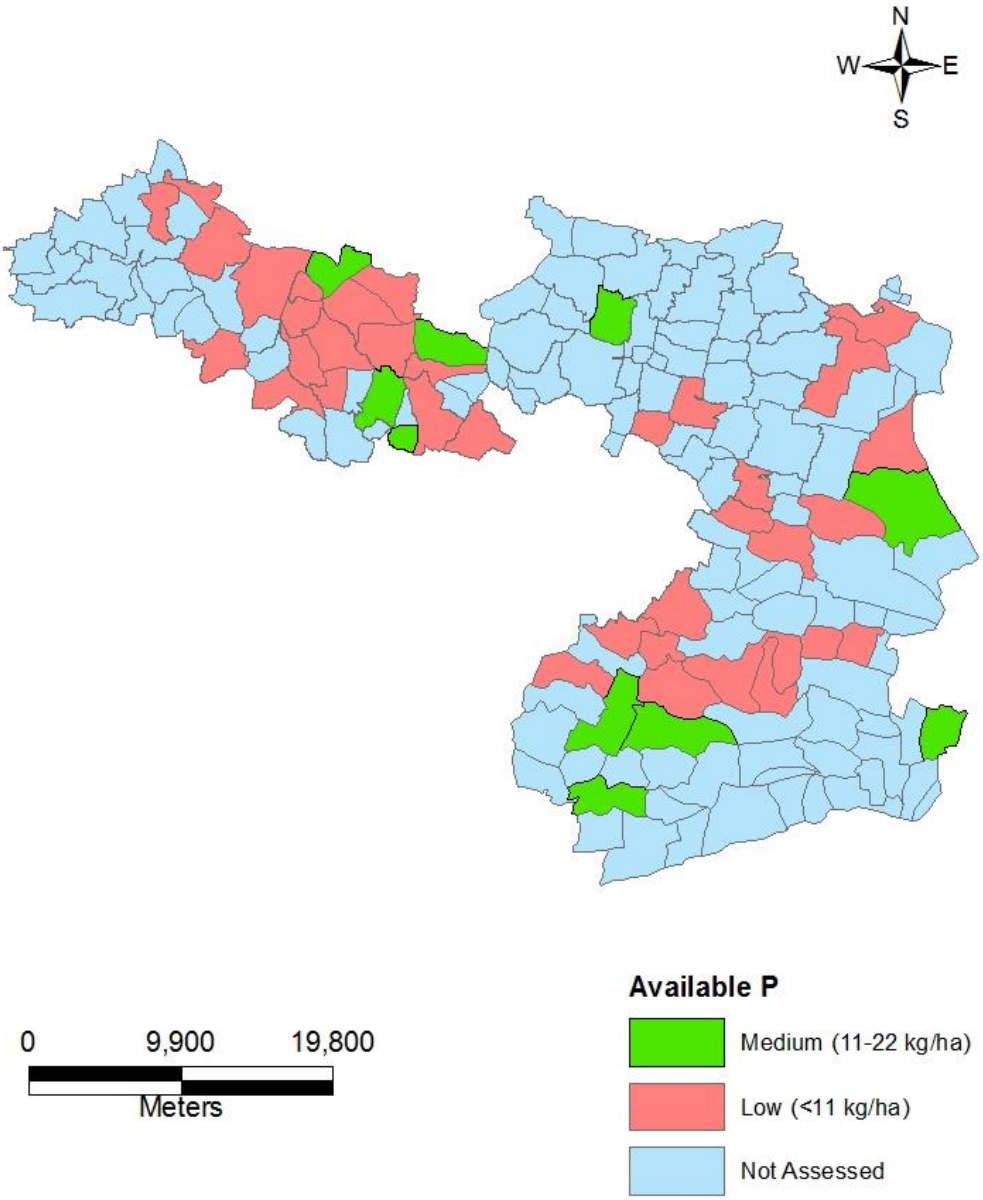


Fig .10. Spatial distribution of soil available K status of semi-dry rice grown soils of Ramanathapuram district

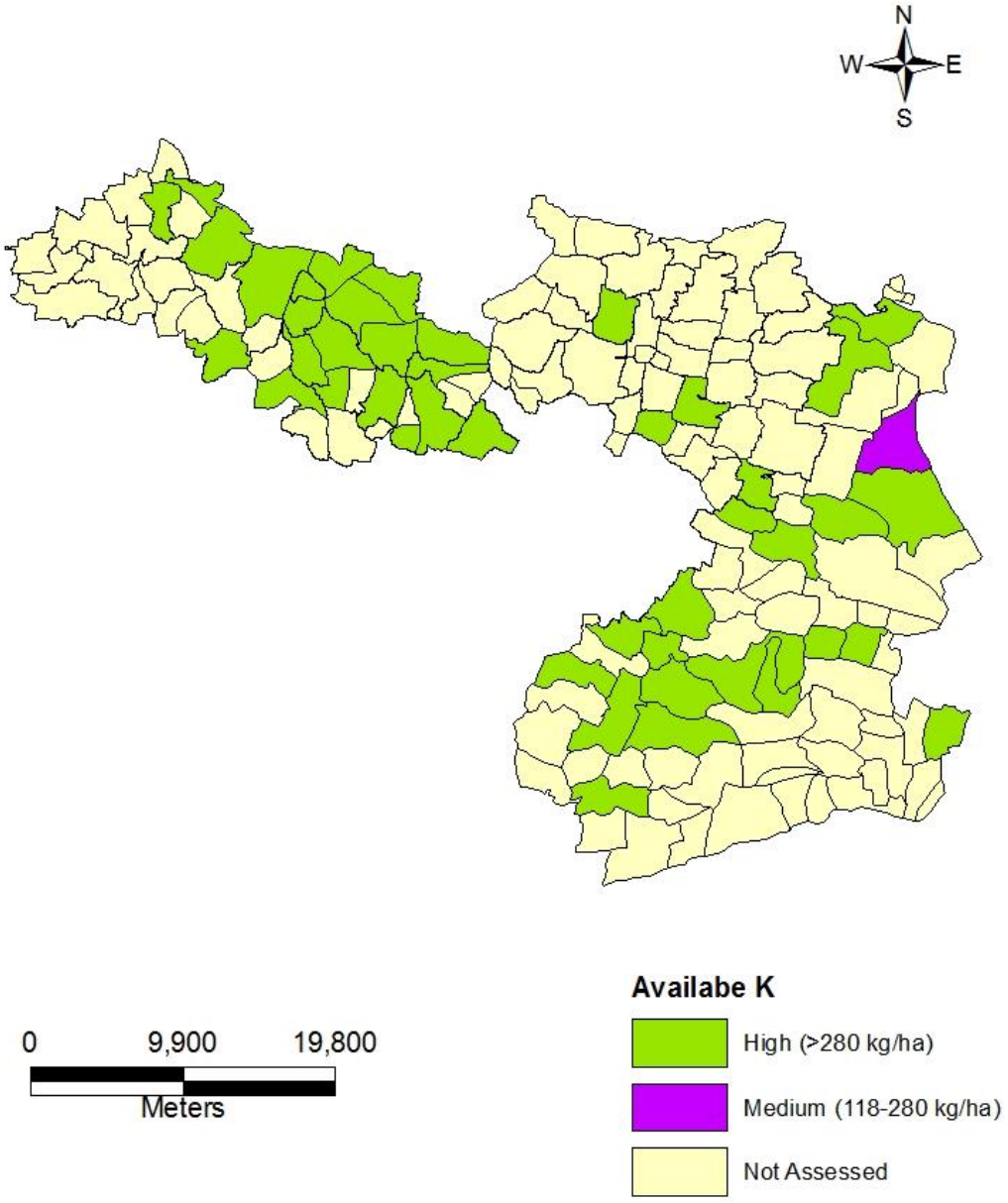


Fig .11. Spatial distribution of available Fe status of semi-dry rice grown soils of Ramanathapuram district

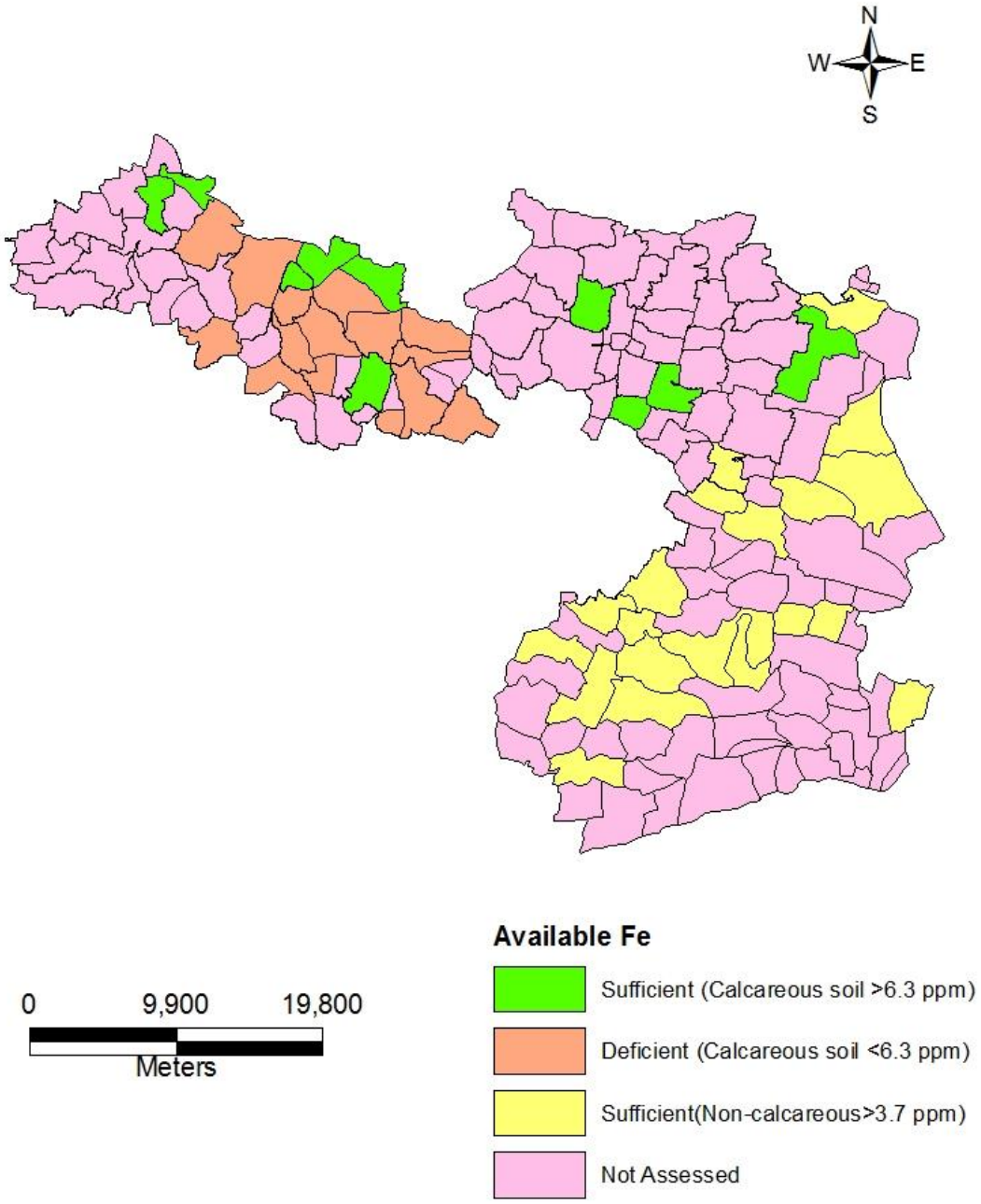


Fig .12. Spatial distribution of available Mn status of semi-dry rice grown soils of Ramanathapuram district

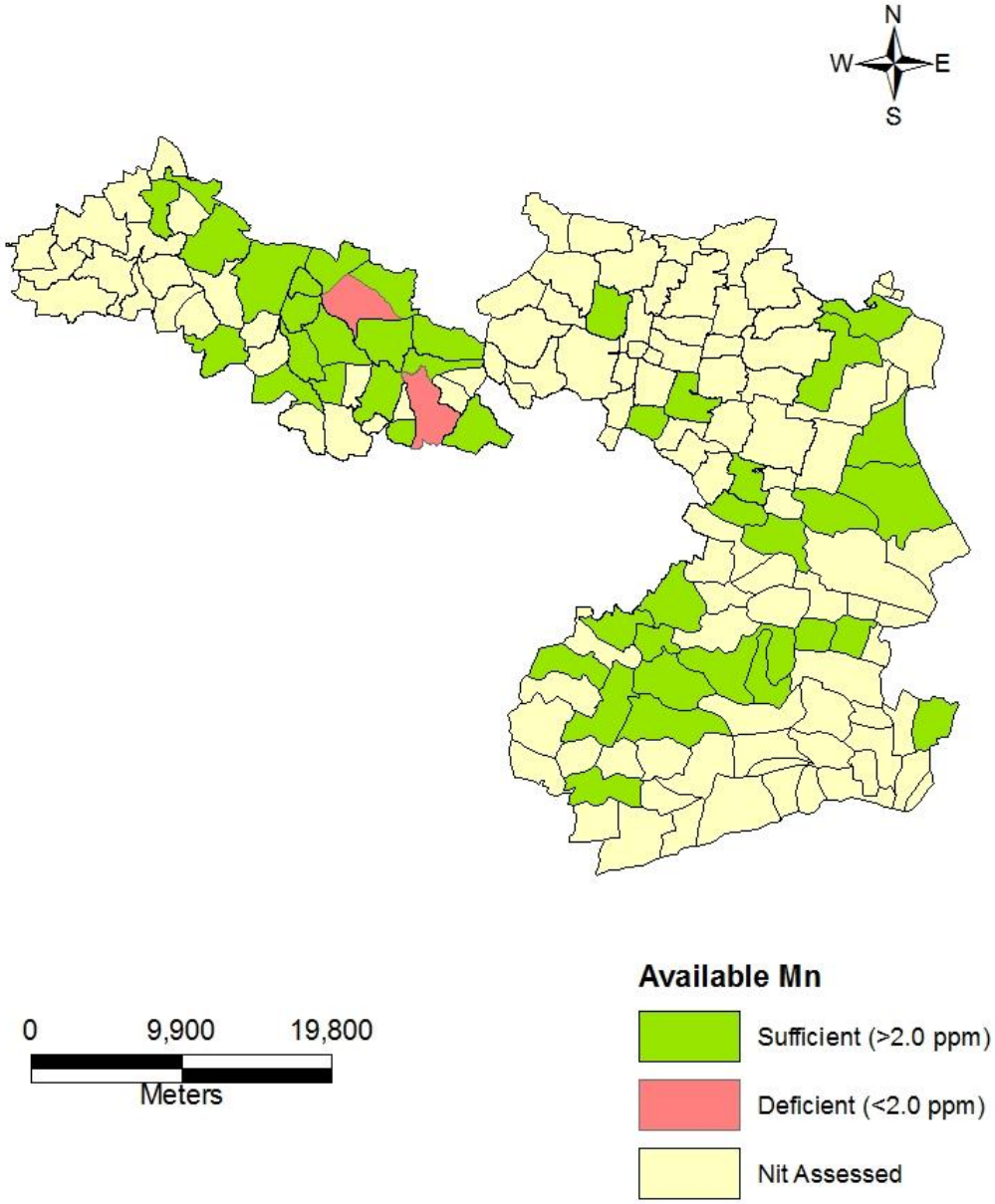


Fig .13. Spatial distribution of available Zn status of semi-dry rice grown soils of Ramanathapuram district

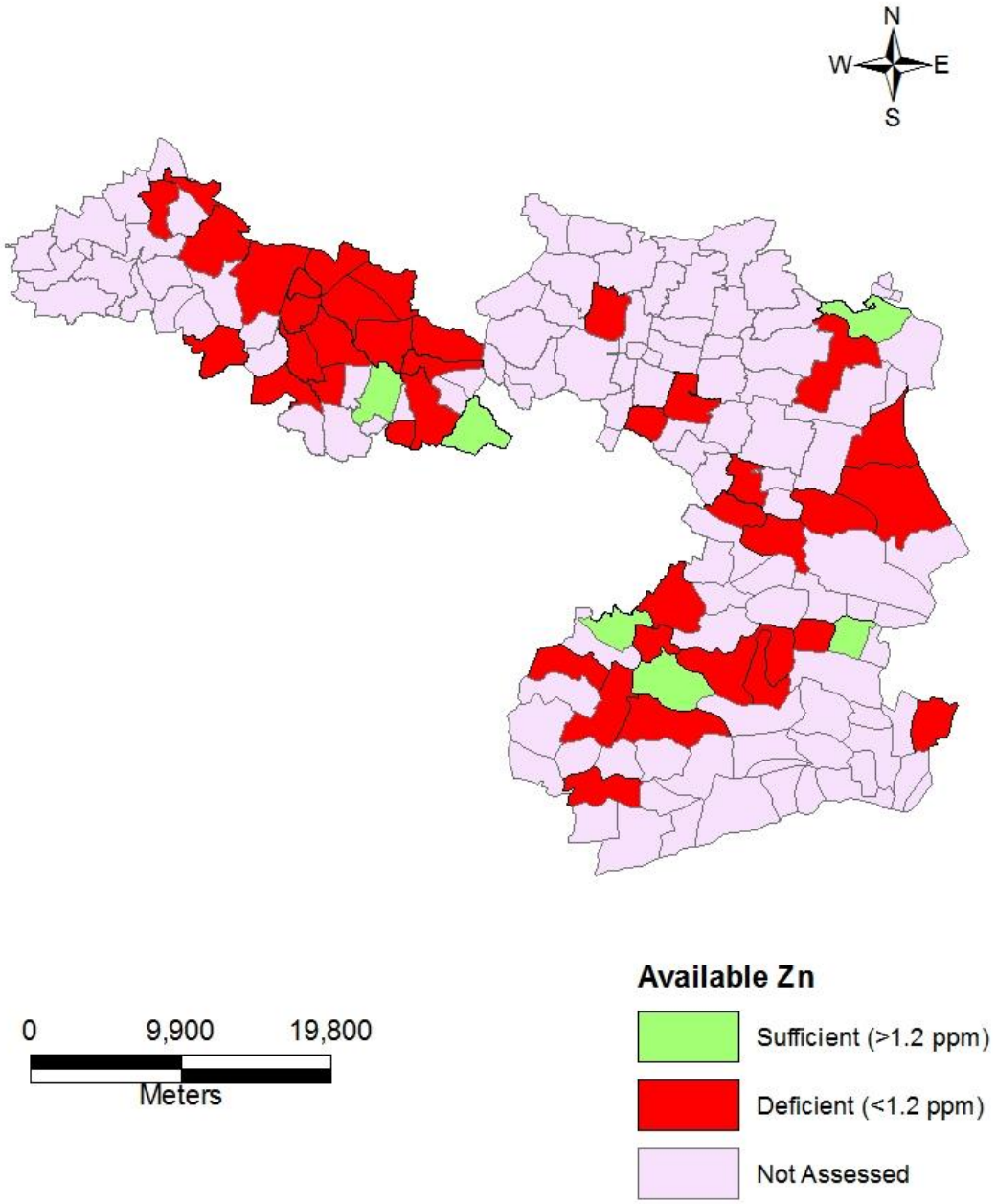


Fig .14. Spatial distribution of available Cu status of semi-dry rice grown soils of Ramanathapuram district

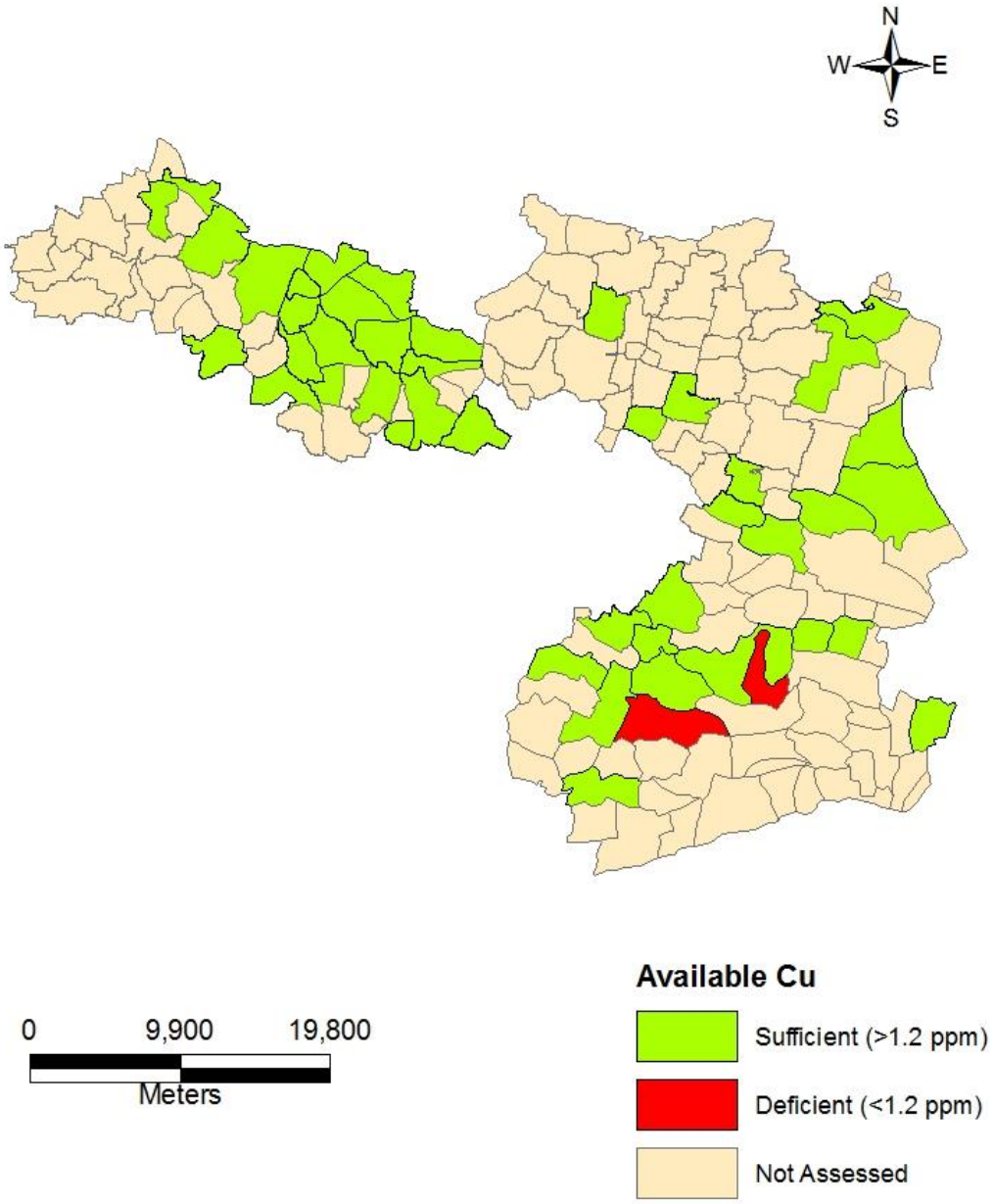


Fig.1. Location map of sampling villages of Ramanathapuram district

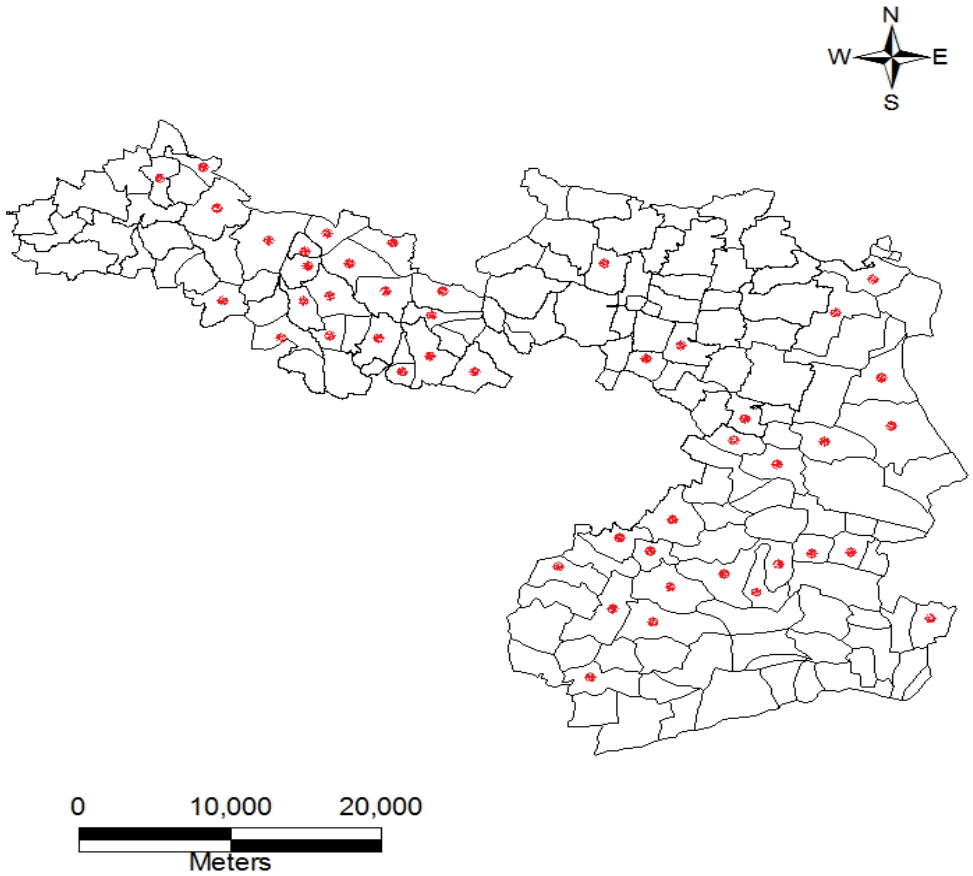
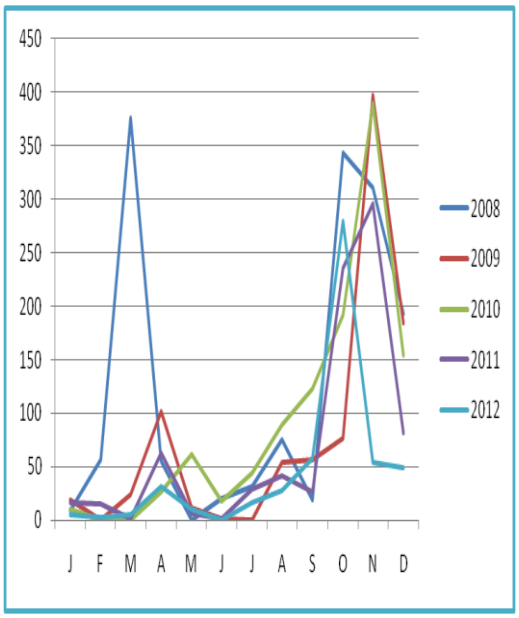


Table.1. District rainfall (mm) pattern for the past five years

YEAR	J	F	M	A	M	J	J	A	S	O	N	D	Total
2008	9.2	56.6	376.6	55.7	0.0	19.9	31.2	75.4	19.1	344.2	311.7	193.1	**3501**
2009	18.8	0.0	24.1	102.1	11.2	1.1	0.1	53.4	55.9	76.1	397.4	184.6	**2934**
2010	10.3	0.0	0.4	26.1	61.0	17.9	44.3	88.6	123.3	192.5	390.1	154.1	**3119**
2011	16.6	15.4	2.0	63.0	7.2	1.7	29.5	41.6	27.2	236.3	295.8	81.4	**2829**
2012	5.0	2.2	4.9	31.6	10.0	0.0	16.2	27.4	57.2	279.9	53.6	48.7	**2549**

Fig.4.Mean annual rainfall of Ramanathapuram district



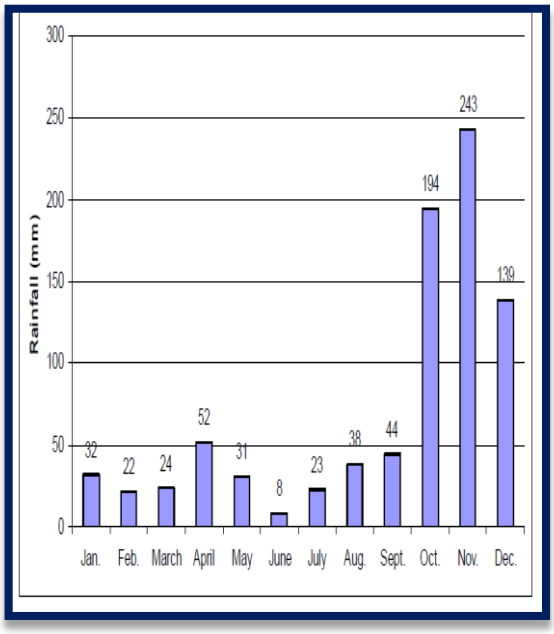


Table 2. The geospatial co-ordinates of the soil sampling villages

S.No	Village name	Latitude	Longitude
1	Parthibanur	9°58'N	78°45'E
2	Perungarai	9°57'N	78°49'E
3	Kamuthakudi	9°57'N	78°50'E
4	Pothuvakudi	9°56'N	78°52'E
5	Kulavipatti	9°55'N	78°54'E
6	Vilathur	9°53'N	78°55'E
7	M.Puram	9°51'N	78°50'E
8	Melayakudi	9°49'N	78°53'E
9	Kavanoor	9°51'N	78°54'E
10	Pamboor	9°51'N	78°56'E
11	Venthoni	9°52'N	78°57'E
12	V.Kurichi	9°49'N	78°55'E
13	Ariyanenthal	9°46'N	78°59'E
14	Kalaiur	9°52'N	78°61'E
15	Oorapli	9°66'N	78°60'E
16	Ariyakottai	9°47'N	78°61'E
17	Nagatchi	9°47'N	78°60'E
18	Kiliyur	9°51'N	78°61'E
19	Keelanotchi	9°50'N	78°62'E
20	Smaputhur	9°44'N	78°73'E
21	Ulakatchi	9°46'N	78°76'E
22	Erumpoor	9°51'N	78°72'E
23	Sakkarkotai	9°55'N	78°55'E
24	R.S.Madai	9°58'N	78°56'E
25	T.pattanam	9°70'N	78°73'E
26	Kalari	9°33'N	78°87'E
27	U.K.Mangai	9°34'N	78°84'E
28	Maruthur	9°29'N	78°82'E
29	Ekkudi	9°30'N	78°77'E
30	Nallankudi	9°31'N	78°74'E
31	Pullankudi	9°31'N	78°72'E
32	Ammari	9°34'N	78°74'E
33	Peruvayal	9°34'N	78°74'E
34	N.Manglam	9°41'N	78°86'E
35	RM.B.Tank	9°42'N	78°89'E
36	Pasalai	9°44'N	78°87'E
37	Karendal	9°51'N	78°87'E
38	Ragupuram	9°39'N	78°81'E
39	Pullandai	9°42'N	78°80'E
40	Anjamadai	9°42'N	78°80'E
41	Setukal	9°28'N	78°92'E
42	Vallam	9°24'N	78°73'E
43	Mudalur	9°28'N	78°74'E

Table 63. Total factor productivity (TFP), Partial factor productivity (PFP), Agronomic efficiency (AE) and Recovery efficiency (RE) of semi-dry rice during 2011-2012

Location-I (Paramakudi)																
Treatment	TFP kg/kg of nutrient				PFP_N kg/kg of N				AE_N kg/kg of N				RE_N kg of N uptake /kg of N			
	ONS1	OFT-1	OFT-2	MEAN	ONS1	OFT-1	OFT-2	MEAN	ONS1	OFT-1	OFT-2	MEAN	ONS1	OFT-1	OFT-2	MEAN
T_4 -NPK	24.7	23.6	23.3	**23.9**	45.3	43.2	42.8	**43.8**	25.2	21.6	19.3	**22.0**	0.64	0.51	0.52	**0.56**
T_5 -NPK+OM	25.4	26.1	25.5	**25.7**	46.5	47.9	46.7	**47.0**	26.4	26.2	23.2	**25.3**	0.55	0.47	0.53	**0.52**
T_6 -FFP	21.4	19.7	18.4	**19.8**	35.6	33.4	27.6	**32.2**	18.9	17.2	13.0	**16.4**	0.54	0.38	0.32	**0.41**
Location-II (Ramanathapuram)																
Treatment	TFP kg/kg of nutrient				PFP_N kg/kg of N				AE_N kg/kg of N				RE_N kg of N uptake /kg of N			
	ONS2	OFT-3	OFT-4	MEAN	ONS2	OFT-3	OFT-4	MEAN	ONS2	OFT-3	OFT-4	MEAN	ONS2	OFT-3	OFT-4	MEAN
T_4 -NPK	22.7	21.7	22.1	**22.2**	41.6	39.8	40.6	**40.7**	21.1	20.9	19.3	**20.4**	0.33	0.38	0.35	**0.35**
T_5 -NPK+OM	24.5	22.7	23.6	**23.6**	44.9	41.6	43.2	**43.2**	24.4	22.6	21.9	**23.0**	0.44	0.37	0.39	**0.40**
T_6 -FFP	18.0	16.0	15.8	**16.6**	30.7	25.4	26.3	**27.5**	15.3	13.5	13.0	**13.9**	0.41	0.28	0.25	**0.31**

Table 64. Total factor productivity (TFP), Partial factor productivity (PFP), Agronomic efficiency (AE) and Recovery efficiency (RE) of semi-dry rice during 2012-13

Location-I (Paramakudi)																
Treatment	TFP kg/kg of nutrient				PFP_N kg/kg of N				AE_N kg/kg of N				RE_N kg of N uptake /kg of N			
	ONS	OFT-1	OFT-2	MEAN	ONS	OFT-1	OFT-2	MEAN	ONS	OFT-1	OFT-2	MEAN	ONS	OFT-1	OFT-2	MEAN
T_4 -NPK	25.2	22.7	23.7	**23.9**	46.1	41.7	43.5	**43.8**	23.6	18.2	22.4	**21.4**	0.45	0.34	0.37	**0.39**
T_5 -NPK+OM	26.1	24.2	24.8	**25.0**	47.9	44.3	45.5	**45.9**	25.4	20.8	24.4	**23.5**	0.46	0.41	0.42	**0.43**
T_6 -SSNM	26.7	23.6	24.2	**24.8**	40.2	34.0	34.9	**36.4**	23.1	18.4	20.9	**20.8**	0.38	0.32	0.33	**0.34**
T_7 -FFP	19.2	17.8	16.0	**17.7**	26.5	24.1	20.8	**23.8**	13.7	11.5	11.4	**12.2**	0.25	0.24	0.22	**0.24**

Location-II (Ramanathapuram)																
Treatment	TFP kg/kg of nutrient				PFP_N kg/kg of N				AE_N kg/kg of N				RE_N kg of N uptake /kg of N			
	OFT-3	OFT-4	OFT-5	MEAN	OFT-3	OFT-4	OFT-5	MEAN	OFT-3	OFT-4	OFT-5	MEAN	OFT-3	OFT-4	OFT-5	MEAN
T_4 -NPK	22.0	21.6	21.9	**21.8**	40.3	39.7	40.2	**40.1**	16.5	15.7	15.0	**15.7**	0.36	0.3	0.35	**0.34**
T_5 -NPK+OM	22.7	23.2	23.9	**23.3**	41.7	42.5	43.8	**42.7**	17.8	18.5	18.6	**18.3**	0.44	0.37	0.39	**0.40**
T_6 -SSNM	23.9	23.4	22.3	**23.2**	36.5	35.6	33.1	**35.1**	17.7	16.9	14.8	**16.5**	0.45	0.35	0.35	**0.38**
T_7 -FFP	17.3	16.2	16.1	**16.5**	23.9	21.7	21.3	**22.3**	10.2	9.6	9.1	**9.6**	0.22	0.19	0.2	**0.20**

Table 65: Fertilizer N,P and K requirement for semi-dry rice

S.No	Yield ($t.ha^{-1}$)				Fertilizer prescription($kg\ ha^{-1}$)		
	Target	Achieved	Variation	(%)	N	P_2O_5	K_2O
I.Paramakudi block							
ONS	4.0	3.97	-0.03	0.75	120	20	30
OFT-1	4.0	3.84	-0.16	4.00	147	20	30
OFT-2	4.0	3.94	-0.06	1.50	185	20	30
II.Rananathapuram block							
OFT-3	3.5	3.46	-0.04	1.10	96	20	30
OFT-4	3.5	3.42	-0.08	2.20	159	20	30
OFT-5	3.5	3.41	-0.09	2.60	158	20	30
Blanket recommentation:75:25:37.5 @N:P_2O_5:K_2O kg ha^{-1}							
Farmer Fertilizer Practices							
Paramakudi block				**Ramanathapuram block**			
	N	**P_2O_5**	**K_2O**		**N**	**P_2O_5**	**K_2O**
ONS(Adjacent)	90	30	30	FFP-3	100	35	35
FFP-1	100	30	40	FFP-4	120	30	40
FFP-2	120	30	30	FFP-5	120	40	40