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Research Article

Effect of organic and inorganic nutrients on rice (*Oryza sativa* var. CO 51) productivity and soil fertility in the Western zone of Tamil Nadu, India

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Abstract
In sustainable agriculture, to ensure high-quality food production, a combination of organic and inorganic nutrient sources are required. During the winter season of 2020, a field experiment was undertaken in the western zone of Tamil Nadu to assess the effects of organics and inorganics on the growth, yield, and soil properties of rice, *Oryza sativa* var. CO 51. The experiment was framed in Random Block Design (RBD) comprising of 8 treatments viz., Recommended dose of fertilizer Soil Test Crop Response (STCR) approach (T_1), RDF 75 % + Farm yard manure @ 12.5 t ha^{-1} (T_2), T_2 + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi (T_3), RDF 75 % + Vermicompost @ 5 t ha^{-1} (T_4), T_4 + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi (T_5), FYM @ 12.5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi (T_6), Vermicompost @ 5 t ha^{-1}+ Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi (T_7) and absolute control (T_8) , replicated thrice. Among the integrated nutrient management practices, T_5 proved its superiority over other treatments with respect to growth and physiological parameters followed by T_3. This would have been because of the solubilization of phosphorus in the soil by AM organisms which is made accessible for crop growth. Utilization of biofertilizer enhanced the N availability and solubilized the inaccessible phosphorus, which thus recorded higher N accessibility and better phosphorus uptake when applied along with a recommended dose of fertilizer for rice

Keywords: Arbuscular mycorrhizae, Farmyard manure, Nutrient uptake, Rice, Soil fertility, Vermicompost

INTRODUCTION

Rice is the basic food for half of the world's population, and it is farmed in over 100 nations (Koumeleh *et al.,* 2007). Rice production reached 759.6 million tonnes (MT) in 2017, with Asia providing for 90% of the totalled (Food and Agriculture Organization, 2018). The task of achieving even higher rice production levels persists as global grain imploration is expected to treble by 2050. Rice is the most important and widely farmed crop in India, with 437.8 lakh hectares under cultivation, a production of 118.4 million tonnes, and an average yield of 2.7 tonnes per hectare in 2020-21 (Department of Agriculture, Cooperation and Farmers' Welfare, 2020

-2021). During 2020-21, the total area under rice in Tamil Nadu would be 18.75 lakh hectares, with a production of 75 lakh tonnes and a productivity of 4.0 t ha^{-1} (Directorate of Economics and Statistics, 2021). To meet the rising demand for rice grain, a combination of organic and inorganic fertilizers must be used to ensure crop sustainability (Datta and Singh, 2010).

In India, rice is the most primary and broadly grown crop occupying an area of 437.8 lakh hectares with a production of 118.4 million tonnes and with average productivity of 2.7 t ha^{-1} during 2020-21. In Tamil Nadu, total area under rice is 18.75 lakh hectares, production of 75 lakh tonnes and with a productivity of 4.0 t ha^{-1} during 2020-21 (Directorate of Economics and Statistics, 2021). The expanding demand in rice grain production must be accomplished by utilizing the incorporation of organic and inorganic fertilizer to sustain the stability in crop production. The ultra-sources for restocking plant nutrients in agricultural soils are a succession of organic, inorganic and bio-fertilizers (Masarirambi *et al*. 2012). Long-term inorganic fertilizer application causes deterioration in soil chemical, physical, and biological qualities, as well as soil health. Because of the negative effects of chemical fertilizers, as well as rising prices, organic fertilisers are becoming more popular as a source of nutrients (Mahajan *et al.* 2008). Since vermicompost produces essential nutrient quantities, boosts cation exchange capacity and improves water retention capacity, it has been examined as a soil supplement to reduce the use of mineral fertilisers (Tejada and Gonzaler, 2009).

Vermicompost not only boosts rice yields but it can also partially replace chemical fertilizers (Guerrero, 2010). However, the use of organic manures alone might not meet the plant requirement due to the presence of a relatively low content of nutrients. An Arbuscular Mycorrhizal Fungus (AMF) is a form of mycorrhiza that enters the cortical cells of a vascular plant's roots and aids in the capture of nutrients such as P, S, N, Zn, and micronutrients from the soil while also enhancing plant development through mobilization. Rice plants commonly develop mycorrhizal connections in upland conditions, so infection is uncommon in submerged situations due to the anoxic environment (Ilag *et al*., 1987). Vesicular Arbuscular Mycorrhiza (VAM) is a complex structure in plant roots formed by mutual interactions of soil fungus and roots tissues. The main role of VAM is to increase the available soil P and hence P uptake by macro symbiont (Toljander, 2006). The mutualistic symbiosis formed by VAM with host plants leads to an improvement in nutrient absorption, plant health and soil fertility, thereby improving plant growth (Ramasamy *et al*. 2011).

Long-term application of organic matter such as farmyard manure can gradually increase crop productivity while maintaining soil health (Sivoshi and Nasiri, 2011). According to Myint *et al*. (2010), the use of organic matter is very important because it contains various types of nutrients needed by plants, including micronutrients, can improve soil physical and chemical properties and increase microbial activity. Moreover, decomposed organic matter provides a source of inorganic P from mineralization or increases soil P availability by producing organic anions that reduce adsorbed P through competition or increase pH.

To maximize crop yields, the use of organic manures combined with inorganic fertilizers is necessary to make the soil rich in organic matter in the form of readily available nutrients (Ramalakshmi *et al.,* 2012). While chemical fertilizers have been used at a greater rate in the past few years, crop productivity has stagnated or decreased. Consequently, agricultural ecosystems remain saturated with chemical nutrients, resulting in large-scale nutrient losses through leaching, runoff, volatilization, emission, and immobilization. Therefore, in view of the importance of the problems from the national point, the present research work was conducted to study the effect of organic and inorganic sources of nutrients on yield, yield attributes and nutrient uptake of rice in the Western zone of Tamil Nadu.

MATERIALS AND METHODS

The present experimental study was conducted at the Tamil Nadu Agricultural University, Coimbatore, representing the Western Zone of Tamil Nadu during winter season 2020 with rice variety CO 51. The soil texture of the experiment site is clay loam belonging to Vertisol (soil order). The experiment was laid out in Randomized Block Design (RBD) with eight treatments and three replications, as mentioned in Table 1. All the

Table 1. Treatment schedule for field experiments at Western zone

T_1	RDF STCR approach
T_2	RDF 75 % + FYM @ 12.5 t ha^{-1}
T_3	RDF 75 % + FYM @ 12.5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi
T_4	RDF 75 % + Vermicompost @ 5 t ha^{-1}
T_5	RDF 75 % + Vermicompost @ 5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi
T_6	FYM @ 12.5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi
T_7	Vermicompost @ 5 t ha^{-1}+ Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi
T_8	Absolute control

treatments received an equal amount of recommended dose of fertilizer. As per the STCR (Soil Test Crop Response) recommendation, the entire dose of phosphorus (37.35 kg/ha) was applied as basal and the remaining N & K were applied as the split application of about 108 kg/ha and 25 kg/ha respectively. However, vermicompost was applied three days before transplanting and Soil application of vesicular arbuscular mycorrhiza at the time of transplanting. Seedlings of 25 days of 'CO 51' rice were transplanted, keeping 2 to 3 seedling/hill at 20 x 10 cm spacing and plot size was 20 sq.m (5 × 4 m) on 20 February in 2020 under puddle conditions.

The crop was harvested at the end of May. The observations viz., the plant height, dry matter production, Leaf Area Index, Soil Plant Analysis Development chlorophyll meter reading, root volume and root length in each plot at active tillering, panicle initiation flowering and harvest stages were taken from randomly five plants. The yield parameters viz., no grains/panicles, no productive tillers/hill, thousand grain weight, panicle length were recorded at the harvesting stage from randomly 25 hills in each plot. The post-harvest data on grain yield, straw yield and harvest index were recorded and statistically analyzed using AGRES. The post-harvest soil samples were collected and analyzed for the soil fertility parameters-the initial soil parameters are depicted in Table 2.

The soil characteristics were estimated by using standard analytical methods *viz*., organic carbon by Chromic acid wet digestion (Walkey and Black 1934), available Nitrogen by Alkaline permanganate method (Subbiah and Asija 1956), available phosphorus by 0.5 $NaHCO_3$ (pH-8.5) (Olsen 1954), available potassium by Neutral normal ammonium acetate method (Stanford and English 1949) and other agronomic practices were followed as per Crop Production Guide (CPG), Tamil Nadu Agricultural University (2020).

Table 2. Initial soil parameters of the experimental site at Western zone of Tamil Nadu

Sl. No	Particulars	Values
I. Physical properties		
1.	Sand (%)	42.3
2.	Silt (%)	21.5
3.	Clay (%)	45.9
4.	Textural class	Clay Loam
5.	Bulk density (Mg m^{-3})	1.32
6.	Particle density (Mg m^{-3})	2.16
7.	Total porosity (%)	38.8
II. Physico-chemical properties		
8.	pH	8.15
9.	EC (dSm^{-1})	0.63
10.	Organic carbon (%)	0.62
III. Chemical properties		
11.	Available nitrogen (kg ha^{-1})	268
12.	Available phosphorous (kg ha^{-1})	22.5
13.	Available potassium (kg ha^{-1})	780

Nutrient uptake

Nutrient uptake/removal in grain and straw of the crops were calculated in kg ha^{-1} in relation to yield ha^{-1} as per (Jackson, 1967)

Nutrient uptake (kg/ha) = Nutrient content (%) × yield (q/ha)

RESULTS AND DISCUSSION

In rice *Oryza sativa* var. CO 51, the plant growth and yield attributes, and soil properties were highly influenced by soil application of organic and inorganic fertilizers.

Effect of organic and inorganic nutrients on growth parameters of rice

The vermicompost application highly impacted the plant growth parameters. Higher plant height is depicted at T_5 (RDF 75 % + Vermicompost @ 5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi) of 53.5 cm, which was on par with T_3 (52.7 cm) and followed by T_4 (50.6 cm). The lowest plant height was recorded in absolute control T_8 (39.7 cm) in the active tillering stage. The same trend of results was observed during panicle initiation, flowering and at harvest stage.

The higher plant height in T_5 can be attributed to the use of vermicompost, which might have expedited the plant's metabolic and physiological activity, allowing it to put up more growth by digesting a greater amount of key nutrients resulting in enhanced plant height. These results are in line with (Thirunavavukkarasu and Vinoth, 2013) who reported that vermicompost and nitrogen on growth, nutrient uptake, and yield attributes of rice. The increased rice plant height is ascribed to applied vermicompost, which might have accelerated the metabolic and physiological activity of the plant and put up more growth by assimilating more amounts of major nutrients and ultimately increased the plant height. Nishi *et al*. (2019) reported that the application of vermicompost 10 tons per ha + $N_{12}P_4K_{10}$ kg/ha significantly promotes rice growth both directly and indirectly by increasing the populations of plant-friendly microorganisms and decreasing soil-borne illnesses. Kamaleshwaran and Elayaraja (2021) reported that T10-RDF+ 100% Enriched vermicompost application increased plant height substantially, which could be attributable to metabolites released by earthworms, which may also be responsible for stimulating plant development. The superior performance of FYM/GM may be attributable to lower nitrogen loss due to NH_4^+ ion fixation with humus present in FYM and improved N availability to crop, resulting in enhanced plant height.

Kumar et al. (2018) found that rice plants treated with organic nutrients possessed more functional leaves, larger leaf areas, and total numbers of tillers, which increased the photosynthesis rate and resulted in higher plant height. Kalam *et al*. 2011 observed that the application of $N_{200}P_{40}$ + VAM had greatly influenced the plant height. This could be owing to the addition of VAM to all of the different doses of N and P, which may have had a positive impact on phosphorus solubilization and nitrogen fertiliser efficiency. Debouba *et al.* (2006) reported that VAM promotes the shoot and root system of the rice crop and also shows the beneficial effects on plant growth were observed after the establishment of the symbiont. As the symbiosis process involves the flux of photosynthates to the roots, this response may be closely linked to mycorrhizal effectiveness.

Leaf Area Index (LAI) at three stages viz., Active tillering, Panicle initiation and Flowering stage recorded higher under-T_5 as 2.37, 6.37 and 8.27, which was on par with T_3 (2.26, 6.06 and 8.16) and the least LAI was recorded in T_8 (1.68, 5.58 and 7.28) (Table 4). When 50 percent RDN was applied as chemical fertiliser and 50 percent RDN applied as vermicompost in identical proportions, the leaf area index and leaf area duration was higher. Kenchaiah (1997) reported increased LAI and LAD due to higher nutrient uptake resulting in increased leaf area and improved LAI and LAD towards the reproductive stage of rice crop resulting from the application of organic sources of nutrients.

The application of VAM would have increased the LAI as the water uptake and nutrients would have been increased and hence would have improved the photosynthesis process resulting in increasing the leaf area. This result is supported by Sowarnalisha *et al*. (2017), who stated that the presence of VAM will increase the availability of phosphorus uptake, which will be useful for photosynthesis. The higher LAI in all periods of growth, the more yield will be obtained as it leads to higher production and yield of biomass.

The higher value of SPAD reading was also recorded in T_5 (44.6) followed by T_3 (43.5) and T_4 (42.9). The lowest SPAD reading was revealed in T_8 (36.6) in Active tillering. Similar results were also observed in panicle initiation and flowering (Table 5). During the panicle initiation, a higher SPAD value in T_5 might be due to increased N requirement and leaf N reduction, which occurred at this stage. These results were in agreement with the study reported by Jia *et al.* (2004). SPAD values were lower near the flowering stage because most N had been mobilized to grains, decreasing leaf greenness. In addition, the biomass of the plant increased in the flowering stage, which decreased the green intensity and reduced the amount of light from the canopy reflected by the plant.

Manivannan and Sriramachandrasekharan (2018) reported that the application of T_{11}-Vermicompost (VC) (50% N) + Urea (50% N) recorded maximum chlorophyll content. This higher chlorophyll content enhances photosynthesis rate and carbohydrate production which in turn increases 1000 grain weight, no. of grains and

Table 3. Nutrient composition and Quantity of organics used in the experimental site at Western zone of Tamil Nadu

Crop	Organics	Nutrient composition (%)			Quantity applied t ha^{-1}
		N	P	K	
Rice	Vermicompost	3.0	1.0	1.5	5
	FYM	0.5	0.2	0.5	12.5
	Vesicular Arbuscular Mycorrhizae	100g/ 10,000 spores			1

Table 4. Influence of organic and inorganic nutrients on plant height and LAI of rice

Treatments	Plant height (cm)			Leaf Area Index		
	Active Tillering	Panicle Initiation	Flowering	Active Tillering	Panicle Initiation	Flowering
T_1	46.3	60.0	73.7	2.0	5.8	7.9
T_2	48.7	62.4	76.1	2.0	5.7	7.8
T_3	52.7	66.4	80.1	2.3	6.1	8.2
T_4	50.6	64.3	78.0	2.1	5.9	8.0
T_5	53.5	67.2	80.9	2.4	6.4	8.3
T_6	42.1	55.8	69.5	1.9	5.8	7.6
T_7	44.5	58.2	71.9	2.0	5.8	7.8
T_8	39.7	53.4	67.1	1.7	5.6	7.3
SEd	1.05	1.38	1.46	0.036	0.103	0.140
CD (0.05)	2.25	2.96	3.12	0.076	0.220	0.300

Table 5. Influence of organic and inorganic nutrients on dry matter production and SPAD of rice

Treatments	DMP (kg/ha)			SPAD		
	Active Tillering	Panicle Initiation	Flowering	Active Tillering	Panicle Initiation	Flowering
T_1	3347	5847	7673	41.1	39.4	29.9
T_2	3570	6070	7896	42.6	40.9	31.4
T_3	3700	6200	8026	43.5	41.8	32.3
T_4	3665	6165	7991	42.9	41.3	31.8
T_5	3950	6450	8276	44.6	42.9	33.4
T_6	2750	5250	7076	39.7	38.0	28.5
T_7	3214	5714	7540	40.4	38.7	29.2
T_8	2220	4713	6539	36.6	34.9	25.4
SEd	61.46	105.29	137.62	0.74	0.71	0.54
CD (0.05)	131.83	225.84	295.20	1.59	1.52	1.17

Table 6. Influence of organic and inorganic nutrients on root length and root volume of rice

Treatments	Active Tillering		Panicle Initiation		Flowering	
	Root volume (cc hill^{-1})	Root length (cm)	Root volume (cc hill^{-1})	Root length (cm)	Root volume (cc hill^{-1})	Root length (cm)
T_1	21.9	12.6	24.8	15.3	27.7	17.8
T_2	22.7	14.3	25.6	15.5	28.5	18
T_3	26.3	15	29.2	19.2	32.1	21.7
T_4	24.6	14.8	27.5	15.7	30.4	18.2
T_5	28.5	15.4	31.4	19.7	34.3	22.2
T_6	20.8	11.5	23.7	13.7	26.6	16.2
T_7	21.3	12.5	24.2	14.2	27.1	16.7
T_8	20.1	10.6	23	13	25.9	15.5
SEd	0.401	0.245	0.451	0.277	0.502	0.321
CD (0.05)	0.859	0.525	0.967	0.595	1.077	0.689

leaf number per plant in rice. Sandhya *et al.* (2013) reported that combined application of VAM + PSB recorded high chlorophyll content at 30, 60 and 90 DAS of rice crop. This could be as a result due to the increase in stomatal conductance and carbon assimilation (Levy and Krikun, 1980). Similar results were also reported by Kate *et al.* (2005); Senthilkumar and Sivagurunathan (2012).

Effect of organic and inorganic nutrients on root length and root volume of rice

The root length and root volume were also enhanced by vermicompost application (Table 6). The treatment T_5 achieved higher root length on Active tillering, panicle initiation and at harvest stage (15.4 cm, 19.7 cm and 22.2 cm) and statistically on par with T_3 (15 cm, 19.2 cm and 21.7 cm) and the lowest value was recorded in T_8 (12.5 cm, 14.2 cm and 16.7 cm) (Table 6). Canellas *et al*. (2002) reported that the humic substances extracted from earthworm compost were capable of inducing lateral root growth in maize plants by stimulation of the plasma membrane H^+-ATPase activity, thus producing similar effects such as the exogenous application of indole-3-acetic acid (IAA). Chen and Aviad (1990) reported that the presence of humic acids in VC increases root biomass and root growth and improves plant development.

Due to the presence of humic acids in VC, a number of effects have been reported, including increased root biomass, root growth, and improved plant development (Chen and Aviad, 1990). Besides, the positive influences of humic acids on plant growth and productivity, which give the impression to be concentration-specific, could be mainly due to hormone-like activities of humic acids through their involvement in cell respiration, photosynthesis, oxidative phosphorylation, protein synthesis and various enzymatic reactions (Zandonadi *et al*. 2007).

In the present study, the treatment T_5 had registered higher root volume (28.5 cc hill^{-1}), which was statistically on par with T_3 (26.3 cc hill^{-1}) and the lowest value was recorded under T_8 (20.1 cc hill^{-1}) on the Active tillering stage. A similar trend of results was also observed in the panicle initiation and flowering stage

(Table 6). Parmesh *et al*. (2013) found that application of 50% RDN through chemical fertilizer and 50% RDN through vermicompost has the potential to generate a massive root system, i.e. greater root system that contacts more soil surface area and, as a result, receives more moisture and nutrients from organic manures and chemical fertilisers. According to Yadav *et al.* (2005), the application of vermicompost to Oryza sativa L improved soil structure, texture, and tilth, allowing for faster and greater availability of plant nutrients and a better environment for root growth and proliferation, resulting in a larger absorptive surface for nutrient uptake.

Effect of organic and inorganic nutrients on yield attributes of rice

The data on yield attributes are furnished in Table 7 and it was significantly influenced by the application of organic and inorganic sources of nutrients along with seed treatment. Higher yield attributes were recorded under T_5 (RDF 75 % + Vermicompost @ 5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi) viz, number of grains per panicle, number of filled grains per panicle, panicle length, number of productive tillers per hill which was on par with T_3 and T_4. The lowest value was recorded under T_8 (Absolute control) (Table 7). The greater yield qualities in T_5 could be attributed to the usage of vermicompost, which had a dual benefit of improving the physical environment of the rhizosphere region while also ensuring adequate nutrient supply to the plant. Singh et al. (2010), who reported that enhanced nitrogen effect on growth and root formation resulted in greater nutrient uptake, increasing the number of panicles, panicle mass, and grains per panicle of rice. This could be owing to the vermicompost's microbial stimulation and the N given through slow mineralization.

The most significant attribute of yield is thousand grain weight, where the change of individual grain weight will make the variations in yield. Application of (T_5) RDF 75 % + Vermicompost @ 5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi recorded higher thousand grain weight which was on par with T_3 (Table 7). This could be owing to the vermicompost being applied at a higher rate to the soil, which would have helped maintain a higher level of nutrient availability and better nutrient assimilation by the plants. Increased levels of photosynthesis and enzymes are crucial to the creation of energy, carbohydrates, fat metabolism, and plant respiration. Hence high levels of inorganic fertilisers are regarded to be a rationale for the greater yield attributes. If organic manures operate as slow-release nitrogen sources and provide other nutrients to meet rice crops' needs more precisely, this could reduce nitrogen losses and enhance nitrogen use efficiency (Becker et al., 1994).

Dry matter accumulation is considered to be the reliable index of crop growth. The treatment T_5 RDF 75 % + Vermicompost @ 5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi achieved higher DMP on Active tillering, panicle initiation and at harvest stage (3950, 6450 and 8276 kg ha^{-1}) statistically on par with T_3 (3700, 6200 and 8026 kg ha^{-1}) and lowest value was recorded in T_8 (2220, 4713 and 6539 kg ha^{-1}). Comparatively, at active tillering, addition of vermicompost at 2 t ha^{-1} was sufficient for rice growing in organic situation, which had increased plant height, effective tillers per hill, DMP and yield (Vasanthi and Kumaraswamy, 1999). Continuous slow release of nutrients might have allowed plants to extend leaf area duration, allowing them to increase photosynthetic rates and thereby accumulate more dry matter. Similar results were obtained by Amanullah *et al*. (2006).

Accordingly, inorganic fertilizers combined with organic manure caused more photosynthates to be translocated from the source to the sink site of rice, causing higher yields (Barik *et al*. 2008). The present study indicated higher grain yield (6740 kg/ha) and straw yield

Table 7. Influence of organic and inorganic nutrients on yield parameters of rice

Treatments	Harvest stage					
	1000 grain weight (g)	Panicle length (cm)	No. of grains/ Panicle (Nos)	No. of grains filled/ panicle (Nos)	No. of productive tillers/ hill	Harvest Index (HI)
T_1	16.4	24.2	249	215	17	45.2
T_2	16.8	25.8	252	218	18	45.5
T_3	17.2	27.2	273	239	20	46.2
T_4	17.0	26.3	264	230	19	46.0
T_5	17.8	28.0	285	251	21	46.2
T_6	15.6	22.5	220	186	13	46.1
T_7	16.0	23.3	229	195	15	45.5
T_8	15.0	20.3	206	176	12	46.7
SEd	0.41	0.70	6.05	4.38	0.34	0.82
CD (0.05)	0.88	1.50	12.98	9.40	0.71	1.76

(7840 kg/ ha) were recorded under T_5 RDF 75 % + Vermicompost @ 5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi than control, RDF and vermicompost and FYM alone. This was followed by treatment 100% RDF + 5 t/ha vermicompost. Minimum grain and straw yield were recorded under control. Application of 75% RDF + 5 t/ ha vermicompost + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi increased the grain yield (12 %) and straw yield (13 %) over control. Inorganic fertilizers combined with organic manures deliver optimum levels of yield since inorganic fertilizers facilitate macro and micronutrient absorption as well as participation in carbon assimilation, photosynthesis, starch formation, transfer of protein and sugar, water entry into plants and root development. As a result, higher grain yields are achieved because the process of tissue differentiation is enhanced, i.e. from somatic to reproductive phase. As long as nitrogen is available, protein synthesis accompanies grain protein accumulation. Perhaps this is connected to the higher yields under this treatment.

Nitrogen, phosphorus and potassium uptake in grain and straw

The data obtained on nitrogen removal by rice grain and straw were highest of 134.1 and 101.1 kg N ha^{-1} in RDF 75 % + Vermicompost @ 5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi which was on par with RDF 75 % + FYM @ 12.5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi and RDF 75 % + Vermicompost @ 5 t ha^{-1} respectively (Table 9). The increased N uptake in the vermicompost applied plot might be due to its highest N content, mineralization of N from organic matter and mineralization effect upon native nitrogen (Sims, 1987). There was an increased concentration of N in grain and straw due to graded levels of N application. This could be as a result of increase in N absorption by plant. These findings corroborate the findings of Bezbaruha *et al*. (2011) who reported that higher nitrogen uptake with the application of nitrogen fertilizer might be due to higher nutrient concentration along with higher biomass production. The combined application of vermicompost along with

Table 8. Influence of organic and inorganic nutrients on yield parameters of rice

Treatments	Harvest stage					
	pH	EC (dS m^{-1})	OC (%)	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
T_1	8.10	0.64	0.64	243	20.2	727
T_2	8.13	0.65	0.66	249	21.6	731
T_3	8.20	0.67	0.73	266	23.9	756
T_4	8.18	0.66	0.69	260	22.5	743
T_5	8.23	0.68	0.79	271	24.4	762
T_6	8.07	0.62	0.59	210	17.7	710
T_7	8.08	0.63	0.62	217	19.1	715
T_8	8.05	0.60	0.55	202	15.4	706
SEd	NS	0.012	0.013	4.86	4.86	13.51
CD (0.05)	NS	0.026	0.027	10.42	10.43	28.99

Table 9. Influence of organic and inorganic nutrients on NPK uptake in grain and straw of rice

Treatments	Nitrogen uptake (Kg ha^{-1})		Phosphorus uptake (Kg ha^{-1})		Potassium uptake (Kg ha^{-1})	
	Grain	Straw	Grain	Straw	Grain	Straw
T_1	98.9	84.6	19.2	15	22.2	95.1
T_2	102.4	86.2	21.4	15.9	23.3	96.8
T_3	117.3	93.5	24.5	17.8	25.8	102
T_4	106.9	88.3	22.7	16.8	24.6	98.2
T_5	134.1	101.1	26.3	18.8	27.0	109.8
T_6	82.8	76.7	16.7	11.2	20.3	85.8
T_7	92.4	79.8	17.7	13.2	21.4	92.3
T_8	73.6	62.4	15.4	8.8	19	75.3
SEd	1.790	1.488	0.363	0.274	0.407	1.679
CD (0.05)	3.838	3.190	0.779	0.588	0.874	3.602

N recorded highest N uptake significantly by rice grain and straw may be due to increased availability of nutrients in soil through vermicompost and N addition.

The P uptake by rice grain and straw were recorded highest for the application of RDF 75 % + Vermicompost @ 5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi which was on par with RDF 75 % + FYM @ 12.5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi (Table 9). Vermicompost might be responsible for the higher P content in grains and straw in combination with the increased P uptake by solubilizing the native phosphorus. As grain and straw contains more N as a result of the synergistic effect between N and P, the P content would be higher. By applying nitrogen splitly, rice grains and straw could have acquired more P because the application of N promotes phosphorus translocation from the vegetative organs to the grain.

The data indicated that K uptake by rice grain and straw were observed highest for the application of RDF 75 % + Vermicompost @ 5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi which was on par with RDF 75 % + FYM @ 12.5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi (Table 9). This could be attributed to higher K content and better availability of nutrient K ion from the vermicompost and also available nutrient content of vermicompost as well as their rate of release were much higher over other treatments (Goswami, 1996).

An increasing trend of K in grain and straw may be due to applied N release more NH_4^+-N and NO_3^{-} N in soil which may occupied the selective exchange sites in the 2:1 layer clay minerals and replaced the K^+ from exchange sites thereby K registered the highest available K in soil solution concentration leading to higher absorption by rice. It may be due to similar ionic radii of both N and K ions.

Effect of organic and inorganics on soil properties of rice

The results obtained from the post-harvest soil analysis are depicted in Table 8. There is no significant difference in the status of pH and EC for the application of vermicompost. Available nutrients and organic carbon determined the nutrient status of the soil fertility. In respect of organic carbon, T_5 (RDF 75 % + Vermicompost @ 5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi) registered higher organic carbon content followed by T_3 (RDF 75 % + FYM @ 12.5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi) in post-harvest soil at the end of the experiment. Vermicompost and crop residue may have built up more humus and have boosted the microbial population. Further, improved physical properties might have provided a conductive environment for humus formation. This overlaps with the views of Ramesh and Chandrasekarn (2004).

Studies on available N status of the soil showed that application of RDF 75 % + Vermicompost @ 5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi recorded maximum soil available N (271 kg ha^{-1}) and was comparable with RDF 75 % + FYM @ 12.5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi (266 kg ha^{-1}). The lowest soil available N was registered with absolute control. (Table 8.) The reason could be due to a lower residual nutrient content in organic fertilizer application. Through leaching or denitrification, inorganic fertilizers release nutrients almost immediately, which the crop utilizes or may lose to the environment. Since nutrients were applied on the basis of N content, the treatment which recorded higher yield significantly recorded lower N content, but the leaching and other losses of nutrient were reduced by the use of organic manure. Higher residual N availability by the use of organic manures such as Vermicompost followed by farmyard manure might be due to higher N content and continuous and slow release of nutrients from organic manures, reduced losses through volatilization, leaching or denitrification and increased biomass and accumulated soil organic matter.

It has been shown that the application of organic manures during crop growth period resulted in increased P availability after harvest, which is mainly a result of minimization of P fixed in the soil. Application of 75 % RDF as inorganic fertilizer + Vermicompost @ 5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi registered maximum soil available P and was comparable with RDF 75 % + FYM @ 12.5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi. Pazhanivel et al. (2006) reported that P availability could have been increased as a result of the decomposition of organic manures into organic acids, which in turn stabilized native insoluble P, resulting in longer availability.

Higher soil available K was recorded by the application of 75 % RDF as inorganic fertilizer + Vermicompost @ 5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi and was comparable with RDF 75 % + FYM @ 12.5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi. The lowest soil available K was registered in control. The beneficial effect of available K may be ascribed to the reduction in K fixation and release of K due to the interaction of organic matter. Kamaleshwaran and Elayaraja (2021) showed that NPK status of post-harvest soil was significantly affected by interaction with vermicompost and FYM. Higher NPK status was recorded in the treatments where vermicompost applied along with NPK.

Though there are many research findings available on the role of INM on different crops, the information regarding combined application of inorganic and bio organics on improving the rice crop yield and soil fertility is found to be meagre. The present study mainly focused on the western zone of Tamil Nadu because the area under paddy in the Coimbatore district has been declining over a period of time. The declining factor for productivity is partly attributed to soil degradation. The main cause of that has been the accumulating nutritional deficiency over 10-15 years. One of the main factors for disturbed nutritional status of the soil is the imbalance in the use of NPK in fertilizers. Hence integrated application of inorganic and organic sources would maintain soil fertility in substantial way and would promote soil ecosystem by nutrient retention which gains greater significance in the Western zone of Tamil Nadu.

Conclusion

The results revealed that the combination of inorganic and organic nutrient sources, i.e. STCR based RDF integrated with organics like vermicompost and VAM application can be beneficial in enhancing growth and physiological attributes of rice under conventional system of cultivating rice in lowlands in clay loam soil of Western zone of Tamil Nadu. The magnitude of increase in grain and straw yield was of 12 and 13%, respectively, with 75 % RDF as inorganic fertilizer + Vermicompost @ 5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi was comparable with RDF 75 % + FYM @ 12.5 t ha^{-1} + Seed treatment with Azospirillum and Phosphobacteria + Soil application of AM fungi over the control. Hence, 5 t ha^{-1} of Vermicompost have a similar potential of 12.5 t ha^{-1} farmyard manure and addition of either of these along with the application of soil test based mineral fertilizers would be a better choice for the farmers of this particular zone by which enhanced and sustainable rice production could be achieved.

Conflict of interest

The authors declare that they have no conflict of interest.

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