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Long Term Effect of Integrated Nutrient Management on Soil Nutrient Status in Rhizosphere Soils of Finger Millet - Groundnut Cropping System

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

To evaluate the long term effect of INM on soil nutrient status in rhizosphere soils of finger millet-groundnut based cropping system, soil samples were collected from an current long term fertilizer experiment at AICRPDA, UAS, GKVK, Bangalore, India. The experiment consists of 16 treatments, replicated twice with combinations of organic manures (FYM and maize residues) and crop rotation (mono-cropping and rotation). Results indicated that both physical and chemical properties were found to be improved in the combined application of FYM @ 10 t ha^{-1} + 100% RDF in the rhizosphere soil of finger millet- groundnut rotation. Most of the primary (N–201.59 kg $ha^{-1}$and K_2O-232.92 kg ha^{-1}), secondary (Ca- 4.65 c mol (p^+) kg^{-1}; Mg- 1.50 c mol (p^+) kg^{-1} and S- 16.10 mg kg^{-1}) and micronutrients (Fe- 34.09 mg kg^{-1}, Mg- 11.42 mg kg^{-1} and Cu- 1.63 mg kg^{-1}) were found to be greater in the rhizosphere soil as when compared to the non-rhizosphere soil. Whereas phosphorus (229.81 kg ha^{-1}) and zinc (3.39) content was found to be higher in the non-rhizosphere soil (CD @ 5%). FYM and maize residues along with the inclusion of the legume crop in the rotation has helped in maintaining the soil fertility status in finger millet based cropping system.

Keywords: Rhizosphere; non-rhizosphere; mono-cropping; rotation.

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1. INTRODUCTION

Fertilizers play a dynamic role in enhancing the production and productivity of any crop, but continuous and excessive use of high analysis chemical fertilizers adversely affects the production potential and soil health. Use of chemical fertilizers in combination with organic manure is crucial to improve the soil health [1]. INM is described as the method of using minimum effective dose of sufficient and balanced quantities of organic and inorganic fertilizers to make nutrients more available and most effective for maintaining high yields without exposing soil native nutrients and polluting the environment [2]. Long-term field experiments using different agronomic management can provide direct observations of changes in soil quality and fertility and can help in prediction of future soil productivity and soil-environment interactions [3,4]. Continuous integrated use of organic and inorganic fertilizers would be quite promising in evaluating the sustainability of crop yield, and plant nutrition vis-à-vis soil properties.

Rhizosphere was described for the first time by Lorenz Hiltner in 1904 as the region around a plant root that is colonized by a distinctive population of microorganisms influenced by the chemicals released from plant roots [5]. It differs with the plant species and the soil, generally considered at 2 mm distance from the root surface known as rhizoplane. Roots provide polysaccharides, organic acids and amino acids [6]. As a result, the community structures of soil microorganisms in rhizosphere are likely to differ significantly from that of in non-rhizosphere soil [7]. The chemical and biological processes occur in rhizosphere not only determines the mobilization and gaining of soil nutrients and microbial dynamics, but also control nutrient use efficiency by crops and thus strongly influence crop productivity and sustainability [8]. A better understanding and controlling rhizosphere process may provide an effective approach for improving nutrient use efficiency and crop productivity. Thus, knowledge of rhizosphere chemistry and rhizosphere process is essential for characterizing nutrient availability in soils. Better understanding of rhizosphere ecosystem will improve our ability to model nutrient dynamics [9].

The long- term experiments provide an ideal base to evaluate the effect of nutrient management practices involving different fertilizers and amendments on changes in soil quality and crop productivity. Studies on long term effect of INM on soil nutrient status in rhizosphere soils of finger millet –groundnut cropping system was carried out to assess the effects of continuous application of organic and inorganic fertilizers on soil physical and chemical properties in rhizosphere soils of *Alfisols* in an current long term experiment on “Response of crops to long-term use of organics, fertilizers and crop rotation” at All India Co- ordinated Research Project for Dryland Agriculture, University of Agricultural Sciences, GKVK, Bangalore. The present investigation is carried out to study long term effect of integrated nutrient management on soil physical and chemical properties in rhizosphere soil of finger millet- groundnut cropping system.

2. MATERIALS AND METHODS

2.1 Experimental Site and Location

The experiment was conducted at All India Coordinated Research Project for Dryland Agriculture (AICRPDA), Bangalore located in the Agro-climatic Zone-V, Eastern Dry Zone of Karnataka at 12°58' N latitude and 77°35' E longitude with an altitude of 929 m above the mean sea level (MSL). University of Agricultural Sciences, Bangalore commenced a long term integrated nutrient management trial during 1978, comprising of different levels of fertilizers and FYM as organic source. Initially, finger millet crop was taken as test crop in mono-cropping systems but later, crop rotation with groundnut was started in the year 1992. Totally, 42 years of experimentation were maintained previously during *kharif* 2020. The land was kept fallow during the summer seasons all the years. The experiment consists of 16 treatments, replicated twice with combinations of organic (FYM: farmyard manure and maize residue), inorganic fertilizers (N-P-K) and crop rotation (Finger millet monocropping and finger millet – groundnut rotation).

The soils of Dryland Agriculture Project represent the typical lateritic area of Bengaluru plateau and belong to Vijayapura series, which is a dominant soil series of Bengaluru plateau. As per USDA classification, soils are classified as fine, Kaolinitic, *Isohyperthermic*, *Typic Kandiustalf*. These soils are yellowish red, lateritic and are derived from granite-gneiss under sub-tropical semi-arid climate. They are very deep, well drained sandy clay loam occurring in nearly level to gently sloping lands.

2.2 Soil Sample Collection

The plot wise groundnut and finger millet rhizosphere soil samples were collected separately by removing the intact root system with adhering soil at the time of harvest [10]. The composite surface soil (0-15 cm) samples were collected in between two plant rows of groundnut and finger millet separately at the time of harvest were considered as non-rhizosphere soil. The collected samples were air dried in shade, grounded with wooden pestle and mortar, passed through 2 mm sieve and stored in the plastic containers for further analysis.

2.3 Soil Analysis

Soil texture was determined using an international pipette method [11]. Bulk density, maximum water holding capacity and porosity were determined using keens cup method [11]. Soil pH and EC was determined in 1:2.5 soil suspension by digital pH meter [12] and conductivity bridge [12], respectively. Soil organic carbon was determined was Walkley and Black oxidation method [13].

Available nitrogen in the soil was determined by alkaline potassium permanganate method [14]. The available phosphorus from the sample was extracted using Bray's No.1 extractant (0.03 N NH_4F + 0.025 N HCl) [15]. Available potassium was determined by flame photometric method [12] using neutral N ammonium acetate. Exchangeable Ca and Mg content was determined by versanate titration method [11]. The available sulphur content was determined using turbidometric method and turbidity formed was estimated using a spectrophotometer at 420 nm [16]. The amount of micro nutrients such as Zn, Cu, Mn and Fe were measured using the process of extraction from DTPA [17] were the concentration of various micronutrients in the soil sample were determined by atomic absorption spectrophotometer (PinAAcle 900F- flame).

2.4 Statistical Analysis

The experiment consists of 16 treatments, replicated twice. The comparative study of experimentally collected results were carried out by implementing Fisher's system of measurement of variance as described by [18]. The significance level used in the 'F' evaluation was offered at 5 per cent. Critical difference (CD) values are presented at a significance level of 5% in the table, wherever the 'F' measure was found to be relevant at 5 per cent.

3. RESULTS AND DISCUSSION

3.1 Physical Properties

In all the treatments the texture was found to be sandy clay loam texture. Continuous application of organic and inorganic fertilizer has not significantly influenced bulk density, porosity and water holding capacity of rhizosphere and non-rhizosphere soil (Table 1). Among the different treatments lower bulk density (R-1.27 Mg m^{-3} and NR- 1.27 Mg m^{-3}), higher MWHC (R- 46.95% and NR- 45.96%) and higher porosity (R- 50.39% and NR- 50.39%) was recorded in FYM @ 10 t ha^{-1} + 100% RDF in finger millet- groundnut rotation (T_{13}). Integrated application of organic and inorganic fertilizers on BD was more pronounced than the sole application of fertilizer NPK. The products of residue decompositions act as a binding materials on the soil particles that improves soil pore volume, aggregation and structure, and thus reducing the density per unit volume of soil [19,20,21].

3.2 pH, EC and Organic Carbon

The data regarding pH, EC and organic carbon is presented in the Table 2. The pH was found to be higher in the non-rhizosphere soil when compared to the rhizosphere soil. Whereas EC and organic carbon content was found to be higher in the rhizosphere as when compared to the non-rhizosphere soil. Significantly, higher pH value (R-5.99; NR-6.25) was recorded in the plot received FYM @ 10 t ha^{-1} in the finger millet-groundnut rotation (T_{11}) and least was recorded in the 100% RDF of finger millet mono-cropping (T_2) (R-3.52; NR-3.6). The changes in rhizosphere soil pH is associated with differences in cation/anion uptake and release of H^+ or OH^- (HCO_3^-) ions by plant roots. If more cations are absorbed, H^+ is released by roots to keep ionic balance and pH decreases. Similarly, when more anions are absorbed, OH^- is released and pH increases [22]. The soil pH with application of FYM, NPK fertilizers and their integration revealed that significantly higher soil pH with FYM application with or without NPK fertilizers and decrease in soil pH in recommended NPK alone applied plots [23].

Table 1. Long term effect of organic and inorganic fertilizers application on soil physical properties in finger millet – groundnut cropping system

Treatments			BD ($Mg\ m^{-3}$)		MWHC (%)		Porosity (%)		Textural class
Finger millet monocropping			**R**	**NR**	**R**	**NR**	**R**	**NR**	
T_1	:	Control (MC)	1.32	1.32	41.66	41.62	49.81	49.81	Sandy clay loam
T_2	:	RDF 100% (MC)	1.32	1.33	41.55	41.50	49.81	49.62	Sandy clay loam
T_3	:	FYM (10 t ha^{-1}) (MC)	1.27	1.27	43.33	43.66	50.39	50.39	Sandy clay loam
T_4	:	FYM (10 t ha^{-1}) + 50% RDF(MC)	1.28	1.28	42.96	42.95	50.39	50.39	Sandy clay loam
T_5	:	FYM (10 t ha^{-1}) + 100% RDF (MC)	1.28	1.28	44.19	44.17	50.39	50.39	Sandy clay loam
T_6	:	MR (5 t ha^{-1}) (MC)	1.29	1.29	44.22	44.24	50.19	50.19	Sandy clay loam
T_7	:	MR (5 t ha^{-1}) + 50% RDF (MC)	1.29	1.29	45.86	45.86	50.19	50.19	Sandy clay loam
T_8	:	MR (5 t ha^{-1}) + 100% RDF (MC)	1.29	1.29	42.81	42.80	50.00	50.00	Sandy clay loam
Finger millet- groundnut crop rotation									
T_9	:	Control (CR)	1.31	1.31	43.88	43.85	49.62	49.62	Sandy clay loam
T_{10}	:	RDF 100% (CR)	1.30	1.30	45.80	45.86	49.81	50.00	Sandy clay loam
T_{11}	:	FYM (10 t ha^{-1}) (CR)	1.27	1.27	43.44	42.42	50.39	50.39	Sandy clay loam
T_{12}	:	FYM (10 t ha^{-1}) + 50% RDF (CR)	1.28	1.28	42.90	42.90	50.39	50.39	Sandy clay loam
T_{13}	:	FYM (10 t ha^{-1}) + 100% RDF (CR)	1.27	1.27	46.95	45.96	50.39	50.39	Sandy clay loam
T_{14}	:	MR (5 t ha^{-1}) (CR)	1.28	1.28	45.14	45.11	49.80	49.80	Sandy clay loam
T_{15}	:	MR (5 t ha^{-1}) + 50% RDF (CR)	1.28	1.28	43.68	43.66	49.80	49.80	Sandy clay loam
T_{16}	:	MR (5 t ha^{-1}) + 100% RDF (CR)	1.28	1.28	43.55	43.56	49.80	49.80	Sandy clay loam
S.Em±			**0.03**	**0.03**	**2.57**	**2.50**	**2.98**	**2.69**	
CD at 5%			**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	

R: rhizosphere, NR: non-rhizosphere, MR: maize residue, RDF: recommended dose of fertilizer, FYM: farm yard manure, BD : bulk density, MWHC: maximum water holding capacity, MC- monocropping, CR- crop rotation.

Significantly higher EC content (R-0.10 dS m^{-1} NR-0.06 dS m^{-1}) was recorded in the treatment received FYM @ 10 t ha^{-1} in finger millet-groundnut rotation (T_{11}) and FYM @ 10 t ha^{-1} + 100% RDF in finger millet-groundnut rotation (T_{13}) (Table 2) and least (R-0.02 dS m^{-1}; NR-0.02 dS m^{-1}) was recorded in the control (T_1) of finger millet mono-cropping. The increase EC in the rhizosphere soil is mainly due to the increase in the organic carbon content and also the accumulation of basic cations has led to increase EC in the soil [24,25].

Finger millet –groundnut rotation treatment received FYM @ 10 t ha^{-1} + 100% RDF (T_{13}) has recorded significantly higher (R-0.86%; NR-0.85%) soil organic carbon when compared to all other treatment (Table 3) and least was recorded in the control treatment of finger millet mono-cropping in case of both rhizosphere (0.33%) and non-rhizosphere soil (0.28%).The rhizosphere soil had higher SOC content compared to the non-rhizosphere soil, this may be due higher SOC contents of the clay fraction of the rhizosphere soil compared to the clay fraction of non-rhizosphere soil were probably due to root exudates [26-30]. Addition of above and below ground biomass to the soil from groundnut crop, resulted in increased soil organic carbon content in the soil [31,32].

Table 2. Long term effect of organic and inorganic fertilizers application on soil chemical properties in finger millet – groundnut cropping system

Treatments			pH		EC (dS m^{-1})		OC (%)	
Finger millet mono-cropping			**R**	**NR**	**R**	**NR**	**R**	**NR**
T_1	:	Control (MC)	4.61	4.84	0.02	0.02	0.33	0.28
T_2	:	RDF 100% (MC)	3.52	3.60	0.06	0.03	0.41	0.33
T_3	:	FYM (10 t ha^{-1}) (MC)	5.80	6.10	0.08	0.05	0.52	0.45
T_4	:	FYM (10 t ha^{-1}) + 50% RDF (MC)	5.41	6.00	0.07	0.04	0.60	0.60
T_5	:	FYM (10 t ha^{-1}) + 100% RDF(MC)	5.74	5.84	0.06	0.04	0.84	0.71
T_6	:	MR (5 t ha^{-1}) (MC)	4.55	4.60	0.03	0.03	0.36	0.31
T_7	:	MR (5 t ha^{-1}) + 50% RDF (MC)	3.83	4.45	0.05	0.03	0.39	0.41
T_8	:	MR (5 t ha^{-1}) + 100% RDF (MC)	4.21	4.29	0.04	0.03	0.42	0.42
Finger millet- groundnut rotation								
T_9	:	Control (CR)	4.13	4.23	0.03	0.04	0.37	0.36
T_{10}	:	RDF 100% (CR)	3.71	4.00	0.04	0.04	0.52	0.45
T_{11}	:	FYM (10 t ha^{-1}) (CR)	5.99	6.25	0.10	0.06	0.73	0.59
T_{12}	:	FYM (10 t ha^{-1}) + 50% RDF (CR)	5.48	5.70	0.07	0.05	0.74	0.62
T_{13}	:	FYM (10 t ha^{-1}) + 100% RDF (CR)	5.10	5.60	0.10	0.05	0.86	0.85
T_{14}	:	MR (5 t ha^{-1}) (CR)	4.90	5.35	0.03	0.04	0.68	0.55
T_{15}	:	MR (5 t ha^{-1}) + 50% RDF (CR)	4.05	4.65	0.03	0.03	0.78	0.69
T_{16}	:	MR (5 t ha^{-1}) + 100% RDF (CR)	4.11	4.57	0.03	0.05	0.76	0.75
S.Em±			**0.26**	**0.19**	**0.01**	**0.004**	**0.04**	**0.05**
CD at 5%			**0.66**	**0.38**	**0.026**	**0.011**	**0.13**	**0.16**

R: rhizosphere, NR: non-rhizosphere, MR: maize residue, RDF: recommended dose of fertilizer, FYM: farm yard manure, EC: electrical conductivity, OC: organic carbon, MC- monocropping, CR- crop rotation

3.3 Available N, P_2O_5 and K_2O

The research results indicated that the available nitrogen and potassium content was found to be higher in the rhizosphere when compared to the non-rhizosphere soil, (Table 3) and Significantly higher available nitrogen content 201.57 kg ha^{-1} and 197.72 kg ha^{-1} was recorded in the treatment FYM @ 10 t ha^{-1} + 100% RDF under finger millet –ground rotation in both rhizosphere and non-rhizosphere soil respectively. Increase in organic matter content in the soil has direct relation with the availability of nitrogen content in the soil [33]. The increased gross mineralization rate in the rhizosphere and the longer turnover time of roots compared to the microbes indicated the long-term soil nitrogen availability to be higher in the rhizosphere soils [34].

Significantly higher phosphorus content was found in the combined application of organic and inorganic fertilizer that is FYM @ 10 t ha^{-1} + 100% RDF (T_{13}) (R-229.25 kg ha^{-1}; NR-229.81 kg ha^{-1}) when compared to the control (16.86 kg ha^{-1}; NR-17.34 kg ha^{-1}) in finger millet- groundnut crop rotation (T_1) (Table 3). In general, the depletion of the available P is because of plant uptake and microbial immobilization of inorganic P when compared with bulk soil [35]. The buildup of available phosphorus was mainly due to the increase in dissolution of native P compounds by the decomposition of FYM and also by the application of phosphorus through fertilizer [33].

The available potassium content was found to be significantly higher in the finger millet mono-cropping of FYM @ 10 t ha^{-1} +100% RDF (R-232.92 kg ha^{-1}; NR-201.60 kg ha^{-1}) (T_5) and least amount of available potassium content was found in control plot (T_9) (R-96.16 kg ha^{-1}; NR-75.94 kg ha^{-1}) of finger millet- groundnut rotation (Table 3) Due to the lower soil pH and release of organic acids has led to the weathering of primary minerals in the soil which has contributed to its higher availability in the rhizosphere [36,37].

Table 3. Long term effect of organic and inorganic fertilizers application on soil primary nutrients in finger millet – groundnut cropping system

Treatments			Available N (kg ha^{-1})		Available P_2O_5 (kg ha^{-1})		Available K_2O (kg ha^{-1})	
Finger millet mono-cropping			**R**	**NR**	**R**	**NR**	**R**	**NR**
T_1	:	Control (MC)	89.58	87.50	16.86	17.34	107.06	76.04
T_2	:	RDF 100% (MC)	134.37	131.60	59.46	60.97	133.09	102.82
T_3	:	FYM (10 t ha^{-1}) (MC)	168.22	162.19	96.73	98.66	147.69	129.89
T_4	:	FYM (10 t ha^{-1}) + 50% RDF (MC)	179.16	175.70	151.31	151.98	205.26	191.52
T_5	:	FYM (10 t ha^{-1}) + 100% RDF (MC)	187.29	183.11	169.50	170.43	232.92	201.60
T_6	:	MR (5 t ha^{-1}) (MC)	162.37	170.08	33.72	36.87	114.44	99.69
T_7	:	MR (5 t ha^{-1}) + 50% RDF (MC)	174.36	173.34	66.11	69.00	167.53	130.66
T_8	:	MR (5 t ha^{-1}) + 100% RDF (MC)	182.51	181.21	130.66	144.43	172.40	165.28
Finger millet – groundnut rotation								
T_9	:	Control (CR)	112.12	102.86	19.10	17.64	96.16	75.94
T_{10}	:	RDF 100% (CR)	145.55	140.44	61.76	62.56	133.24	121.43
T_{11}	:	FYM (10 t ha^{-1}) (CR)	185.91	178.82	103.30	109.15	126.24	116.27
T_{12}	:	FYM (10 t ha^{-1}) + 50% RDF (CR)	190.38	186.13	170.50	174.79	144.46	137.76
T_{13}	:	FYM (10 t ha^{-1}) + 100% RDF (CR)	201.57	197.72	229.25	229.81	150.81	139.10
T_{14}	:	MR (5 t ha^{-1}) (CR)	184.75	181.10	52.45	53.70	116.72	95.42
T_{15}	:	MR (5 t ha^{-1}) + 50% RDF (CR)	182.11	178.82	110.34	112.26	154.41	131.71
T_{16}	:	MR (5 t ha^{-1}) + 100% RDF (CR)	192.44	188.98	158.88	163.90	160.02	153.89
S.Em±			**0.18**	**2.55**	**5.66**	**5.68**	**1.63**	**1.44**
CD at 5%			**0.54**	**7.70**	**17.06**	**17.13**	**4.92**	**4.33**

R: rhizosphere, NR: non-rhizosphere, MR: maize residue, RDF: recommended dose of fertilizer, FYM: farm yard manure, MC- monocropping, CR- crop rotation

3.4 Exchangeable Ca, Mg and Available Sulphur

Long term effect of organic and inorganic fertilizer treatments has significantly influenced the calcium, magnesium and sulphur content in both the rhizosphere and non-rhizosphere soil (Table 4). The research results indicated that the calcium and magnesium content was found to be higher in the rhizosphere soil when compared to the non-rhizosphere soil in both the finger millet mono-cropping and rotation. This was mainly due to the difference in uptake and release of calcium to the root by apparent mass flow of Ca and diffusion of Mg at the root vicinity was large enough to cause accumulation of Ca and Mg near the root [38].

Significantly higher calcium content was recorded in the finger millet mono-cropping with FYM @ 10 t ha^{-1} + 100% RDF (T_5) [R- 4.65 c mol (p^+) kg^{-1} and NR- 3.40 c mol (p^+) kg^{-1}] and least was recorded in the control (T_9) plot of finger millet-groundnut rotation treatment [R- 0.62 c mol (p^+) kg^{-1} and NR-0.58 c mol (p^+) kg^{-1}] (Table 4). Significantly higher Mg content was found in the finger millet mono-cropping system with FYM @ 10 t ha^{-1} + 100% RDF (T_5) [R- 1.50 c mol (p^+) kg^{-1} and NR- 1.20 c mol (p^+) kg^{-1}]. Least was recorded in control plot (T_9) of finger millet mono-cropping in case of both rhizosphere [0.50 c mol (p^+) kg^{-1}] and non-rhizosphere soil [0.43 c mol (p^+) kg^{-1}]. Exchangeable Ca and Mg content was higher in the combined application of FYM + inorganic fertilizer and FYM alone, when compared to the control plot this was mainly due to the addition of FYM which has sufficient amount of Ca and Mg has contributed to the increased content in soil upon decomposition [1,39].

Table 4. Long term effect of organic and inorganic fertilizers application on soil secondary nutrient elements in finger millet – groundnut cropping system

Treatments			Exch.Ca (c mol (p^+) kg^{-1})		Exch. Mg		Available Sulphur (mg kg^{-1})	
Finger millet mono-cropping			**R**	**NR**	**R**	**NR**	**R**	**NR**
T_1	:	Control (MC)	0.80	0.60	0.62	0.44	9.90	9.20
T_2	:	RDF 100% (MC)	1.40	0.85	1.00	0.65	14.45	13.48
T_3	:	FYM (10 t ha^{-1}) (MC)	2.70	2.30	1.25	0.88	15.40	15.05
T_4	:	FYM (10 t ha^{-1}) + 50% RDF (MC)	3.35	2.85	1.25	1.05	15.70	15.25
T_5	:	FYM (10 t ha^{-1}) + 100% RDF (MC)	4.65	3.40	1.50	1.20	16.10	15.85
T_6	:	MR (5 t ha^{-1}) (MC)	1.85	1.20	0.80	0.65	13.25	12.60
T_7	:	MR (5 t ha^{-1}) + 50% RDF (MC)	2.15	1.70	0.90	0.73	13.65	13.10
T_8	:	MR (5 t ha^{-1}) + 100% RDF (MC)	3.65	3.20	0.75	0.75	14.45	14.15
Finger millet- groundnut rotation								
T_9	:	Control (CR)	0.62	0.58	0.50	0.43	9.15	9.20
T_{10}	:	RDF 100% (CR)	0.65	0.65	0.60	0.48	13.10	13.60
T_{11}	:	FYM (10 t ha^{-1}) (CR)	2.00	1.55	0.95	0.70	13.75	14.10
T_{12}	:	FYM (10 t ha^{-1}) + 50% RDF (CR)	2.75	2.25	1.00	0.75	14.85	15.16
T_{13}	:	FYM (10 t ha^{-1}) + 100% RDF (CR)	3.75	2.95	1.15	0.85	15.15	15.35
T_{14}	:	MR (5 t ha^{-1}) (CR)	1.05	0.95	0.70	0.50	12.40	12.89
T_{15}	:	MR (5 t ha^{-1}) + 50% RDF (CR)	1.60	1.25	0.64	0.55	12.20	12.58
T_{16}	:	MR (5 t ha^{-1}) + 100% RDF (CR)	2.45	2.35	0.90	0.60	13.45	13.50
S.Em±			**0.17**	**0.08**	**0.14**	**0.10**	**0.15**	**0.56**
CD at 5%			**0.50**	**0.24**	**0.42**	**0.31**	**0.45**	**1.68**

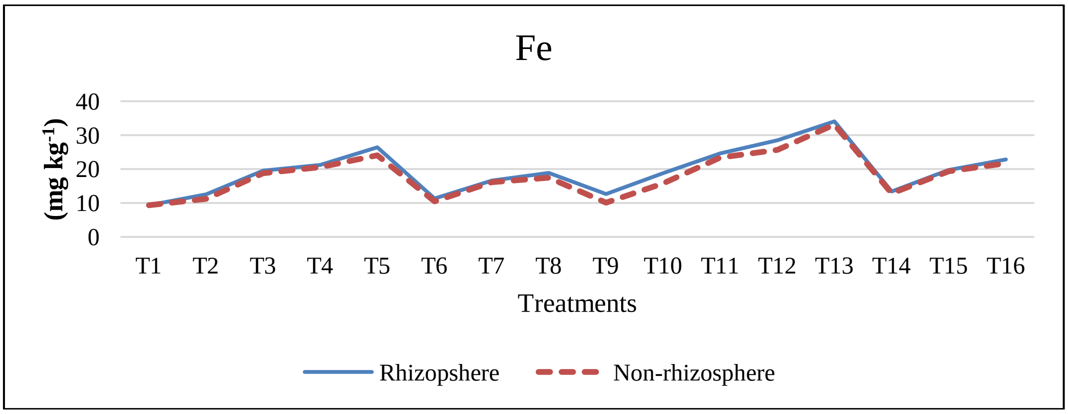
R: rhizosphere, NR: non-rhizosphere, MR: maize residue, RDF: recommended dose of fertilizer, FYM: farm yard manure, MC- monocropping, CR- crop rotation

In the finger millet mono-cropping system, the sulphur content was comparatively higher in the rhizosphere soil and in case of the finger millet and groundnut rotation the sulphur content was lower in the rhizosphere soil (Table 4). due to increased sulphur uptake, which led to the decrease in sulphur content in the rhizosphere of groundnut crop. Significantly higher sulphur content (R-16.10 mg kg^{-1} and NR-15.85 mg kg^{-1}) was recorded in the treatment received FYM @ 10 t ha^{-1} + 100% RDF (T_5) in finger millet mono-cropping. Contribution of available sulphur from the application of inorganic fertilizers and organic matter to the soil. The variation in available sulphur content among the finger millet – groundnut rotation and mono cropping could be due to groundnut, which require more sulphur when compared to the finger millet crop [39,40,41].

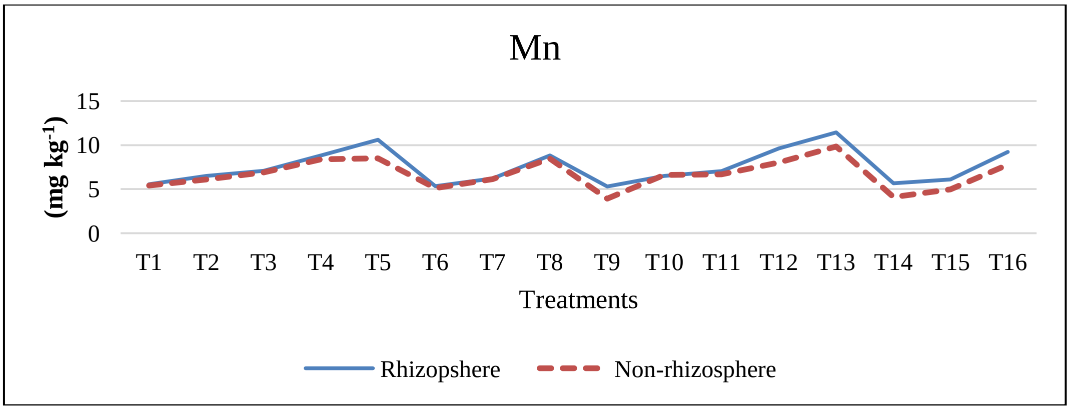
3.5 Micronutrients

All the DTPA extractable micronutrients were found to be higher in the rhizosphere soil expect zinc (Fig. 1). The availability of micronutrients increases with increase in acidic condition of soil, whereas its availability is low under alkaline condition [42]. Phytosiderophores released by the plants, chelates the iron in soil and it is taken up in the chelated from as Fe- phytosiderophores [43]. Some of the rhizosphere bacteria like pseudomonas, bacillus and geobacter reduce oxidized Mn^{4+} to Mn^{2+}, which is the chemical form metabolically useful for plants [42]. The root exudation of dicotyledons enhances mobilization and uptake of Cu in nutrient solutions as Cu-organic ligands [44]. Zinc supplied through the root system may be associated with strong organic chelates [45].

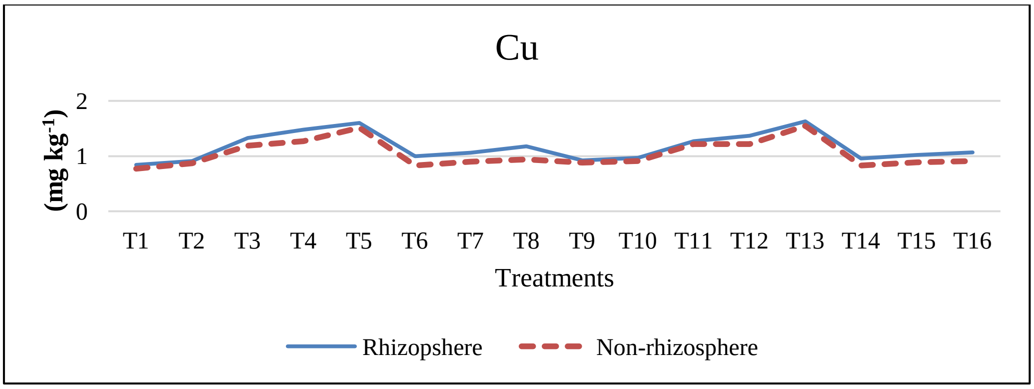
Significantly higher iron content (R- 34.07 mg kg^{-1} and NR- 33.07 mg kg^{-1}) was recorded in the treatment received FYM @ 10 t ha^{-1} + 100% RDF in finger millet- groundnut rotation (T_{13}) significantly lower iron content was recorded in the control treatment (T_1) of finger millet mono-cropping (Fig. 1a). Significantly higher manganese content was recorded in treatments received, FYM @ 10 t ha^{-1} + 100% RDF in finger millet-groundnut rotation (T_{13}) (R- 11.42 mg kg^{-1} and NR- 9.83 mg kg^{-1}) and least was recorded in the control treatment (T_9) of finger millet-groundnut rotation (Fig. 1b). Significantly higher copper content (R- 1.63 mg kg^{-1} and NR- 1.55 mg kg^{-1}) was recorded in the treatment received, FYM @ 10 t ha^{-1} + 100% RDF (T_{13}) in finger millet- groundnut rotation (Fig. 1c). Significantly higher Zn content was recorded in treatment FYM @ 10 t ha^{-1} + 100% RDF in mono-cropping (T_5) (NR- 3.39 mg kg^{-1} and R- 2.72 mg kg^{-1}) and least was recorded in the control treatment (T_9) of finger millet-groundnut rotation (Fig. 1d). Higher availability of micronutrients in soil is due to application of organic manures which has directed to the formation of chelates with organic ligands which have lowered liability of micronutrients to adsorption, fixation and precipitation in the soil and also mineralization of organic manures leads to the discharge of micronutrient to the soil [46,47,48]. Application of NPK fertilizers and control treatments accounted for low DTPA-Zn in the soil even though pH of soil was low, this attributed to lower organic matter and higher P status in NPK applied plots [49,50].



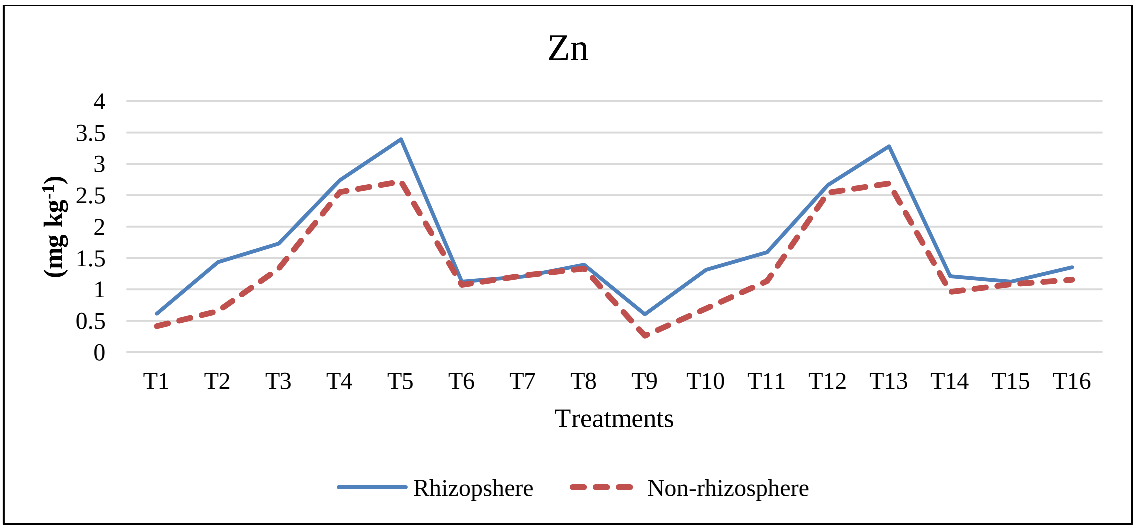
(a)



(b)



(c)



(d)

Fig. 1. a, b, c and d represents the long term effect of organic and inorganic fertilizers application on soil secondary nutrient elements in finger millet – groundnut cropping system.

4. CONCLUSION

Integrated use of organic and inorganic fertilizer has improved physical and chemical properties of soil in both rhizosphere and non-rhizosphere soils. Higher nitrogen (1.94%) and potassium (15.5%) content was recorded in the rhizosphere soil. Uptake of phosphorus near the root vicinity has decreased (0.24%) the available phosphorus content in the rhizosphere soil. The combined application of organic and inorganic fertilizer *(i.e.,* FYM @ 10 t ha^{-1} + 100% RDF) has resulted in the higher nitrogen, phosphorus and potassium when compared to the sole application of organic (*i.e.,* FYM @10 t ha^{-1}) and inorganic source (*i.e.,* 100% RDF). Accumulation of basic cations (Ca and Mg) near the root vicinity has led to the increased calcium (36%) and magnesium (25%) content in the rhizosphere soil. Available sulphur content was found to be higher in the rhizosphere of finger millet mono-cropping and non-rhizosphere of groundnut- finger millet rotation treatment. Micronutrients like iron (3.02%), copper (5.16%) and manganese (16.17%) except zinc were found to be higher in the rhizosphere soil. Integrated application of organic source (FYM @ 10 t ha^{-1} or maize residue @ 5 t ha^{-1}) along with the 100% RDF has increased the secondary and micronutrient nutrient content in the soil. FYM and maize residues along with the inclusion of the legume crop in the rotation can help in maintaining and sustaining the soil fertility status in finger millet based cropping system.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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