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Influence of micronutrient fertilization and fortified organic manures on the growth, yield and nutrients uptake by Sesame (*Sesamum indicum* L.) in coastal saline soil

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Abstract

It is now established that micronutrient deficiency is the prime factor responsible for that low productivity of sesame (*Sesamum indicum* L.) in coastal areas. Hence, inclusion of micronutrient fertilizer in the fertilization programme becomes an imperative need to improve the yield of crops. It is more vivid that applications of micronutrients fertilization along with fortified organic manure sustain soil health and crop productivity in coastal saline soil. Coastal areas in particular are endowed with a variety of natural resources and a wide variety of organic wastes which can be effectively recycled for sustaining soil fertility and productivity of crops. The organic manures incorporation in coastal sandy loam soil has multidimensional effect in improving all the soil related constraints. It improves the physical, chemical and biological environment of soil. Therefore, the present investigation was carried out to study the effect of micronutrients (Zn and Mn) fortified organics on the soil properties and yield of sesame in coastal soil. A field experiment was conducted in the farmer's field at Perampattu coastal village, near Chidambaram in Cuddalore district of Tamilnadu, during March–June, 2021 using sesame variety TMV 4 as test crop. The experimental soil was sandy loam in texture and taxonomically classified as *Typic ustifluvent* with pH-8.41, EC-4.11 dSm^{-1} and analysed low status of soil organic carbon (2.27 g kg^{-1}). The soil analysed low in alkaline $KMnO_4$–N (139.50 kg ha^{-1}), Olsen-P (9.30 kg ha^{-1}) and medium in NH_4OAc-K (162.31 kg ha^{-1}). The available Zn (DTPA extractable Zn) content (0.71 mg kg^{-1}) was also low in soil. The results of the field experiment clearly indicated that application of micronutrients (Zn + Mn) fortified organics + micronutrients either through soil or foliage along with recommended dose of fertilizers (RDF) and PPFM through foliage significantly and positively increased the growth, yield, quality and nutrient uptake by sesame. Addition of micronutrients like Zn and Mn either through chemical fertilizer or Zn and Mn fortified organic manures along with recommended dose of

fertilizer recorded best response in respect of yield and nutrient uptake by sesame. From the results of the present investigation, it was concluded that the combined application of recommended dose of NPK + micronutrients (Zn and Mn) fortified composted coirpith (MNFCCP) @ 6.25 t ha^{-1} through soil application and foliar spray of $ZnSO_4$ + $MnSO_4$ @ 0.5 per cent and pink pigmented methylotrophic bacteria (PPFM) @ 1.0 per cent twice at pre flowering stage and at flowering stage established as the best treatment combination to realize the highest yield and nutrient uptake by sesame cultivation in coastal saline soil.

Key words : Sesame, Micronutrient fertilization, Fortified organic manures. Nutrients uptake Coastal saline soil, Typic ustifluvent.

Large-scale environmental, ecological, and social effects of soil salinization include reduced agricultural output, decreased agricultural area, unstable livelihood security, and poor quality of life. Due to toxic salt concentrations and deficiencies in essential minerals, particularly micronutrients, saline soils have low net primary productivity (NPP)[18]. High salt content and nutritional deficiencies, especially micronutrient shortages, are the main reasons of decreased crop productivity in coastal saline soil[2]. Low agricultural production is the result of the almost whole coastal tracts' exposure to salt, sodicity, and saltwater intrusion in this environment. The coastal ecology supports several million people and contributes significantly to the national economy. Micronutrient deficits in soils reduce food yields and nutritional quality, which in turn has a detrimental impact on human health, particularly in the majority of salt-affected soils in Tamilnadu's coastal districts. The majority of coastal coarse-textured soils are deficient in numerous micronutrients, making them unresponsive to NPK fertilization. Poor agricultural yields, along with diets based mostly on staple foods; result in widespread micronutrient shortages among the population. Agronomic bio-fortification, particularly of staple foods, has been proposed as a way to address micronutrient shortages in this region.

Sesame seeds include a high concentration of protein, minerals, edible oil, and bio-medicine. Sesame seeds are known as "the seeds of immortality" due to their high antioxidant content. The majority of the coastal area's oilseed crops are grown in nutrient-depleted soils. One of the most significant oilseed crops produced on coastal soils is sesame (*Sesamum indicum* L.). India is the world's largest producer of sesame, with an area of 17.6 lakh ha and an output of 7.85 lakh tonnes, however the average yield is quite low (446 kg ha^{-1}) compared to the national average yield[7] of roughly 700-800 kg ha^{-1} . The area under cultivation of sesame in Tamil Nadu is 1.12 lakh hectares, with a yield of around 16,000 tonnes and an average productivity[15] of 589 kg ha^{-1}. The yield attained in coastal locations, on the other hand, is quite poor and significantly below the national average yield. The primary explanation for low yield potential

of oilseed crops has been identified as nutritional imbalance in plants caused by insufficient availability of both macro and micronutrients in coastal saline soil.

There is an urgent need to increase sesame production as India's per capita consumption of oil and fat rises. To feed its 1.75 billion populations by 2050, India will need 38.63 million tonnes of oil seeds[11]. The production of diverse oil seed crops will be greatly expanded by improved technology and greater cropping intensity to complete this Herculean task. Increased agriculture space is limited due to rising land demand for a growing population. The other option is to increase the productivity of crop using scientific management practices including integrated nutrient management. Pink pigmented facultative methylotrophic bacteria (PPFM), ubiquitous in nature and frequently reported on various plant species, are a substantial part of the aerobic, heterotrophic microflora of the surfaces of young leaves[19]. They are capable of growing on C_1 compounds such as formate, formaldehyde and methanol in addition to C_2-C_4 compounds. Moreover, they are able to produce plant growth regulators such as cytokinins and auxins, which affect plant growth and different physiological processes. In addition, the PPFM may generate systemic resistance to illnesses, breakdown a wide spectrum of very toxic compounds, and tolerate heavy metals[8,10]. Foliar spraying with PPFM is also thought to impact crop development by creating plant growth regulators such as zeatin and related cytokinins and auxins. Furthermore, it minimizes blossom drop and increases capsule formation and seed setting %. A foliar spray of PPFM can increase drought tolerance and minimize blossom drop in oil seed crops. Hence, in the present investigation, an attempt has been made to study the effect of zinc and manganese fertilization along with recommended dose of NPK and fortified organic manures to increase the productivity and quality of sesame as well as to improve the soil fertility status for sustainable soil health in coastal saline soil.

A field experiment was conducted in the farmer's field at Perampattu coastal village, near Chidambaram in Cuddalore district of Tamilnadu, during March–June, 2021 using sesame variety TMV 4 as test crop. The experimental soil was sandy loam in texture and taxonomically classified as *Typic Ustifluvent* with pH-8.41, EC-4.11 dSm^{-1} and analysed low status of soil organic carbon (2.27 g kg^{-1}). The soil analysed low in alkaline $KMnO_4$–N (139.50 kg ha^{-1}), Olsen-P (9.30 kg ha^{-1}) and medium in NH_4OAc-K (162.31 kg ha^{-1}). The available Zn (DTPA extractable Zn) content (0.71 mg kg^{-1}) was also low in soil. The various treatments imposed in the study were T_1–Control (RDF/100% NPK alone), T_2 – RDF + FYM @ 12.5 t ha^{-1}, T_3 – RDF + Composted coirpith (CCP) @ 12.5 t ha^{-1}, T_4 – RDF + FYM + $ZnSO_4$ @ 25 kg ha^{-1} + $MnSO_4$ @ 5 kg ha^{-1}, T_5 – RDF + CCP + $ZnSO_4$ @ 25 kg ha^{-1} + $MnSO_4$ @ 5 kg ha^{-1}, T_6 –RDF + Micronutrients (Zn + Mn) Fortified FYM (MnFFYM) @ 6.25 t ha^{-1}, T_7 – RDF + Micronutrients (Zn + Mn) Fortified CCP (MnFCCP) @ 6.25 t ha^{-1}, T_8 – RDF + MnFFYM @ 6. 25 t ha^{-1} + $ZnSO_4$ @ 0.5% + $MnSO_4$ @ 0.5% Foliar application (FA), T_9 – RDF + MnFCCP @ 6.25 t ha^{-1} + ($ZnSO_4$ + $MnSO_4$) FA, T_{10} – RDF + MnFFYM @ 6.25 t

ha^{-1} + ($ZnSO_4$ + $MnSO_4$) FA + Pink Pigmented Facultative Methylotrophic bacteria (PPFM) @ 1.0% FA and T_{11} –RDF + MnFCCP @ 6.25 t ha^{-1} + ($ZnSO_4$ + $MnSO_4$) FA + PPFM @ 1.0% foliar spray twice at pre flowering stage and flowering stage. The experiment was arranged in a Randomized Block Design (RBD) with three replications. Calculated amount of inorganic fertilizer doses of Nitrogen (35 kg N ha^{-1}), Phosphorus (23 kg P_2O_5 ha^{-1}) and Potassium (23 kg K_2O ha^{-1}) were applied through urea, DAP and muriate of potash, respectively. Half of the N and entire P_2O_5 and K_2O were applied as basal and the remaining half dose of N was applied in two splits at flowering and capsule formation stage. Required quantities of different organics *viz*., Farm yard manure and composted coirpith as per the treatment schedule were incorporated into the soil. Enriched organic manures like zinc Fortified FYM (FFYM) and Fortified Composted Coir Pith (FCCP) with Zn and Mn @ 6.25 t ha^{-1} were applied basally and well incorporated into the soil as per the treatment schedule. Required quantities of $ZnSO_4$ and $MnSO_4$ were also applied through soil as per the treatment schedule. Foliar spray of Pink Pigmented Facultative Methylotrophs (PPFM) @ 1.0 per cent twice at Pre Flowering Stage (PFS) and at Flowering Stage (FS) was applied as per the treatment. The soil samples were collected at flowering stage (FS), capsule formation (CFS) and harvest stages (HS) and analyzed for major (N, P and K) and micronutrients (Zn & Mn) status of soil. The plant samples were collected at critical stages of sesame viz., flowering, capsule formation and at harvest stages and analyzed for the concentration of nutrients like N, P, K, Zn and Mn were estimated using the standard procedure as outlined by Jackson[12] and uptake were calculated. At harvest stage, seed and stalk yield were also recorded.

Growth parameters of sesame (Table-1) :

Application of different micronutrient fertilization along with micronutrients fortified organic manures favourably increased the plant height of sesame. Among the various treatments, the treatment (T_{11}), combined application of recommended dose of fertilizer (RDF) + micronutrients fortified composted coirpith (MNFCCP) @ 6.25 t ha^{-1} through soil application along with foliar application of $ZnSO_4$ @ 0.5% + $MnSO_4$ @ 0.5 per cent and Pink Pigmented Facultative Methylotroph (PPFM) @ 1.0 per cent twice at pre flowering stage (PFS) and at flowering stage (FS) recorded the highest growth parameters plant height (155.09 cm), number of branches $plant^{-1}$ (13.97) and dry matter production (2256 kg ha^{-1}) at harvest stages, respectively. This was followed by the treatment which received RDF + MNFCCP @ 6.25 t ha^{-1} through soil application along with foliar application of $ZnSO_4$ @ 0.5% + $MnSO_4$ @ 0.5 per cent twice (T_9). However, it was found to be on par with RDF + micronutrients fortified farmyard manure (MNFFYM) @ 6.25 t ha^{-1} through soil application along with foliar application of $ZnSO_4$ @ 0.5% + $MnSO_4$ @ 0.5 per cent and PPFM @ 1.0 per cent twice (T_{10}), which recorded the comparable plant height (143.70 cm) number of branches $plant^{-1}$ (13.52) and dry matter production (2073 kg ha^{-1}) at harvest stage, respectively. This was followed by the treatments $T_{8,}$ RDF + MNFFYM @ 6.25 t ha^{-1} through soil + $ZnSO_4$ + $MnSO_4$ @ 0.5 per cent (FA) through foliar

application (135.58 cm), T_7, RDF + Micronutrients (Zn + Mn) Fortified CCP (MNFCCP) @ 6.25 t ha^{-1} (SA) through soil application alone, treatment T_6, RDF + MNFFYM @ 6.25 t ha^{-1} (119.21 cm), treatment T_5, RDF + CCP + $ZnSO_4$ @ 25 kg ha^{-1} + $MnSO_4$ @ 5 kg ha^{-1} (111.02 cm), treatment T_4, RDF + FYM + $ZnSO_4$ @ 25 kg ha^{-1} + $MnSO_4$ @ 5 kg ha^{-1} (102.93 cm), treatment T_3, RDF along with composted coirpith @ 12.5 t ha^{-1} and treatment T_2, RDF along with FYM @ 12.5 t ha^{-1} at harvest stage, respectively. The control recorded the lowest growth parameters of plant height (78.75 cm), number of branches $plant^{-1}$ (8.92) and dry matter production (1050 kg ha^{-1}) at harvest stage, respectively over control treatment (RDF alone).

Table-1. Effect of fortified organic manures and micronutrient fertilization on the growth characters of sesame (*Sesamum indicum* L.)

Treatments	Plant height (cm)			Number of branches $plant^{-1}$			Dry matter production (kg ha^{-1})		
	FS	CFS	HS	FS	CFS	HS	FS	CFS	HS
T_1– Control (RDF/100% NPK alone)	21.33	49.14	78.75	3.03	4.13	8.92	379	702	1050
T_2 –RDF + FYM @ 12.5 t ha^{-1}	25.91	54.17	86.78	3.61	4.81	9.51	450	795	1177
T_3 –RDF + Composted coirpith (CCP) @ 12.5 t ha^{-1}	30.59	59.18	94.79	4.02	5.42	10.06	525	896	1313
T_4 –RDF + FYM + $ZnSO_4$ @ 25 kg ha^{-1} + $MnSO_4$ @ 5 kg ha^{-1}	35.46	64.29	102.93	4.59	6.09	10.53	612	1002	1435
T_5 –RDF + CCP + $ZnSO_4$ @ 25 kg ha^{-1} + $MnSO_4$ @ 5 kg ha^{-1}	39.62	69.41	111.02	5.02	6.82	11.08	693	1098	1573
T_6 –RDF + MNFFYM @ 6.25 t ha^{-1}	43.69	74.59	119.21	5.51	7.52	11.64	765	1203	1694
T_7 –RDF + MNFCCP @ 6.25 t ha^{-1}	47.54	79.82	127.43	6.06	8.17	12.08	843	1302	1823
T_8 –RDF + MNFFYM @ 6.25 t ha^{-1} + $ZnSO_4$ + $MnSO_4$ @ 0.5% (FA)	51.51	84.97	135.58	6.52	8.83	12.99	916	1394	1950
T_9 –RDF + MNFCCP @ 6.25 t ha^{-1} + $ZnSO_4$ + $MnSO_4$ @ 0.5% (FA)	56.48	91.01	146.62	7.12	9.68	13.55	1013	1527	2118
T_{10} – RDF + MNFFYM @ 6.25 t ha^{-1} + ($ZnSO_4$ + $MnSO_4$) FA + PPFM @ 1.0% FA	55.61	90.09	143.70	7.05	9.56	13.52	1011	1498	2073
T_{11} –RDF + MNFCCP @ 6.25 t ha^{-1} + ($ZnSO_4$ + $MnSO_4$) FA + PPFM @ 1.0% FA	60.12	96.23	155.09	7.66	10.42	13.97	1088	1624	2256
SE_D	1.51	2.24	3.73	0.17	0.25	0.18	28.66	37.19	46.28
CD (p=0.05)	3.18	4.72	7.85	0.36	0.53	0.38	60.19	78.11	97.19

Table-2. Effect of fortified organic manures and micronutrient fertilization on the yield characters and yield of sesame (*Sesamum indicum* L.)

Treatments	Number of capsules plant^{-1}	Number of seeds capsule^{-1}	1000 seed weight (g)	Yield (kg ha^{-1})	
				Seed	Stalk
T_1– Control (RDF/100% NPK alone)	26.09	29.43	3.28	622	864
T_2–RDF + FYM @ 12.5 t ha^{-1}	29.16	32.14	3.38	656	977
T_3–RDF + Composted coirpith (CCP) @ 12.5 t ha^{-1}	31.91	34.89	3.47	688	1081
T_4–RDF + FYM + $ZnSO_4$ @ 25 kg ha^{-1} + $MnSO_4$ @ 5 kg ha^{-1}	34.73	37.61	3.59	726	1186
T_5–RDF + CCP + $ZnSO_4$ @ 25 kg ha^{-1} + $MnSO_4$ @ 5 kg ha^{-1}	37.36	40.46	3.67	761	1296
T_6–RDF + MNFFYM @ 6.25 t ha^{-1}	40.01	43.17	3.78	802	1392
T_7–RDF + MNFCCP @ 6.25 t ha^{-1}	42.78	45.94	3.86	838	1485
T_8–RDF + MNFFYM @ 6.25 t ha^{-1} + $ZnSO_4$ + $MnSO_4$ @ 0.5% (FA)	45.55	48.51	3.93	877	1589
T_9–RDF + MNFCCP @ 6.25 t ha^{-1} + $ZnSO_4$ + $MnSO_4$ @ 0.5% (FA)	49.27	51.84	4.06	920	1696
T_{10}– RDF + MNFFYM @ 6.25 t ha^{-1} + ($ZnSO_4$ + $MnSO_4$) FA + PPFM @ 1.0% FA	48.44	51.1	4.05	911	1683
T_{11}–RDF + MNFCCP @ 6.25 t ha^{-1} + ($ZnSO_4$ + $MnSO_4$) FA + PPFM @ 1.0% FA	52.09	54.49	4.03	953	1788
SE_D	1.18	1.11	0.13	14.78	34.02
CD (p=0.05)	2.48	2.35	NS	31.04	71.46

The present results clearly indicated that the integrated application of recommended dose of NPK fertilizers along with micronutrients enriched composted coirpith @ 6.25 t ha^{-1} and foliar spray of $ZnSO_4$ + $MnSO_4$ (mineral micronutrients fertilizers) + pink pigmented methylotrophic bacterium (PPFM) @ 1.0% twice were better than recommended NPK alone. This might be due to application of micronutrients like Zn through $ZnSO_4$, Mn through $MnSO_4$ or Zn and Mn fortified with organics, which enhanced plant growth, increased plant metabolites and encouraged the growth of microorganisms as well as organic matter. Further, the presence of organic manure may be tended to slow and steady supplement nutrients continuously to the growing plants. These results are in conformity with Meena *et al.*[20]; and Kodeeswaran[16].

Yield parameters of sesame (Table-2) :

The application of zinc and manganese either through soil or foliage along with recommended dose fertilizer (RDF) and

Table-3. Effect of fortified organic manures and micronutrient fertilization on the major nutrients uptake (kg ha^{-1}) by sesame

Treatments	Nitrogen				Phosphorus				Potassium			
	FS	CFS	HS		FS	CFS	HS		FS	CFS	HS	
			Seed	Stalk			Seed	Stalk			Seed	Stalk
T_1– Control (RDF/100% NPK alone)	9.09	18.03	18.57	15.32	1.37	2.52	2.74	4.32	14.03	19.05	6.85	16.15
T_2 –RDF + FYM @ 12.5 t ha^{-1}	10.53	19.55	20.79	17.12	1.59	2.89	3.01	4.91	15.72	21.34	8.04	18.49
T_3 –RDF + Composted coirpith (CCP) @12.5 t ha^{-1}	12.02	21.24	23.18	19.09	1.96	3.37	3.39	5.54	17.55	23.67	8.97	20.88
T_4 –RDF + FYM + $ZnSO_4$ @ 25 kg ha^{-1} + $MnSO_4$ @ 5 kg ha^{-1}	13.59	22.81	25.45	20.82	2.21	3.70	3.72	6.06	19.17	26.09	9.99	23.46
T_5 –RDF + CCP + $ZnSO_4$ @ 25 kg ha^{-1} + $MnSO_4$ @ 5 kg ha^{-1}	15.06	24.37	27.71	22.67	2.54	4.15	3.95	6.75	20.96	28.46	11.06	26.08
T_6 –RDF + MNFFYM @ 6.25 t ha^{-1}	16.52	26.03	29.92	24.63	2.75	4.47	4.27	7.25	22.57	30.94	11.87	28.63
T_7 –RDF+MNFCCP @ 6.25 t ha^{-1}	18.07	27.68	32.25	26.61	3.14	4.98	4.51	7.86	24.24	33.31	12.98	31.32
T_8 –RDF+MNFFYM @ 6.25t ha^{-1} + $ZnSO_4$ + $MnSO_4$ @ 0.5% (FA)	19.48	29.39	34.56	28.42	3.36	5.46	4.89	8.45	26.06	35.53	14.18	33.86
T_9 –RDF+MNFCCP @ 6.25 t ha^{-1} + $ZnSO_4$ + $MnSO_4$ @ 0.5% (FA)	21.22	31.59	37.96	30.68	3.73	5.87	5.17	9.19	28.22	38.81	15.24	37.65
T_{10} – RDF + MNFFYM @ 6.25 t ha^{-1} + ($ZnSO_4$ + $MnSO_4$) FA + PPFM @ 1.0% FA	21.03	31.04	36.91	30.29	3.71	5.82	5.16	9.08	27.91	37.88	15.11	36.58
T_{11} –RDF + MNFCCP @ 6.25 t ha^{-1} + ($ZnSO_4$ + $MnSO_4$) FA + PPFM @ 1.0% FA	22.64	33.22	40.19	32.66	4.12	6.39	5.39	9.88	30.11	41.02	16.25	40.33
SE_D	0.58	0.66	0.99	0.75	0.07	0.12	0.08	0.20	0.58	0.98	0.31	1.08
CD (p=0.05)	1.23	1.39	2.09	1.59	0.16	0.27	0.17	0.42	1.22	2.07	0.66	2.27

micronutrients fortified organics (MNFFYM, MNFCCP) significantly and positively influenced the yield characters *viz*., number of capsules $plant^{-1}$ and number of seeds $capsule^{-1}$ of sesame. However, the combined application of fortified organics through soil along with micronutrients (Zn + Mn) and PPFM through foliage recorded the better response in respect of yield characters than sole application. Whereas, the 1000 seed weight of sesame was not statistically significant. Among the various micronutrients fortified organic manures treatments, combined application of recommended dose of NPK + zinc and manganese fortified composted coirpith @ 6.25 t ha^{-1} through soil application and foliar spray of $ZnSO_4$ + $MnSO_4$ @ 0.5 per cent and pink pigmented methylotrophic bacteria (PPFM) @ 1.0 per cent twice at pre flowering stage and at flowering stage (T_{11}) recorded the highest number of capsules $plant^{-1}$ (52.09) and number of seeds $capsule^{-1}$ (54.49), respectively. This was followed by the next best treatment T_9, which received RDF +

micronutrients (Zn and Mn) fortified CCP (MNFCCP) @ 6.25 t ha^{-1} through soil application along with foliar spray of $ZnSO_4$ @ 0.5% + $MnSO_4$ @ 0.5 per cent twice at pre flowering and flowering stage, which recorded a mean number of capsules $plant^{-1}$ (49.27) and number of seeds $capsule^{-1}$ (51.84), respectively. However, it was found to be equally efficacious with application of RDF + MNFFYM @ 6.25 t ha^{-1} + ($ZnSO_4$ @ 0.5% + $MnSO_4$ @ 0.5%) along with PPFM foliar spray @ 1.0 per cent (T_{10}) which recorded number of capsules $plant^{-1}$ (48.44) and number seeds $capsule^{-1}$ (51.10), respectively.

This was followed by the treatment T_8, which received with RDF + MNFFYM @ 6.25 t ha^{-1} along with $ZnSO_4$ + $MnSO_4$ @ 0.5% foliar spray, treatment T_7, which received with RDF + MNFCCP @ 6.25 t ha^{-1} and treatment T_6, which received with RDF + MNFFYM @ 6.25 t ha^{-1} which recorded the

Table-4. Effect of fortified organic manures and micronutrient fertilization on the Zn and Mn uptake (g ha^{-1}) by sesame

Treatments	Zinc				Manganese			
	FS	CFS	HS		FS	CFS	HS	
			Seed	Stalk			Seed	Stalk
T_1– Control (RDF/100% NPK alone)	151.02	166.04	105.48	70.78	105.23	120.43	136.58	84.65
T_2–RDF + FYM @ 12.5 t ha^{-1}	164.61	182.63	119.07	81.37	117.82	135.02	150.77	93.84
T_3–RDF + Composted coirpith (CCP) @ 12.5 t ha^{-1}	179.75	200.67	134.11	92.41	129.86	150.06	166.21	104.28
T_4–RDF + FYM + $ZnSO_4$ @ 25 kg ha^{-1} + $MnSO_4$ @ 5 kg ha^{-1}	202.11	221.43	151.87	103.17	143.63	166.83	182.38	115.45
T_5–RDF + CCP + $ZnSO_4$ @ 25 kg ha^{-1} + $MnSO_4$ @ 5 kg ha^{-1}	221.32	238.27	168.71	113.01	158.47	181.67	197.29	125.36
T_6–RDF + MNFFYM @ 6.25 t ha^{-1}	234.41	255.39	185.83	121.13	171.62	198.82	214.34	136.41
T_7–RDF + MNFCCP @ 6.25 t ha^{-1}	250.42	271.41	201.85	132.15	185.64	214.84	231.22	146.28
T_8–RDF + MNFFYM @ 6.25 t ha^{-1} + $ZnSO_4$ + $MnSO_4$ @ 0.5% (FA)	264.55	290.54	215.98	140.28	199.77	229.97	246.25	156.31
T_9–RDF + MNFCCP @ 6.25 t ha^{-1} + $ZnSO_4$ + $MnSO_4$ @ 0.5% (FA)	282.14	314.13	230.43	151.25	215.74	247.61	262.88	166.94
T_{10}–RDF+MNFFYM @ 6.25 t ha^{-1} + ($ZnSO_4$ + $MnSO_4$) FA + PPFM @ 1.0% FA	281.09	312.08	229.52	150.82	213.31	244.51	260.29	166.35
T_{11}–RDF+MNFCCP @ 6.25 t ha^{-1} + ($ZnSO_4$ + $MnSO_4$) FA + PPFM @ 1.0% FA	301.28	333.27	247.57	162.39	227.88	261.75	277.61	178.67
SE_D	4.84	5.89	5.27	3.38	4.78	6.50	6.31	4.11
CD (p=0.05)	10.17	12.37	11.07	7.11	10.04	13.67	13.27	8.64

lowest number of capsules plant^{-1} (45.55 and 42.78) and number seeds capsule^{-1} (48.51 and 45.94), respectively as compared to above said treatments. This was followed by the treatments arranged in the descending order like T_5>T_4>T_3 and T_2 (without fortified organics and PPFM). The lowest number of capsules plant^{-1} (26.09) and number of seeds capsule^{-1} (29.43) was recorded in the treatment T_1, (RDF alone).

Further, betterment increase in yield attributes of sesame might be due to sustained release of nutrient from conjunctive use of NPK along with micronutrients and organics sources of nutrient[21]. In addition, response of sesame to micronutrient application of $ZnSO_4$ and $MnSO_4$ through soil and foliar along with RDF and fortified organics and foliar spray of PPFM significantly increased the yield attributes may be ascribed to better nutrient availability of soils[4]. Further, the addition of fortified organic manure namely micronutrients fortified composted coirpith in these treatments and their subsequent decomposition in soil released the plant nutrients slowly throughout the crop growth and thus improved all the yield characters of sesame. Similar findings were also reported by Duhoon *et al.*[5] and Ravi *et al.*[22].

Yield of sesame (Table-2) :

The sesame responded well for the micronutrients application. The significant influence of micronutrient fertilization (zinc + manganese) along with 100% recommended NPK and Zn + Mn fortified organics in increasing the seed and stalk yield of sesame was well documented in the present study. The yield realized under the nutrient poverished coastal saline soil, the highest seed yield (953 kg ha^{-1}) and stalk yield (1788 kg ha^{-1}) was recorded with combined application of 100 per cent recommended dose of NPK fertilizer + micronutrients fortified composted coirpith (MNFCCP) @ 6.25 t ha^{-1} through soil as well as foliar spray of $ZnSO_4$ @ 0.5% + $MnSO_4$ @ 0.5 per cent + PPFM @ 1.0 % twice at pre flowering and flowering stage (T_{11}). This was followed by the treatments T_9, (RDF + MNFCCP @ 6.25 t ha^{-1} + $ZnSO_4$ @ 0.5% + $MnSO_4$ @ 0.5% FA) and T_{10} (RDF + MNFFYM @ 6.25 t ha^{-1} + $ZnSO_4$ @ 0.5% + $MnSO_4$ @ 0.5% + PPFM @ 1.0 % FA) which recorded the seed (920 and 911 kg ha^{-1}) and stalk (1696 and 1683 kg ha^{-1}) yield of sesame, respectively. The treatments T_9 and T_{10} were found to be on par with each other. This was followed by the treatment T_8, (RDF + MNFFYM @ 6. 25 t ha^{-1} through soil application along with $ZnSO_4$ + $MnSO_4$ @ 0.5 per cent through foliar application).

Individual or sole application of micronutrients (Zn or Mn) fortified organics alone or micronutrients + organics alone (without fortified) along with NPK and organics applied treatments recorded the lowest yield of sesame as compared to above said treatments (RDF+ fortified organics + micronutrients and PPFM). This was followed by the treatments arranged in the descending order like T_7, (RDF + MNFCCP @ 6.25 t ha^{-1}), T_6 (RDF + MNFFYM @ 6.25 t ha^{-1}), T_5 (RDF + CCP +$ZnSO_4$ @ 25 kg ha^{-1} + $MnSO_4$ @ 5 kg ha^{-1}), T_4 (RDF + FYM + $ZnSO_4$ @ 25 kg ha^{-1} + $MnSO_4$ @5 kg ha^{-1}), T_3 (RDF + Composted coirpith (CCP) @12.5 t ha^{-1}) and T_2 (RDF +

FYM @ 12.5 t ha^{-1}) which recorded the seed (838, 802, 761, 726, 688 and 656 kg ha^{-1}) and stalk (1485, 1392, 1296, 1186, 1081 and 977 kg ha^{-1}) yield of sesame, respectively.

Among the various micronutrients fortified organics applied treatments, the treatment (T_{11}), 100% recommended dose of NPK + micronutrients (Zn + Mn) fortified composted coirpith @ 6.25 t ha^{-1} through soil application along with foliar spray of $ZnSO_4$ @ 0.5% + $MnSO_4$ @ 0.5% and PPFM @ 1.0% twice recorded a seed and stalk yield of 953 and 1788 kg ha^{-1} which was 34.73 and 51.67 per cent increase over control or 100 per cent NPK alone (without micronutrients and fortified organics). The control treatment T_1, 100 per cent NPK alone recorded a lower seed (622 kg ha^{-1}) and stalk (864 kg ha^{-1}) yield of sesame, respectively.

The application of recommended dose of NPK + micronutrients fortified composted coirpith through soil and foliar spray of $ZnSO_4$ + $MnSO_4$ along with PPFM twice increased yield to 56.87 and 51.67 per cent of seed and stalk, respectively over NPK alone/control treatment. This could be due to combined effect of nutrients supply synergism and physical and biological properties of soil[3]. The application of NPK as chemical fertilizer supplied nutrients initially required for sesame growth and resulted in higher growth and yield characters leading to increased seed and stalk yield. Thirupathi *et al*.[24] and Jayasingh[13] earlier reported the increased yield of sesame with NPK and enriched organic applications.

Further, higher yield in the enriched organic manures applied treatment might also be due to the contribution of micronutrients released from enriched organic manures attributed to involvement in many enzyme system, recycling functions and auxin production[26] and enhanced synthesis of carbohydrates and their transport to the site of seeds formation[1].

Major nutrients uptake by sesame (Table-3):

The uptake of nitrogen was significantly influenced by the different methods of micronutrients application and fortified organics with micronutrients at all the critical stages *viz.,* flowering, capsule formation and at harvest stages of sesame.

Among the fortified organic manure treatments, the combined application micro-nutrients (Zn and Mn) fortified organics through soil and foliar spray of ($ZnSO_4$ and $MnSO_4$) along with recommended NPK and PPFM (T_{11}) accounted for a highest nutrient uptake at different stages in plants and in seed and stalk. The highest uptake of 40.19, 5.39, 16.25 kg ha^{-1} by seed and 32.66, 9.88, 40.33 kg ha^{-1} by stalk, of nitrogen, phosphorus and potassium, respectively were recorded with RDF + MNFCCP @ 6.25 t ha^{-1} through soil and foliar spray of $ZnSO_4$ + $MnSO_4$ @ 0.5 per cent along with PPFM foliar spray @ 1.0 per cent (T_{11}). This was followed by the treatment T_9, application of RDF + MNFCCP @ 6.25 t ha^{-1} through soil and foliar application of $ZnSO_4$ @ 0.5% + $MnSO_4$ @ 0.5 per cent. However, it was found to be equally efficacious with the treatment T_{10}, (RDF + MNFFYM @ 6.25 t ha^{-1} through soil + $ZnSO_4$ @ 0.5% + $MnSO_4$ @ 0.5% + PPFM @ 1.0 % foliar).

The treatment T_{10} registered the 36.91, 5.16, 15.11 kg ha^{-1} by seed and 30.29, 9.08, 36.58 by stalk of nitrogen, phosphorus and potassium, respectively of sesame. This was followed by the treatment T_8, application of RDF + MNFFYM @ 6.25 t ha^{-1} through soil + $ZnSO_4$ + $MnSO_4$ @ 0.5% foliar.

This was followed by the application of micronutrients (zinc and manganese) either fortified organics alone or organics alone (without fortified) and or both along with NPK without organics significantly decreased the N uptake as compared to combined application of above said treatments (NPK+ Micronutrients fortified organics as soil + foliar spray of $ZnSO_4$ + $MnSO_4$ + PPFM). The treatments T_7, recommended dose of NPK along with MNFCCP @ 6.25 t ha^{-1} and treatments T_6, recommended dose of NPK along with MNFFYM @ 6.25 t ha^{-1}. This was followed by the treatments arranged in the descending order like $T_5 > T_4 > T_3$ and T_2 (without fortified organics and micronutrients). These treatments were also statistically significant. The lowest uptake was noticed in T_1.

The increased NPK uptake by sesame with application of micronutrients (Zn + Mn) either fortified or enriched organics along with $ZnSO_4$ + $MnSO_4$ and PPFM foliar spray might be due to improvement of the soil environment which encouraged proliferation of roots resulting in more absorption of water and nutrients from larger rhizosphere. Moreover, micronutrients like Zn and Mn fortified organic manures, during decomposition release nutrients, which became available to the plants and thus increased NPK concentration. Further, integrated application of plant nutrients results in more uptakes of them as compared to sole use of organic or inorganic or micronutrients fertilizer alone and control (RDF alone). This may be due to the fact that the balanced and combined use of various plant nutrient sources results in proper absorption, translocation and assimilation of those nutrients, ultimately increasing the dry matter accumulation and nutrient contents of plant and thus showing more uptake of NPK nutrients. Similar findings were reported by Tyagi *et al.*[25] and Kalaiyarasi *et al.*[14].

Zinc and Manganese uptake by sesame (Table-4) :

The effect due to the different methods of micronutrient (zinc + manganese) application along with PPFM, NPK and fortified organic manures had significant influence on zinc and manganese uptake by sesame.

Among the various micronutrients fortified organic manure treatments, the highest zinc and manganese uptake by seed (247.57 and 277.61 g ha^{-1}) and stalk (162.39 and 178.67 g ha^{-1}) was recorded with the application of 100 per cent recommended dose of NPK fertilizer along with soil application of micro-nutrients (Zn + Mn) fortified composted coirpith (MNFCCP) @ 6.25 t ha^{-1} and foliar spray ($ZnSO_4$ + $MnSO_4$) @ 0.5 per cent and pink pigmented facultative methylotrophic bacteria (PPFM) @ 1.0% twice at pre flowering stage and flowering stage (T_{11}). This was followed by application of RDF + MNFCCP @ 6.25 t ha^{-1} along with foliar application of $ZnSO_4$ + $MnSO_4$ FA @ 0.5 per cent (T_9). However, this was found to be on par with treatment (T_{10}) which received RDF + MNFFYM @ 6.25 t ha^{-1} through soil and foliar spray of $ZnSO_4$ +

$MnSO_4$ @ 0.5% and PPFM @ 1.0 per cent twice recorded a comparable Zn and Mn uptake of 229.52, 260.29 g ha^{-1} by seed and 150.82, 166.35 g ha^{-1} by stalk, respectively. This was followed by the treatment T_8, application of RDF + MNFFYM @ 6.25 t ha^{-1} along with $ZnSO_4$ + $MnSO_4$ FA @ 0.5 per cent. Application of zinc and manganese fortified organic manures along with RDF or RDF along with organics (without fortified organics) significantly decreased the Zn uptake as compared to above said treatments (micronutrients and fortified organics). The application of RDF along with micronutrients fortified composted coirpith (MNFCCP) @ 6.25 t ha^{-1} (T_7), RDF + MNFFYM @ 6.25 t ha^{-1} (T_6), RDF + CCP + $ZnSO_4$ @ 25 kg ha^{-1} + $MnSO_4$ @ 5 kg ha^{-1} (T_5) and RDF + FYM + $ZnSO_4$ @ 25 kg ha^{-1} + $MnSO_4$ @ 5 kg ha^{-1} (T_4) treatments without fortified organics recorded the lowest Zn uptake by sesame as compared to fortified organics applied treatments (T_7 and T_6). Application of 100 per cent NPK alone (T_1) recorded a comparatively lower Zn and Mn uptake of 105.48 and 136.58 g ha^{-1} by seed as compared to application of RDF along with CCP (T_3) and application of RDF +FYM (T_2).

The treatment receiving 100% recommended dose of NPK along with micronutrients fortified composted coirpith (MNFCCP) @ 6.25 t ha^{-1} through soil and foliar spray of $ZnSO_4$ + $MnSO_4$ @ 0.5% and PPFM @ 1.0% twice registered the highest Zn uptake.

This might be attributed to increase total dry matter production, growth and yield components of sesame. Further, improvement in the availability and higher absorption by sesame resulted in higher uptake of these nutrients. The increased uptake of micronutrient with the Zn has been well documented by Krishnaprabu and Kalyanasundaram[17] and Elayaraja[6].

According to Swati and Dhok[23] the addition of micronutrients supplemented organic manures resulted in greater micronutrient availability due to mineralization. Organics application could result in release of more micronutrients in easily available form, which was reflected in overall growth of the crop plants. These results are in accordance with the earlier reports of Hanumanthappa and Shivaraj[9].

The results of the field experiment clearly indicated the response of sesame to micronutrient fertilization along with micronutrients (Zinc and Manganese) fortified organics and recommended NPK @ 35:23:23 kg of N: P_2O_5: K_2O ha^{-1} in increasing the growth characters of sesame. Among various treatments, the combined application of 100% recommended dose of NPK + micronutrients fortified composted coirpith (MNFCCP) @ 6.25 t ha^{-1} through soil and foliar application of $ZnSO_4$ + $MnSO_4$ @ 0.5% + pink pigmented facultative methylotrophic bacteria (PPFM) @ 1.0 % twice at pre flowering stage and at flowering stage significantly increased the growth characters, yield parameters, yield and nutrient uptake by sesame.

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