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Influence of Microbial-enriched Organic Manures and Nano-emulsion Biofertilizers Combined with Inorganic Nutrients on the Growth, Yield and Economics of Chickpea Cultivation

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ABSTRACT

Background: Enhancing agricultural productivity is crucial for achieving greater yields and boosting farmers' incomes. Chickpeas, prominent pulse crops in India, play a significant role in global agricultural production. Despite their resilience to adverse conditions, optimizing chickpea growth and yield remains a challenge, necessitating integrated nutrient management strategies.

Methods: The two field experiments were carried out consecutively in the same field during the *rabi* seasons of 2023-24 at the Instructional Farm of Karunya Institute of Technology and Sciences, to study the influence of microbial enriched organic manures and nano-emulsion biofertilizers with inorganic fertilizers on chickpea growth, yield and economics. The study consists of twelve treatments of integrated nutrient management practices in randomized block design with three replications.

Result: Application of 75% RDF along with nano-emulsion biofertilizer applied as seed treatment at 10 ml kg^{-1} seeds and two foliar sprays at 10 ml l^{-1} at 30 and 45 DAS proves to be a financially feasible and environmentally sustainable approach for chickpea production.

Key words: Chickpea, Economics, Grain yield, Growth attributes, Microbial enriched FYM, Microbial enriched vermicompost, Stover yield.

INTRODUCTION

Chickpeas (*Cicer arietinum* L.) are the leading pulse crop in India, with red gram coming in a close second position. This versatile legume, belonging to the Leguminosae or Fabaceae family, is recognized by various names, such as Bengal gram and Chana. It is often hailed as the "King of Pulses". According to DES (2023), globally, chickpeas are grown on a vast expanse of 150.04 million ha, resulting in a production of 158.71 million tonnes with an average productivity of 1057.8 kg ha^{-1}. India stands out as the top producer of chickpeas worldwide, contributing to 86% of the global output. India's production stands at 115.70 million tonnes, cultivated across 108.08 million ha, with a yield averaging 1145 kg/ha. Chickpea's ability to fix atmospheric nitrogen, efficient utilization of soil moisture and rich nutritional content make them a valuable crop for sustainable food systems in India. Chickpeas are resilient to adverse climates and contribute to soil health through nitrogen fixation (Dhaliwal *et al*., 2021). The vast of the cultivation of chickpea happens during the *rabi* season, largely dependent on rainfed conditions. Despite India's leading production status, challenges such as soil fertility issues and reliance on synthetic fertilizers persist, leading to nutrient imbalances and environmental concerns.

In the context of Indian agriculture, where nitrogen and phosphorus deficiencies are prevalent, the integration of biofertilizers such as rhizobium and Phosphorus Solubilizing Bacteria (PSB) with synthetic fertilizers becomes crucial for enhancing the crop yields. Organic manures like vermicompost and Farmyard Manure (FYM), when inoculated with beneficial microbes, enhances the nutrient levels and improves the soil fertility, thereby promotes sustainable farming practices. Although organic manures offer numerous advantages for soil health and plant growth, they also come with their inherent drawbacks, in terms of slow nutrient release, limited nutrient content, restricted availability, labour-intensive preparation processes and bulky nature poses challenges in handling organic manures when compared to inorganic fertilizers. Furthermore, in intensive farming conditions where nutrient demands are high, to meet the crop nutrient requirements in a short time, limits the growers from relying solely on organic manures as the primary nutrient source. Instead, it encourages an integrated approach to nutrient management. Therefore, integrating organic and inorganic nutrient sources through integrated nutrient management (INM) is crucial for sustainable crop productivity and enhanced soil health. Recently, a significant stride in agricultural advancement has come from the utilization of nano-fertilizers, largely

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attributable to the distinctive characteristics of nanoparticles, particularly their substantial surface area. This unique combination of minuscule particle size and expansive surface area facilitates enhanced interaction and nutrient absorption by crops (Su *et al*., 2019). Consequently, combining nanoparticles with fertilizers, enhance the nutrient absorption and release, improve the nutrient use efficiency and ultimately boost the agricultural yields (Yousefzadeh *et al.* 2021). Similar to nano-fertilizers, a nano-biofertilizer is an innovative agricultural product that combines nanoparticles with biofertilizers or microbes., which represents a significant advancement in agriculture. These nanoparticle formulations of biofertilizers are specially designed to enhance the efficiency of microbes. In this study, a novel nano-emulsion biofertilizer formulation containing *Rhizobium* and PSB was tested alongside inorganic nutrients to optimize chickpea growth and productivity within an integrated nutrient management framework.

MATERIALS AND METHODS

The present investigation was carried out by laying out the field experiments on chickpea with different levels of recommended doses of fertilizer in combination with organic manures and biofertilizers during the *rabi* season of 2023-24. Two field trials were taken up for the study by raising two crops chickpea consecutively on the same site without changing the randomization, at the instructional farm of School of Agricultural Sciences, Karunya Institute of Technology and Sciences, Coimbatore, Tamil Nadu. The soil of the experimental field was silt clay loam in texture, low in organic carbon (0.45 %), medium in available nitrogen (314 kg ha^{-1}), medium in available phosphorous (16 kg ha^{-1}), high in available potassium (195 kg ha^{-1}) and slightly alkaline in reaction (pH 8.10).

The study comprised of twelve treatments replicated thrice in randomized block design (RBD) namely, T_1 -100% Recommended dose of fertilizer (RDF), T_2 -100% RDF+ FYM @12.5 t ha^{-1}, T_3 -100% RDF+Vermicompost @ 6 t ha^{-1}, T_4 -100% RDF + Microbial enriched FYM @12.5 t ha^{-1}, T_5 -100% RDF+Microbial enriched vermicompost @ 6 t ha^{-1}, T_6 -100% RDF+Nano-emulsion biofertilizer (Seed treatment @ 10 ml kg^{-1} seeds+2 foliar sprays @ 10 ml l^{-1} at 30 and 45 DAS), T_7 -75% RDF+Microbial enriched FYM @ 12.5 t ha^{-1}, T_8 -75% RDF+Microbial enriched vermicompost @ 6 t ha^{-1}, T_9 -75% RDF+Nano-emulsion biofertilizer (Seed treatment @ 10 ml kg^{-1} seeds+2 foliar sprays @ 10 ml l^{-1} at 30 and 45 DAS) , T_{10}- 50% RDF+Microbial enriched FYM @ 12.5 t ha^{-1}, T_{11} -50% RDF + Microbial enriched vermicompost @ 6 t ha^{-1}, T_{12} -50% RDF+Nano-emulsion biofertilizer (Seed treatment @ 10 ml kg^{-1} seeds+2 foliar sprays @ 10 ml l^{-1} at 30 and 45 DAS).

Ridges and furrow method of cultivation was taken up, where the ridges were formed at a distance of 30 cm. The chickpea seeds of variety NBeG-49 were sown manually by maintaining a plant to plant spacing of 10 cm, by dibbling one seed to a depth of about 3 to 4 cm, at 1/3rd distance from the top of the ridge. After sowing, the seeds were adequately covered with soil and each plots were given a light irrigation immediately. At 5 days after sowing, a minor gap filling operation was performed for chickpeas to ensure a complete plant population. Fertilization of the chickpea crop was carried out according to the designated treatments. The recommended dose of fertilizer applied for the crop was 25 kg of nitrogen (N), 50 kg of phosphorus (P_2O_5) and 20 kg of potassium (K_2O) per hectare. The recommended dose of fertilizer was applied in varied proportion as 100%, 75% and 50% as per the treatment details in different treatment plots. Nitrogen was applied in three splits (basal, 25 days after sowing and 45 days after sowing) and the entire dose of P_2O_5 and K_2O were applied as basal dose. The microbial enrichment of farmyard manure (FYM) and vermicompost involved inoculating the bio-inoculants, specifically *Bacillus megatherium var. phosphaticum* (PSB) and *Rhizobium leguminosarum* (Rhizobium), at a ratio of 10 litres (5 litres of PSB+5 litres of Rhizobium) per 50 kilograms of substrate. These microorganisms were propagated on a large scale using conventional culture media such as Nutrient Agar (NA) for PSB and Yeast Extract Mannitol Agar (YEMA) for Rhizobium. A polymer-based oil-in-water (O/W) nano-emulsion was prepared for the study by doing ultrasonication of the components like castor oil, vitamin E, a non-ionic surfactant (Tween 80), carboxymethyl cellulose (CMC) and NaCl. Later, this nano-emulsion was inoculated with the bio-inoculants of *Bacillus megatherium var. phosphaticum* (PSB) and *Rhizobium leguminosarum* (Rhizobium) at the rate of 10 ml of culture (5 ml of PSB+5 ml of Rhizobium) in 90 ml of nano-emulsion to produce the nano-emulsion biofertilizer. This prepared nano-emulsion biofertilizer was administered through seed treatment and foliar sprays. Seed treatment involved mixing of nano-emulsion biofertilizer at a rate of 10 ml/kg of seeds, for foliar spray the nano-emulsion biofertilizers was applied @ 10 ml l^{-1} of water, with a spray volume of 500 litres ha^{-1} by using a knapsack sprayer.

RESULTS AND DISCUSSION

Growth attributes

The periodic measurements of plant height and dry matter production per plant were significantly affected by the combination of inorganic fertilizers and organic manures. The application of 100% RDF+microbial enriched vermicompost @ 6 t ha^{-1} (T_5) recorded a higher plant height and dry matter production (Table 1) at harvest and it was statistically on par with 100% RDF+Microbial enriched FYM @12.5 t ha^{-1} (T_4), 100% RDF+Nano-emulsion biofertilizer (Seed treatment @ 10 ml/kg seeds+2 foliar sprays @ 10 ml l^{-1} at 30 and 45 DAS) (T_6) and 75% RDF+Nano-emulsion biofertilizer (Seed treatment @ 10 ml kg^{-1} seeds+2 foliar sprays @ 10 ml l^{-1} at 30 and 45 DAS) (T_9) during first and second trials. This increased plant height might be due to the synergistic effect of synthetic nutrients and organic amendments which might have worked together to

Table 1: Influence of microbial enriched organic manures and nano-emulsion biofertilizers on growth and yield attributes of chickpea.

Treatments	Plant height at harvest (cm)			DMP at harvest (kg/ha)			Pods/Plant			Seeds/Pod			Test weight (g)		
	Trial I	Trial II	Pooled	Trial I	Trial II	Pooled	Trial I	Trial II	Pooled	Trial I	Trial II	Pooled	Trial I	Trial II	Pooled
T_1	23.37	19.90	21.64	2401.20	1599.20	2000.20	15.00	12.00	13.50	1.00	1.00	1.00	25.20	20.20	22.70
T_2	23.60	19.90	21.75	2451.85	1626.80	2039.33	15.00	12.33	13.67	1.00	1.00	1.00	25.30	20.20	22.75
T_3	23.56	20.10	21.83	2455.09	1663.20	2059.15	15.33	12.33	13.83	1.00	1.00	1.00	25.60	20.30	22.95
T_4	44.65	34.90	39.78	4427.72	3005.60	3716.66	29.33	27.33	28.33	2.33	1.33	1.83	29.80	24.40	27.10
T_5	44.80	35.50	40.15	4449.48	3076.00	3762.74	30.67	27.67	29.17	2.33	1.33	1.83	29.90	24.50	27.20
T_6	44.36	34.10	39.23	4314.80	2898.40	3606.60	28.67	26.67	27.67	2.00	1.33	1.67	29.50	24.10	26.80
T_7	30.80	25.30	28.05	3078.35	2046.40	2562.37	20.33	17.33	18.83	1.33	1.00	1.17	26.20	21.20	23.70
T_8	32.00	25.70	28.85	3155.05	2250.00	2702.53	20.67	17.67	19.17	2.00	1.00	1.50	27.70	22.30	25.00
T_9	43.14	34.70	38.92	4221.93	2871.20	3546.57	28.00	25.00	26.50	2.00	1.33	1.67	28.40	23.10	25.75
T_{10}	29.35	24.50	26.93	2973.21	1973.60	2473.40	19.00	16.00	17.50	1.00	1.00	1.00	25.90	20.90	23.40
T_{11}	29.91	24.60	27.26	3060.72	1988.80	2524.76	19.67	17.00	18.34	1.33	1.00	1.17	26.10	21.10	23.60
T_{12}	37.50	30.20	33.85	3666.45	2560.80	3113.63	24.33	21.33	22.83	2.00	1.00	1.50	28.10	22.40	25.25
Mean	33.84	27.45		3387.99	2296.67		22.17	19.39		1.61	1.11		27.31	22.06	
SE(d)	2.56	2.13		234.52	149.24		1.45	1.45		0.85	0.85		2.56	1.71	
CD (5%)	5.31	4.42		486.37	309.51		3.01	3.01		NS	NS		NS	NS	

T_1 - 100% Recommended dose of fertilizer (RDF), T_2 -100% RDF + FYM @12.5 t ha^{-1}, T_3 -100% RDF + Vermicompost @ 6 t ha^{-1}, T_4 -100% RDF + Microbial enriched FYM @12.5 t ha^{-1}, T_5 -100% RDF + Microbial enriched vermicompost @ 6 t ha^{-1}, T_6 -100% RDF + Nano-emulsion biofertilizer (Seed treatment @ 10 ml/kg seeds + 2 foliar sprays @ 10 ml/l at 30 and 45 DAS), T_7 -75% RDF + Microbial enriched FYM @ 12.5 t ha^{-1}, T_8 -75% RDF + Microbial enriched vermicompost @ 6 t ha^{-1}, T_9 -75% RDF + Nano-emulsion biofertilizer (Seed treatment @ 10 ml/kg seeds + 2 foliar sprays @ 10 ml/l at 30 and 45 DAS), T_{10} -50% RDF + Microbial enriched FYM @ 12.5 t ha^{-1}, T_{11} -50% RDF + Microbial enriched vermicompost @ 6 t ha^{-1}, T_{12} - 50% RDF + Nano-emulsion biofertilizer (Seed treatment @ 10 ml/kg seeds + 2 foliar sprays @ 10 ml/l at 30 and 45 DAS).

enhance the release of nutrients, making them more accessible to the crop during its various growth phases. Additionally, the use of biofertilizers like microbial-enriched organic manure and nano-emulsion biofertilizer could have further contributed to plant growth, as indicated by the observed increase in plant height measurements and the rise in dry matter yield may be credited to the ample nitrogen supply, prolonged availability of essential macro and micronutrients, along with enhanced soil physical properties over the entire crop growing period. The incorporation of nano-scale particles within the bio-fertilizer composition might have additionally enhanced the mobility and efficiency of nutrient uptake, guaranteeing optimal utilization by plants for metabolic functions and biomass accumulation. Similar findings were also reported by Phinehas *et al.* (2022), Rolaniya *et al.* (2023) and Naushad *et al.* (2023).

Yield attributes and yield

The maximum number of pods per plant, seeds per pod and test weight in terms of yield attributes (Table 1) and overall yield (Table 2) were recorded with the application of 100% RDF+microbial enriched vermicompost @ 6 t ha^{-1} (T_5) and it was statistically on par with 100% RDF+microbial enriched FYM @12.5 t ha^{-1} (T_4), 100% RDF+Nano-emulsion biofertilizer (Seed treatment @ 10 ml kg^{-1} seeds+2 foliar sprays @ 10 ml l^{-1} at 30 and 45 DAS) (T_6) and 75% RDF+ Nano-emulsion biofertilizer (Seed treatment @ 10 ml kg^{-1} seeds+2 foliar sprays @ 10 ml l^{-1} at 30 and 45 DAS) (T_9) during first and second trials. This increase in pods per plant can likely be attributed to the improved availability of essential nutrients, facilitated by the utilization of inorganic fertilizers, coupled with the decomposition of enriched farmyard manure and vermicompost containing microorganisms like PSB and Rhizobium, which promote effective nitrogen fixation and phosphorus mobilization. Additionally, the direct application of nano-emulsion biofertilizers to leaves, could have accelerated nutrient absorption by the crop, reaching plant tissues directly through phloem translocation, bypassing the soil limitations and eventually leading to improved yields. Furthermore, this approach may have also augmented nitrogen availability through fixation and phosphorus solubilization in the soil, potentially enhancing root development and flowering. Similar findings were also reported by Changkiri *et al.* (2023), Sodavadiya *et al.* (2023), Choudhary *et al.* (2023) and Arsalan *et al.* (2024).

Economics

The treatment comprising 100% recommended dose of fertilizer (RDF) along with microbial-enriched vermicompost at 6 t ha^{-1} (T_5) resulted in a higher gross returns, this was closely followed by the other microbial enriched FYM treatment (T_4) and nano-emulsion biofertilizer treatments (T_6 and T_9) during both the trials. Similar results were also reported by Bhowmik *et al.* (2022), Patel and Thanki (2022) and Samant and Mishra (2023) and Kaur *et al.* (2023). However, the treatment T_9, involving 75% RDF along with nano-emulsion biofertilizer application, stood out with a higher net returns and benefit-cost ratio (BCR). This was followed by treatment T_6, which also utilized nano-emulsion biofertilizer, during both the trials (Table 3). The greater gross returns observed with microbial-enriched organic manures (T_5 and T_4) can be attributed to their higher grain yields, achieved through effective nutrient management by integrating organic sources of nutrients with inorganic fertilizers. Despite the high gross returns, these treatments yielded lower net returns and BCR due to the significant

Table 2: Influence of microbial enriched organic manures and nano-emulsion biofertilizers on yield of chickpea.

Treatments	Grain yield (kg/ha)			Stover yield (kg/ha)		
	Trial I	Trial II	Pooled	Trial I	Trial II	Pooled
T_1: 100% RDF	834	659	746	1834	1335	1585
T_2: 100% RDF + FYM @12.5 t ha^{-1}	838	667	753	1886	1354	1620
T_3: 100% RDF + Vermicompost @ 6 t ha^{-1}	861	676	768	1928	1373	1651
T_4: 100% RDF + Microbial enriched FYM @12.5 t ha^{-1}	1514	1259	1386	3374	2498	2936
T_5: 100% RDF + Microbial enriched vermicompost @ 6 t ha^{-1}	1569	1276	1423	3406	2569	2987
T_6: 100% RDF + Nano-emulsion biofertilizer (Seed treatment @ 10 ml/kg seeds + 2 foliar sprays @ 10 ml/l at 30 and 45 DAS)	1484	1211	1348	3310	2412	2861
T_7: 75% RDF + Microbial enriched FYM @12.5 t ha^{-1}	1069	869	969	2354	1689	2022
T_8: 75% RDF + Microbial enriched vermicompost @ 6 t ha^{-1}	1079	872	975	2427	1883	2155
T_9: 75% RDF + Nano-emulsion biofertilizer (Seed treatment @ 10 ml/kg seeds + 2 foliar sprays @ 10 ml/l at 30 and 45 DAS)	1448	1197	1322	3243	2392	2818
T_{10}: 50% RDF + Microbial enriched FYM @12.5 t ha^{-1}	1046	839	943	2255	1628	1941
T_{11}: 50% RDF + Microbial enriched vermicompost @ 6 t ha^{-1}	1049	851	950	2352	1635	1993
T_{12}: 50% RDF + Nano-emulsion biofertilizer (Seed treatment @ 10 ml/kg seeds + 2 foliar sprays @ 10 ml/l at 30 and 45 DAS)	1261	1033	1147	2813	2133	2473
Mean	1171.01	950.75		2598.52	1908.42	
SE(d)	85.28	76.75		174.82	119.39	
CD (5%)	176.86	159.17		362.56	247.60	

Table 3: Influence of microbial enriched organic manures and nano-emulsion biofertilizers on economics of chickpea cultivation.

Treatments	Economics (Trial I)					Economics (Trial II)				
	Total cost of cultivation (Rs.)	Gross returns (Rs.)	Net Returns (Rs.)	BCR	Cost of production /kg (Rs.)	Total cost of cultivation (Rs.)	Gross returns (Rs.)	Net returns (Rs.)	BCR	Cost of production /kg (Rs.)
T_1	28640	62550	33910	2.18	34	28640	49425	20785	1.73	43
T_2	41140	62850	21710	1.53	49	41140	50025	8885	1.22	62
T_3	70640	64575	-6065	0.91	82	70640	50700	-19940	0.72	104
T_4	43640	113550	69910	2.60	29	43640	94425	50785	2.16	35
T_5	73140	117675	44535	1.61	47	73140	95700	22560	1.31	57
T_6	34840	111300	76460	3.19	23	34840	90825	55985	2.61	29
T_7	41790	80175	38385	1.92	39	41790	65175	23385	1.56	48
T_8	71290	80925	9635	1.14	66	71290	65400	-5890	0.92	82
T_9	32990	108600	75610	3.29	23	32990	89775	56785	2.72	28
T_{10}	39909	78450	38541	1.97	38	39909	62925	23016	1.58	48
T_{11}	69409	78675	9266	1.13	66	69409	63825	-5584	0.92	82
T_{12}	31109	94575	63466	3.04	25	31109	77475	46366	2.49	30

T_1 - 100% Recommended dose of fertilizer (RDF), T_2 -100% RDF + FYM @12.5 t ha^{-1}, T_3 -100% RDF + Vermicompost @ 6 t ha^{-1}, T_4 -100% RDF + Microbial enriched FYM @12.5 t ha^{-1}, T_5 -100% RDF + Microbial enriched vermicompost @ 6 t ha^{-1}, T_6 -100% RDF + Nano-emulsion biofertilizer (Seed treatment @ 10 ml/kg seeds + 2 foliar sprays @ 10 ml/l at 30 and 45 DAS), T_7 -75% RDF + Microbial enriched FYM @ 12.5 t ha^{-1}, T_8 -75% RDF + Microbial enriched vermicompost @ 6 t ha^{-1}, T_9 -75% RDF + Nano-emulsion biofertilizer (Seed treatment @ 10 ml/kg seeds + 2 foliar sprays @ 10 ml/l at 30 and 45 DAS), T_{10} -50% RDF + Microbial enriched FYM @ 12.5 t ha^{-1}, T_{11} -50% RDF + Microbial enriched vermicompost @ 6 t ha^{-1}, T_{12} - 50% RDF + Nano-emulsion biofertilizer (Seed treatment @ 10 ml/kg seeds + 2 foliar sprays @ 10 ml/l at 30 and 45 DAS).

input costs associated with bulky organic inputs like vermicompost and FYM. On the contrary, treatment T_9, utilizing nano-emulsion biofertilizer, demonstrated higher net returns and BCR, primarily due to the lower input cost of the biofertilizer and 25 per cent reduced expense with regard to the use of inorganic fertilizers resulting from the reduction in the recommended dosage. The success of nano-emulsion biofertilizer in treatments T_9 and T_6 suggests its potential as an effective and economically viable alternative for plant nutrient management.

CONCLUSION

Based on the results, it can be inferred that the though utilization of 100% RDF along with Microbial enriched vermicompost @ 6 t ha^{-1} proved to be advantageous, in enhancing the crop growth characters, yield attributes and overall yield in chickpea., employing 75% RDF along with Nano-emulsion biofertilizer (applied as seed treatment at 10 ml kg^{-1} seeds and two foliar sprays at 10 ml l^{-1} at 30 and 45 DAS) emerges as a financially feasible and environmentally sustainable approach for chickpea production.

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Conflict of interst

The authors declare that they have no conflict of interest.

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