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Residual Effect of Permanent Manurial Trial on Soil Physical, Chemical and Biological Properties under Northern Dry Zone of Karnataka, India

Ria Bhattacharjee [a++*], Vidyavathi G Yadahalli [a], G S Yadahalli [a] and Savita B [b#]

[a] *Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vijayapura, UAS. Dharwad – 580 005, India.*
[b] *AICRP-DLA, Regional Agricultural Research Station, Vijayapura, India.*

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

A field experiment was conducted at Regional Agricultural Research Station (RARS), Vijayapura, Karnataka, India, during *kharif* 2024-25. The study aimed to evaluate the residual effect of permanent manurial trial (initiated during 2017-18) on soil physical, chemical and biological properties established. Treatments comprised of unfertilised control (T_1), sole inorganics (T_2), 50% N through FYM + 50% through inorganic sources (T_3), 50% N through Vermicompost + 50%

++ *M. Sc. (Agri.);*
# *Soil Scientist;*
**Corresponding author: E-mail: riaaabhatt2@gmail.com;*

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through inorganic sources (T_4), 50% N through sunhemp + 50% inorganic sources (T_5), 50% N through Gliricidia loppings + 50% inorganic sources (T_6) and 50% N through crop residues + 50% inorganic sources (T_7). The experiment was laid out in randomised complete block design replicated thrice. In 2024, maize crop was taken as uniformilty trial without addition of manures and fertilizers. The study revealed that, the treatment receiving 50% N through FYM + 50% through inorganic sources (T_3) significantly reduced soil bulk density, improved water holding capacity, soil organic carbon (SOC), available nitrogen, cation exchange capacity (CEC) and dehydrogenase activity followed by treatment receiving 50% N through Vermicompost + 50% through inorganic sources (T_4). Across treatments, SOC and nutrient availabilities declined with soil depth, underscoring the dominance of surface-applied organics and root activity in topsoil layers. The investigation suggests that, Integrated Nutrient Mangemnet (INM) practices has long-term benefits in improving soil health and fertility in semi-arid *vertisols*.

Keywords: Permanent manurial trial, soil organic carbon; uniformity trial; cation exchange capacity; soil depth; Recommended doses of fertilizers; integrated nutrient management.

1. INTRODUCTION

Soil health is determined by an interplay of physical, chemical and biological attributes (Delgado & Gómez, 2024). Beyond agricultural importance, soil serves as a crucial component of natural and engineered ecosystems. It supports infrastructure, filters pollutants and maintains environmental quality (Fausak *et al*., 2024). It regulates water, cycles nutrients and sustains life, earning it the metaphorical title: “the soul of infinite life”. Therefore, preserving soil integrity is not just an agricultural necessity but a global ecological responsibility.

In semi-arid regions such as Northern Dry Zone of Karnataka (Zone-3), specifically Vijayapura, maintaining soil fertility is an ongoing challenge due to erratic rainfall, high temperature and low organic matter content. This region receives an annual precipitation average of approximately 594 mm and features medium to deep black soils of soil order *Vertisol*, with a clayey texture known for their high cation exchange capacity and nutrient retention potential. Under proper management, these soils offer substantial agronomic advantages. However, high temperatures in semi-arid climates accelerate the decomposition of organic matter, often resulting in declining soil organic carbon (SOC) levels (Mazadiego *et al.,* 2020).

To address these region-specific concerns, permanent manurial trials (PMTs) have emerged as essential long-term experiments for evaluating the effects of varied organic and inorganic nutrient management strategies on soil functioning. These trials provide insights into shifts in soil physical properties, nutrient dynamics, microbial activity and organic carbon content.

In long-term field experiments, uniformity trials are essential for quantifying residual nutrient effects and inherent field variability. They help isolate the lasting impacts of previous nutrient applications on crop growth and soil health, providing a clear picture of carry over effects in the absence of fresh inputs. Under the framework of this study, the 2024 maize uniformity trial served to evaluate how seven years of differential nutrient management in *Vertisols* continue to influence productivity and key soil health indicators.

Numerous studies have been documented that prolonged application of organic amendments, such as manures or crop residues, substantially increases topsoil SOC and improves nutrient availability (Zhang *et al.,* 2022). The residual effects of such practices also promote microbial proliferation, enzymatic activity and nutrient mineralization factors that accelerate carbon stabilization.

2. MATERIAL AND METHODS

A field study was carried out during *kharif* 2024-25 taking maize as uniformity trial (without any application of manures and fertilizers) at the Regional Agricultural Research Station, Vijayapura, to evaluate the residual impact of a long-term manurial trial (2017-2023) on soil properties under rainfed *Vertisols*. The site (16°07′ N, 75°07′ E, 593.6 m MSL) was laid out in a randomized block design with seven treatments (Table 1) and three replications.

Table 1. Treatment details

Treatment No.	Treatment Details
T_1	Control
T_2	RDF (Safflower: 40: 40:12 N: P_2O_5: K_2O kg ha^{-1}
	Sorghum: 50: 25: 0 N: P_2O_5: K_2O kg ha^{-1})
T_3	50% through FYM + 50% inorganic sources
T_4	50% N through Vermicompost + 50% through inorganic sources
T_5	50% N through sunhemp + 50% inorganic sources
T_6	50% N through Gliricidia loppings + 50% inorganic sources
T_7	50% N through crop residues + 50% inorganic sources

**The inorganic nutrient sources supplied: Urea, DAP and MOP*

Soil samples were collected from each plot at 0-20, 20-40, and 40-60 cm depths before sowing and at harvest. After air-drying and sieving (2 mm), samples were stored for analysis of bulk density, water holding capacity, SOC, available N, P_2O_5, K_2O, CEC, and dehydrogenase activity using standard procedures.

Bulk density was determined by core sampler (Black, 1965), water holding capacity by Keen's cup (Piper, 2002), SOC by Walkley and Black's wet oxidation (Sparks, 1996) available N by modified alkaline permanganate (Sahrawat & Burford, 1982), available P_2O_5 by Olsen's method, available K_2O by NH_4OAc extraction, CEC by ammonium acetate (Schollenberger & Dreibelbis, 1930), and dehydrogenase activity by Casida *et al.* (1964).

The experimental soil was classified as clayey (>60 cm depth) with 3.5% sand, 36.4% silt, and 60.1% clay. It had a field capacity of 37%, wilting point of 14.9%, and bulk density of 1.43 Mg m^{-3}. Chemically, the soil was slightly alkaline (pH 7.85) with 4.9 g kg^{-1} soil organic carbon, and available nutrients of 201.4 kg ha^{-1} N, 15.8 kg ha^{-1} P_2O_5, and 418.0 kg ha^{-1} K_2O.

3. RESULTS AND DISCUSSION

In 2024-25, the region received higher rainfall then average normal which has influenced the availability of nutrients to some extent due to leaching of salts. However, due to the consistently high temperatures in this area, the improvement of soil organic carbon remains a persistent challenge. Bulk density was significantly improved in the treatment receiving 50% N through FYM + 50% inorganic sources (T_3), both before sowing (1.31, 1.32, and 1.35 Mg m^{-3} at 0-20, 20-40, and 40-60 cm) and at harvest (1.30, 1.31, and 1.34 Mg m^{-3}, respectively) (Table 2), whereas control (T_1) and RDF (T_2) recorded the highest values The results highly correlate with the findings of Aytenew and Bore (2020), who also reported that treatment combinations involving FYM lowers bulk density and improves soil structure and microbial activities.

Slight increase in bulk density was observed, towards the lower depths. This might be because, the lower layers substantially receive low levels of soil organic matter, and has reduced root activity, as the incorporation of treatments in confined to the upper layers. As a result, compaction increases. Similar results were reported by Nazari *et al*. (2021).

Water holding capacity (WHC) was also significantly higher in plots receiving 50% N through FYM + 50% inorganic sources (T_3), both at sowing (55.33, 51.43, and 47.57%) and harvest (56.69, 52.49, and 47.97%) at respective depths (Table 2) while the lowest was in control (T_1) and RDF-T_2. The reason is owing to the fact that FYM incorporated treatments are meant to improve the soil structure as it provides good amount of soil organic matter. Soil organic matter can act like sponge and hence proves high affinity to hold water. (Hudson, 1994). The increase in WHC at harvest, is likely due to residual SOM from prior organic inputs and maize root exudates, which enhance porosity and water retention. Similar results were obtained by Angulo *et al.* (2024).

SOC was recorded highest with application of 50% N through FYM + 50% inorganic sources (T_3) both prior to sowing (6.90, 5.83, and 3.93 g kg^{-1}) and harvest (7.23, 5.97, and 3.97 g kg^{-1}) at respective depths, followed by 50% N through Vermicompost + 50% through inorganic sources (T_4), while control (T_1) and RDF (T_2) recorded the lowest (Table 3). FYM enhanced SOC in surface layers through slow carbon release, while deeper soils showed lower levels due to surface application and root concentration (Singh *et al*., 2020). A slight SOC rise at harvest was due to residual decomposition of past organics and maize root turnover. Lack of fertilizers have reduced microbial priming, conserving SOC while

Table 2. Residual effect of permanent manurial trial on soil bulk density and water holding capacity at different depths under maize crop

Treatments	Bulk density (Mg m^{-3})						WHC (%)					
	Before sowing			at harvest			Before sowing			at harvest		
	0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm
T_1	1.48	1.50	1.52	1.48	1.51	1.52	42.11	38.75	33.64	39.19	37.40	33.07
T_2	1.43	1.44	1.46	1.42	1.43	1.46	44.32	40.30	36.45	44.67	40.55	36.56
T_3	1.31	1.32	1.35	1.30	1.31	1.34	55.33	51.43	47.57	56.69	52.49	47.97
T_4	1.32	1.33	1.37	1.31	1.32	1.36	53.79	50.17	45.57	54.27	51.08	46.02
T_5	1.34	1.36	1.39	1.32	1.34	1.39	49.67	46.92	40.17	50.40	47.72	40.36
T_6	1.36	1.37	1.40	1.35	1.36	1.39	47.12	44.09	41.04	47.88	44.33	41.20
T_7	1.38	1.40	1.41	1.37	1.38	1.40	46.19	43.67	37.78	47.18	44.82	37.97
SEm±	0.05	0.05	0.05	0.05	0.05	0.05	2.69	1.70	3.40	1.95	1.70	3.15
CD (p=0.05)	0.14	0.15	0.16	0.14	0.14	0.16	8.28	5.25	10.48	6.00	5.23	9.70

T_1: Control
T_2: RDF
T_3: 50% N through FYM + 50% inorganic sources
T_4: 50%N through vermicompost + 50% inorganic sources
T_5: 50% N through sunhemp + 50% inorganic sources
T_6: 50% N through Gliricidia loppings + 50% inorganic sources
T_7: 50% N through crop residues + 50% inorganic sources

Table 3. Residual effect of permanent manurial trial on soil organic carbon and available nitrogen at different soil depths under maize crop

Treatments	Soil organic carbon (g kg^{-1})						Available N (kg ha^{-1})					
	Before sowing			at harvest			Before sowing			at harvest		
	0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm
T_1	3.93	3.60	2.73	3.23	2.80	2.53	161.19	145.67	122.78	156.90	142.01	121.90
T_2	4.77	4.37	3.19	4.80	4.40	3.21	172.48	164.14	133.93	168.67	161.67	132.75
T_3	6.90	5.83	3.93	7.23	5.97	3.97	238.85	220.19	183.71	233.52	217.11	182.12
T_4	6.67	5.57	3.87	6.93	5.83	3.90	233.56	216.82	173.26	229.25	213.65	171.70
T_5	6.20	5.23	3.57	6.73	5.60	3.61	226.82	212.68	166.89	220.25	208.67	164.89
T_6	5.83	5.13	3.43	6.17	5.30	3.47	221.67	208.01	160.45	217.55	206.34	159.66
T_7	5.47	4.97	3.30	5.83	5.13	3.33	211.43	203.45	156.84	207.07	201.45	155.77
SEm±	0.34	0.34	0.25	0.35	0.29	0.24	8.20	7.81	8.57	8.87	9.51	9.16
CD (p=0.05)	1.05	1.05	0.71	1.06	0.90	0.73	25.27	24.06	26.39	27.33	29.29	28.23

T_1: Control
T_2: RDF
T_3: 50% N through FYM + 50% inorganic sources
T_4: 50%N through vermicompost + 50% inorganic sources
T_5: 50% N through sunhemp + 50% inorganic sources
T_6: 50% N through Gliricidia loppings + 50% inorganic sources
T_7: 50% N through crop residues + 50% inorganic sources

Table 4. Residual effect of permanent manurial trial on soil available phosphorus and potassium at different soil depths under maize crop

Treatments	Available P_2O_5 (kg ha^{-1})						Available K_2O (kg ha^{-1})					
	Before sowing			at harvest			Before sowing			at harvest		
	0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm
T_1	13.75	12.40	11.15	12.41	11.19	10.63	360.85	353.10	320.29	364.84	345.74	316.0
T_2	15.93	13.50	12.77	14.16	12.34	12.58	376.07	362.52	330.41	370.62	358.88	324.48
T_3	23.62	21.98	20.85	21.72	20.50	20.04	475.11	427.41	395.46	466.58	424.01	390.56
T_4	24.06	22.02	20.95	22.64	21.12	20.12	470.92	425.71	362.95	462.11	421.54	359.32
T_5	22.90	20.85	19.16	19.62	19.15	18.87	479.71	431.16	380.33	471.93	424.01	375.34
T_6	18.37	17.60	16.61	16.73	16.63	16.56	482.37	432.04	410.75	473.93	429.88	405.56
T_7	19.28	18.08	17.78	17.84	17.82	15.55	463.29	390.00	345.50	456.23	382.09	340.45
SEm±	0.93	1.17	0.73	0.80	1.19	1.01	19.03	17.90	22.61	33.00	24.55	25.84
CD (p=0.05)	2.85	3.59	2.25	2.47	3.66	3.11	58.62	55.14	69.65	101.68	75.65	79.60

T_1: Control
T_2: RDF
T_3: 50% N through FYM + 50% inorganic sources
T_4: 50%N through vermicompost + 50% inorganic sources
T_5: 50% N through sunhemp + 50% inorganic sources
T_6: 50% N through Gliricidia loppings + 50% inorganic sources
T_7: 50% N through crop residues + 50% inorganic sources

Table 5. Residual effect of permanent manurial trial on soil cation exchange capacity at different depth under maize crop

Treatments	CEC [cmol (p+) kg^{-1}]					
	Before sowing			at harvest		
	0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm
T_1: Control	44.73	42.38	38.14	44.30	41.12	37.71
T_2: RDF	49.78	47.68	42.67	49.97	47.84	42.51
T_3: 50% N through FYM + 50% inorganic sources	58.02	57.10	52.31	59.78	58.19	52.56
T_4: 50%N through vermicompost + 50% inorganic sources	57.30	54.43	50.19	57.60	55.12	50.66
T_5: 50% N through sunhemp + 50% inorganic sources	55.09	52.05	48.04	55.45	53.22	48.52
T_6: 50% N through Gliricidia loppings + 50% inorganic sources	53.68	50.25	46.48	54.19	51.67	46.77
T_7: 50% N through crop residues + 50% inorganic sources	52.95	49.41	44.02	53.01	50.34	44.69
SEm±	2.24	2.46	3.35	2.07	1.72	3.04
CD (p=0.05)	6.90	7.59	10.31	6.38	5.29	9.35

cooler, wetter conditions likely slowed decomposition. Similar results were obtained by Liu *et al*. (2025).

Available nitrogen was also highest in treatment receiving, 50% N through FYM + 50% inorganic sources (T_3), both before sowing (238.85, 220.19, and 183.71 kg ha^{-1}) and at harvest (233.52, 217.11, and 182.12 kg ha^{-1}) across respective depths (Table 3), followed by 50% N through Vermicompost + 50% through inorganic sources (T_4), while control (T_1) and RDF recorded lower values. This reflected the combined effect of slow-release FYM and available fertilizer N (Meena *et al*., 2022). Higher N in surface soil is attributed to organic input concentration and root activity, while the decline with depth reflects limited organics and microbial activity. Though *Vertisols* restrict leaching, some N loss occur due to precipitation that had taken place during the cropping cycle. Nitrogen decreased from sowing to harvest across treatments is due to plant uptake, volatilization, and minor leaching, especially in alkaline soils (Zhang *et al.* 2021).

Available phosphorus was maximum in treatment, 50% N through vermicompost + 50% inorganic), both before sowing (24.06, 22.02, and 20.95 kg ha^{-1}) and harvest (22.64, 21.12, and 20.12 kg ha^{-1} across depths), compared to control (T_1) and RDF (T_2) recorded the lowest (Table 4). Vermicompost improved P availability by promoting phosphate-solubilizing microbes and reducing Ca^{2+} fixation via its high CEC (Kamaleshwaran & Elayaraja, 2021; Oyege & Balaji, 2023). Phosphorus levels consistently decreased with soil depth, primarily due to lower organic input and microbial activity in subsoil layers. Higher P retention in the topsoil was attributed to localized application and release of root exudates, aligning with observations by Zhang *et al*. (2014).

Available potassium was significantly higher in plots receiving, 50% N through Gliricidia loppings + 50% inorganic sources pre-sowing, (482.37, 432.04, and 410.75 kg ha^{-1}) and at harvest (473.93, 429.88, and 405.56 kg ha^{-1}) at respective depths (Table 4) compared to Control (T_1) and RDF (T_2) recorded lower values. Gliricidia, being rich in potassium and is also a source of organic matter, likely improved soil CEC and microbial activity, enhancing potassium retention and release. Similar findings were also obtained by (Beedy *et al*., 2010) where, it was reported that, gliricidia enhanced nutrient retention and improved soil chemical buffering due to added organic matter by 12%. Surface accumulation and decline with depth reflected typical nutrient cycling patterns, supported by similar trends in integrated nutrient management studies by Gurav et al. (2018) and Johnston and Poulton (2018).

CEC was significantly higher in plots receiving 50% N through FYM + 50% inorganic sources (T_3), both before sowing (58.02, 57.10, and 52.31 c mol(p^+) kg^{-1}) and at harvest (59.78, 58.19, and 52.56 c mol(p^+) kg^{-1} at respective depths, while control (T_1) and RDF (T_2) recorded the lowest (Table 5). Humic substances from FYM improve colloidal properties and buffering capacity in *Vertisols*, as supported by Jha *et al.* (2025). Vermicompost also possesses a high cation exchange capacity (CEC), which contributes to the comparable results observed in both treatments.

CEC declined with depth (0-20 cm > 20-40 cm > 40-60 cm), mainly due to reduced organic matter and microbial activity in subsoil layers. A slight increase at harvest might be due to continued decomposition of previously added manures which was stimulated by root exudates and microbial activity.

Table 6. Residual effect of permanent manurial trial on soil dehydrogenase activity under maize crop at vegetative stage

Treatments	Dehydrogenase activity (µg TPF g^{-1} hr^{-1})
T_1: Control	12.43
T_2: RDF	14.44
T_3: 50% N through FYM + 50% inorganic sources	23.06
T_4: 50%N through vermicompost + 50% inorganic sources	19.31
T_5: 50% N through sunhemp + 50% inorganic sources	16.83
T_6: 50% N through Gliricidia loppings + 50% inorganic sources	16.18
T_7: 50% N through crop residues + 50% inorganic sources	15.59
SEm±	1.37
CD (p=0.05)	4.21

Dehydrogenase activity (DHA) was significantly higher in treatment, 50% N through FYM + 50% inorganic sources (T_3), recording 23.06 µg TPF g^{-1} hr^{-1}, followed by 50% N through vermicompost + 50% inorganic (T_4) (Table 6). Being major carbon source, FYM provides a steady source of energy for soil microorganisms, and increases number of pores, which are considered important in soil-water-plant relationships and maintain good soil structure accompanied by better dehydrogenase activity (Kumawat *et al*., 2025).

4. CONCLUSION

The experimental results revealed that the integration of organic manures with inorganic fertilizers exerted a pronounced residual effect on soil physico-chemical and biological properties compared to sole inorganic fertilization or unfertilized control. Among the treatments, the application of 50% N through FYM + 50% through inorganic sources (T_3) consistently lowered soil bulk density, enhanced water holding capacity, improved soil organic carbon, available nitrogen, cation exchange capacity, and dehydrogenase activity, reflecting the synergistic role of FYM in improving soil structure, nutrient retention, and microbial activity followed by application of 50% N through vermicompost + 50% inorganic sources (T_4). With increase in depth, nutrient availability and SOC declined across all treatments. Overall, the findings establish that long-term integrated nutrient management not only sustains soil fertility but also enhances soil health by improving nutrient cycling, structural stability, and biological activity in *Vertisols*.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper

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