



Influence of long-term nutrient management on soil carbon pools and nitrogen fractions in a maize-chickpea cropping system

Shreyas V H^{1*}, S N Bhat¹, Manjunath Bhanuvaly², Sharan Bhoopal Reddy³, Anand Kamble Shankar⁴

¹ Department of Soil Science, College of Agriculture, Raichur, Karnataka, India

² Department of Soil Science, Agricultural Extension Education Centre, Huvina Hadagali, Karnataka, India

³ Department of Soil Science, College of Agriculture, Bheemarayanagudi, Karnataka, India

⁴ Department of Agronomy, Organic Farming Research Institute, UAS, Raichur, Karnataka, India

Corresponding Author: Shreyas V H

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Abstract

Long-term nutrient management can alter soil carbon pools and nitrogen availability, with implications for soil fertility and sustainability. This study evaluated carbon pools and nitrogen fractions in a long-term field experiment established in 2012-2013 on a *Vertisol* under rainfed conditions at the Organic Farming Research Institute, Main Agricultural Research Station, University of Agricultural Sciences, Raichur, Karnataka, India. Post-harvest soil samples were collected after maize in a maize-chickpea cropping system at 0-15 and 15-30 cm depths. Four production systems were compared: 100% nitrogen through organic sources, integrated nitrogen management (50% N through organics and 50% through inorganic fertilizers), 100% recommended NPK through inorganic fertilizers, and recommended package of practices (RPP; recommended NPK plus farmyard manure at 7.5 t ha⁻¹). Various soil carbon pools were examined, including total and inorganic carbon, permanganate oxidizable carbon, microbial biomass carbon and four oxidizable carbon fractions: very labile, labile, less labile and non-labile carbon. At 0-15 cm, total carbon was highest under the organic system (21.02 g kg⁻¹), followed by integrated management (18.92 g kg⁻¹), RPP (16.80 g kg⁻¹) and inorganic (15.90 g kg⁻¹). Organic management also recorded the highest POXC (0.336 g kg⁻¹), MBC (0.299 g kg⁻¹), very labile C (2.62 g kg⁻¹), labile C (1.72 g kg⁻¹), less labile C (2.63 g kg⁻¹) and non-labile C (17.78 g kg⁻¹). In contrast, RPP recorded the highest surface ammonical N (31.59 mg kg⁻¹), nitrate N (15.92 mg kg⁻¹), organic N (626.93 mg kg⁻¹) and total N (674.44 mg kg⁻¹), with integrated management generally ranking second for the major N pools.

Keywords: Agro-climatic zones, potassium fractions, non-exchangeable potassium, sequential extraction, soil fertility

Introduction

Soil organic matter is central to soil productivity because it influences nutrient cycling, microbial activity, aggregation and the retention of plant-available nutrients. Soil carbon occurs in different pools that vary in their decomposability and stability. Very labile and labile carbon fractions are readily decomposable and provide energy for soil microorganisms, whereas less labile and non-labile fractions contribute to longer-term carbon storage and soil structural stability. Long-term nutrient management practices influence the distribution of these fractions through the continuous addition of organic manures, crop residues and inorganic fertilizers.

The distribution of soil carbon fractions is strongly influenced by the type and duration of nutrient inputs. Regular application of organic amendments, such as farmyard manure, compost and green manure, can favour the accumulation of both labile and relatively stable carbon pools. Permanganate oxidizable carbon (POXC) and microbial biomass carbon (MBC) are useful indicators of active carbon pools and biological activity in soil.

Nitrogen occurs in soil in organic and inorganic forms, with organic nitrogen generally constituting the major proportion of total soil nitrogen. Ammonical nitrogen and nitrate nitrogen represent important mineral forms that contribute to plant nutrition. Their distribution is influenced by organic matter decomposition, nitrogen mineralization, nitrification, crop uptake and nutrient losses. Organic inputs can support

the buildup of soil organic nitrogen, while integrated nutrient management may help maintain both organic and mineral nitrogen pools. Therefore, evaluating ammonical, nitrate, organic and total nitrogen under different production systems is essential for understanding changes in soil nitrogen status and the sustainability of long-term nutrient management.

Material and Methods

The study was conducted at the Organic Farming Research Institute, Main Agricultural Research Station, University of Agricultural Sciences, Raichur, Karnataka, India (16°12'12" N, 77°12'30" E; 393.12 m above mean sea level), under a long-term rainfed experiment initiated in 2012^[4]–2013 on *Vertisol*. The experiment comprised four production systems (T1: 100% recommended N through organic sources; T2: 50% N through organic sources and 50% through inorganic fertilizers; T3: 100% recommended NPK through inorganic fertilizers (100:50:25 kg ha⁻¹); and T4: recommended NPK with FYM at 7.5 t ha⁻¹), arranged in a randomized complete block design with five replications. Composite soil samples were collected at 0–15 and 15–30 cm depths, air-dried, ground and sieved through a 2-mm mesh. Total carbon was determined by ignition (Allen *et al.*, 1986; Negi *et al.*, 2003; Jana *et al.*, 2009)^[1, 7, 10], soil inorganic carbon by rapid titration (Piper, 1966)^[12], permanganate oxidizable carbon using 0.02 M KMnO₄ (Weil *et al.*, 2003)^[14], and microbial biomass carbon by chloroform fumigation-extraction

(Vance *et al.*, 1987) ^[13]. Very labile, labile, less labile and non-labile carbon fractions were determined using H₂SO₄ concentrations of 12 N, 18 N and 24 N (Chan *et al.*, 2001) ^[3]. Total nitrogen was analysed using a Vario EL III CHNS analyser, ammoniacal nitrogen by MgO distillation, nitrate nitrogen using Devarda's alloy, and organic nitrogen by difference (Jackson, 1973; Bremner, 1965) ^[2, 6]. Data were analysed using analysis of variance following Gomez and Gomez (1984) ^[5], and treatment means were compared using the critical difference at the 5% significance level.

Results and Discussion

Total carbon and Inorganic carbon

Total carbon content differed among production systems at both soil depths. The organic production system recorded the highest total carbon content, with 21.02 g kg⁻¹ in surface soil and 18.92 g kg⁻¹ in subsurface soil, whereas the inorganic production system registered the lowest values of 15.90 and 14.50 g kg⁻¹, respectively. The higher carbon content under organic management may be attributed to the regular addition of organic materials, which promotes carbon accumulation in soil. Similar observations were reported by Moharana *et al.* (2012) ^[9].

In contrast, inorganic carbon content was highest under the inorganic production system, recording 7.42 g kg⁻¹ in surface soil and 13.81 g kg⁻¹ in subsurface soil. The higher inorganic carbon content in subsurface soil may be associated with carbonate accumulation and redistribution along the soil profile, particularly under semi-arid conditions, as discussed by Ortas and Lal (2014) ^[11].

Permanganate oxidizable carbon and Microbial biomass carbon

Permanganate oxidizable carbon and microbial biomass carbon showed a declining trend from surface to subsurface soil across all production systems. POXC was highest under the organic system, with values of 0.336 g kg⁻¹ in surface soil and 0.323 g kg⁻¹ in subsurface soil, followed by the integrated and recommended package of practices systems, whereas the inorganic system recorded the lowest values. Microbial biomass carbon also followed a similar pattern, ranging from 0.299 to 0.175 g kg⁻¹ in surface soil and from 0.252 to 0.151 g kg⁻¹ in subsurface soil, with the highest values under the organic system and the lowest under the inorganic system.

The greater POXC and MBC contents under organic management may be associated with regular organic matter inputs that provide substrates for microbial growth and maintain active soil carbon pools.

Oxidizable organic carbon fractions

The oxidizable organic carbon fractions were consistently higher under T₁ (100% organic) and lower under T₃ (100% inorganic) at both soil depths. At the surface, T₁ recorded 2.62, 1.72 and 2.63 g kg⁻¹ of very labile, labile and less labile carbon, respectively, compared with 2.16, 1.22 and

2.10 g kg⁻¹ under T₃. Non-labile carbon followed the same trend, with the highest value under T₁ (17.78 g kg⁻¹), followed by T₄ (16.88 g kg⁻¹), T₂ (15.18 g kg⁻¹) and T₃ (14.49 g kg⁻¹). This consistent response suggests that regular organic inputs favoured the accumulation of both readily oxidizable and relatively stable carbon pools. The greater availability of organic substrates may have contributed to carbon enrichment and stabilization over time.

Non-labile carbon remained the dominant fraction, followed by less labile, very labile and labile carbon. The decline in these fractions with depth indicates that carbon accumulation was more pronounced in the surface layer.

Ammonical and nitrate nitrogen

The distribution of mineral nitrogen fractions was influenced by nutrient management practices, with the recommended package of practices (T₄) recording the maximum ammonical and nitrate nitrogen contents at both soil depths. Ammonical nitrogen under T₄ reached 31.59 mg kg⁻¹ in surface soil and 27.48 mg kg⁻¹ in subsurface soil, while the corresponding nitrate nitrogen values were 15.92 and 13.81 mg kg⁻¹. Conversely, the organic system (T₁) registered the minimum ammonical nitrogen content (24.21 and 21.14 mg kg⁻¹), whereas the inorganic system (T₃) recorded the lowest nitrate nitrogen content (11.44 and 10.54 mg kg⁻¹) at the respective depths.

The decline in both nitrogen fractions with depth may reflect differences in organic matter distribution and nitrogen transformations across the soil profile. The superior performance of T₄ could be associated with the combined application of FYM and inorganic fertilizers, providing both organic substrates and readily available nutrients. Similar benefits of integrated nutrient management for maintaining soil nitrogen pools have been reported by Meena *et al.* (2019) and Ghosh *et al.* (2012) ^[4, 8].

Organic and total nitrogen

Organic nitrogen constituted the predominant fraction of total soil nitrogen, accounting for 92.96-93.94% in surface soil and 93.75-94.49% in subsurface soil. The highest organic nitrogen content was recorded under the recommended package of practices along with FYM (T₄), with 626.93 mg kg⁻¹ in surface soil and 619.97 mg kg⁻¹ in subsurface soil, followed by T₂, which recorded 606.89 and 600.99 mg kg⁻¹, respectively. In contrast, T₃ recorded the lowest organic nitrogen content of 551.87 mg kg⁻¹ in surface soil and 543.64 mg kg⁻¹ in subsurface soil. Total nitrogen followed a similar trend, with T₄ recording 674.44 and 661.27 mg kg⁻¹, compared with 589.05 and 576.59 mg kg⁻¹ under T₃ at the respective depths. The higher nitrogen reserves under T₄ and T₂ may be attributed to the combined contribution of organic manure and mineral fertilizers, which favoured the maintenance of soil nitrogen status. Similar effects of long-term nutrient management on soil nitrogen fractions were reported by Meena *et al.* (2019) ^[8].

Table 1: Total carbon, inorganic carbon permanganate oxidizable carbon and microbial biomass carbon contents in surface and subsurface soils as influenced by different production systems

Treatment	Total carbon		Inorganic carbon		Permanganate oxidizable carbon		Microbial biomass carbon	
	(kg ha ⁻¹)							
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T ₁ -Organic	21.02	18.92	6.44	10.54	0.336	0.323	0.299	0.252
T ₂ -Integrated	18.92	17.26	6.74	11.28	0.316	0.289	0.214	0.170
T ₃ -Inorganic	15.90	14.50	7.42	13.81	0.148	0.128	0.175	0.151

T ₄ - RPP	16.80	15.20	7.11	12.89	0.297	0.274	0.207	0.166
S.Em. $\pm$	0.31	0.33	0.08	0.22	0.04	0.04	0.03	0.02
CD @ 5%	0.95	1.04	0.25	0.68	0.12	0.13	0.11	0.06

Table 2: Oxidisable fractions of organic carbon in surface and subsurface soils as influenced by different production systems

Treatment	Very labile C		Labile C		Less labile C		Non labile C	
	(kg ha ⁻¹)							
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T ₁ -Organic	2.62	2.42	1.72	1.56	2.63	2.53	17.78	11.98
T ₂ -Integrated	2.43	2.24	1.58	1.48	2.44	2.35	15.18	11.84
T ₃ -Inorganic	2.16	2.01	1.22	1.17	2.10	2.07	14.49	10.59
T ₄ -RPP	2.30	2.14	1.40	1.31	2.27	2.17	16.88	10.75
S.Em. ±	0.04	0.05	0.03	0.02	0.04	0.03	0.15	0.15
CD @ 5%	1.22	0.78	0.65	0.55	29.48	33.68	29.86	33.46

Table 3: Ammonical nitrogen, nitrate nitrogen, organic nitrogen and total nitrogen contents in surface and subsurface soils as influenced by different production systems

Treatment	Ammonical N		Nitrate N		Organic N		Total N	
	(kg ha ⁻¹)							
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T ₁ -Organic	24.21	21.14	12.76	11.28	573.35	556.19	610.31	588.61
T ₂ -Integrated	28.68	24.15	14.78	12.89	606.89	600.99	650.35	637.99
T ₃ -Inorganic	25.74	22.41	11.44	10.54	551.87	543.64	589.05	576.59
T ₄ -RPP	31.59	27.48	15.92	13.81	626.93	619.97	674.44	661.27
S.Em. ±	0.39	0.25	0.21	0.18	9.46	10.81	9.58	10.74
CD @ 5%	1.22	0.78	0.65	0.55	29.48	33.68	29.86	33.46

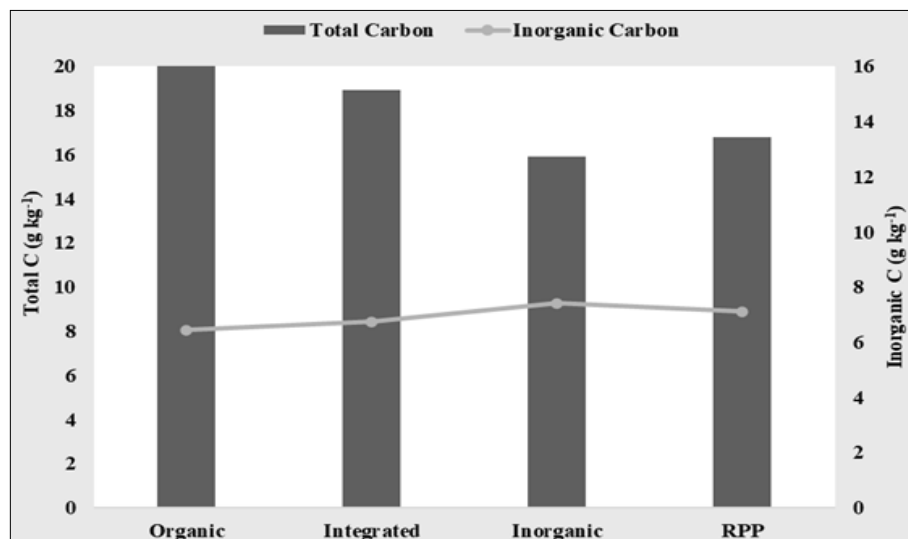


Fig 1: Total carbon and inorganic carbon contents in surface soil as influenced by different production systems

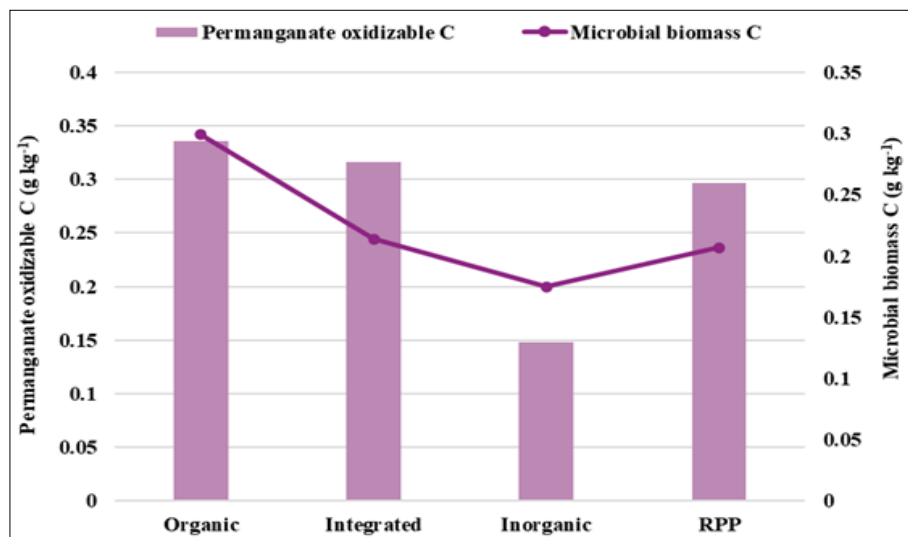


Fig 2: Permanganate oxidisable carbon and microbial biomass carbon contents in surface soil as influenced by different production systems

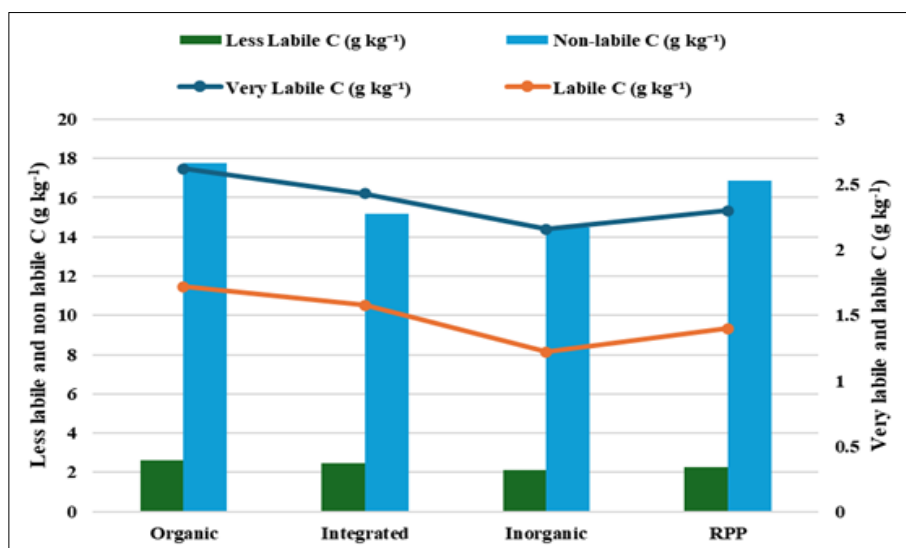


Fig 3: Oxidisable organic carbon contents in surface soil as influenced by different production systems

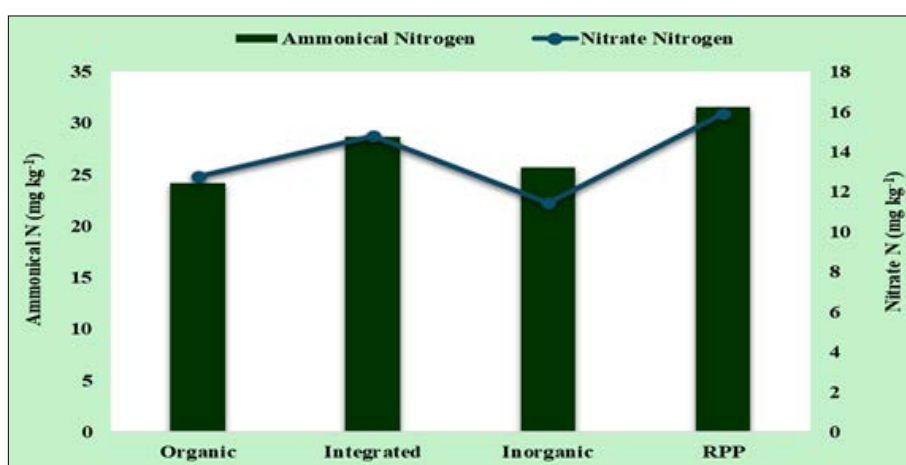


Fig 4: Ammonical nitrogen and nitrate nitrogen contents in surface soil as influenced by different production systems

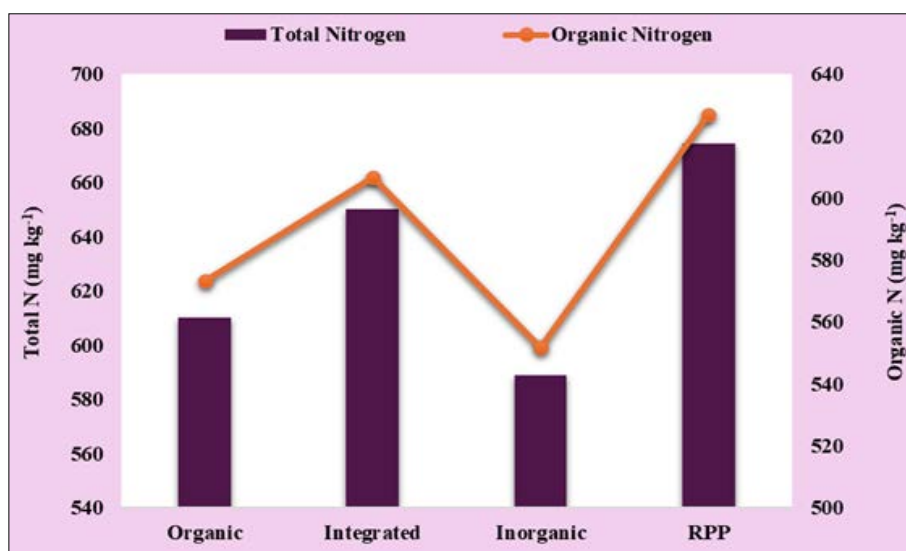


Fig 5: Organic nitrogen and total nitrogen contents in surface soil as influenced by different production systems

Conclusion

Long-term nutrient management altered both soil carbon pools and nitrogen fractions in the rainfed vertisol under the maize-chickpea cropping system. The 100% organic system maintained the highest total carbon, POXC, MBC and all four oxidizable carbon fractions, while inorganic carbon was highest under 100% inorganic fertilization and

increased in the subsurface layer. RPP and integrated nutrient management recorded comparatively higher ammonical, nitrate, organic and total nitrogen, with RPP generally ranking first and integrated management second. Most carbon pools and nitrogen fractions declined with soil depth, whereas inorganic carbon increased at the subsurface. Overall, the findings show that organic inputs were

particularly effective for maintaining soil carbon pools, while combining organic and inorganic nutrient sources with FYM improved nitrogen status.

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 the writing or editing of this manuscript.

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Competing Interests

The authors declare that they have no competing interests.

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