



The Effects of Organic Farming on Soil Physical Properties and Organic Carbon Pools in Groundnut Based Cropping Systems

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Authors' contributions

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

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ABSTRACT

The agricultural production systems leading to loss of soil organic carbon (SOC) might be contributing to release of CO₂ into the atmosphere. Consequently, an attempt was made to assess the organic carbon stock, related soil physical and physico-chemical properties under different groundnut based cropping systems viz., groundnut-groundnut, groundnut-blackgram, groundnut-finger millet and groundnut-foxtail millet. Soil samples (0-15 and 15-30 cm depth) were collected from each cropping system after the harvest of the *rabi* crop. Analysis on particle size distribution and pH revealed that soil was sandy loam and neutral to slightly alkaline in nature. The soil physical properties were varied under organic farming and ICM practice. The lower bulk density (1.51 and 1.60 Mg m⁻³), higher porosity (43.10 and 39.69 per cent), aggregate stability (66.22 and 64.79 per cent), MWD (0.93 and 0.91 mm), infiltration rate (19.02 cm hr⁻¹) and saturated hydraulic conductivity (8.98 and 7.79 cm hr⁻¹) were recorded under organic farming (M₁) compared to ICM practice (M₂) at 0-15 and 15-30 cm, respectively. The soil moisture content was recorded at flowering, peg initiation, and pod development during *kharif* season and higher was recorded under organic farming (17.58, 23.12 and 11.52 per cent; 16.96, 22.48 and 10.86 per cent) compared to ICM practice (M₂) (16.58, 21.32 and 10.28 per cent; 15.88, 20.84 and 9.88 per cent) at 0-15 cm and 15-30 cm, respectively. However, the physical properties were not varied among different groundnut based cropping systems. The higher organic carbon (0.54 and 0.49 per cent), water soluble carbon (13.91 and 11.57 mg kg⁻¹), active carbon pool (0.27 and 0.24 per cent) and passive carbon pool (0.26 and 0.25 per cent) were recorded under organic farming compared to ICM practice at 0-15 and 15-30 cm, respectively.

Keywords: Carbon pools; cropping systems; ICM practice; organic farming; soil physical properties.

1. INTRODUCTION

Climate change and food insecurity are pressing global challenges faced by humanity (Hasegawa et al., 2021). One effective approach to address both issues involve sequestering atmospheric CO₂-C in agricultural soils. Implementing management practices such as suitable crop rotations (Wright & Hons, 2005) and integrated nutrient management (Mandal et al., 2007; Majumder et al., 2008; Reddy et al., 2019) can play a pivotal role for sequestering the atmospheric carbon in to the soil. Soil health, defined as the capacity of soil to function as a living system, is essential for maintaining the stability of terrestrial ecosystems and buffering against disturbances like drought, climate change, pest infestations and soil pollution. However, soil degradation, which undermines soil health, poses significant risks to the well-being of humans, animals and plants (Suresh et al., 2017). Restoring soil health through sustainable farming practices is a time consuming process, especially in regions with limited growing degree days. Therefore, the key challenge lies in identifying soil management techniques that enhance soil organic carbon sequestration and moisture retention, ensuring sustained productivity and profitability for farmers.

The use of organic manures, a traditional agricultural practice employed for centuries, remains vital for providing nutrients and improving soil quality. Organic manure application enhances soil physical properties by increasing soil aggregation and stability, reducing micropore volume while increasing macropores, improving saturated hydraulic conductivity, and boosting water infiltration rate. Additionally, it enhances soil water holding capacity at both field capacity and wilting point (Sulfab, 2013). Groundnut leaves contribute residual fertility, which benefits subsequent crops in rainfed farming systems. Incorporating organic manures like farmyard manure and vermicompost further improves soil structure, microbial activity and moisture conservation, ultimately stabilizing crop productivity in rainfed regions (Lourduraj, 1999). Beneficial double-cropping systems in limited water source areas include groundnut followed by green gram, black gram, finger millet, cowpea, field bean, and horse gram. Groundnuts can also be intercropped with various cereals and millets to enhance productivity and resource efficiency.

2. MATERIALS AND METHODS

A long-term field experiment at Regional Agricultural Research Station, Tirupati of Acharya N. G. Ranga Agricultural University was

started in the year 2016 to study the effect of organic farming practices in groundnut based cropping systems in *Alfisols* and the present investigation was carried out as part of the ongoing experiment during *kharif* and *rabi* 2023-24 which is geographically situated at 13.6° N latitude and 79.3° E longitude with an altitude of 189.2 meters above mean sea level in the Southern Agro-Climatic Zone of Andhra Pradesh. During the *kharif* season, the experiment was laid into two main plots viz., M₁, organic farming (10 t ha⁻¹ FYM applied at last plough, soil application of *PSB*, *Rhizobium*, KRB and *Trichoderma viridae* each @ 5kg ha⁻¹, spraying of neem oil and pheromone traps at 20 no's ha⁻¹) and M₂, ICM (integrated crop management) practice (RDF 20:40:50 of N: P₂O₅: K₂O kg ha⁻¹, seed treatment with Dithane M-45, chemical weed control and need based plant protection measures) with groundnut crop as a rainfed crop. During *rabi* season, each main plots were divided into four sub plots viz., groundnut (S₁), blackgram (S₂), finger millet (S₃) and foxtail millet (S₄). To the organic farming sub plots, 10 t ha⁻¹ FYM was applied at last plough, soil application of *PSB*, *Rhizobium* (for groundnut and blackgram), *Azospirillum* (for finger millet and foxtail millet), KRB and *Trichoderma viridae* each at 5 kg ha⁻¹, pheromone traps @ 20 no's ha⁻¹ and neem oil spraying was done. To the ICM subplots, RDF (20-40-50, 20-50-0, 60-30-20 and 40-20-0 of N: P₂O₅: K₂O kg ha⁻¹ to groundnut, blackgram, finger millet and foxtail millet respectively were applied), seed treatment with Dithane M-45, chemical weed control and need based plant protection measures were taken. Soil samples were collected from each sub plot at depths of 0-15 and 15-30 cm after harvest of the *rabi* crops and analysed for various physical and physico chemical properties. The method of analysis were as outlined by Piper (1950) for particle size distribution using hydrometer, Blake and Hartge (1986) for determination of bulk density and porosity using core sampler, and Yoder (1936) for determination of aggregate stability and MWD. The soil moisture content was recorded by using time domain reflectometry (TDR) during critical stages of *kharif* groundnut in both organic and ICM plots. Soil pH and EC were determined using 1:2.5 soil water suspension as described by Jackson (1973). Soil organic carbon was analysed by wet chromic acid digestion as outlined by Walkley and Black (1934) and water soluble carbon by McGill et al. (1986). Other carbon pools viz., active carbon pool and passive carbon pool were determined as per the procedures outlined by Kolar et al.

(2011) and Chan (2001). Statistical analysis was conducted for the results using t-test and ANOVA with data processed in SPSS.

3. RESULTS AND DISCUSSION

The data pertaining to various soil physical and physio-chemical properties under organic farming and ICM practice with different groundnut based cropping systems were presented and discussed here under.

3.1 Particle Size Distribution

The particle size distribution was not significantly influenced by organic farming (M₁) and ICM practice (M₂). The textural class of both organic and ICM practices was sandy loam only, hence long-term practice of organic or integrated crop management (ICM) have not altered the soil texture, since it was permanent property (Srinivasarao et al., 2012).

3.2 Bulk Density and Porosity

The lower bulk density values were recorded under organic farming (M₁) (1.51 and 1.60 Mg m⁻³) compared to ICM practice (M₂) (1.63 and 1.68 Mg m⁻³) at 0-15 and 15-30 cm, respectively. However, no significant differences in bulk density were observed among the different groundnut based cropping systems adopted (Table 1). Higher soil porosity values (43.10 and 39.69 per cent) were observed under organic farming (M₁) compared to ICM practice (M₂) (38.85 and 36.75 per cent) at 0-15 cm and 15-30 cm, respectively. However, the adoption of different groundnut based cropping systems in both the treatments did not result in any significant changes in soil porosity.

The reduced bulk density under organic farming is primarily attributed to the application of farmyard manure (FYM), which contributes to the development of a well-structured soil profile. FYM enhances soil porosity, particularly microporosity, by adding organic matter that binds soil particles together. This process increases soil volume and consequently reduces bulk density compared to ICM practice (Sharma et al., 2000).

3.3 Aggregate Stability and Mean Weight Diameter

The organic farming (M₁) treatment showed higher aggregate stability (66.22 and 64.79 per cent) and mean weight diameter (MWD) (0.93 and 0.91 mm) as compared to ICM practice (M₂)

(57.96 and 54.47 per cent; 0.81 and 0.76 mm) at 0-15 cm and 15-30 cm, respectively. However, neither aggregate stability nor MWD was not significantly affected by different cropping systems in both the treatments (Table 1).

The increased MWD observed under the organic farming treatment can be attributed to the role of organic matter as a binding agent. Application of farm yard manure facilitated the formation of stable aggregates by cementing primary particles and clay domains together (Hatti et al., 2008).

3.4 Infiltration Rate and Saturated Hydraulic Conductivity

The infiltration rate and saturated hydraulic conductivity was varied under organic farming and ICM practice (Table 1). Infiltration rate which refers to the rate at which water enters the soil, was recorded higher under organic farming (M_1) treatment (19.02 cm hr⁻¹) as compared to ICM practice (M_2) (15.98 cm hr⁻¹). However, the rate of water intake was not significantly influenced by the adoption of different groundnut based cropping systems. Saturated hydraulic conductivity indicates the downward movement of water through saturated soil column and it was slightly higher under organic farming (M_1) (8.98 and 7.79 cm hr⁻¹) compared to ICM practice (7.48 and 6.93 cm hr⁻¹) at 0-15 and 15-30 cm, respectively. But, however, it was not significantly influenced by different groundnut based cropping systems in both the treatments. The higher infiltration rate observed under organic farming can be attributed primarily to the application of FYM. FYM improves soil structure and enhances biological activity, leading to increased aggregation of soil particles. This aggregation creates a more porous soil structure with enhanced macropore formation, facilitating the movement of water into the soil (Sarkar et al., 2003; Fueki et al., 2012).

3.5 Available Soil Moisture Content and Profile Water Storage Depth

The available soil moisture content (Table 2 and Fig. 1) was measured by TDR 350 at 0-15 and 15-30 cm depth at flowering, peg initiation and pod development stages during *khariif* season. The organic farming (M_1) treatment showed higher soil moisture content compared to ICM practice (M_2) at various growth stages (flowering, peg initiation and pod development) and at different soil depths. The mean soil moisture content (%) at flowering, peg initiation and pod development in organic farming (M_1) treatment

were 17.58, 23.12 and 11.52 per cent at 0-15 cm and 16.96, 22.48 and 10.86 at 15-30 cm. The ICM practice (M_2) recorded lower mean moisture content during all the stages with 16.58, 21.32 and 10.28 per cent at 0-15 cm and 15.88, 20.84 and 9.88 at 15-30 cm. According to Lal (2004), organic amendments such as compost, manure and crop residues contribute to increased soil aggregation and porosity, which helps to retain soil moisture and reduce evaporation. The profile water storage depth was not varied between organic farming (M_1) and ICM practice (M_2) and values were at par with 26.3 and 26.2 cm m⁻¹, respectively. Ghuman and Sur (2001) reported higher soil moisture storage in the 1.8 m deep profile was upto 27-85 mm in the manured plots than control during four of six years due to the improvement in organic carbon content of the soil.

3.6 SOIL Reaction (pH)

During the *rabi* 2023-24 season, organic farming (M_1) recorded higher soil pH values (7.42 and 7.37) compared to ICM practice (M_2) (7.38 and 7.29) at 0-15 cm and 15-30 cm, respectively. Among the cropping systems, the groundnut-blackgram system (S_2) exhibited numerically higher soil pH (7.47 and 7.38), followed by the groundnut-groundnut system (S_1) (7.41 and 7.37). The interaction between organic and ICM practices showed no significant effects on soil pH during the season.

A slight increase in soil pH was observed across management practices and cropping systems compared to the initial soil pH of 6.42, recorded at the initiation of the experiment in 2016. These variations in pH could be attributed to the differing effects of chemical fertilizers and organic matter in treated plots. The application of FYM in organic farming likely contributed to the increased soil pH. Enhanced microbial activity facilitated the breakdown of organic matter, improving soil structure and reducing soil acidity by neutralizing excess hydrogen ions.

3.7 Electrical Conductivity

The electrical conductivity was not significantly influenced by management practices and among groundnut based cropping systems and it remained unchanged from the initial EC (0.13 dS m⁻¹, non-saline) recorded during 2016. This might be due to the fact that organic manures do not contain salts and hence there was no influence of organic manures on salt accumulation in soil.

Table 1. Effect of organic farming on soil physical properties after *rabi*, 2023-24

Treatments	Bulk density (Mg m ⁻³)		Porosity (%)		Aggregate stability (%)		Mean weight diameter (mm)		Infiltration rate (cm hr ⁻¹)	Saturated hydraulic conductivity (cm hr ⁻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		0-15 cm	15-30 cm
Main treatments											
M ₁ : Organic farming	1.51	1.60	43.14	39.69	66.22	64.79	0.93	0.91	19.02	8.98	7.79
M ₂ : ICM	1.63	1.68	38.85	36.75	57.96	54.47	0.81	0.76	15.98	7.48	6.93
SEm±	0.08	0.01	0.47	0.39	0.50	0.57	0.01	0.01	0.44	0.13	0.08
CD (P = .05)	0.05	0.06	2.86	2.35	3.04	3.48	0.08	0.09	2.69	0.81	0.47
Sub treatments											
S ₁ : Groundnut - groundnut	1.56	1.64	41.29	38.47	62.61	60.05	0.88	0.84	8.63	7.93	8.63
S ₂ : Groundnut - blackgram	1.54	1.59	42.17	40.35	63.71	60.80	0.89	0.86	8.48	7.45	8.48
S ₃ : Groundnut - finger millet	1.60	1.69	39.98	36.66	60.52	58.43	0.85	0.82	8.00	7.07	8.00
S ₄ : Groundnut - foxtail millet	1.58	1.67	40.54	37.41	61.52	59.25	0.86	0.83	7.82	7.00	7.82
SEm±	0.01	0.02	0.55	0.87	0.78	0.65	0.01	0.01	0.23	0.26	0.23
CD (P = .05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction											
Sub at same level main (S x M)											
SEm±	0.02	0.03	0.77	1.23	1.10	0.92	0.02	0.01	0.33	0.33	0.36
CD (P = .05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Main at same or different level sub (M x S)											
SEm±	0.02	0.03	0.82	1.13	1.08	0.98	0.02	0.02	0.52	0.32	0.32
CD (P = .05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 2. Effect of organic farming on available soil moisture content (%) at critical stages of groundnut during *kharif* 2023

Treatments	0-15 cm						15-30 cm					
	Flowering		Peg initiation		Pod development		Flowering		Peg initiation		Pod development	
	M ₁	M ₂	M ₁	M ₂	M ₁	M ₂	M ₁	M ₂	M ₁	M ₂	M ₁	M ₂
Mean	17.58	16.58	23.12	21.32	11.52	10.28	16.96	15.88	22.48	20.84	10.86	9.88
Standard deviation	1.89	1.73	3.21	3.02	1.48	0.76	1.62	1.59	2.92	2.91	1.60	0.78
SEm±	0.84	0.77	1.44	1.35	0.66	0.34	0.72	0.71	1.30	1.30	0.71	0.35
t-value	0.87		0.91		1.67		1.06		0.89		1.23	
p-value	0.41		0.39		0.13		0.32		0.40		0.25	

Table 3. Effect of organic farming on soil pH, EC and carbon pools after *rabi*, 2023-24

Treatments	pH		Electrical conductivity (dSm ⁻¹)		Organic carbon (%)		Water soluble carbon (mg kg ⁻¹)		Active pools (%)		Passive pools (%)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
	Main treatments											
M ₁ : Organic farming	7.42	7.37	0.13	0.15	0.54	0.49	13.91	11.57	0.27	0.24	0.26	0.25
M ₂ : ICM	7.38	7.29	0.14	0.16	0.44	0.39	11.31	10.06	0.21	0.19	0.20	0.18
SEm±	0.04	0.02	0.002	0.003	0.01	0.01	0.30	0.22	0.006	0.006	0.003	0.005
CD (P = .05)	NS	NS	NS	NS	0.08	0.06	1.84	1.36	0.04	0.04	0.02	0.03
Sub treatments												
S ₁ : Groundnut - groundnut	7.41	7.37	0.13	0.15	0.51	0.46	13.65	11.97	0.26	0.24	0.25	0.23
S ₂ : Groundnut - blackgram	7.47	7.38	0.13	0.15	0.50	0.45	12.63	10.76	0.24	0.22	0.24	0.22
S ₃ : Groundnut - finger millet	7.34	7.28	0.14	0.16	0.47	0.42	11.80	10.04	0.21	0.20	0.21	0.19
S ₄ : Groundnut - foxtail millet	7.37	7.30	0.14	0.16	0.49	0.44	12.35	10.49	0.23	0.21	0.22	0.21
SEm±	0.04	0.04	0.004	0.004	0.01	0.01	0.42	0.44	0.01	0.01	0.01	0.009
CD (P = .05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction												
Sub at same level main (S x M)												
SEm±	0.05	0.05	0.005	0.005	0.02	0.01	0.59	0.63	0.01	0.01	0.01	0.01
CD (P = .05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Main at same or different level sub (M x S)												
SEm±	0.06	0.05	0.005	0.006	0.02	0.02	0.59	0.59	0.01	0.01	0.01	0.01
CD (P = .05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

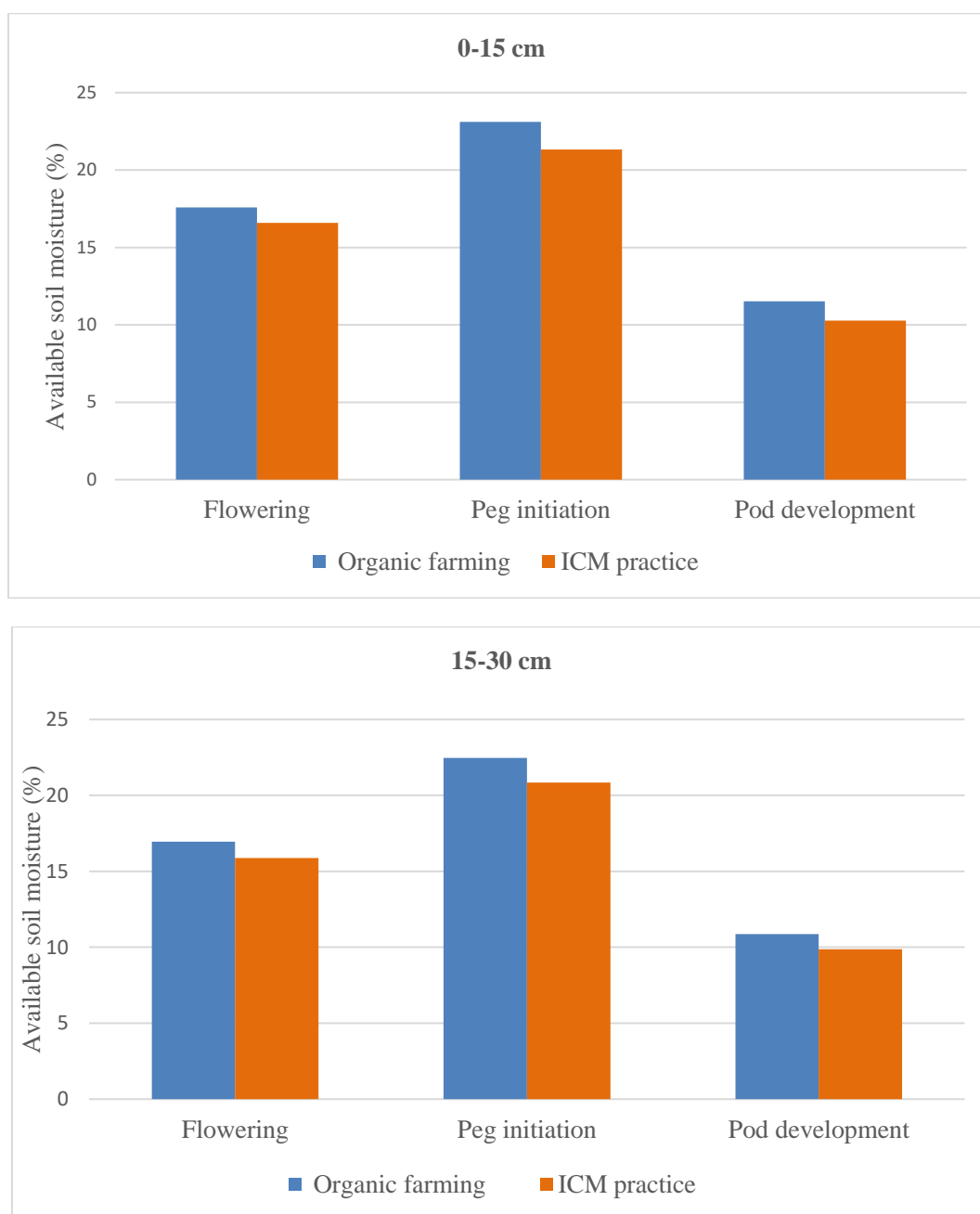


Fig. 1. Effect of organic farming on available soil moisture content (%) at critical stages of groundnut during *kharif* 2023

3.8 Organic Carbon

The higher organic carbon content was recorded under organic farming (M_1) (0.54 and 0.49 per cent) compared to ICM practice (M_2) (0.44 and 0.39 per cent) at 0-15 and 15-30 cm, respectively. Both organic farming and ICM practice exhibited decreased trend in organic carbon content with depth. The groundnut based cropping systems did not significantly influence

organic carbon content. However, the groundnut-groundnut cropping system (S_1) recorded higher organic carbon content at 0-15 cm (0.51%) and 15-30 cm (0.46%). The observed increase in organic carbon in the surface layer, compared to the initial soil organic carbon (SOC) content of 0.38% recorded in 2016, can be attributed to the cumulative effects of FYM application over time. The rise in soil organic carbon reflects the synergistic impact of organic manures on soil

microflora, which enhanced the organic carbon pool over time (Sohan & Kler, 2007).

3.9 Water Soluble Carbon

The organic farming treatment showed higher water soluble carbon content (13.91 mg kg^{-1} and 11.57 mg kg^{-1}) compared to ICM practice (11.31 and 10.06 mg kg^{-1}) at 0-15 cm and 15-30 cm, respectively. However, no significant variation in water soluble carbon content was observed among the different groundnut based cropping systems. The groundnut-groundnut (S_1) cropping system showed relatively higher WSC content, with values of 13.65 mg kg^{-1} at 0-15 cm and 11.97 mg kg^{-1} at 15-30 cm. The increased WSC content in the organic farming treatments can be attributed to the greater carbon input from FYM and enhanced crop productivity (Kumari et al., 2013; Brar et al., 2013).

3.10 Active Carbon Pool (ACP)

The organic farming treatment recorded a higher active carbon (C) pool, with values of 0.27% at 0-15 cm and 0.24% at 15-30 cm, compared to ICM practices, which showed 0.21% at 0-15 cm and 0.19% at 15-30 cm. However, no significant differences in the active C pool were observed among the different groundnut-based cropping systems.

The groundnut-groundnut (S_1) cropping system recorded the highest active C pool, with values of 0.26% at 0-15 cm and 0.24% at 15-30 cm. The active C pool in sub-surface soils may result from the decomposition of root residues or translocation from surface soil.

3.11 Passive Carbon Pool (PCP)

The organic farming treatment recorded a higher passive carbon (C) pool, with values of 0.26% at 0-15 cm and 0.25% at 15-30 cm, compared to ICM practices, which showed 0.20% at 0-15 cm and 0.18% at 15-30 cm. The passive C pool was not significantly influenced by the different groundnut-based cropping systems. However, the groundnut-groundnut (S_1) cropping system exhibited the highest passive C pool, with values of 0.25% at 0-15 cm and 0.23% at 15-30 cm. There was no significant interaction effect between management practices and cropping systems. The application of FYM increased the passive C pool due to the lower C:N ratio and the higher proportion of recalcitrant organic

compounds in FYM compared to crop residues (Mondal et al., 2020).

4. CONCLUSION

The organic farming practice (M_1) played an important role through incorporation of FYM in improving soil physical characteristics viz., bulk density, porosity, infiltration rate, moisture availability and aggregate stability in the soil. The soil organic carbon (SOC), water soluble carbon, and various carbon pools (active and passive pools) were reportedly higher in organic farming (M_1) compared with ICM practice.

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 this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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