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Impact of Inorganic Fertilizers, Organic Manures, and their Integration on Soil Carbon Sequestration in a Long-term Rice-rice Cropping System

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

The present study highlights the impact of Inorganic Fertilizers, Organic Manures, and their integration on Soil Carbon Sequestration in a long-term rice-rice cropping system. Large scale changes in land use like deforestation and agricultural activities like biomass burning, ploughing, drainage, low input farming have resulted in significant changes in SOC pools. A field experiment was carried out under field conditions during both *kharif* and *rabi* seasons of 2016-2017 and 2017-2018 at Andhra Pradesh Rice Research Institute and Regional Agricultural Research Station, Maruteru, West Godavari district in the ongoing All India Coordinated Research Project on Long Term Fertilizer Experiment Project. The results reported that the application of 100 % RDF along with $ZnSO_4$ @ 40 kg ha^{-1} and application of 100 % RDF were not significant. Among different fertilized plots, SOC stocks and carbon sequestration rate in the 15 cm plough layer were

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significantly higher under 100% RDF + FYM + $ZnSO_4$ (T_7) followed by 50 % NPK + 50% N through FYM (T_{10}). At the starting of the experiment in *kharif,* 1989, the soil organic carbon stock was 11.14 Mg ha^{-1} and after 29 years of continuous application of organic and inorganic fertilizers, SOC stocks ranged from 11.06 to 24.39 Mg ha^{-1} at harvest of *rabi* rice in 2018.

Keywords: Organic manures; carbon stock and carbon sequestration; CSR.

1. INTRODUCTION

"India ranks second in rice production with 110.9 million tonnes and productivity 2.28 t ha $^{-1}$ from an area of 39.47 million hectares. In Andhra Pradesh, rice is grown in an area of 23.30 lakh ha with annual production of 104.88 lakh tones and productivity of 2,820 kg ha^{-1}" (Indiastat, 2015-16). Organic carbon is a basic building block for all the life on earth. It is also a major factor in maintaining the overall soil health. "Many tropical soils are poor in nutrients and rely on the recycling of nutrients from soil organic matter to improve and maintain crop productivity. Intensive cultivation, growing of exhaustive crops, use of imbalanced and inadequate fertilizers, restricted use of organic manures has made the soils not only deficient in nutrients but also deteriorate soil health resulting decline in crop response to recommended dose of NPK fertilizers" (Lal et al., 2007).

"Large scale changes in land use like deforestation and agricultural activities like biomass burning, ploughing, drainage, low input farming has resulted in significant changes in SOC pools. By mineralization, leaching, soil erosion, continuous cultivation, 50-70 % of antecedent SOC is lost as CO_2. The global SOC pool constitutes about 1550 Gt (1 Gt = 10^9 t) organic carbon in the top one-meter layer of soil, which is three times the terrestrial vegetation and twice the global atmospheric carbon pools. The soil is the largest terrestrial pool of organic carbon, about 1150 Pg compared with about 700 Pg in the atmosphere and 600 Pg in the land biota" (Lal and Kimble, 1997). "The global potential of soil organic carbon sequestration is estimated at 0.6 to 1.2 GT C yr^{-1}, comprising 0.4 to 0.8 GT C yr^{-1} through adoption of recommended management practices on crop land soils" (Lal et al., 2007).

2. MATERIALS AND METHODS

The experiment was carried out under field conditions during *kharif* and *rabi* seasons of 2016-2017 and 2017- 2018 at Andhra Pradesh Rice Research Institute and Regional Agricultural Research Station, Maruteru, West Godavari district in the ongoing All India Coordinated Research Project on Long Term Fertilizer Experiment Project. The treatments consisted of control, 100 per cent recommended dose of NPK, 100 per cent recommended dose of NK, 100 per cent recommended dose of PK, 100 per cent recommended dose of NP, 100 per cent recommended dose of NPK+$ZnSO_4$ @ 40 kg/ ha, 100 per cent recommended dose of NPK+$ZnSO_4$ @ 40 kg/ ha+ FYM @ 5 t ha^{-1}, 50 per cent recommended dose of NPK, 50 % NPK + 50 % N through green manures, 50 % NPK + 50 % N through FYM, 50 % NPK + 25 % N through green manures + 25 % N through FYM and FYM only @ 10 t/ha. All together there were twelve treatments laid out in RBD with three replications for both *kharif* and *rabi* seasons in two years of study. "Nitrogen was applied through urea in three equal splits ($1/3^{rd}$ basal+$1/3^{rd}$at tillering+$1/3^{rd}$at panicle initiation stage). Phosphorus was applied through DAP was used duly taking its N content into account and potassium as muriate of potash (60 % K_2O) and zinc as zinc sulphate ($ZnSO_4.7H_2O$). The entire dose of phosphorus, potassium and zinc were applied as basal. Recommended dose of fertilizer for *kharif* season was 90: 60: 60 N: P_2O_5: K_2O kg ha^{-1} and for *rabi* season it was 180: 90: 60 N: P_2O_5: K_2O kg ha^{-1}. Well decomposed farmyard manure (FYM) manure and *Calotropis* (green leaf manure) were applied two weeks before transplanting" (Lal et al., 2007). The experiment on rice – rice sequence as detailed above was repeated on a same site during *kharif* 2016-17 and *rabi*2017-18, respectively. Popular cultivars of *kharif* rice and *rabi* rice, MTU-1061, MTU-1010 respectively, were used for the study. The size of total carbon stock is calculated following standard methods described by Bhattacharyya et al. (2000). "Calculation of SOC stock was done by multiplying OC content (%), bulk density (Mg m^{-3}) and thickness (cm) of surface soil. The carbon buildup or depletion is the difference between the final organic carbon and initial organic carbon for 0-15 cm soil depth and expressed as Mg ha^{-1}. Carbon sequestration rate was calculated by dividing the carbon buildup or depletion with the age of the experiments in years and expressed as t ha^{-1} yr^{-1}" (Srinivasarao et al*.,* 2009).

3. RESULTS AND DISCUSSION

3.1 $K_2Cr_2O_7$ - Carbon (Organic Carbon)

The glance of the data (Table 2) revealed that an overall increase in organic carbon content was observed at harvest stage in the present study in all the treatments as compared to their initial stage.

At initial stage, organic carbon content in soil was ranged from 5.0 to 12.1 in (*Kharif*, 2016); 5.1 to 12.3 in (*Rabi*, 2017); 5.2 to 12.6 in (*Kharif*, 2017) and 5.4 to 12.9 in (*Rabi*, 2018) g kg^{-1}. The highest organic carbon content 12.1, 12.3, 12.6 and 12.9 g kg^{-1} in *kharif*, *rabi* 2016-17 and *kharif*, *rabi* 2017-18, respectively was observed with application of 100 % RDF+FYM @ 5 t ha^{-1}+ $ZnSO_4$ (T_7) and it was significantly superior other treatments but however it was on par with T_{10} and T_{12} and the lowest organic carbon content (5.0, 5.1, 5.2 and 5.4 g kg^{-1}) was observed in control (T_1).

At initial stage, among the inorganic treatments (T_2, T_3, T_4, T_5, T_6 and T_8), the treatment T_6 (100% RDF +$ZnSO_4$) recorded higher organic carbon content over other inorganic treatments (T_2, T_3, T_4, T_5 and T_8) and it was significantly superior over treatment T_3 (100% NK), T_4 (100% PK), T_5 (100% NP) and T_8 (50% NPK) but however it was on par with treatment T_2 during both the years of study in *kharif* season. Whereas in *rabi* season the treatment T_6 was significantly superior over treatment T_4 (100% PK), T_5 (100% NP) and T_8 (50% NPK) but however it was on par with treatment T_2 and T_3 (100% NK) during both the years of study.

"The imbalanced use of nutrients or application of nutrients of 100% NK, 100% NP, 50% NPK resulted in decline in SOC. Incorporation of crop residue in less quantity as a result of low productivity under imbalanced nutrient application was the main reason for decline in SOC under imbalanced fertilization" (Annual Report of AICRP on LTFE, Bhopal, 2006).

At harvesting stage, the highest soil organic carbon content (12.4, 12.6, 12.9 and 13.2 g kg^{-1} in *kharif*, *rabi* 2016-17 and *kharif*, *rabi* 2017-18, respectively) was observed in the plots those received FYM along with 100 per cent RDF + $ZnSO_4$ (T_7) and the lowest soil organic carbon content (5.2, 5.3, 5.4 and 5.6) was observed in the control plot (T_1).

At harvesting stage, the highest organic carbon content in all the four seasons during two years was observed in T_7 it was significantly superior over other treatments but however it was on a par with T_{10} (50% NPK+ 50 % N through FYM) and T_{12} (FYM only @ 10t/ha). The lowest organic carbon was observed in control (T_1). The results were same in both years of study during the *kharif* and *rabi* season.

"Use of organic amendments such as FYM, rice straw and green manure improved soil productivity in rice-wheat cropping" (Ghosh et al*.,* 2009) "and had the capacity to add OC and to improve soil condition. Marked increase in soil organic carbon following incorporation of FYM and marginal changes in rest of the treatments indicated that increase in root biomass was responsible for such observed changes" (Akhilesh et al*.,* 2009).

Among the inorganic treatments, the treatment T_6 (100% RDF + $ZnSO_4$) recorded the highest organic carbon and significantly superior over other treatments but however it was on par with treatment T_2 (100% NPK). The results were same in both years of study during the *kharif* and *rabi* season at harvesting stage.

The only organic (T_{12}) treatment recorded significantly highest organic carbon and this was significantly superior over all other inorganic treatments (T_2, T_3, T_4, T_5, T_6, T_8) at initial and harvest stage in *kharif and rabi*, 2016-17 and 2017-18, respectively.

The treatments which received only inorganic fertilizers showed lower organic carbon values which could be due to no addition of organic manures as well as intensive oxidation process aided by degradation and decomposition of organic matter.

The higher amounts of soil organic carbon observed in Godavari Zone might be due to fairly stable and more recalcitrant carbon content in soil and the soils being alluvial in nature had resulted in the carbon getting attached to clay and silt particles and thereby protecting the organic carbon from microbial degradations. Tiwari et al*.* (2002) observed a significant increase in soil organic carbon with continuous use of FYM along with recommended dose of NPK over 29 years.

"However, effect of FYM along with 100% RDF was superior over other treatments at initial and at harvest. The higher content of lignin and phenol in FYM led for formation of stable complexes with protein of plant origin making FYM more resistant to decomposition than that of green manure" (Tian et al*.,* 1992).

Similar results were reported by Sharma et al*.* (2002) and they reported that "the marked increase in the soil organic carbon content following incorporation of FYM along with NPK was attributed to resultant enhanced crop cultivation and associated greater returns of added organic materials in the form of decaying roots, litter and crop residues over the years of study. Further it might had created environment conducive for formation of humic acid which stimulated the activity of soil microorganisms resulting in an increase in the organic carbon content of the soil".

3.2 Carbon Stock (CS)

SOC stocks in the 15 cm plough layer were presented in the Table 4. The data revealed that the highest CS was observed in 100% RDF + FYM + $ZnSO_4$ (T_7) (24.39 Mg ha^{-1}). Lowest was observed in control (T_1) (11.06 Mg ha^{-1}).

At the starting of the experiment in *kharif,* 1989, the soil organic carbon stock was 11.14 Mg ha^{-1} and after 29 years of continuous application of organic and inorganic fertilizers, SOC stocks were ranged from 11.06 to 24.39 Mg ha^{-1} at harvest of *rabi* rice in 2018.

Among all the treatments the significantly highest soil organic carbon stock was obtained in T_7, which received 100% RDF+ $ZnSO_4$ +FYM (24.39 Mg ha^{-1}) it was significantly superior over other treatments receiving inorganics (T_2, T_3, T_4, T_5, T_6, T_8) but however it was on par with T_9 (50% NPK+ 25% N through green manures), T_{10} (50% NPK+ 50 % N through FYM), T_{11} (50% NPK+ 25% N through FYM + 25% N through green manures) and T_{12} (FYM only 10t ha^{-1}).

The results are in concurrence with the earlier studies by Rasmussen et al*.* (1980), who reported that increase in C stock in soils was directly linked to the amount and quality of organic manures or manuring and fertilization, respectively.

Among the inorganic treatments, the treatment T_6 (100% RDF) recorded the significantly highest soil organic carbon stock over treatment T_8 but however it was on par with treatment T_2 (100% RDF), T_3 (100% NK), T_4 (100% PK) and T_5 (100% NP).

The averaged percentage increase of SOC stock in treatments T_2 (100% RDF), T_3 (100% NK), T_4 (100% PK), T_5 (100% NP), T_6 (100% RDF + $ZnSO_4$) and T_8 (50 % NPK) treatments over control (T_1) were 96.38, 91.68, 80.92, 73.59, 96.92 and 61.93.

These results suggested that long-term use of organic manures alone or in combination with recommended dose of fertilizers had resulted in the buildup of soil organic carbon content even under tropical climate. The soils under study were rich in clay content (31 %) (Godavari zone) and high soil organic carbon content (> 0.75%).

"A possible conservation or even increase in C stocks in soil in lowland tropics, despite high temperature prevalent throughout the year, which favored rapid mineralization of C. According to their opinion, it was due to the relatively slow rate of soil C mineralization under anaerobic conditions and also the large C inputs from non- vascular plants (photosynthetic algal communities) in the soil- flood water ecosystem. Results from a few long-term experiments of also showed similar buildup of SOC due to application of manure with balanced fertilization. Organic sources of nutrients decompose slowly resulting in more OC accumulation in soil" (Mandal et al*.,* 2007).

Cultivation with balanced fertilization, however, caused a net enrichment of OC stock of the soil (Table 4). This was obviously associated with a large amount of crop residues and root biomass C left over in the soil owing to the significantly higher yield of the crops grown under those treatments compared to the control. These findings suggested that rice-rice cropping system had improved OC content when cultivated with balanced fertilization, with or without organics while bulding carbon stock in soil.

3.3 Carbon Buildup or Depletion

The data pertaining to soil carbon buildup or depletion under rice-rice cropping system are presented in Table 4.

After 29 years of rice-rice cropping, carbon sequestration in the top 15 cm plough layer ranged from - 0.09 to 13.31 Mg ha^{-1} in *rabi,* 2018 over the initial SOC stock of 11.14 Mg ha^{-1} in 1989. Highest C- sequestration (13.31 Mg ha^{-1}) was observed under 100% RDF+ $ZnSO_4$ + FYM treatment (T_7) and lowest (0.061 Mg ha^{-1}) under control treatment (T_1). The unfertilized control treatment did not show any buildup of SOC met depletion of SOC.

Among all the treatments, the highest carbon buildup was observed in treatment T_7 (100 % RDF + $ZnSO_4$ + FYM) it was significantly superior over other treatments but however it was on par with treatment T_{12} (FYM @10 t ha^{-1}) (Table 4). However, the depletion of organic carbon was observed under control (Table 4.). These findings had support of earlier report by Pedababu (2009). The inorganic treatments did not show any significant effect on carbon buildup.

3.4 Carbon Sequestration Rate (CSR)

The data presented in (Table 4) revealed that highest (0.462 Mg ha^{-1} yr^{-1}) carbon sequestration rate was recorded in T_7 (100 % RDF + $ZnSO_4$+ FYM) under rice which was significantly superior over other treatments but however it was on par with treatment T_{10} (50% NPK + 50% N through FYM) and T_{12} (FYM @10 t ha^{-1}).

The CSR was ranged between (-) 0.005 to 0.462 Mg ha^{-1} yr^{-1} among different treatments (T_1 to T_{12}). The rate of sequestration was 0.462 Mg ha^{-1} yr^{-1} in T_7 (100% RDF + $ZnSO_4$ + FYM) treatment whereas in T_2 (100% RDF) treatment the rate was 0.375 Mg ha^{-1} yr^{-1}. The rate of C-sequestration was negative with depletion (-0.005 Mg ha^{-1} yr^{-1}) in the control treatment (T_1).

"The results revealed that the application of both inorganic fertilizers and organic manures resulted in higher carbon sequestration rate compared to control. Addition of more root biomass carbon to soil with time due to improved physico-chemical properties and biological environment suitable for crop growth resulted in higher carbon sequestration rates. Greater amounts of organic inputs in 100% NPK + FYM treated plots resulted in higher carbon sequestration. Many studies had earlier shown that materials such as FYM with higher lignin content resulted in more carbon sequestration compared to materials with low lignin content. Farmyard manures contained most of carbon in recalcitrant forms resulted in more carbon sequestration as it had already gone under some decomposition before application in agricultural fields" (Bronson et al., 1998).

Table 1. Initial properties of the experimental soil before starting of experiment in 1989

Particulars	VI Block
I. Mechanical analysis	
1. Sand (%)	43
2. Silt (%)	26
3. Clay (%)	31
Textural class	Clay loam
Bulk density (Mg m^{-3})	1.37
pH (1:2.5)	7.0
EC (dS m^{-1})	1.09
Organic carbon (%)	0.55
Available N (kg ha^{-1})	300
Available P_2O_5 (kg ha^{-1})	17.0
Available K_2O (kg ha^{-1})	384.0
Available Fe (mg kg^{-1})	4.98
Available Mn (mg kg^{-1})	5.59
Available Cu (mg kg^{-1})	0.53
Available Zn (mg kg^{-1})	0.62
DHA (µg TPF g^{-1} soil Day^{-1})	166.21
Urease activity (µg of NH_4^+- N g^{-1} soil h^{-1})	15.13

Table 2. Effect of long-term use of inorganic fertilizers, organic manures and their combination on soil $K_2Cr_2O_7$ –C under rice (*Kharif,* 2016) and *Rabi*,2017

Treatments	$K_2Cr_2O_7$ -C (g kg^{-1})		$K_2Cr_2O_7$ -C (g kg^{-1})	
	Initial	**Harvest**	**Initial**	**Harvest**
T_1 Control	5.0	5.2	5.1	5.3
T_2 100 % RDF	10.3	10.6	10.5	10.7
T_3 100% NK	9.8	9.9	9.7	10.1
T_4 100% PK	9.1	9.3	9.2	9.4
T_5 100% NP	8.7	8.9	8.8	8.9
T_6 100 % RDF + $ZnSO_4$ @ 40 kg/ha	10.5	10.8	10.6	10.9
T_7 100 % RDF + $ZnSO_4$ @ 40 kg/ha + FYM @ 5t/ha	12.1	12.4	12.3	12.6
T_8 50% NPK	8.3	8.6	8.5	8.7
T_9 50% NPK + 50 % N through Green Manures	10.7	10.9	10.7	10.9
T_{10} 50% NPK + 50 % N through FYM	11.6	11.8	11.7	12.0
T_{11} 50% NPK + 25 % N through GM + 25 % N through FYM	11.1	11.3	11.2	11.5
T_{12} FYM only @ 10 t/ha	11.9	12.1	12.0	12.3
SEm ±	0.269	0.222	0.242	0.286
CD @ 0.05	0.8	0.6	0.7	0.8
CV (%)	7.10	7.98	6.59	7.54

Table 3. Effect of long-term use of inorganic fertilizers, organic manures and their combination on soil $K_2Cr_2O_7$ –C under rice (*Kharif,* 2017 and *Rabi,* 2018)

Treatments	$K_2Cr_2O_7$ -C (g kg^{-1})		$K_2Cr_2O_7$ -C (g kg^{-1})	
	Initial	**Harvest**	**Initial**	**Harvest**
T_1 Control	5.2	5.4	5.4	5.6
T_2 100 % RDF	10.6	10.9	10.8	11.1
T_3 100% NK	10.1	10.3	10.2	10.5
T_4 100% PK	9.2	9.5	9.5	9.9
T_5 100% NP	8.8	9.1	9.1	9.5
T_6 100 % RDF + $ZnSO_4$ @ 40 kg/ha	10.7	10.9	10.8	11.2
T_7 100 % RDF + $ZnSO_4$ @ 40 kg/ha + FYM @ 5t/ha	12.6	12.9	12.9	13.2
T_8 50% NPK	8.5	8.8	8.7	9.0
T_9 50% NPK + 50 % N through Green Manures	10.7	11.0	11.0	11.4
T_{10} 50% NPK + 50 % N through FYM	12.0	12.4	12.3	12.7
T_{11} 50% NPK + 25 % N through GM + 25 % N through FYM	11.3	11.6	11.6	12.0
T_{12} FYM only @ 10 t/ha	12.3	12.6	12.5	12.8
SEm ±	0.235	0.256	0.276	0.263
CD @ 0.05	0.69	0.75	0.81	0.77
CV (%)	6.79	8.43	7.29	8.43

Table 4. Effect of long-term use of inorganic fertilizers, organic manures and their combination on soil carbon stocks and carbon sequestration rate after 29 years (1989-2018) of rice cultivation

Treatments	SOC (2018)			
	Final carbon stock (Mg ha^{-1})	Initial carbon stock (Mg ha^{-1})	Buildup/depletion	CS rate (Mg ha^{-1}yr^{-1})
T_1 Control	11.06	11.14	- 0.09	- 0.005
T_2 100 % RDF	21.72	11.14	10.69	0.375
T_3 100% NK	21.20	11.14	10.01	0.359
T_4 100% PK	20.01	11.14	8.92	0.312
T_5 100% NP	19.20	11.14	8.09	0.286
T_6 100 % RDF + $ZnSO_4$ @ 40 kg/ha	21.78	11.14	10.75	0.381
T_7 100 % RDF + $ZnSO_4$ @ 40 kg/ha + FYM @ 5t/ha	24.39	11.14	13.31	0.462
T_8 50% NPK	17.91	11.14	6.72	0.239
T_9 50% NPK + 50 % N through Green Manures	21.90	11.14	10.92	0.384
T_{10} 50% NPK + 50 % N through FYM	23.68	11.14	12.59	0.442
T_{11} 50% NPK + 25 % N through GM + 25 % N through FYM	22.71	11.14	11.61	0.405
T_{12} FYM only @ 10 t/ha	23.26	11.14	12.17	0.427
SEm ±	0.992		0.541	0.014
CD @ 0.05	2.91		1.59	0.04
CV (%)	8.30		9.45	7.32

4. CONCLUSIONS

Among different fertilized plots, SOC stocks and carbon sequestration rate in the 15 cm plough layer were significantly higher under 100% RDF + FYM + $ZnSO_4$ (T_7) followed by 50 % NPK + 50% N through FYM (T_{10}). At the starting of the experiment in *kharif,* 1989, the soil organic carbon stock was 11.14 Mg ha^{-1} and after 29 years of continuous application of organic and inorganic fertilizers, SOC stocks were ranged from 11.06 to 24.39 Mg ha^{-1} in different treatments at harvest of *rabi* rice in 2018. Among the treatments T_7, T_9, T_{10}, T_{11} and T_{12}, soil organic carbon stock in T_7, which received 100% RDF+ $ZnSO_4$ +FYM @ 5t ha^{-1}recorded highest (24.39 Mg ha^{-1}) and it was on par with T_9 (50% NPK+ 25% N through green manures), T_{10} (50% NPK+ 50 % N through FYM, T_{11} (50% NPK+ 25% N through FYM + 25% N through green manures) and T_{12} (FYM only 10t ha^{-1}). The treatment T_{10} (50% NPK+ 50 % N through FYM) was on par with treatment T_6 (100% RDF + $ZnSO_4$) and T_2 (100% NPK).

The rate of carbon sequestration was highest (0.462 Mg ha $^{-1}$ yr^{-1}) in T_7 (100% RDF + $ZnSO_4$ + FYM @ 5t ha^{-1}) treatment. The rate of C-sequestration was negative with depletion (-0.005 Mg ha^{-1} yr^{-1}) of carbon in the control treatment (T_1). Among the inorganic treatments the balanced application of RDF along with $ZnSO_4$ treatment (T_6) recorded highest CSR (0.381 Mg ha $^{-1}$ yr^{-1}) and it was significantly superior over other treatments but however it was on par with treatment T_2 (100% NPK).

Among the inorganic treatments, the treatments receiving the balanced application of RDF along with $ZnSO_4$ treatment (T_6) recorded highest CSR (0.381 Mg ha $^{-1}$ yr^{-1}) and significantly superior over other treatments but however it was on par with treatment T_2 (100% RDF). The application of zinc did not show any significant effect on carbon sequestration rate.

No significant variation of carbon sequestration was observed between treatments 100% NPK, 100% NPK + Zn, 100% NK and 100% NP, however, increase in fertilizer rate from 50% NPK to 100% NPK resulted in 37% higher carbon sequestration.

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

Author has declared that no competing interests exist.

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