Assessment of Soil Respiration in Response to Decomposition of Different Crop Residues

ABSTRACT:

C: N ratio of crop residues is the key factor dictating the decomposition of crop residues and soil respiration. Crop residue incorporation is one of the best residue management options, which not only enhances soil health, but also reduces environmental pollution.

Aim: To investigate the effects of various crop residues *viz.*, paddy, sunflower, cotton and red gram on soil respiration.

Study Design: Completely Randomized Design

Place and duration of study: Study was conducted for 120 days at soil science laboratory during the year 2023-24, School of Agriculture, SR university, Warangal.

Methodology: An incubation study was conducted after pre-incubation. Soil respiration was measured by alkali trap method, at different days after incubation.

Results: The results indicated that incorporating crop residues significantly increased soil respiration rates, with the highest CO_2 emissions observed in treatments with both residues and nitrogen. Among the treatments, soil with paddy residue and nitrogen showed the highest respiration rate, demonstrating the synergistic effect of residue incorporation and nitrogen addition in enhancing organic matter decomposition. The lowest soil respiration was recorded in soil alone (control) treatment throughout the incubation period.

Conclusion: The study concludes that the incorporation of crop residues, especially when combined with nitrogen, significantly enhances soil respiration. The research provides critical insights for developing strategies that promote sustainable agriculture, emphasizing the need for residue retention and appropriate nutrient management to maximize soil productivity while minimizing environmental impacts.

Key Words: Crop residues, C:N ratio, Soil respiration, CO_2 emissions, Crop residue incorporation

INTRODUCTION:

Crop residue incorporation in soils is a key practice in agricultural management. Residues provide organic C and N inputs to soils for maintaining or improving the soil stocks of these elements and, ultimately soil health and crop productivity (Janz *et al.*, 2022). Crop residue decomposition may result in the formation of the hotspots of microbial N turnover processes (Janz *et al.*, 2022). Rapid decomposition of soil organic matter, and consequent N loss, is considered as a major limitation for maintaining soil fertility and a threat to the environment. Cox *et al.* (2004) reported that 80% of the crop residues burning took place during the post-harvest period. There as on behind this is attributed to the crop patterns used to ensure a higher economic return which have limited time between two consecutive crop cultivations. Some farmers even resort to a cycle of three crops a year with a short gap between harvesting and sowing of the next crop. Burning of residues emits a significant amount of Green House Gases (GHGs) (Grover and Chaudhry, 2023). Heat from burning of residues elevates soil temperature causing death of beneficial soil organisms also reduces level of C and potentially mineralizable N in the upper (0-15 cm) soil layer. However frequent residue burning leads to complete loss of soil microbial population, though the effect is temporary, as the microbes regenerate. Moreover, residue decomposition in soils potentially releases ammonia gas which is a precursor of secondary aerosol, a harmful pollutant for the environment and human health (Ruijter and Huijsmans 2012). The major environmental problem today is the global warming due to accumulation of gases like CO_2, CH_4, N_2O and Chlorofluoro Carbons along with water vapour in the atmosphere causing greenhouse effect through trapping outgoing thermal radiation and depletion of ozone layer in stratosphere, affecting several aspects of humanity on planet earth, due to increased temperature (0.3-0.6^oC) at the earth's surface (Centre, 1998).

Crop residues with a low C/N ratio (≤15) lead to significant N_2O emissions meanwhile, the incorporation of residues with a high C/N ratio (>40) produced insignificant changes or even reduced soil N_2O emissions (Huang *et al.*, 2025 and Akiyama *et al.*, 2020). Specifically, the composition of organic N and C compounds in the soluble, cellulose, and lignin-like fractions determine the N mineralization potential of residues, and this affects the fate of the incorporated residue N, as it may be immobilized in soil fractions or lost to the environment through the gaseous and hydrological pathways (Li *et al.*, 2024 and Lashermes *et al.*, 2010). Synchronizing soil N availability with plant requirements can improve the soil–plant system N use efficiency and reduce N losses through leaching below the crop rooting depth and/or from gaseous emissions (Vanlauwe *et al*., 2001). Previous studies confirm that C and N dynamics are mainly controlled by the C/N ratio (Liang *et al.,* 2022 and Nicolardot *et al.,* 2001), chemical components (*e.g*., lignin, total phenol, soluble sugar and nutrients) (Bonanomi *et al.,* 2010) and heterogeneity of plant residues applied to soil. Paul *et al.* (2014) reported that plant residues with different physical or chemical properties cause differences in soil microorganism activity levels, metabolic pathways and even community structures, thus contributing to different soil C and N dynamics. Addition of organic materials to agricultural soil (with or without chemical fertilizers) is important for replenishing the annual C losses and for improving both the biological and chemical properties of the soils (Goyal *et al*. 1999). Soil microbial communities are the primary regulators of soil carbon and nutrient cycling processes. Differences in microbial community composition have the potential to affect the fate of carbon and nutrients during decomposition and may therefore influence the retention of C and provisioning of crop nutrients in agro ecosystems.

When these residues are incorporated into soil, they provide a source of carbon and nutrients for soil microbes. This can stimulate microbial activity, leading to increased decomposition of organic matter and nutrient cycling in the soil. Different microbes specialize in breaking down different types of organic residues, so the composition of microbial communities can shift based on the type of organic matter added. Many studies have shown that residues with low C/N ratio are decomposed rapidly and lead to net N mineralization as they satisfy the N demands of microbes (Buysse *et al*., 2013 and Hadas *et al.*, 2004).

Soil respiration is considered a good estimator of overall biological activity and has been proposed as a descriptor of soil quality (Doran and Parkin, 1994). The soil microorganisms break down complex molecules such as cellulose, hemi-cellulose, proteins and lignin into low-molecular-weight substances, which are then oxidized to CO_2 to produce energy or used to provide C for cell growth (van Rijssel *et al.,* 2025). The rate of decomposition is determined by the quantity and quality of organic substrates, the efficiency and population dynamics of various decomposer groups, and the soil's physico-chemical environment including moisture, temperature, oxygen, acidity, and redox potential (Kilham, 1994 and Coleman and Crossley, 1996). Soil respiration measurements are increasingly used in studies of soil C cycling to detect early changes in decomposition rate of soil organic matter in response to various soil or crop management practices (Jensen *et al.*, 1996 and Rochette and Angers, 1999). The composition of easily and slowly mineralizable organic matter significantly differs among various residues and fresh green materials are generally decomposed faster than straw (Schmatz *et al.*, 2017). Due to a decline in soil fertility and adverse physical conditions, application of organic material and N fertilizer is important for sustainable soil fertility and environment.

MATERIAL AND METHODS:

The investigation was carried out in Soil Science Laboratory, School of Agriculture, SRU, Warangal, Telangana, which is located in Warangal district of Telangana state at 79^{0}55' °E longitude and 18^{0}029' N latitude. According to Troll's climatic classification, it falls under Semi Arid Tropical region (SAT). The experimental site is in Southern Telangana Agro-Climatic Zone. The soil sample for the study was collected from D block (field number 21D), at the SR University college farm. The surface soil (0–15 cm) is collected, air–dried and sieved for chemical analysis (Table 1).

Four predominant crop residues (Rice, Cotton, Sunflower and Red gram) available on-farm were selected. Crop residues were oven dried, milled and passed through a 2-mm sieve. Residues were collected, oven dried at 65^{o}C in a hot air oven, and crushed with a willey mill before sieving through a 2 mm sieve. The details of amount of residue added to soil and the treatments is given in table 2 and 3 respectively.

Table 1. Initial soil properties of the experimental site

S.No.	Property	Values
1.	Sand (%)	56.3
2.	Silt (%)	13.4
3.	Clay (%)	30.5
4.	Soil Texture	Sandy clay loam
5.	P^H	7.48
6.	EC (dS m^{-1})	0.24
7.	Organic Carbon (%)	0.78
8.	Available N (kg ha^{-1})	182
9.	Available P (kg ha^{-1})	65
10.	Available K (kg ha^{-1})	268
11.	NH_4^+ - N (mg kg^{-1})	58
12.	NO_3^- - N (mg kg^{-1})	1.12
13.	Bulk Density (Mg m^{-3})	1.00

Table 2. Composition of different crop residues

Component	Paddy Straw (%)	Cotton Straw (%)	Redgram Straw (%)	Sunflower Straw (%)
Carbon (C)	42	48	38	43
Nitrogen (N)	0.6	0.9	1.2	1.2
C:N Ratio	70	53	32	36
Lignin	10	23	14	20
Cellulose	35	33	36	38
Hemicellulose	20	25	15	18
Sugars	7	8	7	8

Table 3. Amount of residue added per 100 g soil (g)

1.	Paddy	0.18
2.	Cotton	0.50
3.	Red gram	0.26
4.	Sun flower	0.16

Table 4. Treatment details

T_1	Control (Soil with no N and no residue)
T_2	Soil + N
T_3	Soil + Paddy residue
T_4	Soil + Sunflower residue
T_5	Soil + Cotton residue
T_6	Soil + Red gram residue
T_7	Soil + Paddy residue + N
T_8	Soil + Sunflower residue + N
T_9	Soil + Cotton residue + N
T_{10}	Soil + Red gram residue + N

*N @ 80 kg ha^{-1} will be applied as urea, to T_2, T_7, T_8, T_9 and T_{10} ; 80kg ha^{-1} is chosen because it is the amount employed for *rabi* maize at the time of sowing as 1/3rd of RDN)

*Recommended dose of P is applied uniformly to all treatments.

Pre-incubation

In 500ml beaker, 100 g weighed soil was taken and the soil was kept at field capacity by adding 13 ml of distilled water and kept in dark for 10 days for pre-incubation. Pre-incubation was done prior to the start of incubation experiment to initiate microbial activity in the soil.

Laboratory incubation

Fresh soil, equivalent to 100 grams of dry soil samples, was pre-incubated, weighed, and transferred into polythene bags. After pre-incubation, residues were thoroughly mixed with the soil as per the treatment requirements and incubated for 120 days. Distilled water was frequently added to maintain a 60% water-filled pore space. The entire experiment followed a completely randomized design and was conducted under controlled room temperature conditions. Soil moisture was monitored and adjusted every five days by weighing the Zip lock bags and adding the necessary amount of distilled water.

EXPERIMENTAL DETAILS

- **Location:** Soil Science Laboratory, School of Agriculture, SRU, Warangal, Telangana
- **Design**: Completely Randomized design (CRD)
- **Treatments**: 10
- **Replications**: 3
- **No. of residues to be employed**: 4 (Paddy, sunflower, cotton, red gram).

- **Rate of paddy straw to be employed**: Based on top residue available from respective crops in Telangana, that is possible to deploy succeeding crops.
- **Frequency of sampling**: 2, 4, 6, 8, 10, 15, 20, 30, 45, 60, 75, 90, 105, 120 days after incubation
- **Duration of lab experiment**: 120 days

The method measures the respiration activity of soil microorganisms as CO_2 production per time unit. When soil samples are incubated in a gas tight closed vessel at 30 ºC for 24 hours, the CO_2 produced is absorbed in sodium hydroxide (NaOH). Thus after adding barium chloride the sodium carbonate is precipitated as the hardly solute barium carbonate and the unused sodium hydroxide is titrated by hydrochloride acid (Ferreira *et al.*, 2018)

$$\mathbf{C \text{ or } CO_2 = (B-V) \times N \times E}$$

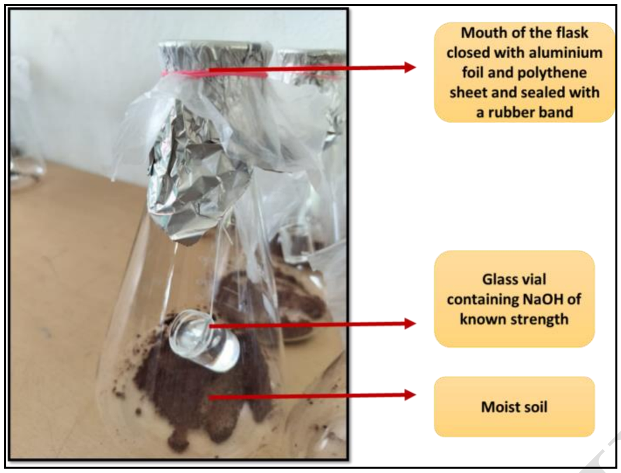

Fig 1: Set-up for measurement of soil respiration by Alkali Trap Method

Statistical analysis: The current incubation study was conducted in a Completely Randomized Design (CRD) with ten treatment and replicated thrice. The statistical analysis was done using SPSS software.

RESULTS AND DISCUSSION:

The result of the soil respiration rate of day two is shown in Figure 2a. Soil respiration on day 2 was influenced by different residues with or without nitrogen addition. There was significant difference ($P < 0.05$) among the treatments. The Soil + Red gram residue (T_6) without nitrogen have shown the highest respiration rate 12.27 mg g^{-1}, which was on par with soil + cotton residue + N (T_9) 11.83 mg g^{-1}, followed by soil + paddy residue + N (T_7), soil + sunflower residue + N (T_8) and soil + N (T_2), which were statistically similar. The result indicated that, among all the treatments, those with addition of nitrogen have recorded higher respiration rate, compared to rest of the treatments. This might be due to the addition of N fertilizer accelerated C mineralization during early stages reported by Hünninghaus *et al.*, 2017 and Wang *et al.* (2004). The higher soil respiration in soil + red gram residue might be due to red gram residues have a relatively low C: N ratio and microbial community might efficiently utilize the nitrogen available from the red gram residues. Also According to Hadas *et al.* (2004), the C mineralization of residues in the early stage of decomposition is influenced by the amount of soluble C present in the added plant materials. Use of inorganic nitrogen application when organic residue of high C/N ratio was used might have either minimized the N immobilization or speed up the microbial decay (Lin *et al.*, 2024 and

Jenkinson *et al*., 1985). In contrast, treatments without nitrogen soil alone (T_1), soil + paddy residue (T_3) and Soil + cotton (T_5) showed statistically similar but lower respiration rates, likely due to limited nutrient availability. The 34.77% overall increase observed with nitrogen, compared to treatments without nitrogen on day two, which highlights significant role N in enhancing nutrient availability. Additionally, nitrogen contributes to a decrease in the carbon-to-nitrogen (C) ratio of the residue. The result is in line with findings of Jenkinson *et al*. (1985) reported that Use of inorganic nitrogen application when organic residue of high C/N ratio was used might have either minimized the N immobilization or speed up the microbial decay (Lin *et al*., 2024 and Jenkinson *et al*., 1985).

The soil respiration rates on day 4, is shown in Figure 2b, there was significant differences among treatments, particularly highlighting the influence of residues and nitrogen addition. Soil + Sunflower residue + N (T_8) shown significantly higher respiration rate compared to remaining treatments, followed by Soil + Red gram residue + N (T_{10}) 25.63 mg g^{-1}, Soil + Cotton residue + N (T_9) 25.50 mg g^{-1} and soil + N (T_2) 24.20 mg g^{-1}, which were statistically similar. The higher soil respiration rate in the Soil + Sunflower residue + N (T_8) treatment might be primarily due to sunflower residues having a lower C ratio, which leads to faster decomposition and increased microbial activity when combined with added nitrogen. This combination maximizes microbial growth and CO_2 release, whereas other residues with higher C ratios decompose more slowly, resulting in lower respiration rates. Zhang *et al*. (2021), Kriauciuniene *et al*. (2012) and Munthali *et al*. (2015) reported that initial C/N ratios were the most critical variables in influencing decomposition of plant residues. Use of inorganic nitrogen application when organic residue of high C/N ratio was used might have either minimized the N immobilization or speed up the microbial decay (Jenkinson *et al*., 1985). The lowest respiration rate on day 4 was observed in soil alone (T_1), which was due to the absence of added organic residues and nitrogen. Without these inputs, there are fewer nutrients available for microbial activity, resulting in lower decomposition rates and reduced soil respiration. The 45.51% increase with nitrogen is primarily due to its impact on soil respiration. Nitrogen enhances microbial activity in the soil, which increases respiration rates and overall soil metabolic activity, leading to improved nutrient breakdown and availability.

The soil respiration rates on day 6, is presented in Figure 2c. It is observed that, there was significant differences among treatments, particularly the influence of differences crop residues and nitrogen addition. Soil + N (T_2) recorded the highest respiration rate of 40.83 mg g^{-1}, which was significantly higher than all other treatments, followed by Soil +Sunflower +N treatment (T_8), which was 33.23 mg g^{-1}. This might be due to acceleration of mineralization. Also Singh (1991) reported that the nitrogen addition, is known to accelerate the mineralization of easily degradable organic carbon. The overall percentage increase in soil respiration rates due to the addition of nitrogen across all residue amended treatments is approximately 47.69%. This indicates a substantial enhancement in microbial activity and decomposition processes when nitrogen is added to the residues. Soil alone (T_1) had the lowest respiration rate of 5.27 (mg g^{-1}), which was significantly lower than all other treatments. This rate reflects minimal microbial activity in the absence of added nutrients or organic matter, serving as a baseline for comparison with the residue and nitrogen-amended treatments.

The soil respiration rates on day 8 is shown in Figure 2d, reveal significant differences among treatments. Soil + sunflower residue + N (T_8) recorded the higher respiration rate of 40.63 mg g^{-1}, significantly higher than all other treatments, followed by Soil + red gram residue + N (T_{10}) showed a respiration rate of 35.07 mg g^{-1}, which was significantly higher than rest of the treatments. On day 8, the high soil respiration rates with sunflower residue + N (T_8) and redgram residue + N (T_{10}) are due to enhanced microbial activity. Nitrogen boosts microbial growth by alleviating nutrient limitations, leading to more efficient decomposition of organic matter. The increased decomposition results in higher carbon dioxide release, which lead to higher respiration rates. The percentage increase in soil respiration rates due to the addition of nitrogen across all residue treatments on day 8 is approximately 51.67% which reveals its critical role in enhancing microbial activity. Nitrogen boosts microbial growth and decomposition efficiency by providing essential nutrients, which accelerates organic matter breakdown and CO_2 release. In contrast, the soil alone (T_1) had the lowest respiration rate due to the absence of added nutrients and organic matter, limiting microbial activity and decomposition. Previous studies support these findings, including research by Zeng *et al*. (2010), which highlighted how nitrogen accelerates the breakdown of crop residues, particularly those rich in cellulose and hemicellulose. Similarly, Craine *et al*. (2007) found that nitrogen availability enhances microbial respiration by reducing the C ratio, allowing microbes to process organic carbon more efficiently. Fierer and Jackson (2006) further demonstrated that nitrogen amendments boost microbial biomass and enzymatic activity, leading to faster organic matter turnover and higher CO_2 emissions. Moreover, Cotrufo *et al*.

(2013) and Kudeyarov (2024) reported that nitrogen additions increase the decomposition rate of recalcitrant plant residues, further contributing to higher soil respiration.

Fig. 2. Impact of different residues decomposition with or without in organic N on Soil Respiration at various days of incubation (2,4,6,8 DAI)

*T1: Control (Soil with no N and no residue), T2: Soil + N, T3: Soil + Paddy residue, T4: Soil + Sunflower residue, T5: Soil + Cotton residue, T6: Soil + Red gram residue, T7: Soil + Paddy residue + N, T8: Soil + Sunflower residue + N, T9: Soil + Cotton residue + N, T10: Soil + Red gram residue + N = P (0.05) value for 2, 4, 6 and 8 DAI were 0.58, 0.69, 1.45 and 0.97, respectively and SE (m) value for 2, 4, 6 and 8 DAI were 0.19, 0.23, 0.49 and 0.32 respectively.

The soil respiration rates on day 10, were presented in figure 3a, which indicates significant differences among the treatments. Soil + red gram residue + N (T_{10}) exhibited the highest respiration rate of 46.17 mg g^{-1}, significantly higher than all other treatments. This may be because on day 10 there is active microbial population to process the red gram residues and also red gram residues (legume) have created more favourable environment compared to other residues for the microbes to break down the complex substances, which accelerated the decomposition rate and finally soil respiration (Liu *et al*., 2025). Muhammad *et al.* (2011) and Mirzaei *et al.* (2022) studied the total C mineralized from residues and suggested that decomposition of organic material in soil initially proceeded at faster rate. The decomposition attained a slower rate after about 15 days. It was mineralized within 14 days and remaining plant materials decomposed at a slower rate. The overall percentage increase in soil respiration rates due to the addition of nitrogen across all residue treatments on day 10 is approximately 53.65%. This indicates a significant improvement in soil respiration with the addition of nitrogen, underscoring its substantial impact on enhancing microbial activity and decomposition processes in the soil. Soil alone (T_1) recorded the lowest respiration rate of 6.60 mg g^{-1}, significantly lower than all other treatments. This low rate reflects minimal microbial activity in the absence of both added nutrients and organic matter, serving as a baseline for comparison with residue and nitrogen-amended treatments.

The soil respiration rates on day 15, as presented in Figure 3b. There was significant differences among treatments, particularly the influence of crop residues and nitrogen addition. Soil + paddy residue + N (T_7) exhibited significantly higher respiration rate at 48.57 mg g^{-1}, this might be due to combine effect of paddy residue and nitrogen which result to significant increase in mineralization which result in lowering the C: N ratio of paddy residue. The result indicated that paddy residue start mineralization were others residues are almost in the mid of mineralization processes. The overall percentage increase in soil respiration rates due to the addition of nitrogen across all residue treatments on Day 15 is approximately 51.09%. This indicates that nitrogen addition leads to a significant enhancement in soil respiration, emphasizing its critical role in boosting microbial activity and decomposition processes in the soil. The decomposition attained a slower rate after about 15 days. Soil + N (T_2) recorded significantly lower respiration rate of 8.57 mg g^{-1}, compared to other treatments. This might be because the microorganisms have utilized the both added nitrogen and mineralized carbon present in the soil. This suggests that while soil microbial activity is ongoing, the addition of organic residues plays a crucial role in further enhancing respiration rates.

The soil respiration rates on day 20, is presented in Figure 3c. There was significant difference among treatments. The soil respiration rates observed on day 20 reflect the influence of various crop residues and nitrogen addition on microbial activity. Soil + paddy residue + N (T_7) recorded the highest respiration rate of 58.33 mg g^{-1}, significantly higher all other treatments. This high rate can be attributed to the combined effect of paddy residue and nitrogen. Despite paddy residue having a high C: N ratio, the addition of nitrogen helps overcome nitrogen immobilization by providing an immediate nitrogen source for microbes, thus accelerating the decomposition of organic matter and increasing microbial activity. This aligns with findings by Jenkinson *et al*. (1985), which state that nitrogen addition can enhance decomposition rates, even with residues of high C ratios. Soil alone (T_1) had a respiration rate of 9.80 mg g^{-1}, which was significantly lower among all treatments. This is expected, as the absence of added organic material or nitrogen limits microbial activity. The overall percentage increase in soil respiration rates due to the addition of nitrogen across all residue treatments on day 20 is approximately 49.90%. Balasubramanium *et al*. (1974) observed that the release of CO_2 by the soil amended with organic material was significantly more as compared control.

The soil respiration rates on day 30, is presented in Figure 3d. There was significant difference among treatments. Significantly higher respiration rate was observed in the treatment with soil + red gram residue + nitrogen (T_{10}) 33.37 mg g^{-1}, followed by soil + paddy residue + nitrogen (T_7) 25.40 mg g^{-1} and soil + cotton residues (T_5) 22.07 mg g^{-1}, which were on par. These values indicate a strong enhancement of microbial activity due to the combined effects of nitrogen and crop residues. Red gram residues generally have a relatively low C ratio, which supports faster microbial decomposition and higher CO_2 emissions. When nitrogen is added, it further stimulates microbial growth and enzyme activity, enhancing the decomposition process and leading to increased soil respiration. Kriauciuniene *et al*. (2012) and Munthali *et al*. (2015) reported that initial C/N ratios were the most critical variables in influencing decomposition of plant residues. The overall percentage increase in soil respiration rates due to the addition of nitrogen across all residue treatments on day 30 is approximately 27.57%. This indicates that while nitrogen addition continues to enhance soil respiration, the degree of increase is less pronounced compared to earlier days. This may reflect the varying impacts of nitrogen over time and the dynamic nature of microbial activity and decomposition processes. The lowest respiration rates were recorded in treatments such as soil alone (T_1) 10.10 mg g^{-1}, indicating that the absence of crop residues or the sole addition of nitrogen results in significantly lower microbial activity.

Fig. 3. Impact of different residues decomposition with or without in organic N on Soil Respiration at various days of incubation (10,15,20,30 DAI)

*T1: Control (Soil with no N and no residue), T2: Soil + N, T3: Soil + Paddy residue, T4: Soil + Sunflower residue, T5: Soil + Cotton residue, T6: Soil + Red gram residue, T7: Soil + Paddy residue + N, T8: Soil + Sunflower residue + N, T9: Soil + Cotton residue + N, T10: Soil + Red gram residue + N = P (0.05) value for 10, 15, 20 and 30 DAI were 0.75, 0.92, 1.38 and 1.14, respectively and SE (m) value for 10, 15, 20 and 30 DAI were 0.25, 0.31, 0.46 and 0.38 respectively.

The soil respiration rates on day 45, is presented in Figure 4a, there was significant differences among the treatments involving various crop residues, nitrogen and their combinations.

Soil with paddy residue (T_3) showed a significantly higher respiration rate of 26.47 mg g^{-1}. The elevated respiration rate in the paddy residue treatment indicates that microbial activity has been strongly stimulated by the paddy residue, which provides a continual source of organic matter for decomposition. Over the 45-day period, the paddy residue has likely undergone substantial decomposition, enhancing microbial activity as nutrients are gradually released and utilized. Saidi *et al*. (2008) reported that a stable C: N ratio could be achieved after 95 days of decomposition. The soil respiration rate for soil alone (T_1) was 10.37 mg g^{-1} establishing the baseline, which was significantly lower among all treatments. On Day 45, the overall percentage increase in soil respiration rates due to nitrogen addition across all residue treatments is approximately 19.13 %. This indicates a modest enhancement in soil respiration with nitrogen, suggesting that while nitrogen still influences soil microbial activity and decomposition, its effect has diminished compared to earlier observations. This decrease in the rate of increase might be due to various factors such as changes in microbial activity, the decomposition stage of residues, or nutrient dynamics over time.

The soil respiration rates on day 60, is presented in Figure 4b, which showed significant differences among the treatments involving various crop residues, nitrogen and their combinations. The higher respiration rate was observed in soil with red gram residue + nitrogen (T_{10}) at 23.57 mg g^{-1}, followed by soil with paddy residue alone (T_3) with a respiration rate of 22.53 mg g^{-1}. On day 60, the higher soil respiration rate in the (T_{10}) treatment is due to advanced decomposition and optimal nutrient conditions. By this time, the red gram residues have fully decomposed, and the added nitrogen has maximized microbial activity and organic matter breakdown, leading to elevated CO_2 emissions. On day 60, the 16.50% increase in soil respiration rates due to nitrogen addition reflects advanced decomposition and stable microbial activity. As decomposition progresses, the impact of nitrogen stabilizes, leading to sustained but moderated increases in microbial respiration. This suggests that while nitrogen continues to enhance microbial activity, the effects have become more consistent over time. The soil alone treatment T_1 (10.067 mg g^{-1}) recorded lower respiration rate which was on par with T_2 (10.83 mg g^{-1}), T_6 (10.98 mg g^{-1}) and T_8 (10.93 mg g^{-1}). Reddy *et al.* (2018) reported that the addition of crop residues significantly enhances soil microbial activity and respiration by providing readily available carbon and nutrients. Similarly, Khan *et al*. (2012) demonstrated that nitrogen application leads to increased microbial biomass and respiration rates, particularly in soils enriched with organic residues.

The result of the soil respiration rate of day 75 is presented in Figure 4c. Soil respiration on day 75 was influenced by different residues with or without nitrogen. On Day 75, the soil respiration rates was higher in soil with paddy residue alone (T_3) with a respiration rate of 18.8 mg g^{-1} and it was on par with soil + red gram +N (T_{10}) demonstrating a notable stimulation of microbial activity by paddy residue, though slightly lower than observed on earlier days. On Day 75, the higher soil respiration rate in (T_3) is due to the delayed mineralization associated with the high carbon-to-nitrogen (C) ratio of paddy residues. Over time, as nitrogen is gradually released from the residues, microbial activity increases, leading to sustained high respiration rates. This effect is comparable to Soil + red gram residue + Nitrogen (T_{10}), reflecting effective microbial stimulation from both types of residues. Soil with cotton residue (T_9) had the lowest respiration rate of 8.67 mg g^{-1}, which was on par with soil alone 9.67 mg g^{-1}. This might due to low C: N ratio of cotton. Use of inorganic nitrogen application when organic residue of high C/N ratio was used might have either minimized the N immobilization or speed up the microbial decay (Jenkinson *et al*., 1985). The reduction in the percentage increase of soil respiration rates due to nitrogen addition from day 75 might be because nitrogen becomes depleted, its stimulating effect on microbial activity wanes, and advanced decomposition stages lead to a stabilization of microbial processes. Additionally, residues without nitrogen start to mineralize and decompose more steadily, contributing to a natural increase in soil respiration rates independent of added nitrogen.

The result of the soil respiration rate of day 90 is presented in Figure 4d. Soil respiration on day 90 was influenced by different residues with or without nitrogen. Soil with paddy residue recorded a respiration rate of 16.47 mg g^{-1}, demonstrating a strong stimulation of microbial activity by paddy residue, though this rate is lower than observed on earlier days and it was on par with soil + redgram + N (T_{10}). Soil alone (T_1) had a respiration rate of 7.87 mg g^{-1}, the lowest among all treatments, which was on par with T_2 (8.55 mg g^{-1}) and T_5 (8.40 mg g^{-1}). On Day 90, Soil + paddy residue (T_3) has a respiration rate of 16.47 (mg g^{-1}), showing continued microbial activity despite a decrease from earlier peaks due to advanced decomposition and reduced nutrient availability. Soil + redgram residue + nitrogen (T_{10}) maintains a similar respiration rate, supported by the ongoing nutrient benefits of red gram residues and added nitrogen. Saidi *et al*. (2008) and Ahlawat *et al.* (2024) reported that a stable C: N ratio could be achieved after 95 days of decomposition. This indicates that both red gram residue + nitrogen and paddy residue alone have strong impacts on microbial activity, with red gram residue + nitrogen showing a comparable effect to paddy residue alone. On Day 90, the 3.45% increase in soil respiration rates due to nitrogen addition indicates a reduced effect over time. This is likely because of advanced decomposition stages, stabilization of microbial communities, and potential nutrient immobilization, which diminish the impact of additional nitrogen (Janz *et al.* 2022).

Fig. 4. Impact of different residues decomposition with or without in organic N on Soil Respiration at various days of incubation (45,60,75,90 DAI)

*T1: Control (Soil with no N and no residue), T2: Soil + N, T3: Soil + Paddy residue, T4: Soil + Sunflower residue, T5: Soil + Cotton residue, T6: Soil + Red gram residue, T7: Soil + Paddy residue + N, T8: Soil + Sunflower residue + N, T9: Soil + Cotton residue + N, T10: Soil + Red gram residue + N = P (0.05) value for 45, 60, 75 and 90 DAI were 0.78, 1.18, 1.05 and 0.94, respectively and SE (m) value for 45, 60, 75 and 90 DAI were 0.26, 0.39, 0.35 and 0.31 respectively.

The result of the soil respiration rate of day 105 is presented in Figure 5a. The results of soil respiration measured on day 105 reveal significant differences in microbial activity influenced by various residue treatments with or without nitrogen. The highest respiration rate was observed in the treatment with soil + paddy residue (T_3) 14.37 mg g^{-1} had the highest rates, followed by soil + red gram residue + N 14.40 mg g^{-1}. These two treatments showed statistically difference high respiration levels. In contrast, soil alone exhibited the lowest respiration rate of 4.40 mg g^{-1}, reflecting minimal microbial activity. The addition of nitrogen to soil alone increased this rate to 5.50 mg g^{-1}, a statistically significant improvement, and emphasizing nitrogen's role in enhancing microbial activity by improving nutrient availability. Saidi *et al*. (2008) reported that a stable C: N ratio could be achieved after 95 days of decomposition. The observed 5.60 % increase in respiration rates without nitrogen addition across all treatments indicates that microbial communities continue to actively decompose residues even in the absence of added nitrogen. N initially boosts microbial activity, its effect diminishes over time as it is used up, whereas the residual microbial activity continues to drive decomposition and soil respiration.

The results presented in Figure 5b illustrate significant differences in microbial activity influenced by various residue treatments, particularly with or without nitrogen, on day 120. The highest respiration rate was recorded in the soil + paddy residue treatment (T_3) at 12.10 mg g^{-1}, highlighting the effectiveness of paddy residue in promoting microbial activity and stable mineralization. This elevated respiration rate indicates a continuous nutrient release from the paddy residue, providing a rich carbon source for microbes, which sustains activity even as carbon sources in other treatments become depleted. The soil + red gram residue + N treatment (T_8) achieved the second-highest respiration rate at 7.80 mg g^{-1}, attributed to the synergistic effect of red gram residue and added nitrogen, enhancing microbial activity. However, the benefits of nitrogen, while significant, do not match the long-term advantages provided by paddy residue. In contrast, the lowest respiration rates were seen in the soil alone (T_1) and soil + N (T_2), both at 3.67 mg g^{-1}. These low rates reflect limited microbial activity due to the lack of organic residues and the exhaustion of carbon sources in the nitrogen-only treatments. Overall, the increase in respiration linked to organic residues alone is approximately 14.57%, underscoring the crucial role of organic matter in stimulating microbial activity. This percentage reinforces that while nitrogen can enhance microbial processes, the sustained high respiration rates and long-term stability are more effectively supported by high-quality organic residues like paddy. The persistent high respiration associated with paddy residue underscores its superior ability to maintain microbial activity and nutrient cycling over time (Kudeyarov, 2024).

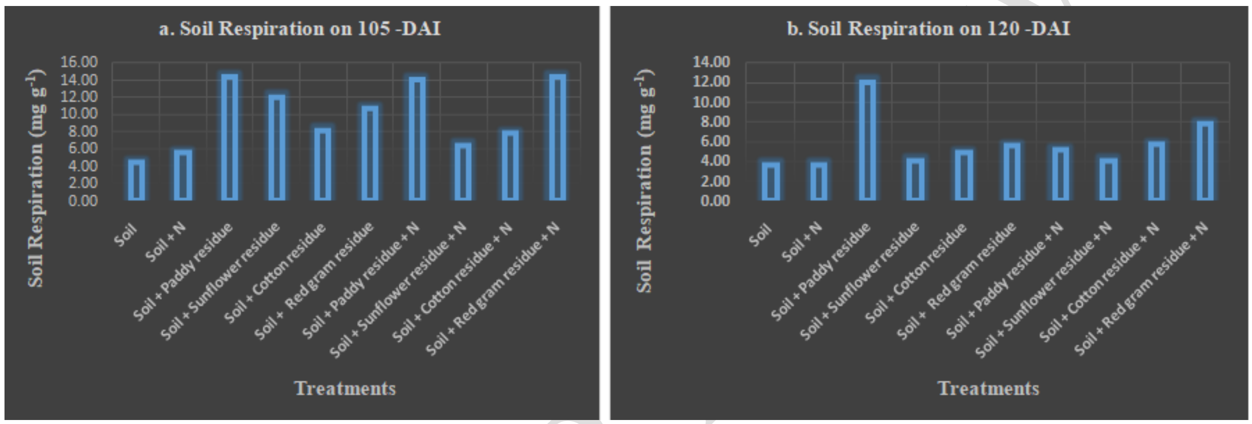

Fig. 5. Impact of different residues decomposition with or without in organic N on

Soil Respiration at various days of incubation (105, 120 DAI)

*T1: Control (Soil with no N and no residue), T2: Soil + N, T3: Soil + Paddy residue, T4: Soil + Sunflower residue, T5: Soil + Cotton residue, T6: Soil + Red gram residue, T7: Soil + Paddy residue + N, T8: Soil + Sunflower residue + N, T9: Soil + Cotton residue + N, T10: Soil + Red gram residue + N = P (0.05) value for 105 and 120 DAI were 0.64 and 0.97, respectively and SE (m) value for 105 and 120 DAI were 0.39 and 0.13 respectively.

The respiration rate of the residue added treatments was high compared to control, throughout the experiment (Figure 6). Over time, soil respiration steadily decreases after rising gradually and peaking on day 15. This pattern most likely represents a rise in microbial activity at first (which was also evident from our study but data not mentioned) brought on by the breakdown of readily available organic matter, this pattern probably indicates that microbial activity increases first due to the decomposition of easily accessible organic matter and subsequently decreases when these substrates become scarcer. Our finding is similar to Vahdat *et al.* (2011), who had reported that, CO_2-C release, in untreated soils (controls) has shown very slow patterns meanwhile treated soils showed an initial rapid increase, followed by a slower, linear release. Incorporation of paddy residue had demonstrated a progressive rise over time, reaching a peak at 25.27 mg g^{-1} on day 45. This indicates sustained microbial activity, likely due to the slow decomposition, which might be due to high C: N ratio. This suggests that microbial activity has persisted, most likely as a result of the paddy residue's gradual breakdown. Our result was consistent with the findings of Kobke *et al*. (2018), who had reported that, legumes typically emit the highest cumulative CO_2 emissions, which decrease over time, while cereals exhibit lower emissions but higher stability. Incorporation of sunflower residue led to increase in soil respiration upto day 30, later there was a sharp decrease after. It falls to 1.15 by day 120, indicating that sunflower residue may break down rapidly and cause an early microbial substrate depletion. Cotton residue exhibits a similar pattern to paddy residue *i.e*., it had shown a gradual increase in respiration that peaks on day 30, then a notable decline by day 120, signifying a slower rate of decomposition.

Rezgui *et al.* (2021) and Cheng *et al.* (2023) reported that the mineralization rate decreased due to the increasing recalcitrance of the remaining residues. Lignin content was negatively correlated with C mineralization due to its resistance to microbial breakdown. Incorporation of red gram residue showed a moderate rate of decomposition which peaked on day 15, followed by a steady fall in microbial activity which reflected in decreased respiration. Cogle *et al*. (1989) estimated that incorporation of straw hastened its decomposition rate only within the first 15 days, thereafter the decomposition rate was similar. Decomposition rate generally peaked between 4 and 15 days. The carbon source however was quickly exhausted. When residues are added once, respiration rates are initially high due to the decomposition of easily available compounds. Thereafter, respiration rates decrease as easily available compounds are depleted. Respiration rates are low in the later stages of decomposition when only more recalcitrant compounds such as lignin-encrusted cellulose and other macromolecules are left (Wang *et al.* 2004). It is well-known that incorporation of plant residues into the soil results in a rapid increase in microbial activity and biomass followed by gradual decrease (Reddy *et al.*, 2024 and Wang *et al*. 2004). Sarma *et al*. (2013) reported that C:N ratio of the different residues were responsible for maximum mineralization of native soil organic matter and added crop residues by increasing microbial activity in soil environment at the particular day of incorporation. Soil + nitrogen treatment showed significant increase in respiration, which peaked on day 6 at 40.83. However, by day 15, respiration drastically drops, suggesting that the initial nitrogen-induced microbial boost is just temporary. On the other hand, respiration dramatically decreases by day 15, indicating that the initial nitrogen-induced microbial boost is transient. After day 20, respiration rates level off and resemble those found in the soil by themselves (Fernández-Ortega *et al*. 2024).

Paddy residue + N treatment, the respiration rate increases dramatically when nitrogen is introduced to paddy residue, peaking at 48.57 on day 15, as compared to paddy residue alone. This suggests that nitrogen significantly accelerates the breakdown of rice residue. Sunflower residue + N treatment showed similar to the impact of nitrogen alone, *i.e.*, respiration peaked early (on day 6), at 40.63. It does, however, decline significantly thereafter, indicating a quick initial breakdown followed by the exhaustion of accessible substrates. Cogle *et al*. (1989) estimated that incorporation of straw hastened its decomposition rate only within the first 15 days, thereafter the decomposition rate was similar. Sakala *et al*. (2000) reported rapid CO_2 evolution within the first 10 days. Alexander and Scow (1989) reported that, as the decomposition proceeds, the organic matter is not attacked as a whole. Some of the constituents are decomposed readily (sugar and starches), followed by proteins, cellulose, hemicellulose and finally lignin, waxes and tannins. Zeng *et al*. (2010) reported maximum degradation of hemicellulose as compared to lignin and cellulose during composting. In all the five trials, it was found that the amount of hemicellulose present in the compost at the end of 20 days was less than 10% indicating very rapid degradation of hemicellulose under microbial activity. This implies that nitrogen is essential for promoting cotton residue breakdown. Red gram residue + N treatment showed a peak on day 10, (respiration reaches 46.17), the greatest peak of all the combinations. The C: N ratio of crop residue is a key factor for its degradation. During the initial decomposition phase, low C: N ratio causes manifold increase in the decomposition rate (Golueke, 1992). This implies that red gram residue, when mixed with nitrogen, the result is in line with Wang *et al*. (2004) also found that addition of N fertilizer accelerated C mineralization during early stages. The C mineralization of residues in the early stage of decomposition is influenced by the amount of soluble C present in the added plant materials (Hadas *et al*., 2004). Muhammad *et al.* (2010) reported that, addition of N fertilizer to sugarcane, maize and sorghum residues to soil promoted CO_2 emissions significantly, compared to the unfertilized N treatment, during the first 10 days of incubation. Ravali *et al*. (2024) also reported that, C:N ratio of crop residue is a key factor for its degradation. During the initial decomposition phase, low C: N ratio causes manifold increase in the decomposition rate. Guhe and Deshmukh (1973) found that crop residues like wheat straw incorporated with fertilizer N in soil favorably enhanced the soil microbial ecology, microbial biomass and yield of legume crop. Gallardo and Merino (1993) studied the rate of organic material breakdown depends on the relative proportion of soluble sugars, cellulose, hemicellulose and lignin content.

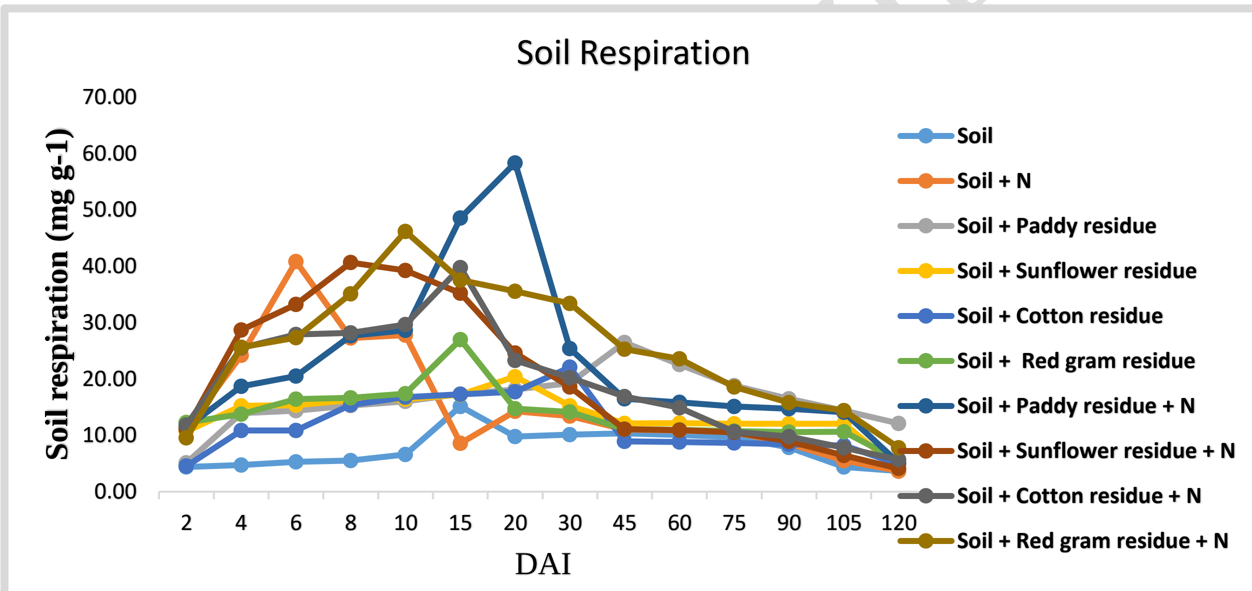

Fig. 6. Temporal dynamics of impact of crop residue decomposition on soil respiration

CONCLUSION:

Incorporating crop residues, particularly when combined with nitrogen, significantly enhances soil respiration. Soil with crop residues showed higher CO_2 emissions compared to soil alone. When crop residues were combined with nitrogen, it had further enhanced respiration rates. Paddy residue + nitrogen (T_7) exhibited the highest respiration rates, highlighting the role of N in accelerating organic matter decomposition. Crop residues with lower C:N ratio enhanced decomposition and increased nutrient availability. After incorporation, there was rise in CO_2

emissions upto 20 DAI, followed by decrease throughout the incubation period. The CO_2 emissions reflected carbon mineralization.

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REFERENCES:

Ahlawat, O.P., Khippal, A., Venkatesh, K., Chhokar, R.S., Gill, S.C., Kashyap, P.L., Kharub, A.S., Kumar, L., Kumar, N., Sharma, A. and Kumari, K. 2024. Impact of Different Tillage and Residue Retention Practices on Soil Nutrients, Microbial Community Composition and Grain Yield of Malt Barley. Journal of Soil Science and Plant Nutrition, 24(4), pp.7651-7668. https://link.springer.com/article/10.1007/s42729-024-02065-5

Akiyama H, Yamamoto A, Uchida Y, Hoshino YT, Tago K, Wang Y and Hayatsu M. 2020. Effect of low C/N crop residue input on N_2O, NO, and CH_4 fluxes from andosol and fluvisol fields. Science of Total Environment. 713: 1–10.

Alexander M and Scow KM. 1989. Kinetics of biodegradation in soil. Reactions and movement of organic chemicals in soils. 22: 243-269. **https://doi.org/10.2136/sssaspecpub22.c10**

Balasubramanium A, Sankar A and Venkataraman A. 1974. Effect of organic matter on the yield and nutrient uptake of crops. Agricultural Science. 82(2): 253-260.

Bonanomi G, Incerti G, Antignani V, Capodilupo M and Mazzoleni S. 2010. Decomposition and nutrient dynamics in mixed litter of Mediterranean species. Plant and Soil. 331: 481-496. https://link.springer.com/article/10.1007/s11104-009-0269-6

Buysse, P., Schnepf-Kiss, A.C., Carnol, M., Malchair, S., Roisin, C. and Aubinet, M. 2013. Fifty years of crop residue management have a limited impact on soil heterotrophic respiration. Agricultural and forest meteorology, 180, pp.102-111. https://doi.org/10.1016/j.agrformet.2013.05.004

Cheng, H., Yu, Q., Qi, Z., Bukovsky, M.S., Xue, L., Jin, V.L., Ma, L., Harmel, R.D., Chen, X., Ji, S. and Miao, L. 2023. Simulating synergistic effects of climate change and conservation practices on greenhouse gas emissions and crop growth in long-term maize cropping systems. Computers and Electronics in Agriculture, 215, p.108404. https://doi.org/10.1016/j.compag.2023.108404

Cogle AL, Saffigna PG. and Strong WM. 1989. Carbon transformations during wheat straw decomposition. Soil Biology and Biochemistry. 1989; 21(3): 367-372. **https://doi.org/10.1016/0038-0717(89)90145-4**

Coleman DC. and Crossley DA. 1996. Decomposition and nutrient cycling. In Fundamentals of soil ecology Associated Press. pp. 109-140.

Cotrufo MF, Wallenstein MD, Boot CM, Denef K. and Paul E. 2013. The Microbial Efficiency-Matrix Stabilization (MEMS) framework integrates plant litter decomposition with soil organic matter stabilization: do labile plant inputs form stable soil organic matter?. Global change biology. 19(4): 988-995. **https://doi.org/10.1111/gcb.12113**

Cox CM, Garrett KA, Bowden RL, Fritz AK, Dendy SP. and Heer WF. 2004. Cultivar mixtures for the simultaneous management of multiple diseases: tan spot and leaf rust of wheat. Phytopathology. 94:961– 969. https://doi.org/10.1094/PHYTO.2004.94.9.961

Craine JM, Morrow C. and Fierer N. 2007. Microbial nitrogen limitation increases decomposition. Ecology. 88(8): 2105-2113. **https://doi.org/10.1890/06-1847.1**

Doran JW. and Parkin TB. 1994. Defining and assessing soil quality. Defining soil quality for a sustainable environment. 35: 1-21. **https://doi.org/10.2136/sssaspecpub35.c1**

Fernández-Ortega, J., Álvaro-Fuentes, J. and Cantero-Martínez, C. 2024. Double-cropping, tillage and nitrogen fertilization effects on soil CO2 and CH4 emissions. Agriculture, Ecosystems & Environment, 359, p.108758. https://doi.org/10.1016/j.agee.2023.108758

Ferreira CRPC, Antonino ACD, Sampaio EVDSB, Correia KG, Lima JRDS, Soares WDA. and Menezes RSC. 2018. Soil CO_2 Efflux Measurements by Alkali Absorption and Infrared Gas Analyzer in the Brazilian Semiarid Region. Revist Brasilerira de Ciencia do Solo. 42, e0160563. https://doi.org/10.1590/18069657rbcs20160563

Fierer N. and Jackson R.B. 2006. The diversity and biogeography of soil bacterial communities. Proceedings of the National Academy of Sciences. 103(3): 626-631. https://doi.org/10.1073/pnas.0507535103

Gallardo JF. and Merino J. 1993. The influence of organic matter on the rate of decomposition of soil. Soil Biology and Biochemistry. 25(3): 337-343.

Golueke CG. 1992. Biological approach to solid waste management. Composting Science. 17(4): 3-8.

Goyal S, Chander K, Mundra MC. and Kapoor KK. 1999. Influence of inorganic fertilizers and organic amendments on soil organic matter and soil microbial properties under tropical conditions. Biology and Fertility of Soils. 29: 196-200. https://link.springer.com/article/10.1007/s003740050544

Grover, D. and Chaudhry, S. 2023. Impact of crop residue burning and tillage practices on soil biological parameters of rice–wheat agro-ecosystems. Tropical Ecology, 64(4), pp.620-634. https://link.springer.com/article/10.1007/s42965-022-00287-1

Guhe A. and Deshmukh M. 1973. Nitrogen and carbon dynamics in soil. Soil Science Society of America Journal. 37(2): 233-237.

Hadas A, Kautsky L, Göek M. and Kara EE. 2024. Rates of decomposition of plant residues and available nitrogen in soil, related to residue composition through simulation of carbon and nitrogen turnover. Soil Biology and Biochemistry. 36(2): 255-266. https://doi.org/10.1016/j.soilbio.2003.09.012

Huang, X., Li, Y., Yu, S., Cui, Y., Guan, F., Li, Y., Wu, J., Hu, Y., Li, Z., Zhuang, P. and Zou, B. 2025. Nitrogen deposition mitigates long-term phosphorus input-induced stimulative effects on soil respiration in a tropical forest. Geoderma, 453, p.117142. https://doi.org/10.1016/j.geoderma.2024.117142

Hünninghaus, M., Koller, R., Kramer, S., Marhan, S., Kandeler, E. and Bonkowski, M. 2017. Changes in bacterial community composition and soil respiration indicate rapid successions of protist grazers during mineralization of maize crop residues. Pedobiologia, 62, pp.1-8. https://doi.org/10.1016/j.pedobi.2017.03.002

Janz, B., Havermann, F., Lashermes, G., Zuazo, P., Engelsberger, F., Torabi, S.M. and Butterbach-Bahl, K. 2022. Effects of crop residue incorporation and properties on combined soil gaseous N2O, NO, and NH3 emissions—A laboratory-based measurement approach. Science of the Total Environment, 807, p.151051. https://doi.org/10.1016/j.scitotenv.2021.151051

Jenkinson DS, Adams DE. and Wild A. 1985. The computation of the organic matter turnover and the influence of land use on its accumulation in soils. Soil Biology and Biochemistry. 17(5): 885-891.

Jensen LS, Mueller T, Tate KR, Ross DJ, Magid J. and Nielsen NE. 1996. Soil-surface CO_2 flux as an index of soil respiration in situ: A comparison of two chamber methods. Soil Biology and Biochemistry. 28:1297–1306. https://doi.org/10.1016/S0038-0717(96)00136-8

Khan KS, Gattinger A, Buegger F, Schloter M. and Joergensen RG. 2008. Microbial use of organic amendments in saline soils monitored by changes in the 13C/12C ratio. Soil Biology and Biochemistry. 40:1217–1224. https://doi.org/10.1016/j.soilbio.2007.12.016

Kilham K. 1994. The ecology of soil nutrient cycling. Soil ecology. (pp. 89-108). Cambridge University Press.

Köbke S, Senbayram M, Pfeiffer B, Nacke H. and Dittert K. 2018. Post-harvest N_2O and CO_2 emissions related to plant residue incorporation of oilseed rape and barley straw depend on soil NO_3^-content. Soil and Tillage Research. 179: 105-113. https://doi.org/10.1016/j.still.2018.01.013

Kriauciuniene J, Karpavičiene B. and Bairaktari E. 2012. Impact of crop rotation and residue management on soil organic carbon and nitrogen. Agronomy Research. 10(1), 221-229.

Kudeyarov, V.N. 2024. Soil Respiration and the Carbon Sequestration Potential in Agroecosystems. Biology Bulletin, 51(Suppl 3), pp.S424-S438. https://link.springer.com/article/10.1134/S1062359024613065

Lashermes G, Recous S, Alavoine G, Janz B, Butterbach-Bahl K, Ernfors M. and Laville P. 2022. N_2O emissions from decomposing crop residues are strongly linked to their initial soluble fraction and early C mineralization. Science of the Total Environment. 806, 150883. https://doi.org/10.1016/j.scitotenv.2021.150883

Li, Q., Zhang, C., Shi, M., Lv, J., Peng, C., Zhang, J., Chang, S.X., Cao, T., Li, T. and Song, X. 2024. Long-term nitrogen addition has a positive legacy effect on soil respiration in subtropical Moso bamboo forests. Geoderma, 452, p.117092. https://doi.org/10.1016/j.geoderma.2024.117092

Liang, Z., Cao, B., Jiao, Y., Liu, C., Li, X., Meng, X., Shi, J. and Tian, X. 2022. Effect of the combined addition of mineral nitrogen and crop residue on soil respiration, organic carbon sequestration, and exogenous nitrogen in stable organic matter. Applied Soil Ecology, 171, p.104324. https://doi.org/10.1016/j.apsoil.2021.104324

Lin, H., Zheng, J., Zhou, M., Xu, P., Lan, T., Kuang, F., Li, Z., Yao, Z. and Zhu, B. 2024. Crop straw incorporation increases the soil carbon stock by improving the soil aggregate structure without stimulating soil heterotrophic respiration. Journal of Integrative Agriculture. https://doi.org/10.1016/j.jia.2024.09.026

Liu, Y., Wang, H., Schindlbacher, A., Liu, S., Yang, Y., Tian, H., Chen, L., Ming, A., Wang, J., Li, J. and Tian, Z. 2025. Soil respiration related to the molecular composition of soil organic matter in subtropical and temperate forests under soil warming. Soil Biology and Biochemistry, 201, p.109661. https://doi.org/10.1016/j.soilbio.2024.109661

Mirzaei, M., Anari, M.G., Razavy-Toosi, E., Zaman, M., Saronjic, N., Zamir, S.M., Mohammed, S. and Caballero-Calvo, A. 2022. Crop residues in corn-wheat rotation in a semi-arid region increase CO2 efflux under conventional tillage but not in a no-tillage system. Pedobiologia, 93, p.150819. https://doi.org/10.1016/j.pedobi.2022.150819

Muhammad W, Vaughan SM, Dalal RC. and Menzies NW. 2011. Crop residues and fertilizer nitrogen influence residue decomposition and nitrous oxide emission from a Vertisol. Biology and Fertility of Soils. 47: 15-23. https://link.springer.com/article/10.1007/s00374-010-0497-1

Munthali C, Aune JB. and Minde IJ. 2015. The impact of agroforestry on soil fertility and maize yield in Malawi. Agroforestry Systems. 89(2): 355-366.

Nicolardot B, Recous S. and Mary B. 2001. Simulation of C and N mineralisation during crop residue decomposition: a simple dynamic model based on the C: N ratio of the residues. Plant and soil. 228(1): .83-103. https://link.springer.com/article/10.1023/A:1004813801728

Paul BK, Lubbers IM. and Van Groenigen JW. 2014. Residue incorporation depth is a controlling factor of earthworm-induced nitrous oxide emissions. Global Change Biology. 18: 1141–1151. **https://doi.org/10.1111/j.1365-2486.2011.02525.x**

Ravali C, Jayasree G, Reddy KS, Pratibha G. and Triveni S. 2024. Impact of Paddy Straw Incorporation along with Different Fertilizer Doses on Mineral N Dynamics and GHG Emissions. International Journal of Plant & Soil Science. 36(5): 673-687. https://doi.org/10.9734/ijpss/2024/v36i54565

Reddy PN, Kumari JA, Mounika C, Raigar BL, Reddy MS., Chandravanshi M. and Kashyap S. 2018. Managing Crop Residues: Impacts on Soil C: N Ratio and microbial activity with the addition of a decomposition enhancer. International Journal of Advanced Biochemistry Research. 8(9S):295-304. https://doi.org/10.33545/26174693.2024.v8.i9Sd.2112

Reddy, M.S.L., Mitra, B., Gaber, A. and Hossain, A. 2024. Growth, Yield, Energetics, CO 2 Emissions and Production Economics of Zero-Tillage Wheat as Influenced by Different

Rice Residue Loads and Nutrient Management Options. Phyton (0031-9457), 93(12). 10.32604/phyton.2024.056789

Rezgui C, Trinsoutrot-Gattin I, Benoit M, Laval K. and Wassila RA. 2021. Linking changes in the soil microbial community to C and N dynamics during crop residue decomposition. Journal of Integrative Agriculture. 20(11): 3039-3059. https://doi.org/10.1016/S2095-3119(20)63567-5

Rochette P. and Angers DA. 1993. Soil-surface CO_2 fluxes induced by spring, summer and fall moldboard plowing in a sandy loam. Soil Science Society of America Journal. 63(3): 621-628. **https://doi.org/10.2136/sssaj1999.03615995006300030027x**

Ruijter FJ. and Huijsmans JFM. 2012. Ammonia emission from crop residues : quantification of ammonia volatilization based on crop residue properties. (Report / Plant Research International; No. 470). Plant Research International. https://edepot.wur.nl/213704.

Saidi N, Cherif M, Jedidi N, Mahrouk M, Fumio M, Boudabous A. and Hassen A. 2008. Evolution of biochemical parameters during composting of various wastes compost. American Journal of Environmental Sciences. 4(4). **http://www.scipub.org/fulltext/ajes/ajes44333-341.pdf**

Sakala WD, Cadisch G. and Giller KE. 2000. Interactions between residues of maize and pigeonpea and mineral N fertilizers during decomposition and N mineralization. Soil Biology and Biochemistry. 32:679–688. https://doi.org/10.1016/S0038-0717(99)00204-7

Sarma UJ, Chakravarty M. and Bhattacharyya HC. 2013. Emission and sequestration of carbon in soil with crop residue incorporation. Journal of the Indian Society of Soil Science. 61(2): 117-121.

Schmatz R, Recous S, Aita C, Tahir MM, Schu AL, Chaves B. and Giacomini SJ. 2017. Crop residue quality and soil type influence the priming effect but not the fate of crop residue C. Plant and Soil. 414: 229–245. https://link.springer.com/article/10.1007/s11104-016-3120-x

Singh B. 1991. Soil organic matter and its role in the maintenance of soil quality. Soil Science. 152(4): 257-265.

Vahdat E, Nourbakhsh F. and Basiri M. 2011. Lignin content of range plant residue controls N mineralization in soil. European Journal of Soil Biology. 47(4): 243-246. https://doi.org/10.1016/j.ejsobi.2011.05.001

Van Rijssel, S.Q., Kuipers, E., Mason-Jones, K., Koorneef, G.J., van der Putten, W.H. and Veen, G.C. 2025. Impact of soil inoculation on crop residue breakdown and carbon and nitrogen cycling in organically and conventionally managed agricultural soils. Applied Soil Ecology, 205, p.105760. https://doi.org/10.1016/j.apsoil.2024.105760

Vanlauwe B, Nwoke OC, Sanginga N. and Merckx R. 2001. Impact of residue quality on the C and N mineralization of leaf and root residues of three agroforestry species. Plant and Soil. 183: 221–231. https://link.springer.com/article/10.1007/bf00011437

Wang FE, Chen YX, Tian GM, Kumar S, He YF, Fu Q L. and Lin Q. 2004. Microbial biomass carbon, nitrogen and phosphorus in the soil profiles of different vegetation covers established for soil rehabilitation in a red soil region of southeastern China. Nutrient Cycling in Agroecosystems. 68: 181- 189. https://link.springer.com/article/10.1023/B:FRES.0000017470.14789.2a

Zeng G, Zhang Y, Huang J. and Wang Y. 2010. Effect of nitrogen on the degradation of cotton residue during composting. Waste Management. 30(12): 2375-2380.

Zhang, X., Xin, X., Yang, W., Ding, S., Ren, G., Li, M. and Zhu, A. 2021. Soil respiration and net carbon flux response to long-term reduced/no-tillage with and without residues in a wheat-maize cropping system. Soil and Tillage Research, 214, p.105182. https://doi.org/10.1016/j.still.2021.105182.