Carbon Dioxide Emission from Maize Straw Incubated with Soil under Various Moisture and Nitrogen Levels

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Summary: A laboratory incubation experiment was conducted to investigate the decomposition of maize straw incorporated into soil amended with nitrogen (N) and moisture (M) levels. Clay loam topsoil amended with maize straw was adjusted to four initial nitrogen treatments (C/N ratios of 72, 36, 18, and 9) and four moisture levels (60%, 70%, 80% and 90 % of field capacity) for the total of 16 treatments and incubated at 20°C for 51 days. CO_2-C evolved was regularly recorded for all treatments during entire incubation period. Results showed that the mixing of straw with soil accelerated decomposition rates and enhanced cumulative CO_2-C production. The incorporation of straw brought about 50% increase in the cumulative CO_2-C production as compared with controls. About 45% of added maize straw C was mineralized to CO_2-C in 51 days. We conclude that incorporation of straw into soil along with the addition of N and moisture levels significantly affected CO_2-C evolution, cumulative CO_2-C, C mineralization and soil organic carbon deposition. The CO_2 emission was in positive correlation with (R^2=0.99) N, moisture and incubation time (days). The straw returning into soil may enhance carbon pools and, thus will improve soil and environmental quality.

Key words; Moisture, nitrogen, soil organic carbon, straw decomposition,

Introduction

Organic manure abandonment, crop straw removal and field practices with low carbon inputs to agricultural soils have depleted soil organic carbon (SOC) contents [1, 2]. The SOC is a key factor affecting soil quality, nutrient availability and flux of green house gases (GHGs) [1, 3]. The decline in SOC is an increasing concern in China as in many other parts of the world, threatening soil quality and environment [1, 4]. The soil organic matter (SOM) addition as crop residues restores SOC, recycles nutrients and increase readily available C and N thereby affecting CO_2 emission to atmosphere [5-7]. Appropriate management practices are needed for the decomposition of crop residues for SOC turnovers, sustained agriculture and sound environment. In the past, farmers returned all organic sources into soils, but during socio-economic development, food demand was increased and organic fertilizers were replaced with synthetic fertilizers. Consequently traditional farming diminished [1]. Guanzhong plain is an important grain production area accounting 19% of total land with typical semi-humid climate prone to drought, located in Shaanxi province Northwest China. Most of crop lands in this area possess relatively low SOC contents due to long intensive cultivation coupled with less organic C returned to soil [1, 2]. Winter wheat and summer maize rotation annually is major cropping system. A huge amount of straw is produced each year but only 15% is returned to soil, some is used for animal feeds or industrial raw materials. The rest is discarded or burnt causing serious environmental problems. Currently maize straw in this region is perceived a rich source of organic C and other minerals. The incorporation of straw is now being promoted to enhance SOC, supply nutrients and reduce CO_2 release [5, 8]. However, using maize straw with high C/N ratio as organic fertilizer presents challenges which may restrict its decomposition. Under these field conditions, growers must rely on decomposition of straw added to soil to promote SOC deposition and nutrient release. Soil microclimate, especially moisture (M), controls microbial activity and plays decisive role in the decomposition of straw and C transformations [9]. Soils do not often maintain constant moisture for long time and are continually affecting drastically the straw decomposition. Some researchers revealed that soil moisture greatly influences residue decomposition rates, CO_2 flux and C mineralization [10-12]. So investigating optimal moisture regime for enhancing

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straw decomposition is very critical as it is poorly understood. Nitrogen is deemed very important for enhancing decomposition of straw added to soil. It is critical in lowering C/N ratios which play crucial in controlling C turnover, and accelerates the rates of straw decomposition [13-15]. Whereas a positive effect of N at initial stages of decomposition and negative effect at later stages are also reported by other researchers [6, 16]. The influence of maize straw incorporation on SOC is still not clear, especially with fixed C/N ratios. Carbon dioxide is difficult to measure in field, while incubation provides best environment to estimate microbial activities and simulated CO_2 measurement [14]. Although, most studies have focused on either N or M affecting residue decomposition, however little information exists on soil incorporation of maize straw and interactive effects of N at different moisture regimes on CO_2 evolution. Major aim of this study was to investigate the carbon mineralization of maize straw in soil through observing CO_2-C emission rates and cumulative production under various N and M levels at controlled temperature, to determine optimum N and M levels for straw decomposition and to evaluate the effect of incorporating straw on SOC.

Results and Discussion

Effect of Moisture and Nitrogen on Emission Rates and Cumulative CO_2-C

The evolution pattern of maize straw decomposition (CO_2-C evolution) showed that addition of N increased decomposition rate in first phase however, positive effects disappeared after one week due to rapid mineralization of soluble compounds, and later the rates were declined. The mixing of straw with soil caused about 50% increase in the cumulative CO_2-C production as compared with control. The similar results are found by other researcher [13]. After 30 days, the respiration rates were close to initial rates suggesting that maximum straw C was mineralized. Mineral N applied increased the decomposition rate of maize straw by satisfying N requirements of decomposing microbes and there might be a shift in decomposers community composition towards organisms that are more efficient but have greater N requirement [15]. Comparatively higher CO_2-C emission rates were maintained at N_M with all (M_{60}, M_{70}, M_{80} and M_{90}) moisture regimes. CO_2-C evolution increased consecutively at nitrogen rates N_L, N_M, N_H applied along with increasing moisture but little less C was evolved at N_v suggesting that N rates could be applied to a certain levels otherwise CO_2-C emission will be reduced (Table-1). At N_V, less CO_2-C production, may be due to luxurious consumption of N by soil microbes that suppressed the CO_2-C production, or might be attributed to N immobilization per unit CO_2 evolved when N is in abundance [14, 19]. The addition of $(NH_4)_2SO_4$ decreased or did not changed soil respiration in laboratory studies as reported by Henriksen and Breland [6]. The cumulative CO_2-C emission was significantly reduced in M_{60} and M_{70} treatments with the increase of N level from N_H to N_V. However, when moisture was at 80% and 90%, N supplied to soil at N_L, N_M, and N_H rates increased the cumulative amount of CO_2-C emission and then significantly decreased at N_V rates. This suggests that excess N supply reduced C mineralization. At N_H rate due to appropriate C/N ratio around 20, more CO_2-C was evolved along with fairly higher M_{70} moisture level. At two high adjusted C/N ratios, the maize straw decomposition was declined due to N depletion but did not stop the rate completely [6, 17]. More N was mineralized from organic residues with reduced C/N ratios [18] and significant relationship of decomposition of maize residue mixed into soil with addition of N was found [13]. The cumulative CO_2-C emission was 1.33, 1.16, 1.04 times higher in $M_{90,}$ $M_{80,}$ M_{70} treatments, respectively compared to the M_{60} treatment. The highest CO_2-C emission was observed in the treatments N_H+M_{90}. These results are in agreement with the results obtained by other researchers on straw incubation [13, 15, 16]. Higher moisture levels (M_{80}, M_{90}) yielded high CO_2-C evolution throughout incubation experiment. This finding may rule out negative influence of higher moisture content on microbial activity due to occurrence of possible anaerobic conditions. There was greater CO_2-C evolution rate at 80% than 70% moisture level of WHC [20]. However, the moisture trend in our study showed a linear trend with CO_2-C production as 60%>70%>80%>90% of field capacity. CO_2-C emission was linearly related with increasing moisture levels from soil samples [21]. Recently, [22] found that mineralization of wheat straw was highly dependant on soil moistening in incubation experiment. There are also some contradicting results. In an other study 5 moisture levels as 20, 40, 60, 80 and 100% of WHC were applied and it was observed that CO_2 evolution increased up to 60-80% while it was suppressed at 100% moisture level [8]. In an other incubation study on cotton leaves with constant and alternate moisture it was found that C mineralization rates were not significantly affected by the moisture [23]. Rate of CO_2-C evolution is better parameter to assess SOC decomposition process than total evolved amount. Therefore, in the field, nitrogen application at N_H level and higher irrigation management could increase the cumulative CO_2-C emission.

Table-1: Cumulative amount of CO_2-C evolved during maize straw decomposition in relation with four N and four moisture levels.

Cumulative CO_2-C evolution (mg pot^{-1})					
N Rates	Moisture Regimes				Average %
	M_{60}	M_{70}	M_{80}	M_{90}	
N_L	212.0±5.6g	251.1±8.6 de	256.5+6.2 d	269.9±5.9 bc	247.4 A
N_M	225.9±2.9 f	249.6±9.3 de	259.0±7.3 cd	269.0±8.3 bc	250.9 A
N_H	184.6±3.3 h	243.1±6.9 e	276.9±7.1 ab	288.6±6.4 a	248.3 A
N_V	189.5±6.2 h	193.3±7.3 h	252.0±6.2 de	255.6±4.7 d	222.6 B
Average	203.0 C	234.3 B	261.1 A	270.8 A	

* Significant difference among treatments are indicated at $p<0.05$: significant difference among means are indicated at $p<0.01$.

Correlation of CO_2-C Emission with Incubation Time

The cumulative CO_2-C showed linear correlation with incubation time for both nitrogen rates and moisture levels (Fig. 1). The CO_2-C accumulation was increased at different N rates (except N_V) and moisture levels. The effect of N supply or moisture treatment on CO_2-C evolution showed similar trend with increasing periods of incubation. Furthermore, the CO_2-C evolution was increased as moisture increased from 60% to 90%. At N_V level, CO_2-C emission was significantly decreased with increasing incubation period while the CO_2-C was increased with increasing moisture. The cumulative CO_2-C evolution was normally higher at N_L and N_M rates against higher moisture levels during early stages at M_{80} and M_{90} but at final stage more CO_2-C was maintained at two higher N rates but in both cases at elevated moistures (Fig. 1). Individual treatment behavior varied significantly and considerably among all the treatments (Fig. 2). Thus increase in moisture levels increased the cumulative evolution of the CO_2-C evolved, irrespective of N rates applied. The highest value of about 290 mg CO_2-C was found at N_H rate with M_{80} and M_{90} moisture levels. The amount of CO_2-C evolved was decreased at N_V. At N_V, the N immobilization per unit CO_2 might be evolved due to luxury consumption by microbes when present in abundance and no statistically significant difference was found between M_{80} and M_{90} at N_v.

Percent C mineralized as Organic C

The percent C mineralization of straw C respired (mg CO_2-C/ mg of added straw C) during 51 days varied significantly ($p<0.05$) among all treatments. Percent C mineralized was calculated from straw C added after subtracting the net CO_2-C mg evolved from control treatments (Table-2). The percent carbon mineralized at different N rates combined with certain moisture levels showed similar pattern as that of CO_2-C flux. The effect declined with increasing N content. The respired straw C ranged from about 34.63- 48.95% in treatments N_V+M_{60} and N_H+ M_{90}, respectively. On an average, about 44.34% of added straw C was mineralized to CO_2-C proportion being higher for M_{70} moisture followed by M_{80} at all N rates applied. Whereas at lower C/N ratios the 85% moisture remained significant, however, less difference was observed between 80 and 90% moisture of WHC. The moisture trend showed increase in CO_2 evolution with increasing moisture 60>70>80>90% of field capacity (Table-2). In our study about 44.33% of maize straw C was mineralized to CO_2 within 51 days at 20^{o}C. According to previous reports, the range of maize straw mineralization was 36-66% [18, 24, 25]. Owing to favorable nitrogen rates, moisture levels and controlled temporal incubation conditions, C mineralization is fairly higher.

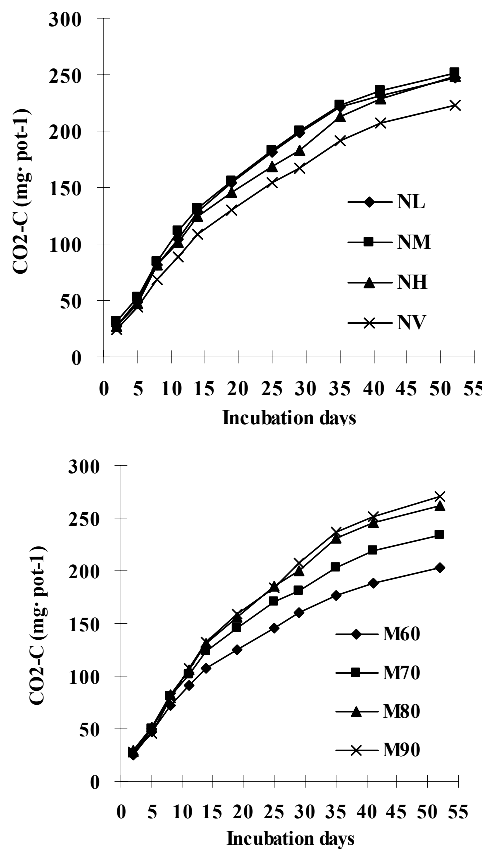


Fig. 1: The correlation of individual and interactive response of nitrogen rates and moisture regimes to incubation time for cumulative CO_2-C flux.

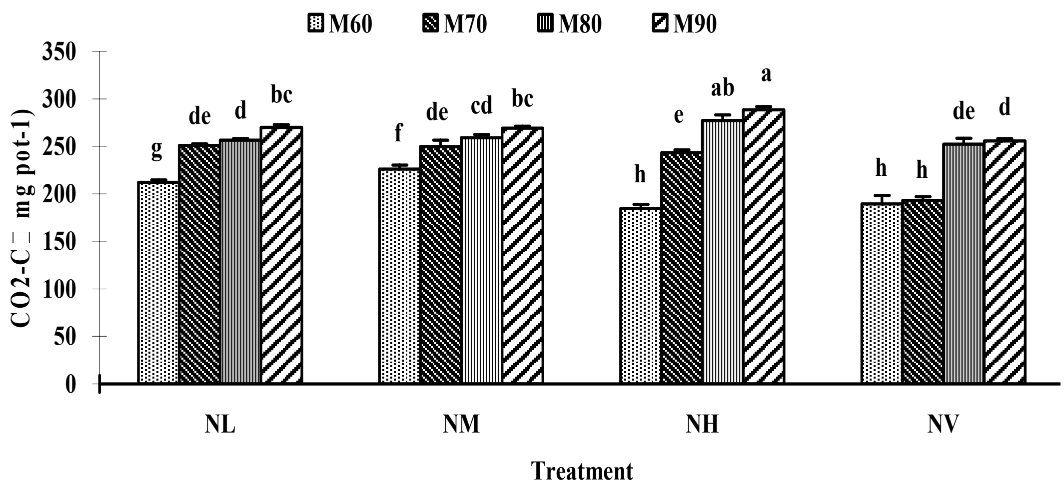


Fig. 2: Individual treatment behavior for carbon dioxide fluxes (respiration) from soil straw amended treatments (soil mixed with straw) at N_L N_M N_H and N_V added nitrogen against M_{60}, M_{70}, M_{80} and M_{90} moisture levels in entire incubation experiment.

Table-2: C mineralized as percent of added organic C at 20°C for 51 days from soils amended with maize straw treated with different N rates at various moisture levels.

C mineralized (% of Organic C)					
N Rates	Moisture Regimes				Average %
	M_{60}	M_{70}	M_{80}	M_{90}	
N_L	40.38±0.06 m	42.13±0.04 n	34.69±0.13 p	31.09±0.12 q	44.78 A
N_M	44.72±0.07 k	46.92±0.11 g	42.94±0.10 l	35.61±0.09 o	46.36 A
N_H	45.23±0.04 i	47.22±0.04 b	45.87±0.10 f	45.76±0.12 h	43.62 A
N_V	47.74±0.12 d	48.07±0.02 c	48.95±0.12 a	46.45±0.12 e	40.63 B
Average	37.25 C	42.99 B	47.07 A	48.07 A	

* Significant difference among treatments are indicated at $p<0.05$: significant difference among means are indicated at $p<0.01$.

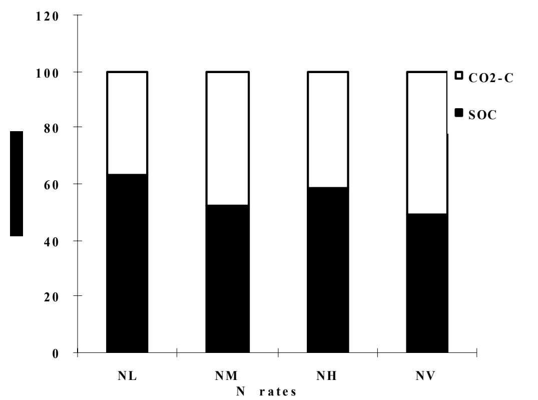
Soil Organic Carbon Accumulation

Mixing of the straw with soil significantly increased the SOC levels in soils in comparison with control, however, different moisture levels and N rates after analysis also showed effect on SOC (Table-3). Incorporation of crop residues is very beneficial for the SOC accumulation in soils [24]. Higher N rates with higher moistures yielded more SOC, while in all treatments it varied significantly at all N and moisture levels. The average value of SOC at N_L was 2.11 g kg^{-1} followed by 1.84, 2.29 and 1.43 g kg^{-1} at N_M, N_H and Nv, respectively. Whereas the average values of SOC obtained for different moistures ranged from 2.36, 1.57, 2.30 and 2.20 g kg^{-1}at M_{60}, $M_{70,}$ M_{80} and M_{90} moisture levels, respectively. The amount of SOC significantly increased with incorporation of straw into soil and highest value for SOC was obtained for N_H+M_{80}. The increase in N is deemed as a way to sequester SOC [8]. Nitrogen additions enhanced the SOC contents of maize straw incubated with soil under controlled conditions [5]. Currently, the nutrient input is mainly dependent on chemical fertilizers, large amount of crop straw were discarded or burnt, so in long time scales, this caused the continuous decline of SOC content. With increase of 1 g SOC kg^{-1}, maize yield can be increased about 328 kg ha^{-1} [4]. The CO_2 emission in recent years has become global environment concern and counter measures are being suggested to limit emissions of GHGs [26] and increasing the carbon reserves of terrestrial ecosystem is very effective measure to reduce CO_2 emissions. The increase in SOC has ecological effects, through increasing soil fertility and productivity and alleviate GHGs effect. Further it was revealed that CO_2-C / SOC ratio in soils was significantly influenced by the maize straw incorporation with different N and M levels (Fig. 3). The CO_2-C loss/SOC ratios were 36.54:63.46 and 50.97:49.03 at N_1 and N_4, respectively, with average ratio of 44.27: 55.73. The CO_2-C / SOC ratio ranged from 36.54:63.46 and 50.97:49.03 at N_L and N_V, respectively and averaged to 44.27: 55.73. While at M_{60} and M_{70} moisture content the ratio was 36.45:63.55 and 51.07:48.93 and averaged to 43.62: 56.38 with almost a similar trend. In our study the inorganic CO_2-C to organic SOC ratio remained almost equal at reasonably higher N rates and moisture. This study found that addition of maize straw can significantly increase SOC contents. The CO_2 emission from straw decomposition in the short term at least can retain half of the carbon and half will be evolved as CO_2-C [27-29].

Table-3: Soil organic carbon accumulation in soil amended with maize straw along with different N rates at various moisture levels applied.

N Rates	Soil Organic Carbon g kg^{-1}				Average
	Moisture Regimes				
	M_{60}	M_{70}	M_{80}	M_{90}	
N_L	2.89±0.6 bc	0.95±0.1 ghij	2.03±0.8cd	2.58±0.1 de	2.16 B
N_M	1.96±0.6 defg	1.89±0.6 defg	1.80 ±0.8efg	1.71±0.2 efgh	1.84 BC
N_H	1.81±0.6 efgh	2.12±0.4 def	4.45±0.8 a	0.80±0.4 hij	2.29 A
N_V	0.12±0.1 j	1.32±0.8 fghi	0.56±0.4 ij	3.71±0.6 ab	1.43 C
Average	2.36 A	1.57 B	2.3 A	2.2 A	

* Significant difference among treatments are indicated at *$p<0.05$:* significant difference among means are indicated at p<0.01.



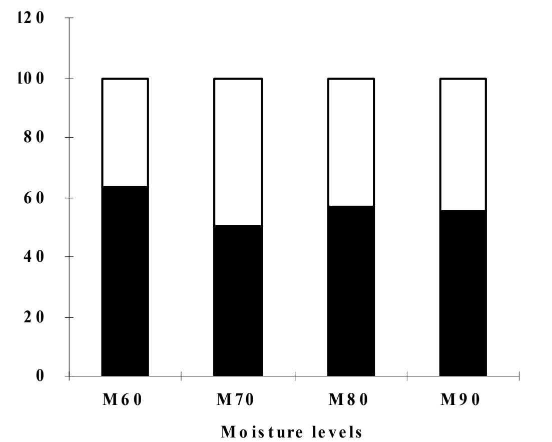


Fig. 3: Proportion of organic (SOC) to inorganic carbon (CO_2-C) at different nitrogen and moisture levels recorded for entire incubation experiment.

Experimental

Preparation of Soil and Straw Samples

The soil samples used for the incubations in this study were collected from surface horizon (0-15 cm) using 4 cm diameter auger from an ongoing straw returning to fields, in winter wheat-summer maize rotation cropping system of 2009 at Sanyuan County, Guanzhong Plain, Shaanxi Province, Northwest China. The soils were classified as Earth-cumuli-Orthic-Anthrosols**.** The mean annual temperature and precipitation is around 13.6°C and 656 mm, respectively. The soil was clay loam in texture with pH, 7.3; organic carbon, 9.2 g kg^{-1} and total N, 0.86 g kg^{-1}. During growing season, the average annual rate of fertilization for N was 116 kg $ha^{-1}$and for P_2O_5 was 97 kg ha^{-1}. The soil was air dried and kept in plastic bags, visible plant residues were removed by hand. The soil was ground and sieved through 2 mm sieve and then stored for less than one week at 4°C. Maize straw (including leaves and stems) was collected from the same field after the grain harvest, washed with distilled water, oven dried at 70°C then pulverized. Maize straw was cut into small pieces, ground and mixed with the soil samples for incubation. The straw carbon content was 42.3% while total nitrogen was 0.51%**.**

Experimental Design and Incubation Procedure

The experiment was set up with factorial arrangement of 16 treatments with five replicates and each 5th replication was set as control (no straw addition) for every treatment. Nitrogen was applied at four rates 0.03(N_L), 0.06 (N_M), 0.14 (N_H) and 0.28(N_V) g kg^{-1} soil to adjust C/N ratios of maize straw mixed with soil. The ground straw was thoroughly mixed and filled into PVC pots (height 11cm, inner diameter 250 mm) at the rate of 150 g soil and 125 g maize straw pot^{-1}. The amount of the straw added to soil ensured sufficient amount of C for microbial respiration and was chosen to simulate field conditions of the 8 t DM ha^{-1} incorporated into plough layer. The soil-residue mixture with N adjusted C/N ratios along with four moisture levels 60% (M_{60}), 70% (M_{70}), 80% (M_{80}) and 90% (M_{90}) of water holding capacity was incubated at 20°C. Nitrogen as $(NH_4)_2SO_4$ and phosphorus as K_2HPO_4 were applied to pots as water solution to obtain C/N ratios of 72, 36, 18, and 9. Samples were watered with calculated amount of deionized water to maintain approximately 60, 70, 80 and 90% moisture contents of water holding capacity. The pots were then kept in incubator at the constant temperature for the accumulation of carbon dioxide. Carbon dioxide evolution was regularly monitored using alkali absorption method, throughout incubation experiment.

CO_2-C and SOC Determination

For the determination of CO_2-C, 25 mL vials containing 10 mL of 1M NaOH solution were placed on soil surface inside the pot to absorb CO_2, covered with polyethylene sheets and kept for incubation in the darkness at 20°C. Excessive NaOH was titrated with 0.2 M HCl after precipitating carbonates with $BaCl_2$ using phenolphthalein as an indicator and subtracted from the amount titrated in control without straw. All the pots were taken out and opened periodically, aerated for few minutes and soil water contents were checked, weighing and then adjusted by adding distilled water. The CO_2 evolved was measured at 2, 5, 8, 11, 14, 20, 24, 30, 36, 41 and 51st day of incubation. At the end of incubation, samples were analyzed for Soil organic carbon. This SOC was determined using dichromate H_2SO_4-$K_2Cr_2O_7$ wet oxidation method of Walkley and Black.

Statistical Analysis

The means were subjected to two way ANOVA to assess individual and interactive effects of N rates and moisture levels on C mineralization. Multiple comparisons among means of treatments for C evolution, mineralization and SOC were performed using Duncan's multiple range test at P=0.05. All statistical analysis was performed using (SPSS 16.00 for windows) statistical package and Microsoft Excels, 2003.

Conclusions

Straw returning to soil along with N and M levels had profound effects on straw decomposition rates, CO_2 evolution, cumulative CO_2, SOC, and nutrient release. N_H rate and higher moisture enhanced decomposition rate with higher CO_2-C due to adjusted C/N ratio. Additional research work should further be conducted to find interactive effects of N and M on maize straw decomposition in long term study. The incorporation of maize straw was effective in improving the SOC reserves and nutrient cycling.

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