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. CO2-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 CO2-C production. The incorporation of straw brought about 50% increase in the cumulative CO2-C production as compared with controls. About 45% of added maize straw C was mineralized to CO2-C in 51 days. We conclude that incorporation of straw into soil along with the addition of N and moisture levels significantly affected CO2-C evolution, cumulative CO2-C, C mineralization and soil organic carbon deposition. The CO2 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 greenhouse 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 CO2 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 CO2 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, CO2 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 CO2 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 CO2 evolution. Major aim of this study was to investigate the carbon mineralization of maize straw in soil through observing CO2-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 CO2-C

The evolution pattern of maize straw decomposition (CO2-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 CO2-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 CO2-C emission rates were maintained at NM with all (M60, M70, M80 and M90) moisture regimes. CO2-C evolution increased consecutively at nitrogen rates N1, NM, NH applied along with increasing moisture but little less C was evolved at N, suggesting that N rates could be applied to a certain levels otherwise CO2-C emission will be reduced (Table-1). At Nv, less CO2-C production, may be due to luxurious consumption of N by soil microbes that suppressed the CO2-C production, or might be attributed to N immobilization per unit CO2 evolved when N is in abundance [14, 19]. The addition of (NH4)2SO4 decreased or did not changed soil respiration in laboratory studies as reported by Henriksen and Breland [6]. The cumulative CO2-C emission was significantly reduced in M60 and M70 treatments with the increase of N level from N1 to Nv. However, when moisture was at 80% and 90%, N supplied to soil at N1, NM, and NH rates increased the cumulative amount of CO2-C emission and then significantly decreased at Nv rates. This suggests that excess N supply reduced C mineralization. At Nv rate due to appropriate C/N ratio around 20, more CO2-C was evolved along with fairly higher M70 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 CO2-C emission was 1.33, 1.16, 1.04 times higher in M60, M80, M90 treatments, respectively compared to the M60 treatment. The highest CO2-C emission was observed in the treatments NH+M90. These results are in agreement with the results obtained by other researchers on straw incubation [13, 15, 16]. Higher moisture levels (M60, M90) yielded high CO2-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 CO2-C evolution rate at 80% than 70% moisture level of WHC [20]. However, the moisture trend in our study showed a linear trend with CO2-C production as 60%>70%>80%>90% of field capacity. CO2-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 CO2 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 CO2-C evolution is better parameter to assess SOC decomposition process than total evolved amount. Therefore, in the field, nitrogen
application at N<sub>II</sub> level and higher irrigation management could increase the cumulative CO<sub>2</sub>-C emission.

Table-1: Cumulative amount of CO<sub>2</sub>-C evolved during maize straw decomposition in relation with four N and four moisture levels.

<table>
<thead>
<tr>
<th>N Rates</th>
<th>Moisture Regimes</th>
<th>Average %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M&lt;sub&gt;60&lt;/sub&gt;</td>
<td>M&lt;sub&gt;70&lt;/sub&gt;</td>
</tr>
<tr>
<td>N&lt;sub&gt;II&lt;/sub&gt;</td>
<td>212.0±5.6g</td>
<td>251.1±8.6 de</td>
</tr>
<tr>
<td>N&lt;sub&gt;I&lt;/sub&gt;</td>
<td>225.9±2.9 f</td>
<td>249.6±9.3 de</td>
</tr>
<tr>
<td>N&lt;sub&gt;0&lt;/sub&gt;</td>
<td>184.6±3.3 h</td>
<td>243.1±6.9 e</td>
</tr>
<tr>
<td>N&lt;sub&gt;V&lt;/sub&gt;</td>
<td>189.5±6.2 h</td>
<td>193.3±7.3 h</td>
</tr>
<tr>
<td>Average</td>
<td>203.9 C</td>
<td>234.3 B</td>
</tr>
</tbody>
</table>

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

Correlation of CO<sub>2</sub>-C Emission with Incubation Time

The cumulative CO<sub>2</sub>-C showed linear correlation with incubation time for both nitrogen rates and moisture levels (Fig. 1). The CO<sub>2</sub>-C accumulation was increased at different N rates (except N<sub>V</sub>) and moisture levels. The effect of N supply or moisture treatment on CO<sub>2</sub>-C evolution showed similar trend with increasing periods of incubation. Furthermore, the CO<sub>2</sub>-C evolution was increased as moisture increased from 60% to 90%. At N<sub>V</sub> level, CO<sub>2</sub>-C emission was significantly decreased with increasing incubation period while the CO<sub>2</sub>-C was increased with increasing moisture. The cumulative CO<sub>2</sub>-C evolution was normally higher at N<sub>II</sub> and N<sub>M</sub> rates against higher moisture levels during early stages at M<sub>80</sub> and M<sub>90</sub> but at final stage more CO<sub>2</sub>-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<sub>2</sub>-C evolved, irrespective of N rates applied. The highest value of about 290 mg CO<sub>2</sub>-C was found at N<sub>II</sub> rate with M<sub>80</sub> and M<sub>90</sub> moisture levels. The amount of CO<sub>2</sub>-C evolved was decreased at N<sub>V</sub>. At N<sub>V</sub>, the N immobilization per unit CO<sub>2</sub> might be evolved due to luxury consumption by microbes when present in abundance and no statistically significant difference was found between M<sub>80</sub> and M<sub>90</sub> at N<sub>V</sub>.

Percent C mineralized as Organic C

The percent C mineralization of straw C respired (mg CO<sub>2</sub>-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<sub>2</sub>-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<sub>2</sub>-C flux. The effect declined with increasing N content. The respired straw C ranged from about 34.63- 48.95% in treatments N<sub>V</sub>+M<sub>60</sub> and N<sub>II</sub> + M<sub>90</sub>, respectively. On an average, about 44.34% of added straw C was mineralized to CO<sub>2</sub>-C proportion being higher for M<sub>70</sub> moisture followed by M<sub>80</sub> 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<sub>2</sub> 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<sub>2</sub> within 51 days at 20°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. 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.

<table>
<thead>
<tr>
<th>Moisture Regimes</th>
<th>N Rates</th>
<th>Average %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M_60</td>
<td>M_70</td>
</tr>
<tr>
<td>NL</td>
<td>40.38±0.06 m</td>
<td>42.13±0.04 a</td>
</tr>
<tr>
<td>NM</td>
<td>44.72±0.07 k</td>
<td>46.92±0.11 g</td>
</tr>
<tr>
<td>NH</td>
<td>45.23±0.04 i</td>
<td>47.22±0.04 b</td>
</tr>
<tr>
<td>NV</td>
<td>47.74±0.12 d</td>
<td>48.07±0.02 e</td>
</tr>
<tr>
<td>Average</td>
<td>37.25 C</td>
<td>42.99 B</td>
</tr>
</tbody>
</table>

* 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 2.29 and 1.43 g kg⁻¹ at N_M, N_H and N_V, 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 CO₂ 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 CO₂ emissions. The increase in SOC has ecological effects, through increasing soil fertility and productivity and alleviate GHGs effect. Further it was revealed that CO₂-C / SOC ratio in soils was significantly influenced by the maize straw incorporation with different N and M levels (Fig. 3). The CO₂-C loss/SOC ratios were 36.54:63.46 and 50.97:49.03 at N_L and N_V, respectively, with average ratio of 44.27: 55.73. The CO₂-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 CO₂-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 CO₂ emission from straw decomposition in the short term at least can retain half of the carbon and half will be evolved as CO₂-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.

<table>
<thead>
<tr>
<th>N Rates</th>
<th>Soil Organic Carbon g kg⁻¹</th>
<th>Moisture Regimes</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M₆₀</td>
<td>M₇₀</td>
<td>M₈₀</td>
</tr>
<tr>
<td>N₁</td>
<td>2.89±0.6 bc 0.95±0.1 ghij</td>
<td>2.03±0.8cd 1.71±0.2 efgh</td>
<td>1.84 BC</td>
</tr>
<tr>
<td>N₂</td>
<td>1.81±0.6 efgh 2.12±0.4 defg</td>
<td>4.45±0.8 a 0.80±0.4 hij</td>
<td>2.29 A</td>
</tr>
<tr>
<td>N₃</td>
<td>0.12±0.1 j 1.32±0.8 fghi</td>
<td>0.56±0.4 ij 3.71±0.6 ab</td>
<td>1.43 C</td>
</tr>
<tr>
<td>Average</td>
<td>2.36 A</td>
<td>1.57 B</td>
<td>2.3 A</td>
</tr>
</tbody>
</table>

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

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(N₁), 0.06 (N₂), 0.14 (N₃) and 0.28(N₄) 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 11 cm, 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% (M₆₀), 70% (M₇₀), 80% (M₈₀) and 90% (M₉₀) of water holding capacity was incubated at 20°C. Nitrogen as (NH₄)₂SO₄ and phosphorus as K₂HPO₄ 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. CO₂-C and SOC Determination

For the determination of CO₂-C, 25 mL vials containing 10 mL of 1M NaOH solution were placed on soil surface inside the pot to absorb CO₂, 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 BaCl₂ 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 CO₂ 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 H₂SO₄-K₂Cr₂O₇ 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, CO₂ evolution, cumulative CO₂, SOC, and nutrient release. N rate and higher moisture enhanced decomposition rate with higher CO₂-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.

Acknowledgements

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References