Emission of carbon dioxide influenced by nitrogen and water levels from soil incubated straw


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ABSTRACT

An incubation study was carried out to investigate the influence of nitrogen rates to determine optimum C/N ratio under various moisture levels for straw decomposition and sequester carbon (C) in the soil. The aim was to observe straw carbon mineralization through measuring the amount of CO$_2$ evolution. A clay loam topsoil mixed with maize straw was supplied with four nitrogen rates (0.04, 0.08, 0.16, 0.32 g N/kg) using (NH$_4$)$_2$SO$_4$ to adjust C/N ratios at 82, 42, 20, and 10. Soil moisture was maintained at 55%, 70%, 85%, and 100% of field capacity incubated at 25°C for 53 days. The experiment was set up with 16 treatments arranged in complete randomized design. Results showed that mixing of straw with soil increased 50% cumulative CO$_2$-C compared to controls. Averagely, about 44% of added maize straw C was mineralized to CO$_2$-C. Straw addition along with nitrogen and moisture had significant relationships ($P < 0.05$) to cumulative CO$_2$-C, soil organic C and microbial biomass C. There was a highly significant relationship ($R^2 = 0.99$) between CO$_2$-C emission and incubation time.

Keywords: CO$_2$-C evolution; moisture; nitrogen; straw decomposition

Field practices with low carbon inputs to arable soils as crop straw removal and manure abandonment deplete soil organic carbon (SOC) (Feiziene and Kadziene 2008, Zhang et al. 2008). It plays a vital role in improving quality and productivity affecting soil chemical, physical and biological properties and influences greenhouse gases (GHGs) emissions (Rivero et al. 2004, Rasool and Kakul 2008). However, returning residues impacts microbial decomposition processes, restores SOC, recycles nutrients and reduces C emission to atmosphere (Hadas et al. 2004).

Farmers used to return farm residues to soil, but increasing food demand, enhanced or gearedup use of synthetic fertilizers in China including the Guanzhong Plain (Wang et al. 2008). This is an important grain production area and accounts for 19% of total land with typical semi-humid climate prone to drought, located in Shaanxi Province in Northwest China. Due to long intensive cultivation with less organic C returns, soils in this region possess low SOC. Maize is the major crop of the area, producing huge quantity of straw which needs valuable disposal solution. Presently, only 15% of the straw is being returned directly to fields. Some is used for animals and industry while the rest is discarded or burned causing air pollution such as release of CO$_2$ (Lu et al. 2002). However, using maize straw with high C/N ratio as organic fertilizer presents challenges which may restrict its decomposition under limited water resources. Decomposition of straw added to soil is governed by many factors such as moisture, temperature and nutrient addition. Soil moisture could greatly enhance straw decomposition and CO$_2$ flux (Lomander et al. 1998, Li et al. 2006, Tulina et al. 2009) or reduce it (Kruse et al. 2004, Iqbal et al. 2009). Nitrogen (N) addition enhances decomposition of straw by lowering C/N ratios (Potthoff et al. 2005, Chen et al. 2007) but negative effects in the later stages (Henriksen and Breland 1999).

Most research work has focused on effects of either nitrogen or moisture on straw decomposition. However influence of fixed C/N ratios of maize straw mixed into soil on CO$_2$-C evolution and SOC under different moisture levels is still

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not clear. This study was undertaken (1) to investigate the impact of N amendment (C/N ratio) on decomposition of maize straw mixed with soil by measuring CO$_2$-C emission under various moisture regimes (2) to evaluate subsequent effects of incorporating straw on SOC, microbial biomass carbon under controlled conditions.

MATERIALS AND METHODS

Site, soil and plant sampling. The soil used in this study was collected in August, 2009 from the Guanzhong Plain, Sanyuan County, Shaanxi Province, Northwest China. Annual winter wheat and summer maize rotation is major cropping system in this area. The mean annual temperature and precipitation are approximately 13.6°C and 656 mm, respectively. The soils were classified as Earth-cumuli-Orthic-Anthrosols. The texture of soil was clayey loam with water holding capacity of 300 g/kg, pH 7.3, organic C 9.2 g/kg, and total nitrogen 0.86 g/kg. Maize (Zea mays L.) straw C was 42% and total nitrogen was 0.61%. Soil samples were collected from surface horizon (0–15 cm) using soil auger. The soil was air dried and kept in plastic bags. Then soil was ground and sieved through 2 mm sieve and then stored for 5 days at 4°C. Maize straw was collected from the same field after grain harvest. Then it was washed with distilled water and dried at 70°C in laboratory. The straw was cut into small pieces (< 1 cm), ground and mixed with soil samples for incubation.

Experimental design and incubation procedure. The experiment was set up using complete randomized design with 16 treatments, replicated five times (each 5$^{th}$ replication as control). Nitrogen (N) was applied at four levels: 0.04 (N$_1$), 0.08 (N$_2$), 0.16 (N$_3$) and 0.32 (N$_4$) g/kg in order to adjust C/N ratios of maize straw to 80, 40, 20, and 10, respectively. Four moisture (M) levels: 55% low water (W$_{L}$), 70% medium water (W$_{M}$), 85% high water (W$_{H}$), and 100% very high (W$_{V}$) of field capacity (FC) were used. Each of four nitrogen amended C/N ratios was tested against four moisture levels. The ground straw was thoroughly mixed with soil then transferred into PVC pots (height 11 cm, inner dia. 250 mm) for an equivalent of 150 g soil to 1.25 g maize straw/pot. Nitrogen as (NH$_4$)$_2$SO$_4$ and phosphorus as K$_2$HPO$_4$ were applied to pots as water solution. Samples were wetted slowly with calculated amount of deionized water to maintain designed moisture contents. The pots were then incubated at the constant temperature of 25°C.

RESULTS AND DISCUSSION

Carbon dioxide evolution. Results revealed that mixing of maize straw with soil along with nitrogen and moisture levels significantly affected rates and cumulative CO$_2$-C evolution. It brought roughly a 50% increase in cumulative CO$_2$-C production, compared to control. CO$_2$-C emission significantly increased at N$_1$, N$_2$ and N$_3$ treatments but declined at N$_4$ (Table 1). A significant relationship was found between decomposition of maize residue and addition of mineral nitrogen (Potthoff et al. 2005, Chen et al. 2007). The highest CO$_2$-C emission was observed in the treatment (N$_3$ + W$_{V}$). Enhanced cumulative CO$_2$-C production observed in N$_3$ treatments is because C/N ratio around 20 favors bacterial activity with optimum moisture. The reason why decomposition efficiency increases with
increasing N is that there is a shift in microbial community with greater N requirements (Agren et al. 2001). Decline in cumulative CO$_2$-C at N$_4$ suggested that N addition can enhance CO$_2$-C evolution to certain level, otherwise reduction occurs. This may be due to luxury consumption of N by soil microbes that suppressed CO$_2$-C production. Decomposition declined due to N depletion in latter stages of incubation but did not halt completely, and ratios of immobilized N to added C were altered (Henriksen and Breland 1999).

The CO$_2$-C emission was increased with increasing moisture and was 1.33, 1.16, 1.04 times higher in W$_V$, W$_H$, W$_M$ treatments compared to W$_L$. However W$_H$ moisture remained economical in terms of CO$_2$-C production. Throughout incubation the treatments with fairly higher (W$_H$, W$_V$) moistures yielded more CO$_2$-C evolution, compared to W$_L$ and W$_M$. This finding may rule out negative influence of higher moisture on microbial activity due to anaerobic conditions. Li et al. (2006) found that, CO$_2$-C evolution was increased at 25% w/w compared to 17% w/w moisture levels from decomposing straw. It shows that the increasing moisture had tendency to enhance straw decomposition mixed with soil. Tulina et al. (2009) reported that mineralization of straw highly depended on soil moistening in incubations. Whereas, Iqbal et al. (2009) observed that CO$_2$-C evolution increased up to 60–80% while, suppressed at 100% moisture level. Cotton leaves were incubated with constant and alternate moisture but C mineralization rates were not significantly affected by the soil moisture (Kruse et al. 2004). The cumulative CO$_2$-C showed significantly linear correlations with incubation time for both nitrogen and moisture levels (Figure 1). It means that with longevity of incubation period more CO$_2$-C could have evolved. In this study, on average about 44% of maize straw C was mineralized to CO$_2$. However 36–50% mineralization of

<table>
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<td>N$_3$</td>
<td>184.6 ± 3.3$^h$</td>
<td>243.1 ± 6.9$^e$</td>
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<tr>
<td>N$_4$</td>
<td>189.5 ± 6.2$^h$</td>
<td>193.3 ± 7.3$^h$</td>
</tr>
<tr>
<td>Average</td>
<td>203.0$^C$</td>
<td>234.3$^b$</td>
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</table>

*significant differences among treatments are indicated at $P < 0.05$; significant difference among means are indicated at $P < 0.01$

Figure 1. Correlation of individual and interactive response of (a) nitrogen rates and (b) moisture regimes to incubation time for cumulative CO$_2$-C flux incubated at 25°C for 53 days
added straw C to CO$_2$ is reported by Abiven and Recous (2007), Jin et al. (2008).

**Soil organic carbon accumulation.** Mixing of maize straw with soil significantly ($P < 0.05$) increased SOC levels compared to controls. Generally, straw contains half of carbon, which increases SOC upon mineralization. Chen et al. (2007) incubated maize straw with soil along with N addition and found that the SOC content was enhanced. Fairly higher N rates with optimum moistures yielded more SOC, while in all treatments SOC varied significantly based on N and moisture applied (Table 2). The highest value of SOC was obtained for relatively higher N applied in treatment (N$_3$ + W$_H$). This may be due to optimum C/N ratio and moisture for microbial decomposition of straw. Iqbal et al. (2009) while working with straw and N combination reported that N addition is the best strategy for sequestrating more organic C in the soil. The average value of SOC at N and moisture levels were 2.29 g/kg followed by 2.11, 1.84, and 1.43 g/kg at N rate 1, 2, and 4 and 2.36, 1.57, 2.30, and 2.20 g/kg at W$_L$, W$_M$, W$_H$, and W$_V$. Clearly, by an increase of 1 g/kg SOC, maize yield can be increased to about 328 kg/ha in the Northwest China (Qiu et al. 2009). High CO$_2$ emission in recent years became of increasing concern to global community. Countermeasures are taken to limit GHGs emissions (Morgan 2000) and increasing carbon reserves of terrestrial ecosystems is effective to reduce CO$_2$ emission. Further, it was observed that after straw decomposition, the amounts of soil retained and evolved C into atmosphere as CO$_2$ were equal. However among them, the influence of water and N was obvious (Figure 2). The CO$_2$-C loss/SOC average ratios were 44.27:55.73 and 45.07:59 with N and moisture, respectively. By returning straw to soil, C emission from decomposition will be reduced, as half of the carbon could be retained.

**Effect of soil straw mixing on MBC.** Results revealed that straw incorporation into soil with

### Table 2. Soil organic carbon (g/kg) accumulated in soils amended with maize straw influenced by different N rates under various moisture regimes incubated at 25°C for 53 days

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<td></td>
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<td>W$_M$</td>
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<tr>
<td>N$_1$</td>
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<td>N$_4$</td>
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<td>1.32 ± 0.8$^{rghi}$</td>
</tr>
<tr>
<td>Average</td>
<td>2.36$^A$</td>
<td>1.57$^B$</td>
</tr>
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</table>

*significant differences among treatments are indicated at $P < 0.05$; significant differences among means are indicated at $P < 0.01$

![Figure 2]( Figure 2: Proportion of organic (SOC) and inorganic (CO$_2$-C) C influenced by various nitrogen rates (a) and moisture regimes (b) incubated at 25°C for 53 days)

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nitrogen and moisture treatments can obviously influence the soil MBC (Table 3). MBC averagely increased from N$_1$ to N$_3$ and subsequently reduced at N$_4$. Similarly, MBC enhanced with increasing moisture levels at W$_L$, W$_M$ however little less MBC was yielded at W$_H$. Comparing to control, straw mixing brought about 40% increase in soil MBC (Potthoff et al. 2005, Lou et al. 2007). Microbial biomass decomposes organic residues through degradation and C transformation, enhances organic matter and is a living index that reflects soil quality, fertility and environment (Spedding et al. 2004). Clearly, at least in short term, straw returned to soil can significantly increase MBC. Incorporation of maize straw into soil, nitrogen and moisture interactively affected CO$_2$ evolution, C mineralization, SOC and MBC contents. The research findings show that N$_3$ rate (C/N ratio 20) and W$_H$ (85%) of FC seem to be the most suitable for effective straw decomposition. This will also reduce the use of mineral fertilizers having economic gains. Soil incorporation of maize straw is effective in improving soil quality, and environment thus needs to be promoted in the Guanzhong plain.

**REFERENCES**


**Table 3. Microbial biomass carbon (mg/kg) in maize straw-amended soils influenced by different N rates under various moisture regimes incubated at 25°C for 53 days**

<table>
<thead>
<tr>
<th>N rate</th>
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<td></td>
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<td>168.95$^{abc}$</td>
<td>122.38$^d$</td>
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<tr>
<td>N$_4$</td>
<td>139.13$^{bcd}$</td>
<td>166.68$^{abc}$</td>
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<tr>
<td>Average</td>
<td>152.33$^{AB}$</td>
<td>154.95$^{AB}$</td>
</tr>
</tbody>
</table>

*significant differences among treatments are indicated at P < 0.05; significant differences among means are indicated at P < 0.01

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