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 $(NH_4)_2SO_4$ 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 5th 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 $(NH_4)_2SO_4$ and phosphorus as K_2HPO_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.

CO_2-C determination. The pots filled with a soil-straw mixture and 25 ml vials containing 10 ml of 1 mol/L NaOH solution were placed on soil surface inside pot to absorb CO_2. Pots were covered with polyethylene sheets and incubated in the darkness at 25°C. Excess NaOH was titrated with 0.2 mol/L HCl after precipitating carbonates with $BaCl_2$ using phenolphthalein as indicator and subtracted from controls. All the pots were taken out and opened periodically, aerated for few minutes and soil water content was checked and adjusted by adding distilled water. The CO_2 evolved was measured at 2, 5, 8, 11, 14, 20, 24, 30, 36, 41, and 53rd day of incubation.

Soil organic carbon. SOC concentration was determined using dichromate H_2SO_4-$K_2Cr_2O_7$ wet oxidation method of Walkley and Black (Nelson and Sommers 1996).

Microbial biomass carbon (MBC). MBC was measured by chloroform fumigation extraction (Vance et al. 1987). A 40 g sample of moist soil was split into two portions shaken at 250 rev/min with 100 ml K_2SO_4 and filtered. Organic C in 0.5 mol/L K_2SO_4 extracts was measured by Dohrman DC 80. Soil MBC was estimated from the relationship between organic carbons extracted from fumigated and subtracted from non fumigated soil samples.

Statistical analysis. Data were obtained as treatment means per day for cumulative CO_2-C evolution and were analyzed using two way analysis of variance (ANOVA) by the statistical package SPSS 16.00 (for Windows) and Microsoft excel, 2003. Differences in mean values were considered significant at $P < 0.05$.

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

Table 1. Cumulative amounts of CO_2-C (mg/pot) influenced by different N rates under various moisture regimes incubated at 25°C for 53 days

N rate	Moisture regimes				Average rate
	W_L	W_M	W_H	W_V	
N_1	212.0 ± 5.6^{g}	251.1 ± 8.6^{de}	256.5 ± 6.2^{d}	269.9 ± 5.9^{bc}	247.4^{A}
N_2	225.9 ± 2.9^{f}	249.6 ± 9.3^{de}	259.0 ± 7.3^{cd}	269.0 ± 8.3^{bc}	250.9^{A}
N_3	184.6 ± 3.3^{h}	243.1 ± 6.9^{e}	276.9 ± 7.1^{ab}	288.6 ± 6.4^{a}	248.3^{A}
N_4	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 differences among treatments are indicated at $P < 0.05$; significant difference among means are indicated at $P < 0.01$

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

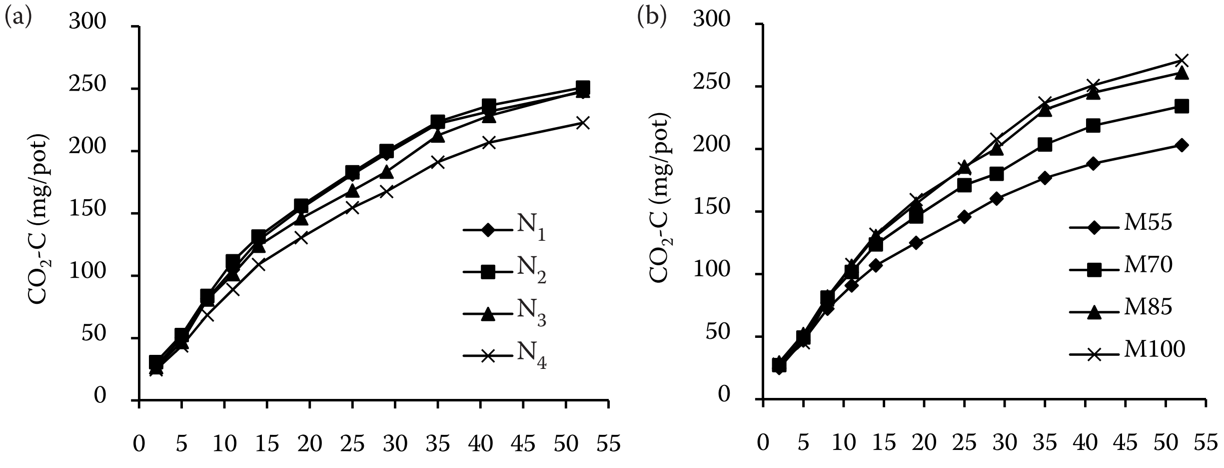

Figure 1. Correlation of individual and interactive response of (a) nitrogen rates and (b) moisture regimes to incubation time for cumulative CO_2-C flux incubated at 25°C for 53 days

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

N rate	Moisture regimes				Average
	W_L	W_M	W_H	W_V	
N_1	2.89 ± 0.6^{cd}	0.95 ± 0.1^{ghij}	2.03 ± 0.8^{ab}	2.58 ± 0.1^{de}	2.11^{B}
N_2	1.96 ± 0.6^{defg}	1.89 ± 0.6^{defg}	1.80 ± 0.8^{efgh}	1.71 ± 0.2^{efgh}	1.84^{BC}
N_3	1.81 ± 0.6^{efgh}	2.12 ± 0.4^{def}	4.45 ± 0.8^{a}	0.80 ± 0.4^{hij}	2.29^{A}
N_4	0.12 ± 0.1^{j}	1.32 ± 0.8^{fghi}	0.56 ± 0.4^{ij}	3.71 ± 0.6^{bc}	1.43^{C}
Average	2.36^{A}	1.57^{B}	2.3^{A}	2.2^{A}	

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

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

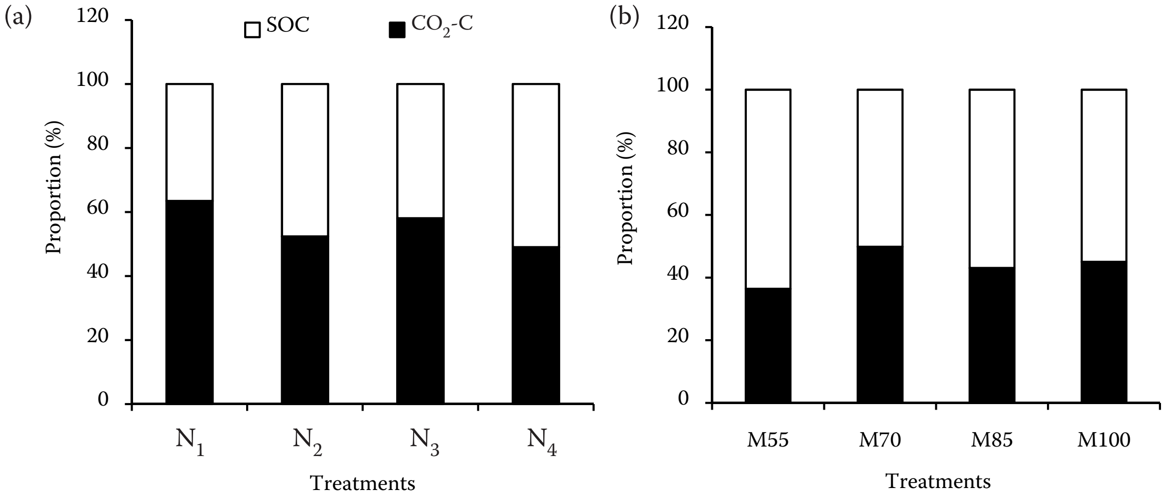

Figure 2. Proportion of organic (SOC) and inorganic (CO_2-C) C influenced by various nitrogen rates (a) and moisture regimes (b) incubated at 25°C for 53 days

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

N rate	Moisture regimes				Average
	W_L	W_M	W_H	W_V	
N_1	160.35^{abcd}	150.71^{abcd}	131.76^{cd}	138.53^{bcd}	145.34^{A}
N_2	140.90^{bcd}	180.03^{ab}	138.83^{bcd}	151.43^{abcd}	152.80^{A}
N_3	168.95^{abc}	122.38^{d}	140.82^{bcd}	193.17^{a}	156.33^{A}
N_4	139.13^{bcd}	166.68^{abc}	131.92^{cd}	153.19^{abcd}	147.73^{A}
Average	152.33^{AB}	154.95^{AB}	135.83^{B}	159.08^{A}	

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

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.

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