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Changes of the components and energy of corn stalk during decomposition process in cropland with different fertility

Liu Shuai*, Chen Xian Ni and Wang Xu Dong

College of Resource and Environment, Northwest A and F University, Yangling, Shaanxi 712100 China.

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In order to discuss the effect of soil fertility on components transformation and energy change of corn stalk during decomposition, carborundum tube was used to study the decomposition of corn stalk buried in different soils with high, medium and low fertility for 480 days. The decomposition rate and change of energy state of corn stalk were revealed. The results showed that the fractions of alcohol-benzene soluble and water soluble decreased in the decomposition process. The concentration of semi cellulose and cellulose increased firstly and then decreased. However, the concentration of lignin increased. The change of energetic state of corn stalk throughout the whole process could be divided into three stages such as fluctuating stage, decreasing stage and stable stage. Totally, the humification was a process of energy release and the relationship of combustion heat and components of corn stalk could be expressed by linear regression. For 480 days of decomposition, the decomposition rate was highest in soil with medium fertility and lowest in soil with low fertility among three type of fertility. The decomposition of water soluble factions and lignin were promoted in medium fertile soil. However, alcohol-benzene soluble fractions, and semi cellulose and cellulose fractions were decayed accelerated in soil with high fertility. Furthermore, more humic substance was formed and energy state of decayed corn stalk was high in soil with high fertility.

Key words: Corn stalk, energetic state, decomposition rate, soil fertility.

INTRODUCTION

Agro-ecosystems comprise 38% of the Earth's terrestrial land area. Large losses of soil carbon occurred with the conversion of natural land areas to agricultural systems due to plowing and soil disturbance (Matson et al., 1997). A proposed mitigation strategy for atmospheric CO_2 concentration is sequestering carbon in terrestrial ecosystems, either in plant biomass or soil organic matter. In the temperate northern hemisphere, some practice such as conservational tillage has been identified to promote agricultural ecosystems to be potential carbon sinks (Allmaras et al., 2000; Lal et al., 1999; Sauerbeck, 2001).

Carbon pools in agro-ecosystems include two majorcomponents: a soil organic matter pool, with a residence time of months to thousands of years, and a litter pool with a turnover of months to several years. The litter-C pool represents a short-retention time C pool that will either be respired back to the atmosphere via decomposer organisms or incorporated into stable soil organic matter-C (Hutchinson et al., 2007).

In order to attain long-term carbon storage in temperate maize-based agro-ecosystems, C must be physically and chemically protected as humified soil organic carbon.

*Corresponding author. E-mail: nyliushuai@gmail.com.

Table 1. The primary properties of soil with different fertility.

Fertility level	pH	Organic matter/g/kg	Total P/g/kg	Total N/g/kg	CEC/cmol (+)/kg	Particle size (<0.01mm)/%	Microbial carbon/g/kg
High	7.8	19.8	0.992	1.32	14.45	46.3	1.72
Medium	7.9	14.8	0.785	0.89	13.88	46.9	1.35
Low	8.1	11.3	0.681	0.81	12.06	45.9	0.92

Therefore, understanding the decomposition patterns of plant litter and the fate of this C is necessary to determine how long agricultural systems can retain carbon in increased litter pools and the amount of litter-C that is eventually incorporated into stable soil organic matter.

In China, annual production of crop residue is 0.7 billion ton, which contains carbon 0.3 billion ton, nitrogen 3 million ton, phosphorus 0.7 million ton and potassium 7 million ton. Returning the crop residue into soil directly or indirectly can not only compensate nutrients, but also increase soil carbon pool, and reduce CO_2 emission and air pollution resulting from burning (Zhang et al., 2006; Sheng et al., 2006; Han et al., 2008). Guanzhong Plain in Shaan Xi province originated from Weihe River. The main planting mode in this region is winter wheat-summer corn rotation.

Annual wheat stalk output is about 4885 thousand ton, while corn stalk is about 3133 thousand ton. Leaving wheat stubble in field and then planting summer corn has been accepted and applied by farmer. However, returning corn stalk into soil and then seeding winter wheat has not been widely accepted. This reason is that it would affect the germination of wheat seed and also cause chlorisis in seedling stage because of low decomposition rate of corn stalk caused by low temperature and less rainfall of this region in the winter.

The decomposition rate of crop straw would be affected by not only its tissue constitution, but also the environment condition such as temperature, moisture and soil character. Better water availability could have a direct impact on decomposition by creating a more hospitable abiotic environment for decomposers (Amy et al., 2009).

Studies have shown that the effects of inorganic N addition to litter have variable effects on litter decomposition rates. While some studies show that inorganic N addition can increase litter decomposition rates (Carreiro et al., 2000), others show no effect (Hobbie, 2005) or even a decrease in litter decomposition rates (Knorr et al., 2005). Low tissue quality would result from increased lignin or other complex structural components which leads to higher recalcitrance of litter (Vasconcelos and Laurance, 2005). The order of ease of decomposition of biomass fractions by soil microbes are starches > hemicelluloses > cellulose > lignin (Coyne, 1999).

Corn components differed significantly in their decomposition. The soluble fraction appears to control the decomposition rate in addition to the C:N ratio of the plant components, since leaves, having the highest percentage of the soluble fraction and the lowest C:N ratio, decomposed rapidly even though they contained higher lignin than stalks or cobs (Tarkalson et al., 2008).

Soil with different fertility varies in nutrient content and microorganism activity and soil organic carbon sequestration potential, which will affect the rate of mineralization and humification of crop straw incorporated in soil. However, there is insufficient information about the decomposition rate of crop straw in soils with different fertility. This is important for guiding us where should be adopt straw returning firstly to promote more organic carbon storage in soil.

Although previous research on the mineralization of straw in soil and its impact on soil organic carbon have been documented (Pang and Huang, 2006; Zeng et al., 2002), most of them just considered total organic carbon content as indicator (Yin et al., 2007; Song and Yang, 2006), few of them study the changes of different components such as hemi-cellulous, cellulose and lignin. Straw is consisted of sugar, starch, amino acid, hemi-cellulose, cellulose, lignin and some other components, whose molecular size and stability are different and the availability is different for microorganisms. Tissue components of straw determined the mineralization rate. Therefore, the transformation characteristic of different components of straw in soil should be clarified.

MATERIALS AND METHODS

Description of experimental site

The experimental site is situated in Guanzhong plain in Shaanxi province, south part to the loess plateau. The soil is classified as *Eum-Orthric Anthrosols*. The decomposition experiment of corn stalk was conducted in the field with different fertile level such as high, medium and low. The soil with high fertility is always applied more compost and chemical fertilizer, and the wheat yield is more than 9000 kg/hm. The soil with medium fertility is applied; only chemical fertilizer and the wheat yield is about 5250 to 6000 kg/hm. The soil with low fertility is applied less amount chemical fertilizer and the wheat yield is under 4500 kg/hm. Soil with different fertility varied in soil organic matter. The characteristics of soil were showed in Table 1.

Corn stalk decomposing experiment

Carborundum tube was used to study the decomposition rate of corn stalk in field (Lin et al., 1981). In the experiment, corn stalk was cut into short piece (< 0.5 cm) and put into carborundum tube (inner diameter is 5 cm, length is 10 cm), then controlled the water content is 50% dry weight of the straw and was characterized by a C/N ratio of 25:1 with

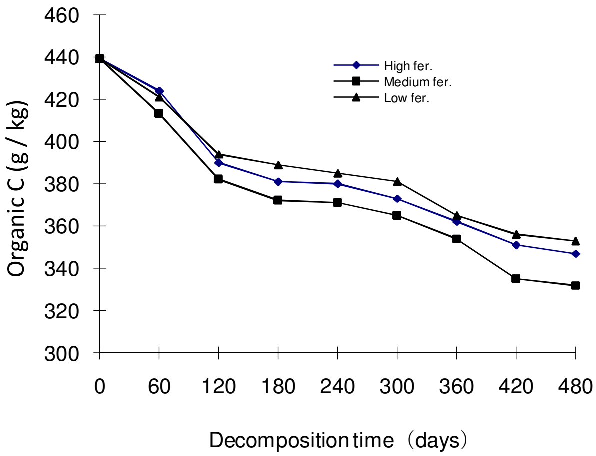

Figure 1. Content of OC during corn stalk decomposition.

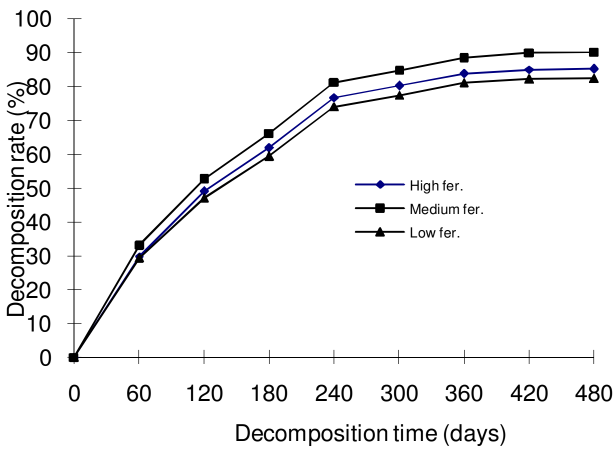

Figure 2. Decomposition rate of OC in corn stalk.

urea. After that, the carborundum tube was sealed and buried under the topsoil layer (10 cm) of soil with different fertility on October 15, 2005, for corn stalk decomposition, which was the same time when farmers returned corn stalk into field after corn harvest. 5 tubes of the buried Carborundum in each filed fertility level were taken out at the 60th, 120th, 180th, 240th, 300th, 360th, 420th and 480th days, respectively. Decayed corn stalk was collected from the Carborundum for the analysis of the dry mass, organic carbon, ash content and the constituent of cellulose, semi-cellulose and lignin. The precipitation in the field was 613 mm during the decomposing period, and 70% of the precipitation was in autumn (July, August and September). Field management was complied with the habits of local farmers, the winter wheat was irrigated in the December and corn was irrigated in the July.

Measurements and statistical analysis

The corn stalks were fractionated according to the system analysis method (Waksman and Stevens, 1930). Extraction with 1:1 alcohol-benzene solution removed the soluble parts of the corn stalk (mainly are fat, waxiness and pigment). Extraction with water removed starch, sugar, oligose, fructose, amino acid. Semi-cellulose, cellulose and lignin were isolated according to the Deriaz (1961) method. The energy of the decomposition matter was determined with an oxygen bomb calorimeter. The OC was analyzed using $K_4Cr_2O_7$ oxidation method, the humic substances was analyzed using $NaOH$-$Na_4P_2O_7$ extraction and $K_4Cr_2O_7$ oxidation method. Others were analyzed using conventional methods.

Calculation and statistical method

The decomposition rate (%) = $[(W_i \times C_i - W_f \times C_f) / W_i \times C_i] \times 100$. W_i – initial dry weight of straw(kg), C_i – initial carbon content of straw (g/kg), W_f – dry weight of straw at a certain time during decomposition (kg), C_f – carbon content of straw at a certain time during decomposition (g/kg). Statistical analysis was performed by SAS and Excel, REG in the SAS package were used for analysis of the linear regression.

RESULTS

Content and decomposition rate of organic carbon (OC) in corn stalk during decomposition

OC content of the fresh corn stalk used in the experiment was 439 g/kg (Figure 1), the content of OC decreased rapidly in decayed corn stalk in the process of decomposition during the first 120 days, and then declined slowly. In the whole decomposition period, the OC content of the decayed corn stalk dropped to 344 g/kg (the average value in three kind of field fertility) at the end of 480 days decomposition. Results from three kinds of fields showed that although OC content in the decayed corn stalk was relatively lower in the field with medium fertility (332 g/kg), and relatively higher in the field with low fertility and mediated in the field with high fertility.

The decomposition rate calculated by the change of OC content showed that during the first 240 day incubation, the decomposition rate reach 77% averagely in three treatments, and then changed slowly (Figure 2). The accumulative total decomposition rate of OC came up to around 86% during the whole decomposition process of 480 days, meant that only 14% of OC in decayed corn stalk was remained. The decomposition rate of corn stalk on different fertility conditions showed the trend of medium fertility (90%) > high fertility (85%) > low fertility (82%). This illustrated that the field with medium fertility can promote the mineralization of corn stalk.

In addition, the ash content in corn stalk increased along with the mineralization of OC (Figure 3). The average ash content of corn stalk in three kind of fertility increased from 26 g/kg at the beginning (day 0) to 150 g/kg at the end of incubation (day 480). Since day 180, the changing trend of the ash contents in different fertility soil are medium fertility > high fertility > low fertility. High ash content in decayed corn stalk suggested that more OC had been mineralized.

The change of humus of the decayed corn stalk

With the decomposition process, humus was synthesized

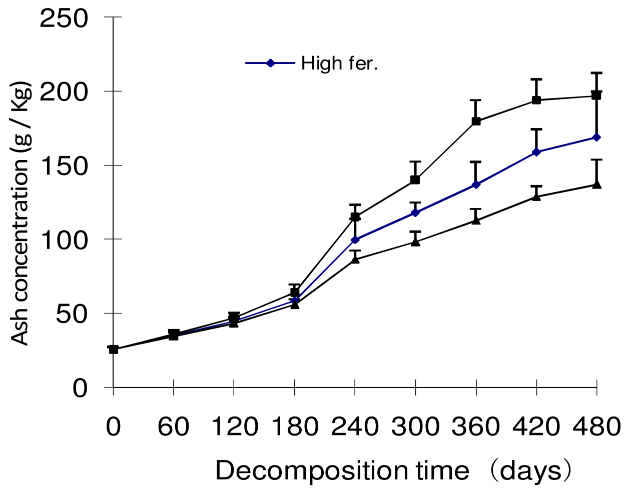

Figure 3. Change of ash concentration during corn stalk decomposition.

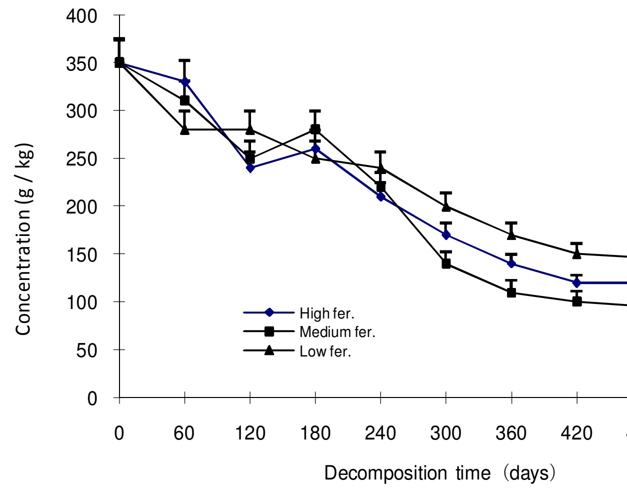

Figure 6. Change of water soluble fraction.

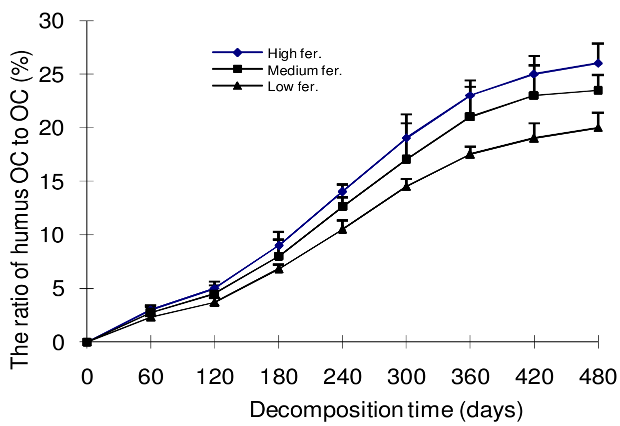

Figure 4. The ratio of humus OC to OC.

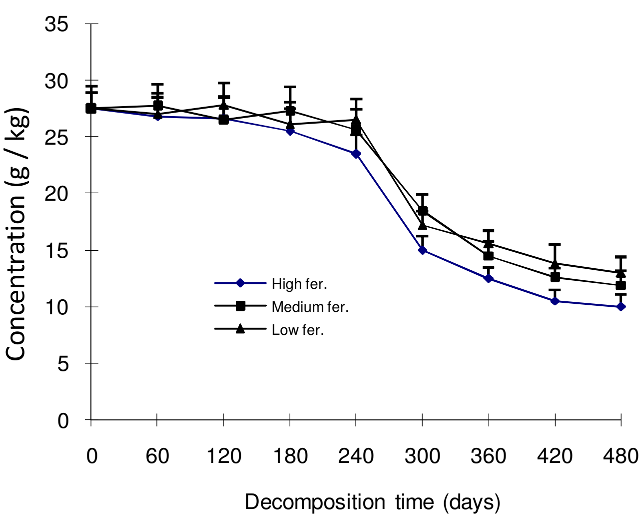

Figure 5. Change of alcohol-benzene soluble faction.

and the ratio of humus of OC increased (Figure 4). Soil fertility had effect on the ratio of humus of OC. At day 480, the ratio was 26% in high fertility, 23.5% in medium fertility and 20% in low fertility. Furthermore, during the period from day 120 to day 360, the ratio increased fast from 4.4 to 20.3% and changed slowly after day 360. This implied that more humus was secondly synthesized after 120 days' decomposition and more humic substance was synthesized in high fertility soil.

The change of component of corn stalk

The alcohol-benzene soluble fractions

The alcohol-benzene soluble fraction of corn stalk, mainly the components of fat, wax and pigment, was 27.5 g/kg in undecayed corn stalk in present experiment. In decomposition process, it fluctuated and showed a decrease tread during the first 240 day (Figure 5), then declined obviously. The average content of the alcohol-benzene soluble fraction was 12 g/kg at the end of incubation for 480 days.

In different fertility, the alcohol-benzene soluble fraction showed the order: low fertility > medium fertility > high fertility, and there was a significant difference between the low fertility treatment and the high fertility treatment, suggested that high fertility promoted more mineralization of the alcohol-benzene soluble fraction.

The fraction of water soluble

Although the water soluble fraction went up and down during the first 180 days, it showed a decline tread from 350 g/kg at day 0 to 263 g/kg at day 180 (Figure 6).

During the period from day 180 to day 360, the water

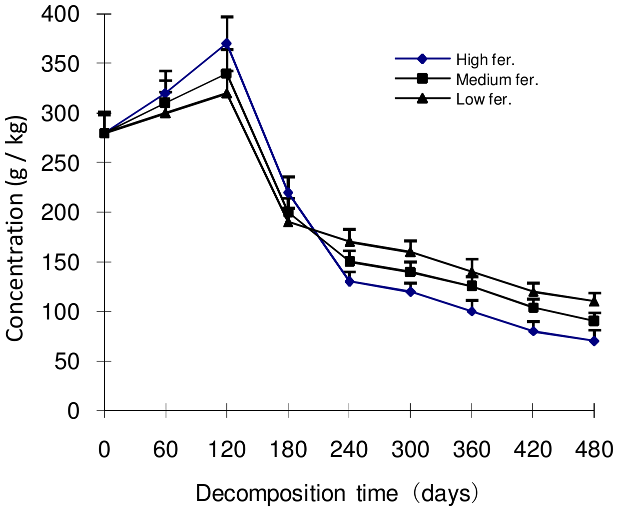

Figure 7. Change of semi-cellulose and cellulose.

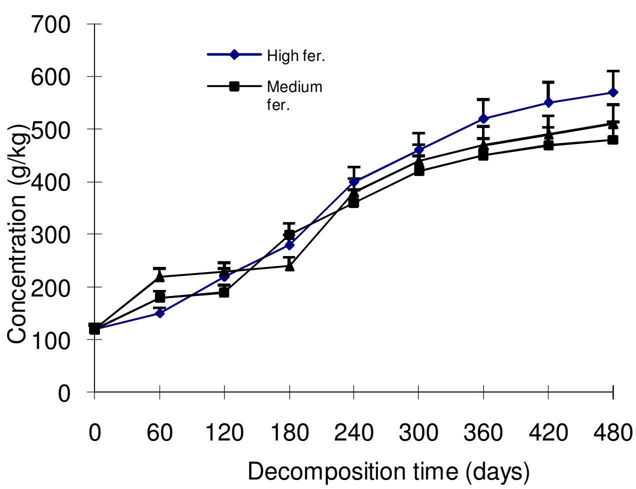

Figure 8. Change of lignin.

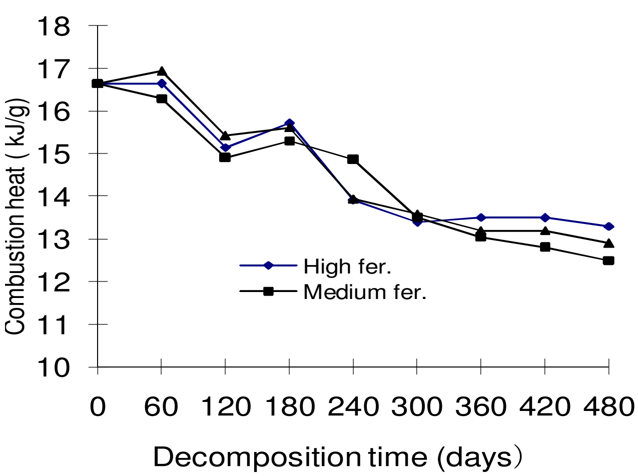

Figure 9. Energetic state of decaying corn stalk.

soluble fraction decreased obviously and then declined slightly to 120 g/kg at day 480. The order of the water soluble fraction in different fertility was low fertility > high fertility > medium fertility, which was significant difference between the medium fertility treatment and low fertility. The water soluble fraction of corn stalk mainly contained starch, sugar, oligose, fructose, amino acid and other compounds. Therefore, the results suggested that these compounds decomposed more rapidly in the field with medium fertility.

The change of cellulose and semi-cellulose

In decomposition process, cellulose and semi-cellulose increased from 280 g/kg at day 0 to 340 g/kg at day 120 (Figure 7), and then decreased rapidly to 150 g/kg at day 240. Since day 240, the content of cellulose and semi-cellulose showed a slowly decrease trend to 90 g/kg at day 480. The fertility had influence on the content of cellulose and semi-cellulose.

The order of cellulose and semi-cellulose content was high fertility > medium fertility > low fertility before 180 days incubation, but it showed the adverse trend after day 240. The difference between the low fertility and the high fertility was significant. This implied that in the early decomposition period (240 days), cellulose and semi-cellulose were broken down more in soil with low fertility, but after certain time incubation, cellulose and semi-cellulose were mineralized more with high fertility.

The change of lignin

The content of lignin in undecayed corn stalk was 120 g/kg, it presented an increase trend totally along with decomposition. The average content of lignin in the three types of fertility was 520 g/kg at the end of 480 day incubation (Figure 8). In the period from 240 to 480 days, the content order of lignin in different fertility was high fertility > low fertility > medium fertility, indicating indicated that on the one hand, lignin was hard to be decomposed and results in accumulation with while other fractions broken down, on the other hand, lignin was decomposed more in the medium fertility.

The change of combustion heat of corn stalk

The combustion heat of corn stalk or decayed materials measured by oxygen bomb calorimeter represents the energy state of the materials. The combustion heat of fresh corn stalk was 16.7 kJ/g, while decayed corn stalk materials showed a decreased trend with in decomposition process totally. However, it fluctuated from 0 to 180 days period and decreased rapidly from 180 to 360 days, and then declined slightly (Figure 9). With in process of 480 day's decomposition, it dropped to 12.9 kJ/g, decreased by 22% compared to the initial combustion heat. After incubation of 300 days, the combustion heat of decayed corn stalk in different fertility presented a trend of high fertility > low fertility > medium fertility. This illustrated that the energy state of decayed materials was the highest in the high fertility treatment and the lowest in the medium fertility after certain time's decomposition. REG in the SAS package were used for analysis of linear regression. The regression equation was $y = 12171 + 4.26736x_1 + 1.16351x_2 + 17.93849x_3 – 69.61412x_4 – 19.20369x_5$ ($p = 0.015<0.05$, $r^2=0.9727$. y represented the combustion heat, and x_1, x_2, x_3, x_4, x_5 represented the content of lignin, cellulose and semi-cellulose, water soluble fractions, alcohol-benzene soluble fractions and ash, respectively). The equation suggested that water soluble fractions and lignin fraction had more contribution to the increase of combustion heat, however, ash and alcohol-benzene soluble fractions caused the decrease of combustion heat.

DISCUSSION

The process of decomposition and transformation of corn stalk in soil included mineralization and humification with microorganism and enzyme. Corn stalk consisted of sugar, starch, amino acid, protein, cellulose, tannin, lignin and other components. The cellulose and semi-cellulose among them had certain stability for anti-decomposition (Wu et al., 2000), therefore, the content of them increased relatively at the beginning stage of incubation when the fractions of water soluble and other easily decomposed components were consumed by microorganism. However, with the decomposition proceeding, cellulose and semi-cellulose also were decomposed by microorganism and resulted in the content of them decreased obviously in the later stage.

Lignin was the most stable component in corn stalk for anti-decomposition. Through mineralization process, it increased relatively in decayed materials because other fractions were decomposed by microorganism. The conclusion was similar to the result of Jiang's study (Jiang et al., 2009).

The carborundum tube has capillary pores for aeration and exchange of water and nutrients with soil in field condition (Zhang et al., 2006). Therefore, the carborundum tube can keep the similar condition as field ecology when it is buried in soil. The present paper found that the mineralization rate of corn stalk was the highest in the medium fertility among three different types of fertility such as low, medium and high. This could be interpreted by that, on the one hand, chemical fertilizers including N, P and K were always applied more in the medium fertility field, which could infiltrate and disperse in carborundum tube and result in high mineralization rate of corn stalk (Chivenge et al., 2011), on the other hand, microbial community structure, changing with different fertility, was also a regulating factor in the mineralization rate of plant-derived substance (Grayston et al., 2004). Of cause, the basis of microbial community structure and activity being consider as determinants of SOM mineralization rate have been questioned (Brookes et al., 2008).

In this paper, although quantity of microorganism was larger in high fertility soil than in medium and low fertility soil, the mineralization rate was not equivalent to it. The change of energetic state of corn stalk throughout the whole process could be divided into three stages such as fluctuating stage, decreasing stage and stable stage. The fluctuating stage lasted about 6 months, The decreasing stage began after 6 months' decomposition and lasted 180 days, The stable stage begin after 12 months' decomposition, the energy state was relatively stable. The equation of combustion heat and the components suggested that water soluble fractions and lignin fraction had more contribution to the increase of combustion heat, however, ash and alcohol-benzene soluble fractions caused the decrease of combustion heat.

Conclusion

(1) Along with the decomposition of corn stalk, the fractions of alcohol-benzene soluble and water soluble in decomposition products decreased, the content of cellulose and semi-cellulose ascended first and then descended, while the content of lignin increased.
(2) The change of energy state of decayed materials could be divided into three stages, fluctuated in earlier stage (0 to 180 days), decreased in the medium stage (180 to 360 days) and kept stable in later stage (360 to 480 days). The energy was mainly released through the decomposition process. The relationship of combustion heat and components could be expressed by linear regression.
(3) Compared with the three types of fertility throughout the whole decomposition process, the mineralization rate was highest in the medium fertility treatment and lowest in the low fertility treatment. Medium fertility can promote the decomposition of the fraction of water soluble and lignin, while high fertility can boost the decomposition of the fraction of alcohol-benzene soluble, cellulose and semi-cellulose and benefit the formation of humus.

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