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Research Article

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The Short-Term Effects of Wheat Straw Cellulose on Soil Carbon Mineralization

Buğday Samanı Selülozunun Toprak Karbon Mineralizasyonu Üzerindeki Kısa Vadeli Etkileri

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ABSTRACT

Cellulosic wastes constitute the majority of agricultural fields. The purpose of this study was to utilize these cellulosic wastes such as wheat straw and wheat straw cellulose on soil carbon mineralization in a sandy loam soils. Two different doses (100 and 1000 mg) of wheat straw cellulose were used to determine the carbon mineralization using the CO_2 respiration method. The cumulative carbon mineralization was found to be highest at the minimum doses of wheat straw cellulose with nitrogen (W-CL-N, 19.65 mg) and the lowest at the maximum doses of wheat straw (W-Straw, 14.32 mg). The results showed that the application of wheat straw cellulose at minimum doses resulted in higher carbon mineralization rate. The maximum carbon mineralization rate was observed in soil with minimum wheat straw cellulose and nitrogen source were added (1.41%). Whereas, the minimum carbon mineralization rate was determined in the soil mixed maximum wheat straw (1.03 %). The soil mixed maximum wheat straw was determined the lowest carbon mineralization rate due to its complex structure. The use of nitrogen source and organic matter with cellulose have a positive effect on soil carbon mineralization. It might be said that these results describe an effective way to dispose of organic wastes.

Key Words

Cellulose, carbon mineralization, soil microorganism, carbon.

ÖZ

Tarım alanlarının büyük çoğunluğunu selülozik atıklar oluşturmaktadır. Bu çalışmanın amacı, buğday samanı ve buğday samanı selülozu gibi atıkların kumlu-tınlı topraklarda toprak karbon mineralizasyonunda değerlendirilmesidir. CO_2 solunum yöntemi kullanılarak karbon mineralizasyonunu belirlemek için iki farklı dozda (100 ve 1000 mg) buğday samanı selülozu kullanılmıştır. Kümülatif karbon mineralizasyonunun, azotlu buğday samanı selülozunun minimum dozlarında (W-CL-N, 19.65 mg) en yüksek ve buğday samanının maksimum dozlarında (W-Straw, 14.32 mg) en düşük olduğu bulunmuştur. Sonuçlar, buğday samanı selülozunun minimum dozlarda uygulanmasının daha yüksek karbon mineralizasyon oranı ile sonuçlandığını göstermiştir. En yüksek karbon mineralizasyon oranı, minimum buğday samanı selülozu ve azot kaynağı (%1.41) ilave edilmiş toprakta gözlenmiştir. En düşük karbon mineralizasyon oranı ise en fazla buğday samanı (% 1.03) ile karıştırılan toprakta belirlenmiştir. Kompleks yapısından dolayı toprakla karıştırılan maksimum buğday samanı en düşük karbon mineralizasyon oranı olarak belirlenmiştir. Azot kaynağı ve selüloz ile birlikte organik madde kullanımı toprak karbon mineralizasyonu üzerinde olumlu etkiye sahiptir. Bu sonuçlar organik atıkların bertarafı için mineralizasyonun etkili bir yol olduğunu göstermiştir.

Anahtar Kelimeler

Selüloz, karbon mineralizasyonu, toprak mikroorganizmaları, karbon.

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INTRODUCTION

Plant, animal, and the agricultural activities have been carried out in harmony with nature in the natural environment conditions for thousands of years and neither interferes with the environment nor cause environmental problems. The usage of artificial elements in agriculture gained great importance to supply food for the rapidly growing population and get more products from the unit area. The usage of artificial elements, however, disrupts the natural environment and creates irreversible environmental problems. In contrast to the rapid growth of the world population, the size of cultivated areas remains virtually stable. In this regard, evaluation of agricultural residue is of great importance for the use of limited resources.

Turkey is listed among the top ten countries all over the world in terms of many agricultural productions such as vegetables and fruits. Total cereals production in Turkey is 34.912 million tonnes [1]. In a total of 54.4 million tons of annual straw produced in Turkey, and a great majority of production consists of wheat (26.4 million tons) and barley (13.5 million tons) straws in the country [2]. In this regard, the country has a great agricultural residue potential. Therefore, the utilization of agricultural residues is of great importance for the sustainable use of natural resources. The disposal of agricultural residues on the land has been accepted as a traditional practice. However, more crop production per unit area could be achieved with the efficiency-enhancing effect of technological conditions in agriculture. The agricultural production technologies increased agricultural residues such as straw, stem, and grass which are commonly left to a small area in large quantities. It caused the soil to be negatively affected and the habitats of many living organisms in the soil to be destroyed. The agricultural residues can be converted to value-added products instead of leaving agricultural residues randomly in nature. Many studies have been carried out in the direction of conversion.

Million tons of wheat straw are an excellent compost conditioner and create dead plant biomass on soil is composed of cellulose, hemicellulose, and lignin [3]. Previous studies showed that wheat straw contains 70-75% holocellulose, which is approximately 35% are alpha-cellulose [4]. Cellulose, which is the main component of the plant cell wall, is the most available biopolymer in the world. It is a self-renewable, non-toxic, cheap, high power and thermal resistance and natural environmentally friendly polymer that can be degraded by many soil microorganisms [5]. The highly stable carbon molecules in cellulose and lignin forms must be decomposed by soil microorganisms such as bacteria and fungi and converted into carbohydrates form soil fertility. These microorganisms tend to grow rapidly to decompose large carbon molecules, and for this, there must be sufficient amounts of carbon, nitrogen, air, and water in living environments.

All kinds of plant and animal residues that accumulate on or in the soil are separated by microorganisms through several complex processes. Cellulose decomposition in soil has been investigated for decades. It is known that microorganisms found in soil have an important role in cellulose decomposition [6]. This study aims to investigate the role of isolated wheat straw cellulose and wheat straw on soil carbon mineralization. In addition, factors such as nitrogen and organic matter affecting cellulose decomposition in soil were also examined.

MATERIALS and METHODS

Materials

Wheat straw was provided from local supplier and the experimental soil samples were taken from the upper 0-20 cm from Adana, a city located in the East-Mediterranean region of Turkey.

The results of the premliminarly analysis of wheat straw and soil are given Table 1 and Table 2, respectively. Sucrose and methionine were used as organic matter and nitrogen source, respectively. And used these chemicals were analytical grade.

Methods

The Isolation of Cellulose from Wheat Straw

Monoethanolamine (C_2H_7NO), sulfuric acid (H_2SO_4) sodium hypochlorite (NaOCl) sodium sulfite (Na_2SO_3) acetic acid (CH_3COOH) ammonium hydroxide (NH_4OH) and distilled water were used to isolate the cellulose from wheat straw using a method described by Foyle et al [7]. The characterization of the isolated cellulose was subsequently determined by using FT-IR and SEM. The cellulose content was found to be 48.65±0.70%.

Table 1. The analytical analysis of wheat straw.

Sample	Wheat Straw
Proximate analysis (wt.%)	
Moisture	8.8
Ash	9.1
Elemental analysis (wt.%)	
C	46.48
H	4.45
N	0.33
O	38.66

Table 2. The physical and chemical properties of soils.

Glycerol Concentrations (%)			
Sand (%)	52.02	±	1.51
Silt (%)	36.49	±	0.51
Clay (%)	11.49	±	0.12
Texture type	SL	35.70	1.93
(Sandy Loam)			
Field capacity (%)	35.17	±	0.42
pH	7.86	±	0.02
C (%)	1.44	±	0.13
N (%)	0.11	±	0.01
C/N	13.22	±	0.21

Soil Carbon Mineralization

The effects of two different doses (100 and 1000 mg kg^{-1}) of wheat straw cellulose and wheat straw, on soil-carbon mineralization were investigated in the study. Carbon mineralization in soils was determined by incubation of samples under controlled conditions (28ºC, 80% humidity) [8]. Three replicates were used for each treatment. CO_2 derived from microbial activities was absorbed in saturated $Ba(OH)_2$ solution (40 mL) by using beakers that was placed in the center of the soils in closed incubation vessels. The amount of CO_2 was measured by titration using an oxalic acid at three day intervals [9]. The blank vessels were served as control. The rate (%) of carbon mineralization was calculated by dividing the cumulative amount of C (CO_2) produced in 30 days by total organic carbon. 100 mg of methionine as a nitrogen source and sucrose as an organic source were added to soils.

Statistical Analysis

A Repeated Measures (General Linear Model) analysis of variance was performed to determine the differences in carbon mineralization between the two doses (100 and 1000 mg) of wheat straw and wheat straw cellulose over 3 days [10]. Three replicates were used for each combined soil for statistical comparisons. Data were analyzed by a series of analyses of variance. Differences between data were assumed significant at $P < 0.05$. All statistical analyses were carried out using SPSS 21.0.

RESULTS and DISCUSSION

The cellulose obtained from wheat straw was determined using FT-IR. Figure 1 shows the infrared spectra of wheat straw cellulose (W-CL) . As seen in the spectra, wide and broad bands at 3347-3374 cm^{-1} include O-H vibrations. This band belongs to O-H groups, which are together with hydrogen bonds between repeating units in the cellulose matrix. The band between 2890-2915 cm^{-1} and 1160-1000 cm^{-1} were related to C-H and C-O vibrations, respectively. The band at 1109 cm^{-1} belongs to the stretching of the glucose rings in cellulose. The β-glycosidic bonds in cellulose were observed at 898 cm^{-1} [11,12]. The C-H bond streching in cellulose are visible at 1375 cm^{-1} [12].

The elementel analysis of wheat straw and the physical and chemical properties of soils used in this study were given in Table 1 and Table 2, respectively. The soil was slightly alkaline and sandy loam-textured. The field capacity (FC) of soils was 31.17%. Soil organic carbon content (%) and soil nitrogen content (%) were 1.44% and 0.11%, respectively. Also, the ratio of C/N was 13.22.

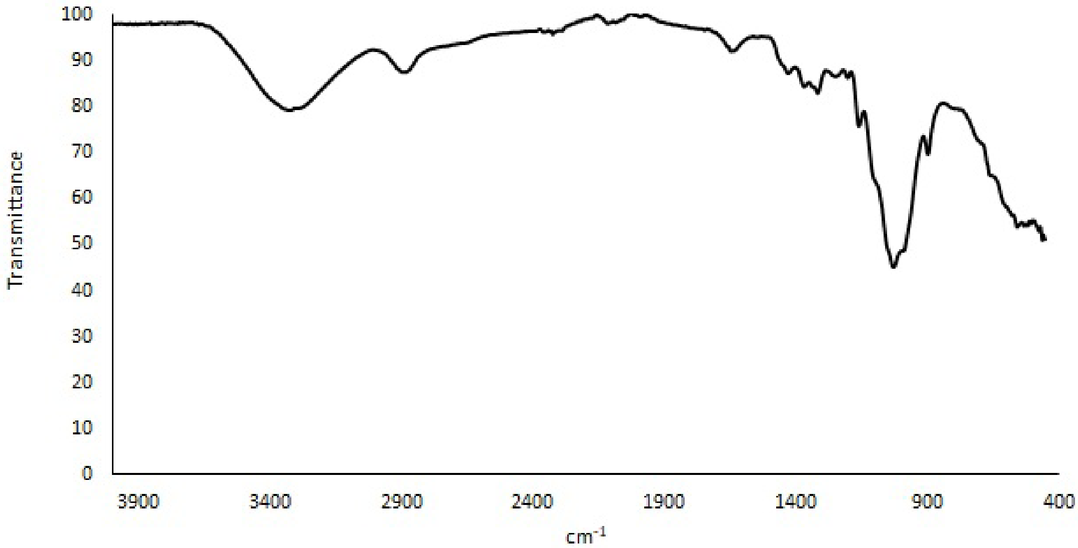

Figure 1. The FT-IR spectrum of W-CL.

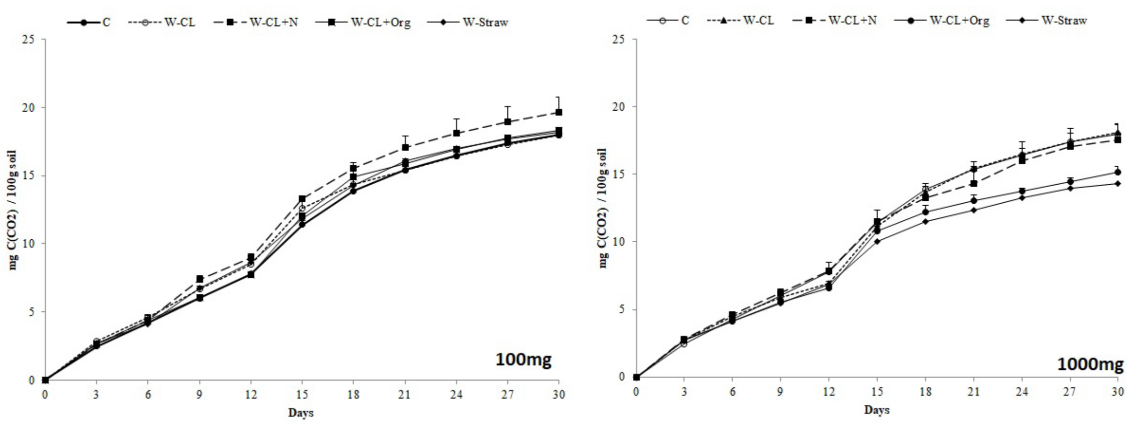

Figure 2. The carbon mineralization of soils with added W-CL and W-Straw.

The soil is a living ecosystem with a complex interactions. Most of the microorganisms in the world are of soil origin or closely related with the soil environment. Soil microorganisms help the decomposition of plant and animal residues. A comparison between W-Straw as a plant residue and W-CL decomposition on carbon minarelization were worked out in this research. The W-CL and W-Straw were added to soil in different doses. Some experiments were performed by adding methionine as a nitrogen source and sucrose as an organic source to soil contaning W-CL. It was studied at minimum and maximumW-CL and W-Straw doses. The cumulative carbon mineralization for 30 days was observed.

In the experiments, the effects of minimum and maximum W-CL and W-Straw applications on carbon mineralization are given in Figure 2. It was observed that the addition of both of them increased the microbial activity of the soil. There was some increase in carbon mineralization of soils mixed with W-CL and W-Straw compared to control. In soils with both maxiumum and minimum cellulose applications, cumulative carbon mineralization was increased depending on the incubation time (Figure 2). In terms of carbon mineralization, there is a statistically significant difference between control soils and soils mixed with both max W-CL + organic and max W-straw ($P<0,05$). There was a significant difference between the control soils and the soils mixed with both maximum W-CL + organic and maximum W-straw in terms of carbon mineralization (Figure 2) ($P <0.05$). Significant differences were also observed between applications (nitrogen, organic matter, and straw) added to the soil at maximum and minimum doses ($P <0.05$). Cumulative carbon mineralization was found to be the highest at the minimum doses of wheat straw cellulose mixed with the highest nitrogen (19.65 mg), while the lowest at the maximum doses of wheat straw (14.32 mg) ($P <0.001$). The CO_2 in the soil is released as a result of microorganisms decompose the organic matter. If there is so much organic matter in soil, there will be high CO_2 production and microbial acitivity [13,14]. As can be seen in Figure 1a and Figure 1b, it was determined that microbial activities were generally fast in the three days. The changes in the following days were much slower. All organic matter additives have beneficial effects on CO_2 production [15]. As the doses of cellulose increased, the CO_2 production decreased (Figure 2).

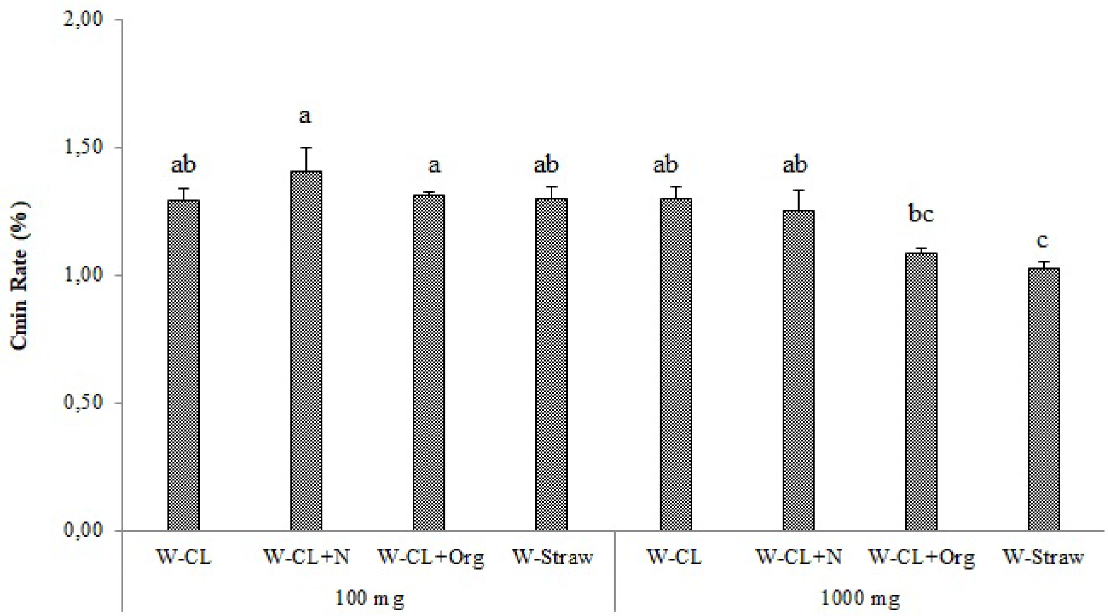

Figure 3. The carbon mineralization rate of soils(n = 3, mean ± standart error).

The carbon mineralization rate of soils mixed W-CL and W-Straw were showed in Figure 3. The results showed that adding cellulose and straw to the soil causes an increase in the carbon mineralization rate. The rate of carbon mineralization varied between 1.03% and 1.41% in all applications. The effect of W-CL applied at increasing concentration on carbon mineralization rate in all applications was not significantly different (P>0.05). It is known that the rate of decomposition of cellulose is affected by structure, size of particles, and cellulose amount rather than mechanical or chemical treatment [16,17]. Therefore, cellulose amount itself was a limiting factor of the cellulose decomposers. The carbon mineralization rate did not change when maximum W-CL compared to control. The carbon mineralization rate in all soil suspensions tended to decrease with increasing doses. Although cellulose is resistant to decompose most microorganisms living in the soil, it is broken down by some special groups of bacteria, fungi, and actinomycetes. The results showed that the cellulose decomposition by microorganisms primarily depends on the cellulose amount. At higher doses, cellulose decomposition does not ocur according to control. Microbial decomposition became so fast if cellulose amount (<1000 mg) was less in the soil. As can be seen in Figure 3, increasing cellulose doses 10 times, a decrease was observed in the rate of decomposition.

When cellulose doses were increased from 100 mg to 1000 mg, the rate of decomposition decreased (Figure 3). In the applications where wheat straw was added to soil, it had the lowest carbon mineralization rate (1.03%). The highest carbon mineralization rate, however, was found when the minimum W-CL and nitrogen source was added to the soil (1.41%). Factors affecting cellulose decomposition in soils are adding nitrogen source and organic matter. Microorganisms need both carbon and nitrogen for the biosynthesis of cellular materials. Cellulose contains carbon (44%) but it doesn’t contain nitrogen. For this reason, nitrogen deficiency can be observed in plants as a result of adding cellulose to the soil. Therefore, the cellulose decomposition by microorganisms does not occur without nitrogen sources. The results showed that adding nitrogen to soil with mixed W-CL considerably affect the carbon mineralization rate. Also, microorganisms are the main sources that breaks down cellulose and hemicelluloses in the soil, making them the most important players in plant biomass decomposition [18,19].

One of the most important activities of microorganisms is to decompose complex organic matter to simple inorganic compounds or nutrient ions. When these compounds remain high polymer compounds, microorganisms cannot directly benefit from them. Wheat straw, is an organic compound, that consists of cellulose, hemicellulose and lignin. Cellulose is also decomposed by fungi and bacteria, but the hardly degraded lignin is released. All other organic matter decomposition products are used by microorganisms in the soil and the organic materials are completely decomposed into water and CO_2. Lignin negatively affects the decomposition of wheat straw. Because of that, wheat straw decomposition in soil by microorganisms was quite slow. Wheat straw is water-insoluble compounds that is not directly used by microorganisms due to its molecular size. These compounds are separated by extracellular enzymes and are absorbed before being extracted by microorganisms. The researchers emphasized that microbial activity may cause the increase of activity in soils treated with organic wastes rather than organic sources [20-23].In this study, the adding organic matter to soil was not as effective as nitrogen source. Soil organisms play a major role in degradation events. The presence and abundance of microorganisms are extremely important for the soils related to organic matter which is the main food source [24]. Sugars are the carbon source for soil microorganisms and increase decomposition rate. So, a disaccharide sucrose, was used as a organic matter in this research. Sucrose addition to soil with cellulose has improved the rate of carbon mineralization at minimum cellulose doses compared to control. However, the rate of cellulose decomposition depended on cellulose amount. Because, our results showed that at higher (max) cellulose amonut with organic matter, microbial activity was less than control. It was thought that higher cellulose doses have a toxic effect on some microorganisms.

Some experimental studies carried out to examine the effect of incubation time on decomposition rate (Figure 4). It was found that the decomposition continued but started to slow down. It was thought that the reason for this slowing down was due to the adaptation of microorganisms to the media.

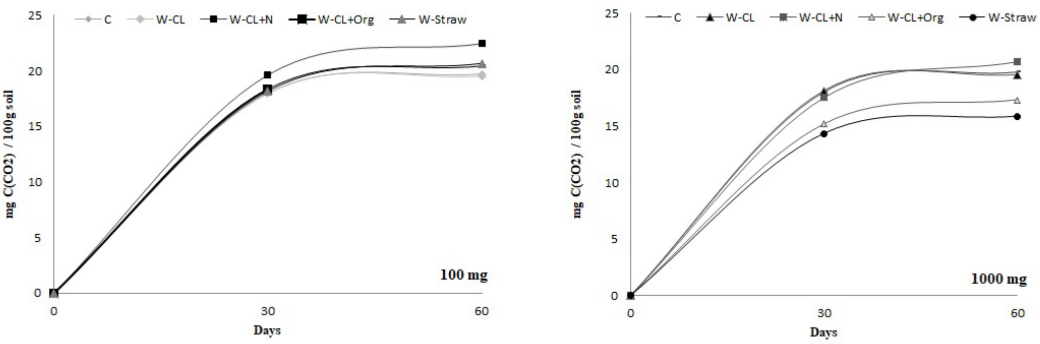

Figure 4. The carbon mineralization of soils with added W-CL and W-Straw at diffent days

CONCLUSION

The results of this work indicated that wheat straw cellulose decomposition was faster than wheat straw. It was clearly seen that adding nitrogen to soil with cellulose increased decomposition rate at moderate doses. Whereas, the decomposition rate decreased at higher cellulose doses. As a result, the cellulose is biodegradable, and it has beneficial effects on soil. This study presents an important contribution for clear underastanding of the disposal of organic wastes that return to agricultural production.

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