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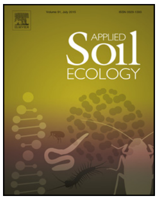

Mineralizable carbon in biosolids/fly ash/sugar beet lime treated soil under field conditions

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ABSTRACT

Fly ash (FA) from coal burning power plants is generally used for biosolids stabilization to reduce numbers of pathogens and availabilities of heavy metals contained in biosolids. The objective of this study was to determine the suitability of sugar beet lime (SBL) from sugar beet processing factories as fly ash substitute. Post-harvest soil samples were employed in a 180 d incubation study for each of two year field experiments. A first order logistic model was used to estimate sizes of labile and delayed logistic C pools. All treatments with one exception significantly ($P < 0.05$) reduced plant biomass compared to the mineral fertilization treatment in the first year under maximum water stress conditions. However, biosolids (7.5 Mg ha^{-1}), biosolids + FA (7.5 Mg ha^{-1}), and biosolids + SBL (7.5 Mg ha^{-1}) significantly ($P < 0.05$) raised plant biomass compared to the mineral fertilization in the second year under minimum water stress. Applications of biosolids together with either FA (7.5 and 15 Mg ha^{-1}) or SBL (7.5 and 15 Mg ha^{-1}) significantly ($P < 0.05$) increased sizes of labile and delayed logistic pools in the first year, but they did not in the second year. The sizes of potentially mineralizable carbon pools were bigger in the second year probably due to increased accumulation of wheat root biomass originating from enhanced soil water regime. Carbon mineralization in soils treated with biosolid/fly ash/sugar beet lime at agronomic application rates depends also on plant biomass accumulation, which affects total root biomass and rhizodeposition. Sugar beet lime containing 70% CaO and 5% organic carbon seems to be a good biosolids stabilizing agent compared to fly ash in terms of plant biomass accumulation and mineralizable carbon.

1. Introduction

Biosolids, the residue from wastewater treatment facilities are increasingly applied to agricultural fields as a means of waste disposal worldwide. Land application of biosolids also improves soil properties. However, there are two major concerns with biosolids application to soils, namely human pathogens and heavy metals contained in biosolids. Mixing biosolids with alkaline waste materials such as fly ash (FA) from coal burning power plants helps to eliminate the pathogens and reduce heavy metal availability (Sajwan et al., 2003; Su and Wong 2003; Wong and Su 1997; Wong et al. 2001). The fly ashes containing CaO are used in biosolids stabilization, however, there are limited numbers of coal burning power plants in many countries, limiting transportation of fly ash to biosolids producing cities. Alternative biosolids stabilizing waste materials, such as sugar beet lime (SBL), a waste material containing 70–80% $CaCO_3$ from sugar beet processing factories can be employed in municipality districts, which do not produce fly ash. However, there is no information regarding the use of SBL as an alternative biosolids stabilizing waste material.

Since biosolids contain microbially available organic carbon (C) sources, biosolids C mineralization in soil is important. Biosolids application increases the microbial numbers, enzyme activities and mineralization rates in soil rapidly (Fernandes et al., 2005b; Hattori, 1988; Varanka et al., 1976). Increased in numbers, the heterotrophic populations raise C mineralization rates to the maximum within days (Hsieh et al., 1981). Carbon mineralization in biosolids controls the release of carbon dioxide which contributes towards the greenhouse effect. For example, Fernandes et al. (2005a) determined that biosolids application more than doubled the carbon dioxide emission compared to the control in the field conditions. Simultaneously, as the readily available biosolids C is decomposed, relatively recalcitrant organic material is humified to become part of "soil" organic matter. The studies of mineralization kinetics in biosolids treated soils dates back to 90s. Lerch et al. (1992) examined the single

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and double exponential models in soils treated with different biosolids. A first order logistic model was developed by Gillis and Price (2011) more recently.

Laboratory studies involving carbon mineralization in sludge treated soils have been employed to estimate "potentially" mineralizable carbon from biosolids under favorable environmental conditions. Furthermore, Öğüt et al. (2009) determined that co-application of "weathered" FA together with biosolids does not alter biosolids carbon mineralization in soil. On the other hand, Camps Arbestain et al. (2009), and Pichtel and Hayes (1990) found negative effects of fly ash on biosolids carbon mineralization in soil. Biosolids and FAwere mixed with soil just before the experiment started in most incubation studies. However, there is limited information regarding how soil mineralizable C in previously biosolids/FA and biosolids/SBL treated fields compare after plant cultivation, which could also affect total mineralizable carbon. It should also be emphasized that the overall carbon mineralization in sludge treated soils is more important than the portion of mineralizable carbon arising only from sludge in terms of global carbon cycle. The objective of this study was to determine whether or not the applications of biosolids/FA and biosolids/SBL mixtures similarly affect "overall" soil mineralizable carbon in cultivated field conditions.

2. Materials and methods

2.1. Soil, biosolids, fly ash, and sugar beet lime

The soil was classified as Aridisol (clayey, typic Calciorthid). Aerobically activated biosolids was provided from Wastewater Treatment Facility in Ankara (the capital city of Turkey with a population of around 5 million). The fly ash was supplied from Yatağan Coal Burning Power Plant located in Muğla, Turkiye. Sugar beet lime was taken from settling ponds in Çumra Sugar Beet Processing Factory (Konya, Turkiye). There was not any pre-handling of the waste materials before their field applications. Some important properties of soil, biosolids, fly ash, and sugar beet lime are given in Table 1.

2.2. Field experiments

Field experiments were conducted in the experimental field of Çumra Vocational College (Selcuk University) in Çumra-Konya (37°34′N 32°46′E). The application rates of the waste materials in the field trials performed between 2007 and 2009 are given in Table 2. A mineral fertilization treatment was included as a positive control (Table 2). The initial biosolid rate was chosen to meet plant nitrogen requirement. The initial fly ash and sugar beet lime rates were preferred to determine optimum application rate for biosolid stabilization. The waste treatment was discontinued after the second year field trial, since co-application of fly ash and sugar beet lime reduced aboveground plant biomass in the second year. Wheat (*Triticum aestivum* ssp. vulgare L. cv Bezostaja) was the test crop in the field experiments. There were four rows (2.5 m) separated by 0.2 m in each plot spaced at 1 m intervals. The seeds were manually sown at a sowing rate of 100 seeds m^{-2}. Whole plot was used for biomass determination at harvest. A soil sample (0–20 cm) from each plot was collected in October after each harvest, air-dried, and sieved to pass to 2 mm. Soil organic matter and potentially mineralizable carbon was determined in soil samples. Mean monthly rainfall, temperature and sunshine duration values during the field experiments are given in Fig. 1.

Table 1
Some chemical and physical properties of the soil, biosolid, sugar beet lime and fly ash used in the study.

Constituent	Soil	Biosolid	Sugar beet lime	Fly ash
pH	8.2	7.2	7.5	9.7
EC (dS^{-1} m)	0.17	3.1	1.8	2.5
Organic carbon (%)	0.80	32.0	5.1	0.7
Organic nitrogen (%)	0.06	2.19	0.24	BD
Metals (mg kg^{-1})[a]				
Fe	1.6	17	42	17
Mn	1.5	7	11	0.8
Zn	0.2	52	6	0.3
Cu	0.8	0.1	0.7	0.1
Ni	0.08	8.9	1.4	0.05
Pb	0.4	0.2	1.1	0.05
Texture (%)				
Clay	55.5	ND	ND	ND
Silt	25.5	ND	ND	ND
Sand	19	ND	ND	ND
Field capacity (%)	29.7	ND	ND	ND
Wilting point (%)	21.7	ND	ND	ND

BD: below detection limit; ND: not determined.
[a] Metals by DTPA-extraction.

2.3. Soil organic matter content

Soil organic matter analysis on soil samples were performed according to Walkley and Black Method (Nelson and Sommers, 1982). One g of soil sample was placed into 500 ml Erlenmeyer. Ten ml of 1 N potassium dichromate ($K_2Cr_2O_7$) and 20 ml of concentrated sulfuric acid were added to the Erlenmeyer consecutively. The mixture was stirred slowly and let it to stand for 30 min at room temperature. Then, 300 ml ultra-pure water, 10 ml phosphoric acid (H_3PO_4) solution (85%), and 1 ml of 0.16% barium diphenylamine sulfonate solution were added. The Erlenmeyer content was titrated with 1.1 M iron sulfate ($FeSO_4{\cdot}7H_2O$) solution until the color of soil suspension became purple/blue. Then, the titration was continued with smaller volumes until the color of the suspension became green. The volume of iron sulfate solution consumed in the titration for the blank and the samples were used to calculate % soil organic carbon data, which were then multiplied by 1.72 to estimate % soil organic matter.

2.4. Carbon mineralization study

Each pre-handled soil sample (35 g) was mixed with sand (35 g) and the mixture was placed into a Mason jar (1000 ml) for a static carbon mineralization study, which is based on trapping the CO_2 evolved in NaOH and measuring the trapped CO_2–C titrimetrically. Soil moisture content was brought to 65% of soil water holding capacity by spraying ultra purewater onto the mixtures of soil + sand. Each jar received two 50 ml Erlenmeyer, one containing 0.25 M NaOH and the other pure water. The jars were incubated at 28 °C for 180 days. The alkali trap was removed from each jar periodically to determine trapped CO_2–C at 2, 5, 10, 15, 30, 90, and 180 days after the incubation started. A fresh alkali trap was placed into the Mason jar, each time the old one was removed. Consequently, the trapped CO_2–C in the jars was measured by titration with 0.5 M HCl. The end point of titration was determined by use of phenolphthalein indicator. The volume of HCl solution consumed in the titration for the blank and the samples were used to calculate the amount of the trapped CO_2–C.

2.5. Estimation of carbon mineralization model parameters

A first order logistic model developed by Gillis and Price (2011) was used in the current study (Eq. (1)).

$$C_t = C_{lab}(1 - e^{-k_{lab}t}) + \frac{C_{delog}}{1 + e^{-t + t_{inf}/t_{3/4max}}} \quad (1)$$