A Study on Microbial Carbon Use Efficiency in Soil

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Journal papers and book chapters

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ABSTRACT

Soil organic carbon (SOC) plays a critical role in soil health and also in maintaining its ecological service. The stabilization of SOC involves physical, chemical, and biological processes in soil. Soil microorganisms serve as a carbon (C) biological sink as well as biochemical agents in C transformation in soil. The plant litter inputs and root exudates provide microorganisms with both labile and recalcitrant C sources. The C availability and soil habitat environment alter microbiota, consequently impacting the organic C decomposition processes in soil. Anthropogenic disturbances such as organic amendments, contaminants, tillage and grazing practices impact soil 'biophysicochemical' properties. The addition of organic C sources such as manure composts and biochar can lead to processes such as priming effect and microbial population shifts. In metal contaminated soils, organic-metal bonding can be beneficial to the immobilization of heavy metals, thereby reducing their bioavailability and biotoxicity. Microorganisms also develop strategies for the purpose to adapt to soil environment stress conditions. These stress tolerance processes include alteration of microbial community composition, and the redistribution of energy between catabolism (respired CO_2) and anabolism (biomass C).

Although a number of studies have examined soil C biogeochemical dynamics, very few comprehensive studies have been reported on the role of soil microorganisms in relation to the mobilization and immobilization ((im)mobilization) processes of organic C dynamics. In this research, soil microbial function and community composition in relation to C dynamics as affected by environmental factors were investigated. The definition of 'microbial carbon use efficiency' (CUE) was introduced for the purpose of assessing the fraction of microbially decomposed organic C that is subsequently assimilated into microbial biomass. The specific objectives of this research include: (i) to determine microbial CUE involving different approaches in relation with various sources of C and nitrogen (N) inputs; (ii) to investigate the influence of land use practices on soil microbial functions in relation to CUE; (iii) to evaluate metal stress on microbial function in relation to CUE; and (iv) to examine the influence of biochar on metal toxicity in relation to microbial CUE.

The first experiment was aimed to compare four approaches to measure microbial CUE using isotopic labelled glucose as an organic C source. The first approach (C_s) for microbial CUE measurement was based on monitoring C depletion, while the second (C_m) and third (C_p) approaches were based on detecting of microbial biomass accumulation, the forth approach (C_r) was aimed at calculating the ratio of the increased microbial biomass to the decreased C content. The microbial CUE values varied amongst the four approaches, and the C_m values

were generally higher than other measurements. Because the main aims of the subsequent experiments were to understand the microbial mediation of soil C and the accumulation of C in microbial community, the microbial CUE measurement based on the accumulation of microbial biomass C (C_m) was used in the remaining chapters. In the first experiment, the ^{13}C labelled glucose was evenly applied to soils to trace the C flow as measured by the release of CO_2, C incorporation into microbial biomass, and C remaining as undecomposed C input. Microbial phospholipid fatty acids (PLFAs) were extracted and analysed as biomarkers in order to identify the microbial community composition. Results revealed that organic amendment coupled with mineral N [$(NH_4)_2SO_4$] stimulated both microbial activity and biomass, leading to a positive priming effect (PE). However, as different C:N ratios were introduced in this experiment, the PE intensity stimulated by different exogenous C and mineral N sources showed variation amongst C sources, similar to microbial CUE values as determined by above approaches. The labile C source (glucose) with low N contributed to relatively higher microbial PE. Microbial community varied with C input sources, the readily available C source (glucose) favoured bacteria community growth over fungi, while fungi population increased with mineral N application. In conclusion, microbial CUE measurements are related to the methods and parameters used, and the C use preference and community composition are highly dependent on the exogenous C and mineral sources.

Based on the microbial CUE measurement results of the first experiment, the second experiment used soils from three land use systems: cropping, pasture and natural forest soil. Three types of organic amendments were introduced: glucose as a labile C source, and wheat straw and macadamia nutshell biochar as a relatively recalcitrant C material. Microbial biomass C, and basal and substrate-induced respiration were measured to determine microbial CUE. Microbial community composition was determined based on the measurement of PLFAs. Land use history generally affects soil physiochemical and microbial properties. The natural forest soil had the highest organic C content while having relatively low soil nutrient contents. Because of constant disturbance and management, cropping soil had relatively lower values in microbial activity and biomass. Although there were no significant differences of microbial CUE values in soils from different land systems, the organic amendments lead to distinct microbial CUE values. Therefore, the exogenous C source applied to cropping land during cultivation played a more important role in terms of microbial C use preference. Glucose input significantly ($p > 0.05$) increased microbial respiration with less biomass formation, thereby resulting in a decrease in microbial CUE, while wheat straw and biochar inputs increased microbial CUE compared to glucose. However, microbial community composition differed among land use systems. Fungi was dominant in natural forest soil while bacteria population was larger in cropping and pasture soils. The type of organic amendment inputs also altered microbial community composition. The addition of an easily degradable C source such as glucose stimulated a growth in Gram-positive bacteria, while biochar input favoured fungi population growth.

The biotoxicity of heavy metal(loid)s was evaluated by monitoring microbial CUE and community composition in soil samples spiked with Cd(II) and Pb(II), both individually and in combination. The bioavailable metal concentrations, soil properties, and microbial parameters including microbial respiration, biomass and microbial PLFAs were determined at two sampling periods during the 49 days incubation experiments. Microbial CUE was determined as the ratio of accumulated biomass to decomposed C amount. Metal contamination had no significant effect on ($p > 0.05$) on soil properties such as pH and EC, while significantly ($p < 0.05$) inhibiting microbial activity and biomass formation. Notably, the microbial CUE decreased due to metal contamination, and the higher heavy metal concentration lead to lower microbial CUE values. Both total PLFAs and PLFA diversity decreased under metal stress. The microbial community composition and PLFA patterns also differed among treatments. Heavy metal pollution had greater negative influences on fungi population compared to bacteria. This might result in a vulnerable soil ecosystem with less resilience ability.

Based on the third experiment, biochar was introduced as an effective method for the remediation of metal contaminated soils. In this fourth experiment, Cd and Pb spiked soils treated with macadamia nutshell biochar (5% *w/w*) were monitored during a 49 days incubation period. Soil properties, metal bioavailability, microbial respiration, and microbial biomass C were measured after the incubation period. Microbial CUE was calculated from the ratio of C incorporated into microbial biomass to the C mineralised. Microbial community composition was determined by measuring microbial PLFAs. Results showed that total PLFA concentration decreased to a greater extent in metal contaminated soils than uncontaminated soils. Microbial CUE also decreased due to metal toxicity. However, biochar addition alleviated the metal toxicity, and increased total PLFA concentration. Both microbial respiration and biomass C increased due to biochar application, and CUE was significantly ($p < 0.01$) higher in biochar treated soils than untreated soils. Heavy metals reduced the microbial C sequestration in contaminated soils by negatively influencing the CUE. The improvement of CUE through biochar addition in the contaminated soils could be attributed to the decrease in metal bioavailability, thereby mitigating the biotoxicity to soil microorganisms.

In conclusion, microbial properties are essential indicators in the determination of soil health. The microbial CUE values vary depending on the measurement adopted. As such, there is a need for a comprehensive conceptual understanding and unified method of determination of microbial CUE. For the purpose of this research, the microbial CUE measured based on the accumulation of microbial biomass was more appropriate to examine microbial function in terms of microbial C utilization. Land use histories, organic amendments and environmental factor all alter the direction and dimension of microbial CUE, as well altering the microbial community composition. Especially certain microbial species such as bacteria and fungi could reveal soil functional status because of the difference in C use and allocation preference among these communities. Biochar could be beneficial to microbiota under metal stress, not only because of its high C content, but also because of its remediation ability as metal sorbents.

DECLARATION

I hereby certify that the work embodied in the thesis is my own work, conducted under normal supervision.

The thesis contains published scholarly work of which I am a co-author. As the author of this Elsevier article, I retain the right to include it in a thesis or dissertation, provided it is not published commercially. The article in Science of the Total Environment Journal is the original source.

The thesis contains no other material which has been accepted, or is being examined, for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. I give consent to the final version of my thesis being made available worldwide when deposited in the University's Digital Repository, subject to the provisions of the Copyright Act 1968 and any approved embargo.

Yilu Xu

Signed___ ____ Date___03/03/2018___________

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