Surface Charge governs the adsorption behaviour of glyphosate in Australian Oxisol Soil System

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Research Article

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Abstract

Glyphosate adsorption pattern is important for determining its environmental fate. Oxisol soil systems adsorb maximum glyphosate in the presence of biochar, however, the mechanism was not known. This article provides information concerning the role of surface charge in the case of Oxisol soil systems. Batch sorption experiments were conducted at the University of Sydney, Australia. Potentiometric titrations were done to calculate the surface charge in the case of Oxisol soil systems. Maximum adsorption of glyphosate in the Oxisol soil systems in the presence of char was due to an increase in net positive surface charge. This finding is of great importance to understanding the mechanism of herbicide soil interactions.

1. Introduction

Glyphosate (N-phosphonomethylglycine, $C_3PNO_5H_8$) is a broad-spectrum herbicide. The molecule was introduced in 1974 by Monsanto and became the largest selling single crop protection chemical (Franz, Mao et al. 1997). Glyphosate has three functional groups (Amine, Carboxylate and Phosphonate) which are responsible for strong coordination with metal ions (Borggaard and Gimsing 2008). In soils, glyphosate sorption is by ligand exchange through the phosphonic acid moiety, a mechanism similar to phosphate adsorption (Gimsing and Borggaard 2007).

Glyphosate and phosphate ion compete for adsorption sites. Iron and aluminium oxides adsorb a greater amount of glyphosate and phosphates in comparison to clay silicates (Gimsing, Borggaard et al. 2004) and strong competition between glyphosate and phosphates for adsorption sites has been observed on surfaces of iron and aluminium oxides versus those of silicate clays indicating the role of soil mineralogy concerning glyphosate sorption. The adsorption process is important to assess the role of soil to act as a filter for protecting groundwater against pollution with glyphosate (Gimsing, Borggaard et al. 2004).

The bioavailability of herbicides can be greatly reduced with the application of biochar (Beesley, Moreno-Jimenez et al. 2010). The physical and chemical properties of biochar can affect the sorption behaviour of herbicides (Kookana, Sarmah et al. 2011). The adsorption behaviour of glyphosate has been reported in Australian soil systems (Gerritse, Beltran et al. 1996), however, for updated information on glyphosate behaviour, experiments were conducted at the University of Sydney, Australia. The adsorption behaviour of glyphosate in the presence and absence of biochar have been previously reported (Sharma and Lai 2019, Sharma 2020, Sharma, Singh et al. 2021), however, the present article would elucidate in detail the mechanism for the maximum adsorption of glyphosate in the Oxisol soil system in the presence of biochar.

2. Materials And Methods

This experiment was part of PhD study at the University of Sydney (Fang, Singh et al. 2014, Sharma and Lai 2019, Sharma 2020). As the Oxisol soil system showed maximum adsorption of glyphosate, potentiometric titration was used as a tool for surface charge determination (Lutzenkirchen, Preocanin et al. 2012) in this system. The potentiometric titration was done with 836 Titrando (Metrohm) involving strong acid (0.1N Nitric Acid) in one dosing unit and 0.1 N NaOH as a strong base in another dosing unit. Substrate involved 0.2 g (Soil / Soil+ char) + 10 mL (1 M KNO₃) + 90 mL (water). Calibration was done on a pH scale. pH was calibrated with known buffers and 0.025 mL of acid/base from the dosing units was added slowly in continuous iterations. To check for CO₂ contamination, nitrogen gas was introduced. In a continuous acid-base titration, dependency of the “equilibrium”-pH values of the colloid dispersion on the incremental added volume of titrant (strong acid/ strong base) was measured. The relative charge was obtained by plotting the pH as a function of the volume of the titrant.

Statistical Analysis

The batch experiments were repeated and the data were pooled as there was no significant interaction between treatments and experiments observed. The data were analyzed using Analysis of variance (SAS 9.4) and the means were separated by Tukey's 95% confidence intervals (Sharma and Lai 2019).

3. Results And Discussion

Titration curves Fig 1(a) and Fig 1(b) revealed that the surface charge in the Oxisol soil system was higher than the charge in the Oxisol soil system without char. This aspect explained the reason for the highest amount of glyphosate adsorbed in the Oxisol soil system (Fig.1a- 1b) (Sharma and Lai 2019, Sharma 2020). The presence of char increased the protonation and hence net surface charge became more positive on oxide surfaces; consequently, increasing the adsorption of anionic glyphosate (Sharma 2020). The finding is of great practical significance to understand soil-herbicide interactions.

4. Conclusions

Potentiometric titrations revealed that biochar increased the net positive surface charge in the case of Oxisol soil systems and glyphosate being the anion adsorbed in higher amounts in these systems.

5. Declarations

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Data Availability Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Figures

Figure 1

(a) Surface charge distribution in Oxisol soil system with char (b) Surface charge distribution in Oxisol soil system without char