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Vetiver Grass and Micropollutant Leaching Through Structured Soil Columns Under Outdoor Conditions

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ABSTRACT

In Burkina Faso, significant amounts of endosulfan are applied to cotton fields; in addition, urban vegetable agriculture is often characterised by high fertiliser inputs, such as urban solid wastes containing heavy metals (*e.g.*, Cu and Cd). Thus, the relevance of surrounding cotton and urban vegetable plots with vetiver (*Vetiveria zizanioides*) hedges to reduce environmental pollution by micropollutants was investigated using a leaching experiment, with outdoor lysimeters filled with two representative agricultural soils of Burkina Faso: Vertisol and Lixisol. After 6 months, little Cu was found in the leachates (< 0.010% of the applied amount) due to its high adsorption coefficient and its tendency to remain at the soil surface. Despite leachate and bromide recoveries being greater in soils planted with vetiver grass than in the bare soils, smaller amounts of endosulfan and Cd were found in the effluents from the planted soils (0.01% to 0.70% of the applied amount) than in those from the bare soils (0.01% to 1.48% of the applied amount), in agreement with their adsorption coefficients. These results may also be explained by a greater degradation of endosulfan in planted soils compared to bare soils and the absorption of Cd by vetiver. Thus, vetiver may decrease the risk of groundwater contamination, especially for Cd and endosulfan, which are more mobile than Cu. In addition, despite the smaller amounts of endosulfan and Cd measured in the Vertisol leachates (0.01% and 0.04% of the applied amount, respectively) compared to the Lixisol leachates, vetiver was more effective in decreasing the leaching of micropollutants if planted on Lixisol rather than on Vertisol. Further field monitoring is necessary to demonstrate the effectiveness of vetiver under the climatic conditions of Burkina Faso.

Key Words: cadmium, copper, endosulfan, Lixisol, lysimeter, transfer, Vertisol

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INTRODUCTION

Agriculture is the most important economic activity in Burkina Faso. More than 85% of the active population is employed in the agriculture industry, which contributes approximately 33% of the gross domestic product. Cotton is the principal cash crop in Burkina Faso and contributes 50% to 60% of export revenues (Renaudin, 2010). Approximately 2 500 t of insecticides are used each year to control agricultural pests in cotton-growing areas (Gnankiné *et al.*, 2007). In West Africa, one-third of commercial insecticide formulations contain endosulfan (Ton, 2006). Due to the persistence and bioaccumulation, this organochlorine insecticide has been detected in air, sediments, water and living organisms in remote areas, such as the Arctic (Weber *et al.*, 2010). Alarming rates of endosulfan were measured in water, sediment and some fish from several Benin aquatic biotopes (Agbohessi *et al.*, 2012). Tapsoba and Bonzi-Coulibaly (2006) found high concentrations of endosulfan (ranging from 0.05 to 3.80 μg L^{-1}) in surface waters of the cotton zones in Burkina Faso during the rainy season of 2005. Due to the toxicity and persistence, technical endosulfan and its related isomers were listed in 2011 as a persistent organic pollutant of the Stockholm Convention (UNEP, 2011). Otherwise, urban vegetable agriculture is often characterised by high fertiliser inputs, such as urban solid wastes. Cu and Cd have been detected in soils and lettuce leaves in urban vegetable gardens near Ouagadougou (Kiba *et al.*, 2012). The increasing use of pesticides and urban solid wastes in the soils of Burkina Faso should not be compromised with the consumer's health or the environment.

A project was initiated to study the effectiveness of vetiver (*Vetiveria zizanioides*) hedges surrounding cotton plots and market gardens in reducing soil and water pollution by micropollutants (Cu, Cd and endosulfan) in Burkina Faso. *V. zizanioides* is a native to the Indian subcontinent and has the potential to meet

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all of the criteria required for phytoremediation. Vetiver is a non-invasive, rapidly growing, low-maintenance perennial plant (Srivastava *et al.*, 2008). Vetiver thrives in extreme climatic conditions and grows in tropical regions such as Burkina Faso. Vetiver can also accumulate heavy metals (Antiochia *et al.*, 2007; Ondo Zue Abaga *et al.*, 2014a) and promote the biodegradation of organic contaminants such as organophosphorus pesticides and endosulfan (Boonsaner *et al.*, 2005; Ondo Zue Abaga *et al.*, 2014b). Vetiver grass plantations can be promoted by the economic returns obtained through essential oil production (Danh *et al.*, 2009).

Several studies have shown that the use of grass covers, generally *Lolium perenne* (Liaghat and Prasher, 1996; Landry *et al.*, 2005; Dousset *et al.*, 2010) or *Phalaris arundinacea* (Neuschütz and Greger, 2010), reduces the amounts of pesticides and metals leached compared with the amounts leached from bare soils. However, several contradictory results have been reported in the literature, including the studies by Belden and Coats (2004), who found no difference between vegetated and bare soils (several grasses studied), and Antonious and Byers (1997), who reported greater concentrations of β-endosulfan in leachates from vegetated soil than from bare soil (*Festuca* sp.). Few studies have been conducted to assess the ability of vetiver to reduce pollutant leaching into soils; the laboratory study of Chen *et al.* (2004) reported lower amounts of Cu and Cd in the leachates of sieved soil planted with vetiver compared with bare soil, and no previous studies have examined endosulfan in this context. Thus, our work assessed the effectiveness of vetiver grass in reducing the leaching of Cu and Cd through cotton plots and the leaching of endosulfan through market gardens into groundwater. The effect of vetiver on micropollutant leaching was determined using outdoor lysimeters filled with two representative agricultural soils of Burkina Faso: Vertisol and Lixisol.

MATERIALS AND METHODS

Soil sampling and characterisation

Two soils, Lixisol and Vertisol (IUSS Working Group WRB, 2006), were collected from the surface (0–20 cm) at two experimental stations, Saria and Kaïbo, in the West African nation of Burkina Faso.

The soils were air-dried, separated through a 2-mm sieve and characterised for their texture (NF X 31-107), pH (NF ISO 10390), total organic carbon (NF ISO 10694), N (NF ISO 13878), cation exchange capacity (CEC) (NF X 31-130), and the total major elements (NF X 31-147) at INRA-Arras, France.

A 40-mL of the clay fraction (0–2 µm) obtained from 6 g of soil per 500 mL of water was used to determine the mineralogical composition of the clay. Clay mineral characterisation was performed using a Bruker® D8 diffractometer (Karlsruhe, Germany) with CoK_α radiation. Diffractograms were recorded from 3° to 40° 2θ with a step scan of 0.035° 2θ and time per step of 3 s for two preparations: a deposit oriented toward air-dried clays and a deposit oriented toward saturated clays at ambient temperature for 24 h in ethylene glycol vapours (Mosser-Ruck and Cathelineau, 2004).

Chemicals

The α- and β-endosulfan mixture ($\alpha+\beta$), in a ratio of 70:30, was purchased from Cluzeau (Sainte-Foy-la-Grande, France). The purity of the mixture was 97.5%. For ($\alpha+\beta$) endosulfan, the reported half-life is 28–50 d in laboratory studies and 62–126 d in field studies; the solubility in water has been reported to be 0.32 mg L^{-1} at 20 °C; the adsorption coefficient has been reported to be 11 500 L kg^{-1}; and a moderate vapour pressure of 0.83 mPa at 25 °C has been reported (Lewis *et al.*, 2016). $CuCl_2$ and $CdCl_2$, with respective purities of 97% and 99%, were purchased from Sigma-Aldrich Chimie (Lyon, France). KBr, with a purity of 99.5%, was obtained from Merck Eurolab (Fontenay-sous-bois, France).

In a previous study, we measured the adsorption coefficients of endosulfan, Cu and Cd in planted and bare Lixisol and Vertisol (Ondo Zue Abaga *et al.*, 2014a, b). The adsorption coefficients (K_f) of endosulfan, Cu and Cd were higher in Vertisol (K_f = 7.2, 2 922 and 206 mg^{1-n} L^n kg^{-1}, respectively) than in Lixisol (K_f = 6.3, 328 and 37 mg^{1-n} L^n kg^{-1}, respectively). The clay and organic carbon (OC) contents and CEC, which were higher in Vertisol (28.8%, 10 g kg^{-1} and 13.9 cmol kg^{-1}, respectively) than in Lixisol (9.3%, 4 g kg^{-1} and 1.7 cmol kg^{-1}, respectively), could explain the greater adsorption of the pollutants on Vertisol (Table I). Planted soils adsorbed more endosulfan, Cu and Cd (K_f = 6.5, 3 163 and 75 mg^{1-n} L^n kg^{-1}, respectively, for Lixisol and 9.7, 4 445 and 280 mg^{1-n} L^n kg^{-1}, respectively, for Vertisol) compared with bare soils. These results could be a result of slight increases in the OC content in planted soils (Ondo Zue Abaga *et al.*, 2014a, b).

Column setup

Ten 30-cm long polyvinyl chloride (PVC) pipes with 20-cm internal diameters were placed in an outdoor, in-ground lysimeter collection system in the Bo-