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Evidence of chlordane resurrection by glyphosate using Paleo-Critical Zone approach in French West Indies

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Context

The widespread use of pesticides in agriculture during the last several decades has contaminated soils and different Critical Zone (CZ) compartments. However, the long-term fate, storage, and transfer dynamics of persistent pesticides in CZ in a changing world remain poorly understood. In the French West Indies (FWI), chlordane (CLD), a toxic organochlorine insecticide, was extensively applied to banana fields to control banana weevil from 1972 to 1993 after which it was banned. However, CLD is still persistent in most of the CZ compartments with severe toxic effects to human populations. Depending on the soil type and considering negligible CLD degradation, it was estimated that CLD could remain in soils for at least several decades and up to centuries (Cabidoche et al., 2009). Thus, if erosion of cultivated soils increases in response to changes in agricultural practices, such as herbicide use (glyphosate), soils will be converting from sinks into sources of pesticides (Sabatier et al., 2014). To test this hypothesis, in the context of intensive glyphosate application, we applied a retrospective observation based on the analysis of marine sediment cores in order to monitor long-term CLD transfer from watersheds thanks to a multiproxies approach.

Sampling and methods

A 1.13 m long (GAL17-04) was collected in the Baie du Galion in Martinique and a 1.33 m long core (GUA17-01) in Petit Cul-de-Sac Marin in Guadeloupe on April 2017 (Figure 1). Surface soil horizons were sampled on the Galion (Martinique, n = 44) and Pérou (Guadeloupe, n = 35) watersheds under different soil types and land use contexts.

Short-lived radionuclides on watershed samples show that the banana and sugarcane plantations provide a significant supply of sediment to river systems on these islands through erosion.

Cores have been dated thanks to short-lived radionuclides (Figure 2) and show a synchronous drastic change in accumulation rate in 1999 with an increase of 4 (GAL) and 10 fold (GUA) attributed to terrigenous inputs through erosion thanks to sedimentological and geochemical data (Figure 3).

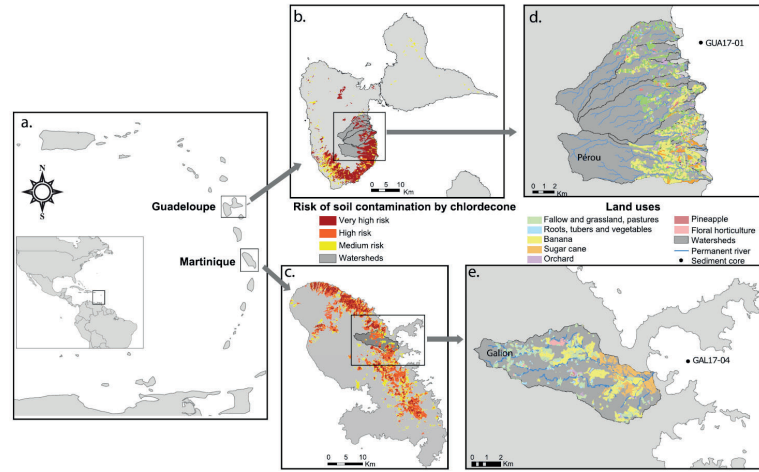


Figure 1 : (a) Map of the Caribbean arc with the two French islands. (b, c) Maps of Guadeloupe and Martinique showing the risk of soil contamination by CLD; (d, e) Localization of the studied watershed (dark gray) with types of crops. Two sampled marine sediment cores are indicated by black dots. Pérou and Galion river watersheds (d, e) were also sampled.

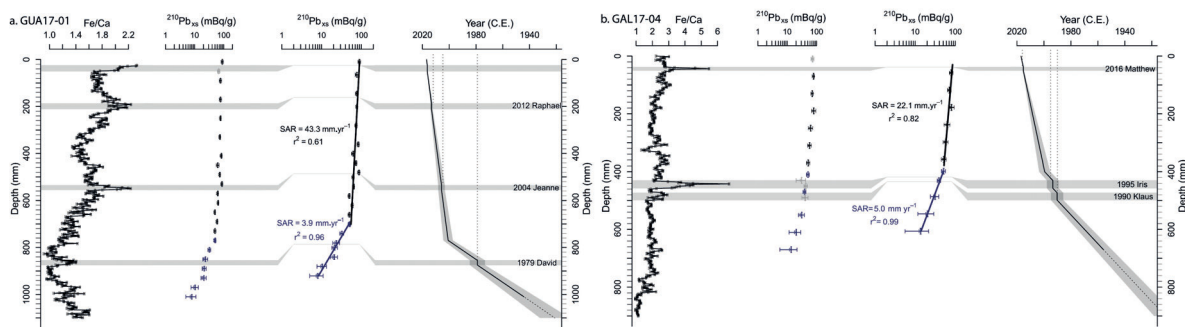


Figure 2 : Chronology for the GUA17-01 (a) and GAL17-04 (b) cores with the Fe/Ca, ²¹⁰Pb activity, instantaneous event-corrected ²¹⁰Pb activity and age model with uncertainties (gray area) realized with the serac R package (Bruel and Sabatier 2020). Dotted lines extending from the black lines indicate age model extrapolation. On the right part of this figure ages and names correspond to historical hurricanes.

CLD transfer in CZ

At both sites, we observed a synchronous increase in CLD + CLO and erosional fluxes when glyphosate was first widely applied to banana fields at the end of the 1990s (Figure 3). The application of glyphosate, which disrupts grass development, has a strong effect on soil erosion as previous demonstrated in vineyard (Sabatier et al., 2014).

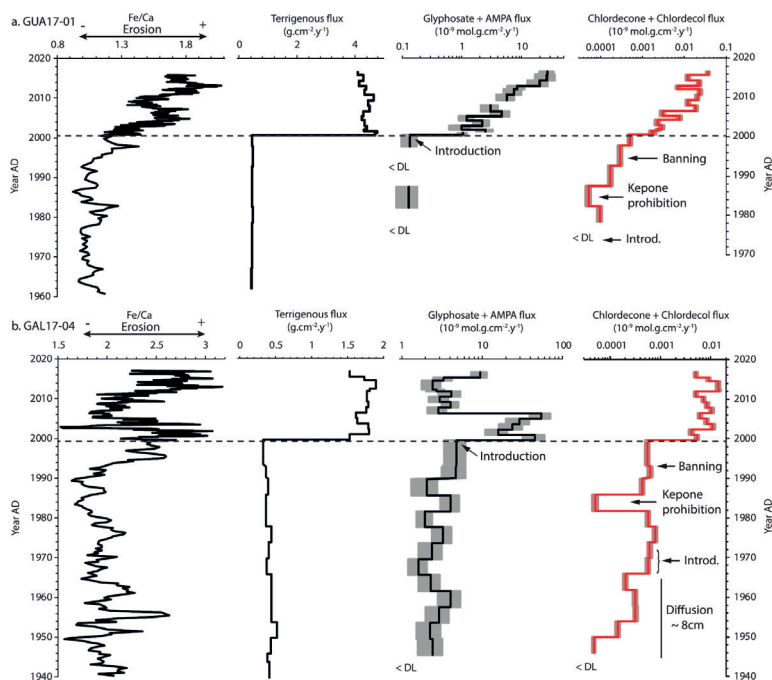


Figure 3 : Guadeloupe (a) and Martinique (b): Erosion proxies with Fe/Ca and terrigenous fluxes compared to a pesticides fluxes (logarithmic scale) of sum of glyphosate and AMPA and the sum of CLD and CLO. The horizontal dotted line corresponds to the large erosion increases.

Putting all our observations together, we argue that the widespread use of a non-specific systemic herbicide (glyphosate) since the late 1990s' could be responsible of an unprecedented rise in soil erosion and downstream of a major release of remnant CLD pesticides that were trapped in banana field soils since their ban in the late 1990s' (Figure 3).

In this study, we highlight that new agricultural practices may induce complex interactions in the CZ dynamic converting soils from sinks into sources of formerly used pesticides. This happened in FWI where CLD was probably resurrected by glyphosate-induced soil erosion (Figure 4). The retrospective observation applied here allowed us to reconstruct long-term CZ trajectories under human effort, hence proving its strength in providing novel and complementary information to modern-day CZ observatories.

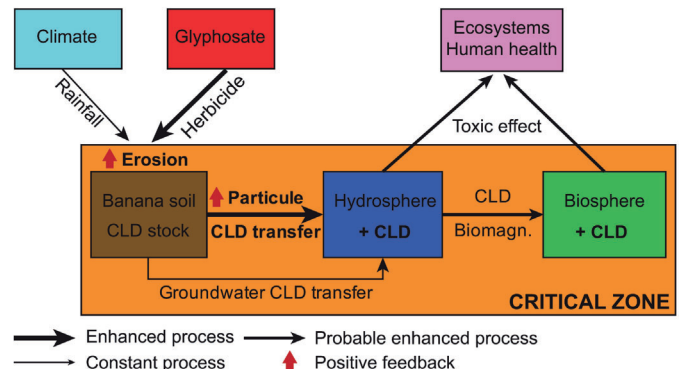


Figure 4 : CZ dynamics and responses in FWI in relation to past (CLD) and modern (Glyphosate) agricultural practices

Ref.: Bruel & Sabatier 2020, J. Environ. Radioact. 225, 106449 ; Cabidoche et al., 2009, Environ. Pollut. 157, 1697–1705 ; Sabatier et al., 2014, PNAS 111, 15647–15652