High-throughput on-site screening of soil cadmium contamination to inform cacao management

Cacao production in Latin America and Caribbean (LAC) is on the rise, in part because cacao is being promoted as an alternative to the production of illicit crops. However, cadmium (Cd) contamination of soils due to use of phosphate rock and irrigation with compromised wastewater has become a concern among cacao producers and consumers because this heavy metal can accumulate in cacao beans. Human health risks of Cd has led to new regulation by the European Union posing strict limits regarding Cd concentrations in chocolate and other cacao by-products, which will be implemented in 2019. Expectations are that other countries (Canada, US, Japan) will reconsider their regulation for Cd levels in cacao as well. These developments have raised strong concerns among cacao producers and other supply chain actors in LAC countries about access to export markets for cocoa products.

Decision making to anticipate changing regulation and mitigate Cd contamination problems is strongly limited by a lack of information on the extent, origin and geographical distribution of the problem. To enable fast and cost-effective site-specific predictions of contamination risks for cacao products, the level of contamination in cacao production sites, as well as related soil properties, must be obtained together with genotypic variation in Cd uptake and allocation within different plant tissues. Identifying contaminated areas before establishing new plantations is of crucial importance and should be part of a suitability assessment for cacao production, cacao varieties and target markets. For areas already under cacao production Cd assessments can be used to inform mitigation strategies. However, site specific characterization based on soil and plant sampling followed by laboratory analysis is time-consuming and extremely expensive.

We hypothesize that high-throughput soil sensing techniques can be used to collect big data sets that can be used to make site specific predictions of Cd risks and inform soil fertility management, which can be translated into decision support tools across cacao growing regions in LAC. In situ and high-throughput soil and plant tissue analysis such as portable x-ray fluorescence spectrometry (pXRF) and mid-infrared (MIR) spectroscopy are promising options to develop fast, affordable and reliable predictions based on big data bases. Ultimately this enable updating site-specific Cd risk assessments at national and regional levels, and inform monitoring of and action on soil Cd risk to cacao. pXRF provides total concentrations of 80+ elements within minutes, including heavy metals such as Cd. In combination with MIR data, predictions can be developed based on soil properties that affect the availability of Cd for plant uptake, because soil Cd availability depends on the interaction of total Cd and soil properties. Such complexity necessitates a big data approach involving biogeochemists, soil scientists, and soil mappers to develop actionable recommendations. An important added value of our approach is that the collected data will not only be used to develop novel techniques to inform producers about Cd risks and mitigation strategies, but also provide important information on soil fertility status that can be translated directly into management recommendations to optimize production levels, based on proven methodologies. **We propose to develop a novel, big data approach based on high-throughput pXRF and MIRS soil and tissue analysis, that will generate key information to support decision making on mitigation of cacao production risks and improve productivity. Our goal is a proof of concept using cacao production sites in Ecuador that has high translatability across cacao growing countries in LAC.**

Implementation Plan: We will leverage existing on-farm and experimental studies to evaluate the potential role of pXRF for rapid in-situ screening of soil Cd. Since pXRF requires minimal soil processing, and can be performed on-site, we expect to develop a method that enables rapid screening for soil Cd at sufficiently high spatial resolution to inform management decisions. Three approaches to conducting pXRF will be tested to evaluate trade-offs between fastness and accuracy of data generated: (1) in situ analysis (no sample

preparation, in the field), (2) indirect analysis (minor sample preparation, in the field), and (3) ex situ analysis (lab preparation). Values for total Cd obtained by pXRF will be compared with values measured by inductively coupled plasma mass spectrometry (ICP-MS). Previous assessments have reported high correspondence of Cd values obtained by pXRF and ICP-MS (e.g., $R^2 > 0.99$).

We have a unique opportunity to build on an existing database of 500 samples of soils and cacao beans of several cultivars across Ecuadorian production regions. Given that the relationship between total soil Cd content and Cd availability, uptake and allocation within the cacao plant is site and cultivar specific, further data will be collected to provide useful predictions of Cd risks based on (i) total soil Cd content, (ii) relevant soil properties (texture, pH, OC) and (iii) total Cd in cacao beans. To establish these relationships, variability and correlations in soil properties and Cd concentrations in cacao beans will be addressed by multivariate analyses, including total Cd by pXRF (elemental composition) and basic soil properties that can be rapidly measured in the field and/or by MIR (e.g., pH, soil organic carbon, clay content).

The prediction of Cd and soil properties relevant to Cd uptake by cacao will be tested using chemometric models (e.g., partial least squares regression), which has shown success in prediction of Cd as well as texture, pH, and total organic carbon in soils. We will include 2-3 cacao cultivars to evaluate potential cultivar effects on Cd risk predictions. High resolution maps of Cd risk and soil fertility parameters will be generated using digital soil mapping approaches by combining the results from pXRF and MIR with variates that can explain soil variability (e.g., climate, topography, parent material). Global climate datasets calibrated with available local data and the digital elevation model SRTM 90m (http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1) will be used to perform the topography variables needed for soil mapping.

Feasibility (budget + time): Funds will be used to collect and analyze pXRF data and MIR by supporting graduate students working across partner institutes. A scientific workshop among partners will also be carried out in order to define the best approaches for predictions. Mileage per funding dollar will be maximized by integrating the proposed work by ongoing characterization research program on Cd uptake in cacao, including anticipated outside support for travel and research costs. The proposed work will strategically capitalize on pre-existing efforts and datasets. This is essential to the project success because it provides a large soil Cd dataset necessary to test the potential of high-throughput pXRF for in situ generation of large datasets for on-site prediction of Cd contamination risk in cacao. The PIs have possession and expertise of equipment for proposed and supporting analyses (ICP-MS, pXRF, MIR), and analysis of soil Cd for ICP-MS is already underway.

Essential data that will be generated: Data that will be generated include: (1) total soil concentrations of 80+ elements (pXRF), (2) MIR spectra of soils and prediction models from producers' fields in Ecuador, and (3) digital soil maps. These data have great value in furthering the work of CIAT, and cacao producer stakeholders, because such data provide additional information on soil factor related to Cd uptake risk, as well as soil fertility. For example, by quantifying Zn, an element that competes with Cd for plant uptake, pXRF data can provide insight on soil-based Cd management strategies.

Potential Next Steps: As high Cd levels are found in cocoa products from the entire region, the methodologies to be developed have potential to be applied in other LAC countries to develop regional mitigation strategies at production or processing levels so that the cacao sector in LAC will be prepared to comply with the new regulations on Cd limits in cocoa products. Our ultimate goal (beyond the time frame of the 1 year project) is to establish a platform, accessible through computer and smartphones, to provide farmers and extensionists with high resolution data and decision support tools to mitigate market and health risks related to Cd contamination while optimizing production based on soil fertility status. Our technologies also have potential to contribute to build a system to analyze soil status, fertilizers and cacao beans to continually update the information and monitor changes on Cd levels in soils, agroinputs and products.