Developing low-cost soil health and carbon indicators in West African cocoa plantations

Second Year Student Progress Report

Submitted to the Sue White Fund

By

Gideon Asamoah

(PhD Student at Cranfield University)

April 2025

Background and rationale

Cocoa, a vital commodity and cash crop, supports the livelihoods of 5–6 million smallholder farmers across tropical countries such as Ghana and Côte d'Ivoire. It is a key driver of economic growth in many rural regions, particularly in West Africa. However, cocoa production faces numerous challenges that threaten the sustainability of its value chain. These challenges include climate change, soil erosion, declining soil health, and significant greenhouse gas emissions from agrochemical inputs, all contributing to environmental degradation at both field and catchment scales. Declining soil productivity often drives agricultural expansion into forested areas, leading to substantial carbon losses and catchment-wide pollution. Addressing these issues requires not only halting further degradation but also urgently measuring and enhancing carbon storage and soil health in already converted areas.

Soil health, defined as the soil's capacity to function as a vital living ecosystem within its boundaries, sustains productivity, maintains water and air quality, and promotes the health of plants, animals, and humans. To assess soil health, soil health indices comprising measurable parameters that reflect soil properties, processes, and characteristics are used. These indices typically include physical, chemical, and biological indicators. Effective soil health indices must correlate with specific soil functions, respond to management practices, be accessible and interpretable by users, cost-effective, applicable across diverse management systems, and scalable from field to national levels to align with climate change mitigation and adaptation goals.

However, conventional methods for assessing soil health indicators are often costly, time-consuming, prone to sampling and laboratory errors, and involve harmful chemicals that negatively impact the environment. While soil health indices have been developed for various agricultural systems, particularly annual temperate crops, there is limited work on perennial ecosystems like cocoa. This gap highlights the need to integrate low-cost measurement approaches, such as near-infrared reflectance spectroscopy (NIRS) and semi-quantitative test strips, with conventional methods. These approaches require minimal soil preparation, use little to no chemicals, and offer significant advantages in supporting timely and spatially informed soil health management decisions, thereby promoting sustainable cocoa production.

Additionally, the pathways of carbon inputs in cocoa systems involve the transformation of atmospheric carbon dioxide into organic molecules through photosynthesis. These organic molecules are subsequently transferred into soils as litter or rhizodeposition, where they are partly decomposed or utilized by soil organisms, with the residuals contributing to soil organic matter buildup. It is estimated that approximately 60 Pg of carbon enter soils annually. These carbon inputs are crucial for soil organic carbon accumulation, which drives several ecosystem functions, such as soil formation. Carbon inputs from plants occur mainly through aboveground and belowground biomass. Aboveground biomass carbon inputs originate from litter (leaves, stems, fruits, and twigs) and dissolved organic matter from tree surfaces, decomposing litter, and partly decomposed materials on the forest floor. Belowground carbon inputs include root litter, root-associated fungal turnover, and rhizodeposition (passive exudation and active secretion). Conversely, soil respiration, erosion, runoff, and leaching are the dominant pathways of carbon loss from the ecosystem. Enhancing carbon storage in cocoa systems is critical for improving the sustainability of cocoa farming and contributing to climate change mitigation. Over the years, various interventions such as adopting agroforestry systems and regenerative agricultural practices (e.g., reduced agrochemical use, organic management, and shade control) have been proposed to enhance carbon storage in cocoa systems. However, questions remain about how management practices, including shaded and unshaded cocoa systems, as well as plantation age, influence carbon flows and soil health in cocoa systems.

Despite growing recognition of the importance of carbon dynamics in cocoa systems, there is limited understanding of how shading systems and plantation age regulate carbon inputs and losses. While some studies have examined carbon sequestration in cocoa agroforestry, comprehensive research evaluating the interaction between shading practices, plantation age, and carbon flux pathways is still lacking. This study aims to fill this knowledge gap by assessing how different shading systems (e.g., monoculture vs. shaded cocoa) and plantation age influence carbon input and loss pathways. It also seeks to develop simple carbon budgets to determine the overall carbon balance of cocoa plantations and explore the potential of cocoa agroforestry systems to mitigate climate change through enhanced carbon sequestration. By investigating the relationships between shading, plantation age, and carbon flows, this research will provide valuable insights for improving cocoa production practices, supporting sustainable land-use management, and contributing to global climate change mitigation efforts through enhanced carbon management in agricultural systems.

The objectives of the research are to;

1. Identify and develop low-cost indicators for monitoring carbon and soil health in cocoa farms.
2. Assess the role of time under management in accounting for the spatial and temporal heterogeneity of carbon flows and soil health.

3. Use the DNDC and SWAT models to assess the resilience of carbon storage and upscale.

Progress made in the second year.

Objective 1.

In the second year of the project, I travelled to Côte d'Ivoire to collect soil samples from cocoa plantations in three key cocoa-producing regions: the eastern, central, and western parts of the country. Samples were collected from both shaded and unshaded cocoa farms of varying ages (1–5, 6–10, 11–20, and 20+ years). Following the same approach used in Ghana, each identified cocoa farm was divided into three sections, and composite soil samples were collected from each section. These composite samples were obtained by thoroughly mixing soil from 10 spots along a 'W-plane' using an auger. Samples were taken from two soil depths: 0–20 cm and 20–40 cm. Additionally, bulk density samples were collected using a core sampler (5 cm height, 3 cm diameter) at the 3 different sections of the farm.

In the laboratory, the soil samples were air-dried for five days, sieved through a 2 mm mesh, and stored for further analysis. Following sample preparation for both Ghana and Côte d'Ivoire, the soils were analyzed using both low-cost and wet chemistry methods. Low-cost methods included semi-quantitative test strips for total nitrogen and available phosphorus, as well as spectroscopic analysis using NIR spectrometers. The NIR spectrometers were used to collect spectra of the soil samples to develop models for predicting total nitrogen, soil organic carbon, exchangeable cations, cation exchange capacity (CEC), and soil texture (sand, silt, and clay). To support model development, approximately 50 soil samples were analyzed using traditional wet chemistry methods for routine physical and chemical parameters.

The laboratory analyses have now been completed, and the data is being analyzed for model development. The goal is to predict soil parameters and develop soil health indices based on cocoa management practices and age gradients. Below were some photos taken as far as implementation of the objective 1 is concerned.




Objective 2.

Following the establishment of monitoring plots and the collection of preliminary data in Year 1, field measurements and sample collection were conducted in the second year. These activities took place in February, May, August, and December 2024, with additional visits planned for March and June 2025.

During each field visit, total and autotrophic soil respiration were measured using an EGM-5 infrared gas analyzer from the open and closed mesocosms installed in the first year. Additionally, all litter within the litter traps was collected, placed in appropriately labelled bags (indicating site, plot, date, and measurement point number), and transported to the laboratory. Fine root biomass was also recovered from the installed root in-growth cores, washed to remove soil particles and gravel, and placed in labelled paper envelopes.

In the laboratory, the biomass samples were oven-dried at 60°C for 48 hours until a constant mass was achieved. The dried samples were then weighed to determine litterfall and fine root biomass production rates. These samples were further analyzed for carbon and nitrogen content to quantify carbon and nitrogen inputs into the cocoa system.

The data from soil respiration, litterfall, and fine root biomass measurements were used to estimate carbon balances and budgets across the study gradients. Below are some photos documenting the implementation of Objective 2.




Potential impact of the project

Improved Income and Livelihood: Smallholder cocoa farmers often struggle to assess soil health and fertility due to financial constraints, leading to low cocoa productivity. If successful, this project will enable farmers to evaluate soil health and fertility using low-cost measurement approaches. This will empower them to make informed investments for the necessary inputs to maintain and enhance soil health, ultimately increasing cocoa yields and improving their income and livelihoods.

Carbon Sequestration: This study will identify practices that minimize carbon losses and enhance carbon storage in cocoa systems. By scaling up these practices, the project will contribute to climate change mitigation efforts.

Environmental Sustainability: The study aims to identify management practices that improve carbon storage, thereby reducing nutrient losses through leaching and runoff, which can pollute water bodies. Additionally, proper investments in maintaining soil health will reduce the need for deforestation, promoting environmental sustainability.

Capacity Building: The project will enhance my expertise in cocoa production systems, soil health indices development, carbon flows in cocoa systems, and modelling carbon storage. With this enhanced capacity, I will be better equipped to contribute to sustainable cocoa production.