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Harnessing UAVs and Large Scale Data Analytics for
Low Cost, High-Throughput Soil Health Monitoring

Essence of the Idea

In landscapes dominated by smallholder agriculture such as western Kenya, high spatial heterogeneity of management necessitates dense sampling schemes. While infrared and other dry spectroscopy methods have reduced the cost of laboratory-based measurements, soil sampling in the field and sample processing remain by far the largest cost items, constraining sample size and thus resolution of soil health mapping across landscapes. **We propose to harness recent advances in large scale data analytics (Big Data) and low-flying UAVs (unmanned aerial vehicles or drones) equipped with NIR cameras to extend the power and reach of soil spectroscopy in the area of high throughput landscape assessment and soil health monitoring especially in developing countries.** By demonstrating the feasibility of UAVs to harvest soil NIR spectra and advanced machine-learning to extract actionable knowledge about soil properties and the underlying biophysiochemical phenomena from the resulting large spectral libraries, the proposed work would ***catalyze, transform, and guide*** the already exponentially growing application of NIR as an inexpensive, rapid tool for soil measurements.

A creative coupling of technologies and analytics

The use of soil NIR to predict soil properties is widespread, both globally and in sub-Saharan Africa. The application of UAVs to monitor agroecosystems by farmers, researchers, and private industry is likewise exploding around the globe. We will therefore capitalize on these pre-existing but parallel applications of high-throughput data collection technologies that have yet to be merged.

Soil spectroscopy remains largely laboratory-based, and UAVs have yet to be used to acquire hyperspectral NIR data on soils. Robustness, accuracy, and applicability of UAV based measurement of soil spectral properties over large and heterogeneous terrains are open questions. We propose that low-flying drones can improve soil spectroscopy by generating large spectral datasets from which models can be developed with deep learning to improve prediction of soil health indicators. Key questions that we will address include: what are the trade-offs among the altitude and speed of the UAV and quality of NIR spectra? Can soil spectra be unmixed from partially vegetated pixels, and can drones be programmed to hover over or distinguish bare soil areas? How much data is needed for models to be reliable? To tackle these questions, **our team** is composed of computer engineers, soil scientists and spectroscopists, **experienced in big data analytics** (UCD)and **UAVs** (UCD, CIAT), **soil spectroscopy** (ICRAF, UI), and **soil health** (CIAT, UCD, UI).

Rationale

We hypothesize that low flying UAVs will be able to collect soil NIR data to enable high-resolution (with-in field) prediction of soil properties across agricultural landscapes in western Kenya. Prediction will include indicators of soil health such as permanganate-oxidizable carbon (POXC) as well as variables routinely predicted from soil spectra, such as total soil organic carbon and texture. Additionally, we hypothesize the accompanying application of machine learning to process large data sets harvested by UAVs will (1) Address current methodological constraints to predicting soil properties from NIR due to processing and performance penalties of traditional prediction models (e.g., partial least squares regression), namely (a) processing unconventionally large spectral datasets, (b) developing accurate models across diverse soil types, and (c) accounting for noise in NIR spectra due to acquisition (e.g., time of day, soil moisture).

Piloting for Impact

We propose to marry two high-throughput tools to revolutionize the study of soil landscapes. The rapidity of UAVs in accessing geography disparate sites and collect NIR data, coupled with the ability of hundreds and potentially thousands of NIR spectra to be digested in chemometric models for soil property prediction, is a match made for providing rapid feedback.

By addressing considerations on how to collect large NIR datasets via UAVs to yield accurate soil predictions, the proposed work is anticipated to produce methodology for collecting data using drones that is reliable and that can be adapted to different regions. Additionally, the proposed work will synergize and advance ongoing work by ICRAF, CIAT, and University of Illinois on the use of NIR as a rapid, inexpensive replacement of traditional laboratory measurement of POXC.

Implementation Plan

We will leverage the existing on-farm studies and long-term trials in western Kenya that evaluate conservation agriculture and represent a chronosequence of deforestation (14-80 years) to help validate the models and outcomes of the proposed research. The long-term trials, which are some of the longest ongoing in East Africa (16-18 years) evaluate conservation agriculture and a suite of integrated soil fertility management practices. Large datasets of soil NIR at intra-field scale will be produced for all sites. In order to validate UAV-acquired NIR data, soils will be sampled and characterized for novel soil health indicators (POXC) as well as routinely measured soil properties, and analyzed using benchtop NIR spectroscopy. The large amount of data gathered will be processed by advanced deep learning tools (Tensorflow) to create models which will be validated against the lab based predictive models developed by the PIs' prior work.

Feasibility (budget + time)

Funds will be primarily used to collect and analyze spectral data by supported graduate students, who will work with PI's across partner institutes. In addition, a portion of funds will be used to travel to the data collection sites in East Africa and renting the equipment (UAVs) and the associated cameras. Mileage per funding dollar will be maximized by dovetailing the timeline of the proposed work with planned travel to sites and ongoing characterization of soil health and application of traditional infrared spectroscopy to predict soil properties in western Kenya by the PIs. By virtue of its integration into ongoing research programs involving 3 of the 4 institutions, we expect the proposed work to be highly feasible.

Essential data that will be generated

Data that will be generated include: (1) NIR spectra of soils from farmer fields and long-term CIAT trials in western Kenya. Irrespective of the success of **UAV-acquired NIR to predict soil health indicators**, this data has great value in furthering the work of ICRAF and CIAT in monitoring soil degradation and C sequestration in this region. (2) UAV operation data (e.g., flight speed and altitude, flight duration and energy costs) and quality of NIR data. This means that even if not successful, data from this project can be used to address challenges in order to develop a successful approach.

Potential Next Steps

If successful, the next steps are: **(1) Scale up** approach to evaluate suitability for greater complexity (temporal, spatial, management) within the region (western Kenya). This would entail assessment of additional land use types beyond annual cultivation in the Nandi landscape. In doing so, we would **(2) Partner** with additional institutes in western Kenya (GIZ, KALRO, OneAcre Fund) to support their activities on spectroscopy-based diagnostics of soil constraints and providing feedback on management to smallholders.