#7422 MAPPING AFRICAN SOILS AT 30M RESOLUTION – ISDASOIL: LEVERAGING SPATIAL AGRONOMY IN FARM-LEVEL ADVISORY FOR SMALLHOLDERS

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ABSTRACT

Field level soil data has been the foundation of agronomic advisory, but traditional methods involving on-farm sampling are too expensive for a large proportion of African smallholders. Building on the work of the African Soil Information Service (AfSIS), Innovative Solutions for Decision Agriculture (iSDA) and partners have created an agronomic soil database which covers the entire African continent at a spatial resolution of 30 m. At this resolution each soil property prediction map results in over 24 billion pixels.

"iSDAsoil" combines remote sensing data and other geospatial information with point samples subjected to spectral analysis and traditional wet chemistry reference analysis – and is freely available via a user-friendly web interface, with full data available under an open license (CC-BY 4.0) and developer API at: https://www.isda-africa.com/isdasoil/

Our digital maps cover 17 agronomically important soil properties at two depths and include soil texture, soil pH, macronutrients (soil organic carbon, nitrogen, phosphorous, and potassium, magnesium), micronutrients, CEC, electrical conductivity etc. Each property includes estimates of uncertainty and from these raw properties a fertility capability classification (FCC) has been calculated for each 30m point, enabling users to identify yield limiting constraints in soil properties on a per-field basis.

iSDAsoil is designed to encourage sharing and we hope that the owners of other soil and agronomic data, in industry and academia, will share their datasets to help create ever more accurate maps. The mapping infrastructure has been designed to allow fast updates for regular addition of new data. We view these agronomy data stacks as the starting point, rather than an end-product per se. Our aim is to catalyse opportunities to develop and deliver products and services supporting low-cost agronomic advisory for millions of smallholders across Africa – as well as bring greater efficiency to agribusinesses supporting smallholder value chains.

Together with its partners across Africa and elsewhere, iSDA is building site-specific fertilizer recommendation services, yield prediction and risk-return tools based on iSDAsoil. These are currently being validated through a network of on-farm trials in Ghana. iSDA is also designing end-to-end solutions for commercial aggregators and off-takers in Kenya, Ghana and Rwanda, each based on a different blend of technologies including iSDAsoil. This paper will provide an overview of these and other applications including consortium data-sharing opportunities and plans for a central referencing and calibration service.

INTRODUCTION

Soil has long been appreciated as an important factor in determining crop yields. However, until recently soil information for Africa has only been available at relatively coarse resolutions (Jones et al., 2013). In high income countries, farmers frequently pay for lab-based soil testing to understand their constraints in soil fertility down to the field level and even finer levels of detail. But smallholders in Africa have access to neither the testing infrastructure, nor

the finances to routinely adopt this approach. As a result, it is impossible for most farmers in Africa to consider the current soil nutrient status of their fields when making management decisions, such as the type and quantity of fertiliser to apply.

More recently, continental scale soil sampling initiatives, such as the AfSIS project (funded by the Bill and Melinda Gates Foundation) have allowed for the creation of a pan-African database of soil information (Leenaars et al., 2014). Coupled with high resolution satellite information, predictive soil mapping (PSM) has now become possible; this uses machine learning algorithms to predict soil properties on a consistent spatial scale (Malone at al., 2017). Hengl et al. (2015, 2017) and Vagen et al. (2016) pioneered this approach for Africa, initially at a resolution of 250m. These maps proved useful for strategy formulation and policy-making, but the resolution is too coarse for interface with farm-level advisory.

iSDAsoil, at 30m resolution, bridges the gap to farm-level information. It is available through Open and FAIR data access principles in order to empower researchers, businesses, governments and others to make data-informed decisions for improving the productivity of African agriculture, ranging from the field to the country level.

The data platform is designed to encourage sharing and we hope that the owners of other soil and agronomic data, in industry and academia, will share their datasets to help create ever more accurate maps. With this in mind, the mapping infrastructure was designed to allow fast updates for regular addition of new data. As well as being able to explore the data visually at the iSDAsoil website, the data can be queried via a free API, and downloaded in bulk via Zenodo.

We hope to create a virtuous cycle, whereby contributors of point data will benefit from increasingly accurate maps as more data is added. While additional soil sampling will always be required, it is hoped that users of iSDAsoil will be able to focus on incorporating the data into their applications and products.

MATERIALS AND METHODS

iSDAsoil is a collection of spatial predictions of soil nutrients and properties, based on the predictive soil mapping (PSM) techniques described in Hengl and Macmillan. The first step in this process was to standardise all the input soil data as follows:

- Ensuring all measured units were in the same format
- Harmonizing properties measured using different techniques
- Removing any erroneous datapoints

An extensive selection of covariates was then used to predict soil properties across Africa. We apply a multiscale ensemble machine learning approach that combines input covariates at two different geospatial resolutions:

- Coarse scale: 250m (includes climatic and vegetation variables based on MODIS satellite products and similar)
- Fine scale: 30m (includes digital terrain model (DTM) derivatives, as well as Sentinel-2 satellite and Landsat-7/8 cloud-free composite images)

We then applied five regression modelling algorithms:

- Random forest as implemented in the Ranger package
- Gradient boosting as implemented in the XGBoost package
- Cubist regression models as implemented in the Cubist package
- Neural network algorithms as implemented in the deepnet package

- GLM with Lasso or Elasticnet Regularization as implemented in the glmnet package

All programming was implemented using R software for statistical computing and open-source packages and applications for spatial analysis. For each property, we ran model fine tuning, feature selection (to reduce the number of covariates) and ensemble machine learning, using the SuperLearner algorithm as implemented in the mlr package. Predictions at the coarse (250m) and fine (30m) resolutions were generated independently, then merged using ensembling. We first predict values at three depths: 0, 20cm and 50cm, then aggregate values to standard depth intervals (0–20cm and 20–50cm). In principle, all steps, except the soil data import and feature selection, are fully automated. Computing was implemented in a high-performance system with tasks fully parallelized using the R snowfall package. As training points, we have used a compilation of legacy soil profiles and point data from various datasets. The total number of training points used depends on the soil property, but is generally higher than 100,000. Please see our website for further details at: https://www.isda-africa.com/isdasoil/technical-information/

RESULTS AND DISCUSSION

iSDA's unique focus is combining new low-cost technologies, rigorous on-farm science and viable last mile delivery business models. We are initially focusing on advisory for maize, rice, potato and coffee but will expand to cover all major crops of importance to smallholders in Africa. iSDA is currently carrying out a series of on-farm trials to verify the use of iSDAsoil as a "virtual soil test" for fertiliser recommendations. This purely digital solution offers the possibility of a radically lower cost alternative to physical soil tests, while providing a substantial improvement on currently available national (blanket) fertilizer recommendations by virtue of providing recommendations tailored to individual farms. This could potentially allow a route to low-cost yet customised agronomic advisory for millions of smallholders who could not afford a service based on a traditional soil test. If this provides a reliable foundation, we will then augment this with historical agronomic and economic data in combination to generate probabilistic, risk-based return-on-investment advisory.

Agronomic advisory for paddy rice, particularly fertilizer recommendation, is extremely challenging as flooding substantially alters soil chemistry and traditional soil tests tend to give inconsistent results in diagnosing nutrient deficiencies. iSDA is therefore investigating whether iSDAsoil can help determine optimum stratification of nutrient omission trials in order to provide fertilizer recommendations at the community level. This would then be implemented as a public-private-partnership with government extension services and commercial aggregators.

The maps in iSDAsoil include prediction uncertainty for all data points. These can be useful in identifying areas where soil property predictions are of lower accuracy, and thus care should be taken in terms of associated conclusions. These areas should also be primary targets for additional soil sampling campaigns. We are also better able to understand what covariates are important for predicting specific soil properties.

Soil infrared spectroscopy is the most promising technology that has emerged over the past 20 years for measuring soil health at low cost. However, this potential is constrained by the lack of regional spectral calibration libraries, and the limited capacity and large inter-lab variability of conventional soil testing labs in Africa needed to develop the calibrations. To overcome this, iSDA has joined an initiative to provide a centralised soil reference laboratory service, and a centralised high quality service for developing spectral calibrations. The initiative has been housed under the Global Soil Partnership (GSP) and implemented through

the *Global Soil Laboratory Network*, hosted by FAO, as well as linked to the GSP's Global Soil Information System (GLOSIS).

There are many other possible uses for iSDAsoil, such as in the fight against climate change. Carbon budgeting has recently become an important topic as governments and companies attempt to offset their carbon emissions. An important aspect of carbon budgets is being able to estimate the amount of carbon stored in the soil. iSDAsoil provides estimates of both organic and total carbon.

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