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Climate Smart Agriculture and Soil Fertility Mapping: Nigeria Soil Information Service (NiSIS) Pilot Project

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Citation: Aduramigba-Modupe V.O and Amapu I. (2023) Climate Smart Agriculture and Soil Fertility Mapping: Nigeria Soil Information Service (NiSIS) Pilot Project. FARA Research Report *Vol 7(54):671-676*. https://doi.org/10.59101/frr072354

Abstract

Inherently low soil fertility constitutes threats to agricultural productivity and ecosystem in Nigeria, with the changing climatic conditions disrupting current land use systems; with sustainability depending on interactions between climate, land management and policies that enable or undermine them. The rapidly growing population (projected to ~262.6 M by 2030) will require substantial increases in either productivity per unit cultivated land area and/or expansion to meet food demands. There is an urgent need for accurate, and spatially geo-referenced soil fertility mapping using recent techniques to support agricultural development. The NiSIS pilot project assessment aims to provide spatially explicit measurements and predictions of nutrient levels, for main crops grown in the cropland areas of Ebonyi and Kebbi states, Nigeria. The main geographical region of interest (ROI) for this assessment (1590 sampling locations) were identified based on the geo-survey (https://geosurvey.qed.ai) of Nigeria. Using the AfSIS field protocol, geographically matched (using R-script and grid layers) composite topsoil (0-20cm) and subsoil (20-50cm) were collected in circular 100m^2 plots. All the field observations were recorded in Open Data Kit forms, using preprinted QR code labels for uniquely identifying individual soil samples; and samples were analyzed with mid-infrared (MIR) spectroscopy. The assessment provided a key reference point for evaluating changes and impact on the current distribution of essential macronutrients and micronutrients in soils; and established a statistical baseline for comparing yields before-and-after nutrient interventions in a control-impact-pairing framework. The approach can be readily expanded to include climate-smart agricultural validation trials, thereby enhancing interpretation of largely disconnected case studies.

Introduction

Inherently low soil fertility, nutrient imbalances and potentially accelerating soil physical, chemical and biological degradation, are thought to constitute threats to maintaining agricultural productivity and other ecosystem services in Nigeria (Aduramigba-Modupe *et al.*, 2003; Aduramigba-Modupe and Olanipekun, 2017; Aduramigba-Modupe, 2017; Denton et al., 2021). The rapidly growing population in Nigeria (projected to ~262.6 M by 2030) will require substantial increases in either productivity per unit cultivated land area and/or expansion to meet food demands (FAO, 2018).

Presently, the geographical extent of existing soil problems in croplands, their location specific trends and opportunities for managing them over time are highly uncertain. Key information gaps including, cropland area and proportion of arable land that is being used for cultivation have not been identified with sufficient accuracy to allow spatial targeting of appropriate management practices (Aduramigba-Modupe, 2017; Kone et al., 2017).

The assessment of spatial variability is an important approach to understanding the distributions of soil properties at field scale, since soil properties vary spatially from a field to a larger regional scale and is affected by both intrinsic and extrinsic factors (Aduramigba-Modupe *et al.*, 2003; Denton *et al.*, 2021).

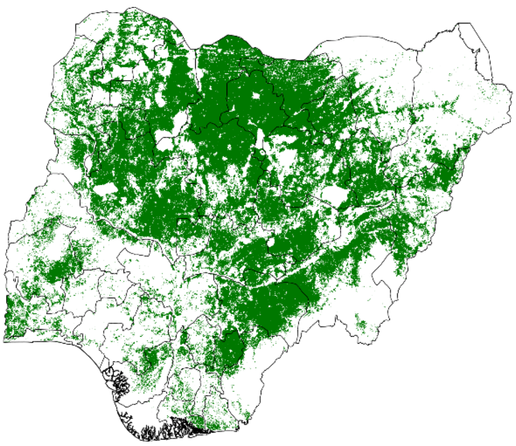
The Africa Soil Information Service (AfSIS: http://www.africasoils.net) has developed freely accessible, open source soil information that are applicable to mapping and monitoring soil resources at any spatial scale and at any given location in sub Saharan Africa. The assessment of soil mapping through spatial variability is an important approach to understanding the extrinsic factor of soil management practices and fertilizer usage which is important for developing specialty fertilizer for site and crop specific balanced fertilization management which helps in saving cost as only specific nutrients needed in the field are added (Aduramigba-Modupe *et al.,* 2003; Aduramigba-Modupe, 2017; Ciceri and Allanore, 2019).

The NiSIS project assessment seeks to provide spatially explicit observations, measurements and predictions of nutrient levels and cycling indicators controlling soil-plant nutrient transfers and also provide spatially yield predictions and nutrient management recommendations for main crops grown under varying environmental conditions and management practices in the cropland areas of Ebonyi and Kebbi states, Nigeria. The project also aimed to develop soil information that will serve as guide for specialty fertilizers formulations for land areas under cultivation for crop production and generation of digital soil maps.

Materials & Methods

Region of interest

The main geographical region of interest (ROI) for this assessment was identified from the Nigeria-wide sampling frame of 14,087 cropland and soil sample locations distributed throughout the country (Figures 1 and 2).



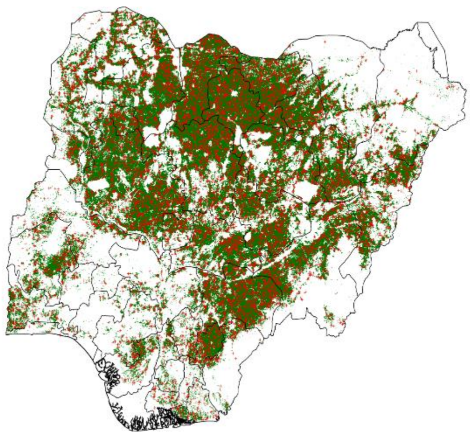


Figure 1: Cropland mask of Nigeria, 2017   Figure 2: Nigeria cropland sampling frame

Sampling plan

The spatially balanced sampling approach developed by AfSIS (Leenaars *et al.*, 2015) was used for the NiSIS project in Kebbi and Ebonyi states. The ROI (1590 locations) were identified based on the geosurvey (https://geosurvey.qed.ai) of Nigeria. Following the AfSIS standard operating procedures and field protocol, geographically matched (using R-script and grid layers for balanced randomization composite topsoil (0-20 cm) and subsoil (20-50cm) samples were collected in a circular 100 m^2 plots. All the field observations were recorded in Open Data Kit (ODK) forms, on tablets with GPS and using preprinted QR code labels for uniquely identifying individual soil samples (http://tag.qed.ai). All the samples were analyzed using the Bruker-Alpha mid-infrared (MIR) and portable X-ray fluorescence (pXRF) spectroscopy at ICRAF laboratory in Nairobi, Kenya. A 15% reference subset of all samples were analyzed for essential macronutrients (S, P, Mg, Ca, K), micronutrients (Mn, Cu, Zn, Mo, B) and beneficial nutrients (Si, Na, Co, Ni, Se, Al) contents using inductively coupled plasma mass spectroscopy (ICP-MS). C, N and S were measured by dry combustion mass spectroscopy. The reference measurements were used for calibrating machine-learning and geostatistical models for predicting nutrient contents.

Brief Results and Discussion

The transformation of Africa agriculture is key to ensuring food security, ending hunger and increasing farmers' productivity; through the knowledge of spatial analysis and precise mapping of soil properties.

Tables 1 and 2 presents the macro and micro nutrients data summary of Kebbi and Ebonyi states, Nigeria, using the Bruker-Alpha spectral models which predict nutrient contents as well as pH, EC, SOC and total N of all the soil samples. The macro and micro nutrient values were higher in Ebonyi than Kebbi; generally they were however low in the two states and can induce hidden hunger which might lead to an important form of human malnutrition resulting in serious health concerns and economic burden of Nigeria as found in most developing countries (Welch et al., 2013; Godecke et al., 2018). Our data supported the assertions of Joy *et al.*, (2015); Kone *et al.*, (2017); Aduramigba-Modupe (2017) and Ciceri and Allanore (2019) that macro and micro nutrients fertilization through an integrated mineral nutrient management offers more benefits for agronomic fertilizer strategy. Although the most likely cases of specific nutrient deficiencies are found among samples from Kebbi, falling into the low reference range (Tables 1 and 2); there is no evidence to suggest that these values represent critical deficiency limits to crop production or responsiveness to specific fertilizer amendments in the 2 states. The results of the topsoil (0-20 cm) from Tables 1 and 2 are relevant for determining fertilizer formulations incorporating the major macronutrients (N, P, K, Ca, Mg) and selected micronutrients (Zn and Mn).

While our data is a largely exploratory method, it does provide potentially useful summaries for location-specific soil information systems and fertility mapping, soil nutrient constraints and climate-smart agricultural validation trials, based on the MIR predictions. Other main benefits would be that additional data about crop yields, good agronomic practices, environmental and socio-economic circumstances could be readily collected for monitoring and evaluation purposes. Such a framework might be linked to systematic agronomy trial networks that provide evidence for (or against) specific management recommendations.

Recommendations

The assessment provided a key reference point for evaluating current distribution of essential macronutrients and micronutrients in soils; their main benefit would be that additional data about crop yields and agronomic practices could be readily collected for monitoring and evaluation purposes. Such a framework might also be linked to systematic agronomy trial networks that provide evidence for (or against) specific management recommendations. The approach can be readily expanded to include climate-smart agricultural validation trials, thereby enhancing interpretation of largely disconnected case studies.

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Table 1: Macronutrients composition in the soil (0-20cm) from Kebbi and Ebonyi states, Nigeria

State		pH	EC	TC	TN	Olsen P	P	Ca	Mg	K	PBI
Kebbi (n=536)	Min	4.79	20.19	0.09	0.01	0.19	0.52	61	12	14	10.38
	Max	8.25	227.12	2.07	0.19	31.16	188.47	4714	1306	406	307.69
	Mean	5.98	61.82	0.51	0.04	1.16	5.69	510	101	47	33.69
	SD	0.42	29.87	0.32	0.03	1.53	9.24	537	116	39	27.65
Ebonyi (n=208)	Min	4.75	21.76	0.29	0.02	0.20	0.73	72	12	11	12.06
	Max	8.14	220.08	3.29	0.23	18.59	68.90	4169	722	271	231.19
	Mean	5.76	54.51	1.06	0.08	2.38	7.97	511	143	63	55.27
	SD	0.45	25.93	0.59	0.04	2.46	8.18	432	90	47	32.71

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Table 2: Micronutrients composition in the soil (0-20cm) from Kebbi and Ebonyi states, Nigeria

State		**Co**	**Cr**	**Cu**	**Ni**	**Pb**	**Si**	**Ti**	**Zn**	**Fe**	**Mn**	**Al**
Kebbi (n=536)	Min	0.05	0.03	0.14	0.09	0.25	1.14	0.11	0.06	37	8	165
	Max	5.88	0.31	4.11	3.07	3.05	56.44	1.18	5.17	554	252	1029
	Mean	1.00	0.12	0.76	0.41	1.26	3.52	0.49	0.84	101	53	477
	SD	0.82	0.04	0.66	0.38	0.43	3.31	0.11	0.78	52	33	154
Ebonyi (n=208)	Min	0.10	0.04	0.20	0.10	0.94	1.14	0.07	0.21	60	7	284
	Max	8.80	0.26	4.01	2.14	6.78	30.23	2.25	29.96	405	494	1322
	Mean	2.17	0.10	0.78	0.63	2.74	5.16	0.36	2.15	153	134	603
	SD	1.56	0.03	0.45	0.34	1.01	2.90	0.22	3.34	58	89	202

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