D2.1: A set of use cases plus supporting soil quality indicators

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1. Abstract

Agricultural production in Africa is not meeting up with the growing demand for agricultural produce; the current production system is largely unsustainable as it tends towards an overexploitation of the natural resources and in particular the soil. The increase in production is mainly achieved by expansion of agricultural land and the shortening of traditional fallow period; implying extensification in time and space. The limits of this approach have been reached and passed leading to widespread degradation of soil qualities and the associated soil function. To continue meeting the growing demand for agricultural produce, it is widely recognised that agriculture needs to be intensified in a more sustainable way. Such approach will need to yield more from less land and the use of external inputs. This double goal of increasing both productivity and soil quality on agricultural land (Sustainable Intensification of agriculture in Africa) corresponds with SDG 2.4 and forms the context of the current project Soils4Africa. The scope of the project is to collect soil data and develop a Soil Information System for Africa (SIS); this system will inform decision making and other activities towards sustainable agricultural intensification in Africa and facilitate future monitoring and evaluation and it will enhance the performance of other land uses.

The opinion of African stakeholders on the nature and structure of a suitable SIS was captured in this report following a short study as well as three broad use case categories, seventeen use case topics and five use case examples representing these opinions. The stakeholders were drawn from expert listing of various agriculturally based research groups in Africa (FARA D-Group platform); Africa partners in the EC based scope A projects and Africa Chapter of the Global Soil Alliance. Their opinion was captured using a semi-structured questionnaire, administered through emails to these purposive sample of stakeholders using a Google Docs link. The questionnaire was completed by 184 respondents. This was followed by the identification of key informants with broad knowledge, and or playing leadership role in well-known initiatives or statutory functions, that match the use case categories and correspond to the needs for Soil information expressed by the stakeholders. The selected informants interviews were developed into use case examples. The following inferences were drawn from the survey and interviews. A veritable SIS for Africa, with relevance for Sustainable Intensification, should:

- host or provide access to harmonised data on soil physical, chemical and biological properties;
- cover both the topsoil and deeper layers;
- cover the entire agricultural land at detailed scale;
- include information on the sampling and analysis methods used to derive the measures without ambiguity;
- be accessible online and downloadable in a basic format and useable for further analyses;
- provide baseline information on site-specific soil qualities and soil quality indicators that are relevant for future monitoring of the impact of Sustainable Intensification interventions;
- provide interpretations and explanations of the data that are understandable and useable by none soil scientists;
- use state of the art GIS and ICT methods to generate up-to-date and location specific measures that are validated at intervals;
- contain maps with sufficient high resolution and accuracy to enhance usability; and
- be interoperable with existing (soil) information systems to ensure broad based use in Africa.

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2. Executive Summary

The need for a veritable Soil Information System (SIS) for Africa is considered important by stakeholders in agricultural research, development, land management and natural resources management (Bhattacharyya et al., 2010). The SIS is intended to provide support to the implementation and evaluation of interventions on Sustainable Intensification of agriculture in Africa. The unavailability of a well systemised SIS at continental level and the evolving needs of stakeholders calls for the need to develop a unique SIS. Such SIS needs to contribute to learning and sustainable use of soil as a treasured resource for sustaining life on earth, and in particular for informing and evaluating the impact of interventions aiming at Sustainable Intensification of agriculture in Africa.

The Soils4Africa project was developed with the aim of developing a SIS for Africa within the context of sustainable intensification of agriculture in Africa. It is envisaged that such a system will have the required characteristics to meet the need of broad stakeholder groups in African agriculture as well as in land resource management and environmental studies. A useful SIS for Africa will need to be jointly developed with input from a broad group of stakeholders in order to meet their specific needs and secure the sense of ownership as well as to evaluate the impact of agricultural practices and interventions on soil qualities. Work package 2 of the Soils4Africa project aims to facilitate the engagement processes of the broad stakeholders and ensure their needs are the basis for the development of the SIS as well as its relevance and sustainable use. This report documents the key use case categories, topics and examples, from the interactions of the Soils4Africa team with relevant stakeholders engaged.

The methodology used for this engagement includes the administration of an online questionnaire. The questionnaire link was sent via email to more than 565 preselected stakeholders that are involved in agricultural research, soil science, extension services, academics, fertilizer manufacturers and policy makers. The stakeholders were drawn from expert listing of various agriculturally based research groups in Africa (FARA D-Group platform); African partners in the EC based scope A projects; Africa Chapter of the Global Soil Alliance and list of technocrats in African agriculture. Their opinion was captured using a semi-structured questionnaire, administered through emails to these purposive sample of stakeholders using a Google Docs link. The questionnaire contained 20 questions on key issues that would inform the design and content of the SIS (see Appendix 1). The questionnaire was completed by 184 respondents. This was followed by the identification of key informants with broad knowledge, and or a leadership role in well-known initiatives or statutory functions, that match the broad use categories and a number of use topics and correspond to the needs for Soil information expressed by the stakeholders.

Most of the respondents were from the knowledge generation sector, viz., researchers, academics and also policy analysts serving the governance sector. Other respondents included the end users of knowledge such as farmers, fertilizer manufacturers and blenders etc. Many of the respondents (96.2%) are involved in the production and use of soil data in their direct vocation. The application of data and information was further defined into use topics based on individual average use: 1) 60% of the soil information is utilised for Integrated Soil Fertility Management (ISFM) as well as agronomic decisions for productivity and sustainability of the agricultural systems in Africa; 2) while 40% was associated with data for climate change mitigation, as well as soil quality monitoring and natural resource management; and 3) other uses of soil information include land evaluation, land use planning, environmental management, extension services, policy analysis and decisions; these use topics were all below the aggregated 40% of the needs. Three broad

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categories of soil information use were implied from this survey and include: (1) governance, (2) knowledge generation including technology development and transfer, (3) operational use, e. g. farming, and are further referred to as the use cases or use case categories.

Stakeholders' responses to series of questions indicated that soil data should include analyses of the soil physical, chemical and biological properties from samples that should be collected from soil profiles including the upper horizons (topsoil) and deeper horizons (mid and subsoil). The stakeholders indicated that part of the limitation to utilising data from available SIS' includes the clarity on data collection and analysis methods. This is largely missing or not presented in a coherent manner on some of the soil database, which often made the interpretation of results from such databases difficult and not relevant to the broad stakeholders group. The mapping of soil variables needs to have a scale of about 1:250,000 for ease of interpretation and especially relevance for use. Most of the stakeholders (53%) preferred digital presentation of the soil data using IT based facilities. Presentation of numerals is imperative for further analysis and use of the data and to tease out inferences. Presentation of data in graphical form also needs to be provided to ensure broad based use of the database by none-soil scientists. It is vital to include an analytics function in the system to facilitate an extended utility and relevance to the need of the broad stakeholders.

The prime data needs of the stakeholders revolve around the basic soil physical, chemical and biological properties such as texture, Soil hydrogen ion concentration (Soil pH), Electrical Conductivity (EC), Cation Exchange Capacity (CEC), Base Saturation (BS), Exchangeable Bases, Soil Organic Carbon (SOC), Nitrogen (N), Phosphorus (P), Potassium (K), as well as micronutrients and heavy metals. This is due to the possibility of interpreting and using these soil data for multiple purposes including the possibility to derive (possibly composite) variables such as soil qualities or soil quality indicators. The indicators should be sufficiently stable in time to permit reliable baseline assessments and sufficiently dynamic to permit detection of change over time.

Five use case examples illustrating the three broad use case categories were derived from key informant interviews following the stakeholders survey. The key informants were selected from the identified user groups of soil information as well as known initiatives that are examples of use of soil information. The use case examples include: (1). soil information use in integrated landscape management; (2). soil data use for a sustainable intensification program in African farming systems; (3). soil data use in agricultural extension and advisory services; (4). use of soil information in public land resource conservation and; (5). use of soil information by fertilizer producers and suppliers. These use case examples represent interventions on the ground; such interventions provide information for the development of relevant soil quality indicators, which determine the soil parameters to be included in the SIS. The examples showed the prospective interaction between the user of the SIS and the "System" itself. They pointed out the basic requirements that will enhance the utility of the system in terms of the required content (soil parameters including soil quality measures) and the format needed. They also indicate the boundary issues (software, hardware etc.) and the influence of such on the functionality of the system.

The use case examples pointed at the need to have an exhaustive listing of soil physical, chemical and biological properties in the SIS; it also indicated the need to have a good listing of soil quality indicators (of a possibly composite nature). The unit of measurement of these parameters should be the most conventional ones and should be presented in an easy-to-understand format. In the case of the soil quality indicators, the methods of calculation need to be explained without ambiguity. In the same manner, the laboratory methods used for analysis of basic soil physical, chemical and biological properties need to be clearly stated. Most striking feedback was the wish to

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provide relevant and easy to understand interpretations of the soil data to make the data relevant and useable for not-soil scientists.

The SIS needs to have an analytic component that could generate measures over time and space based on available data. The functionality of the system will be enhanced when the data are interoperability, facilitating linkages with existing and upcoming (soil) data systems. The use case examples also indicate the need to have maps with sufficient resolution to meet user needs. Generally, data and maps should be downloadable to give room for further analysis by the end users. There should also be the possibility for the user of the system to provide feedback after every use in order to accumulate data for key improvement as well as tracking user's satisfaction.

3. Background

3.1 Imperative for a Soil Information System for Africa

The need for information on the nature and status of soil is vital to the management of the ecosystem functions from one location to another on the globe. This stems from the importance of soil as the source and sink of many essential activities that contribute to the balance of functions in the rhizosphere, atmosphere and for sustaining life. The known scientific linkages among the various elements of nature and the apparent cause and effect relationship necessitates the need for measurements and mapping to monitor the changes in order to provide precise information to the agencies that are responsible for managing the natural resources for policy development as well as complementary process and action for the industry and community to effectively manage the natural resources to sustain life on earth.

The soil data and information need to be collected and stored in a database for monitoring the temporal and spatial variation in the status of soil and the landscape. Such a database will provide metrics that could improve the understanding of the dynamics of various biophysical processes, as well as information to develop intervention to ensure sustainable use of the soil.
A number of systems have been developed for monitoring ecosystem functioning including the soil with its soil qualities in various locations in the world (Tallis et al., 2012), however, no system is completely dedicated to monitoring the soil across Africa. Considering the increase in demand for agricultural products in Africa, combined with only a small increase in production resulting from land expansion and a decline in the productive quality of the soil resource, new agricultural practices need to be introduced (such as sustainable intensification) to keep production up with demand while sustaining the quality of the soil resource and other production assets(Pretty and Bharucha, 1997) It is therefore vital to support the future monitoring of African soil quality through a functional soil information system that is reliable, and can provide both technical and systemic information on the status of the soil.

Africa is largely an agrarian continent where more than 60% of the population is engaged in agricultural activities (FAO, 2016), largely with rudimentary tools and low inputs. Recent advances in the agricultural sector indicated a growth that is gravitating towards promoting the use of more efficient tools and more inputs (intensification) which implies a more business-oriented way of farming which is not necessarily environmentally sustainable in the long term (Struik and Kuyper, 2016). The possible implication of this business-oriented intensification on the sustainability of the natural resource base, and especially the soil functioning, will depend on the development and use of appropriate soil management techniques. The appropriateness of these new techniques needs to be evaluated; this requires the monitoring of the impact on productivity as well as the integrity of the soil ecosystem. For instance, one of the techniques to intensify agriculture in Africa is the use

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of more fertilizers or the use of the Integrated Soil Fertility Management (ISFM). This is because the African soil has erstwhile been described as generally low in fertility, with low cation exchange capacity, due to its prolonged soil formation (leaching) without significant soil rejuvenation combined with widespread agricultural practices that imply soil nutrient mining without restoring the nutrient stocks through sufficiently long fallow periods and/or fertilization. In the same way, the soil organic matter content in most areas is rather limited, indicating low fertility and physical fragility of the soils. There is the need to reflect and evaluate the appropriateness of soil fertility management and tillage techniques in order to devise appropriate strategies; including the use of organic and/or inorganic fertilizers and the use of (heavy) machinery. Such evaluation should be relative to the appropriateness of the traditional farming systems, where, organic materials are translocated from one location to another causing a reduction in soil organic carbon stock and the associated effects on soil qualities and crop productivity.

Recent estimates of land degradation rate, including soil fertility decline in Africa indicated that 65% of the arable land suffers severe degradation, implying a loss of a billion euros per year in the cost needed to restore the land to its arable status (Le, Nkonya, and Mirzabaev 2014). It is imperative therefore to positively consider the development of a veritable soil information system that will support informed investment- and policy-making in Africa. Such a system should be populated by harmoniously collected soil data at appropriate scale (Size and geographical spread). This effort should also be integrated into, or build upon, existing soil data or systems, such as those from national partner organization, Global Soil Partnership (GSP), Africa Soil Information Service [AfSIS] and ISRIC. A useful soil information system will need to be jointly developed with the end user to ensure relevance.

3.2 Brief on Soils4Africa Project

The Soils4Africa project aims to provide an open-access Soil Information System (SIS) with a set of key indicators of Soil Quality and underpinning data, accompanied with a sound methodology for repeated soil monitoring across the African continent. The soil information system will become part of the knowledge and information system of the FNSSA and will be hosted by an African organization with the requisite capacity to manage the system. Activities of the project include:

i. define use cases and indicators in consultation with stakeholders;
ii. make a functional design of the soil information system;
iii. develop detailed procedures and tools for the field activities based on the LUCAS methodology and collect 20,000 soil samples;
iv. develop detailed procedures for laboratory work and analyze the collected soil samples at one reference laboratory located in Africa; and
v. develop the technical infrastructure for the soil information system and serve the results as open data linked with open EO data.

More detailed information is available on the project web page www.soils4africa-h2020.com.

The soils4Africa project is made up of seven interlinked work packages, while work package one (WP1) deals with project coordination, Work package two (WP2) aims to structure out an effective engagement of the stakeholders for the development and delivery of a usable SIS for Africa. To achieve this aim, WP2 will seek out the needed stakeholder group and develop the needed engagement process. It will facilitate the stakeholder’s interaction to identify the central and specific needs for a SIS in order to define the structure of the upcoming system. The prospective approach is to gather and analyse information that will lead to the identification of use cases and prospective indicators of soil quality. These will further be broken down to determine the specific variables to be measured and included in the SIS.

3.3 What is a Use Case?

The term Use Case is applied in software and database development to identify the functional requirements of a specific application (in this case a Soil Information System) which describes the demand/requirements by identified future users of the system (actors). This is an important

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development step in database and information system development. Deliverable 2.1 provides an overview of the methodology applied in the Soils4Africa project to identify key users and associated use cases to support the design and implementation of the Soil Information System. The actors defined in the Soils4Africa project were stakeholders who will potentially apply soil data derived from the SIS to support decision making. This may occur at the local, catchment, regional or national level, for example by farmers/advisors, scientists/researchers, planners, local and national government. The actors were surveyed with a questionnaire to determine the uses of the SIS and associated data requirements. In addition, actors were also asked to identify key soil quality issues for consideration, particularly of relevance when considering Sustainable Intensification of agricultural systems. The outcome of the questionnaire was used to identify user categories for the types of information required and also a list of key issues to help in identifying the relevant data needed. Finally, a number of use case examples were developed to give an example of how the data could be utilized. The use case examples will support the design phase of the SIS within this project.

3.4 Sampling method

In defining the use cases, a questionnaire with a set of 20 questions were administered to a broad group of stakeholders in African agriculture, using a purposive sampling method (Ames et al., 2019). The questionnaire link was sent via email to more than 565 preselected stakeholders that are involved in agricultural research, soil science, extension services, academics, fertilizer manufacturers and policy makers. The broad group of respondents represented actors in African agricultural research and development, private sector practitioners viz., farmers and agro-industries, fertilizer manufacturers, policy makers in agriculture, and farmers. The core group of stakeholders were identified from the African Chapter of the Global Soil Partnership (AfGSP) and many were also engaged as partners in the four Horizon 2020 projects on Scope A of Sustainable Intensification of agriculture.

184 responses were received and subjected to summary statistics. The analysis of the stakeholders' responses from the questionnaire was followed by key informant interviews. The key informants were selected from the stakeholder list which represented examples of the specific categories of users of soil information, as well as initiatives that are using soil information. The discussion point in the interview was structured to generate information that will contribute to the development of use case examples for the SIS (Annex 2)

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4. Stakeholders Opinion on Soil Information System

The information presented in this segment is drawn from the survey of stakeholders conducted between 5th to 20th November 2020 using Google forms disseminated to respondents by email. The responses collation was automated and is available in an excel format. The respondent was adequately informed on the purpose of the survey and the use of the data. No personal information was requested and the data will only be presented in summary form.

Respondents were informed on what the data would be used for in a disclaimer statement at the start of the questionnaire.

4.1 Respondent Categorization

The spread of the respondents is shown in Table 1. About 50% of the respondents are from the research, extension and education sectors. It is followed closely by respondents in the agricultural production sector, which covers 25%. A further 10% of respondents are from the policy sector, largely stakeholders in government ministries and regional organizations. The structure of respondents largely represented the expected proportion of actors in each of the categories. This observation suggests that the larger proportion of individuals with interest in Soil Information Systems (SIS) are the stakeholders within the knowledge generation, dissemination and use sub-sector.

Table 1. Categories of Stakeholders Based on Sub-sector

Response	Value	%
Agricultural production system	42	25
Nature preservation	7	4.2
Water regulation	0	0
Agri-business	5	3.0
Applied research and extension	43	25.6
University and other tertiary institutions	41	24.4
Public sector (Government ministries)	17	10.1
NGO/Consultancy	13	7.7
Total	**168**	**100**

Figure 1 defines the nature of the respondents' work, where 92.4% of the respondents are engaged in knowledge, technology generation and dissemination related activities. The remaining are policy makers and commodity production and marketing. The main African agro-ecological areas associated with respondents were primarily the Humid, sub humid and semi-arid agroecological zones (Figure 2), contributions from other agroecological zones are marginal.

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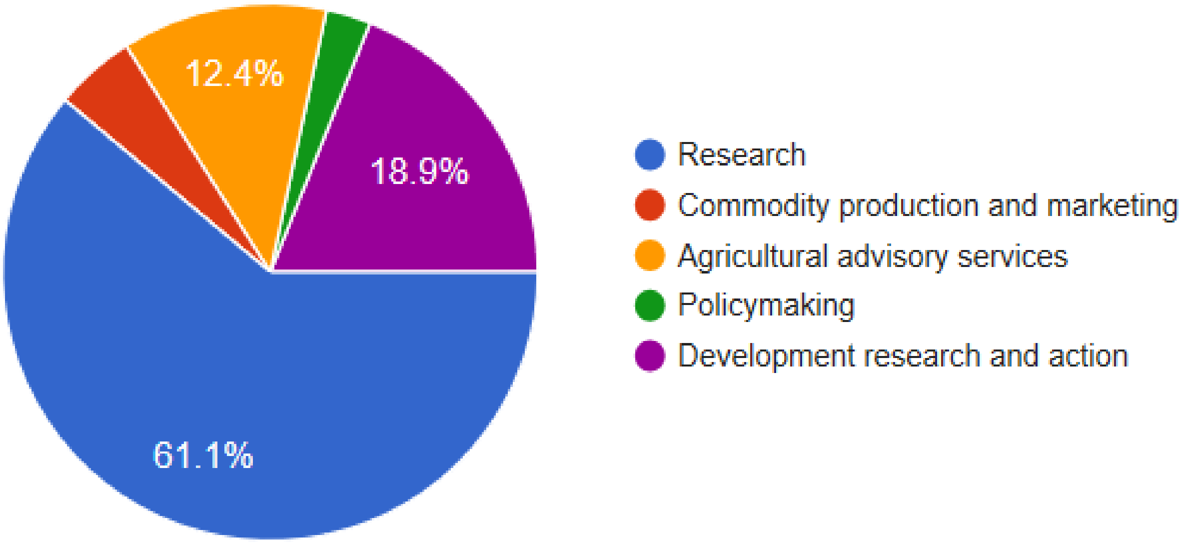

Figure 1: Nature of Respondents Work

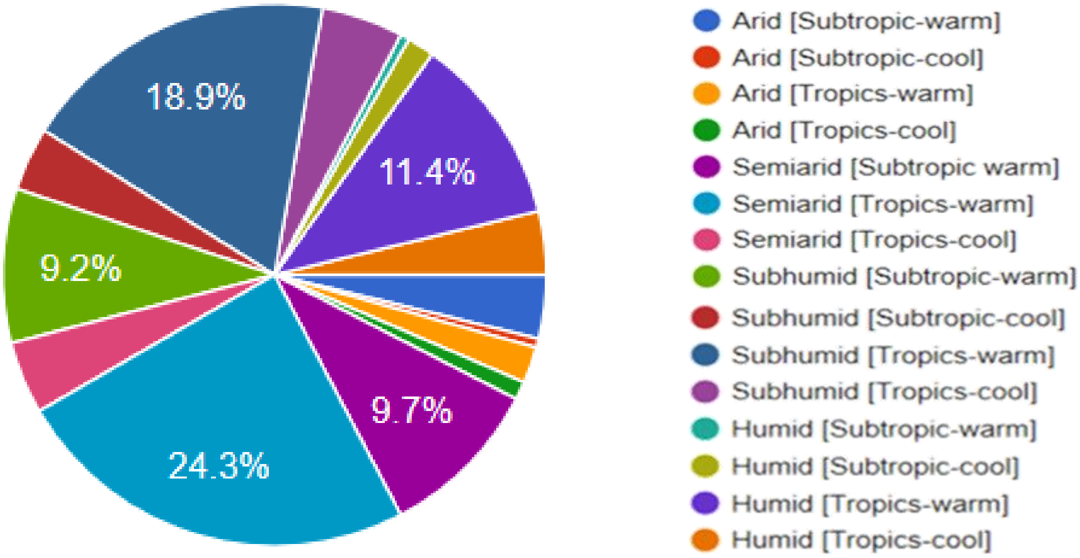

Figure 2: Contribution to Agroecological Zones in Africa

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4.2 Generation and Use of Soil Data

The vast majority (96.2%, Figure 3) of respondents are involved in the production and use of soil data in their vocation. This validates the authenticity of the information derived from this survey on the various characteristics desired of the SIS.

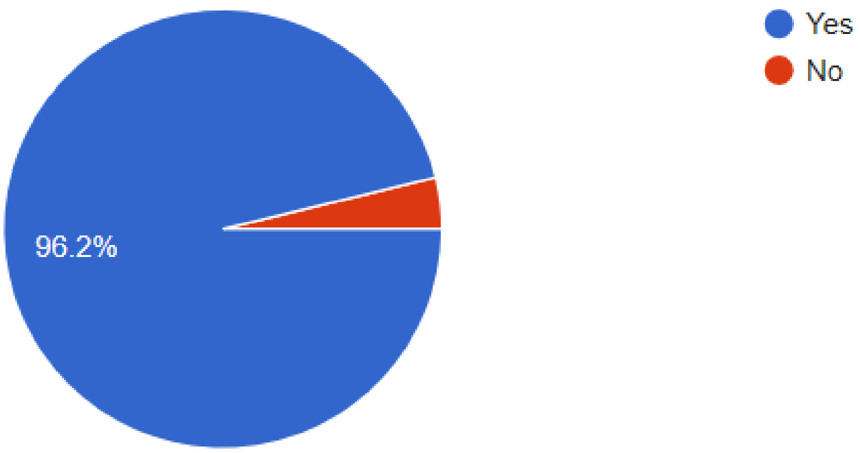

Figure 3: Engagement in the Generation and Use of Soil Data

Understanding the main user requirements of soil information by stakeholders is fundamental to the design of a useful SIS for Africa. Respondents were asked to define for which purpose/activity soil data would be utilised in their work. Figure 4 shows the typical use of soil information by respondents in the survey. The highest percentage of the respondents who could indicate more than one use purpose (resulting in percentages exceeding 100%), Over 60% of respondents require soil information for local-scale decision making including; Integrated soil fertility management as well as agronomic decisions for productivity. While data to inform agronomic decisions for sustainability of the agrarian systems in Africa, was considered by 58%. The application of data resources for research and education were also considered important by stakeholders.

The application of data for the assessment of climate regulation, soil quality, nature and resource (water, air) management and agricultural decision making (which relates to more policy objectives rather than management objectives) was defined by over 40% of the respondents. Interestingly these categories relate to a wider context associated with policy or governmental/regional scale decision making.

The final categories, such as for land evaluation, land use planning, environmental management, extension services, policy analysis and decision were considered by less than 40% of respondents.

The quantum of the kind of uses for soil information from this survey is only indicative as the percentages corresponds to the nature of the respondent work. For the purpose of the Soils4Africa project and the need to develop a relevant SIS for Africa, three broad soil information use categories of are implied from this analysis.

1. GOVERNANCE : This use category includes the use of soil information to enhance policy analysis and advocacy to ultimately develop policies and land use plans and to govern the private and communal use of land at any level e.g., local to national, for e.g., analysis towards climate change adaptation and mitigation including soil properties that inform the need and possibilities for carbon sequestration and climate smart agriculture and also forms a pillar

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under policies towards Sustainable Intensification. Soil information for natural resource management, soil and water conservation and land use planning also falls under this category.

2. KNOWLEDGE GENERATION (Research and development, monitoring and technology development and transfer): This category of soil information use entails the assessment and generation of solution options for agriculture, as well as environmental management issues. It revolves around the development of technologies for improving crop production or decreasing nutrient loss, leaching and pollution issues. It includes soil information for fertilizer manufacturing, including nutrient blending for site specific use, and distribution. It includes packaging of soil information to enhance technology transfer and extension services. It also covers the provision of soil information to foster a change by technology development and transfer and the use of soil information for academic and research purposes. Also information from Soil monitoring activities is vital for creating opportunities for learning and expansion of knowledge base on the nature and properties of soils and more importantly it permits the evaluation of the impact of agricultural strategies and technologies on soil quality.

3. OPERATIONAL USE. Soil fertility management (incl. maintenance) for sustainable and increased crop productivity: This category includes the use of soil information to assess soil fertility, and water, status and define crop production practices that will ensure sustainable productivity and maintenance of the natural resource integrity and can be seen as a key pillar of Sustainable Intensification. This category will also embrace issues of site-specific fertilizer recommendation and soil nutrient management strategy development, as the central use of soil information.

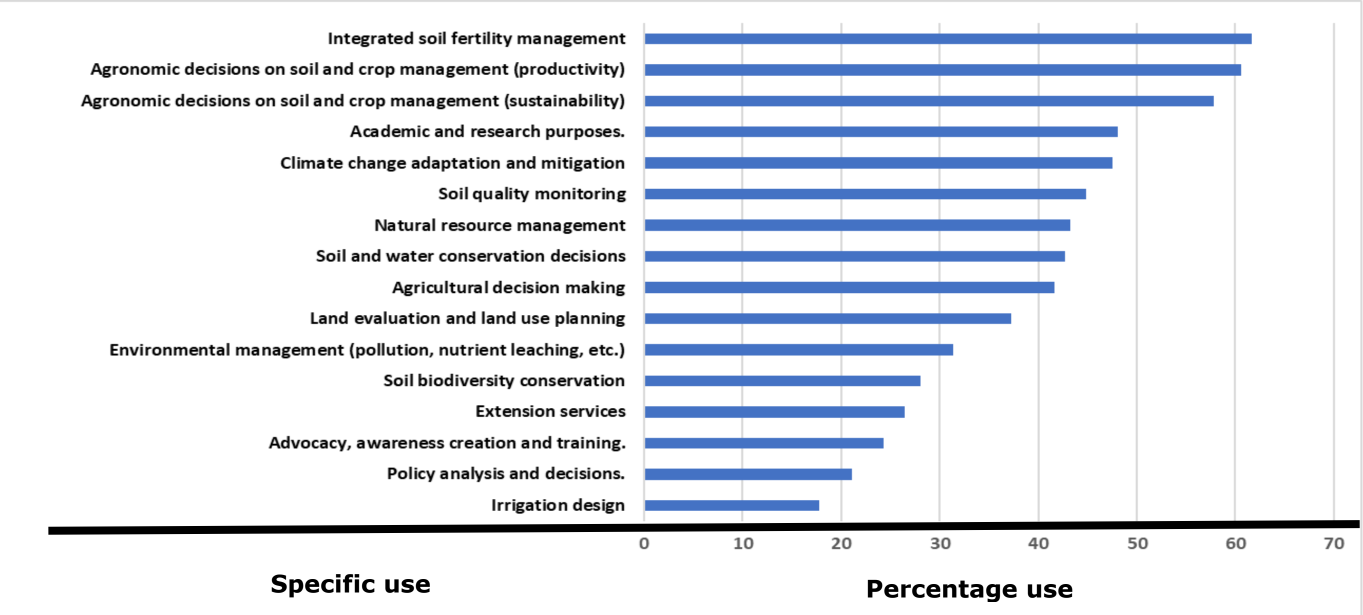

Figure 4: Specific Use Topics of Soil Information by Stakeholders

In order to bring out the fine details for the possible use cases, the three broad use categories are further grouped into:

(1). Governance (Policy and strategy development),

(2). Knowledge generation (Technology development, research and development and Monitoring),

(3). Operational issues (Farming, environmental management, development projects) (Figure 4b)

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Figure 4b: Grouping of Soil Information needs for use case development

4.3 Soil Data Need by Stakeholders

Soil data are presented in various formats; the conventional format are the numerals, map, digital code graphics etc. The information type also varies from the basic soil chemical analysis down to structure forms and general surface scan. Table 2 presents the kind of soil data the stakeholders currently require for their various endeavours.

Table 2. Kind of Soil Data Required by Stakeholders

Soil data type	Proportion of use (%)
a. Soil analytical data (soil samples along soil profiles)	90.9
b. Soil analytical data (soil property maps)	52.4
c. Soil descriptive data (soil horizons & soil profiles)	49.7
d. Soil descriptive data (soil class maps)	41.7
e. Collaborative Inquiry for Collective Intelligence	0.5
f. Indigenous knowledge	0.5
g. Microbial populations and enzymatic activities	0.5

All respondents indicated the use of data from soil analysis, these include analysis of the soil physical, chemical and biological properties collected from soil depth intervals. The data are largely generated from laboratory analysis that followed detailed methodologies. The soil analytical data constitute the basic form of information that is needed to describe Soil Quality. Other forms of soil data are packaged into maps using Digital Soil Mapping techniques including Geographical Information System (GIS) tools as well as other Information Communication Technique (ICT). Soil analysis information that are packaged into composites and presented as maps attracted 52.4% of the use category, while descriptive data of soil horizon and profiles represents 49.7% and the descriptive data packed into soil maps represents 41.7%. Other forms of soil information that are indicated are seldomly used by most stakeholders possibly for being speculative and lacking in empirical evidence. An example is the subjective information from peer discussions or collective

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intelligence. The indigenous knowledge collated over years also falls into this category, the use is low for lack of empirical evidence and linkage with scientific proof even though this type of soil information provides the largest opportunity to communicate effectively with the agricultural practitioners. Data from microbial population and enzymatic analysis is indicated to be used marginally. The low percentage of use may be due to the emerging nature of the soil biology components of the soil body of knowledge (Gurjar et al., 2017). Data relating to soil biology are quite dynamic in nature and can experience rapid changes, nonetheless, soil biological data is growing in importance with the growing attention giving to ecological and organic agriculture as well as carbon sequestration thoughts for climate change mitigation and would be key when assessing soil quality and its sustainability.

A useful SIS will need to give prime attention to the physical, chemical and biological characterization; this will yield the much-needed information by stakeholders to make decisions that drive farm production, productivity, natural resource management, active decision making, fertilizer manufacture and blending businesses. Provision of these information from time to time will be the defining character of a veritable SIS. In developing the Africa SIS, thoughts need to be given to the development of algorithms that can predict not only the location-specific status of the soil, including its properties and qualities, but also the specific status following specific land utilization- e. g. the delivery of predicted soil information to the end-users when location-specific land-utilization data are fitted into the system. It is proposed that such user defined data should also be fitted into a prediction model that can give the plausible scenario of the soil considering the use and management regime.

4.4 Sources of Soil Information

The stakeholder's response on sources of soil data is presented in Table 3. It indicates the availability of a few platforms that are currently providing soil information for Africa. The larger proportion, 68% of the surveyed stakeholders tend to use available data from various National Soil research institutes.

Table 3. Available Sources of Soil Data

	Sources of soil data	Proportion of use (%)
a.	**National soil research institute (reports, maps, databases)**	**68.1**
b.	**International organization open-source databases**	
i.	ISRIC – World Soil Information library (www.isric.org : reports, maps)	**27.0**
ii.	ISRIC – World Soil Information datahub (data.isric.org)	**19.5**
iii.	SoilGrids ; (www.soilgrids.org)	**13.5**
iv.	FAO Data (http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/en/	**50.8**
v.	World Bank (https://datacatalog.worldbank.org/dataset/soil-classifications)	**14.1**
vi.	Europa soil dataset (https://esdac.jrc.ec.europa.eu/ESDB_Archive/Soil_Data/Global.htm)	**5.4**
vii.	Soil geographic dataset (https://www.isric.org/explore/soil-geographic-databases)	**10.3**
c.	**Own collected primary data and maps.**	**51.4**
d.	**Published Literature**	**36.2**
e.	**Other sources (Specify)**	
	Country based documented soil data	
	Farmers background	
	Indigenous knowledge	

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The use of available open-source databases is still limited among stakeholders, a wide range of 5.4% – 51 % of the stakeholders do consult online databases hosted by various international organization. The soil portal of the FAO database has enjoyed the consultation of 50% of the respondent in this survey, it is followed closely by the ISRIC world Soil Information Library and its World Soil information datahub at 27% and 19.5% respectively. The use of other open-source data bases is minimal, but still vital to the provision of information to the end users. Other sources of soil data are the published literatures, country-based data pool and own collected data. The various sources of soil data have its own unique method of sample collection, analysis and data storage; this makes cross comparison of data from different sources more difficult.

A number of constraints were identified by users of soil data as impediments to their utility. Table 4 provided a listing of these constraints and the stakeholders wish-list for a desired soil database.

Table 4. Required Improvement on Existing Database

	Desired Database Features	Percentage
1.	Specify data lineage	19.3
2.	Indicate complete metadata	47.6
3.	Data license should be made explicit.	28.9
4.	Include more parameters	50.8
5.	Include deeper depth intervals (topsoil, mid soil, subsoil)	41.2
6.	Enhance data visualization	38.0
7.	Provide data with (modern) unit of measurement.	36.9
8.	Provide data with specification of data collection & analysis method.	64.7
9.	An app – that can provide location data on your device and brings up soil type for where you are standing, but which can be edited with more accurate information from cloud sourcing	0.5
10.	Development of region-specific dataset using localized data for calibration	0.5
11.	homogenized data sets	0.5
12.	Improve data density	0.5
13.	Improve linkages, interoperability with other relevant global database	0.5
14.	Improve spatial resolution to 5x5 m^2	0.5
15.	Include any important soil pollution and biological states to the physical and chemical characterization if possible, of soils	0.5
16.	Provide soil classification systems that define relevant soils characteristics.	0.5
17.	Sensors streaming data for real time graphic interpretation of trend lines	0.5
18.	Update to reflect changes	0.5
19.	Using adequate data tools	0.5

The central interest of most stakeholders (65% of the respondents) is clarity on data collection and analysis methods. This is largely missing or not presented in a coherent or explicit manner on most soil databases, this makes interpretation of results from such databases difficult and less relevant to the broad stakeholder's group. Data presentation needs to be simple, easy to understand and use an easy-to-understand unit of measurement. Furthermore, the need to provide data from an increased depth along the soil profile was raised by 41% of the stakeholders. This will enhance the robustness of the data as well as the agronomic interpretation; it will create opportunity for further learning. With advances in ICT and its integration into all walks of life, the stakeholders expressed the need to have a system that can provide on the spot information on the status of the soil. Such systems would need to combine and harness the advantages of the GIS system, ICT and mobile devices to make soil data available for use.

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The presentation style of a soil data is thus vital to its utility, Figure 5 presented the desired data presentation mode by stakeholders.

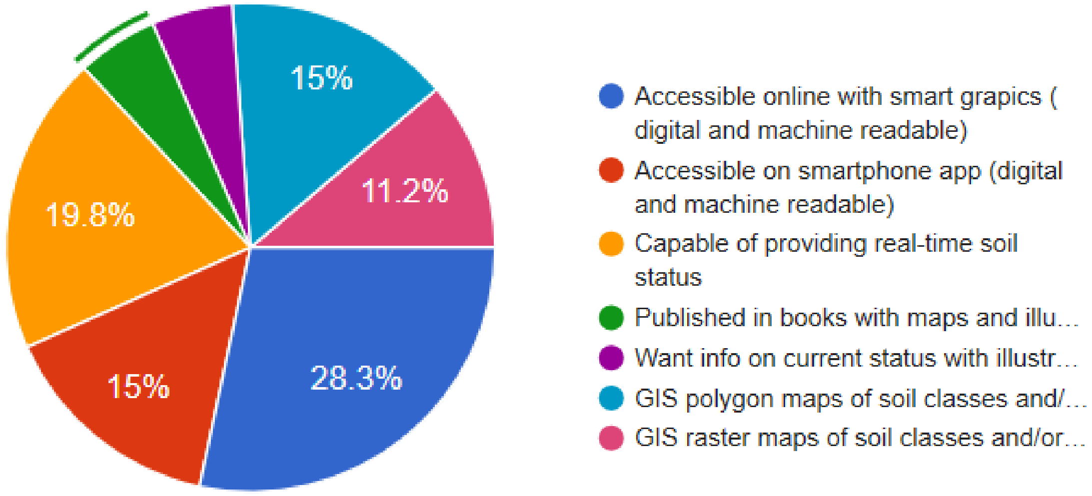

Figure 5. Preferred Format for Presentation of Soil Information

Cumulative 53.1% of the stakeholders preferred digital presentation of the soil data using ICT based facilities. This percentage comprised of 28.3% that preferred online access with smart graphic displays; 15% desired data that is accessible on a smartphone and is machine readable, while 19.8% wants a data system that can provide soil status from any location. This further underscore the need to have a soil information system that make the best use of advanced ICT technologies to run continuous projection and provide relatively accurate information. The need for soil map was emphasised by 15% of the respondents, while other graphic based presentation referred to raster and polygon maps. While the presentation of numerals will be useful for further analysis of data to tease out inferences; the presentation of data in graphical form also needs to be provided to ensure broad based use of the data base. It is thus vital to include an analytic page in the database to facilitate the utility of the system.

4.5 Parametric Composition of Soil Information System

The prime data needs of the stakeholders revolves around the basic soil parameters such as pH, EC, SOC, CEC, BS, particle size analysis, etc. Soil quality indicators, of possibly composite nature, can be derived from these parameters such as e.g., soil water availability being composed of soil volume (depth and stoniness) and water retention characteristics with the latter being determined by a. o. texture and organic matter content and assessable by pedo-transfer functions. Figure 6 shows the stakeholder's preferences for presenting the soil parameters in the soil information system. An equal blend of soil basic parameters and derived soil quality indicators is most preferred by 40% of the stakeholders.

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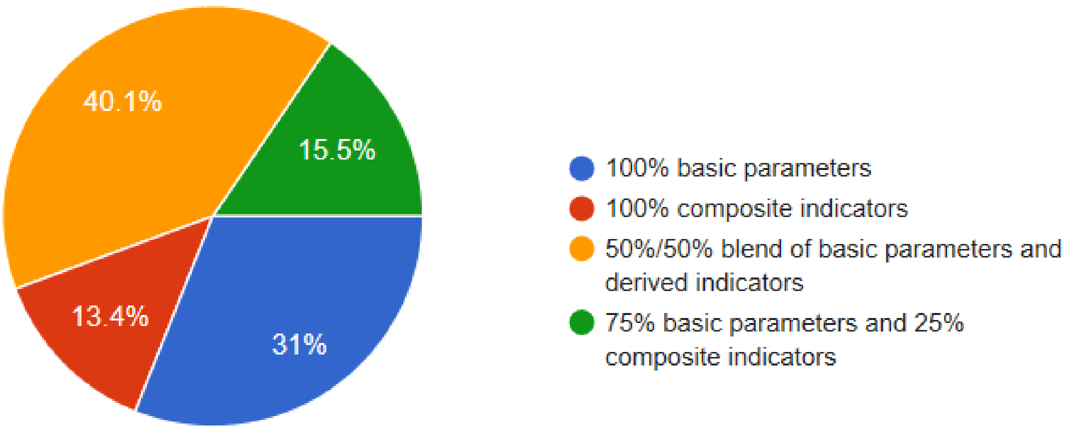

Figure 6. Preferred Format for Presentation of Soil Information

The depth of sampling was also considered within this survey for each of the parameters. A higher percentage of the stakeholders had preference for parameters measured from samples taken at the top layers followed by the middle and sub-soil. This could be attributed to the importance of the topsoil (generally classified as horizon O and A in a non-degraded soil profile) as the main source and sink of plant nutrients and beneficial biological activities, but also because it is simply the first layer. Nonetheless, the transitional and deeper layers (generally classified as E, B and C horizons) provide the anchor for plant rooting systems and retain moisture for supporting crop growth and also nutrients. The ensemble of horizons is important in understanding soil formation issues and inform actions towards the management of the soil for different purposes and may be studied at reference sites. Table 5 listed the desired soil parameters; the 23 parameters listed are not exhaustive but represents key stakeholders' preferences. Other descriptive properties of soil may also be needed to define a particular soil type, as such it will form an essential part the SIS. Notably, labile soil properties such as dissolved soil nutrient contents are not considered in mapping exercises due to the tendency to change over a very short time (days) due to weather-related factors or management practices applied. Available nutrient contents change within years due to human activities and these are therefore suitable for monitoring purposes. The Global Soil Map project proposed about ten soil properties that are relatively stable (Arrouays et al., 2014) and include Soil depth to bedrock, coarse fragments content, organic carbon content, pH, soil texture fractions, bulk density, effective cation exchange capacity, electrical conductivity, effective soil depth (rooting depth) and plant-available water holding capacity.

Table 5. Desired Soil Parameters in the SIS and the Depth of Sampling

Soil properties		Sampling Depth		
		Top	Mid	Sub
a.	Coarse fragments content	119	37	12
b.	Sand, silt, clay content (textural fractions)	123	30	15
c.	Bulk density	92	60	16
d.	pH (measured in water)	126	33	9
e.	pH (measured in KCl or CaCl2)	115	42	11
f.	Electrical conductivity	112	41	15

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g.	Soluble salts contents	107	47	14
h.	Exchangeable bases (Ca, Mg, K, Na, Al)	115	41	12
i.	Exchangeable acids (H, Al)	104	46	18
j.	Effective cation exchange capacity	117	40	11
k.	Cation exchange capacity	115	42	11
l.	Base saturation	107	48	13
m.	Total carbon content	111	42	15
n.	Organic carbon content	131	25	12
o.	Total N content (macronutrients)	128	31	9
p.	Total P content (macronutrients)	123	34	11
q.	Available (extractable) P content (macronutrients)	123	32	13
r.	Available (extractable) K content (macronutrients)	126	33	9
s.	Mesonutrients (incl. Ca, Mg)	110	45	13
t.	Micronutrients (incl. B, Cu, Zn, S)	111	43	14
u.	Water retention at wilting point, field capacity and saturation	101	48	19
v.	Water holding capacity	106	47	15
w.	Soil depth	86	38	44

Relevant soil quality issues for the SIS are presented in Table 6 from which the final indicators can be derived. Issues that addressed nutrient availability and balances (ratios) were proposed by the stakeholders as well as more elaborated complex issues including interpretations of soil quality relative to land use requirements (soil health and suitability of soil for agricultural purposes). The highest rated issue by the stakeholders, with 77% was the importance of the soil organic matter (SOM) to support soil biological functioning. Soil physical quality issues listed were indicated by a lower percentage of stakeholders, except, soil water availability, this however does not limit their importance to be included in the SIS.

Table 6. Relevant Soil Quality Issues for SIS

Soil Quality Issues	Percentage
Rootability	33.7
Sodicity	35.3
Soil functioning	36.4
Workability	39
Availability of soil volume (foothold) and of topsoil	43.3
Permeability	43.9
Aeration	47.6
Toxicity	49.7
Agricultural intensification potential	49.7
Infiltrability (surface permeability)	51.3
Salinity	52.9
Alkalinity	55.6
Porosity	59.9
Nutrient balance (ratios)	63
Water availability	63.6
Agricultural suitability	70.6
Soil quality status	72.2

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Soil health	72.7
Nutrient availability	75.4
Acidity	75.9
Organic carbon (SOC) availability (feed for microbes)	77

Soil functions are vital to sustaining life on earth and refer to the general capability of the soil to contribute to processes that provide needed services. (They are comparable with soil qualities that express the capability of the soil to meet specific land use requirements whereby the land use types constitute a narrow definition of the mentioned services). The soil functions which are considered vital in agriculture, environmental management, nature protection, landscape management are; 1) production of food and fibre (primary productivity), 2) cycling and storage of nutrients 3) a habitat for a myriad of micro-organism and other soil animals that ensure recycling of nutrient and degradation of biomass into its elemental forms (habitat and biodiversity), 4) purification and storage of water below-ground (water quality and purification) and finally, 5) climate regulation by storing atmospheric C as soil organic matter (C cycling and sequestration and climate regulation) and reducing excess greenhouse gas emissions from soil (Schulte et al., 2014).

The development of the SIS needs to target vital soil functions based on the needs of the stakeholders. Figure 7 shows the key soil functions as graded on average by all the stakeholders that responded to the survey and figure 8 shows the same functions as graded per stakeholders of different categories.

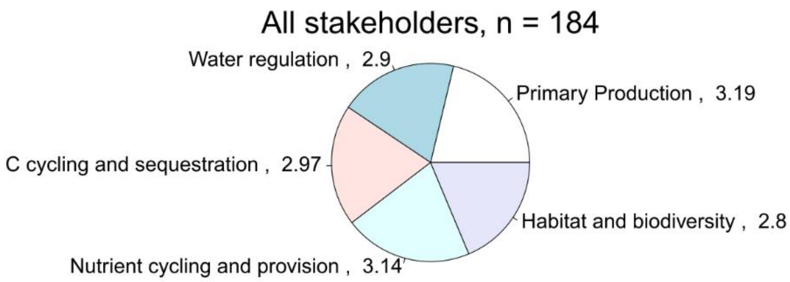

Figure 7. Key soil functions that define the content of the SIS. Each stakeholder was asked to grade from 1 to 5 each of the five functions so that the sum of the five grades would equal 15. For the cases for which the sum of grades was different than 15, the scores were normalized to bring this sum to 15 while keeping the relative proportion of each function to the total constant (Normalized score = (score x 15) / sum of scores).

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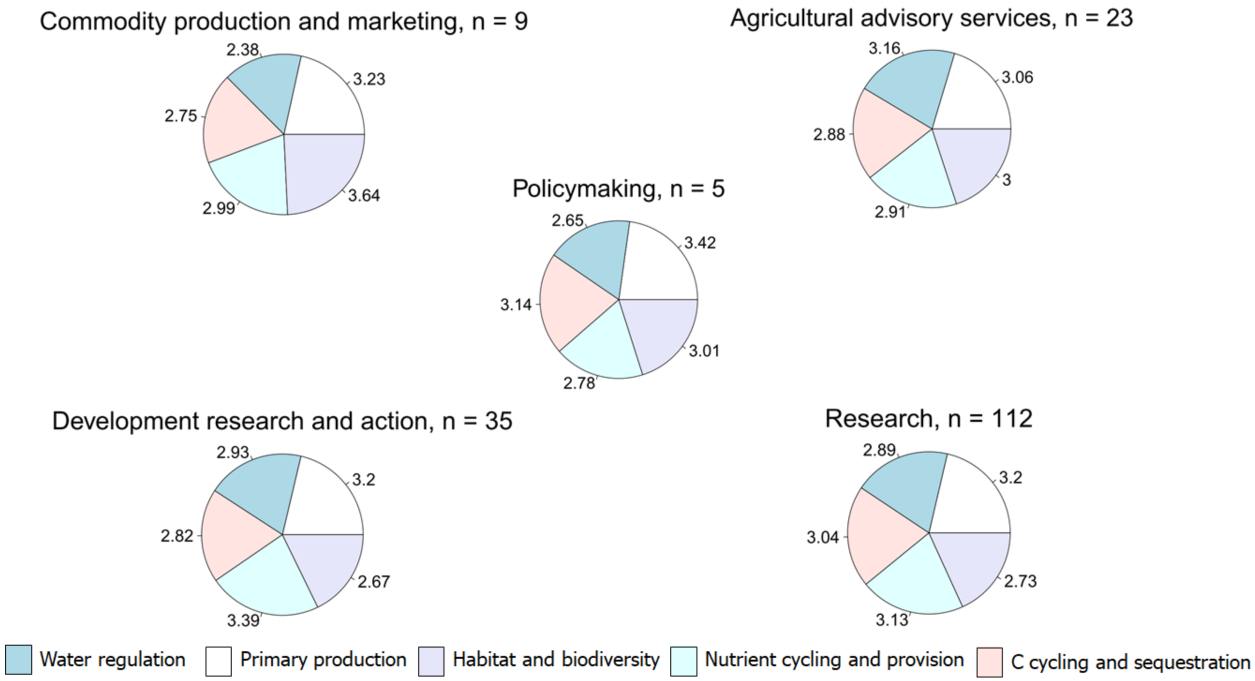

Figure 8. Key soil functions that define the content of the SIS ranked according to stakeholders from different categories. The data were normalized using the same method as in in figure 7.

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Primary productivity of crops and nutrient provision were overall graded slightly higher than the other functions. However, it is clear that none of the functions were poorly graded, with all average scores close to 3.5. Furthermore, different functions scored highest according to different stakeholders' categories, with water regulation leading the ranking for stakeholders engaged in agricultural advisory service, habitat and biodiversity leading for stakeholders engaged in commodity production and marketing and carbon cycling and sequestration scoring second, after primary productivity but before nutrient cycling and provision for stakeholders engaged in policy making. All five functions, therefore, were given significant importance overall and they all should be part of a good soil information system for the African context.

The central issue in the development of a useful SIS is the need to continuously improve soil management, 95.2% of the stakeholders agreed that improving soil management will translate into improved soil qualities and ultimately the provision of high-quality agroecosystem function and agricultural productivity. On the SIS, 97.3% of the stakeholders agreed that a functional SIS with good data can translate (but not automatically) into good agricultural soil management practices. A good soil information system will also help to monitor the impact of agricultural practices on soil quality.

4.6 Summary of stakeholder's response to need for soil information

From the stakeholder's responses to the questionnaire, we derived three broad user groups that make use of Soil information, and possibly the SIS, for three broad use case categories:

(1). Governance (Policy and strategy development),

(2). Knowledge generation (Technology development, research and development and Monitoring),

(3). Operational issues (Farming, environmental management, rural development projects).

These three broad use case categories are defined here as broad USE CASES. We further refined these categories by the specific use case topics that the stakeholders are involved in. The matrix below (Table 7) indicates the applicable combinations of the three use case categories and seventeen specific use topics with the latter ordered by importance according to the stakeholders.

Table 7 : Categorization of soil information use defining the use case categories and use case topics

Sr/n	Information Uses	1	2	3
		Governance	Knowledge generation	Operational use
1	Integrated soil fertility management, incl. nutrient cycling & provision	X	X	X
2	Agronomic decisions on soil and crop management (productivity), incl. primary productivity	X	X	X

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3	Agronomic decisions on soil and crop management (sustainability)	X	X	X
4	Academic and research purposes		X	
5	Climate change adaptation and mitigation, incl. carbon sequestration, cycling & regulation	X	X	
6	Soil quality monitoring		X	
7	Natural resource management	X	X	
8	Soil and water conservation decisions	X	X	X
9	Agricultural decision making			X
10	Land evaluation and land use planning	X		
11	Environmental management (pollution, nutrient leaching, etc.)	X		
12	Soil biodiversity conservation, incl. habitat and biodiversity	X		
13	Extension services	X	X	
14	Advocacy, awareness creation and training	X	X	
15	Policy analysis and decisions (policy making)	X		
16	Irrigation design		X	
17	Others (specify)			
18	Water regulation	X		

The USE CASE categories and topics defined for the project in above matrix are illustrated by use case examples in the next chapter. These use case examples are formulated by key informants and provide examples of soil quality issues mentioned by those informants and will serve the definition of the relevant soil quality indicators.

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5. Use Case examples for Soil Information Systems in Africa

Each use case example is represented as a sequence of simple steps, beginning with a user's goal, its needs in terms of soil information, linkage with the third party and ending when an indication of what should be in the SIS to deliver the required output.

The use case examples described in this report respond to ongoing initiatives and conventional endeavors that require soil information in order to deliver good outputs. Most of the cases have ongoing interaction with existing soil information systems and have acquired experiences that could inform the gaps to be filled and other useful considerations for developing a more user friendly and relevant system for Africa. The use case example presentations in this document take cognizance of the following components:

A. **Actors** – The actors refer to the users of the system or the people interacting with the process. In the case of SIS, these are scientist, extension agent, farmers, fertilizer blending technician etc.

B. **Stakeholders** – This refers to the indirect users of the system or individuals that benefit as third-party beneficiary of the system output. They often have vested interest in the system function and capacity to respond to their needs.

C. **System or basic flow** – This refers to the basic items or process required to get the final outcome. In the case of SIS, this refers to the key hardware, software and information pool including the programs for delivery of user's demand.

D. **Preconditions** – The preconditions are specific user requirements that make the system relevant to them.

E. **Outcome** – This is what the user desires to have for successful completion.

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5.1 Use Case example 1 - Use of Soil Information System in Integrated Landscape Management

Example of use cases 3/1, 3/2, 3/7, 3/10 (ref. Table 7)

1. Introduction

Integrated Landscape Management is one of the prominent uses of the SIS. The Food and Agricultural Organization of the United Nations (FAO) defines the Integrated Landscape Management (ILM) as landscape or ecosystem management at scale. The definition most relevant to this Use Case is "the management of production systems and natural resources in an area large enough to produce vital ecosystem services and small enough to be managed by the people using the land and producing those services." The definition of ILM also embraces the long- term collaboration among different groups of stakeholders to achieve the multiple objectives required from sustainable use of the landscape, such as agricultural production, the delivery of ecosystem services, cultural heritage and values, and rural development.

The application of the ILM approach is becoming increasingly widespread. An example is the Famer Managed Natural Regeneration project implemented in Dodoma, Tanzania, by JustDiggit, MetaMeta, and Lead Foundation. The project aims to **foster an improved agricultural productivity** for more than 180,000 farmers from 300 villages in the region, through a combination of:

- water harvesting and storage in the landscape (as groundwater, in reservoirs, and as soil moisture)
- regreening measures

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This particular project typifies an ILM endeavor. [1] This specific example is provided here to help visualize the nature and scope of such projects.

This Use Case for SIS is prepared based on an interview with Francesco Sambalino (Land & Water Management Expert, MetaMeta), who has designed and managed the technical aspects of the project since 2017. He also has a decade-long experience designing, implementing, monitoring, and evaluation various other ILM projects.

Figure 7: Integrated Landscape Management activities in Dodoma, Tanzania (Source: JustDiggit)

2. Soil Information Needs and Usage in ILM projects

There are at least two distinct sets of ILM activities that deal with soil management: erosion control and soil fertility management. In both, soil data are sought in order to create a baseline and to monitor change. In order to model erosion processes, data regarding physical soil properties are needed such as Sand, Silt, and Clay content; as well as chemical properties such as Soil Organic Carbon (SOC). In order to monitor soil fertility, chemical indicators such as pH, Base Saturation, SOC and Cation Exchange Capacity are commonly used.

The most commonly used sources of soil data are AfSIS and SoilGrids. The project also frequently uses land datasets available through the Google Earth Engine, since that’s where the more elaborate models and computations are run.

3. Soil Information Gaps in ILM

The availability, coverage, and resolution of data relevant to ILM is largely satisfactory. However, a crucial gap exists in the form of lack of tools and guidelines for easy interpretation of that data and inferring what actions to take as a consequence.

For example, while it is possible to find out the Cation Exchange Capacity of soil over a given area, existing soil information systems do not provide interpretive guidelines such as what a CEC value of 229 mmol(c)/kg (at pH 7) mean: does it show whether the fertility of the soil is on the higher side or on the lower side, whether the soil is in need of fertilizers or fertility interventions, and so on. Making such interpretations is challenging, not only in Africa, and absolutely key.

Other soil information users without a background in Soil science will have to go back to scientific literature to understand the technical jargon. While it is possible for hydrologists, geologists and agronomists to do so, lack of interpretation guidelines limits the usability of existing soil

[1] More information: https://justdiggit.org/project/tanzania-dodoma-2-2/

information systems. This makes existing systems more difficult to use for those without a strong technical or academic background.

It is important to mention here that the need for interpretation guidelines for soil data is compounded by the complex nature of soil and its properties. In contrast, other information systems relevant to ILM and agriculture such as those related to water use and productivity (such as the WaPOR database) present indicators that are comparatively easier to interpret and apply, by their very nature (such as biomass, evapotranspiration, water stress, land surface temperature, etc.). A comparable soil indicator could be the availability of e.g. water or a nutrient relative to the crop requirement.

Another noticeable gap in existing soil information systems is insufficient information regarding soil microbiology. Microbial processes are a significant determinant of soil fertility as microbes move nutrients around. For example, Phosphorous by itself is quite inert and not easily absorbed by plants. However, certain microbes can carry it around and exchange it with plants for sugar, through their roots.

Soil property data

Establish baseline status of soil properties, monitor changes , modelling of erosion proces

Erosion control, soil fertility management

Use Case Diagram

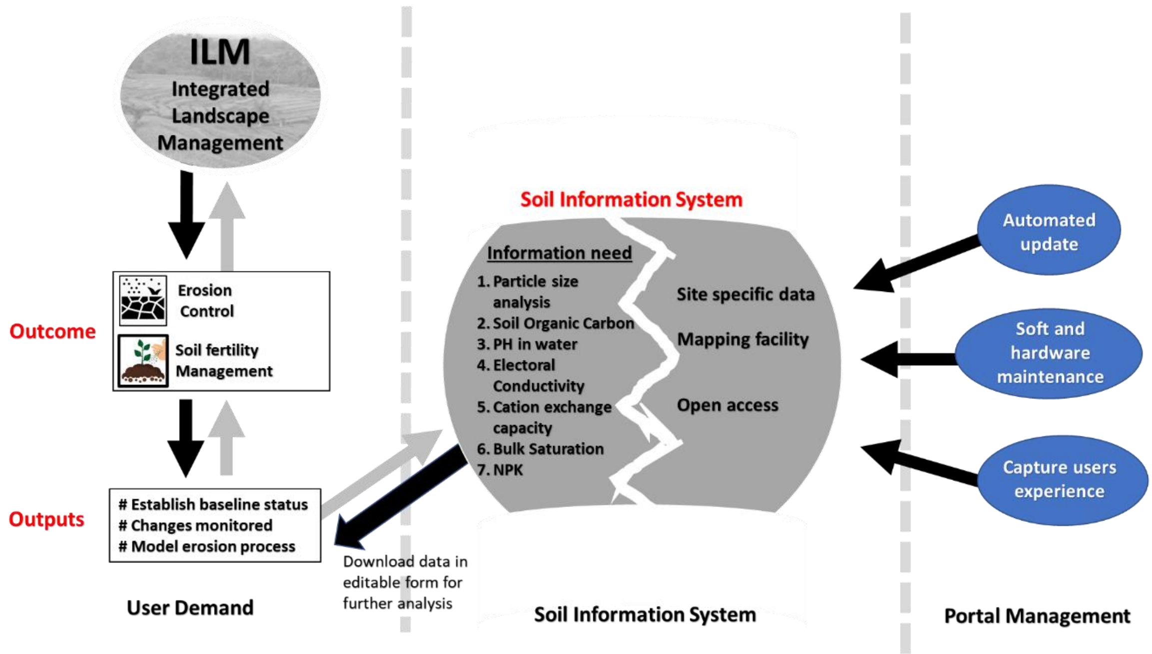

Figure 8. Use Case Diagram for an Integrated Landscape Management project

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4. Pointers for the Soils4Africa Soil Information System

Experiences of the ILM community with incorporating soil data in their work provide the following indications to the Soils4Africa project:

It would be imperative to develop guidelines for interpreting soil data, necessary for making soil data actionable, and to make those guidelines or interpretations easily available within the SIS itself. This will help extend the usability of the SIS beyond the soil science community and into other fields that contribute towards Sustainable Intensification of agriculture in Africa.

Soils4Africa plans to sample for soil biological indicators at a selection of the project's 20,000 sampling sites. Experiences from the SLM community validate this idea to include soil biological indicators. The Soils4Africa project team also needs to discuss how the number of such sites can be maximized.

Since the Google Earth engine is widely used for running the more complex models and computations, the SIS data should be made easily available through it. At the same time, the data should be easy to download, for the benefit of those working in parts of Africa where internet connectivity is sub-optimal.

A common challenge across information systems based on Earth Observation data is the need to provide intelligence and insight that is relevant and actionable within the complexities of smallholder, mixed, farming systems, with small, scattered fields, that characterize African agriculture. The map of agricultural land in Africa, one of the planned deliverables of Soils4Africa with a level of detail exceeding that of yet existing maps, will be a much-needed step in the right direction. The map would be based on a concept of 'cropland probability' that will help identify certain land cover patterns on satellite maps as being agricultural land. Apart from helping to identify appropriate soil sampling sites within Soils4Africa, such a map will have much wider utility across sectors and interventions.

5.2 Use Case example 2 - Soil Data Usage for a Sustainable Intensification Program in African Farming Systems

Example of use cases 3/1, 3/2, 3/3, 3/5 (ref Table 7)

1. Introduction

Soil information is pertinent to improving [sustainable intensification of] the African farming systems. This use case is drawn from SustInAfrica[2], one of five projects funded under Scope A of the Horizon 2020 programme supported by the EC. The project code is SFS**-35-2019-2020** [3] . The rationale for developing a Use Case around sustainable intensification is based on the following facts:

a. 'Sustainable Intensification' is a shared goal common to Soils4Africa (Scope B) and Scope A projects. It aims at enhancing both agricultural productivity and soil quality, in line with SDG 2.4, but the impact of possible measures is still to be confirmed, by this use case. Sustainable Intensification also cuts across many continental frameworks for the development of agriculture in Africa.
b. SustInAfrica is a project funded under the same Horizon 2020 program, it is contingent upon Soils4Africa (Scope B) and Scope A projects to cooperate and complement each other. There is a natural synergy between them.

This Use Case is based on interviews with key project personnel Nils Borchard (National Resources Institute Finland), Pierre Ellßel, and Bernhard Freyer (University of Natural Resources and Life Science, Vienna).

2. Soil Information User Profile: Scope A Horizon 2020 Projects for Sustainable Intensification of Agriculture

SustInAfrica is a research project which aims to empower West and North African smallholder farmers and small- and medium-sized enterprises (SMEs) by facilitating sustainable intensification of their farming systems. Large areas of agricultural land in West and North Africa are heavily degraded, with water scarcity, low soil fertility and poor plant health, due to agroecological limitations combined with increasing pressure on the land by the traditional agronomic systems and management practices that fall short to counteract the impact of that pressure. In West Africa, food productivity, and production, is limited by poor water supply (including crust formation), low availability of organic matter and nutrient retention and shortage, whilst in North Africa, salinisation, wind erosion, formation of crusts and compaction threaten rainfed cropland and silvo-pastures.

The project consists of seven work packages. Work Package 1 (WP1) aims to conduct a baseline study and design a monitoring system for West and North Africa farming systems. Work Package 3 (WP3) looks into the design and implementation of trials for resilient and sustainable production and delivery of ecosystem services. One of the methods to test sustainable and resilient farming methods and systems is to use indicators that can give a measure of farming system performance in general and soil fertility in particular.

Given the wide scope of the project—both in terms of geographical area and the range of Sustainable Intensification measures being considered under it— it is fairly representative of the various Scope A projects.

[2] https://www.sustinafrica.com/
[3] https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/sfs-35-2019-2020

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The project views soil indicators as falling under 3 distinct categories:

a) Stable Indicators

Stable properties are those with little variation over time. The project seeks to use them to build a baseline, which help plan and design the intervention (choice of crops and farming practices to promote) and measure progress in course of the project.

Stable Indicators	Purpose
Soil pH	- to choose the appropriate crops - to choose corrective measures (such as liming, or addition of organic matter) in case of pH being too high or too low
Soil texture	- to understand the water requirements of the crops and choose appropriate water management techniques
Total nutrients	Knowing Total nutrients (the total stocks of Nitrogen, potassium, phosphorous in the soil) is as important as knowing available nutrients (the amount of nutrients available in forms that can be readily absorbed by the plants). Knowing the Total Nutrients available in soil, one can determine whether improving fertility requires adding extra nutrients to the soil (fertilization) or measures that mobilise a greater portion of the Total nutrients (such as adding organic matter). This has practical implications, as the latter are much less expensive than the former but regrettably insufficiently available at scale.

b) Other Indicators

This is a set of indicators that the project considers useful to achieving its objectives. While this set of indicators would be desirable, the project recognises the difficulties associated with sampling/analysing for them. As such, they make for a 'wish list' for the project.

Apart from stable indicators, management of agriculture and development of ecosystem services

Indicators	Purpose	Difficulties
Available nutrients	To assess the availability of nutrients (such as N, P, K) in chemical forms that can easily accessed by the plant roots (such as Ammonium, Nitrate compounds)	Soil samples need to be transported and analyzed within 24 hours, or refrigerated. This is difficult to do in remote areas in Africa. One can 'pre-fractionate' in the country/region of extraction, but then the same standards for pre-fractionating would need to be followed in every location which is difficult to ensure.
Electrical conductivity	Important measure in areas where salinization is a big issue	Various
Potential Cation Exchange Capacity	influences the soil's ability to hold onto essential nutrients and provides a buffer against soil acidification	The difficulty is to determine the pH value where to measure it, and to ensure that the same value is used everywhere.
Biological indicators	Help develop a microbial profile of the soil, a key determinant of its fertility	Soil samples need to be analyses quickly after they are extracted, or put in refrigerated storage. This is

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		expensive, and often impossible (such as in remote areas)

c) Clustered indicators/ Actionable soil information

Experts/ projects rooted in disciplines other than the soil sciences often need 'actionable soil information'—the kind that can guide their intervention—apart from raw data such as nitrogen, phosphorous, potassium, carbon content in soil. What is useful to them is data with a certain amount of interpretation and contextualization. For example, soil is often described in terms of its 'suitability' (defined here loosely as its capacity to produce biomass) or 'fertility' (its availability of soil nutrients to produce biomass). Suitability and fertility are not directly measurable indicators; one can combine different parameters--- texture, nutrients, pH, etc.--- in a way that provides an indication of the suitability or fertility of the soil. SustInAfrica visualizes such indicators as 'clustered' indicators (or composite data). The project shares with Soils4Africa the following clustered indicators as suggestions to consider for the soil information system:

- Suitability and Fertility
- Ecosystem Services
- Carbon Sequestration Potential: This indicator is already on Soils4Africa's radar. SustInAfrica's suggestion is to sample for carbon sequestration potential at up to 2 meters depth.
- Soil moisture capacity

SustInAfrica makes special mention here of Soils4Africa's forthcoming 'map of agricultural land in Africa,' as an example of clustered, actionable information that could potentially be of great practical utility.

3. Known Soil Information Sources

Work Package 1 is tasked with creating a baseline information for the project. Data collected for the purpose could be traced back to ISRIC and FAO.

4. Limitations of existing soil information sources

The SustInAfrica project requires data of high resolution. They especially need maps of a scale of at least 1:250,000 (1:25,000 while planning at the village level). The project found it difficult to locate such maps in harmonised information systems. Eventually, they were able to find relevant data in publications (sourced from ISRIC).

Besides, they found that a lot of soil data in the project area was modelled from point data. It would be much more useful for them to have access to the real point data.

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Use Case Diagram

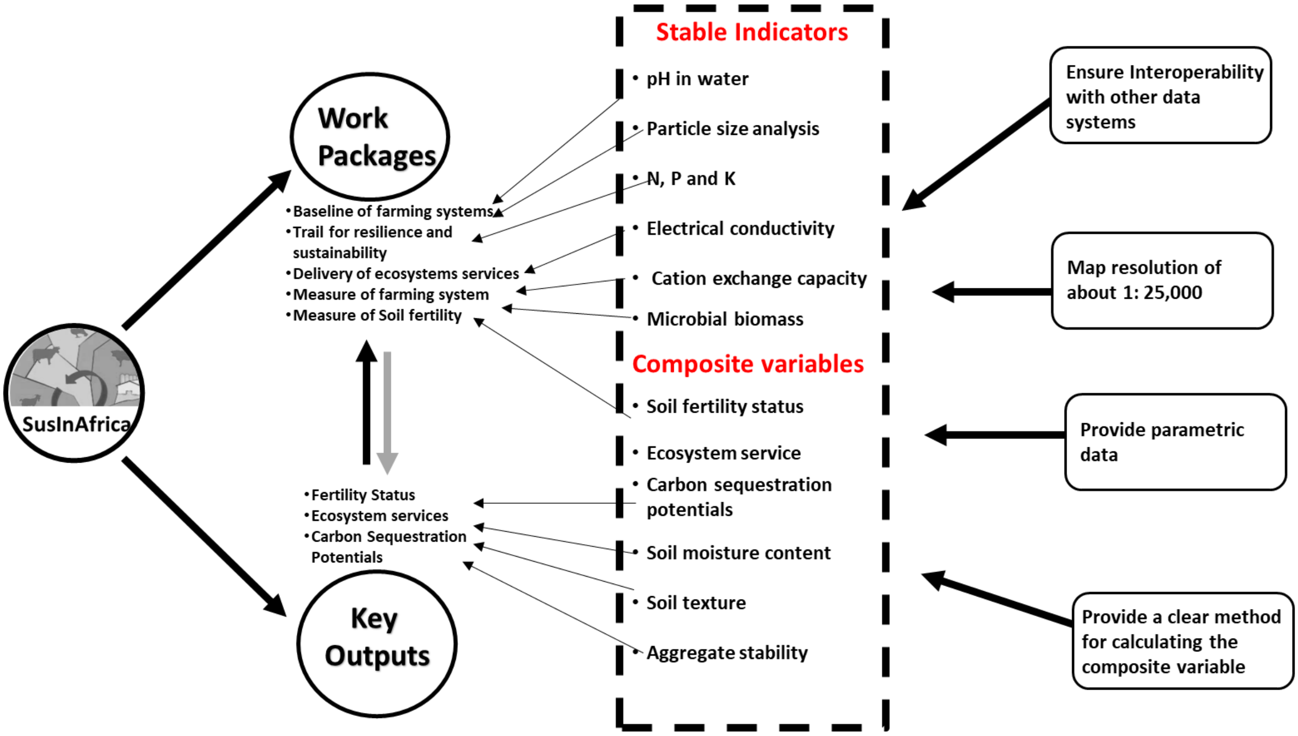

Figure 9. Use Cases Diagram for a Sustainable Intensification Related Endeavors.

Pointers for Soils4Africa and the Soil Information System

- SustInAfrica's data needs are detailed in Section 2. It would be safe to assume that such indicators will also be useful to other projects whose goal it is to achieve Sustainable Intensification at the ground level (especially H2020 Scope A projects).
- Going ahead, it will be useful to discuss within Soils4Africa which data needs, apart from stable indicators, such as 'other indicators' and 'clustered data' can be met by the soil information system. As also indicated by other use cases, the need for clustered indicators/actionable soil information (see Section 2b) is felt widely across soil information users who are not Soil Science specialist. In the absence of such indicators, primary soil indicators such as (N, P, K, pH, C, etc.) are of limited utility to them.
- While presence of soil data is a problem, the problem gets aggravated when analyzing soil maps. Resolution offered by such maps is inadequate (too coarse) with respect to their needs. This is likely to be true for projects that aim to implement Sustainable Intensification measures on the ground.
- As stated earlier, there is much scope for synergy between Soils4Africa and Scope A projects. SustInAfrica, for one, is willing to assist the Soils4Africa project in soil sample collection, in return for the soil analytical data and the possibility to compare their baseline data and project results against information from the rest of Africa.

The project will also be helpful as they can assist in locating and collecting samples from soil pits to take soil samples representative of agro-ecological zones or reference soil groups.

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5.3 Use Case example 3 - Soil Data Use in Agricultural Extension and Advisory Services

Example of use cases 2/9, 2/13 (ref Table 7)

[Left]Susan Nguku, Ward Extension Officer Kyome/Thana Ward (Mwing West sub-county Kitui County). [Right] Daniel Munyoki, Soil Extension Officer, Kitui County

1. Introduction

The use of soil information in extension and technology transfer is vital to the sustainability of agricultural productivity at field level and production at the country level. This use case for SIS was developed following an interview with extension officers in Kenya: Susan Nguku, Ward Extension Officer, Kyome/Thana Wards, (Mwingi West sub-county) Kitui County; and Daniel Munyoki, Soil Extension Officer, Kitui County.

The rationale behind building a Use Case around agricultural extension work is self-evident. Soils4Africa is driven by the overarching goal of informing sustainable intensification in Africa. The continent comprises of around 33 million smallholder farms that contribute almost 70% to the food supply.[4] Extension workers, in most cases, are employees of government departments, they are the single most important source of agricultural information for smallholder farmers besides upcoming digital solutions. Any significant push towards the uptake of sustainable intensification practices would have to engage the extension workers and provide all the necessary scientific information. From a soil data point of view, extension workers would only advise the farmers to prescribe soil management measures on the basis of, a. o., soil data resulting from soil samples collected and analyzed from smallholder farms. Thus, the extension workers will be the ones who further breakdown the soil information into the action bits that will be used at the farm level.

2. Soil Information User Type and Profile: Agriculture Extension

Susan Nguku is the Ward Extension Officer for the Kyome/Thana wards in Kitui county (Mwingi West sub-county) in southeast Kenya. Her office comes under the federal ministry of agriculture.

[4] IFAD: https://www.ifad.org/thefieldreport/

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Kitui is a mostly agrarian county, with a population of around 1.1 million over 30,000 square kilometers. It is further divided into 8 sub-counties and 40 wards. The elevation varies between 400 and 1830 meters above the sea level. Temperatures vary between a minimum of 14-22 degrees centigrade to a maximum of 26-35 degrees centigrade. Rainfall is distributed over two rainy seasons annually and varies between 500-1050mm with about 40% reliability. [5] It lies in the 'Sub-humid [Tropics-Warm].'[6] agro-ecological zone. The soil in the area is identified as 'well drained, moderately deep to deep, dark reddish brown to dark yellowish brown, friable to firm, sandy clay to clay; in many places with a topsoil of loamy sand to sandy loam.'[7]

The role of the supervisor includes supervising all extension work happening in the county, organizing field days and field visits, organizing capacity building trainings for farmers, providing advisory on various aspects of agricultural production and livestock rearing, and facilitating farmer-to-farmer learning. Soil lies at the core of advisory services provided to farmers. Soil samples are collected and tested at the beginning of the sowing season. This happens at least once every 2 years, and additionally as per demand by individual farmers. Based on the results, farmers are advised with regards to land preparation measures, crop choice, and fertilization needs.

The soil extension officer for Kitui county oversees the soil sample collection process. He then takes the samples to the soil laboratory at University of Nairobi himself, where he puts the samples through various tests, analyses the results and prepares reports and advisories that are eventually relayed to farmers in Kitui county through extension offices at sub-county and ward levels.

3. Soil Information Needs and Usage in Agricultural Extension

The main indicators that the Kitui county agriculture extension office tests for are:

- soil structure, mostly to determine drainage needs of the land
- chemical indicators such as Nitrogen, Phosphorous, Potassium, and pH
- micronutrients, especially Iron and Boron since Kitui county soils are deficient in these nutrients

Based on the results of tests for these indicators, the office advises farmers as to what kind of crops farmers could grow, what kind of land preparation and soil fertility measures they need to take; whether additional fertilizers are needed, what kind (organic fertilizer, NPK, CAN) and in what dosage. Further, soil acidity is an issue across much of the county, and knowing the pH of soil helps determine whether measures to control soil pH are necessary and of what kind (e. g. liming is commonly used).

Further, Daniel would like to test for heavy metals, but the University of Nairobi laboratory is not equipped for that test. However, this is not a big problem as heavy metal contamination is not a significant problem in Kitui.

The only source of secondary data Daniel uses is a handbook that catalogues various crop varieties and lists the conditions necessary for their cultivation (including soil conditions). He formulates his advisory regarding crop choice by comparing the soil test results with the information in the handbook.

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[5] Evelyn JM, Charles KN, Patricia M (2017) Smallholder Farmers' Perceptions and Adaptations to Climate Change and Variability in Kitui County, Kenya. J Earth Sci Clim Change 8:389. doi: 10.4172/2157-7617.1000389

[6] Sebastian, Kate, 2009, "Agro-ecological Zones of Africa", https://doi.org/10.7910/DVN/HJYYTI, Harvard Dataverse, V2)

[7] Sombroek, W. G., Braun, H. M. H. and Pouw, B. J. A. van der (1980) Exploratory soil map, scale 1:1,000,000, 827 Exploratory Soil Survey Report No. E1.

At the sub-county/ ward level where Susan operates, farmers as well as extension officers are more interested in the advisory rather than specific soil indicators and test results.

4. Soil Information Gaps in Agriculture Extension

The soil information gap in Kitui county's agriculture extension office is one of technical capacity among personnel. There is one Soil Extension Officer for an entire county, catering for almost 1000 farmers annually on average. Each round of lab work takes 2 to 7 days. Training packages for newly recruited extension officers focus mostly on communication and community outreach. This does not help the concentration of responsibilities regarding soil information management upon the Soil Extension Officer.

Another gap is in terms of soil testing infrastructure. According to Susan, when it is not possible to collect and test soil samples, they have to be sent to other labs which can take and run the tests and return the results. For example, results of some samples sent to a regional laboratory in December 2019 are still awaited as of December 2020.

5. Pointers for the Soils4Africa Soil Information System

For its soil information needs, Kitui county's agriculture extension office depends almost exclusively on primary data collection and analysis. Given that, what would be the utility of a soil information system like the one Soils4Africa aims to develop?

- From the point of view of an extension officer specializing in soil and having some grounding in soil sciences, a SIS would serve as a, not field-specific, baseline to monitor changes in soil properties for a certain period of time. However, for it to have long-term utility, the data would have to be updated every 5 years or so (since various key soil properties change over that period) and for having farm specificity, and extension relevance, it would have to be based on high density data.
- For a soil-specialist extension officer, who is closely involved in sample collection and laboratory analysis, standard protocols should be developed by Soils4Africa as they can help them repeat these processes year after year and monitor change with greater accuracy. Conversely, from Soils4Africa's point of view, it would be worth exploring whether/how extension workers can be engaged in soil sampling and analysis during the project, and in continuing to grow the soil information system after the project period. This would require particular attention to assuring the application of adequate, harmonized, laboratory procedures.
- From the point of view of an extension officer tasked with a wide range of responsibilities (not a soil specialist) a soil information system will be of utility if, apart from specific soil indicators, it also has a guide that helps interpret their values.

6. Use Case Diagram

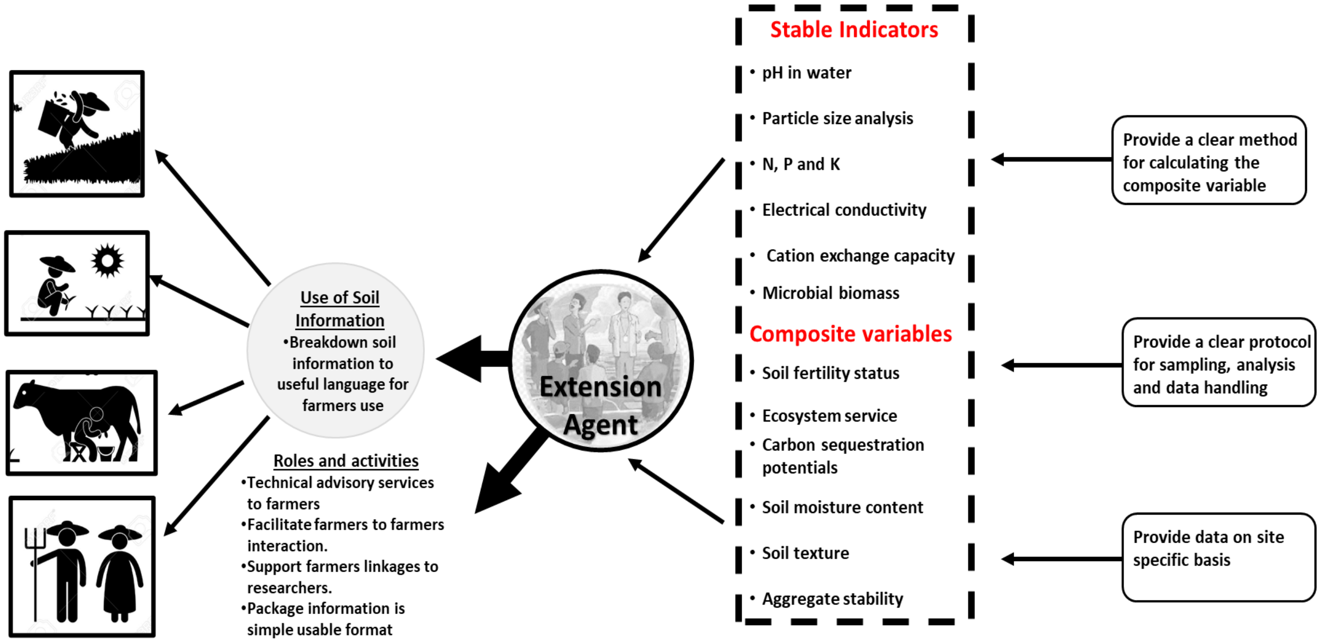

Figure 10. Use Case Diagram for SIS in Agricultural Extension and Advisory Services

5.4 Use Case example 4 - Use of Soil Information in a Public System Land Resource Conservation Department

Example of use case 1/8 (ref Table 7)

(Right) Macpherson Nthara, Chief land Resources Conservation Officer, Lilongwe Agriculture Division, Ministry of Agriculture

1. Introduction

This use case responds to the typical need by staff in the national government to provide information for policy development and well as infrastructure for agriculture and land resource management. In most African countries, government departments have the mandate to gather and provide soil information to end users. In Malawi the department is the biggest producer and user of soil data and the most influential driving force behind the spread of sustainable intensification practices.

This case was developed from the interaction with Macpherson Nthara, the Chief Land Resource Conservation Officer of the Ministry of Agriculture. The case covers experience from three districts in Malawi.

2. Soil Information User Type and Profile: A Federal Government Department with Mandate to Manage and Conserve Land Resources

Malawi's Land Resources Conservation Department is within the federal Ministry of Agriculture. It has the mandate to ensure sustainable management of agricultural land across the 8 Agro-ecological zones in the country. Within this mandate, the department implements and monitors a wide range of interventions in the areas of water harvesting, soil conservation, soil fertility improvement, etc.

One of the main focus-areas of the department is to reduce soil erosion, caused by wind and water action. Soil erosion is land degradation leading to loss of soil and nutrients. Thus, as a remedy, the

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department implements a host of soil fertility improvement measures apart from erosion control initiatives. Such measures include documentation and promotion of organic as well as chemical fertilizers, manure, and various indigenous soil fertility management practices. Soil data is collected across the country in order to monitor the impact of such activities.

Over the past 2-3 years, there has been a concerted effort to map soil fertility in different parts of the country. Private companies have also been involved in the effort. Over the same period, efforts have been made to develop recommendations for inorganic fertilizer use specific to the 8 Agro-ecological zones in the country.

3. Soil Information Needs and Usage

For the purposes of planning, monitoring, and evaluating interventions related to soil management, the Land Resources Conservation Department mostly uses its own data, data produced by other government departments (most notably the Department of Agricultural Research Services- DARS)[8], educational institutions such as the Lilongwe University of Agriculture and Natural Resources (LUANAR)[9].

DARS collects soil data (among other agricultural data) regularly through its 10 research stations in different parts of the country. It also has vast legacy datasets drawing on extensive data collection carried out from the 1960s to the 1980s. Large-scale push to this effect was provided by the Land Resources Evaluation Project (1985-92). For various administrative and political reasons, data collection efforts decelerated starting the 1990s. They have started picking up pace again over the last 3-4 years.

Much of the recently collected data has been digitized, some of it is available in various formats including shape files through various departmental websites. Most of the legacy data still exists in analogue form. Both kinds of data are scattered across a variety of sources, platforms, and publications; there aren't any harmonized platforms that bring all this data together. The data collected by the Land Resources Evaluation Project have been compiled in the Africa Soil Profiles database and informed the production of the Africa SoilGrids (maps).

For the purposes of the Land Resources Conservation Department programs, the most utilized soil indicators are physical properties such as bulk density; and chemical properties such as pH, Nitrogen, Phosphorus, Potassium, and Soil Organic Carbon. These indicators are used mainly to assess soil's acidity, water retention capacity and soil fertility. They are analyzed to develop advisories regarding land preparation, water harvesting measures, and soil inputs such as fertilizers.

Apart from the soil data generated by various government departments and institutions, secondary data from ISRIC and FAO is commonly used, mainly to fill gaps in government-generated data.

4. Soil Information Gaps

- The biggest gap in the available soil information is the lack of recent data. As mentioned earlier, agricultural/soil data collection efforts decelerated in the 1990s and have only now started picking up pace. The key hindrance is the extensive, financial, resources required to carry out soil sampling at a large scale. Thus, soil sampling and analysis is limited to small-

[8] http://dars.mw/
[9] http://www.bunda.luanar.mw/luanar/

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scale, piecemeal exercises carried out from time to time to meet specific needs arising in individual projects.
- Another gap is at the level of ease-of-access. Much of the legacy data sits in physical reports and documents, undigitized. Besides, in the absence of a harmonized database bringing together data from various sources, accessing relevant data is expensive and cumbersome.
- One set of data which is in short supply (including legacy data) is that regarding micronutrients such as Boron and Zinc.

5. Pointers for the Soils4Africa Soil Information System

- Malawi's Land Resource Conservation Department values the concept of a soil information system as a prospective boost to the amount of recent soil data collected systematically using modern techniques and methodology.
- Availability of standardized soil sample collection and laboratory protocols will be valuable to steadily increasing the stocks of Malawi soil data over the long term.
- For the soil information system to be valuable over a long term, it would be important to ensure that the data is updated from time-to-time (at least every five years). This suggestion is common across a number of interviews conducted to prepare use cases.
- Another view that found resonance with other interviewees was that there is a need for the SIS to have tools that can help interpret and apply the technical information it offers with a particular focus on helping extension workers.
- It was suggested that micronutrient indicators such as Boron and Zinc content will be of particular relevance to the Malawian context.
- As mentioned earlier, in recent years, soil data collection efforts have been stepped up in Malawi. It might be worth examining whether such recent data could be incorporated in the SIS in a way that enhances it and vice versa. The Land Resource Conservation Department is interested in cooperating with Soils4Africa in this regard.
- The Department is also keen to offer the technical expertise it has to offer in the form of soil experts and soil laboratories. In particular, it is keen to discuss the possibility of helping Soils4Africa sample for biological indicators at sites close to government laboratories equipped to carry out such analysis.

6. Use Case Diagram

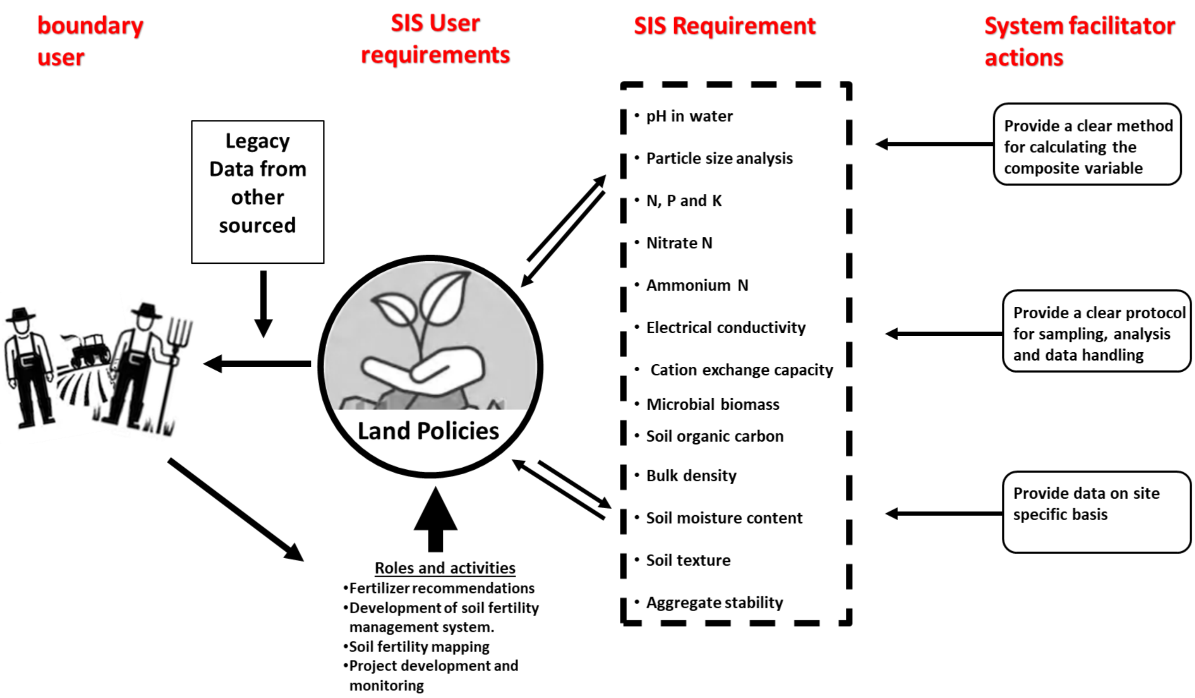

Figure 11. Use Case Diagram for SIS in Government-led Agricultural Department Interventions

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5.5 Use Case example 5 - Use of Soil Information for Fertilizer Producers and Suppliers Association

Example of use cases 1/2, 2/2 (ref Table 7)

1. Introduction

This SIS use case represents a typical need for fertilizer blenders and manufacturers. It is drawn from interactions with the Fertilizer Producers and Suppliers Association of Nigeria (FEPSAN).

2. Soil Information User Type and Profile: Fertilizer Producer and Suppliers Association of Nigeria (FEPSAN)

The Fertilizer Suppliers Association of Nigeria (FEPSAN) is the national trade association set up to represent the needs and interests of fertilizer manufacturers, importers, blending plants, major distributors and dealers in Nigeria.[10] They are in the business of:

- Producing and selling fertilizers
- Educating farmers over fertilizer use through capacity building. FEPSAN is trying to promote cost-effective ways of soil testing. An innovative solution they have adopted is the use of SoilDoc system of soil data collection.
- Advising governments in terms of policy formulation with respect to use of fertilizer.
- Collaborating with fertilizer manufacturers across the world, especially for soil data collection across Nigeria, for example with OCP Africa in Morocco who intends to build a huge fertilizer plant in Nigeria.

FEPSAN has a political head and they have been recently involved in passing of the fertilizer quality control law. They have also collaborated with different organisations that has helped them in conducting an elaborate soil testing exercise in Nigeria. As Nigeria is one of the world's largest producer of Urea, FEPSAN in general and the Executive Secretary in particular is responsible for engaging with different members to reach a common understanding over production levels of Urea in the country alongside the procurement of different fertilizers.

Apart from FEPSAN, there are other organizations like Farmers Organizations, Research Institutions, professional bodies like the Soil Sciences Association of Nigeria, Government agencies and transporters who are also in the fertilizer business. However, the involvement of the private sector players in the fertilizer business is quite recent. Prior to this development, the private sectors are largely subservient waiting for the government to publish its policies and they comply. In the last 7 years, there has been an expansion of private sector and this has led to the development of new projects, for instance, one of the biggest fertilizer projects in the world is being implemented in Nigeria. The Dangote Urea Plant is set to be the second largest fertilizer plant in the world and this is projected to help Nigeria become self-sufficient in terms of fertilizer production and use and possibly in food production.

Over the last 10 years, organizations in the fertilizer business have started collecting, using, and validating fertilizer data with the different associations like Fertilizer Technical Working Group which includes FAO, the International Fertilizer Association and others that are spread across the agricultural sector in Nigeria. However, the quality of the agricultural data is still sub-optimal.

[10] http://www.ipcinfo.org/fileadmin/user_upload/countrystat_fenix/congo/docs/FEPSAN%20brochure%202013.pdf)

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Though the data appears to be voluminous, the methodology is not adequate and the coverage area is little. The data collected by FAO in 2005 and published on www.africafertilizer.org appears to be rich and accurate. It shows an increase in fertilizer use by focusing more on the usage patterns in fertilizer. Other data sources like OCP Morocco could help to understand the consumption and use patterns for fertilizer in Africa.

Soil data in Nigeria though are of a very scattered and incomplete nature and coherent soil data collection initiatives at scale could improve that information deficit.

3. Relevant Soil Indicators

There has been an increase in soil testing in Nigeria and this has led to an expansion in the kind of fertilizers demanded. This is in contrast to earlier times when both demand and supply were restricted to NPK. However, farmers are now making specific demands for fertilizers such as Zinc Sulphate to boost corn production or silicon. Changes in demand from farmers come as they shift from subsistent farming to a more business-oriented farming. This tends to coincide with changes in cropping patterns. As land use is changing to a more profit-based uses with larger (pre-season) investments, so does dependency on knowledge, skills and expertise in soil fertility. Farmers are keenly interested in knowing the status of different soil indicators like: macro nutrients (NPK), Micro- nutrients (Boron and Zinc, Cu, Fe, Mn and Ni), the pH value of the soil and Cation Exchange Capacity.

In Nigeria, there is a shift in the major food production belt which necessitate the need to conducting a systematic and empirical study that will look into how the soil characteristics are changing overtime. It may also be very worthwhile to assess the depth and water holding capacity of the Nigeria soils, especially in the sub-humid to semi-arid cereal belt, to better define fertiliser recommendations that do not only consider soil nutrient availability but also the water-limited production potential which defines crop nutrient demand.

4. Understanding the Needs of Farmers and Demands for Fertilizer Production

To determine what is needed by the farmers and estimating the production levels of fertilizers, fertilizer companies respond to market research and government policies. They also conduct their own research, although this is an expensive endeavour. A handful of the companies still rely on existing data. There has been increase in the use of the available data, but this is limited as data collation from the various sources is still a major problem as well as the quality of much of the legacy data in Nigeria.

The FAO along with the national government of Nigeria has produced a set of recommendations called Fertilizer Management Practices which are updated every 3-4 years. Fertilizer companies do depend on such data to determine the kind of fertilizers that are needed and what to produce. The dataset is stratified according to location and specific crop recommendations. This kind of dataset has gained popularity in recent years after the private sector began expanding its business in the fertilizer sector. With the help of data, FEPSAN is better able to promote the uptake of fertilizers among smallholder farmers. As good quality inorganic fertilizers are available at affordable prices, their usage is expanding. Nigeria sells around 1.5 million tons of fertilizer domestically and the same amount is also exported. With Nigeria being the country with the largest population in Africa, there is a potential to increase domestic demand to 4 million tons. With improved access to products and to credit lines, 4 million tons of fertilizer production and delivery is easily achievable. The growth of private sector is a testimony to the transformation of the small holder farming into an organised and productive sector.

Governments and NGOs are also promoting smallholder farming groups (per commodity: rice farmer groups, sorghum, farmer groups etc.) by funding them and enabling them to do soil testing themselves. This will help them in understanding the soil characteristics, soil nutritional needs and demanding fertilizers based on this. Other kind of farmers like commercial and large-scale farmers already engage in soil testing so they are in a better position to demand fertilizers based on the soil requirements.

5. Association Between FEPSAN and Soils for Africa

Soils4Africa project can help FEPSAN in identifying the relevant indicators mentioned above and in interpreting them. FEPSAN understands that the reliability of soil information is consistent with the number of samples collected, it hoped that the Soils4Africa project will collect sufficient samples and are confident that the methodology for analysis and data presentation will be suitable. They are hopeful that an increase in sample size, for example collecting 20,000 samples from Nigeria, would be a good start considering the importance and size of the country. FEPSAN would like to have good access to the data and wishes that the data should remain open and the user interface will be friendly. This will help in expanding the use of SIS to a large number of people. In turn FEPSAN can provide technical inputs and help in siting the sampling locations among others. It can also help the project to get access to soil laboratories if need be.

6. Recommendations/ Pointers for Soils for Africa Project

There is a felt need for the Soil Information System to be interpretable by a wide range of users apart from soil scientists (similar pointers arise from other use cases as well)

Additionally, there is a need to update SIS continuously to ensure that it expands to a large number, and possibly to sufficient depth, over a period of time so that it can be used as a Decision Support System. In this context it may be worthwhile mentioning that ISRIC is collaborating with OCP Africa in developing a decision support platform for interpreting soil data for developing crop and site-specific fertiliser recommendations.

New connections can be examined by collaborating with existing institutional infrastructure like the Fertilizer Technical Working group. This would help Soils4Africa as it can provide data and information that boost Soils4Africa activities.

7. Use Case Diagram

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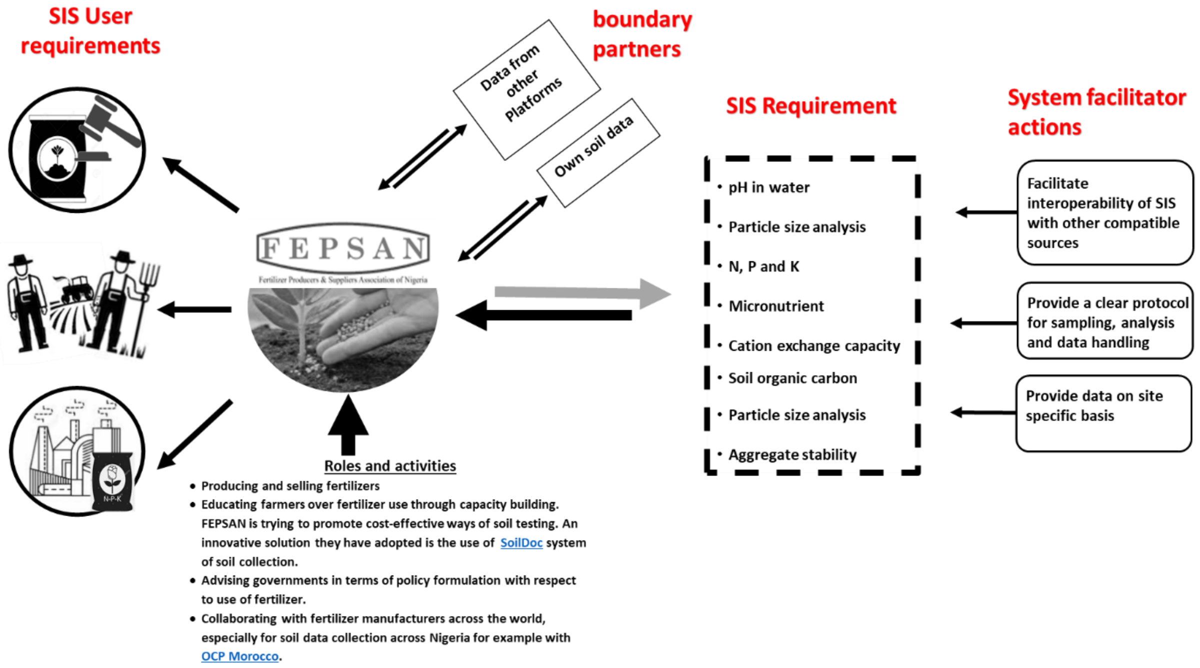

Figure 12. Use Case Diagram for SIS in Fertilizer Manufacture and Use

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6 Soil Quality Issues

The use case examples described coalesce into the indication of quality issues that should support the definition of soil quality indicators useful for the development of SIS for Africa. Soil qualities are defined as the capacities of soil to meet the requirements of given land-use types or functions. Soil qualities are, composites of, physical, chemical and biological soil properties that can be measured, over time, and soil quality indicators are designed to monitor changes in the soil over time at a scale of years. Indicators are expected to respond directly to specific agricultural soil use or soil management practices. The issues listed here come forward to the needs expressed in the use case examples.

Technically, the quality or function of soil includes the provision of the physical, chemical and biological habitat for the activities of microorganism and the capacity for receipt and supply and recycling of plant nutrients. Soil quality also includes the capacity of soil to provide mechanical anchor for the root of plant as well as all symbiotic association between the plant and the constituents of the rooting zone including uptake of soil water and soil nutrients. The provision of the capacity for filtration, buffering, degradation, detoxifying and re-use of organic and inorganic materials is also an important quality function of the soil. The integrities of these qualities or functions are assessed using indicators that are based on, and possibly composed of, soil properties that are measured. These indicative soil properties are categorized in Table 8 as visual, physical, chemical and biological in nature and inform clusters of indicative soil quality issues. The indicative soil quality issues, collected from the use case examples, will form input for further analysis in WP3 to define the soil qualities and soil quality indicators that the project will further report on, relative to the defined use case categories and use case topics, and the soil properties that the soil qualities depend on. A first effort towards that purpose is given in Table 9.

Table 8. Indicative Soil Quality Issues

Soil Quality Issues	Kind of possible indicators	Descriptor	Measurement
• Root-ability • Workability, • Availability of soil volume (foothold) and of topsoil,	**Visual indicators** Visual evidence can be a clear indicator of degrading or regenerating processes. They do not necessarily reflect the state of soil qualities but the trend.	• Exposure of the subsoil or rocks • Soil color • Ephemeral gullies • Ponding, signs of runoff • Plant response, type of weeds • Evidence of blowing and deposition	Site visit and description by well-trained expert
• Permeability, • Aeration, • Toxicity • Surface permeability (infiltration), • Porosity, • Water availability,	**Physical indicators** are related to the arrangement of solid particles and pores. Physical indicators primarily reflect limitations or qualities to root growth, seedling emergence, infiltration, and holding capacity and movement of water within the soil profile, affecting soil-plant relations.	• Soil depth • Topsoil depth • Coarse fragments content • Bulk density • Porosity • Aggregate size and stability • Stickiness • Texture • Crusting • Compaction	Site visit, soil description, measurements, soil sampling and laboratory analysis
• Sodicity, • Agricultural intensification potential	**Chemical indicators** The soil's chemical condition affect soil-plant relations, water quality,	• Soil pH • Salinity • Organic matter content	Soil sampling and laboratory analysis

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• Salinity, • Alkalinity • Nutrient balance • Nutrient availability, • Acidity,	buffering capacities, availability of nutrients and water to plants and other organisms, mobility of contaminants etc.	• C/N ratio • Organic matter components • Phosphorus concentrations • Cation-exchange capacity • Exchangeable bases and acids • NPK and micronutrients • Heavy metals Etc.	using standard methodology
• Agricultural suitability • Organic carbon (SOC) availability (feed for microbes). • Soil health • Soil quality status	**Biological indicators** The soil's biological conditions affect soil capacity to recycle nutrients from organic matter. It affects nutrient fixation and cycling functions. It works on degradation of biotics and other contaminants, availability of nutrients and water to plants and other organisms, mobility of contaminants etc.	• Micro and macro-organisms, • Earthworm, nematode, or termite populations • Soil Fungal formation and stability of soil aggregates. • Measurement of residue of decomposition rates • Mycorrhizae and Rhyzobium	Soil sampling and laboratory analysis using standard methodology.

Table 9. Soil qualities relevant for the distinguished use case categories and use case topics (incomplete)

Uses	Users	1 Governance	2 Knowledge generation	3 Operational use
1	Integrated soil fertility management, incl. nutrient cycling & provision	- Nutrient availability - Water availability - Acidity	X	X
2	Agronomic decisions on soil and crop management (productivity), incl. primary productivity	- Nutrient availability - Water availability - Acidity - Workability	X	X
3	Agronomic decisions on soil and crop management (sustainability)	- Nutrient availability - Nutrient retention - Acidity	X	X
4	Academic and research purposes		X	
5	Climate change adaptation and mitigation, incl. carbon sequestration, cycling & regulation	X	X	

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6	Soil quality monitoring		X	
7	Natural resource management	X	X	
8	Soil and water conservation decisions	X	X	X
9	Agricultural decision making			X
10	Land evaluation and land use planning	X		
11	Environmental management (pollution, nutrient leaching, etc.)	X		
12	Soil biodiversity conservation, incl. habitat and biodiversity	X		
13	Extension services	X	X	
14	Advocacy, awareness creation and training	X	X	
15	Policy analysis and decisions (policy making)	X		
16	Irrigation design		X	
17	Others (specify)			
18	Water regulation	X		

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7 Conclusion

The need to develop a veritable SIS for Africa is felt by all stakeholders in the agricultural sector and related fields including those involved in sustainable Intensification. The SIS is proposed to be a repository of basic soil data and derived soil information including soil quality indicators that will be made accessible to broad stakeholders' group that may require such information in their various fields of endeavour. Distinguished were three broad use case categories knowing (1) governance, (2) knowledge generation including technology development and transfer and monitoring and (3) operational use issues such as e.g. farming, and these use categories were further refined according to specific use case topics. Selected use case examples indicated that the basic soil physical, chemical and biological parameters are the most solicited by the selected end users, together with guidelines for their interpretation, including soil quality issues, of possibly composite nature, that could either be measured directly through sampling and laboratory analysis or calculated based on well tested methodology such as e. g. pedo-transfer functions. Definitive soil quality indicators, relevant for the three distinguished broad use case categories, will be worked out in detail in work package 3 based on the here indicated soil quality issues. The structure of the SIS will endear interoperability with other soil databases or systems as well as ancillary information portals on vegetation, land degradation etc. The development of the system may consider the provision of data on the status of the soil and its qualities on location-specific basis. The use of state-of-the-art methods for Digital Soil Mapping will provide the opportunity to predict and map the status of the various soil parameters and derive the soil quality indicators. The accuracy of these predictions as well as the relevance can be enhanced by including location-specific user information, on land use and management, as additional input to predict the status and later evaluate the impact of the land use and management practices. Regular update of the SIS is vital to its continuous relevance for Sustainable Intensification, both in terms of decision making and for monitoring purposes, including provision of accurate data to the end users.

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Annex 1. Information sheet for Soil Info User Questionnaire

Background

The purpose of this questionnaire is to collate stakeholders' thoughts on soil information needs that would inform the collection of relevant soil data and information for the development of a useful Soil Information System (SIS). The Soils4Africa project is a Horizon 2020 initiative supported by the European Commission (EC), to collect soil data across Africa and develop a robust SIS for broad based uses. It will form a baseline for future soil monitoring purposes and intends to facilitate informed decision-making towards sustainable agricultural intensification practices.

You have been selected as a stakeholder and respondent to these questions based on the recognition of your institute and your expertise to contribute to the development of soil information in Africa. Thank you for your contribution.

Introductory questions

1. Which of the following land resource management (sub-)sectors do you contribute to?
    I. Agricultural Production System (for map see www.fao.org/farmingsystems/)
        a. Irrigated
        b. Tree crop
        c. Forest based
        d. Rice-tree crop
        e. Highland perennial
        f. Highland temperate mixed
        g. Root crop
        h. Cereal-root crop mixed
        i. Maize mixed
        j. Large commercial & smallholder

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k. Agro-pastoral millet/sorghum
l. Pastoral
m. Sparse (arid)
n. Coastal artisanal fishing
o. Urban based
p. Dryland mixed
q. Rainfed mixed

II. Nature Preservation
   a. Rangeland conservation
   b. Park, forest and nature reserve management
   c. Soil and water conservation
   d. Ecotourism
   e. Others (Indicate)

III. Water regulation

IV. Agri-business (processing, input distribution, outgrowing, marketing, etc)

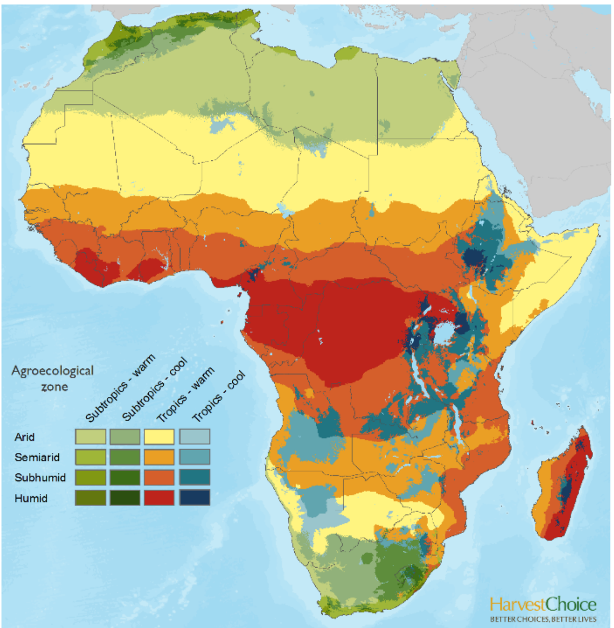
V. Applied research and extension

VI. University

VII. Public sector (Government ministries)

VIII. NGO/Consultancy

2. What is the nature of your/your organization's work ?
   a. Research
   b. Commodity production and marketing
   c. Agricultural advisory services
   d. Policy making
   e. Development research and action
3. What agroecological zone do you work in (With the aid of this map Please tick the appropriate box)
   a. Arid [Subtropic-warm] ☐
   b. Arid [Subtropic-cool] ☐
   c. Arid [Tropics-warm] ☐
   d. Arid [Tropics -cool] ☐
   e. Semiarid [Subtropic-warm] ☐
   f. Semiarid [Subtropic-cool] ☐
   g. Semiarid [Tropics-warm] ☐
   h. Semiarid [Tropics -cool] ☐
   i. Subhumid [Subtropic-warm] ☐
   j. Subhumid [Subtropic-cool] ☐
   k. Subhumid [Tropics-warm] ☐
   l. Subhumid [Tropics -cool] ☐
   m. Humid [Subtropic-warm] ☐
   n. Humid [Subtropic-cool] ☐
   o. Humid [Tropics-warm] ☐
   p. Humid [Tropics -cool] ☐



Sebastian, Kate, 2009, "Agro-ecological Zones of Africa", https://doi.org/10.7910/DVN/HJYYTI, Harvard Dataverse, V2)

Soil data usage-related questions

4. Do you produce or use soil data in your work?
    a. Yes
    b. No
5. For which purposes (Tick as many option as relevant)
    a. Land evaluation and land use planning
    b. Agronomic decisions on soil and crop management (productivity)
    c. Agronomic decisions on soil and crop management (sustainability)
    d. Integrated soil fertility management
    e. Irrigation design
    f. Soil and water conservation decisions
    g. Natural resource management
    h. Climate change adaptation and mitigation
    i. Advocacy, awareness creation and training.
    j. Soil biodiversity conservation
    k. Environmental management (pollution, nutrient leaching, etc.)
    l. Agricultural decision making
    m. Soil quality monitoring
    n. Academic and research purposes.
    o. Extension services
    p. Policy analysis and decisions.
    q. Others (Specify)
6. What type of soil data do you use?
    a. Soil analytical data (soil samples & soil profiles)
    b. Soil analytical data (soil property maps)
    c. Soil descriptive data (soil horizons & soil profiles)
    d. Soil descriptive data (soil class maps)
    e. Others (Specify)
7. What soil data sources do you use? (tick the relevant options)
    a. National soil research institute (reports, maps, databases)
    b. International organization open source databases.
        i. ISRIC – World Soil Information library (www.isric.org : reports, maps)
        ii. ISRIC – World Soil Information datahub (data.isric.org)
        iii. SoilGrids ; www.soilgrids.org)
        iv. FAO Data (http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/en/)
        v. World Bank (https://datacatalog.worldbank.org/dataset/soil-classifications)
        vi. Europa soil dataset (https://esdac.jrc.ec.europa.eu/ESDB_Archive/Soil_Data/Global.htm)
        vii. Soil geographic dataset (https://www.isric.org/explore/soil-geographic-databases)

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c. Own collected primary data and maps.
d. Literature
e. Other sources (Specify)

8. What are the difficulties in using these data sources? (Tick relevant options)
    a. Data are not FAIR and thus not complete
        i. Findable (metadata of data sources, infrastructure)
        ii. Accessible (difficulty and high cost of accessing data, infrastructure)
        iii. Interoperable (data not available in GIS format (e.g. shapefile, raster layer, GeoTiff) or DBase format
        iv. Reusable (metadata describing the data is insufficient)
    b. Data are irrelevant for the use purpose. Scope of the data is insufficient (too shallow depth, too few properties)
    c. Data (interpretation for use purpose is difficult
    d. Cannot be downloaded. Technically too complex
    e. Inadequate scale or resolution of data.
    f. Data are of a too heterogeneous nature.
    g. Inadequate or not existing data license
    h. Others (Specify)
9. How could existing data sources be improved?
    a. Specify lineage
    b. Complete metadata
    c. Data license made explicit.
    d. Include more parameters
    e. Include deeper depth intervals (topsoil, mid soil, subsoil)
    f. Enhance data visualization
    g. Provide data with (modern) unit of measurement.
    h. Provide data with specification of data collection & analysis method.
    i. Others (Indicate)
10. In what format will you prefer to have your soil data
    a. Accessible online with smart graphics (digital and machine readable)
    b. Accessible on smart phone app (digital and machine readable)
    c. Capable of providing real time soil status.
    d. Published in books with map and illustration (analogue)
    e. Want info on current status with projection.
    f. GIS polygon maps of soil classes and/or properties
    g. GIS raster maps of soil classes and/or properties
11. To what extent are you interested in a soil Information system that provides basic parameters like pH, EC, SOC, CEC, BS, texture, etc., to derived composite quality indicators like a soil fertility status, agricultural suitability, agricultural potential, erodibility, soil degradation indicators etc. [tick one option]
    a. 100% basic parameters
    b. 100% composite indicators
    c. 50%/50% blend of basic parameters and derived indicators

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   d. 75% basic parameters and 25% composite indicators

12. What basic soil properties are you keenly interest in having in your SIS and at what depth interval (topsoil, mid soil, subsoil)? (Tick relevant options)
    a. Coarse fragments content [top mid sub]
    b. Sand, silt, clay content (textural fractions) [top mid sub]
    c. Bulk density [top mid sub]
    d. pH (measured in water) [top mid sub]
    e. pH (measured in KCl or CaCl2) [top mid sub]
    f. Electrical conductivity [top mid sub]
    g. Soluble salts contents [top mid sub]
    h. Exchangeable bases (Ca, Mg, K, Na, Al) [top mid sub]
    i. Exchangeable acids (H, Al) [top mid sub]
    j. Effective cation exchange capacity [top mid sub]
    k. Cation exchange capacity [top mid sub]
    l. Base saturation [top mid sub]
    m. Total carbon content [top mid sub]
    n. Organic carbon content [top mid sub]
    o. Total N content (macronutrients) [top mid sub]
    p. Total P content (macronutrients) [top mid sub]
    q. Available (extractable) P content (macronutrients) [top mid sub]
    r. Available (extractable) K content (macronutrients) [top mid sub]
    s. Mesonutrients (incl. Ca, Mg) [top mid sub]
    t. Micronutrients (incl. B, Cu, Zn, S) [top mid sub]
    u. Water retention at wilting point, field capacity and saturation [top mid sub]
    v. Water holding capacity [top mid sub]
    w. Soil depth
    x. Others (Specify)

13. Which soil qualities (from FAO) are most relevant to your work ? (Tick as many as appropriate)
    a. Availability of soil volume (foothold) and of topsoil,
    b. Porosity,
    c. Acidity,
    d. Alkalinity
    e. Toxicity,
    f. Surface permeability (infiltration),
    g. Salinity,
    h. Sodicity,
    i. Aeration,
    j. Workability,
    k. Nutrient balance
    l. Nutrient availability,
    m. Organic carbon (SOC) availability (feed for microbes).
    n. Water availability,

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   o. Permeability,
   p. R
   q. Soil health
   r. Soil functioning
   s. Agricultural suitability
   t. Agricultural intensification potential
   u. Soil quality status

14. Please indicate the importance of the following soil functions with regard to Sustainable Intensification of agriculture in your region. Which functions are considered most important? Allocate 15 points between the five soil functions, where one function can receive a maximum of 5 points.

Soil functions	Points
Primary productivity The capacity of a soil to, actually or potentially, produce plant biomass for human use, providing food, feed, fiber and fuel within climatic and natural or managed ecosystem boundaries.	
Water regulation (and purification) The capacity of a soil to receive, store and conduct water for subsequent use, prevent droughts, flooding, erosion (and to remove harmful compounds) codefining primary productivity potential in agriculture .	
Carbon sequestration, cycling and regulation The capacity of a soil to reduce the negative impact of increased greenhouse gas emissions (i.e., CO2, CH4, and N2O) on climate, among which its capacity to store carbon.	
Nutrient cycling and provision The capacity of a soil to receive, provide and carry over nutrients into harvested crops codefining primary productivity potential in agriculture.	
Habitat and biodiversity The multitude of soil organisms and processes, interacting in an ecosystem, providing society with a rich biodiversity source and contributing to a habitat for above ground organisms	

Reflective Questions

15. How important is improving soil management to improve soil qualities ?
   a. Most important
   b. Highly important
   c. Important
   d. Seldomly used
   e. Not important.
16. How important is improving soil qualities to improve agricultural productivity?
   a. Most important
   b. Highly important

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   c. Important
   d. Seldomly used
   e. Not important.

17. How important is good soil information/data to good agricultural soil management practices?
   a. Most important
   b. Highly important
   c. Important
   d. Seldomly used
   e. Not important.
18. How important is good soil information/data to monitor the impact of agricultural soil management practices on soil qualities?
   a. Most important
   b. Highly important
   c. Important
   d. Seldomly used
   e. Not important.
19. What is your opinion about "soil quality" in your region and what are your concerns regarding soils? (from your professional and not your personal point of view)?………
……
……
……………………………..

20. Do you implement policies or actions regarding land use and soil management? Which?

- ……
……
……
………………………………

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Annex 2. Discussion points for key informant interview on SIS use cases

Discussion Points: Use Case Interviews

Introduction and Background

- An explanation of the nature of their work

Soil information needs and usage

- What part of their work is related to soil management? (Try to get information related to specific projects as well, apart from general information about overall portfolio)
- Do they use soil data in their work? What kind of indicators do they use?
- What are the sources of soil data that they refer to?

Gaps

- What is their assessment of the soil data sources/ soil information systems they do have access to? What do they find useful about them? What are their shortcomings? How could they be improved?
- Are there any soil data sources that they are aware of but do not have access to?
- Are there any indicators that they would like to use but do not have access to?
- What are the reasons for the lack of access?

Specific reflections upon Soils4Africa's efforts to build a SIS

- We explain to them the Soils4Africa project and the ideas behind the SIS. (This writeup can help: https://www.soils4africa-h2020.eu/why-build-sis-for-africa). And we ask them what would be their wishlist from such a Soil Information System. What indicators should it have? What should the interface be like? Etc.
- Please refer to the questionnaire for pointers and supplementary information that can help guide the discussion further: https://docs.google.com/forms/d/1wsEvC46PDWcbVQZWhvXfKh7j526gSxsD4Yz4yf8IwZg/edit

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