Identifying, Cataloguing, and Mapping Soil and Agronomic Data in Ethiopia

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Identifying, Cataloguing, and Mapping Soil and Agronomic Data in Ethiopia

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Acronyms and abbreviations

AGP	Agricultural Growth Program
AFSIS	Africa Soil Information Service
AFSP	Africa Soil Profiles Database
AGRA	Alliance for a Green Revolution in Africa
ATA	Agricultural Transformation Agency
BENEFIT	Bilateral Ethiopia-Netherlands Effort for Food, Income, and Trade
BMGF	Bill & Melinda Gates Foundation
CABI	Centre for Agriculture and Bioscience International
Cascape	Capacity building for scaling up of evidence-based best practices in agricultural production in Ethiopia
CDE	Centre for Development and Environment
CIMMYT	International Maize and Wheat Improvement Center
DEM	Digital Elevation Model
DSM	Digital Soil Mapping
ECDSWCo	Ethiopian Construction Design and Supervision Works Corporation
ENTAG	Ethiopia-Netherlands Trade Facilitation for Agribusiness
EthioSIS	Ethiopian Soil Information System
FAO	Food and Agriculture Organization of the United Nations
GIS	geographic information system
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics

ILRI	International Livestock Research Institute
ISRIC	International Soil Resources Information Centre
ISSD	Integrated Seed Sector Development
OFRA	Optimizing Fertilizer Recommendations in Africa
ODI	Open Data Institute
MoA	Ministry of Agriculture
RARIs	Regional Agricultural Research Institutes
REALISE	Realising Sustainable Agricultural Livelihood Security in Ethiopia
SBN	Sesame Business Network
SILMLESA	Sustainable Intensification of Maize-Legume Systems for Food Security in Eastern and Southern Africa
SRTM	Shuttle Radar Topography Mission
SSPF	Soil Spatial Prediction Function
TAMASA	Taking Maize Agronomy to Scale in Africa
UNDP	United Nations Development Programme
WLRC	Water and Land Resource Centre
WOSSAC	World Soil Survey Archive Catalogue
WWDSE	Water Works Design and Supervision Enterprises

Contents

Tables

Figures

Appendix Tables

Photo: CIAT/GeorginaSmith

Executive summary

The Government of Ethiopia and its various sectors, supported by international research centers and development organizations, are demonstrating their eagerness to embrace new developments and technological advances. Efforts are underway to "modernize" the agricultural sector and partner organizations are working to assist in building capacity in data collection, management, access, and reuse. In this regard, GIZ is supporting an effort by the International Center for Tropical Agriculture (CIAT) (now part of the Alliance of Bioversity International and CIAT) and other partners to bring soil and agronomic data together and facilitate informed decision-making. As part of this exercise, the Coalition of the Willing (CoW), individuals and institutions that are willing to share data and facilitate data access, was established in 2018. To facilitate the process, the CoW created a taskforce composed of senior experts on soil and agronomy. Among its various ventures, the taskforce met and laid out its short- and long-term plans, including identifying, cataloguing, and mapping soil and agronomic data in the country. This report is part of the effort to "map the data ecosystem" (identify where major soil and agronomic data are located, characterize them in terms of pre-defined attributes, and pave the way to collate and reuse those data to facilitate informed decision-making). The report covers the efforts made **to identify, catalogue, and map soil and agronomic data** as well as corresponding metadata from relevant public, international, federal, and regional research and development institutions in Ethiopia.

For ease of synthesis and data description, the report categorizes the soil and agronomic data into:

1 Soil survey and mapping data

2 Research-based soil and agronomy data

For the assessment, a template was prepared to guide the review process. The tabular template was designated to capture data object/title, geospatial frame, data holding institution, publication type, year of publication, geometry, scale/ resolution, area coverage, format and data access/sharing.

The data sources were also evaluated in accordance with the **FAIR data principles.** The review enabled to map institutes, sectors and organizations which hold soils and agronomy data, assess whether those datasets have adequate metadata and identify which of the stakeholders are willing to share their data and under what conditions.

The exercises demonstrated that there are enormous soils and agronomy related data scattered across different organizations, data collection is based on inconsistent approaches and close to 45% of the data holders are willing to share provided that official request is made.

A centralised digital database containing national soils and agronomy data/metadata is lacking. Consequently, access to soil and agronomy data is difficult. In addition, in the national agricultural research system most research-based soil and agronomy raw dataset are not available neither as standalone publications nor as annex/appendices of main publications. Moreover, raw dataset documentation, access, and sharing within the national agricultural research system and higher learning institutions are weak, which likely make source/mother data vulnerable to permanent loss and cause duplication of efforts.

To implement a sustainable national soil and agronomic database and facilitate soil and agronomic data access and sharing, it is important to create awareness about the Soil and Agronomy Data Sharing Policy to promote wider access to soil and agronomic data; use legal and policy tools to enforce data sharing among relevant institutions; establish a centralized digital repository for both published and raw datasets to host soil and agronomic data that can be accessible to relevant organizations; adopt guidelines for soil and agronomic research and survey missions that include open data standards; ensure that duplicated data are dealt with appropriately when collating existing data from across the soil and agronomic data ecosystem; ensure that data publication and data acquisition/sampling dates are correct when collating existing data; ensure that best practices for geo-references are embedded into the guidelines for research on soil and agronomy; ensure that institutions using public money to collect public data are obliged to establish accessible data repositories for both raw data and publications and/or share data in a timely fashion within the institutions and with nationally mandated public bodies; and create capacity and awareness to collect geo-referenced data.

In addition, it is vital that the support of GIZ, BMGF, and other development partners continue so that a national digital soil and agronomy database is established. This will support agricultural transformation in the country and strengthen the national digital spatial data infrastructure aligned with the digital economy plan envisioned to build digital agricultural platforms in Ethiopia. If successful in collating all the data available across the data landscape, high potential exists to employ recent developments in big data analytics and artificial intelligence and generate valuable information that can support informed decision-making and facilitate agricultural transformation.

1. Introduction

1.1. General

Soil and agronomic studies have been conducted in Ethiopia since the 1950s. A great deal of work has been conducted related to crop response to fertilizer applications and soil survey and mapping. However, the data collected from the studies are scattered across different individuals and organizations and exist in diverse formats. As a result, most of the data are difficult to access and lack standards or are incomplete, which diminishes their utility. This resulted in duplication of effort and wasting of resources to collect redundant data.

These bottlenecks necessitated collating available datasets and creating a standardized database. An organized and concerted effort to collate soil/agronomic data started in 2017 with support from GIZ, which provided financial and technical support to CIAT and other partners. Steps taken to achieve this involved (a) conducting bilateral discussions to create awareness on the overall data ecosystem, (b) inquiring about and accessing data from individuals and institutes that were willing to share, (c) formally approaching individuals and institutions to access their data, and (d) collating published data from peer-reviewed journals. A notable success from these steps was that data collated from peer-reviewed publications led to metadata analysis, which demonstrated the benefits of bringing datasets together and enabled awareness creation. The results of the meta-analysis by CIAT and other reviews conducted by national and regional research centers were presented during a national workshop held at the beginning of 2018. This served as an eye-opener and incentivized the team to pursue further data collection efforts. With continued support from GIZ, CIAT and its partners continued engagement with different data holders, which resulted in the creation of the Coalition of the Willing (CoW). The CoW is a team of experts and institutes that are willing to share their data and support the process that promotes data-sharing efforts. The CoW formed various taskforces composed of senior soil scientists and agronomists to support its activities, including awareness creation and capacity development. Among the outcomes of this effort was the development and launching by the Ministry of Agriculture (MoA) of the Soil and Agronomy Data Sharing (SADS) Policy. Based on FAIR data principles, the policy is an important breakthrough toward facilitating data sharing in support of Ethiopia's agricultural transformation efforts.

Despite this progress, most of the soil/agronomic data remain scattered. In addition, a gap still exists in our knowledge of data holders and the nature of the data available. The lack of access to legacy soil and agronomic data has constrained the national data analysis needed to generate site-specific optimized fertilizer recommendations and to guide policymakers regarding season-based fertilizer purchase and distribution systems. This has necessitated the exploration of the soil and agronomic data in the country as part of realizing the provisions of the policy. Cognizant of this, CIAT and EIAR, supported by GIZ, are engaging in data collation, storing, and analysis endeavors. This report is part of the dedicated efforts to map and characterize the soil and agronomic data that are available across different institutes and organizations to facilitate data access and sharing.

1.2. Mission overview

Advances in Earth observation sciences, data storage facilities, and data-mining techniques enable exploring patterns, which would not have been possible a few decades ago. However, the agricultural sector is not benefiting from this rate of development despite recognizable advances that are being made in developed regions. Common sense generally points to the fact that advanced options, technologies, tools, and techniques should be applied in the places where they are needed the most. Globally, developing regions and the agricultural sector are those that deserve the best technologies available. Agriculture is the prime means of livelihood for millions and the basis for industrialization in most developing countries.

The government of Ethiopia and its various sectors, supported by international research and development organizations, have demonstrated readiness to embrace new developments and technological advances. Various activities are underway to support these government efforts through building capacity in data collection, management, access, and reuse. The creation of the CoW and its taskforce is an example of important breakthroughs in defining a sequence of activities. Among the prioritized activities of the taskforce was to identify, catalogue, map, and characterize soil and agronomic data.

This report provides an overview of the available soil and agronomic data from various research programs and survey initiatives in the country. To enhance the data description and interpretation, the report describes the soil and agronomic data by categorizing them into (a) soil and agronomic survey and mapping data and (b) research-based soil and agronomic data related to crop response to input applications. The report provides the data object/title, geospatial frame, data holding institution, publication type, publication year, geometry, scale/resolution, area coverage, data availability format, and data access/sharing captured by a predefined tabular template. The data sources were also evaluated in accordance with the FAIR data principles, which state that data should be Findable, Accessible, Interoperable, and Reusable. The review also included a question to investigate the willingness and the preconditions of the data holders to share their data.

1.3. Objective

The general objective of this mission is to improve the collection, management, access, and reuse of soil and agronomic data in Ethiopia. The specific objective is to identify, catalogue, map, and characterize the soil and agronomic data that reside in different institutions. The ultimate goal is to map the data ecosystem and develop a central database to facilitate data access/sharing following FAIR principles.

1.4. Scope of the study

The CoW and taskforce members developed a tabular template to be filled during the review. The authors also conducted a literature review to assess elements that can be used to characterize datasets. Considering this, the scope of the study was designed to include the following key components:

- Identify, list, and map institutions that have soil- and agronomy-related data;
- Define the kinds/types of data held by each of the institutions;
- Indicate the name of the data and/or projects, institutions, individuals, etc., that have collected/collated the data;
- Identify the purpose for which the data have been collected and other processed data/output types, if any;
- Characterize the data in terms of temporal and spatial coverage;
- Describe the approaches used to collect and/or collate the data;
- Indicate whether the data have been geo-referenced and show how the location attribute was made/assigned;
- Check and describe how the data are stored (in a database, office computer, individual PC, analogue form, etc.);
- Evaluate whether there is a process to check data accuracy and, if so, indicate how standards are set and check whether those are met during data collection;
- Evaluate whether the data have metadata and describe the attributes within;
- Assess whether the metadata are indexed;
- Evaluate whether there is additional documentation of the data (e.g., publication);
- Assess whether the data are licensed and what the licenses stipulate; and
- Evaluate the data in terms of the FAIR data principles (data are Findable, Accessible, Interoperable, and Reusable).

2. Approach and methods

2.1. Organizational visits and interviews

Organizations collecting and holding soil and agronomic data were visited to undertake inventory and characterization of the data using a predefined template. The initial list of potential data holders was made during the CoW meeting in an exercise called "soil/agronomic data ecosystem mapping." The visits were accompanied by interviews of responsible people and those believed to have data. The visits and interviews were conducted from August to October 2019. When a direct visit was not possible, information was obtained from official websites and by contacting the persons in charge via email or phone.

2.2. Online resources access and review

International and national institutional online soil and agronomic data repositories were accessed and reviewed as per the scope of this assignment. The international institutional online search and review included:

CGIAR (https://cgspace.cgiar.org) for CIAT, CIMMYT (TAMASA and SILMLESA projects), ICRISAT, ILRI, and AGRA-OFRA;
ISRIC (https://www.isric.org/explore/library);
WOSSAC (http://www.wossac.com/index.cfm); and
FAO (https://bit.ly/3lqvs8c).
For the national institutional online review, the major ones involved EIAR DSpace (https://bit.ly/33w0h5z);
WLRC (https://www.wlrc-eth.org/);
Haramaya University (https://bit.ly/37kbTtr);
Mekelle University (http://.mekelle.edu.et);
Hawassa University (http://.hawassa.edu.et);
AAU institutional repository (hhttps://bit.ly/3obOYHr);
Bahirdar University (http://bdu.edu.et);
SINET Journal of Science (https://www.ajol.info/index.php/sinet);
Ethiopian Journal of Agricultural Sciences (EJAS) (https://bit.ly/2VmNDBo);
Journal of Agriculture and Environmental Sciences (https://bit.ly/36mlxMD); and
Journal of the Drylands (https://bit.ly/3o9qu1n).

3. Results and discussion

3.1. Soil and agronomic metadata/ data description and interpretation

The soil and agronomic metadata/data description and interpretation are based on the template provided to conduct the assessment. The key components included in the tabulated template are listed in Table 1.

Table 1: Basic attributes and descriptions of soil and agronomic data categories used during mapping and characterization of soil and agronomic data in Ethiopia

TABLE COLUMN TITLE	DESCRIPTION
Data object /data repository	Title of the dataset/publication
Geospatial frame	Information about the area and where the data are related to
Data holding nstitution	Name of the data holding institute/organization/agency/commission
Publication type	Distinguishes the various publication types
Publication year	Year of the data object/data repository publication (but not the data acquisition year)
Geometry	Distinguishes between raster and geographic features: polygon, point, and line
Scale/resolution	The study/mapping scale or resolution
Area coverage (ha)	The size of the area covered by the survey/study
Data availability format	Distinguishes among analogue, digital, database, standalone PC, online repository
Purpose	The purpose for which the data are collected
Metadata	Whether the data have associated metadata and whether they are indexed
Data accuracy	Whether there is a process to check data accuracy and quality assurance
Approach	Approach(es) used to collect and/or collate the data
FAIR	Findability, Accessibility, Interoperability, and Reusability of data and data infrastructure
Data sharing	Information about willingness to share (yes or no with reasons)

3.2. Soil and agronomic data hosting institutions

3.2.1. Soil Survey and Exploration Data Hosting Institutions

Soil and agronomic data in Ethiopia are generated/collected, held, and shared by various international, national, and regional institutions. Significant soil survey and mapping published and raw datasets are available at the Agricultural Transformation Agency (ATA) collected through the EthioSIS project. The Ministry of Water, Irrigation and Energy; the Water and Land Resource Centre (WLRC) of Addis Ababa University; Ethiopian Construction Design and Supervision Works Corporation (ECDSWCo); regional Water Works Design and Supervision Enterprises; the Ministry of Agriculture (MoA); federal and regional soil testing laboratories; and Bilateral Ethiopian-Netherlands Effort for Food, Income and Trade (BENEFIT) partnership programs (Cascape and REALISE) also hold huge published and unpublished survey-based soil- and agronomy-related datasets.

International development and research organizations have also been identified as important soil and agronomic data stewards. Internationally, a lot of ongoing activities are underway to harmonize and integrate these data, especially for soil profile data. These activities are mainly linked by the ISRIC–World Data Centre for Soils. ISRIC hosts about 380 soil and agronomic reports and maps, and around 1,800 legacy soil profile datasets of Ethiopia. In addition, the World Soil Survey Archive Centre (WOSSAC) collated approximately 260 soil maps and reports while the FAO legacy soil data portal hosts 32 legacy soil reports and maps related to Ethiopia.

3.2.2. Soil fertility and agronomy research data hosting institutions

Research-based soil and agronomic data (mainly related to crop response to fertilizer application) are collected and held primarily by researchers from federal and regional agricultural research institutions and higher learning institutes. Some national research institutes such as the Ethiopian Institute of Agricultural Research (EIAR) have institutional online repositories (EIAR DSpace Repository) of published soil and agronomic data, which have mainly been collected by the institute's centers. This repository also hosts published data collected and shared by Regional Agricultural Research Institutes (RARIs). The accessible data type in EIAR DSpace involves progress reports, annual reports, research reports, research proceedings, theses/dissertations, and journal articles. These data can be freely accessed via the EIAR local area network.

Efforts had also been made by the soil fertility directorate of the MoA to collate and create a metadata and national soil and agronomic database under the retired Africa Soil Health Consortium (ASHC) project, which was part of the AGRA-OFRA project. From this project, a document repository of approximately 400 research-based publications on soil and agronomy, collated from various research centers and higher learning institutes, was created. The repository hosted digital (scanned/pdf) versions of various research outputs, proceedings, journal articles, and theses/dissertations created from soil and agronomic data. However, the digital repository platform of the original datasets is in personal computers, presumably under individual access, and therefore less accessible and likely vulnerable to loss.

Among the higher learning institutes, the Haramaya University institutional online repository (https://bit.ly/3obNSvc) is a notable one. It hosts approximately 2,300 soil- and agronomy-based theses/dissertations that have used a significant amount of soil and agronomic research outputs/datasets.

Efforts by various development partners have been ongoing to complement the existing soil information system of Ethiopia and to facilitate the promotion of balanced soil fertilizer use in the country. In this regard, the BENEFIT-Partnership (Cascape program) and Sasakawa Global 2000 Ethiopia office have generated voluminous soil and agronomic data in more than 120 weredas and 18,000 demonstration sites. The published and raw datasets are available at the respective program offices.

In parallel, international research institutes such as CIAT, CIMMYT (TAMASA and SILMLESA projects), ICRISAT, ILRI, and AGRA-OFRA have collected and collated a lot of research-based soil and agronomic data. These published data along with the raw input datasets can be accessed online in the CGIAR CGSpace repository (https://cgspace.cgiar.org).

3.3. Geospatial frame

The geospatial frame indicates information about the area where the data are related to and/or whether the data are geo-referenced or not. Approximately 72% of the national soil and agronomic data are sourced from research and development projects for watershed and sub-basin-based as well as plot-/farm-based studies. The remaining 28% of the data are related to basin, regional, and nationwide research and development study outputs (Figure 1).

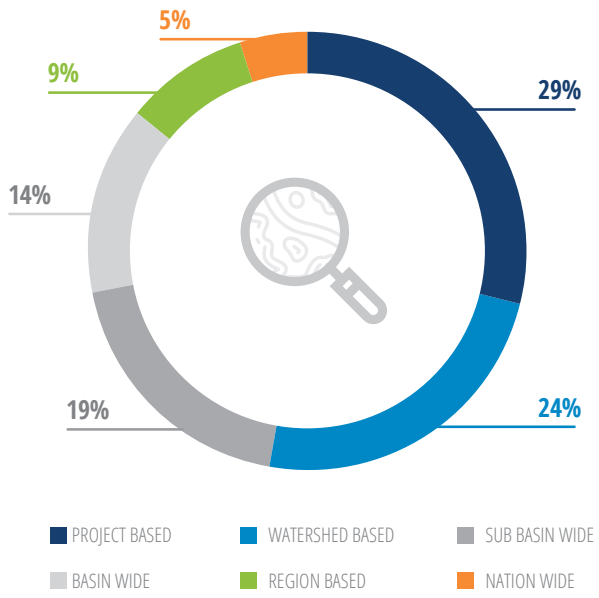


Figure 1: Geospatial frame of national soil and agronomic data available in Ethiopia.

Most survey-based soil and agronomic data are geo-referenced although geo-referencing has some limitations. For instance, most projected coordinate (UTM) usage does not indicate the datum and hence the data positional accuracy is constrained for further application. In addition, most of the survey-based data directly or indirectly collected by the regional soil laboratories are not geo-referenced. Soil sampling from farmers' fields is carried out by laboratory experts, development agents, and farmers but, in most cases, is not supported by geographic coordinates. This is mainly attributed to the shortage of GPS handsets and the limited GPS usage skill of the wereda development practitioners.

Furthermore, most on-station and on-farm research-based soil and agronomic data from the national agricultural research system are not geo-referenced properly. The soil and agronomic research outputs indicate only the geographic coordinates of either the

Photo: CIAT/GeorginaSmith

entire research station or the woreda/kebelle sites where the research is conducted. Indicating only the name or geographic coordinates of the research locality does not give the exact location of the data. In some cases, a location of the household/homestead of the plot/farm owner is registered that doesn't align with the location of the plot/farm under consideration. A common weakness also is that a single location is mentioned for experimental sites located at dispersed locations. These challenges make integrated data analysis as well as extrapolation of soil/agronomic data analysis outputs difficult, and limit wider applicability.

3.4. Published and unpublished information: type and year of publication

3.4.1. Published information

The national research-based soil and agronomic data hosted by various institutions are mainly published as research or project reports, proceedings, journal articles, technical papers, and theses/dissertations. Some similar data are found to be available in more than two publication types. For instance, some research-based data originally collected and used in research reports have later been found published in separate journal articles.

Likewise, it is quite common to see point or spatial survey-based data generated for a specific project being used for wider spatial scale applications at watershed, sub-basin, and basin levels. This demonstrates the need for caution during implementation of a soil and agronomic data repository platform to ensure that duplicated and interrelated information is correctly addressed.

Survey-based soil and agronomic data collected by various survey missions have been mainly reported as project reports (Figure 2). However, approximately 28% and 6% of the survey-based data are available in technical papers and maps/atlases, respectively.

The temporal resolution of the national soil and agronomic research and survey-based data varies from the 1950s to the 2010s (Figure 3). Most of the data (75%) were published from 2001 to 2019. However, data acquisition versus publication year were not properly indicated separately in most publications. Most of the soil and agronomic data are published within a few years after the research or survey is completed. Accordingly, those publications believed to be up to date probably do not contain the most recent data.

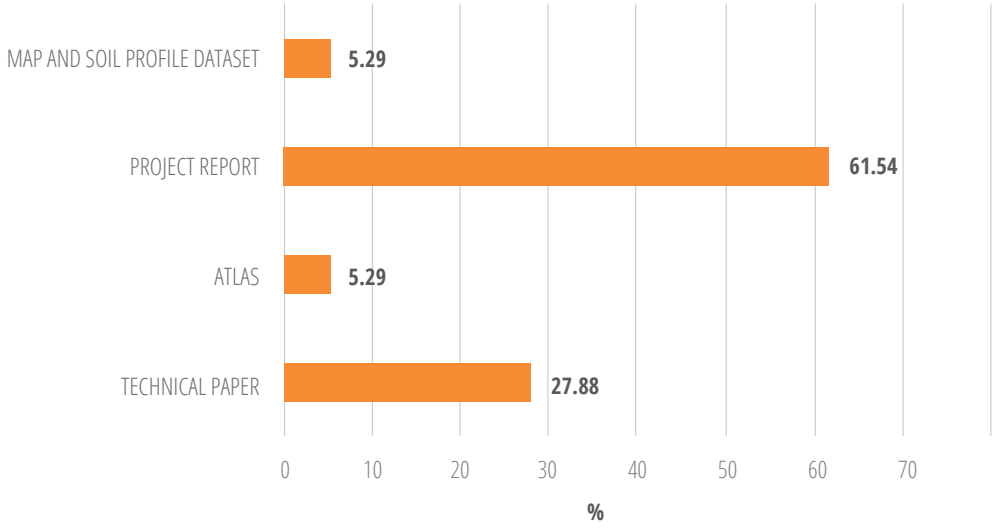


Figure 2: Survey-based soil and agronomic data categorized by publication type in Ethiopia.

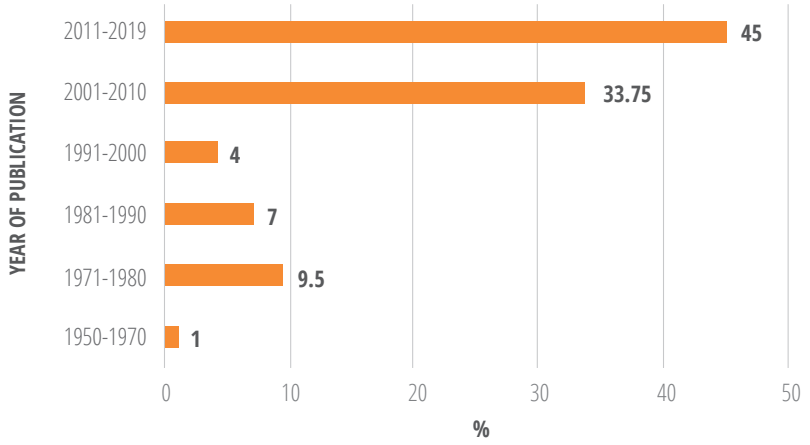


Figure 3: Percentage of soil and agronomic data categorized by year of publication in Ethiopia.

3.4.2. Unpublished information

3.4.2.1. Survey-based unpublished information

Significant unprocessed legacy data are currently available within various survey-based data hosting institutions, which requires revelation and bringing on board to the national central digital system. Moreover, most of the published survey-based data are presented in the form of project reports. These reports in most cases contain associated raw datasets as annex/appendix tables. It has been observed that the survey-based legacy data and data currently being generated by various survey missions are commonly analyzed and interpreted to meet given project objectives. However, under common circumstances, the data have several attributes for wider spatio-temporal application if analyzed and interpreted properly using state-of-the-art techniques evolved over time. This implies that, even if the data along with the raw datasets are published for a specific project scope, their unused attributes might be vital for another application. Furthermore, full legacy raw datasets generated for a specific project objective can be pooled/aggregated and used as an input for various ecosystem service spatio-temporal dynamics and simulation studies. Hence, adding new data to the existing data demanding system

and also unveiling unexplored patterns in legacy data using state-of-the-art big data analytics will likely improve various data-driven decision support systems.

Most of the published survey-based data in the form of maps/atlases do not contain published quantitative point datasets used to build that specific spatially explicit predictive soil and agronomic information. These point datasets are not only the basis to fully understand the map product but can also serve as a potential secondary data input for further analysis. For instance, huge (about 100,000) country-wide point soil spectra and wet-chemistry-based datasets of the ATA/EthioSIS project have not been shared (along with the region-wide predicted raster soil property maps) with the public for various reasons. This requires a quick fix to avail of public data collected by public bodies timely for the public and before the data become legacy data.

3.4.2.2. Research-based unpublished information

Most research-based raw datasets used for various data publication types are not available either as standalone publications or as annexes/appendices of main publications. Moreover, research-based raw dataset documentation, access, and sharing within the national agricultural research system (both federal and regional) and postgraduate research studies of higher learning institutes

Photo: CIAT/ Georgina Smith

are weak, which makes the source/mother data highly vulnerable to permanent loss, and causes duplication of efforts and wasting of resources in redoing similar activities. Therefore, it is highly advisable to timely publish raw datasets as part of main data publication, which in most cases are presented as aggregated results and constrained integrated analysis at various spatio-temporal scales. The upcoming Soil and Agronomy Data Sharing Policy is expected to improve this situation and enable research-based raw data generated by public bodies/taxpayer money to be made available timely to the public before these data become legacy data.

In line with research-based soil and agronomic data, sometimes data generated by centrally coordinated country-wide research missions were abandoned either without being totally analyzed or were partially analyzed for selected data. This scenario in most cases was accompanied without a comprehensive sustained data archiving and sharing mechanism. One of the showcases for such an unfortunate and disappointing situation is the country-wide P-fertilizer calibration study coordinated by the then National Soil Research Centre (NSRC) (currently renamed the National Soil Testing Centre, NSTC), which was implemented by 15 Regional Soil Testing Laboratories (RSTLs) across the country. The generated soil test-based P-calibration data were not completely analyzed and were left abandoned without analysis and proper documentation. This might be attributed to organizational mandate change and staff turnover. Moreover, according to Farina (2011), the main contributing factors were the nature of the experiments (multi-site single-season experiments on different farms each year) and differences in the field methodologies (varied sampling depth, number of subsamples per composite, and subsample volume) for soil test-based calibration trials. Accordingly, these nationally generated huge soil and agronomic datasets were abandoned and left untraceable for not meeting specific objectives. However, if the data do not work for soil test-based P-fertilizer calibration, the soil and crop response data probably fit other purposes to address systemic production and productivity problems across locations. It is worth noting that big data have several attributes that serve wider applications and enabling environments currently exist for dealing with big data. Recent advances in data analysis using machine learning/artificial intelligence have demonstrated that research capacity exists to draw meaningful patterns and relationships from big data, which was impossible some time ago. Hence, abandoned and untraceable data should be tracked down and brought on board in a central digital database for further analysis and interpretation by various users.

3.5. Data geometry

The geometry of the data distinguishes between raster and the geographic features polygon, point, and line. The features of most (80%) of the data are either point or polygon. The point features indicate auger and a profile-based point dataset while the polygon features include soil and agronomic data produced in the form of conventional maps.

The soil maps represented as polygon feature products have some limitations: inconsistency in geo-referencing, mapping procedure, and map display standard protocols. Consequently, the map display does not follow the norms as per the scale, minimum legible delineation, and minimum legible area standards in most cases. Hence, often small (non-mappable) areas as per the set study scale are being populated and presented as mappable units in most conventional soil property and soil type maps or vice versa. This indicates the need to set or adapt national soil and agronomic data geo-referencing and mapping standards, which will be an integral part of a harmonized national soil and agronomic data and research guideline. The recent efforts in terms of developing data standardization guidelines being implemented by the CoW team can help resolve some of these challenges.

The review-based analysis results show that approximately 13% of the data geometry is found to be a raster feature, mainly representing predicted soil property and type maps. The predicted raster maps also have limitations, including failure to transparently communicate the accuracy and sensitivity of the maps to users. This is because the maps are presented as if they are error-free although they vary according to each soil property and geographic region/study area. In some cases, detailed methods about the steps employed and datasets used to develop predictive maps are not provided. Nowadays, various quantitative soil spatial prediction models have internal accuracy measures unlike conventional qualitative techniques. Hence, the accuracy level of predicted soil property or class maps needs to be indicated and transparently communicated to users rather than simply displaying state-of-the-

art predicted raster maps. Moreover, enforcing a harmonized norm to release the geo-referenced point datasets used for the creation of predicted soil maps at the time of publication is needed nationally. This could enhance transparency as well as enable the use of larger datasets.

3.6. Data availability format, sharing, and FAIR principles

The national soil and agronomic datasets collected and published are available in various formats and databases. Most datasets (71%) are available in analogue format and/or digitally in office personal computers (Figure 4). However, only a few datasets are available only in either a centralized database or analogue format.

Most datasets do not have metadata or a catalogue and are directly or indirectly found under individual control. Consequently, access to soil and agronomic data is difficult and sometimes impossible as the data are found in various formats and locations, and in the hands of individuals, and are quite vulnerable to permanent loss. Furthermore, the accessible data are not standardized and harmonized to provide functional information.

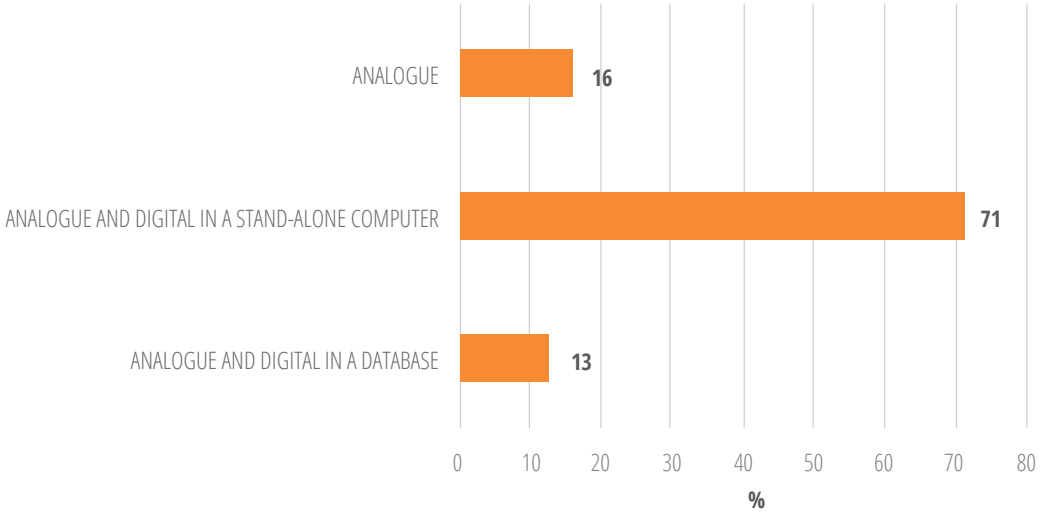


Figure 4: Current soil and agronomic data availability characterized in terms of format in Ethiopia.

Approximately 46% of the national soil and agronomic data holding institutions are willing to share their data if users can provide an official request letter from their respective organizations. In this regard, the notable institutions are WLRC; Ministry of Water, Irrigation and Energy; Oromia Water Works Design and Supervision Enterprise; and SASAKAWA Global 2000. These are encouraging signs as close to half of the data holders are willing to share their data.

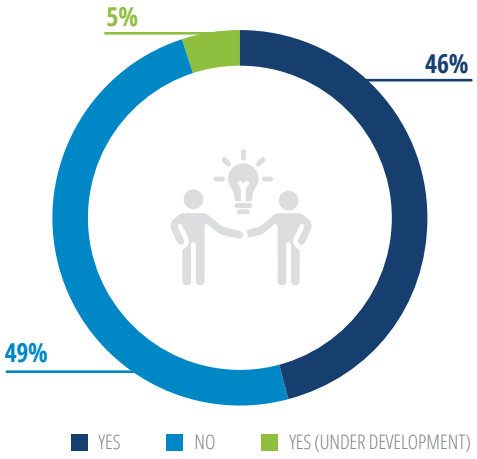


Figure 5: Soil and agronomic data characterized by access/sharing willingness of data holders in Ethiopia.

Access to data in 49% of the data holding national institutions is generally not free (Figure 5). Organizations that are not willing to share soil and agronomic data have not been able to provide approved institutional policies or regulations that prohibit public data sharing. Hence, there is a need to continue interactions and awareness creation so that the remaining data holders will be willing to share. The recent national Soil and Agronomy Data Sharing Policy approved by the Ministry of Agriculture can also facilitate access and sharing.

Similarly, some organizations, especially public consulting firms, are not willing to share data and some oblige their clients not to share their data with third parties. Public consultants usually put indicators in their reports to demonstrate that the data or reports are produced solely for a specific project and presented as their own intellectual property right. Hence, if the data or reports are required for other uses, consultants may demand authorization to access them. This scenario has constrained the national soil and agronomic data sharing ecosystem although the data providers (clients) are willing to share public data with diverse users but are restricted by consultants' internal policy.

In many circumstances, public consultants and other organizations have been found to use secondary data for various ongoing projects without consulting and obtaining formal approval from the data providers (clients). Data collected for one specific project are also being used for watershed or sub-basin or regional synthesis without the consent of the data provider. The lack of valid reasons for not being willing to share data and the opposite practices by consultants demonstrate the limitations of a lack of a national soil and agronomic data sharing policy or failure to enforce the available policy by the respective national institutes. There is thus a need for fast-tracking the approval and implementation of the recently developed national Soil and Agronomy Data Sharing Policy. In addition, engagement with stakeholders and awareness creation will be essential to facilitate enforcing the policy.

Most data of various institutions are held in analogue form and, if they are digitized, they are likely held on an individual's computer, making them difficult to access. In addition, data loss may occur due to the misplacement of analogue data, staff turnover, frequent restructuring of institutions, malfunctioning of personal computers, and computer virus attacks. Because the majority of data are in analogue form, this will constrain sharing and usability by others. Digitalization of these data using standard approaches can improve data sharing.

As part of the new data sharing policy, institutions that collected data using public money need to be obliged to establish institutional data repositories and/or share data in a timely fashion with nationally mandated public bodies to facilitate data access and avoid duplication of effort and inefficient use of resources. For instance, soil survey missions are expensive and usually consume 1,000 euro per soil profile/3D soil dataset (Rossiter, 2008). Hence, if the survey is not properly conducted and the information is lost, that resource is lost and more will be spent repeating a similar activity. This is quite unaffordable for countries such as Ethiopia that have limited financial resources. A speedy intervention to establish a national soil and agronomic data repository platform containing the available data in a standardized format is thus a necessity.

Our review shows that data are collected using different methods, stored in different formats, and processed using different approaches (most of them providing few technical details). This can undermine data sharing and integrated analysis. The datasets available in different institutes were evaluated using the FAIR data principles (Hodson et al., 2018; Wilkinson et al., 2016). Our assessment shows that most of the data fulfill minimal reusability standards but fail to meet the requirements of findability, accessibility, and interoperability. Although most data do not have machine-readable metadata, they have some qualified information about data provenance, which enables users to determine the usability of the data. Most institutions do not provide comprehensive metadata and data standards, which makes data access tiresome and difficult even within an organization.

Conclusions

To avoid duplication of effort and resource misuse, access to existing national soil and agronomic datasets, reports, maps, and other relevant information is vital. However, a centralized digital soil database containing national soil and agronomic data and metadata is lacking. Consequently, access to soil and agronomic data is difficult and sometimes impossible. Moreover, the accessible data are either not detailed enough/content complete or do not provide the functional information required, thus constraining their further use.

Most of the existing soil and agronomic data in Ethiopia are held by international and national (federal and regional) research and development institutions, mainly in analogue format or digitally in office/personal computers. A significant amount of data have been created and held by research-, watershed-, and sub-basin-based study development projects. Sometimes, similar datasets are available in more than two publication types, which requires filtering of redundant information when developing a database.

The temporal resolution of the data varied from the 1950s to 2010s although most data were published from 2001 to 2019. Most research- and survey-based soil and agronomic data were officially published some years after completion of the research or survey, implying that up-to-date publications may not provide the most recent data. Furthermore, in the national agricultural research system, including in both EIAR and RARIs and higher learning institutes, raw research-based soil and agronomic datasets are not available either as standalone publications or as annexes/appendices of main publications. Moreover, research-based raw dataset documentation, access, and sharing within and among organizations are weak, which likely makes the source/mother data vulnerable to permanent loss and also causes duplication of effort.

Most of the accessible survey-based soil and agronomic data are geo-referenced although sometimes geo-referencing has some limitations in specifying the type of datum when projected coordinate systems are employed. Similarly, most on-station and on-farm research-based data from the national agricultural research system are not geo-referenced properly. About half of the national soil and agronomic data holding institutions are willing to share data with minimal preconditions. However, some significant institutions are not willing to share data and at the same time do not have approved institutional policies or regulations, which can hinder public data sharing. The available datasets evaluated as per the FAIR principles revealed that most of the data meet minimal reusability standards but fail to meet the requirements of findability, accessibility, and interoperability.

To develop a sustainable national soil and agronomic database and facilitate soil and agronomic data access and sharing, it is important to consider the following recommendations:

Recommendations

Create awareness about the **Soil and Agronomy Data Sharing Policy** to promote wider access to soil and agronomic data.

Devise mechanisms for incentivizing those that share data in terms of joint publications,acknowledgment, promotion, training to build capacity, and the like depending on the policy of each institute/organization.

Use legal and policy tools to enforce data sharing among relevant institutions.

Establish a centralized digital **repository to host soil and agronomic data** that can be accessible to relevant organizations.

Adopt guidelines for soil and agronomic research and survey missions that include open data standards.

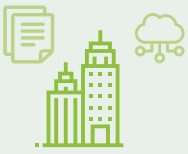
Ensure that duplicated data are dealt with appropriately when collating existing data from across the soil and agronomic data ecosystem.

Ensure that data publication and data acquisition/sampling dates are correct when collating existing data from across the soil and agronomic data ecosystem.

Ensure that best practices for geo-references are embedded into the guidelines for research on soil and agronomy.

Review the use of polygon-based conventional legacy soil maps due to inconsistent mapping protocols requiring harmonization as per map scale, minimum legible delineation, and minimum legible area standards.

Ensure that institutions using public money to collect public data are obliged to establish **accessible digital data repositories**, for both raw data and publications, and/or share data in a timely fashion within the institutions and with nationally mandated public bodies.



Create capacity and awareness to collect geo-referenced data.

Photo: CIAT/Georgina Smith

It is essential that the support of GIZ and BMGF continue so that a national digital database can be built to support agricultural transformation in the country and strengthen the national digital spatial data infrastructure. This will assist the government effort in transforming the predominantly analogue economy into a digital economy whereby the pathway includes building digital agricultural platforms and an integrated system that offers new insights capable of enhancing the ability to make decisions.

If there is a possibility to gather all the data available across institutions and owned by individuals, high potential exists to employ recent developments in big data analytics and artificial intelligence and to generate valuable information that can support informed decision-making and facilitate agricultural transformation. In this regard, the efforts of the CoW and its taskforce are laudable and with some sustained support there is a possibility to develop a model in Ethiopia that can be scaled to other countries.

Appendices

Description of major soil and agronomic data hosting initiatives and institutions

Appendix 1. Soil and Agronomic Data in the Ethiopian Institute of Agricultural Research

Research-based soil and agronomic data are originated and hosted mainly by federal and regional agricultural research institutions and in higher learning institutes. Some national research institutes such as the Ethiopian Institute of Agricultural Research (EIAR) have institutional online repositories (EIAR DSpace Repository) for soil and agronomic data mainly collected by the institute's federal research centers. This repository also hosts some data collected and shared by Regional Agricultural Research Institutes (RARIs).

The EIAR DSpace is a digital service that collects, preserves, and distributes digital material. Accordingly, EIAR has put its institutional publications in DSpace for the public to use them freely. The accessible data type in the EIAR DSpace online repository includes progress reports, annual reports, complete research reports, various research proceedings, theses/dissertations, and journal articles. However, raw soil and agronomic datasets are not available either as standalone publications or as annexes/appendices of main publications. Moreover, raw dataset documentation and access within the research system are poor, which makes the data vulnerable to permanent loss and also causes duplication of effort.

Most EIAR research-based soil and agronomic data have been reported to be officially published some years after the research has been conducted. This requires a quick fix to avail of the public data collected by public bodies timely before the data become legacy data.

Appendix 2. Agricultural Transformation Agency (ATA)-Ethiopian Soil Information System (EthioSIS)

To address many of the soil fertility management and fertilizer use-related problems, the government of Ethiopia (MoA/ATA) in 2010 established the project "The Ethiopian Soil Information System (EthioSIS)" under the overall Soil Fertility Road Map of MoA mainly to conduct soil fertility mapping to reformulate fertilizer recommendations.

Accordingly, huge efforts and investments were made to prepare digital maps of soil fertility parameters from data collected through intensive soil sampling campaigns in cultivated and arable lands. The approach was limited to auger-based composite sampling mainly in the top 20 cm for annual crops and in some cases at 20-50 cm.

The digital soil fertility maps are predicted soil property maps developed using Digital Soil Mapping (DSM)-Soil Spatial Prediction Models (SSPM). The ATA/EthioSIS project has finalized and released the digital soil fertility and fertilizer formulation maps/atlas for almost all regions and has collected approximately 100,000 soil datasets. The EthioSIS predicted digital soil fertility and fertilizer recommendation maps/atlas in general do not present the prediction accuracy for each soil fertility parameter and geographic region. However, research demonstrated that DSM modeling procedures are quantitative and include accuracy/uncertainty assessment capabilities. Failure to transparently communicate the predicted map accuracy parameters to users could lead to skepticism regarding DSM products/maps.

The wereda-based predicted soil property maps do not display geographic coordinates except for depicting simple wereda/kebelle boundary delineations, which constrained extraction of the absolute location of the extent and spatial distribution of soil properties over the map. In addition, soil data acquisition/sampling year versus map publication year was not properly indicated in the EthioSIS maps/atlas. Simply obtaining the map publication year does not confirm whether the publication believed to be updated held the latest data or not. Moreover, the huge point soil spectra and wet-chemistry-based datasets of the ATA/EthioSIS project have not been shared with the public for various reasons. This requires a quick fix to avail of the public data collected by public bodies timely for the public and before these data become legacy data.

Appendix 3. Regional Agricultural Research Institutes (RARIs)

Like EIAR, regional agricultural research institutes have collected and collated huge amounts of research-based soil and agronomic data. Most of the regional agricultural research institutes do not have either an online or offline data repository platform. Most of the data are available in analogue format and/or digitally as scanned versions in personal computers, which makes data access and sharing difficult. The accessible data publication types include progress reports, annual reports, completed research reports, various research proceedings, theses/dissertations, and journal articles. However, like in EIAR, in RARIs, raw datasets are not available either as standalone publications or as annexes/appendices of main publications. Moreover, raw dataset access and sharing within the RARI system is highly fragmented, making source/mother data having wider application highly vulnerable to permanent loss and also causing duplication of effort within the research system.

Mainstream soil and agronomic data are published as proceedings of completed research/experiments by the respective regional research institutes, with the support of various projects. These proceedings are found to be a compendium of annually collected soil and agronomic data for quick data access and timely application.

Appendix 4. Soil Data Hosted by the Ministry of Water, Irrigation and Energy

Land resource studies of river basins started in the 1960s under the then Valley Development Authority and Ministry of Water Resources for integrated development master plan preparation. Reconnaissance soil surveys at a scale of 1:250,000 had been conducted for all major river basins of the country: the Abay, Tekeze, Awash, Omo-Gibe, Wabeshebele, Genale Dawa, Baro Akobo, Genale Dawa, and Rift Valley lake basins. Many soil profile observations and laboratory analyses were made to determine the morphological, physical, and chemical properties of the soils, in addition to irrigation agronomic studies. The data are available in both analogue and digital formats at the current Ministry of Water, Irrigation and Energy. However, the data suffer from a lack of consistency in scope, approach, and methods as different basins were studied at different times by different firms following different approaches and soil classification/correlation systems. It is acknowledged that the basin studies cover the country at a 1:250,000 scale and collect significant soil data (point datasets, reports, and maps). In addition, as part of basin studies, quite significant irrigation and hydropower project studies have been conducted and they have collected much soil information (maps and reports) from 1990 to date.

Appendix 5. Federal and Regional Water Works Design and Supervision Enterprises

To meet soil and irrigation agronomy data demand in the water and energy development projects in Ethiopia, federal and regional Water Works Design and Supervision Enterprises have conducted quite a large number of soil survey, irrigation agronomy, land suitability evaluation, and watershed studies. These enterprises are public consulting firms and they have been commissioned by various clients to conduct studies on many irrigation, hydropower, and basin-wide development master plan preparation projects. Accordingly, these firms have collected a huge amount of soil and irrigation agronomy information. For instance, several site-specific detailed soil survey investigations and irrigation agronomy studies (at scales varying from 1:2,500 to 1:25,000) have been carried out for more than 45 irrigation and multi-purpose projects by the Ethiopian Construction Design and Supervision Works Corporation (ECDSWCo). Soil and terrain information has been collected from 54,585 soil auger observation sites and 4,147+ soil profile pit description sites. Laboratory analysis of soil physico-chemical properties was conducted for more than 12,000 soil samples.

Appendix 5

Similarly, regional water works enterprises such as Oromia Water Works Design and Supervision Enterprise (OWWDSE), Amhara Design and Supervision Works Enterprise (ADSWE), and Tigray Water Works Design and Supervision Enterprise (TWWDSE) have conducted various basin-wide, sub-basin-level, and semi-detailed and detailed soil surveys and irrigation agronomy studies. These studies conducted in various irrigation, hydropower, and masterplan development projects collected voluminous soil and irrigation agronomic data. Data sharing by public water works consulting firms is highly variable. Most of the firms are not willing to share data as they claim that their firms are consultants and are not mandated to share the data of their clients. Furthermore, some consultants oblige their clients not to share data with third parties. This enforcement comes about by putting an article in the report preamble that the data or reports are produced solely for that specific project and belong to the intellectual property right of the consultant. Hence, if required for another use, authorization is required from the consultant, which in most cases does not provide a positive response.

Appendix 6. Soil Data of the Water and Land Resource Centre (WLRC)

WLRC has managed several ongoing platforms to contribute to the development of the national spatial data infrastructure. For instance, the national geospatial information system base of Ethiopia (Ethio-GIS) is a project that was created within the Centre for Development and Environment (CDE), University of Bern. It is a development of all relevant spatial data about terrain, soil, land cover and use, climate, drainage, infrastructure, population, and agriculture. The first release in 1999 was a collection of well-organized spatial data, it was updated for a second release in 2008 with more state-of-the-art components (Zeleke et al., 2008), and in 2016 Ethio-GIS II was released by including updated and additional land resource information.

Regarding soil information, one of the notable achievements of various platforms managed by WLRC in Ethiopia is rescuing various legacy soil maps and reports (studied from the 1960s to 1990s) and integrated as soil layers. The aim was to rescue land resource data including soil data (maps and reports) that were previously studied by the then Land Use Planning and Regulatory Department of the MoA and Soil Conservation and Research Project (SCRP) in the 1970s and 1980s, which were on the verge of being permanently lost. Accordingly, documents converted into digital format and digital data were made available to various users free of charge.

The Centre for Environment and Development in 2012 attempted to update the national soil information of Ethiopia through a master's thesis research work referred to as "A National Soil Model of Ethiopia: A geo-statistical approach to create a national soil map of Ethiopia." The main aim of this research work was to develop and document a procedure to position existing soil information more precisely with support from a 90-m SRTM-DEM topographic base positioning and terrain unit's delineations (Brunner, 2012). The output was synthetic soil layers at 1:500,000 scale. The maps are not intended for use in the field but the model's tools and procedures offer various starting points for further development and adaptation in Ethiopia (Brunner, 2012). Hence, this requires caution and/or transparent metadata communication when the maps are shared with users.

In Ethiopia, soil survey and mapping studies at various scales have been conducted by various institutions since the 1950s. Among those studies, soil profile-based studies conducted by various basin-wide master plan preparation missions, area-based irrigation development studies, and baseline surveys of watersheds of the WLRC are the most prominent ones. These studies collected huge soil profile datasets along with soil maps (WLRC, 2018, Unpublished). Subsequently, using those legacy data, the basin and nationwide polygon-based soil type and soil depth map updating task (at 1:250,000 scale) was conducted by WLRC in 2018 (Figure 6). This study collated more than 3,000 unique and up-to-date soil profile data and 286+ soil study documents from various legacy datasets.

The huge soil data collation task coupled with previous soil data rescue missions make WLRC a national soil data hub to facilitate access and data sharing. WLRC has an online and offline water and land resource repository platform: the Water and Land Resource Information System (WALRIS) (http://walris.wlrc-eth.org/). WLRC follows a free land resource/soil data sharing policy for the public, but users are required to submit an official request letter as a minimal precondition.

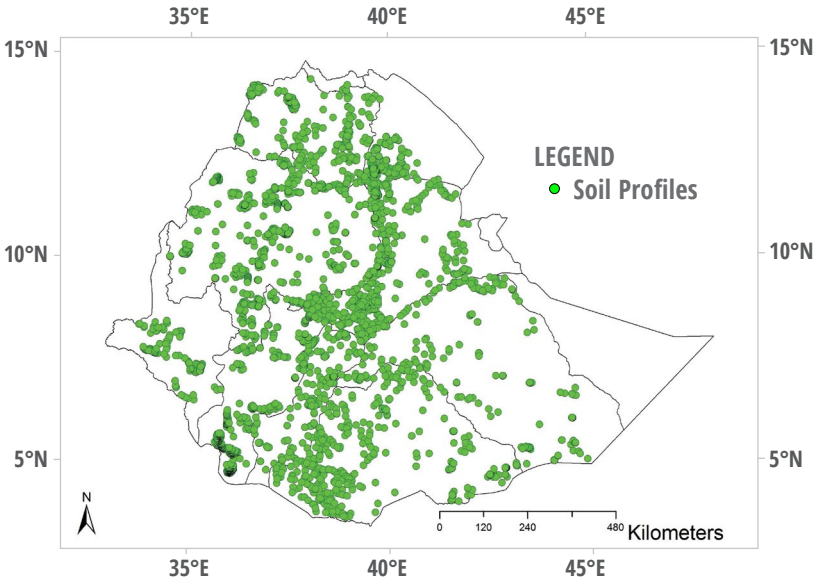


Figure 6: Legacy soil profiles collated by WLRC (after WLRC, 2018, Unpublished).

Appendix 7. Ethiopian soil, plant, and water laboratory infrastructure: federal and regional soil testing laboratories

There are one federal and 17 regional soil testing laboratories across Ethiopia. These laboratories were originally established to provide a fertilizer recommendation advisory service to smallholder farmers and planned to be administered by regional bureaus of agriculture. Currently, these laboratories have different organizational structures in different regions. The laboratories located in Tigray (Mekelle and Shire) and Oromia (Nekemet, Bedelle, Fiche, and Batu/Ziway) regional states are currently administered by regional agricultural institutes and some have been changed to soil research centers. These centers are now conducting research on soil and agronomy. The data collected by laboratories managed under this research system can be accessed through the various research publications of the respective regional agricultural research institutes.

The soil laboratories of Amhara (Debremarkos, Desee, Bahir Dar, and Gonder), SNNPR (Hawassa, Wolaita Sodo, Tepi, and Welkite), Somali (Jigjiga), Assosa (Assosa), and Gambela (Gambela) regional states are owned and managed by regional bureaus of agriculture. These laboratories have collected quite large amounts of data from various missions, but the data can be accessed only directly from the laboratories. Currently, these laboratories are analyzing huge amounts of soil samples from farmers' fields for soil acidity determination and associated lime recommendations. Soil samples are collected by either development agents or the farmers themselves. Hence, quite large amounts of soil and agronomy data are being collected by the regional soil laboratories but the data are not geo-referenced. Soil sampling from farmers' fields is being carried out by farmer names but not supported by GPS coordinates. The main reasons are a shortage of GPS and usage skills, if available. Cognizant of the huge amounts of soil data being collected directly or indirectly by regional soil laboratories annually, there should be a provision for training and implementation of GPS for geo-referenced soil sample collection.

Decision-making by policymakers, farmers, and researchers depends on reliable data on soils, water, and crops. However, a study conducted in 2016 on the status of Ethiopian soil laboratory infrastructure indicated that the data collected (in the chain of soil sampling to laboratory output) are not reliable enough for decision-making purposes (Bakker et al., 2016). Accordingly, the study emphasized the need to improve the output of Ethiopian soil, plant, and water laboratories and suggested strategies for them to fully reach their potential.

The findings of the study cast a shadow over the quality of the legacy data and data being collected and/or analyzed by the Ethiopian public and private laboratory infrastructure. Therefore, besides collating legacy soil and agronomic data, the implementation of a careful standardization and harmonization mission for legacy data is indispensable for national synthesis. It is advisable to follow global and national soil data standardization and harmonization guidelines such as the World Soil Information Service (WoSIS)-Towards the standardization and harmonization of world soil data (ISRIC, 2018).

It is worth mentioning one unreachable national legacy soil and agronomy dataset collected by the federal and regional soil laboratories. From 2001 to 2006, intensive soil test-based fertilizer calibration trials (mainly phosphorus calibration trials) took place. These trials were coordinated by the federal National Soil Testing Centre (NSTC) (then NSRC) and implemented by 15 regional soil laboratories. This nationwide fertilizer calibration mission had collected a huge soil and agronomic dataset for various major crops across diverse agroecosystems. However, this dataset was not interpreted as per the set methodology mainly because of limitations in the experimental protocol used after all the field and lab data were collected (Farina, 2011). This nationally collected huge soil and agronomy dataset currently lies abandoned, left in the hands of individuals and unreachable due to staff turnover and restructuring of laboratories. However, if the data do not work for soil test-based P-fertilizer calibration, the soil and crop response data probably are fit for other purposes to address systemic production and productivity problems across locations. It is worth mentioning that big data have several attributes that serve wider applications. Therefore, it is highly recommended to track down these voluminous nationwide data and bring them on board to the national database for further analysis and interpretation by various data users.

Recent advances in data analysis using machine learning/artificial intelligence have demonstrated that reach capacity exists to draw meaningful patterns and relationships from big data, which was impossible some time ago.

Appendix 8. Soil Data Collected from 1960s to 1990s in Soil Survey Missions

Various institutions have made efforts since 1963 to generate soil information for Ethiopia for assessing the agricultural development potential of each soil. These studies varied widely in scope, scale, and approach as well as in the quality of outputs (Esayas and Debele, 2006). The first attempt to map the soils of Ethiopia was made by Schantz and Marbut in 1923 as part of the mission of mapping the soils of Africa at a scale of 1:25 million. Among early efforts was the soil fertility survey conducted by Murphy (1968), who also studied the general fertility status of soils in Ethiopia by collecting some 2,600 samples along the main roads across the country.

After the establishment of the Institute of Agricultural Research (IAR) in 1961, the first-ever soil survey unit was established under the Holeta Research Centre. The unit was mandated to carry out soil surveys and map soils in agricultural research stations. It conducted soil surveys of the agricultural soils of Holeta, Bako, and Jimma stations and collected soil data (reports and maps) from the three stations. The soil survey unit of IAR was later transferred to the Land Use Planning and Regulatory Department (LUPRD) of the Ministry of Agriculture in 1973 (Esayas and Debele, 2006). The unit under LUPRD, funded by UNDP with technical assistance of FAO, conducted many soil surveys at different scales. The most comprehensive nationwide land resource inventory output was the report "Geomorphology and soils map of Ethiopia at 1:1 million scale (FAO, 1984), and its successor the provisional soil association map of Ethiopia (1:2 million scale), which was prepared in support of the preparation of a master land use plan under the LUPRD of the MoA.

In addition, other area-/Awraja-specific soil maps and reports at 1:50,000 and 1:250,000 scales were the major outputs of the soil surveys under this unit. However, since the decentralization of the federal government into regional states in 1993, the soil survey unit of the MoA relinquished its role and apparently no institution remained at the national level for the soil resource studies of the country until 1999 (Esayas and Debele, 2006). However, the former Institute for Agricultural Research or Ethiopian Agricultural Research Organization was renamed the Ethiopian Institute of Agricultural Research (EIAR), and it reinitiated soil surveys at research centers by establishing a Soil Survey and Land Evaluation Research Section under the then National Soil Research Centre now renamed the National Soil Testing Centre under the MoA. Accordingly, the section collected soil information from the main agricultural research centers, subcenters, and testing sites from 1999 to 2008. However, this section abandoned its role because of the restructuring of the then National Soil Research Centre.

Appendix 9. Global and Regional Soil Mapping Initiatives: Layering Ethiopia

Besides various national soil resource investigation studies, several endeavors are being made globally and regionally to coordinate soil information generation, sharing, and improving access to soil information by various institutions. These include the Africa Soil Information Service (AfSIS), Harmonized World Soil Database (HWSD), Global Soil Information Facilities (GSIF), Global Soil Map.net (GSM), Global Soil Profile Database (GSP), Soil and Terrain (SOTER) database, Africa Soil Profile (AfSP) database, and ISRIC-Soil Grids.

Many initiatives are designed to avail of soil information (soil maps and point profile data) at global and regional scales although most global initiatives are based on datasets collected nationally. For instance, AfSIS is developing continent-wide digital soil maps for sub-Saharan Africa using new types of soil analysis and statistical methods, and conducting agronomic field trials at selected sentinel sites (http://africasoils.net/publications/). These efforts include the compilation and rescue of legacy soil profile data, new data collection and analysis, and system development for large-scale soil mapping using remote-sensing imagery and crowd-sourced ground observations (http://africasoils.net/services/data/). Regionally, the SOTER initiative has collected legacy soil maps and soil profiles and organized these with a standardized common methodology and soil classification system. This has allowed a certain regional harmonization of information in Africa, including Ethiopia, at 1:1 million scale (FAO-ISRIC, 1998). Compared to the geomorphology and soils of Ethiopia and provisional Soil Association Map of Ethiopia (FAO, 1984) that used the FAO-UNESCO 1974 soil legend, the SOTER map could be considered as the latest nationwide soil and terrain information of Ethiopia and nowadays its maps and derived statistics are being cited by all nationwide soil-type map data users.

The other latest regional initiative is the African Soil Profile (AfSP) database containing about 1,820 standardized and harmonized soil profiles of Ethiopia (Leenaars, 2012; Leenaars et al., 2014). Although it contains point data, it has great information for updating existing soil information as it is standardized, quality-controlled, and harmonized.

Globally, the Harmonized World Soil Database brings together the available information from different national and regional soil mapping programs such as Digital Soil Map of the World (DSMW) and SOTER, and is, at present, the only digital global soil product available. The Harmonized World Soil Database (FAO/IIASA/ISRIC/JRC/CAS, 2009) contains a digital soil map of the world, with soil units classified according to the Revised FAO Legend (FAO, 1988) at a fixed grid resolution of 1 km by 1 km, with associated soil properties and soil qualities (Hengl et al., 2014). This digital global dataset is not fully harmonized as it is based 40% on the original DSMW and 60% on regional and national updates made after the DSMW was completed. Therefore, currently, global soil mapping initiatives are limited in their ability to provide up-to-date data on the actual status of global and regional soil resources unless national soil information is strengthened and updated.

The other global initiative is Soil Grids-global gridded soil information. It is a system for global digital soil mapping that uses state-of-the-art machine-learning methods to map the spatial distribution of soil properties across the globe. The outputs of Soil Grids are global soil property maps at six standard depth intervals at spatial resolution of 250 meters. Maps of the following soil properties are freely available: pH, soil organic carbon content, bulk density, coarse fragments content, sand content, silt content, clay content, cation exchange capacity (CEC), total nitrogen, as well as soil organic carbon density and soil organic carbon stock. Soil Grids has been updated since its previous release in 2017; the new updated version 2020 is freely available for users from the ISRIC website (https://www.isric.org/news/new-edition-soil-property-estimates-world-associated-web-platform-released-soilgrids250m).

Appendix 10. Alliance for a Green Revolution in Africa (AGRA)-Optimizing Fertilizer Recommendations in Africa (OFRA) Project

The Optimizing Fertilizer Recommendations in Africa (OFRA) project is funded by AGRA and administered through the CABI-coordinated Africa Soil Health Consortium (ASHC) in partnership with the University of Nebraska, Lincoln (UNL). The project is implemented by 13 national agricultural research systems, including those in Ethiopia. The project aims to improve the profitability of fertilizer use by smallholder farmers within an integrated soil fertility management (ISFM) framework. The fertilizer-use optimization in the project targets staple food crop systems. Accordingly, the OFRA project collected primary soil and agronomic data and collated more than 200 geo-referenced legacy data of Ethiopia. The AGRA-OFRA data can be accessed by sending an email request to CABI (http://ec2-54-93-187-255.eu-central-1.compute.amazonaws.com).

Appendix 11. CIMMYT-TAMASA

The CIMMYT-TAMASA Ethiopia project conducted an agronomic and yield survey in Oromia and Amhara regions. Replicated crop cuts in farmers' fields along with additional data on agronomy, household characteristics, fertilizer use, variety, and soil analysis were collected. TAMASA agronomic and household data are available on the CIMMYT Research Data & Software Repository Network, which is a Dataverse repository (https://tamasa.cimmyt.org/tamasa-data/). Personal data and geo-points have been removed from the files but are available upon request. The data can be freely downloaded subject to a standard Terms of Use while proper credit should be given via the citation generated by Dataverse (https://tamasa.cimmyt.org/tamasa-data/).

Appendix 12. CGIAR (CIAT/ICRISAT) and EIAR

The International Center for Tropical Agriculture (CIAT) carried out a review of soil fertility management and crop response to fertilizer application in Ethiopia with the aim of developing site- and context-specific fertilizer recommendations. This review work contains a comprehensive dataset specifically on crop response to fertilizers and is obtained from accessible published journal articles, theses, and proceedings spanning at least five decades. It represents all the agriculturally productive regions of Ethiopia. The data contain information on region, crop type, and soil type under which experiments were conducted as well as application rates of nutrients (N, P, K, and others) and yields of the control and fertilized treatments on which the crop response ratios were derived. The collated dataset used can be freely accessed from the CIAT website (http://hdl.handle.net/10568/82996) or CGIAR CGSpace repository (https://cgspace. cgiar .org/handle/10568/82824).

Appendix 13. Bilateral Ethiopian-Netherlands Effort for Food, Income and Trade (BENEFIT) Partnership

Efforts by various development partners have been ongoing to complement the existing soil information system of Ethiopia. In this regard, the BENEFIT Partnership is a notable one. This partnership is a portfolio of five programs (ISSD, Cascape, ENTAG, SBN, and REALISE) and is funded by the government of the Kingdom of Netherlands through its embassy in Addis Ababa.

BENEFIT-REALISE

The BENEFIT-REALISE program implements its interventions in 60 PSNP weredas in four regions (Tigray, Amhara, Oromia, and SNNPR). Accordingly, in 2019, BENEFIT-REALISE along with the MoA initiated a wereda-wide soil resource characterization and mapping task at 1:50,000 scale in 15 BENEFIT-REALISE intervention weredas: 3 of Tigray, 6 of Amhara, 3 of Oromia, and 3 of SNNPR.

In addition, to assist in the effective implementation of the demanding soil survey and mapping assignment by various stakeholders, such as the MoA, a country-wide finer resolution (50-meter) geomorphic map (Leenaars, 2019) has been produced using state-of-the-art remote-sensing-based techniques by BENEFIT-REALISE through its technical partner, International Soil Reference and Information Centre (ISRIC), Wageningen University and Research (WUR) (https://benefitethiopia.org/2020/03/13/benefit-realise-handed-over-a-countrywide-50-meter-geomorphic-map/).

The country-wide 50-meter geomorphic map is presumed to have wider national application not only for soil and agronomic mapping studies but also for other biophysical mapping and updating missions. Moreover, in the current digital ecosystem where we have come across mosaic remote-sensing digital products derived from various methodologies, the 50-meter geomorphic map prepared by BENEFIT-REALISE through ISRIC-WUR will serve as a benchmark for various national institutions mandated for similar assignments. Both the countrywide (50-meter) geomorphic map and soil dataset of the program are freely available at the BENEFIT-REALISE program office and MoA-Soil Resource Information and Mapping Directorate.

BENEFIT-CASCAPE

The Cascape program has conducted several studies, including soil surveys and mappings in AGP weredas in Tigray, Amhara, Oromia, and SNNPR in Ethiopia. The program (then Cascape project) as a collaborator of MoA/ATA has produced a map-database and soil dataset of the major soil types (at 250-m resolution) of the landscapes of the 30 Cascape intervention-AGP weredas studied in 2013-2015: 5 of Tigray, 5 of Amhara, 15 of Oromia, and 5 of SNNPR. The study employed digital soil mapping techniques by combining primary field soil observations with legacy soil data (Leenaars et al., 2016). All the data and reports are available at https://research.wur.nl/en/publications/major-soil-landscape-resources-of-the-cascape-intervention-woreda.

In addition, the Cascape program (then Cascape project) in 2016 conducted an inventory of Ethiopia's laboratory infrastructure to enable decision-making by policymakers, farmers, and researchers depending on reliable data on soils, water, and crops. It is obvious that knowledge on soil resources highly depends on reliable soil test results. The program conducted an inventory of Ethiopia's laboratory infrastructure and produced a comprehensive report (Bakker et al., 2016). The report emphasized the need to improve the output/data of Ethiopian soil, plant, and water laboratories and suggested strategies to fully reach their potential. The report is available free of charge and can be downloaded at https://research.wur.nl/en/publications/major-soil-landscape-resources-of-the-cascape-intervention-woreda.

Furthermore, the Cascape program has conducted crop response to fertilizer application trials, since 2011, across AGP weredas and has generated voluminous data. The fertilizer trial data across AGP weredas and also the soil survey data in Matama, Farta, and Kafta Humera weredas are available at the Cascape program office and respective program coordinating/implementing universities.

Appendix 14. Sasakawa Global 2000 Ethiopia

In 2016-2017, a project known as *Large-Scale Popularization of Potassium Fertilizer Use in Ethiopia* was implemented from October 2015 to March 2017 by Sasakawa Africa Association/Sasakawa Global 2000 in collaboration with the Ministry of Agriculture, ATA, AGRA, and other stakeholders. The objectives of the project were to demonstrate to farmers the increased crop productivity due to potassium fertilizer on larger plots in four major regions and 18,000 farmers' plots; create awareness for at least 180,000 farmers and 2,500 extension agents through training, experience-sharing visits, and field days; and generate information that can help develop area- and crop-specific fertilizer recommendation packages. To achieve the set objectives in the 2016-2017 cropping season, 18,203 KCl demonstrations were implemented on five crops (teff, wheat, maize, barley, and sesame) across 64 weredas in the four project regions (Amhara, Oromia, SNNPR, and Tigray).

Similarly, from October 2015 to March 2017, the Sasakawa Africa Association (SAA)/Sasakawa Global 2000 (SG 2000) Ethiopia in collaboration with the Ministry of Agriculture promoted urea deep placement on teff, wheat, and maize crops through the project "Promotion of Fertilizer Blends (NPSZn, NPSB, & NPSZnB) & Introduction of Urea Deep Placement (UDP)" across seven weredas at 118 demonstration sites. Accordingly, voluminous crop response to fertilizer application data were generated and both the data and report are freely available from the Sasakawa Global 2000 Ethiopia country office by providing an official request letter and/or signing a data-sharing agreement (https://www.saa-safe.org/www/ethiopia.html).

Appendix 15. Soil and Agronomy Publications Review

Diverse research-based soil and agronomic data are available in various publication types and formats. However, several available review and annotated/bibliography publications are worth mentioning. These specific publications are a compendium of huge soil and agronomic data publications and hence can quickly indicate data location faster than piecemeal data searches. Moreover, these publications facilitate quick retrieval and access of soil and agronomic data. The most notable soil and agronomic data review and bibliographic publications for quick data access are the following:

- Bibliography of Scientific Documents 1969 – 2019 (MARC-EIAR, 2019)
- Soil Fertility and Plant Nutrient Management (Agegnehu et al., 2018)
- A review of soil fertility management and crop response to fertilizer application in Ethiopia: towards development of site- and context-specific fertilizer recommendation (Tamene et al., 2017)
- Technical Report on Evaluation of Balanced Fertilizer Types and Validation of Soil Fertility Map-based Fertilizer Recommendation for Major Crops (EIAR, 2017)
- Ethiopian Journal of Natural Resources (EJNR). 2016. Special Issue, Volume 16, No. 1 & 2
- Achievements of Integrated Crop, Soil, and Water Management Research Activities on Wheat (Habte et al., 2015)
- Annotated bibliography of Tef (Zerihun, 2011)
- Review of Soil and Water Technologies: Case of SNNPRs (Ayalew et al., 2010)
- The Status of Micro-nutrients in Nitisols, Vertisols, Cambisols and Fluvisols in Major Maize, Wheat, Teff and Citrus Growing Areas of Ethiopia (Asgelil et al., 2007)
- Soil type and soil depth map updating of Ethiopia (1:250,000 scale). WLRC. 2018. Unpublished technical report.
- Annotated bibliography of soils (Debele, 1994)
- Properties of Major Agricultural Soils of Ethiopia (Zewdie, 2013)

Cont. Appendix 15

- Nature and Management of Ethiopian Soils (Mesfin, 1998)
- Major Soil-Landscape Resources of the CASCAPE Intervention Woredas of Ethiopia: Soil information in support to scaling up of evidence-based best practices in agricultural production (with dataset) (Leenaars et al., 2016)
- Soil reference collection and data base formation (Zewdie, 1994)

Appendix 16. Soil and Agronomic Data from the Ministry of Agriculture

The Ministry of Agriculture has various development projects/programs, including Sustainable Land Management (SLM), Productive Safety Net Program (PSNP), Participatory Small-Scale Irrigation (PSSI), Drought Resilient and Sustainable Livelihood Project (DRSLP), and the Agricultural Investment Agency. These projects/programs have collected significant soil and/or agronomic data as part of the baseline information for various watershed, irrigation, and pasture development planning activities. Some of the projects commissioned various consultants and collected soil and agronomic data. These data can be accessed directly from the respective programs/projects. The data are available in digital format and in office/personal computers.

Appendix 17. Online/Offline Agricultural Journals

Various national online and offline journals provide soil and agronomic data for users. Some of the common peer-reviewed journals follow:

- SINET: Journal of Science (https://www.ajol.info/index.php/sinet)
- Ethiopian Journal of Natural Resources (EJNR)
- Ethiopian Journal of Agricultural Sciences (EJAS) https://www.ajol.info/index.php/index/search/search
- Journal of Agriculture and Environmental Sciences. Bahir Dar University http://journals.bdu.edu.et/index.php/jaes/search/titles
- Journal of the Drylands. Mekelle University http://www.mu.edu.et/jd/index.php/jd/about

Appendix 18. Other Soil and Agronomic Data Sources

- Ethiopian Sugar Corporation (ESC). This corporation has a research directorate and many research centres in the respective sugar states, including Wonji, Metahara, Kesem-Kebena, Tendaho, Fincha, Jawi, and Kuraz sugarcane plantation sites. Since its establishment, the ESC has collected voluminous soil and agronomic data through various publications, mainly related to the sugarcane crop. These data can be accessed from the corporation research head office or directly from the respective research centers of the sugarcane plantation sites.
- Tobacco Monopoly Company. This company has many tobacco farms and has conducted many soil- and agronomy-based feasibility studies. Accordingly, soil and agronomic data related to tobacco cultivation have been collected. The soil and agronomic data of the Bilate tobacco farm can be accessed from the company head office or from the former National Soil Research Centre (now the National Soil Testing Centre).
- Arsi and Bale Agricultural Development Enterprises. These enterprises represent many state farms dedicated mainly to wheat and barley cultivation. Most of the state farms were running at a loss because of poor agronomic practices and inefficient large-scale farm management. To improve the state farms' productivity, significant soil and agronomic studies were conducted. Accordingly, soil and agronomic data related to wheat and barley cultivation were generated. At present, these data can be accessed either from the enterprises' head office or from the Ethiopian Institute of Agricultural Research-National Soil Testing Centre.

Appendix Table 1: List of people interviewed and organizations visited.

ORGANIZATION	LOCATION	INTERVIEWEES
Ethiopian Institute of Agricultural Research (EIAR)	Addis Ababa	Dr. Tesfaye Shimber, Dr. Degefe Tibebe, Mr. Abebe Kirub
Ministry of Agriculture (MoA)/ATA	Addis Ababa	Mr. Tefera Tadesse, Mr. Mulugeta Abera
Water and Land Resource Centre of Addis Ababa University	Addis Ababa	Dr. Tibebeu Kassawmar
Ministry of Water, Irrigation & Electricity	Addis Ababa	Mr. Tewodros Mergia
Tigray Agricultural Research Institute (TARI)	Mekelle	Dr.Bereket H. Silase, Mr. Geberemedhin Berhe, Mr. Tasdik Tadele
Mekelle University	Mekelle	Dr. Gebeyehu Taye, Prof. Mitiku Haile
Haramaya University	Haramaya	Mr. Tefereie Tadesse, Dr. Lema Wogi
Hawasssa University	Hawassa	Prof. Sheleme Beyene
Jimma University	Jimma	Dr. Alemayehu Reggassa
Bahir Dar University	Bahir Dar	Dr. Asmare Bimewrew
Amhara Design and Supervision Works Enterprise (ADSWE)	Bahir Dar	Mr. Adane Desie/Dr. Eng. Dagenet Fenta
Oromia Agricultural Research Institute (ORARI)	Addis Ababa/ Finfine	Mr. Kefyalew Tesfay
National Soil Testing Centre (NSTC)	Addis Ababa	Mr. Fekre Mekuria
Amhara Agricultural Research Institute (ARARI)	Bahir Dar	Mr. Mulugeta Alemayehu
Ethiopian Construction, Design and Supervision Works Corporation (ECDSWC)	Addis Ababa	Mr. Solomon Taddesse
Oromia Water Works Design and Supervision Enterprise (OWWDSE)	Addis Ababa	Mr. Legesse Dadi
Ethiopian Sugar Corporation (ESC)	Addis Ababa	Mr. Zeleke Teshome
SASAKAWA Global 2000 Ethiopia	Addis Ababa	Dr. Fentahun Mengistu/Melese Liyeh

Appendix Table 2: Major soil and agronomic data hosting institutions in Ethiopia.

S. NO.	SOIL AND AGRONOMIC DATA HOSTING ORGANIZATIONS
1	Ethiopian Institute of Agricultural Research (EIAR)
2	Regional Agricultural Research Institutes (TARI, ORARI, ARARI, SARI)
3	Higher Learning Institutes: Haramaya, Mekelle, AAU, Hawassa, Jimma, Bahir Dar, Gondar, Deberebrhan, and Wollo universities
4	Ministry of Agriculture: Agricultural Transformation Agency (ATA)-EthioSIS, National Soil Testing Centre (NSTC), Sustainable Land Management (SLM) Program, Soil Fertility Directorate, Soil Resource Information and Mapping Directorate, Drought Resilient and Pastoral Livelihood Project, and Participatory Small-Scale Project
5	Ministry of Water, Irrigation and Energy; Geospatial & Information Directorate; and Irrigation Development Commission Head Office
6	Ethiopian Construction Design and Supervision Works Corporation (ECDSWCo). Soil Study and Agricultural Planning Sub-Process
7	Water and Land Resource Centre (WLRC), Addis Ababa University, Head Office
8	Oromia Water Works Design and Supervision Enterprise (OWWDSE), Addis Ababa/Finfine
9	Oromia Irrigation Development Authority, Addis Ababa/Finfine
10	Oromia Land and Environmental Protection Bureau (OLEPB), Addis Ababa/Finfine
11	Amhara Design and Supervision Works Enterprise (ADSWE), public consultant, Bahir Dar
12	Amhara Bureau of Environmental Protection, Land Administration and Use (BoEPLAU), Bahir Dar
13	Amhar Investment Bureau, Bahir Dar, Head Office
14	Tigray Water Works Study, Design and Supervision Enterprise (TWWSDS), Head Office, Mekelle
15	SNNPR, Irrigation Development Scheme Administration Agency, Hwassa
16	Ethiopian Sugar Corporation (ESC), Research Directorate/Business Development Directorate, Head Office, Addis Ababa
17	Regional Soil Testing Laboratories (Bahir Dar, Dessie, Debremarkos, Gondar; Hawassa, Wolita Sodo, Welkite, Tepi, Bedele, Nekemte, Batu Zeway, Fiche, Jigjiga, Assosa, Gambella, Mekelle, and Shere soil laboratories)
18	Afar National Regional State Bureau of Finance & Economy; Water Resource Bureau. Semera
19	BENEFIT-partnership (BENEFIT-REALISE and BENEFIT-Cascape programs), Head Office, Addis Ababa
20	Gambela Land Utilization & Environmental Protection Authority, Gambela
21	Tobacco Monopoly Company/Enterprise. Tobacco Farm Division, Addis Ababa
22	Livestock, Crop and Rural Development Bureau of Somali Regional State, Jigjiga
23	SASAKAWA Global 2000 Ethiopia

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