Digital solutions to transform agriculture: lessons and experiences in Ethiopia

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List of Acronyms

CCAFS	-	Climate Change, Agriculture and Food Security
CGIAR	-	Consultative Group on International Agricultural Research
CIAT	-	International Center for Tropical Agriculture
CoW	-	Coalition of the Wiling
EIAR	-	Ethiopian Institute of Agricultural Research
EU	-	European Union
IFAD	-	International Fund for Agricultural Development
ISFM	-	Integrated Soil Fertility Management
GIS	-	Geographical Information System
GIZ	-	Deutsche Gesellschaft fuer Internationale Zusammenarbeit
SSHI	-	Soil Fertility and Health Interventions in Ethiopia (SSHI)
CABI	-	Centre for Agriculture and Biosciences International
ODI	-	Open Data Institute

1. Introduction

The advent of big data is pushing research and development frontiers. Advancements in data storage, processing, and sharing capacities as well as analytics and modeling competencies are optimizing agricultural decision making by predicting various complexities involved in agricultural processes. The introduction of machine learning, drone technology, and robotics are making way for greater agriculture breakthroughs that were not possible before. Using data and technological innovations farmers in many parts of the world can now practice precision agriculture and thus increase their productivity.

Such scientific advances are good news to the developing world including Ethiopia that is most threatened by food insecurity. The country can plug-into the fascinating world of big-data analytics to gain quick-wins as well as enjoy sustainable benefits. To benefit from such advancement the country however needs to satisfy the basics – quality data at the required resolution! The transition towards data-driven agriculture requires the availability of big data and computing technologies that can support high-volume multivariable analysis in real-time.

Despite the collection of agricultural data in Ethiopia over the last 60 years, no systematic database contains these data in an accessible and interoperable format. Data access and sharing systems operating per the FAIR (Findable, Accessible, Interoperable, and Reusable) principle are nonexistent or at a very early stage of development. As a result, integrated analysis that can inform best agricultural decisions were very difficult to perform. The lack of standard data collection guidelines and absence of data sharing 'culture' undermined the use of improved analytics because existing agronomic data were either not preserved, not shared, not standardized or not brought together in a useful way. This situation undermined data-driven and knowledge-based decision making which ultimately affected the effectiveness of agricultural decisions and interventions. This is because decision-makers have been forced to rely on less-data driven blanket recommendations, which do not meet the needs of farmers spread across Ethiopia's highly diverse and heterogeneous landscapes.

In the quest to develop a data-driven fertilizer recommendation tool, the Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT) hereafter the Alliance and its partners realized the challenges of the lack of FAIR data and the need for advanced analytics. This critical challenge has been discussed for some time through various fora but little progress was made to tackle the problem. A group of soil scientists and agronomists coordinated by the Alliance and with the support of GIZ-Ethiopia started to make concerted effort since 2015 to tackle the problem. Their quick response to bridge the observed gap was the creation of the collation of the willing (CoW) - experts in the fields of soil and agronomy who are willing to support data sharing and/or support the processes, engagements and undertakings related to data sharing. The critical move these experts did was to collate soil and agronomy data in their deposal as well as in the ownership of various researchers and institutions to build a database. This move has become critical turning point not only because the CoW members moved from below 30 during the time of formation to over 100 in less than two years and also enabled to gather crop response to fertilizer data for over 10,000 points for some crops.

The experts took different measures in a cascading manner starting from individual conversations to organizing meetings and workshops to discuss and substantiate the idea. These were followed by further discussions on how to support a systematic and institutionalized process of soil and agronomy data sharing which lead to the creation of CoW data access and sharing guideline. Observing that data interoperability was a serious problem the team also develop various guidelines that can enable collecting standard datasets. Developing web portal and capacity building in big data analytics and machine leaning were also integral components of the CoW activities over the last two years. Through continued engagement, the CoW team has gained experiences and lessons related to the necessary steps to facilitate data gathering, sharing and improved analytics (example see the lessons and steps). With some fine-tuning the team is now closer to develop fertilizer recommendation decision support tool which will facilitate data-driven and knowledge-based decision making. Through integrating with weather advisory and disease surveillance tools the team aspires to develop integrated agroadvisories as well as support the Digital Ethiopia 2025 Strategy. With these advancements the CoW has become one of the thriving African initiatives towards data-driven agriculture.

This report outlines some of the most important activities undertaken by the CoW. The first section will present the major undertakings related to data and database development. The second section will discuss the key steps taken to make data FAIR and facilitate data success and sharing. The third section presents the major analytical steps undertaken associated with the gathered datasets. The fourth section outlines activities related to capacity building. The last section is about activities aimed to undertake to take the 'content' to the next level – agroadvisory services dissemination.

2. Data and Database

2.1. Collate soils/agronomy data

Global developments are gearing towards digital solutions. Ethiopia has embraced this trajectory and has developed its "Digital Ethiopia 2025 Strategy". Agriculture is a very important and major pillar of this strategy. To support and facilitate the transformation agenda, data is of paramount importance. This is why the CoW team put collating available data as the basis of the transformation effort. To materialize this effort, the team designed three approaches: (a) review published literature and extract available data related to crop response to fertilizer application; (b) collate data available in the hands of the CoW members, and (c) collate data that are available at the hands of different institutes (research and academic organization, development organizations, NGOs, etc.). The three process enable to gather ample amount of data that helped to demonstrate the benefits and big data and convinced large number of partners and stakeholders to share their data.

Before the data collation exercise an attempt was made to assess the soils/agronomy data landscape – who owns what data, in what format and whether the data can be accessible. This mapping exercise enabled to identify the key institutes who are in possession of soils/agronomy data and understand the major features of the dataset (see details here). 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. The report also highlights that some significant number of institutes do not have approved institutional policies or regulations related to data sharing, 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.

With the above evaluation, the data gathering exercise started in earnest. The review-based effort (mining data from peer-reviewed journals) enabled the acquisition of large number of data points for major crops – wheat, maize, barley, teff and the likes (Tamene et al., 2017). This was a very significant move that inspired many because it clearly demonstrated the value of data to conduced detailed analysis and build knowledge for informed decision making. It also highlighted how problem of scarcity of data despite long-term (close to six decades) soils and agronomy research in the country. This effort was also critical because it inspired the relatively few CoW members (less than 30) at the initial stage to share their data and create awareness to attract others that took the members to be more than 100 by the end of 2020. With this development, it was also possible to collate additional data from the CoW members and other sources, which enabled us to build soils/agronomy database with more than 10,000 data points of some crops such as wheat.

2.2. Develop guidelines to make the datasets interoperable and facilitate data sharing

While the above effort is commendable and great success has been made, there are still lots of data out there which are 'unaccounted for". A concerted effort is thus underway to bring those remaining datasets. An important gap observed during the "mapping and characterization" of soils and agronomy data revealed lack of guideline to be one of the critical bottlenecks that undermined data access and sharing. It was also observed that lack of functional and consistent data management and sharing systems are common problems in many African countries. One of the important interventions of the CoW was thus development of Soil and Agronomy Data Sharing Guidelines aligned with the FAIR data principles. The CoW data access and sharing guideline outlines the requirements that the CoW members must adhere to when accessing and sharing among themselves and beyond. The Guideline outlines an open and transparent approach to sharing Soil and Agronomy Data, which also assessed challenges and opportunities.

2.3. *Develop data standardization guidelines*

The data landscape mapping and collation efforts demonstrated that the lack of standards make the data less interoperable. Such lack of standards made bringing those into a database for integrated analysis a challenge. During several of the CoW's trainings and writeshops significant effort was being spent to standardize data and also it was not possible to make use of some crucial dataset because of lack of critical information including location. These largely undermine ensuring data quality and jeopardize the possibility of combined analysis to draw far-reaching and dependable lessons. As a result, data standardization and quality assurance are crucial.

Cognizant of the above challenges, the CoW team have developed a strategy on how standardized data collection and analysis can be materialized. Discussions were held and agreement reached on how to start embarking on soils/agronomy data standardization starting from sampling design all through to laboratory data analysis. Recommendations were also given on how the 'standardization' exercise can be approached to make the process more efficient and effective. An important step in this regard was the creation of a 'technical team' who led the soils/agronomy data acquisition and laboratory analysis. The technical team, which is composed of senior experts in relevant fields laid a procedure to be followed and outlined key processes for the development of the guidelines. Accordingly, a total of six soils/agronomy guidelines have been developed by the technical team. The guidelines were organized under *Agronomy and Soil Fertility*, *Soil Microbiology*, *Soil Survey and Mapping*, *Agricultural Water Management*, *Laboratory Analysis (soil, water and plant tissues)*, and *Integrated Watershed Management* themes. All the guidelines were reviewed by independent senior experts(s) corresponding to each theme. Two of the guidelines (*Agronomy and Soil Fertility and Soil Biology*) and were ready and published while the others are under development. See this Link and this Link for the Agronomy and Soil fertility and Soil Biology guidelines, respectively.

Trainings and awareness creation sessions will be conducted to familiarize the guidelines and capacitate users to apply them while operationalizing data collection. An effort will also be made to embed these guidelines into the "Agricultural University curricula".

2.4. Develop web-portal with interface for data storage, management and visualization

The collated datasets were stored in a preliminary database for temporary storage and access. The next step was to develop web-portal with visualization interface in order to enable data entry by individual members and view the meta-data to facilitate sharing. Accordingly, team of experts with data portal development conducted a review to identify a system that is up-to-date and flexible enough to be integrated with others. Based on the review and consultation with experts, the team has identified Dataverse (https://dataverse.org/) to be suitable for the CoW purpose. A web portal that can list, capture and showcase all relevant and useful datasets including geospatial and multimedia data was developed and deployed in the Ethiopian Institute of Agricultural Research (EIAR) (Fig. 1). The portal has various functionalities and features including user interface, data exploration and visualization options, support multiple data type uploading and downloading, data quality control, licensing and permission features, user registration, search and visualization function, and the likes. The portal will be up and running once the IP configuration is finalized.

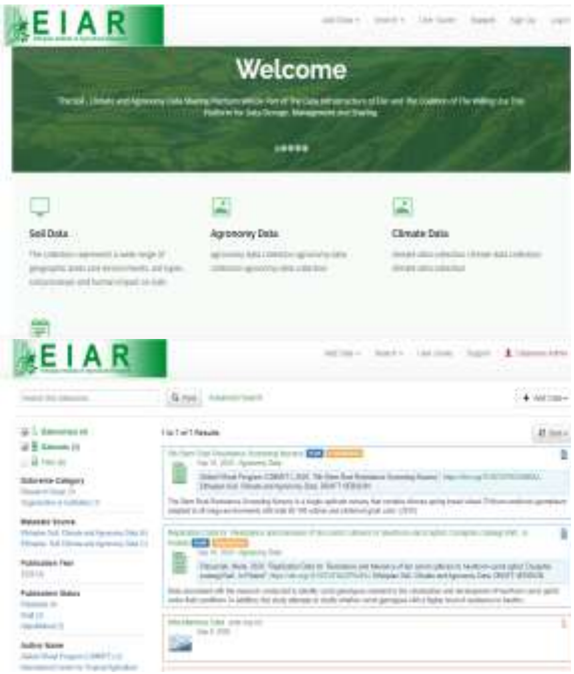


Figure 1. Configuration of the soils/agronomy data portal installed at the EIAR

3. Data processing and analysis

3.1. Crop yield estimation using earth-observation method

Proper estimation of crop yield is of fundamental importance in quantifying the production potential, enhancing the area of food production, addressing food security threats, building sustainable agricultural activities, formulating promotional agricultural policy and programs at the regional and national levels. However, crop yield estimations in Ethiopia are often betting on the conventional techniques that include crop cutting, sample surveys and farmer interviews, and the results are aggregated at the zonal administrative level, the second-largest administrative unit in the country. These techniques are costly, labor-intensive, at risk of large errors, and are not easily scalable and readily available on time. As a result, introducing an alternative and effective yield estimation method that can reduce the labor required for conventional approaches and provide a timely and reliable estimation is highly needed. As part of the digital transformation effort, developing methods to estimate crop yield using remote sensing data and associated methods was thus given due attention by the CoW.

Recent developments have shown great strides in crop yield estimation using remotely sensed data. These data can provide timely and continues information over the vegetated surface at a range of spatial and temporal scales and can be helpful to accurately estimate and forecast crop yield. The approach spectrally measures biophysical variables associated to crop conditions and yield, which can subsequently be used to estimate actual yield using different forms of deterministic or regression methods. Numerous methods have been introduced to estimate and predict crop yields using remotely sensed data. In this report, different approaches were used to estimate teff crop yield. Teff was selected as pilot because few studies are available to estimate its yield using remote sensing and geospatial techniques.

In this report, we present results of teff yield estimation based on light-use-efficiency method, which is based on the assumption that crop aboveground biomass is proportional to the total amount of absorbed photosynthetically active radiation (APAR) all over the growing period. The light use efficiency, which is defined as the effectiveness with which crops can use the APAR to produce photosynthesis, is a function of net primary production (NPP) and APAR. The APAR describes the portion of the total amount of photosynthetically active radiation (PAR) absorbed by green plants for photosynthesis. APAR is usually estimated as the product of the incident PAR and fPAR absorbed by the crop canopy, summed over the crop growing periods. Once the crop aboveground biomass is estimated, crop yield can be derived using the harvest index (HI) or ratio of grain mass to crop aboveground biomass. The HI could be estimated based on the developed assumptions that the ratio of NDVI data collected after crop pick growing season to that for the entire growing period. The HI value, in this case, was estimated based on the ratio of NDVI data collected after teff pick growing season to that of the entire growing period. Teff yield was estimated for the years 2010-2017.

Fig. 2 shows the estimated grain yield of teff in the study area using NDVI based HI fractions and was found to be between 365 to 4000 kg ha^{-1} with an average of 2807.54 Kg ha^{-1}. These results are significantly high compared to the values for zone average teff yield officially reported by CSA. Other researchers (e.g., Tekelu and Tefera, 2005; Birhanu et al., 2020) have also reported teff grain yield ranging from 1558 to 4599 Kg ha^{-1} even though these studies were conducted at the experimental plots. The total amount of teff crop biomass generated throughout the growing period ranges from 504 to 6209 kg ha^{-1} with an average of 4112.51 kg ha^{-1}. Indeed, comparable teff biomass values of 6314 kg ha^{-1} was reported by other studies over agricultural experimental plots in Ethiopia. The HI values ranged from 0.10 to 0.99, with a mean values of 0.68. This value of HI is high for teff comparable to the HI values published for other C4 crops (e.g., maize, millet, and sorghum), which ranged from 0.30 – 0.45. Similarly, different teff experimental researches conducted at plot levels reveal that the HI of teff is very low (could generally lie within the range of 0.17 to 0.37) comparing to other cereal crops.

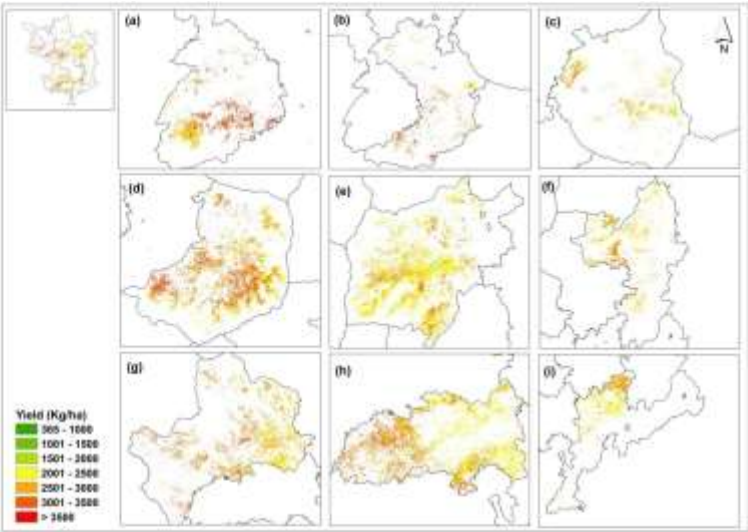


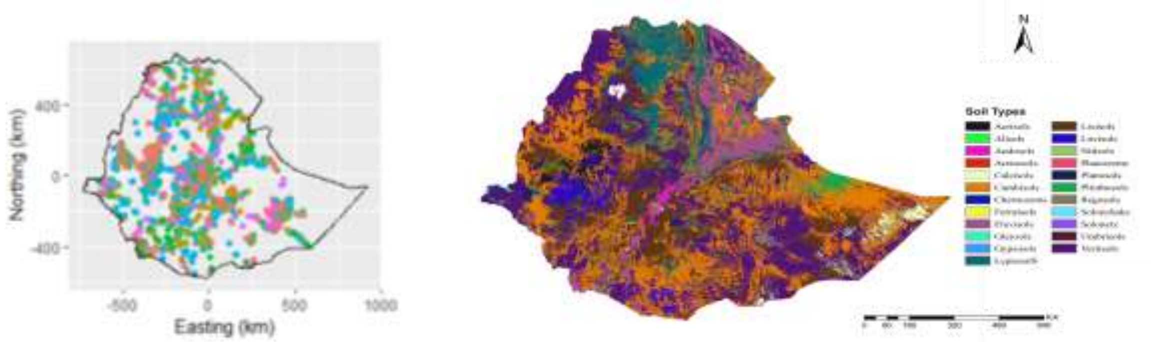
Figure 2. The spatial variability of teff grain yield over nine zones: (a) Awi, (b) West Gojjam, (c) South Gondar, (d) East Gojjam, (e) South Wolo, (f) North Shewa, (g) West Shewa, (h) South-West Shewa, and (i) East Shewa

3.2. Develop soil resources map of Ethiopia

Soil maps are critical foundation to support agricultural transformation. However, the current soil resource map of Ethiopia is either obsolete or very coarse resolution making it less useful. As a result, the need to have updated and gridded country-wide soil resource/type map has been raised by the national soil science community and various soil data users. Due to the costly nature of conventional soil surveys, lack of national soil data base, and absence of mandated body, this pressing request has not yet been implemented. Recent developments under the CoW and its follow-up activities in facilitating soil and agronomy data in Ethiopia has created enabling environments to curve such long-lasting request. One of the main enabling environments was the collation of voluminous soil profile data to central data repository system by the CoW. These data coupled with the creation of soil mapping community of practices recognized as input to generate updated country-wide soil resource maps which has been lacking at various spatio-temporal scales.

Recognizing recent state-of-the art developments in digital soil mapping and other machine learning techniques, members of the CoW developed preliminary soil resource map at 250 m resolution. Integrated approaches of digital soil mapping using legacy soil dataset, remote sensing-based soil covariates and machine learning-spatial soil predictive models were used to develop the soil resource map.

The key basis of the mapping exercise was the ~ 8,700 soil profile data (Fig. 3a) collated from various sources. Various co-variates in the form of climate, topography, parent material, vegetation and their derivatives were also collated to be used in the. These efforts led to the first prototype soil type probable map at 1 km resolution (Fig. 3b), which will be fine-tuned and improved with more data.



(a) (b)

Figure 3. (a) The spatial distribution of compiled soil profile data and (b) most probable soil type/reference group map of Ethiopia at 1km grid

3.3. Develop crop response to fertilizer application

Despite the increase in the use of fertilizer and improved seed for many of the crops, crop yield in Ethiopia is far below the optimal and compared to the global level. One of the reasons for this is inadequate use of the right types of inputs for the right place at the right time. Often blanket recommendations are made despite complex and heterogeneous environmental conditions. In addition, the adoption of recommended input is variable across households due to socio-economic factors that determine needs, preferences and capacity to access and use inputs. It is thus important to understand the spatio-temporal dynamics of production conditions as well as the types and amounts of inputs required for farmers to use on their diverse fields. Site-specific fertilizer application can be an essential component to address low crop response to fertilizers and seed inputs in agricultural landscapes.

Against this background, an effort is being made to develop crop response prediction model that can be a basis for fertilizer recommendations. A machine learning technique has been employed to identify the most important site-specific variables determining crop yield and generate spatially distributed nutrient response curves. The approach has been tested for four nutrients i.e. N, P, K, and S for wheat crop in Ethiopia. The model performance ranges from $R^2 = 0.45$ to $R^2 = 0.81$ for N and P, respectively (Fig. 4). Based on the training model, crop response curve that can guide optimal nutrient application for each location has been developed (Fig. 5).

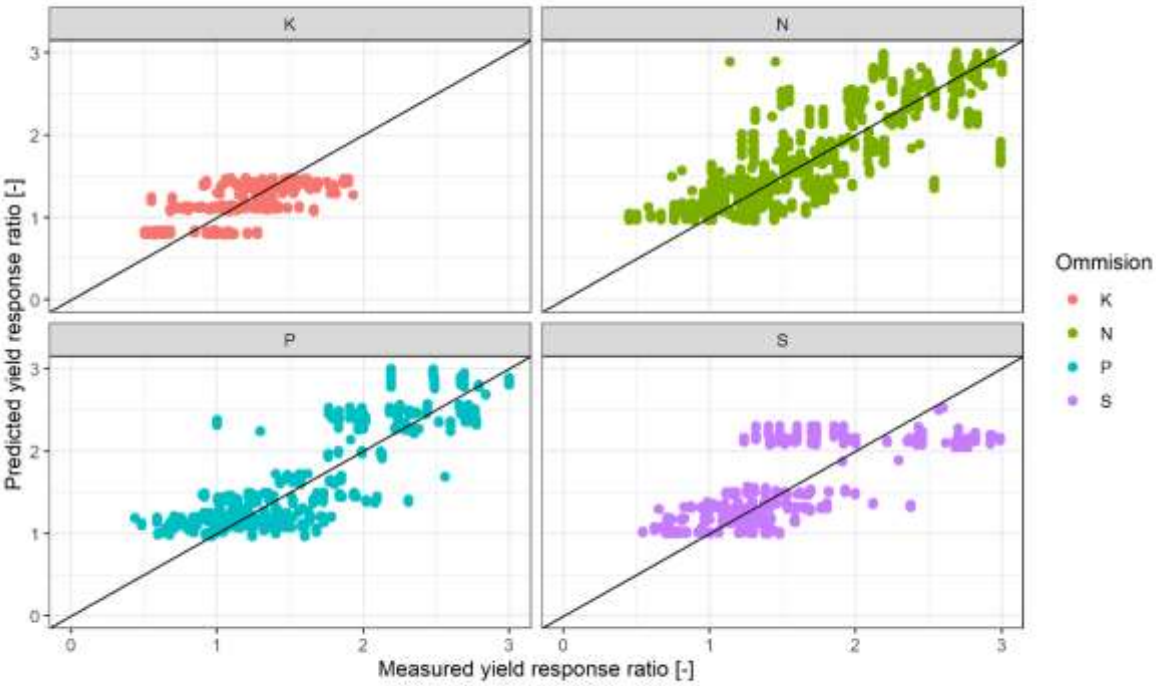


Figure 4. Scatter plot of measured and predicted wheat yield response ratio for four nutrients

The tool is able to produce yield prediction for a given level of nutrient application at any location of interest considering the climate, soil and topography of the site. With more data and further improvement, the model can be deployed as an operational tool to guide farmers' investment as it indicates the level of fertilizer they need to apply and as a strategic tool to support the government to provide improved estimation of fertilizer amount to be imported in the upcoming growing season. The tool will later be integrated with climate advisory services and options to develop integrated advisories including good agronomic practices and crop diseases for early warning systems (Fig. 6). An effort will also be made to contextualize the advisory services to specific households through analysis of typologies.

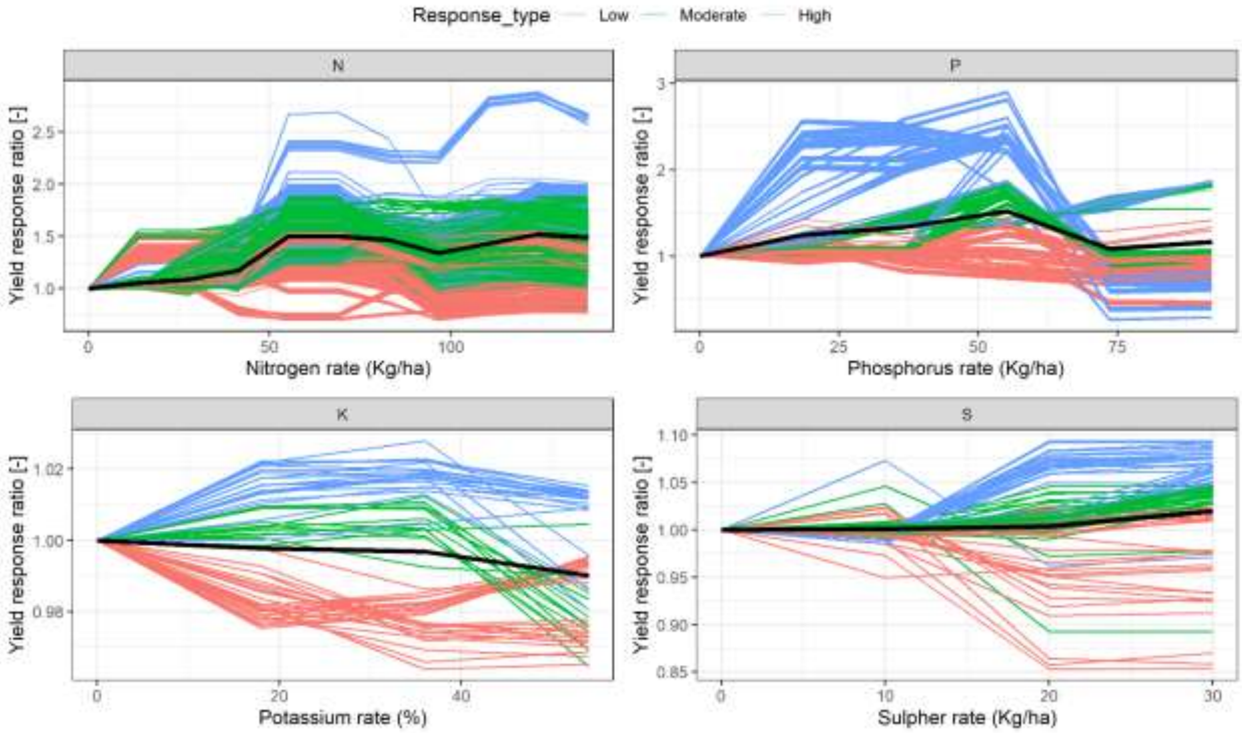


Figure 5. Yield to nutrient response curve for wheat at the evaluation dataset for Ethiopia

<u>3.4. Develop integrated agroadvisory services</u>

Building on the above developments and successes stories, the next step was designed to develop integrated agroadvisory services. The overall aim is to build on the earlier efforts to further strengthen Ethiopia's national research and development framework through a broader portfolio of project activities and transformative outcomes, potentially reaching Ethiopia's 12 million small-scale farmers. The upcoming effort aims at taking data and data use to the next level, whereby data is "translated" into information and farmer-relevant, gender-specific extension content and disseminated digitally and via analog agricultural advisory. At the same time, an effort will be made to give farming communities a stronger say in determining regional and national research agendas. Building on the priorities identified in the agricultural extension strategy of the Ministry of Agriculture, and in close collaboration with national stakeholders, an effort will be made to facilitate the co-creation of an improved Farmer-Data-Research-Extension linkage mechanism for improving the flow and exchange of information between male and female farmers, rural youth, and research and extension actors (Fig. 6). In the end, enhanced information feedback and linkages will enable extension providers to iteratively and continually improve the quality and efficiency of agricultural advisory services, thereby contributing to transformative agricultural development in Ethiopia.

The upcoming intervention aims to facilitate the co-creation of an improved farmer-data-research-extension linkage mechanism for contributing to a functional, two-way flow of information between the project's core stakeholders (e.g., farmers, researchers and extension providers, and data holders). The benefits of this framework are twofold. Farmers gain a greater say in regional and national research agendas, as the framework mechanism strengthens the critical "bottom-up" two-way feedback loop from male and female farmers to researchers and extension providers. Second, the intervention will help increase the use of data and information for developing farmer-relevant, gender-specific soil and agronomy extension messages for more targeted impact. The content will be communicated both digitally and analog by agroadvisory service providers, thereby supporting the scaling of successful soil and agronomy technologies and practices. As a pilot, the digital agroadvisory tool will be composed of fertilizer-weather-good agronomic practices and disease surveillance (Fig 6).

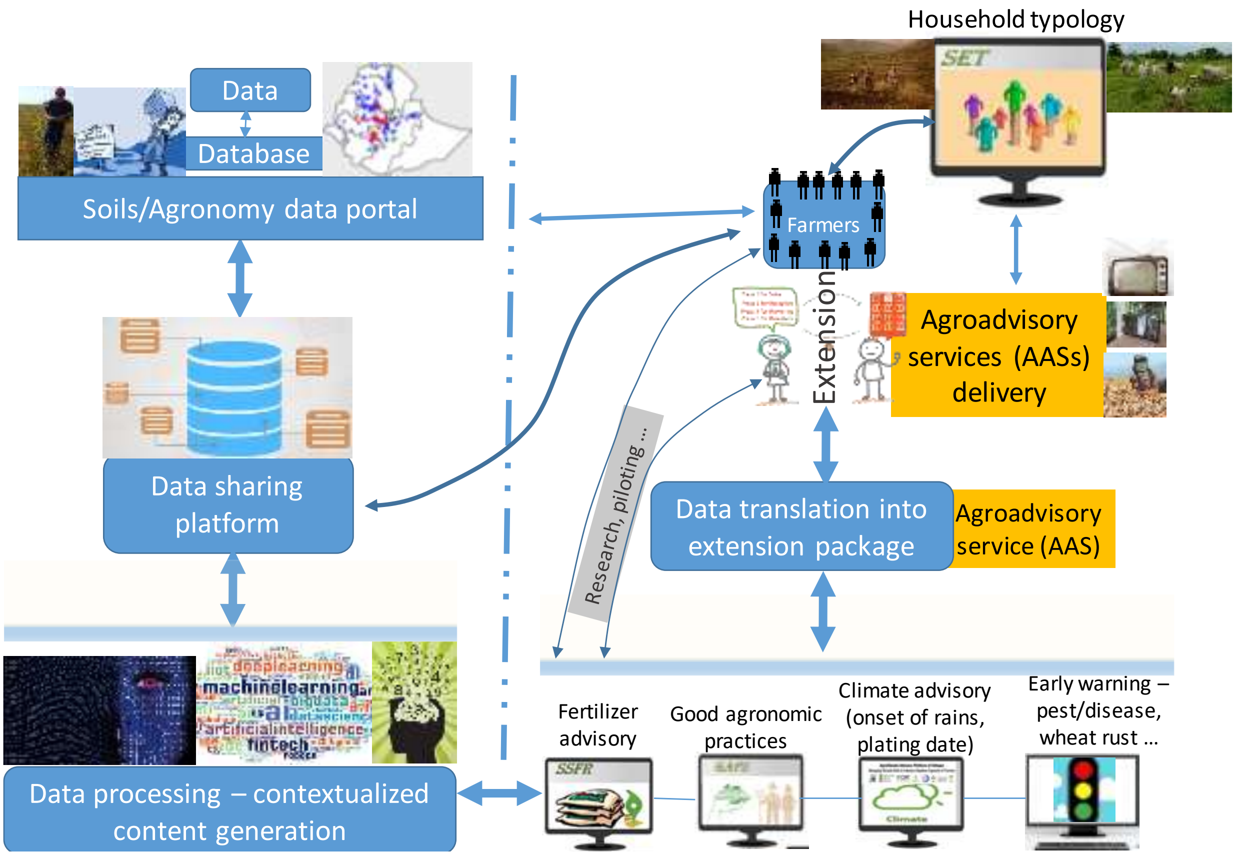


Fig. 6. Schematic of the digital agroadvisory system designed to produce content and agile means to disseminate advisories to farmers and received feedback for adaptive learning

4. Capacity building

Several awarness creation and training sessions were conducted the last five years related to data sharing, we-portal and data analysis. A minimum of two workshprs per year enabled to create awarness and bring the team together for a common goal. Three dtailed writeshop sessions were conducted for handson work on analyzing the data collated by the CoW team. About 15 particants were given trainings on high-evel analysis using various machine learning techniques. This was an eye-oeening exercise for the national team which capacitated them to analyse their own data using up-to-date mehtods. Recently, two sets of training sessions were organized for training of trainers (ToTs) on web-portal for managing soils/agronomy data (Fig. 7), and training on the soils/agronomy data standardization guidelines. The ToT involved 25 data creators and managers that will be using and managing the system (training of trainers on the use of soils/agronomy data web-portal). The ToTs also trained their counterparts in each of the regions. In addition, training sessions where organized to train the use of Agronomy and Soil Fertility and Soil Biology standardization guidelines. In total (including ToTs), about 120 partners from EIAR and regional centers were trained on data standardization guidelines and web portal. On top of these, the taskforce of CoW meet three times a year to discuss on plans, activities and assess progress. All these actions were instrumental for the success of the CoW engagement in its support to transform the Ethiopian agriculture.

Figure 7. Members of the CoW who participated the first soils/agronomy web portal ToT session

5. Summary and conclusion

The CoW has made telling contributions in the areas of data, database, data sharing and data analytics. Creating of CoW has been an innovative step that ignited successive achievements (Fig. 8). The CoW taskforce was instrumental in defining the roadmap that the team should follow every year. The geospatial analysis experts who are members of the CoW are collaborating with the soil scientists and agronomists to tackle practical problems related to agricultural transformation. The analytical exercises to develop 'content' and relevant means to 'disseminate the content' can take advantage of the existing developments in data science to fast track developments and fine-tune for our conditions. These developments are attracting attention, which also led to a selection of Ethiopia to host two Use Cases for the Excellence in Agronomy program. The approaches the CoW has been following are also being scaled to other areas such as India and Rwanda (e.g., watch this).

The whole process of the CoW including the measure taken by the Ministry of Agriculture to develop data sharing policy are already being recognized outside of Ethiopia and are becoming inspiration for other countries such as India and Rwanda. This link provides the recordings of one of the events including critical remarks by key partners and stakeholders. It was very interesting to note how the CoW activities are valued and observe the potential the team can contribute to support the agricultural transformation agenda of the country. It was also pleasing to note that some donors recognize the efforts and closely follows the progress of the CoW and learn that our approaches are inspiriting partners in other countries.

With these developments, the team is very inspired with the products thus far and are committed to continue working on developing interventions that can support the agricultural transformation agenda of the country. This shows that the coming years can even be brighter as the team will engage more in the generation of tangible products through analysis of the available data. There is great hope that the CoW team will provide positive contributions to support the "Digital Ethiopia 2025 Strategy" and be part of the exciting agricultura transformation initiatives of the country.

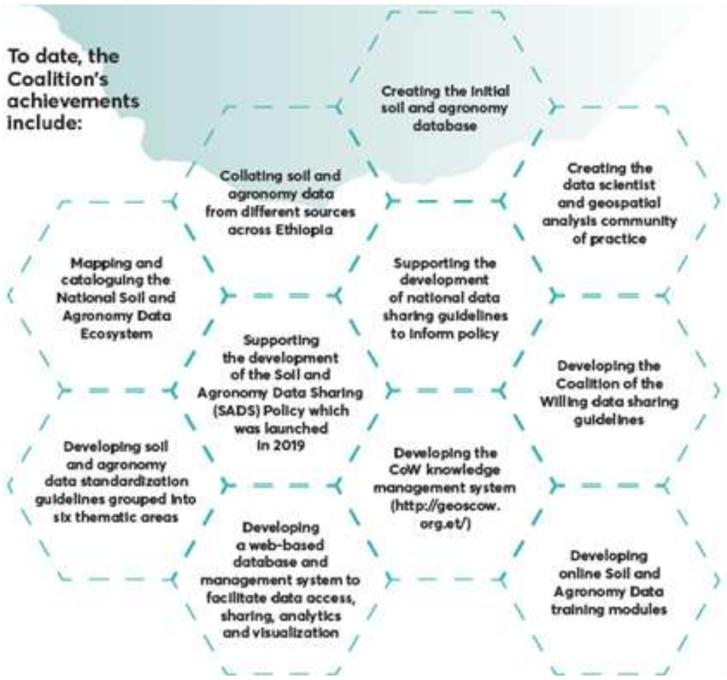


Figure 8. Some of the key activities implemented by the CoW the last few years starting from data gathering to example analysis

Acknowledgments

The over 100 CoW members and the CoW taskforce members who are instrumental in the facilitation and/or implementation of the planned activities are hugely acknowledged. The Technical Team who developed the data standardization guidelines by working for over a week until late in the evening deserve huge acknowledgment. They are real professionals and will be great examples! The geospatial and data science experts who volunteered to support topics and agendas in agriculture and beyond and who always stood up for challenges are very much appreciated. They were ready to tackle challenges thrown at them and hope this will go further to support the big picture of "Digital Ethiopia 2025". The team who fought sometimes difficult and challenging circumstances while developing the web-portal deserve a lot of credit. There were never letdown with technical and administrative hiccups. The supports received from the Ethiopian Institute of Agricultural Research and the Ministry of Agriculture were instrumental to sustain the CoW efforts and succeed in the implementation of the planned activities. We would also like to sincerely thank GIZ for its usual technical and financial support. The Water, Land and Ecosystems (WLE) and Climate Change, Agriculture and Food Security (CCAFS) programs of the CGIAR also provided support in various forms. CABI and ODI brought their experiences in policies, data sharing and other skills that boosted the performances of some of the CoW activities. We also thank their team who supported organizing the very successful first CoW webinar!

References

Ali, A.; Lulseged; T.; Teklu, E. (2020) Identifying, cataloguing, and mapping soil and agronomic data in Ethiopia. CIAT Publication no. 506. Addis Ababa (Ethiopia): International Center for Tropical Agriculture (CIAT). 42 p. https://hdl.handle.net/10568/110868

Birhanu A.; Degenet Y. and Tahir Z. (2020). Yield and agronomic performance of released Tef [Eragrostis tef (Zucc.) Trotter] varieties under irrigation at Dembia, Northweastrn, Ethiopia. Cogent Food & Agriculture 6:1, 1762979. DOI: 10.1080/23311932.2020.1762979

Coalition of the Willing (CoW). 2020. Coalition of the Willing for soil and agronomy data access, management and sharing. Data Sharing Guidelines. Ethiopian Institute of Agricultural Research (EIAR). Addis Ababa, Ethiopia. 28 p. Available at: https://hdl.handle.net/10568/107988

Tamene L; Amede T; Kihara J; Tibebe D; Schulz S. (eds.). 2017. A review of soil fertility management and crop response to fertilizer application in Ethiopia: towards development of site- and context-specific fertilizer recommendation. CIAT

Publication No. 443. International Center for Tropical Agriculture (CIAT), Addis Ababa, Ethiopia. 86 p. Available at: http://hdl.handle.net/10568/82996

Teklu Y.; Tefera H. (2005). Genetic improvement in grain yield potential and associated agronomic traits of tef (Eragrostis tef). Euphytica, 141, 247–254.